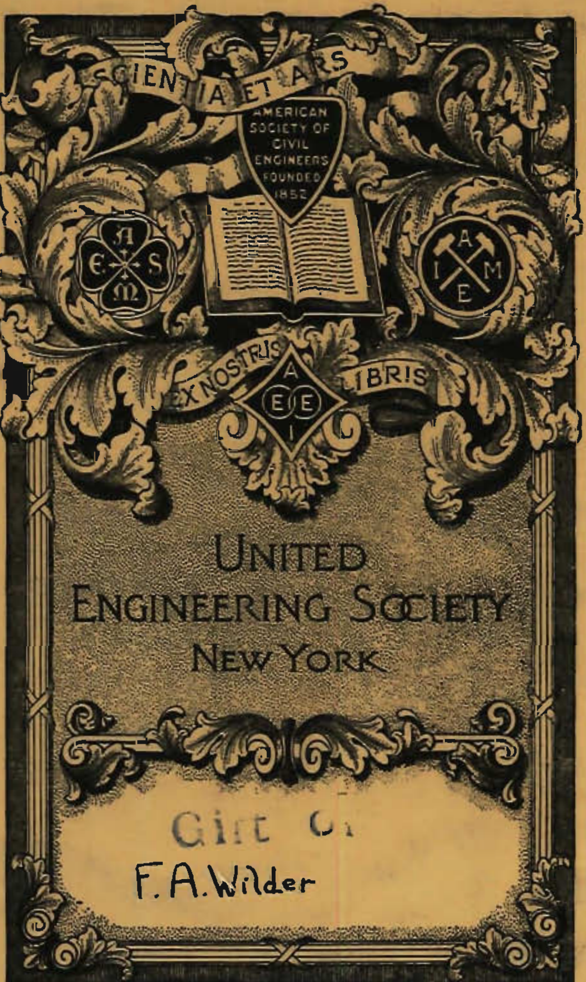
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IOWA
GEOLOGICAL SURVEY

VOLUME XXVIII

Annual Reports, 1917 and 1918
with
Accompanying Papers

GEORGE F. KAY, Ph. D., State Geologist
JAMES H. LEES, Ph. D., Assistant State Geologist

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Geological Survey Organization

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CONTENTS

PAGE
LETTER OF TRANSMITTAL, GEORGE F. KAY 1
MINERAL PRODUCTION IN IOWA IN 1917 AND 1918, JAMES H. LEES 3
GYPSUM: ITS OCCURRENCE, ORIGIN, TECHNOLOGY AND USES, FRANK A. WILDER 47
  Preface 61
  Chapter I, Physical and Chemical Properties of Gypsum 63
  Chapter II, Important Deposits of Gypsum in the United States and Foreign Countries 79
  Chapter III, Origin of Gypsum and Anhydrite 110
  Chapter IV, General Descriptions of the Iowa Gypsum Fields 130
  Chapter V, Stratigraphy of the Iowa Gypsum Areas 136
  Chapter VI, History of the Gypsum Industry 185
  Chapter VII, Physical and Chemical Characteristics of Iowa Gypsum 200
  Chapter VIII, Technology of Gypsum and Gypsum Plaster 211
  Chapter IX, Gypsum in Portland Cement 246
  Chapter X, Gypsum in Agriculture 248
  Chapter XI, Other Uses for Raw Gypsum 270
  Chapter XII, Chemical Characteristics of Calcined Gypsum 273
  Chapter XIII, Physical Properties of Calcined Gypsum 279
  Chapter XIV, Uses of Calcined Gypsum 304
  Chapter XV, Composition and Properties of Gypsum Plasters 308
  Chapter XVI, Gypsum Blocks for Floors, Walls and Roofs 322
  Chapter XVII, Gypsum Plaster Board and Wall Board 329
  Chapter XVIII, Structural Gypsum 342
  Chapter XIX, Hydraulic Gypsum and Keene's Cement 354
  Chapter XX, Retarders and Accelerators 370
  Chapter XXI, Hardening and Coloring of Gypsum and Calcined Gypsum 373
  Chapter XXII, Statistics 376
  Appendix I, Results of Testing Gypsum Products 383
  Appendix II, Microscopic Examination of Gypsum 392
  Appendix III, German Methods of Testing Gypsum 400
  Appendix IV, Measurement of Time of Set of Calcined Gypsum 407
  Appendix V, Factors Influencing Time of Set of Calcined Gypsum 419
  Appendix VI, Gypsum Composition Slab Construction for Roofs and Floors 426
  Appendix VII, Emley Patent for Plastic Gypsum 449
  Appendix VIII, Design of Reinforced Gypsum Beams 454
  Appendix IX, Gypsum Companies in United States, Mexico and Canada, 1921 468
  Bibliography 473
  Index 537

LIST OF ILLUSTRATIONS

PLATES PAGE

I. Topographic and geologic map of Fort Dodge Region ..... in Pocket
II. Selenite Crystals from Centerville 69
III. Map showing location of gypsum deposits and mills in the United States 80
IV. Map showing location of gypsum bearing deposits of Nova Scotia and New Brunswick 99
V. Gypsum near Des Moines river 151
VI. Cross sections along Des Moines valley and Soldier and Lizard creeks 176
VII. Quarry of Iowa Plaster Company 197
VIII. Banded structure of Fort Dodge gypsum 203
IX. Flow sheet of a typical gypsum mill 220
X. Raymond roller mill 221
XI. Cummer calciner, side elevation 238
XII. Diagram showing fuel and power consumption in Gypsum industry, 1916 and 1917 245
XIII. Loading a gypsum roof for tests 447

FIGURES PAGE

1. Selenite crystals 66
2. Diagrams of gypsum crystals 67
3. Selenite crystals imbedded in gypsum 68
4. Satin spar, or fibrous gypsum 71
5. Satin spar, with clay inclusions 71
6. Gypsum quarry at Krölpa, Germany 103
7. Sketch showing precipitation of salts from sea water 113
8. Map of Iowa showing gypsum beds 131
9. Airplane view of the Soldier creek valley, Fort Dodge 137
10. Shales and sandstones near lower viaduct over Soldier creek, Fort Dodge 139
11. Gypsum on Soldier creek, Fort Dodge 141
12. Gypsum at the Vincent Clay Pit, Shady Oak 150
13. Conglomerate at base of Fort Dodge beds 169
14. Keyes' section across the gypsum area 174
15. Pyramid of Cheops 185
16. Egyptian calcining oven 186
17. Lower mill of the Iowa Plaster Association 187
18. The Blandon mill 188
19. The Cardiff mill, the first mill on the prairie 189
20. The Plymouth mill 190
21. American Cement Plaster Company Mill 191
22. The Wasem Mill 192
23. The Iowana Mill 193
24. The U. S. Gypsum Co. Mill 195
25. The Centerville Mill 199
26. Interior of the American mine 200
27. House in Fort Dodge built of gypsum 201
28. Domes in Gypsum Hollow 202
29. Solution in gypsum, Vincent pit 205
30. View in Centerville mine 209

FIGURES PAGE

31. View in Plymouth mine 212
32. Ehrsam jaw crusher 213
33. Cracker used in breaking gypsum 214
34. Burr mill at Centerville mill 216
35. Vertical emery mill 217
36. Disintegrator, or hammer mill 217
37. Fineness tests of 1922 226
38. Effect of grinding on setting time and rise in temperature 227
39. Kettle and section of bottom 228
40. Kettles at Centerville 229
41. Ehrsam kettle setting 230
42. Temperature chart 233
43. Cross section of calcining mill 235
44. Cummer calciner, end view 239
45. Ehrsam mixer 242
46. Bates packer 243
47. Effect of gypsum on alfalfa in Oregon 260
48. Root system of alfalfa 263
49. Clover with gypsum dressing 264
50. Pot culture showing effect of sulphates on plants 266
51. Temperature curve during calcining 275
52. Vicat needle 281
53. Southard viscosimeter 284
54. Curve of setting time 288
55. Temperature progress in gypsum coating of pillar 292
56. Temperature progress in gravel concrete 293
57. Diagram of briquette 294
58. Gang mold 295
59. Apparatus for expansion tests 299
60. Expansion curve 301
61. Tensile strength, mixture of gypsum and Portland cement 302
62. Diagram of block machine 324
63. Gypsum blocks as fire proofing 325
64. Sawing a four inch block for furring 328
65. Penetration by gypsum in plaster board 331
66. Adhesion of plaster board 332
67. Putting plaster board on the wall 334
68. Plaster board and coatings 336
69. Plaster board ceilings, Maywood hospital 338
70. Section of wall board 339
71. Effect of hydrated lime on compressive strength 344
72. Reinforcement in the Hammerstein theatre 348
73. Making precast gypsum roof tile 351
74. Laying precast tile on purlins 352
75. Surfacing a gypsum tile roof 352
76. Gypsum floor deck 353
77. Diagram showing Estrich kiln 356
78. Cross section of kiln for burning hydraulic gypsum 357
79. Laying a floor of hydraulic gypsum 360
80. Pouring the hydraulic plaster 361
81. Distributing the mortar 362
82. Tamping the mortar 362
83. Smoothing down the mortar 363
84. Ruined cloister of Walkenreed 364
85. Modern building using gypsum plaster 365
86. Relation between compressive strength and tensile strength 389
87. Tensile strength and gypsum content 389
88. Temperature and time of set 390
89. Effect of time of working on strength 410
90. Stages in the setting of calcined gypsum 410
91. Setting time of calcined gypsum 412
92. Expansion of calcined gypsum while setting 412

FIGURES PAGE

93. Temperature changes in calcined gypsum while setting 415
94. Time intervals for initial and final set 415
95. Relation between water used and setting time 420
96. Relation of water used to viscosity 421
97. Effect of stirring on time of set 422
98. Effect of rate of stirring on time of set 423
99. Effect of temperature of water used in mixing on time of set 424
100. Sections showing loading test of gypsum composition floor 433
101. Tables showing deflection of gypsum floor 437
102. Plans showing measurements of gypsum composition floor 438
103. Curves showing deflection of supporting beams 439
104. Curves showing deflection of floor slab 440
105. Curves showing elongation of reinforcing cables 442
106. Plan showing cracks in test slab 443
107. Deformation of panels and beams 445
108. Diagrams showing reinforcement of gypsum beams 459
109. Diagrams showing pressure on gypsum beams 459
110. Spacing of reinforcement in gypsum beams 460
111. Curves showing amounts of reinforcement 463
112. Diagram showing shear in gypsum beams 464
113. Cross section of gypsum beam 465

TWENTY-SIXTH AND TWENTY-SEVENTH ANNUAL REPORTS OF THE STATE GEOLOGIST.

IOWA GEOLOGICAL SURVEY,
DES MOINES, DECEMBER 31, 1918.

To Governor William L. Harding and Members of the Geological Board:

GENTLEMEN: I transmit to you herewith a comprehensive report on Gypsum by Dr. Frank A. Wilder, and a report on the Mineral Production in Iowa for 1917 and 1918 by Dr. James H. Lees. I recommend that these two papers be published as Volume XXVIII of the Survey. This Volume will constitute the Twenty-Sixth and Twenty-Seventh Annual Reports of the Iowa Geological Survey.

Respectfully submitted,

GEORGE F. KAY.
State Geologist.

MINERAL PRODUCTION IN IOWA FOR 1917 AND 1918

By JAMES H. LEES

MINERAL PRODUCTION IN IOWA FOR 1917 AND 1918[1]

By JAMES H. LEES

VALUE OF MINERAL PRODUCTION

1916

Product	Unit	Quantity	Value
Cement	barrels	4,853,789	$ 6,165,547
Clay products			7,383,289
Clay, raw	short tons	21,829	2,427(a)
Coal	short tons	7,260,800	13,530,383
Gypsum	short tons	522,293	1,496,795
Iron ore	long tons	10,151	(b)
Lead	short tons	14	1,932
Mineral waters	gallons sold	148,732	14,404
Natural gas	M cubic feet		275
Sand and gravel	short tons	3,321,691	980,272
Stone and lime			610,534
Zinc	short tons	21	5,628
Miscellaneous (c)			103,875
Total value			$30,210,284

1917

Product	Unit	Quantity	Value
Cement	barrels	4,428,765	$ 6,870,863
Clay products			7,540,213
Clay, raw	short tons	5,488	3,012(a)
Coal	short tons	8,965,830	21,096,408
Gypsum	short tons	461,864	2,041,997
Iron ore	long tons	22,612	(b)
Lead	short tons	34	5,848
Mineral waters	gallons sold	99,103	12,125
Natural gas	M cubic feet	225	225
Sand and gravel	short tons	2,909,441	1,060,586
Stone and lime			580,750
Zinc	short tons	18	3,672
Miscellaneous (a, c)			478,995
Total value			$39,336,372

1918

Product	Unit	Quantity	Value
Cement	barrels	3,188,669	$ 5,423,926
Clay products			5,315,143
Clay, raw	short tons	5,416	3,705(a)
Coal	short tons	8,192,195	24,703,237
Gypsum	short tons	327,927	1,946,414
Mineral waters	gallons sold	87,703	3,937
Natural gas	M cubic feet	1,758	245
Sand and gravel	short tons	2,004,444	904,307
Stone and lime			444,800
Miscellaneous (a, c)			1,120,418
Total value			38,742,009

---

a Value not included in total value for state.

b Value included under "Miscellaneous".

c 1916: Ferroalloys and iron ore; 1917: Ferroalloys and iron ore; 1918: Ferroalloys.

[1] The mineral statistics were compiled by the Iowa Geological Survey in coöperation with the United States Geological Survey. The reports of the federal survey have been freely used in preparing the following statements.

In 1917 the total value of the minerals produced in Iowa was $39,336,372, and in 1918 the value was $38,742,009, a decrease of $594,363. Both of these figures are much the largest in the history of the state and represent both increased production and increased prices due to war conditions. The largest production previous to that of 1917 was gained during 1916, when the value of $30,210,284 was reached. Mineral production in the state has shown a steady advance, both in amount and value of output, as the following summary sets forth.

VALUE OF MINERAL PRODUCTION IN IOWA, 1909 TO 1918

1909	$20,365,721
1910	22,744,572
1911	21,119,111
1912	22,910,066
1913	25,612,345
1914	26,301,865
1915	27,062,950
1916	30,210,284
1917	39,336,380
1918	38,742,009

The table shows that the value of the output at the close of this decade was nearly 48 per cent greater than that at the beginning, and that the production of each year has had a higher value than the production of the preceding year, except those for 1911 and 1918. In the latter case the decrease undoubtedly was due to the abrupt termination of the war and the disturbance of industrial conditions which ensued.

In each of the years 1917 and 1918 coal, cement, clay products, gypsum, and sand and gravel have been the most important products, and have held the rank here indicated except that clay products was second in 1917 and third in 1918, alternating with cement. The rise of the cement industry in Iowa is quite phenomenal and indicates the possibility for its future. The gypsum industry also has had a rapid growth in recent years and has brought the state into prominence in this line of production. This growth is well brought out by the chapter on statistics in the report forming the main part of this volume.

The distribution of the mineral products is given in Table I which shows the total production of the state during the two years here under discussion. This table shows that the mineral production of the state was drawn from eighty-three counties in 1917 and from the same number in 1918. Twenty of these counties produced coal in 1917 and twenty in 1918; fifty-seven produced clay wares in 1917 and fifty-nine in 1918; twenty produced stone and lime in 1917 and nineteen in 1918; forty-seven produced sand and gravel in 1917 and the same number in 1918.

TABLE I

TABLE OF MINERAL PRODUCTION IN IOWA IN 1917

Counties	No. of Producers	Coal	Clay and Clay Products	Stone and Lime	Sand and Gravel	Other Products[1]	Total
Adams	3	$ 13,285					$ 13,285
Allamakee	5		*	$ 3,523		*	142,167
Appanoose	46	4,318,243	*				*
Audubon	2		*				*
Benton	5		62,791	*			62,791
Black Hawk	8			*	17,081		74,822
Boone	9	762,986	*		*		934,086
Bremer	2				*		*
Buena Vista	5		30,606		*		30,606
Butler	1				*		*
Carroll	1				*		*
Cass	1		*				*
Cedar	2		*	*			*
Cerro Gordo	11		2,011,844		118,782	*	7,094,484
Cherokee	2				*		*
Clay	1				*		*
Clayton	2			*	*		*
Clinton	9		*	*	12,658		26,308
Crawford	1				*		*
Dallas	8	1,430,508	388,870				1,819,378
Des Moines	3		*		*		27,213
Dickinson	2				*		*
Dubuque	10		*	59,126	35,805	*	126,138
Emmet	2				*		*
Fayette	2		*		*		*
Floyd	3		*	*			166,237
Franklin	5		*		*		219,213
Greene	2	*					*
Grundy	1		*				*
Guthrie	2	*	*				*
Hamilton	3		*	*			274,075
Hancock	1		*				*
Hardin	4		*	*	*		98,543
Henry	4		*	*			35,846
Howard	4		*	*	*		4,650
Humboldt	1				*		*
Iowa	2		*				*
Jackson	8		*	*	18,824		60,280
Jasper	11	619,040	17,529			*	646,059
Jefferson	4	*	38,097				*

* Included in county values and totals.

[1] Includes iron ore, 22,612 tons; gypsum, $2,041,997; cement, $6,870,863; gas, $225; mineral water, $12,125; lead, $5,848; zinc, $3,672.

TABLE I (Continued)

PRODUCTION IN 1917

Counties	No. of Producers	Coal	Clay and Clay Products	Stone and Lime	Sand and Gravel	Other Products[1]	Total
Johnson	2		*				*
Jones	9		*	72,036	*		92,807
Keokuk	9		261,132				261,132
Kossuth	2		*		*		*
Lee	8		*	87,558	*		124,367
Linn	8		*	*	43,510		51,661
Louisa	3		*	*		*	7,483
Lucas	2	*					*
Lyon	1				*		*
Madison	2			*			*
Mahaska	12	380,478	*		*		453,541
Marion	17	1,148,395	69,501		*		1,229,496
Marshall	5		*	*	*		28,213
Mills	2		*				*
Mitchell	1			*			*
Monroe	18	5,082,822					5,082,822
Muscatine	9		18,558		55,259		73,817
O'Brien	3				1,410		1,410
Osceola	2				*		*
Page	4	*	*		*		45,927
Palo Alto	2				*		*
Plymouth	3				11,090		11,090
Pocahontas	2			*		*	*
Polk	40	4,561,922	932,786		277,355	*	7,652,063
Pottawattamie	1		*				*
Poweshiek	4		35,167				35,167
Sac	3		*		*		201,656
Scott	9		*	157,385	*	*	239,995
Sioux	6				53,370		53,370
Story	4		*		*		54,930
Tama	5		43,130				43,130
Taylor	2	*					*
Union	1		*				*
Van Buren	8	19,555	*	*	*		33,150
Wapello	16	844,641	116,119		44,590		1,005,350
Warren	3	*	*				272,705
Washington	4		51,457				51,457
Wayne	1	*					*
Webster	21	*	1,209,863		*	2,041,997	3,325,492
Winnebago	1		*				*
Winneshiek	3		*		*		10,725

* Included in county values and totals.

[1] Includes iron ore, 22,612 tons; gypsum, $2,041,997; cement, $6,870,863; gas, $225; mineral water, $12,125; lead, $5,848; zinc, $3,672.

TABLE I (Contined)

PRODUCTION IN 1917

Counties	No. of Producers	Coal	Clay and Clay Products	Stone and Lime	Sand and Gravel	Other Products[1]	Total
Woodbury	4		*		*	*	539,625
Wright	4		*		*		19,643
County values representing less than three producers and small coal mines		1,914,533	2,286,381	201,122	367,482	7,016,418	6,477,442
Totals	464	$21,096,408	$7,543,225	$580,750	$1,060,586	$9,058,415	$39,336,372

---

* Included in county values and totals.

[1] Includes iron ore, 22,612 tons; gypsum, $2,041,997; cement, $6,870,863; gas, $225; mineral water, $12,125; lead, $5,848; zinc, $3,672.

TABLE I (Contined)

TABLE OF MINERAL PRODUCTION IN IOWA IN 1918

Counties	No. of Producers	Coal	Clay and Clay Products	Stone and Lime	Sand and Gravel	Other Products[2]	Total
Adams	5	$ 19,258	......	......	......	......	$ 19,258
Allamakee	6	......	*	$ 15,381	......	*	35,729
Appanoose	52	5,076,714	*	......	......	......	*
Audubon	2	......	*	......	......	......	*
Benton	3	......	37,189	......	......	......	37,189
Black Hawk	6	......	......	*	$ 35,578	......	*
Boone	11	958,527	*	......	*	......	1,095,805
Bremer	1	......	......	......	*	......	*
Buena Vista	5	......	11,367	......	*	......	*
Butler	1	......	......	......	*	......	*
Carroll	1	......	......	......	*	......	*
Cass	1	......	*	......	......	......	*
Cedar	1	......	*	......	......	......	*
Cerro Gordo	10	......	1,278,719	......	*	*	5,149,729
Cherokee	2	......	......	......	*	......	*
Clay	1	......	......	......	*	......	*
Clayton	1	......	......	......	*	......	*
Clinton	8	......	*	*	9,300	......	23,623
Crawford	1	......	......	......	*	......	*
Dallas	7	1,606,831	354,608	......	......	......	1,961,439
Davis	1	*	......	......	......	......	*
Des Moines	4	......	*	*	*	......	21,412
Dickinson	1	......	......	......	*	......	*
Dubuque	9	......	*	44,099	*	*	75,395
Fayette	3	......	*	......	*	......	2,050
Floyd	3	......	*	*	*	......	101,991
Franklin	5	......	*	......	705	......	*
Greene	2	*	......	......	......	......	*
Grundy	1	......	*	......	......	......	*
Guthrie	2	*	*	......	......	......	*
Hamilton	2	......	*	......	......	......	*
Hancock	1	......	*	......	......	......	*
Hardin	7	......	36,807	*	*	......	52,901
Henry	3	......	*	*	......	......	24,847
Howard	3	......	*	*	*	......	3,293
Humboldt	2	......	*	......	*	......	*
Ida	1	......	......	......	*	......	*
Iowa	2	......	*	......	......	......	*
Jackson	4	......	*	*	*	......	52,415
Jasper	9	757,046	*	......	......	*	764,738

* Included in county values and totals.

[2] Includes gas, $245; mineral water, $3,937; gypsum, $1,946,414; cement, $5,423,926.

TABLE I (Contined)

PRODUCTION IN 1918

Counties	No. of Producers	Coal	Clay and Clay Products	Stone and Lime	Sand and Gravel	Other Products[2]	Total
Jefferson	3		31,887				31,887
Johnson	4		*		*		17,930
Jones	8		*	58,420	*		68,906
Keokuk	7		169,606	*			*
Kossuth	1		*				*
Lee	6		*	38,060	*		46,712
Linn	7		*	*	25,271		32,081
Louisa	4		*			245	*
Lucas	3	1,388,637					1,388,637
Lyon	1				*		*
Madison	2		*	*			*
Mahaska	13	630,326	*		*		674,362
Marion	18	1,806,146	71,735		*		*
Marshall	4		*	*	*		6,091
Mills	1		*				*
Mitchell	1			*			*
Monroe	15	6,445,648					6,445,648
Montgomery	1				*		*
Muscatine	8		7,445		59,436		66,881
O'Brien	4				3,408		3,408
Osceola	2				*		*
Page	3	*	*				41,708
Palo Alto	2				*		*
Plymouth	3				10,000		10,000
Pocahontas	2			*		*	*
Polk	39	4,504,727	648,501		221,634	*	6,858,485
Pottawattamie	2		*				*
Poweshiek	3		20,400				20,400
Sac	4		*		86,457		*
Scott	10		*	172,758	*		246,059
Sioux	6				49,270		49,270
Story	3		51,810				51,810
Tama	3		31,939				31,939
Taylor	2	*					*
Union	1		*				*
Van Buren	6	43,185	*		*		47,929
Wapello	14	744,667	24,754		*		*
Warren	3	*	*				367,100
Washington	4		42,203				42,203
Wayne	1	*					*
Webster	20	*	1,112,157		*	1,946,414	3,149,366

* Included in county values and totals.

[2] Includes gas, $245; mineral water, $3,937; gypsum, $1,946,414; cement, $5,423,926.

TABLE I (Contined)

PRODUCTION IN 1918

Counties	No. of Producers	Coal	Clay and Clay Products	Stone and Lime	Sand and Gravel	Other Products[2]	Total
Winnebago	1	....	*	....	....	....	*
Winneshiek	3	....	*	....	*	....	9,266
Woodbury	5	....	*	....	*	*	373,938
Wright	4	....	*	....	8,949	....	*
County values representing less than three producers and small coal mines		721,525	1,387,721	116,082	385,843	5,427,863	9,238,181
Totals	446	$24,703,237	$5,318,848	$444,800	$ 904,307	$7,374,522	$38,742,009

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* Included in county values and totals.

[2] Includes gas, $245; mineral water, $3,937; gypsum, $1,946,414; cement, $5,423,926.

COAL MINING.

For many years coal has been the chief mineral product of the state. As early as 1840 coal was being mined from the banks near Farmington. Some of the coal was hauled by team to Keokuk and some was used by the steamboats which came up the Des Moines. In these early days coal retailed at $4.50 to $5.00 per ton, but it had difficulty in competing with wood, which was then very plentiful. By 1843 the blacksmiths along Des Moines valley had come to appreciate the value of coal in their work and it was in use in the army forges at Fort Des Moines.

By 1865 the mining industry was well established and since then it has advanced in importance with fairly uniform rapidity. Iowa's coal reserves have proved to be one of the foundations of her material prosperity. The following table gives the production from the earliest recorded date to the present.

PRODUCTION OF COAL IN IOWA 1840–1918

In Short Tons

Years	Tonnage	Years	Tonnage	Years	Tonnage
1840	400	1867	150,000	1893	3,972,220
1841	500	1868	241,453	1894	3,967,253
1842	750	1869	295,105	1895	4,156,074
1843	1,000	1870	263,487	1896	3,954,028
1844	2,500	1871	300,000	1897	4,611,865
1845	5,000	1872	336,000	1898	4,618,842
1846	6,500	1873	392,000	1899	5,177,479
1847	8,000	1874	799,936	1900	5,202,939
1848	10,000	1875	1,231,547	1901	5,617,499
1849	12,500	1876	1,250,000	1902	5,904,766
1850	15,000	1877	1,300,000	1903	6,419,811
1851	18,000	1878	1,350,000	1904	6,519,933
1852	20,000	1879	1,400,000	1905	6,798,609
1853	23,000	1880	1,461,116	1906	7,266,224
1854	25,000	1881	1,960,000	1907	7,574,322
1855	28,000	1882	3,920,000	1908	7,149,517
1856	30,000	1883	4,457,540	1909	7,757,762
1857	33,000	1884	4,370,566	1910	7,928,120
1858	37,500	1885	4,012,575	1911	7,331,648
1859	42,000	1886	4,315,779	1912	7,289,529
1860	41,920	1887	4,473,828	1913	7,525,936
1861	50,000	1888	4,952,440	1914	7,451,022
1862	53,000	1889	4,095,358	1915	7,614,143
1863	57,000	1890	4,021,739	1916	7,260,800
1864	63,000	1891	3,825,495	1917	8,965,830
1865	69,574	1892	3,918,491	1918	8,192,195
1866	99,320				

It will be seen from this table that production of coal in Iowa reached the eight million ton mark for the first time in 1917, and again in 1918 this mark was attained, although with a considerable decrease from the figure of the preceding year. The remarkable increase of 1,705,030 tons in the production for 1917 over that of 1916, an increase of 23.5 per cent, was due to the greatly increased demand for fuel for manufacturing and allied industries connected with the production of war materials. In normal times the demand is seasonal and is greater in the colder months when coal is required for heating. In 1917, however, the demand was good throughout the year as is shown by the fact that the mines were worked 251 days out of a possible 304 days. The severe weather of the winter of 1917-18 was an appreciable factor in maintaining production.

Conditions in 1918 were somewhat different from those prevailing during the preceding year. In the spring of 1918 demand was so slack that some mines were closed for weeks and many miners left the Iowa fields. Hence when production was stabilized through the work of the Fuel Administration there was a shortage of workers. After the signing of the Armistice on November 11 the demand slackened somewhat, and the mild weather of the ensuing winter lessened the demand for heating coal. Because of these factors the output of coal in 1918 was 773,635 tons less than that for 1917, a shrinkage of 8.6 per cent, and the number of employes decreased from 14,266 in 1917 to 13,328 in 1918, while the average number of days worked in 1918 was 245, or six less than in 1917.

The following tables will give the details of production in 1917 and 1918.

TABLE II.

COAL PRODUCTION FOR IOWA IN 1917 BY COUNTIES

COUNTY	LOADED AT MINES FOR SHIPMENT		SOLD TO LOCAL TRADE & USED BY EMPLOYEES		USED AT MINE FOR STEAM AND HEAT	
	Short tons	Value	Short tons	Value	Short tons	Value
Adams	....	....	4,016	$ 13,285	....	....
Appanoose	1,529,622	$ 4,035,430	85,776	200,336	48,056	$ 82,477
Boone	181,761	580,997	56,103	169,669	6,857	12,320
Dallas	567,338	1,381,139	8,510	25,062	12,629	24,307
Greene, Lucas, Warren and Wayne	734,649	1,557,482	23,027	68,988	18,644	34,099
Guthrie and Webster	25,876	68,996	3,803	12,330	....	....
Jasper	280,532	549,162	22,715	67,728	965	2,150
Mahaska	128,478	344,522	14,107	31,213	3,235	4,743
Marion	459,177	1,051,980	21,187	49,828	24,635	46,587
Monroe	2,331,400	4,872,267	44,365	108,634	70,905	101,921
Page and Taylor	7,500	26,250	10,443	42,200	....	....
Polk	1,409,684	3,340,616	403,992	1,158,759	32,163	62,547
Van Buren	2,207	6,860	4,224	12,695	....	....
Wapello	296,242	708,245	41,962	113,921	8,305	22,475
Small Mines (a)	....	....	40,740	104,188	....	....
	7,954,466	$18,523,946	784,970	$2,178,836	226,394	$393,626
Average value per ton		$2.33		$2.78		$1.74

[a] Includes Jefferson county.

TABLE II (Continued)
COAL PRODUCTION FOR IOWA IN 1917 BY COUNTIES

COUNTY	TOTAL QUANTITY		AV. VAL. PER TON	NUMBER OF EMPLOYEES			AV. NO. OF DAYS WK'D.
	Short tons	Value		UNDER-GROUND	SURFACE	TOTAL	
Adams	4,016	$ 13,285	$3.31	26	7	33	141
Appanoose	1,663,454	4,318,243	2.60	3,325	401	3,726	243
Boone	244,721	762,986	3.12	465	57	522	206
Dallas	588,477	1,430,508	2.43	832	109	941	258
Greene, Lucas, Warren and Wayne	776,320	1,660,569	2.14	1,063	94	1,157	255
Guthrie and Webster	29,679	81,326	2.74	63	7	70	276
Jasper	304,212	619,040	2.03	397	47	444	255
Mahaska	145,820	380,478	2.61	216	24	240	234
Marion	504,999	1,148,395	2.27	748	130	878	211
Monroe	2,446,670	5,082,822	2.08	2,662	404	3,066	266
Page and Taylor	17,943	68,450	3.81	48	6	54	212
Polk	1,845,839	4,561,922	2.47	2,363	246	2,609	267
Van Buren	6,431	19,555	3.04	14	2	16	223
Wapello	346,509	844,641	2.44	450	60	510	248
Small Mines (a)	40,740	104,188	2.56	....	......	....	......
	8,965,830	21,096,408		12,672	1594	14,266	251
Average value per ton		2.35	2.35				

a Includes Jefferson county.

TABLE II (Continued)
COAL PRODUCTION FOR IOWA IN 1918 BY COUNTIES

COUNTY	LOADED AT MINES FOR SHIPMENT		SOLD TO LOCAL TRADE & USED BY EMPLOYEES		USED AT MINES FOR STEAM AND HEAT	
	Short tons	Value	Short tons	Value	Short tons	Value
Adams	....	....	5,405	$ 19,247	13	$ 11
Appanoose	1,478,943	$ 4,837,340	57,084	183,206	23,226	56,162
Boone	211,599	718,360	58,430	222,875	7,590	17,292
Dallas	509,543	1,549,048	10,972	39,142	6,963	18,641
Davis, Greene, Warren and Wayne	129,959	412,988	13,180	43,672	3,733	6,575
Guthrie and Webster	18,889	61,833	11,237	38,152	600	1,000
Jasper	216,148	658,679	22,246	70,485	10,557	27,882
Lucas	485,292	1,330,958	5,993	23,418	12,236	34,261
Mahaska	206,775	589,742	10,285	31,510	4,800	9,074
Marion	566,079	1,694,976	26,114	70,283	17,073	40,887
Monroe	2,212,243	6,191,328	34,143	99,910	71,543	154,410
Page and Taylor	5,645	19,193	10,557	35,874	....	....
Polk	1,153,000	3,512,434	258,464	935,197	22,969	57,096
Van Buren	6,017	18,464	6,928	24,159	250	562
Wapello	198,898	611,948	37,212	108,447	9,056	24,272
Small Mines	....	....	34,306	102,238	....	....
	7,399,030	$22,207,297	602,556	$2,047,815	190,609	$448,125
Average value per ton		$3.00		$3.40		$2.35

TABLE II (Continued)

COUNTY	TOTAL QUANTITY		AVERAGE PRICE PER TON	NUMBER OF EMPLOYEES			AVERAGE NUMBER OF DAYS WORKED	INCREASE OR DECREASE IN TONNAGE FROM 1917
	Short tons	Value		UNDER-GROUND	SURFACE	TOTAL		
Adams	5,418	$ 19,258	$3.55	26	4	30	237	+1,402
Appanoose	1,559,253	5,076,714	3.26	3,082	397	3,479	241	—104,201
Boone	277,619	958,527	3.45	453	115	568	238	+32,898
Dallas	527,478	1,606,831	3.05	799	70	869	234	—60,999
Davis, Greene, Warren and Wayne	146,872	463,235	3.15	240	33	273	197	—125,927[a]
Guthrie and Webster	30,726	100,985	3.29	65	9	74	236	+1,047
Jasper	248,951	757,046	3.04	359	42	401	227	—55,261
Lucas	503,521	1,388,637	2.76	358	60	418	273	..............[a]
Mahaska	221,860	630,326	2.84	274	44	318	258	+76,040
Marion	609,266	1,806,146	2.96	875	134	1,009	240	+104,267
Monroe	2,317,929	6,445,648	2.78	2,743	347	3,090	258	—128,741
Page and Taylor	16,202	55,067	3.40	47	5	52	201	—1,741
Polk	1,434,433	4,504,727	3.14	2,068	228	2,296	251	—411,406
Van Buren	13,195	43,185	3.27	13	16	29	211	+6,764
Wapello	245,166	744,667	3.04	372	50	422	208	—101,343
Small Mines	34,306	102,238	2.98	....	....	....	......	—6,434
	8,192,195	$24,703,237	....	11,774	1,554	13,328	245	—773,635
Average value per ton			$3.02					+$3,606,298

[a] Davis, etc., included Lucas in 1917.

Most of the coal produced in Iowa is used within the state or by railroads. The following table presents interesting data relative to the ultimate distribution of Iowa coal.

	Quantity, Short Tons	
Used in Iowa	1917	1918
Used at mines for steam and heat	226,394	190,609
Sold to local trade, not shipped	784,970	602,556
Shipped to Iowa points	2,876,137	3,026,262
	3,887,501	3,819,427
Percentage of total	43.4	46.6
Shipped to Other States		
Arkansas	—	2,117
Illinois	—	1,703
Kansas	15,000	14,265
Louisiana	—	138
Minnesota	31,000	5,318
Missouri	239,000	271,239
Nebraska	130,000	163,073
Oklahoma	—	1,254
South Dakota	30,000	15,948
Texas	—	90
	445,000	475,145
Percentage of total	5.0	5.8
Used by railroads	4,633,329	3,897,623
Percentage of total	51.6	47.6
Total production	8,965,830	8,192,195

It will be seen that the demand by the railroads was considerably less in 1918 than in 1917, the decrease amounting to 735,000 tons. The extension of the market for Iowa coal was on account of the zoning system established by the Fuel Administration in 1918, which prohibited shipments of eastern coal west of the Mississippi. The increase in the average price at the mine was due also to the prices fixed by Presidential order and by the Fuel Administration.

A few facts relative to the source of the coal consumed in Iowa will be of interest as showing the wide range from which the state draws its fuel supplies. It will be noted that coal is brought to Iowa from practically all the producing fields of the United States except those of the extreme southeast and the far west.

Source	Quantity, short tons 1917	1918
Arkansas	9,000	26,044
Colorado	15,000	135,151
Illinois	4,026,000	3,597,048
Indiana	247,000	89,796
Iowa	3,887,501	3,819,427
Kansas	81,000	79,660
Kentucky	297,000	67,956
Missouri	58,000	93,216
Montana and northern Wyoming	324,000	236,013
Oklahoma	2,000	10,983
Tennessee	9,000	----------
Utah and southern Wyoming	54,000	46,622
West Virginia	165,000	28,974
Great Lake docks	271,560	225,000
Total domestic and industrial	9,446,061	8,455,890
Pennsylvania Anthracite	471,694	----------
Used by railroads	4,633,329	3,897,623

Perhaps the most significant facts in the above table are the great amount of Illinois coal used in Iowa, the amount of "dock" coal and the amount of coal which comes from Utah, Wyoming and Montana. Dock coal is used chiefly in northern Iowa. It originates at Lake Erie ports and is transshipped chiefly from Duluth to the markets of the northwest. The lack of figures for consumption of anthracite in 1918 is due to the order of the Fuel Administration forbidding shipments to the western and southern states.

Iowa maintained very nearly the same relative rank among the coal-producing states as she has held for several years past. The rank and output of the eleven leading states are shown by the following table:

	1917		1918	
STATE	SHORT TONS	VALUE	SHORT TONS	VALUE
Pennsylvania				
Anthracite	99,611,811	$283,650,723	98,826,084	$336,480,347
Bituminous	172,448,142	421,268,808	178,550,741	436,159,736
West Virginia	86,441,667	200,659,368	89,935,839	230,508,846
Illinois	86,199,387	162,281,822	89,291,105	206,860,291
Ohio	40,748,734	100,897,148	45,812,943	118,095,518
Kentucky	27,807,971	60,297,653	31,612,617	80,666,842
Indiana	26,539,329	52,940,106	30,678,634	70,384,601
Alabama	20,068,074	45,616,992	19,184,962	54,752,329
Colorado	12,483,336	27,669,129	12,407,571	33,404,743
Virginia	10,087,091	20,125,713	10,289,808	25,865,895
Iowa	8,965,830	21,096,408	8,192,195	24,703,237
Wyoming	8,575,619	16,593,283	9,438,688	22,581,019
Total for U. S.	651,402,374	1,532,923,560	678,211,904	1,828,290,287

CLAY PRODUCTS.

The value of the output of clay wares in 1917 was $7,543,225. This represents an increase over the preceding year of $161,509, or 2.18 per cent. Inasmuch as the output in 1916 was the greatest in the history of the industry the increase here recorded was decidedly gratifying. In 1918, however, the production was considerably less, amounting to $5,318,848. This meant a drop of $2,225,377 in the output, a decrease of 29 per cent. These conditions simply reflect a condition which was nation-wide, for the nation was at war and building operations were restricted to governmental needs and essential war industries. Under these conditions the output of nearly all branches of the industry decreased in value in 1918 as compared with the output in 1917. Manufacturing operations were affected severely by high cost and scarcity of materials, uncertainty and high prices of labor, unfavorable transportation conditions and fuel restrictions imposed by the Fuel Administration. It was reported by that organization that whereas the average annual consumption of coal at Iowa clay manufacturing plants from 1915 to 1917 was 399,183 tons, in the first half of 1918 the coal consumed amounted to only 140,609 tons, a reduction of over fifty per cent.

The development of the clay industry during the preceding decade is shown by the following table:

	DRAIN TILE.	FIREPROOFING	COMMON BRICK	TOTAL
1909	$2,830,910	$ 304,398	$1,072,340	$4,916,513
1910	3,457,455	94,366	1,088,266	5,335,030
1911	2,468,962	374,628	1,025,011	4,436,839
1912	2,293,084	535,254	1,017,097	4,524,492
1913	2,798,816	762,563	1,052,036	5,575,581
1914	3,180,836	1,083,397	1,067,746	6,405,995
1915	3,802,599	1,008,457	898,851	6,749,088
1916	3,986,163	1,141,291	947,247	7,375,716
1917	4,004,989	1,542,884	1,045,790	7,543,225
1918	2,256,200	1,550,076	749,325	5,318,848

The distribution of the output of clay ware is shown in greater detail in the following table:

PRODUCT	1913		1914		1915	
	Quantity in M	VALUE	Quantity in M	VALUE	Quantity in M	VALUE
Common brick	143,263	$1,052,036	143,534	$1,067,746	125,752	$ 898,851
Vitrified brick or block	16,398	222,105	14,997	211,905	30,573	300,785
Face brick	14,078	181,911	11,183	148,394	11,916	153,324
Drain tile		2,798,816		3,180,836		3,802,599
Sewer pipe		503,360		558,751		448,721
Fireproofing		762,563		1,083,397		1,008,457
Other products		32,192		150,716		130,878
Pottery and clay		22,598		37,000		10,898
		$5,575,581		$6,405,995		$6,749,088

	1916		1917		1918	
	QUANT. IN M	VALUE	QUANT. IN M	VALUE	QUANT. IN M	VALUE
Common brick	132,676	$ 947,247	119,984	$1,045,790	67,292	$ 749,325
Vit. brick or block	24,265	393,038	5,927	83,310	6,793	116,522
Face brick	22,112	283,559	18,425	282,840	11,383	188,041
Drain tile		3,986,163		4,004,989		2,256,200
Sewer pipe		494,428		455,561		398,848
Fireproofing		1,141,291	261,488 tons	1,542,884	238,789 tons	1,550,076
Other products		127,563		72,145		33,206
Pottery and clay		6,427		7,912		5,454
		$7,375,716		$7,543,225		$5,318,848

The table shows some fluctuation in the output of common brick although the value maintained a fairly high plane. Similar fluctuation is shown in the case of vitrified brick, especially during the last two years. Drain tile has experienced a marked growth in value of output and the same is true of fireproofing materials, which have increased in value even during the last two troubled years. Since 1914 drain tile, fireproofing and common brick have held rank as first, second and third in importance of output. As in previous years Iowa led the United States in value of drain tile manufactured and Cerro Gordo county was the banner county of the state. The output from this county in 1917 was valued at $1,640,020 and in 1918 at $810,037. In 1917 the leading states in drain tile manufacture were: Iowa, $4,004,989; Ohio, $1,696,763; Indiana, $1,564,542; and Illinois, $1,314,006. In 1918 the production was less in all these states although Iowa suffered the most. Their output was: Iowa, $2,256,200; Ohio, $1,572,996; Indiana, $1,427,237; and Illinois, $1,077,861.

The total production and the rank of the ten leading states are shown in the appended table.

TEN LEADING STATES IN VALUE OF CLAY PRODUCTS IN 1917 AND '18

STATE	1917				1918			
	Rank	Number of firms reporting	Value not including clay sold	Percentage of total	Rank	Number of firms reporting	Value not including clay sold	Percentage of total
Ohio	1	470	$51,957,043	22.3	1	424	$52,899,180	23.8
Pennsylvania	2	315	38,743,105	16.7	2	288	40,467,104	18.2
New Jersey	3	142	22,529,232	9.7	3	132	20,741,244	9.3
Illinois	4	207	17,190,753	7.4	4	168	12,459,777	5.6
New York	5	167	11,428,399	4.9	6	141	10,892,954	4.9
Missouri	6	77	10,291,977	4.4	7	65	9,155,088	4.1
Indiana	7	178	9,718,752	4.2	8	157	7,950,926	3.6
West Virginia	8	57	9,608,065	4.1	5	56	10,988,677	5.0
Iowa	9	137	7,540,213	3.2	10	123	5,313,394[a]	2.4
Kentucky	10	55	5,037,636	2.2	9	47	6,172,554	2.8
Total for U. S.		3,153	232,512,773			2,783	221,884,651[b]	

[a] Pottery not included.

[b] Decrease from 1917, $10,628,122.

The noteworthy features of this table are the marked decline in Iowa's output, which caused her to drop from ninth to tenth place, and the notable advance of West Virginia from eighth place to fifth. It should be noted that in the production of brick and tile proper Iowa ranked seventh in 1917 and eighth in 1918.

The average price of common brick rose from $8.72 per thousand in 1917 to $11.14 in 1918, vitrified brick rose from $14.06 to $17.15, front brick rose from $15.35 to $16.52 and hollow building tile and fireproofing rose from $5.90 per ton to $6.49.

Table III will show the output of the various classes of clay ware as distributed among the counties of the state.

TABLE III

VALUE OF IOWA CLAY PRODUCTS IN 1917 TABULATED BY COUNTIES

County	No. of Producers	Common Brick	Drain Tile	Fireproofing and Hollow Building Tile	Other Products[a]	Total Value
Allamakee	1	*	*	*		*
Appanoose	1	*				*
Audubon	2	*	*	*		*
Benton	4	*	$ 43,593	*		$ 62,791
Boone	2	*	*	*	*	*
Buena Vista	3	*	30,357			*
Cass	1	*	*	*		*
Cedar	1	*	*	*		*
Cerro Gordo	7	$ 20,150	1,640,020	$351,674		2,011,844
Clinton	2	*	*			*
Dallas	5	*	273,154	107,916	*	388,870
Des Moines	1	*	*	*		*
Dubuque	2	*				*
Fayette	1	*		*		*
Floyd	1	*	*	*		*
Franklin	1	*	*	*		*
Grundy	1	*			*	*
Guthrie	1		*	*		*
Hamilton	2	*	*	*	*	*
Hancock	1		*			*
Hardin	2		*	*	*	*

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* Included under "Counties with less than three producers."

[a] Includes: Vitrified brick, $83,310; front brick, $282,840; sewer pipe, $455,561; fire brick, $4,000; roofing tile, stove lining fancy brick, sewer block, segment block, brickbats, $89,928; flue lining, $18,940; wall coping, $7,071; pottery and clay, $7,912.

TABLE III (Continued)

County	No. of Producers	Common Brick	Drain Tile	Fireproofing and Hollow Building Tile	Other Products[a]	Total Value
Henry	2	*	*	*		*
Howard	1	*	*	*		*
Iowa	2	*	*	*		*
Jackson	1			*	*	*
Jasper	4	5,229	12,300			17,529
Jefferson	3	*	32,232	*		38,097
Johnson	2	*	*			*
Jones	2	*	*	*		*
Keokuk	8	*	189,652	*	$ 65,673	261,132
Kossuth	1		*			*
Lee	2	*			*	*
Linn	2	*	*			*
Louisa	1	*	*	*		*
Mahaska	2	*	*	*	*	*
Marion	4	10,559	19,865	39,077		69,501
Marshall	2	*	*	*		*
Mills	2	*				*
Muscatine	7	8,150	*	*	*	18,558
Page	1	*	*	*		*
Polk	9	203,367	200,661	184,826	343,932	932,786
Pottawattamie	1	*	*	*		*
Poweshiek	4	576	30,705	3,886		35,167
Sac	1	*	*	*		*
Scott	2	*	*	*	*	*
Story	2	*	*	*	*	*
Tama	5	15,400	16,408	*	*	43,130
Union	1	*	*	*		*
Van Buren	2	*	*	*		*
Wapello	3	39,765	*	*	3,799	116,119
Warren	1		*	*		*
Washington	4	6,597	37,635	7,225		51,457
Webster	11	51,218	477,715	376,876	304,054	1,209,863
Winnebago	1		*			*
Winneshiek	1	*				*
Woodbury	2	*		*	*	*
Wright	1		*			*
Pottery and clay sold						7,912
Counties with less than three producers		684,779	988,992	471,404	232,104	2,286,381
Totals	142	1,045,790	4,004,989	1,542,884	949,562	7,543,225

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* Included under "Counties with less than three producers."

[a] Includes: Vitrified brick, $83,310; front brick, $282,840; sewer pipe, $455,561; fire brick, $4,000; roofing tile, stove lining fancy brick, sewer block, segment block, brickbats, $89,928; flue lining, $18,940; wall coping, $7,071; pottery and clay, $7,912.

TABLE III (Continued)

VALUE OF IOWA CLAY PRODUCTS IN 1918
TABULATED BY COUNTIES

County	No. of Producers	Common Brick	Drain Tile	Fireproofing and Hollow Building Tile	Other Products[b]	Total Value
Allamakee	1	*	*	*	....	*
Appanoose	1	*	....	....	....	*
Audubon	2	*	*	*	....	*
Benton	3	*	*	9,787	....	37,189
Boone	2	*	*	*	*	*
Buena Vista	3	*	*	....	....	11,367
Cass	1	*	*	*	....	*
Cedar	1	*	*	*	....	*
Cerro Gordo	7	33,045	810,037	435,637	....	1,278,719
Clinton	2	*	*	....	....	*
Dallas	4	*	133,125	211,612	*	354,608
Des Moines	1	....	*	....	....	*
Dubuque	1	*	....	....	....	*
Fayette	1	....	....	....	....	*
Floyd	1	*	*	*	....	*
Franklin	2	*	*	*	....	*
Grundy	1	*	....	....	*	*
Guthrie	1	....	*	*	....	*
Hamilton	2	*	*	*	*	*
Hancock	1	....	*	....	....	*
Hardin	3	....	*	....	*	36,807
Henry	2	*	*	*	....	*
Howard	1	*	*	*	....	*
Humboldt	1	....	*	....	....	*
Iowa	2	*	*	....	....	*
Jackson	1	....	....	*	*	*
Jasper	2	*	*	....	....	*
Jefferson	3	*	27,084	*	....	31,887
Johnson	2	*	*	....	....	*
Jones	2	*	*	*	....	*
Keokuk	6	*	126,950	2,784	*	169,606
Kossuth	1	....	*	....	....	*
Lee	1	*	....	....	....	*
Linn	1	....	*	....	....	*
Louisa	1	*	*	*	....	*
Madison	1	*	*	....	....	*
Mahaska	2	*	*	*	*	*
Marion	3	5,070	32,085	34,580	....	71,735
Marshall	2	*	....	....	....	*

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[b] Includes: Vitrified brick or block, $116,522; front brick, $188,041; sewer pipe, $398,848; flue lining, $12,852; wall coping, $4,208; roofing tile, segment block, fittings, broken ware, $37,322; pottery and clay, $5,454.

TABLE III (Continued)

County	No. of Producers	Common Brick	Drain Tile	Fireproofing and Hollow Building Tile	Other Products[b]	Total Value
Mills	1	*				*
Muscatine	4	6,575			*	7,445
Page	1	*	*	*		*
Polk	7	89,537	79,493	144,489	334,982	648,501
Pottawattamie	2	*	*	*		*
Poweshiek	3	*	17,708	*		20,400
Sac	1	*	*	*		*
Scott	2	*	*	*		*
Story	3	*	*	*	*	51,810
Tama	3	16,916	*	*	*	31,939
Union	1	*	*	*		*
Van Buren	1		*	*		*
Wapello	3	9,438	*	*	3,316	24,754
Warren	1		*	*		*
Washington	4	4,604	29,344	8,255		42,203
Webster	10	45,251	429,205	381,178	256,523	1,112,157
Winnebago	1		*			*
Winneshiek	1	*				*
Woodbury	2	*		*	*	*
Wright	1		*			*
Pottery and clay sold						5,454
Counties with less than three producers		538,889	571,169	321,754	168,426	1,387,721
Totals	127	749,325	2,256,200	1,550,076	763,247	5,318,848

* Included under "Counties with less than three producers."

b Includes: Vitrified brick or block, $116,522; front brick, $188,041; sewer pipe, $398,848 flue lining, $12,852; wall coping, $4,208; roofing tile, segment block, fittings, broken ware, $37,322; pottery and clay, $5,454

STONE AND LIME.

The value of the stone and lime produced in Iowa in 1917 was $580,758 and the value of the output of 1918 was $444,800. Both of these figures represent a considerable decline in the industry from 1916 when the output was valued at $610,534. The decline in this industry reflects the unfavorable conditions which were general in building trades and particularly in the uses for crushed stone. Building stone forms a relatively insignificant element of Iowa's stone output and hence the increase in value of this class as well as of rubble and riprap was insufficient to offset the large decline in output of stone crushed for use in roadmaking and concrete. The output of railroad ballast was negligible in the two years here considered and the same is true of sandstone, of which there was no production reported in 1918. One of the redeeming features shown by the tables is the marked increase in the use of crushed limestone for agricultural purposes. The slump in this industry in 1918 doubtless will be regained in succeeding years.

In considering the output of limestone in this state the fact must be borne in mind that large quantities are quarried annually for use in cement making and that of this amount no record appears in the tables or discussion here presented.

The following table will show in summarized form the output of stone in the past three years and its distribution in the various branches of industry.

	1916	1917	1918
Limestone used for			
Building	$ 12,018	$ 15,101	$ 22,749
Rubble and riprap	93,259	59,998	71,879
Crushed stone			
Road making (a)	88,303	50,215	52,179
Concrete	342,082	339,622	192,869
Agriculture	9,630	24,584	19,273
Other purposes (b)	65,242	90,930	85,851
Total	$610,534	$580,758	$444,800

[a] Includes railroad ballast.

[b] Includes sandstone, lime, paving, flagging, curbing, flux, sugar factories, paper mills, whiting, uses not stated.

As lime is produced in Iowa by only two firms, the Eagle Point Lime Works of Dubuque and the Alfred Hurst Estate of Maquoketa, Jackson county, it is not possible to reveal figures of output but it is of interest to note the uses to which the product is put. The statements show that much the larger part of the output of these plants is used by the building trades, that a smaller share is taken by paper mills and that a few hundred tons annually are used in metallurgical plants. Wood is used as fuel for the most part, though some coal is burned.

Iowa does not hold a high rank among the stone producing states of the union. In 1917 she stood thirtieth and in 1918 thirty-third. The state contributed 0.63 per cent to the total value of the output in 1917 and 0.46 in 1918. The rank of the state in the lime industry is a little higher as in 1917 she stood twenty-fifth in quantity and twenty-sixth in value with an average price per ton of $6.45 as compared with a national average of $6.29. In 1918 her rank was twenty-third in quantity and twenty-fourth in value with an average price per ton of $7.65 compared with a national average of $8.36.

Table IV shows in detail the production by counties for 1917 and 1918.

TABLE IV

PRODUCTION OF STONE AND LIME IN 1917

Counties	No. of Producers	Building Stone	Rubble and Riprap	Crushed Stone			Other Uses[a]	Total Value
				Road Making and Railroad Ballast	Concrete	Agricultural		
Allamakee	3	*	*	*	$	$	$	$ 3,523
Benton	1	....	....	....	....	....	*	*
Black Hawk	2	*	....	*	*	*	....	*
Cedar	1	....	....	*	*	....	....	*
Clayton	1	....	....	....	*	*	....	*
Clinton	1	*	*	....	....	....	....	*
Dubuque	6	*	13,688	*	*	....	*	59,126
Floyd	2	....	....	....	....	....	*	*
Hamilton	1	....	....	....	....	....	*	*
Hardin	1	....	....	....	*	*	....	*
Henry	2	....	*	....	*	....	....	*
Howard	1	*	....	*	....	....	....	*
Jackson	1	....	....	....	....	....	*	*
Jones	5	10,885	9,060	*	49,631	1,126	*	72,036
Lee	4	*	29,325	*	32,792	*	*	87,558
Linn	2	....	....	*	*	....	....	*
Louisa	1	*	....	....	....	....	....	*
Madison	2	....	....	....	*	*	*	*
Marshall	1	....	*	*	*	....	....	*
Mitchell	1	....	....	....	....	....	*	*
Pocahontas	1	....	....	....	*	....	....	*
Scott	4	....	4,630	6,065	116,122	14,662	15,906	157,385
Van Buren	2	*	....	....	....	....	....	*
Counties with less than three producers		4,216	3,295	44,450	141,077	8,796	75,024	201,122
Total	46	$ 15,101	$ 59,998	$ 50,515	$339,622	$ 24,584	$ 90,930	$580,750

[a] Includes: Lime and sandstone, $60,817; flux, $18,895; sugar factories, paper mills, whiting, $7,353; paving, curbing and miscellaneous, $3,865.

TABLE IV (Continued)

PRODUCTION OF STONE AND LIME IN 1918

Counties	No. of Producers	Building Stone	Rubble and Riprap	Crushed Stone			Other Uses[a]	Total Value
				Road Making and Railroad Ballast	Concrete	Agricultural		
Allamakee	4	$ *	$ 11,381	$ *	$	$	$	$ 15,381
Black Hawk	1	....	....	....	*	*	....	*
Clinton	1	*	*	....	....	....	....	*
Des Moines	1	....	*	....	....	....	....	*
Dubuque	5	*	8,947	*	*	....	*	44,099
Floyd	1	....	....	....	....	....	*	*
Hardin	1	....	....	*	....	....	....	*
Henry	1	....	*	....	*	....	....	*
Howard	1	....	....	....	*	....	....	*
Jackson	2	....	....	*	....	....	*	*
Jones	4	*	12,977	*	*	*	....	58,420
Keokuk	1	....	....	....	*	....	....	*
Lee	3	*	*	*	14,300	*	....	38,060
Linn	2	....	....	*	*	*	....	*
Madison	1	....	....	....	*	....	....	*
Marshall	1	....	*	*	....	....	....	*
Mitchell	1	....	....	....	....	....	*	*
Pocahontas	1	....	*	....	*	....	....	*
Scott	6	....	15,014	*	130,320	14,381	*	172,758
Counties with less than three producers		....	23,560	....	48,249	4,892	....	116,082
Total	38	$ 22,749	$ 71,879	$ 52,179	$192,869	$ 19,273	$ 85,851	$444,800

[a] Includes: Lime, and stone sold to sugar factories, $71,613; flux, $14,238.

SAND AND GRAVEL.

The value of sand and gravel produced in Iowa in 1917 was somewhat in advance of that produced in 1916. In the earlier year the production amounted to $980,272, while in the later year it was $1,060,586. In the same period, however, the production diminished from 3,321,691 tons in 1916 to 2,909,441 tons in 1917. In 1918, on the other hand, the output was smaller both in volume and in value than in 1917, for it amounted to 2,004,444 tons with a value of $904,307.

Iowa ranked eleventh among the states in value of output in 1917 and twelfth in 1918. Forty-seven counties of the state reported production in both 1917 and 1918 and each year Polk county was well in the lead in both quantity and value of output. Clayton county is the leader in the finer grades of sand, as the St. Peter sandstone yields sand of exceptional fineness and purity of quality combined with ease of recovery. Most of the sand and gravel produced in Iowa, however, is derived either directly or indirectly from the glacial drift.

The following table will summarize briefly the distribution of the output.

	1916		1917		1918	
KIND	TONS	VALUE	TONS	VALUE	TONS	VALUE
Sand used for						
Building	1,181,505	$388,080	1,194,878	$ 372,756	903,425	$391,120
Engines	19,177	5,296	21,093	6,146	33,283	14,748
Railroad ballast	924,191	164,800	471,822	119,223	397,795	71,356
Paving	231,300	72,571	191,099	67,497	62,577	30,202
Molding		3,080	72,844	26,028	29,219	13,469
Filters	31,948	9,250	26,735	8,616	10,686	5,649
Glass sand, grinding and polishing, fire or furnace sand		4,678	4,000	3,000	9,561	5,286
Miscellaneous	68,880	23,218	48,052	12,798	33,357	11,277
Gravel	853,277	309,299	878,918	444,522	524,541	361,200
Total	3,321,691	$980,272	2,909,441	$1,060,586	2,004,444	$904,307

Apparently the most valuable sand regained in the state is "fire or furnace sand", which is valued at one dollar per ton. Glass sand ranks next with a valuation of ninety cents per ton. On the other hand some of the railway companies value their ballast at only ten cents per ton and one company valued the entire output from one pit at only one dollar. These low figures of course tend to reduce the total output much below its true value as indicated by the service it performs.

Table V gives in detail the statistics of production by counties in-so-far as these can be revealed:

TABLE V

PRODUCTION OF SAND AND GRAVEL IN 1917

Counties	No. of Producers	Building Sand	Engine Sand*and RR.Bal'st Sand†	Paving Sand	Other Sand[b]	Gravel	Quantity Tons	Value
Black Hawk	6	$ *	$......	$......	$ *	$ 10,470	55,819	$ 17,081
Boone	1	......	......	*	......	*	*	*
Bremer	2	*	......	*	......	......	*	*
Buena Vista	2	*	......	......	......	*	*	*
Butler	1	*	......	......	......	......	*	*
Carroll	1	*	......	......	......	......	*	*
Cerro Gordo	3	*	*†	*	*	69,523	252,301	118,782
Cherokee	2	*	†	......	*	*	*	*
Clay	1	*	......	......	......	*	*	*
Clayton	1	......	......	......	*	......	*	*
Clinton	6	*	*	......	......	9,054	30,090	12,658
Crawford	1	......	*	......	......	......	*	*
Des Moines	2	*	......	*	......	*	*	*
Dickinson	2	......	†	......	......	*	*	*
Dubuque	3	15,446	*	......	......	*	55,926	35,805
Emmet	2	*	†	......	......	......	*	*
Fayette	1	*	......	......	......	......	*	*
Franklin	4	*	......	......	......	*	3,109	1,370
Hardin	2	......	......	......	......	*	*	*
Howard	2	*	......	......	......	*	*	*
Humboldt	1	*	†	......	*	*	*	*
Jackson	6	10,178	†	*	......	5,692	49,718	18,824
Jones	2	*	*	......	......	......	*	*
Kossuth	1	*	......	......	......	......	*	*

[a] Includes: Engine sand, $6,146; railroad ballast, $119,223.

[b] Includes: Glass sand, grinding and polishing sand, fire or furnace sand, $3,000; molding sand, $26,028; filter sand, $8,616; uses not specified, $12,798.

* Included under Counties with less than three producers.

TABLE V (Continued)

Counties	No. of Producers	Building Sand	Engine Sand*and RR.Bal'st Sand†	Paving Sand	Other Sand[b]	Gravel	Quantity Tons	Value
Lee	2	*		*		*	*	*
Linn	4	*				*	141,346	43,510
Lyon	1	*		*		*	*	*
Mahaska	1	*	*			*	*	*
Marion	2	*			*	*	*	*
Marshall	2	*		*		*	*	*
Muscatine	3	*	*	*	*	30,737	153,664	55,259
O'Brien	3	*				*	2,580	1,410
Osceola	2	*	†				*	*
Page	1	*					*	*
Palo Alto	2	*		*		*	*	*
Plymouth	3	*				*	29,981	11,090
Polk	12	67,499	104,465	2,196	24,321	78,874	747,225	277,355
Sac	2	*			*	*	*	*
Scott	2	*					*	*
Sioux	6	25,311	*	*	*	19,688	113,353	53,370
Story	2	*				*	*	*
Van Buren	1	*					*	*
Wapello	4	22,281	*	*	*	*	133,247	44,590
Webster	3	*		*			11,117	*
Winneshiek	2	*				*	*	*
Woodbury	1	*					*	*
Wright	3		†			*	36,228	*
Counties with less than three producers		232,041	20,905	65,301	26,121	220,484	1,093,737	367,482
Total	119	$ 372,756	$ 125,369[a]	$ 67,497	$ 50,442	$ 444,522	2,909,441	$1,060,586

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[a] Includes: Engine sand, $6,146; railroad ballast, $119,223.

[b] Includes: Glass sand, grinding and polishing sand, fire or furnace sand, $3,000; molding sand, $26,028; filter sand, $8,616; uses not specified, $12,798.

* Included under Counties with less than three producers.

TABLE V (Continued)

PRODUCTION OF SAND AND GRAVEL IN 1918

Counties	No. of Producers	Building Sand	Engine Sand*and RR.Bal'st Sand†	Paving Sand	Other Sand[b]	Gravel	Quantity Tons	Value
Black Hawk	5	$ 18,860	$ *	$	$ *	$ 13,185	81,443	$ 35,578
Boone	1	*				*	*	*
Bremer	1	*					*	*
Buena Vista	2					*	*	*
Butler	1	*					*	*
Carroll	1	*					*	*
Cerro Gordo	1	*	*†	*		*	*	*
Cherokee	2	*	†	*	*	*	*	*
Clay	1	*			*		*	*
Clayton	1				*		*	*
Clinton	5	*	*			6,340	18,992	9,300
Crawford	1		*				*	*
Des Moines	2	*		*		*	*	*
Dickinson	1	*		*			*	*
Dubuque	2	*				*	*	*
Fayette	2	*				*	*	*
Floyd	1	*	*				*	*
Franklin	3	*		*			2,032	705
Hardin	3			*	*	*	13,580	4,094
Howard	1	*					*	*
Humboldt	1	*	†		*	*	*	*
Ida	1	*					*	*
Jackson	1	*				*	*	*
Johnson	2	*				*	*	*

[a] Includes: Engine sand, $14,748; railroad ballast, $71,356.

[b] Includes: Glass sand and fire or furnace sand, $2,525; molding sand, $13,469; grinding and polishing sand, $2,761; filter sand, $5,649; uses not specified, $11,277.

* Included under Counties with less than three producers.

TABLE V (Continued)

Counties	No. of Producers	Building Sand	Engine Sand* and RR. Bal'st Sand†	Paving Sand	Other Sand^b.	Gravel	Quantity Tons	Value
Jones	2	*	*†	....	....	....	*	*
Lee	2	*	....	....	....	....	*	*
Linn	4	*	....	....	....	*	57,599	25,271
Lyon	1	....	....	....	....	*	*	*
Mahaska	1	*	*	*	....	*	*	*
Marion	2	*	....	....	....	*	*	*
Marshall	1	*	....	....	....	*	*	*
Montgomery	1	*	....	*	....	....	*	*
Muscatine	4	*	*	....	1,200	28,580	117,247	59,436
O'Brien	4	*	....	....	....	*	3,776	3,408
Osceola	2	*	†	....	....	....	*	*
Palo Alto	2	*	....	....	....	....	*	*
Plymouth	3	10,000	....	....	....	....	18,648	10,000
Polk	11	85,180	25,442	6,481	15,674	88,857	534,955	221,634
Sac	3	*	†	....	....	*	230,006	86,457
Scott	2	*	....	*	....	....	*	*
Sioux	6	21,636	*	....	....	*	71,867	49,270
Van Buren	1	*	....	....	....	....	*	*
Wapello	2	*	*†	*	*	*	*	*
Webster	3	*	....	....	*	*	9,075	4,362
Winneshiek	2	*	....	....	....	*	*	*
Woodbury	2	*	....	....	....	*	*	*
Wright	3	....	†	....	....	*	53,330	8,949
Counties with less than three producers		255,444	60,662	23,721	18,807	224,238	791,894	385,843
Total	106	$ 391,120	$ 86,104^a	$ 30,202	$ 35,681	$ 361,200	2,004,444	$ 904,307

[a] Includes: Engine sand, $14,748; railroad ballast, $71,356.

[b] Includes: Glass sand and fire or furnace sand, $2,525; molding sand, $13,469; grinding and polishing sand, $2,761; filter sand, $5,649; uses not specified, $11,277.

* Included under Counties with less than three producers.

GYPSUM.

Iowa maintained its rank as the second producer of gypsum and its products in the United States in both 1917 and 1918, being exceeded by New York alone. The value of the output during 1917 was the largest in the history of the industry to date, even though the amount of crude gypsum mined and also of the finished product was less than that of the year before. This increase in value was due to the increased costs of production, including labor charges, costs of fuel and supplies and the abnormal conditions attending the prosecution of a great war. These abnormal conditions became especially marked during the later months of 1917 and through 1918.

All of the gypsum mined in the state was produced by the five mills at Fort Dodge, as the mill at Centerville was not operated during the two years here under discussion. The mill of the Wasem Plaster Company was burned May 16, 1918, but was rebuilt as a fireproof structure later during the year. Iowa, being far from the industrial centers which were most benefited by the war, showed a decline in 1918 in both quantity of raw material and finished product handled and in the total value of the output as compared with some of the eastern states. Thus the decrease in quantity mined in 1918 in Iowa as compared with that mined in 1917 was 29 per cent and the decrease in the value of the output was 5 per cent during the same period. In New York, on the contrary, the decrease in quantity mined in 1918 was 12 per cent but the value of the output increased 16 per cent over the 1917 output.

One of the encouraging features of the gypsum industry in Iowa is the increasing use of the crude rock for agricultural fertilizer. In 1916 there was sold 12,923 tons valued at $18,428. In 1917 the amount was increased to 14,194 tons valued at $30,253 and in 1918, while the amount decreased to 10,546 tons, its value increased to $37,823. There seems to be no doubt that as the valuable qualities of raw gypsum as a fertilizer become better known the demand for it will increase largely. It will be of interest to compare the production of the leading states for 1916, 1917 and 1918 as shown in the following table:

State	TONS MINED 1916	1917	1918
New York	579,827	606,268	531,038
Iowa	522,293	461,864	327,927
Michigan	457,375	375,803	286,768
Ohio	286,678	270,538	199,456
Texas	197,785	257,328	157,388
Total for the United States	2,757,730	2,696,226	2,057,015

SOLD CRUDE

State	1916		1917		1918	
	TONS		TONS		TONS	
New York	195,246	$292,032	223,392	$ 420,071	183,107	$ 466,639
Iowa	60,846	59,294	65,012	110,741	57,719	160,148
Michigan	80,298	90,973	68,155	116,653	46,608	131,438
Ohio	11,615	18,683	10,610	28,380	14,005	48,572
Texas	----------	----------	----------	----------	----------	----------
Total for U. S.	547,119	$790,430	623,995	$1,124,370	470,192	$1,236,552
Average price per ton		$1.44		$1.80		$2.63

	SOLD CALCINED						TOTAL VALUE		
STATE	1916		1917		1918		1916	1917	1918
	TONS		TONS		TONS				
New York	311,264	$1,167,555	295,646	$1,872,347	275,333	$ 2,213,460	$ 1,459,587	$ 2,293,418	$ 2,670,099
Iowa	373,416	1,437,498	322,198	1,931,256	218,178	1,786,266	1,496,795	2,041,997	1,946,414
Michigan	292,109	975,626	257,588	1,452,002	207,059	1,629,711	1,066,599	1,568,655	1,761,149
Ohio	247,802	909,176	219,679	1,276,117	162,626	1,191,077	927,859	1,304,497	1,239,649
Texas	163,444	653,288	220,983	996,262	129,034	834,560	653,288	996,262	834,500
Total for U. S.	1,805,814	$7,168,602	1,677,390	$9,992,082	1,328,209	$10,234,302	$7,959,032	$11,116,452	$11,470,854
Average price per ton		$3.97		$5.96		$7.70			

The nearness of the New York mills to the great Portland cement manufacturing districts of the east gives the state a fine market for crude gypsum to be used as a retarder in the finished cement. Nearly 45 per cent of the gypsum used in the United States for this purpose comes from New York. Nearly forty per cent of the gypsum used for land plaster comes from Virginia, while Iowa ranks second and Nevada third in sales of gypsum used for this purpose. Iowa furnishes about 15 per cent of the calcined gypsum used in plate-glass manufacture, Michigan produces 25 per cent and Ohio furnishes the other 60 per cent.

The following table will show in some detail the output of gypsum in Iowa in 1917 and 1918 and the various uses to which it was applied. The Iowa Paint Company of Fort Dodge, which used ground raw gypsum as the base of its paints, was not operating during 1917 or 1918. The Fort Dodge mill of the Acme Cement Plaster Company was burned previously and has not been rebuilt.

VALUE OF GYPSUM PRODUCED IN IOWA.

	1917		1918	
	TONS	VALUE	TONS	VALUE
Crude gypsum mined	461,864		327,927	
Sold crude				
To Portland Cement Mills	50,818	$80,488	46,259	$119,583
As land plaster	14,194	30,253	10,546	37,823
To paint mills and for other purposes	....	....	914	2,742
Total sold crude	65,012	110,741	57,719	160,148
Sold calcined as stucco	59,916	232,813	20,115	128,977
As mixed wall plaster	224,893	1,371,012	159,322	1,225,924
As plaster of paris, Keene's cement, to plate glass works, to				

Portland Cement mills, and for uses not specified	885	6,045	1,975	14,997
As boards, tile or blocks	36,504	321,386	36,766	416,368
Total sold calcined	322,198	1,931,256	218,178	1,786,266
Total	387,210	2,041,997	275,897	1,946,414

CEMENT.

As was the case in most branches of the mineral industry cement manufacture in Iowa was adversely affected by the war as may be seen from the following summarized table:

	1916		1917		% change in quantity, 1917	1918		% change in quantity, 1918
	Barrels	Value	Barrels	Value		Barrels	Value	
Shipments	4,853,789	$6,165,547	4,408,765	$6,870,863	-8.8	3,188,669	$5,423,926	-28.0
Production	4,703,213		4,626,141		-1.6	3,626,455		-21.6

This decrease in both quantity and value of production prevailed in spite of the gradual increase of the price per barrel of the finished cement, which rose from $1.270 in 1916 to $1.551 in 1917 and to $1.701 in 1918. This condition prevailed throughout the commercial district in which Iowa belongs and which includes also Missouri and Minnesota. In this district the decline in value of shipments from 1917 to 1918 was 24.3 per cent though the average factory price per barrel rose 9.8 per cent. The per capita consumption in Iowa has decreased correspondingly. In 1916 Iowa led the states of the Union with a consumption of 1.77 barrels per capita; in 1917 she had dropped to second place with a consumption of 1.57 barrels per person, while Montana led with a per capita consumption of 1.69 barrels. In 1918 the leader was the District of Columbia with a per capita consumption of 1.61 barrels while Iowa had gone down to seventh place, as her consumption was only 1.03 barrels per capita. The total consumption in the state during these years was as follows:

	1916	1917	1918
Population (estimated)	2,220,321	2,224,771	2,224,771
Consumption (barrels)	3,930,325	3,501,871	2,298,157
Estimated consumption per capita	1.77 bbls.	1.57 bbls.	1.03 bbls.

The year 1917 was marked by the introduction in the field of the Fort Dodge Portland Cement Corporation, with mill at Gilmore, Pocahontas county, where an excellent quality of limestone is readily available in practically unlimited quantities. Shale is obtained from just below Fort Dodge. This plant has two kilns 8 by 125 feet in dimensions and has a daily capacity of 1500 barrels of cement. There are now four cement factories in Iowa with a total of twenty-six kilns and a daily capacity of 15,100 barrels, a total of 4,900,000 barrels for the year. Three of the companies use the dry process, namely the Lehigh and Northwestern States of Mason City and the Fort Dodge of Gilmore. The Hawkeye Portland Cement Company of Des Moines uses the wet process.

The following table will show the importance of the industry in the United States and the rank of the ten leading states.

SHIPMENT OF PORTLAND CEMENT BY TEN LEADING STATES

	Active plants		1917		1918		Percentage of change in quantity in 1918	Average price per barrel	
State	1917	1918	Barrels	Value	Barrels	Value		1917	1918
Pennsylvania	21	21	27,709,442	$ 34,512,388	22,238,689	$ 33,600,956	–19.7	$1.246	$1.511
Indiana	5	5	8,148,678	11,084,930	6,205,326	9,580,563	–23.8	1.360	1.544
Missouri	5	5	5,800,988	8,248,007	4,515,695	7,132,470	–22.2	1.422	1.579
California	9	10	5,659,547	7,426,097	4,238,424	7,091,789	–25.1	1.312	1.673
New York	9	8	5,408,708	7,050,656	4,074,159	6,568,746	–24.7	1.304	1.612
Michigan	11	10	4,313,771	6,122,887	3,618,088	6,078,167	–16.1	1.419	1.680
Iowa	4	4	4,428,765	6,870,863	3,188,669	5,423,926	–28.0	1.551	1.701
Illinois	4	4	4,378,233	6,090,158	3,703,471	5,695,186	–15.4	1.391	1.538
Kansas	8	7	3,772,884	5,271,721	2,586,834	4,219,203	–31.4	1.397	1.631
Texas	5	5	2,358,944	3,661,328	1,918,919	3,297,977	–18.7	1.552	1.719
Total of United States	118	115	90,703,474	122,775,085	70,915,508	113,153,513	–21.8	1.354	1.596

In 1917 the United States Geological Survey began the collection of statistics on the production of "concrete stone" in the United States in response to numerous requests for information on the subject. These figures show that the industry is one of considerable importance and that Iowa ranks among the leading states in the use of cement for this purpose. The output in Iowa was chiefly in the form of concrete blocks and bricks. In 1917 there were made 1,407,824 of these blocks and bricks which were valued at $193,480. A small quantity of "Architectural stone" was made also. The output for 1918 was 2,401,772 blocks and bricks with a value of $225,054. The total production for the United States was valued at $3,127,937 in 1917 and at $3,372,277 in 1918, an increase of 8 per cent.

LEAD AND ZINC.

The lead and zinc industry of Iowa has not been in a flourishing condition for some years. Even the great demand for these metals in war time did not stimulate mining here as it did in some districts. The reports to the United States Geological Survey show that during 1917 about a thousand tons of lead-zinc ore was produced and treated. From this ore there were derived 60 tons of zinc carbonate and silicate concentrates which yielded 18 tons of metallic zinc, and 43 tons of lead sulphide concentrate which yielded 34 tons of lead. At the average prices received—8.6 cents per pound for lead in New York and 10.2 cents per pound for zinc of all grades—the value of these metals would be $5,848 for the lead and $3,672 for zinc, a total of $9,520.

No production of either lead or zinc was reported in 1918.

MINERAL WATER.

During 1917 and 1918 there were five active mineral springs in Iowa from which water was sold. These were Fry's well and the Grand Hotel Mineral Springs at Colfax, the Hawkeye Hygeia Well at Sioux City, the Lime Rock Spring near Dubuque and the White Sulphur Spring at Linwood, Scott county. No report of sales from the last of these was received in 1918 and the Dubuque spring was a new addition in 1918.

The reported output from these springs for 1917 was as follows: The total mineral water sold was 99,103 gallons, valued at $12,125, an average price of twelve cents per gallon. These figures, compared with sales of 148,732 gallons valued at $14,404 in 1916, show a decrease of 33 per cent in quantity and 16 per cent in value, as the average price received in 1916 was ten cents per gallon. In addition 144,443 gallons of mineral water was used in 1917 in making soft drinks. One mineral water bathing establishment and one resort were maintained. The waters sold were classed as medicinal, valued at $4,375, and table waters, valued at $7,750.

In 1918 there was sold 87,703 gallons at an average price of four cents per gallon, giving a total value of $3,937, of which sum $2,479 was received for medicinal waters and $1,458 for table waters. The decrease in quantity and value amounted to 12 per cent and 68 per cent respectively. About 215,000 gallons of mineral water was used in making soft drinks.

POTASH.

It is interesting to note that in 1918 some potash was recovered from the waste material resulting from beet sugar refining. This potash is recovered by the Steffens process, which consists in diluting the beet-sugar molasses, precipitating the remaining sugar content with lime, and filtering. This filtrate contains about 0.35 per cent of potash along with other solids and these are concentrated after removal of the lime. This concentrate is sold for fertilizer and contains the nitrogenous matter originally present. From 10 to 34 per cent of potash is present in the final product, depending on the degree of concentration.

NATURAL GAS.

For many years Iowa has been a small but persistent producer of natural gas from wells in the glacial materials. These wells are all shallow and range from ninety to one hundred twenty feet in depth. They are situated near Herndon, Guthrie county, and near Letts in Louisa county. In 1917 the total production was 225,000 cubic feet valued at $225. Six wells were reported as being active on January 1, and seven at the close of the year.

The production in 1918 was much larger, amounting to 1,758,000 cubic feet, but the price per thousand feet was so much lower—from twelve to fifteen cents per thousand feet—that the value was only $245.

IRON ORE.

The Mississippi Valley Iron Company of St. Louis continued operations at its mine near Waukon and in 1917 it marketed 22,612 tons of beneficiated brown ore, with an average metallic iron content of about 51 per cent.

In 1918 over 7000 tons of ore was mined, but in the latter part of the year the plant was closed on account of adverse market conditions due to the war. It is worthy of note that the price received for Iowa ore is higher than the average from other states for ores of the same class.

The manufacture of ferrosilicon during 1916, 1917 and 1918 was reported by one Iowa firm.

GYPSUM: ITS OCCURRENCE, ORIGIN, TECHNOLOGY AND USES

WITH SPECIAL CHAPTERS DEVOTED TO

GYPSUM IN IOWA

BY

FRANK A. WILDER

TABLE OF CONTENTS

PAGE

Preface 61

Chapter I. Physical and Chemical Properties of Gypsum 63

- Physical Properties 63
  - Hardness 63
  - Weight 63
  - Solubility 63
  - Compressive Strength 64
  - Absorption 65
- Varieties of Gypsum 66
  - Selenite 66
  - Satin Spar 68
  - Rock Gypsum 72
    - Alabaster 72
    - Gypsite 72
- Chemical Composition of Gypsum 72
  - Standard Analysis 72
  - Type Analyses 73
  - Analyses of Oklahoma Gypsum 74
  - Analyses of New York Gypsum 75
  - Analyses of Colorado and Wyoming Gypsum 75
  - Analyses of Michigan Gypsum 75
  - Analyses of South Dakota Gypsum 76
  - Analyses of Montana Gypsum 76
  - Analyses of Australia Gypsum 77
  - (For Iowa Analyses see Chapter VII, pages 207, 208, 210)
- Physical and Chemical Properties of Anhydrite 77
  - Physical Properties 77
    - Hardness 77
    - Weight 77
    - Color 78
    - Texture 78
    - Structure 78
  - Chemical Composition 78

Chapter II. Description of Important Deposits of Gypsum in the United States and Foreign Countries 79

- United States 79
  - Alaska 79
  - Arizona 81
  - Arkansas 82
  - California 82
  - Colorado 83
  - Florida 84
  - Idaho 85
  - Iowa 85
  - Kansas 85

PAGE
Louisiana 86
Michigan 86
Montana 87
Nevada 88
New Mexico 89
New York 89
Ohio 91
Oklahoma 92
Oregon 93
Pennsylvania 93
South Dakota 94
Texas 94
Utah 95
Virginia 96
Wyoming 97
Canada 98
Nova Scotia 100
New Brunswick 100
Ontario 100
Quebec 100
Manitoba 100
British Columbia 101
Mexico 102
South America 102
Cuba 102
Germany 103
Austria 104
Switzerland 104
France 104
England 104
Russia 104
Spain 105
Italy 105
Persia 105
China 106
Australia 106
Africa 106
Geological Age of the More Important Gypsum Deposits of the World 107
Chapter III. Origin of Gypsum and Anhydrite 110
Introduction 110
Early Opinions 110
Recent Classifications 110
Deposition from Sea Water 111
Nature of Salts in Sea Water 112
Deposition of Salts from Sea Water 113
Karabugas Gulf 114
Nile Delta and Salt Pans 115
Red Sea Salinas 115
Difficulties of Evaporating Basin Theory 115
Branson's "Modified bar" Hypothesis 116

PAGE

    The Lime Carbonate Problem ... 117
      Stieglitz on Atmospheric Equilibrium ... 117
  Disseminated Gypsum ... 121
    From Connate Waters ... 121
    By Chemical Reaction ... 121
  Concentration of Disseminated Gypsum ... 121
    The Dead Sea ... 122
    Great Salt Lake ... 122
    Spring Deposits ... 124
    Seepages ... 125
      Satin Spar Veins ... 125
    Efflorescent Deposits ... 126
      Gypsum Dunes ... 126
  Gypsum Produced by Alteration ... 126
    From Limestone ... 126
    From Anhydrite ... 127
  Origin of Fort Dodge Gypsum ... 127
  Origin of Centerville Gypsum ... 129
  Origin of Anhydrite ... 129
    Newland's Interpretation of Van't Hoff's Work ... 129
    Newland's Theory ... 130
    Udden's Theory ... 130
Chapter IV. General Description of Iowa Gypsum Areas ... 131
  The Fort Dodge Area ... 131
    Early Geological Work ... 131
    General Location ... 132
      Location with Reference to Markets ... 133
    Size and Shape ... 133
  The Centerville Area ... 134
    Location ... 134
      With Reference to Markets ... 134
    Extent and Discovery ... 134
Chapter V. Stratigraphy of the Iowa Gypsum Areas ... 136
  General Relationships ... 136
    Table of Geological Formations ... 136
  Exposures Along Soldier Creek ... 136
    Kohl's Brewery Section ... 137
    Viaduct Section ... 138
    Iron Works Section ... 139
    Stone Bridge Section ... 140
    Hawkeye Clay Works Section ... 140
    Sections East of the Clay Works ... 140
  Des Moines River Sections North of Soldier Creek ... 142
    Brick and Tile Works Section ... 142
    Sections near the Dam ... 144
  Lizard Creek Sections ... 145
    Fort Dodge Clay Works Section ... 146
  Des Moines River Sections below Lizard Creek ... 147
    Fort Dodge Clay Works ... 147
    Bradshaw Clay Pit ... 148

PAGE

- Plymouth Mine 149
- Interurban Railway Exposures 149
- Vincent Clay Pit 150
- Gypsum Hollow Exposures 153
- Gilmore Portland Cement Company's Pit 153
- Johnson Brothers Clay Pit 154
- Pit of Plymouth Clay Products Co. 154
- Craig's Hollow 155
- Holiday Creek 155
- Well Data 156
  - Poor Farm Wells 156
  - Tabulation of Wells 159
  - Records of Prospect Holes 160
  - Miscellaneous Well Data 161
- St. Louis Limestone 163
  - Type Section (Lizard Creek) 164
- Ste. Genevieve 164
- Pennsylvanian 167
  - Des Moines Stage 167
- Permian 168
  - Fort Dodge Beds 168
  - Geological Age of the Fort Dodge Gypsum 171
- Structural Problems Connected with the Fort Dodge Beds 173
  - Unconformities 173
  - Keyes' Earlier Views 174
  - Keyes' later Hypothesis 174
  - Argument for Basin Structure 175
- Origin of the Gypsum 177
  - Possible Sources of the Gypsum 177
    - Analysis of St. Louis Limestone 177
    - From Gypsiferous Shales 178
    - Ste. Genevieve 178
    - Coal Measures 178
- Extent of the Fort Dodge Gypsum 179
  - Duration of the Gypsum Supply 180
- The Centerville Field 181
  - General Relationships 181
    - Table of Formations 181
    - Drill Records 182
  - Origin of the Centerville Gypsum 184

Chapter VI. History of the Gypsum Industry 185

- Egypt 185
- Greece 186
- Rome 186
- Germany 187
- America 187
  - Agricultural Gypsum 187
  - Calcining Introduced 190
  - Decline of Agricultural Gypsum 190
  - Revival of Agricultural Gypsum 191

PAGE

Gypsum Plasters 192
Gypsum Blocks 192
Gypsum Boards 193
Hydraulic Gypsum 194
Structural Gypsum 194
History of the Gypsum Industry in Webster County 194
Mills in Gypsum Hollow 194
The Blandon Mill 195
The Cardiff Mill 195
The Mineral City Mill 195
The Crawford Mill 196
The United States Gypsum Company 196
The Waterloo Mill 196
The Plymouth Mill 196
Iowa Hard Plaster Company 196
Acme Cement Plaster Company 196
The Wasem Mill 196
The Iowana Company 196
History of the Centerville Field 199
Chapter VII. Physical and Chemical Characteristics of Iowa Gypsum 200
The Fort Dodge Beds 200
Bedding 200
Ledges 201
Lamination 201
Expansion Peculiarities 202
Domes 205
Solution Surfaces 205
Chemical Composition 207
Earlier Analyses 207
Recent Analyses 208
The Centerville Gypsum 209
Physical Properties 209
Color 209
Texture 209
Associated Minerals 209
Anhydrite 209
Chemical Composition 209
Caves 210
Chapter VIII. Technology of Gypsum and Gypsum Plasters 211
Winning of Gypsite 211
Quarrying Gypsum 211
Drilling 211
Explosives 211
Mining Methods 212
Crushing 213
Drying 215
Grinding 216
Burr Mills 216
Horizontal Emery Mills 216
Disintegrators 218

PAGE

  Screens 218
  Roller Mills 218
  Fineness 219
    Tests of 1918 223
    Tests of 1922 225
    Plasticity and Fineness 226
 Calcining 227
  Kettles 228
    Suitable Coal 231
    Mechanical Agitation 231
    Fuel Requirements 232
    First Settle 232
    Second Settle 233
      Uses of Second Settle Calcined Gypsum 233
    Calcining Gypsite 234
  Rotary Calciners 235
    German Type 236
    Cummer Process 237
    Cement Mill Rotary 239
 Regrinding 239
 Plastic Gypsum 240
 Mixing for Wall Plastor 240
  Retarder 240
  Fibre 241
    Hair Picker 241
    Wood Fibre Machines 241
  Mixing 242
 Automatic Packing 243
  Bags 244
    Jute 244
    Paper 244
Chapter IX. Use of Gypsum in Portland Cement 246
 Purpose 246
 Limits 246
 Forms Used 246
  Gypsum 246
  Calcined Gypsum 246
  Anhydrite 246
    Objections to Use of Anhydrite 247
Chapter X. Gypsum in Agriculture 248
 Early History 248
  In Europe 248
    Mayer's Statement 248
    Kirchberger's Paper 249
    Tschiffeli's Paper 249
  In America 249
    Judge Peters' Book 249
    Binns' Book 252
    Benjamin Franklin 253
    George Washington 254

PAGE
C. F. Grece 254
Edmund Ruffin 254
In England 255
Fothergill 255
Smithe 255
Johnson 256
Storer 257
Gypsum as an Indirect Fertilizer 257
The Potash Problem 258
Gypsum as a Direct Fertilizer 258
Sulphur as Plant Food 258
Wisconsin Bulletin No. 14 258
Shedd in Kentucky 259
Brown and Kellogg 260
Reimer's Work in Oregon 260
Gypsum and Nitrogen-Secreting Bacteria 262
Work of St. John and Olsen 262
A Permanent System of Soil Fertility 265
Gypsum for Cotton 266
Gypsum for Sugar Cane 268
Gypsum as Manure Preservative 269
Chapter XI. Other Uses for Raw Gypsum 270
Terra Alba 270
Flux 270
Insecticides 270
Alabaster 271
Crayons 271
Imitation Marble 271
Sulphuric Acid 271
Miscellaneous Uses 271
Possible Future Uses 272
Chapter XII. Chemical Characteristics of Calcined Gypsum 273
Natural Forms 273
Artificial Forms 273
Existing Confusion 273
Importance of Careful Investigation 273
Historical Sketch 274
Work of Lavoisier 274
Payen 274
Berthier 274
Le Chatelier 274
Glasenapp's Classification 276
"First Settle" Calcined Gypsum 276
"Second Settle" Calcined Gypsum 277
Soluble Anhydrite 277
The Setting of Calcined Gypsum 277
Chapter XIII. Physical Properties of Calcined Gypsum 279
Color 279
Fineness 280
Normal Consistency 280

PAGE
German Method 280
Iowa City Method 281
Southard's Viscosimeter 282
Setting Time 285
Definition 285
Initial Set 285
How Determined 286
Final Set 286
How Determined 286
Rise of Temperature Method 286
Vicat Needle Method 286
German Method 287
Factors Governing Time of Set 288
Consistency 288
Calcining 288
Impurities 289
Plasticity 289
Definition 289
Hardness 291
Compressive Strength 291
Heat Conductivity 291
Lightness 293
Tensile Strength 294
Tables of 295
Factors Governing Tensile Strength 298
Adhesion 299
Expansion and Contraction 299
Change in Volume while Setting 300
Heat Conductivity 301
Sound Conductivity 302
Behavior of Mixtures of Gypsum and Portland Cement 302
Chapter XIV. Uses of Calcined Gypsum 304
Interior Plasters 304
Cement Retarder 304
Gypsum Blocks 305
Plaster Boards 305
Poured Roof Decks 305
Plate Glass Industry 305
Insulation 305
Pottery Molds 306
Statuary 306
Surgical Uses 306
Scagliola 306
Dental Plaster 306
Cold Water Paints 306
In "Staff" 306
Miscellaneous 307
Chapter XV. Composition and Properties of Gypsum Plasters; Their Manipulation and Specifications for Their Use 308
Neat Gypsum Plaster 308

PAGE

- Composition 308
  - Fibre 308
  - Nature and Purpose of Other Ingredients 308
- Setting Time 309
- Coatings 309
  - Composition of 309
- Gypsum Wood Fibre Plasters 310
  - Composition of 310
- Gypsum Ready Mixed Plasters 310
- Tensile Strength 311
  - Methods of Testing 311
  - Effects of Retarder 311
  - Effects of Other Ingredients 311
  - Tables 312
  - Minimum Tensile Strength 314
- Compressive Strength 314
- Adhesion 314
- Backgrounds for Gypsum Plasters 315
- Application of Gypsum Plasters 315
  - Specifications for 315

Chapter XVI. Gypsum Blocks 322
- Definition 322
- Historical Sketch 322
- Composition of 322
- Types of 322
  - Partition Blocks 323
    - Standard Specifications for 323
    - Manufacturing Methods 323
    - Advantages of 324
      - Fire Protection 324
      - Light Weight 325
      - Nonconductivity 326
      - Economy 326
      - Strength 326
    - Specifications for Setting 325
  - Furring Blocks 328

Chapter XVII. Gypsum Plaster Board and Gypsum Wall Board 329
- Definitions 329
- Plaster Board 329
  - Composition 329
  - Twoply 329
    - Specifications 329
  - Impregnation of Binding Material 331
  - Adhesion of Plaster to 331
  - Fire Tests 332
  - Sound Tests 334
  - Rules for Application 335
    - Rules for Applying Plaster on 335
      - Mortar 335
      - Finishing Coats 336

PAGE

- Wall Board 338
  - Definition 338
  - Nature of 338
  - Advantages of 340
- Manufacture of 340

Chapter XVIII. Structural Gypsum 342

- Definition 342
- Slater's Tests 342
- Advantages of 346
  - Fire Resistance 346
  - Lightness 347
  - Elasticity 347
  - Nonconductivity 347
  - Speed in Construction 347
  - Strength 348
  - Durability 349
- Gypsum Roof Construction 349
  - Historical 349
  - Types of 350
    - The Poured Roof 350
    - Roof Blocks 351
- Gypsum Floors 353

Chapter XIX. Hydraulic Gypsum and Keene's Cement 354

- Definition 354
- The German "Estrich" 354
- How Calcined 355
- Made from Anhydrite 355
- Chemical Nature of 355
- Theory of Set 356
- Manufacture of 356
- Properties of 358
- Advantages of 358
- Application of 359
- Keene's Cement 366
  - Composition of 366
    - American 366
    - English 366
  - Manufacture of 367
    - Rotary Kilns 367
  - Properties of 369
- Parian Cement 369
- Mack's Cement 369

Chapter XX. Retarders and Accelerators 370

- Retarders 370
  - Clay 370
  - Organic Matter 370
  - Standard Retarders 370
  - Amounts Used 370
  - Treatment of Over Retarded Plaster 371
- Accelerators 371

PAGE
Nature of 371
Raw Gypsum 371
Dried Mortar 371
Zinc Sulphate 372
Alum 372
Portland Cement 372
Effect of 372
Chapter XXI. Hardening and Coloring of Gypsum and Gypsum Plasters.. 373
Hardening Gypsum 373
Hardening Calcined Gypsum 374
Hardening Surfaces 374
Hardening by Mixing Chemicals 374
Coloring Wall Plasters 375
Chapter XXII. Statistics 376
Statistics for the United States 376
Iowa Statistics 380
Appendices
I. Results of Testing Gypsum. W. E. Emley and C. F. Faxon, Bureau of Standards 383
II. Microscopic Examination of Raw and Calcined Gypsum. Dr. E. S. Larsen, U. S. Geological Survey 392
III. German Methods of Testing Gypsum 400
IV. Measurement of the Time of Set of Calcined Gypsum. Warren E. Emley, American Ceramic Society 407
V. Some Factors Influencing the Time of Set of Calcined Gypsum. F. F. Householder 419
VI. Gypsum Composition Slab Construction for Roofs and Floors. Public Works of the Navy, Bulletin 25 426
VII. Emley Patent for Plastic Gypsum. W. E. Emley 449
VIII. Report on Design of Reinforced Gypsum Beams. W. A. Slater........ 454
IX. Gypsum Companies Operating in the United States, Canada, and Mexico in 1921 468
Bibliography 473
Books Treating of Gypsum in General 474
Locality References 475
General for the United States 475
References by States 476
Foreign 491
Canada 491
England 492
France 492
Germany 493
Switzerland 493
Australia 493
Egypt 493
Geology 493
Chemical and Mineralogical 494
Technical 497
Structural Uses 499
Tests 503

PAGE
Hydraulic Gypsum 508
Gypsum in Portland Cement 508
Miscellaneous References 509
Gypsum in Agriculture 511
  Older References 511
  Miscellaneous References 513
  Bibliography of George H. Olsen and J. L. St. John 514
  Bibliography of Courtenay De Kalb on the Value of Sulphur as a Fertilizer 533
Index 537

PREFACE

This volume is the outgrowth of an interest in gypsum which has extended over twenty-five years. While the writer was teaching science in the Fort Dodge high school from 1894 to 1897 the gypsum beds furnished a most interesting field for personal study and for class excursions. Later, while he was acting as Assistant State Geologist, the preparation of the report on Webster county was assigned to him, and opportunity was given for further study of the Fort Dodge beds. The Webster county gypsum furnished the theme for a doctor's thesis in 1902. During the past fifteen years an active interest in the industrial applications of gypsum has not lessened interest in the theoretical problems connected with this mineral, while it has led to a study of the literature dealing with its technology and chemistry. The report of the Iowa Survey on Webster county appeared in 1902. Prior to that date Grimsley's reports on the gypsum of Kansas and Michigan had appeared and were of great value to the gypsum industry. D. H. Newland's report on gypsum in New York appeared in 1910 and was followed by Snider's report on Oklahoma gypsum in 1913. R. W. Stone in Bulletin 697 of the United States Geological Survey described American gypsum quite fully and devoted a few pages to technology. A briefer paper along similar lines, by the same author, appeared somewhat earlier as Bulletin 155 of the Bureau of Mines.

Cole's report on gypsum in Canada, and Winterbottom's report for Australia have appeared in recent years and have added materially to the literature on this subject.

In view of the rapid growth of the gypsum industry and particularly on account of the present importance of the industry in Iowa and its great promise for the future, it has seemed proper to prepare a volume which should present all the available information in regard to Iowa gypsum and to supplement this geological study with a statement as complete as possible of manufacturing processes and of uses. The hope may be expressed that the volume will be of service to the industry in general and particularly to the gypsum industry in Iowa.

I wish to acknowledge the assistance received from the works of Pedrotti, V. Waldegg, Grimsley, Newland, Snider, Stone, Cole, Winterbottom, and from the recent writings of Mr. Marani and Dr. Crocker. In connection with the chapter on the origin of gypsum Professor T. C. Chamberlin and Professor Julius Steiglitz have made valuable suggestions. The Bureau of Standards and particularly Mr. Emley and Mr. Hull have made investigations and published papers on gypsum which are of great value. Members of Committee C-11 of the American Society for Testing Materials have contributed valuable information which is acknowledged at various places.

The topographic map has been prepared by the United States Geological Survey co-operating with the Iowa Geological Survey. The value of such a map for industrial and mining purposes is apparent. At the same time it furnishes an essential base on which to present the geology of the region.

Thanks are due the gypsum companies in Iowa, makers of gypsum machinery, and the Gypsum Industries Association for illustrative material.

Dr. James H. Lees has rendered valuable assistance in connection with all of the recent field work in Webster county and his aid was particularly valuable in connection with the preparation of sections of the Fort Dodge beds.

The engineering department of the State University conducted important physical tests and the chemical department made analyses of numerous samples from Fort Dodge and Centerville.

The assistance of Doctor Lees and Miss Newman in preparing the monograph for the press is gratefully acknowledged.

Respectfully,

FRANK A. WILDER.

GYPSUM

CHAPTER I

PHYSICAL AND CHEMICAL PROPERTIES OF GYPSUM

According to its texture, or crystalline structure, gypsum is known as massive gypsum, as selenite and as satin spar. These three varieties are alike in their specific gravity, in hardness and in solubility.

Hardness

Gypsum is one of the softest minerals, its hardness being placed at 1.5 to 2 in the Mohs scale, and it may be easily scratched with the finger nail. It lacks the greasy feel that characterizes other soft minerals like talc, soapstone, and graphite.

Weight

The specific gravity of gypsum, (that is its weight as compared with an equal volume of pure water) is 2.3 to 2.4. The specific gravity of a number of familiar substances is given in the following table, for purposes of comparison.

Limestone	2.46 to 2.84
Quicklime	2.30 to 3.18
Lime mortar	1.64 to 1.86
Gypsum	2.30 to 2.40
Anhydrite	2.90 to 2.98
Calcined Gypsum	1.81
Portland Cement	2.72 to 3.05

Weights of gypsum[1]

		Weight in lb. per cu. ft.[1]
(1)	Natural gypsum rock, free from surface water, not calcined, in block form	140 to 145
(2)	Crushed gypsum rock not calcined, all to pass through 1 inch ring	90 to 100
(3)	Gypsum rock ground so that 90 per cent of product will pass 100 mesh screen, dried of all free moisture, not calcined, commonly known as land plaster	75 to 80
(4)	Gypsum rock ground so that 90 per cent will pass 100 mesh screen, calcined, commonly known as stucco or plaster of Paris—	
	Loose	56 to 65
	Well shaken down or in bins	65 to 75
(5)	Plaster of Paris or stucco mixed with water into a stiff mass, such as mortar, set and dried out	77

Solubility

Gypsum is somewhat soluble in water, the solubility varying with the temperature, as shown in the following table of Marignac which has been verified by Grimsley.[2]

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[1] These figures were submitted in 1918, by V. C. Marani for use in Kidder's Architects' and Builders' Pocket-Book.

[2] Annales de Chimie Paris, 5th Ed., Vol. I, pp. 274-281. Quoted by Chatard, 7th Ann. Rept. U. S. Geol. Survey, and by Grimsley in the Univ. Geol. Survey of Kansas, Vol. V. p. 86.

TEMPERATURE	ONE PART GYPSUM DISSOLVES IN	ONE PART ANHYDROUS SULPHATE LIME DISSOLVES IN
At 32 °F— 0°C	415 parts of water	525 parts of water
At 64.5°F— 18°C	386 parts of water	488 parts of water
At 75.2°F— 24°C	378 parts of water	479 parts of water
At 89.6°F— 32°C	371 parts of water	470 parts of water
At 100.4°F— 38°C	368 parts of water	466 parts of water
At 105.8°F— 41°C	370 parts of water	468 parts of water
At 127.4°F— 53°C	375 parts of water	474 parts of water
At 161.6°F— 72°C	391 parts of water	495 parts of water
At 186.8°F— 86°C	417 parts of water	528 parts of water
At 212 °F—100°C	452 parts of water	572 parts of water

H. S. Gale[3] sums up certain investigations of Van't Hoff and Meyerhoff, stating that they "have shown that the solubility of gypsum gradually increases with rise of temperature from about 0.18 per cent at 0°C (32°F) to a maximum of about 0.21 per cent at about 40°C (104°F). With further increase in temperature the solubility steadily decreases until at 100°C (212°F) it is again 0.18 per cent or about the same as it was in ice water. The solubility may be increased more than three times by the addition of sodium chloride and more than four times by the addition of magnesium chloride.

"In summary the authors cited state that there are but two forms of calcium sulphate which are stable in the presence of any solution—gypsum and natural anhydrite—and the stability of one or the other form depends on the temperature and nature of the solution with which it is in contact. In pure solution gypsum is stable only up to 66°C when it begins to be transformed into anhydrite, but as the change takes place slowly the solubility may be determined beyond the point of its stability."

Compressive strength

The compressive strength of gypsum is a matter of great practical importance, inasmuch as the load that may be assigned to gypsum pillars in the mine is directly dependent on this property.

A test of the compressive strength of the Fort Dodge gypsum was made by the Watertown Arsenal in 1894, and the specimen showed strength sufficient to sustain a pressure of 2900 pounds per square inch.[4]

More elaborate tests have been made on three six-inch cubes

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[3] U. S. Geol. Survey, Bulletin 580, p. 302.

[4] S. W. Stratton, Director Bureau of Standards, in personal letter to the writer, dated April 29, 1914.

of Virginia gypsum and the results are closely in line with the single recorded test on the Fort Dodge mineral. The report of the Bureau of Standards follows:

> Gentlemen:
>
> Enclosed is a report of compression tests on three of the cubes of gypsum rock sent to this Bureau. Cube No. 2721 was previously soaked in water for two days and crushed by bringing the load on the bed faces; No. 2722 was crushed dry by loading parallel to the bed faces, and No. 2723 was crushed dry on the bed faces.
>
> Respectfully,
> S. W. STRATTON,
> Director.

COMPRESSION TESTS ON THREE CUBES OF GYPSUM

Submitted by

SOUTHERN GYPSUM COMPANY, NORTH HOLSTON, VIRGINIA

LAB. No.	DIMENSIONS FACES IN.	DIMENSIONS HEIGHT IN.	AREA SQ. IN.	ULTIMATE LOAD LBS.	COMPRESSIVE STRENGTH LBS. PER SQ. IN.	REMARKS
2721	5.97x5.98	6.00	35.70	105001	2944	Wet-loaded on bed
2722	6.00x5.98	5.98	35.88	93900	2617	Dry-loaded on edge
2723	5.90x5.90	5.98	34.81	112220	3224	Dry-loaded on bed

The amount of water absorbed by a specimen of Virginia gypsum, as determined by the Bureau of Standards at Washington, is as follows:

Absorption

TEST NO. 16143	LAB. NO. 2724
Percentage of water absorption by weight	0.20

The method of testing as described in a letter from the Bureau of Standards was as follows:

> "The gypsum was cut into cubes approximately three inches on the side, which were dried in the laboratory for several weeks. The cubes were then weighed, and this weight recorded as the dry weight. It should be noted that it was not possible to dry these cubes by heating on account of the readiness with which the composition of this material is changed. After obtaining the weight of the cubes which were dried in the laboratory, they were placed in a basin containing alcohol, and allowed to stand 48 hours. They were next weighed, and the increase in weight obtained was reduced to the equivalent weight of water. This equivalent weight was divided by the dry weight of the cubes,

> and multiplied by 100, which gave the percentage of water absorption by weight.
>
> "The reason for using alcohol instead of water was because it was found that the water dissolved a considerable amount of the gypsum when the test was made in the usual way. However, it may be pointed out that in the method used, it was assumed that alcohol would be absorbed to the same degree as water, an assumption which may not be warranted. We are inclined to believe now that a better determination could be made with special apparatus using water, and making a correction for solubility."

Several varieties of gypsum are recognized, depending on **Varieties** the presence or absence of crystalline structure, crystalline form and color.

Selenite is generally colorless, and is to some degree transparent, in many cases completely so. It possesses remarkably **Selenite** perfect cleavage and splits into thin plates like mica, from which it can be distinguished by its lack of flexibility and its crumbling on exposure to heat.

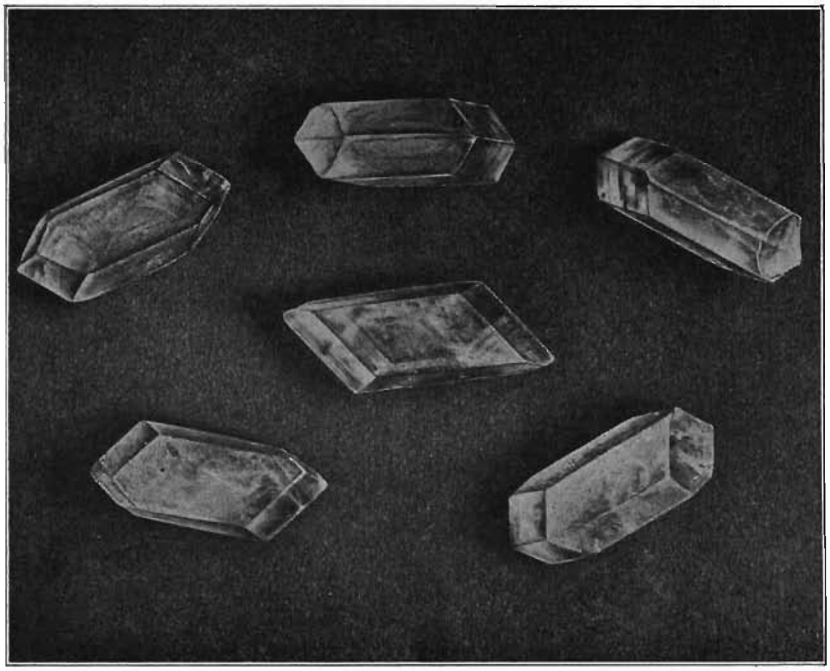

FIG. 1.—Gypsum crystals as developed when growth in all directions is unimpeded. Such crystals are found in the Coal Measures shales about Fort Dodge. More slender forms, often twinned, are found in the Mississippian marls north of Fort Dodge. Courtesy U. S. Geol. Survey.

Selenite often occurs in distinct crystals, which belong to the monoclinic system. The relative length of the axis is represented by the formula 0.6891 : 1 : 0.4156 and the angle of the inclined axis to the vertical is 81°5′. Twin crystals are common, the twinning being on the orthopinacoidal face. Beautiful selenite crystals, both individuals and twins, may be found in the Coal Measures clays of Iowa, and in the Cretaceous clays of the northwestern part of the state. The typical forms are shown in figures 1 and 2.

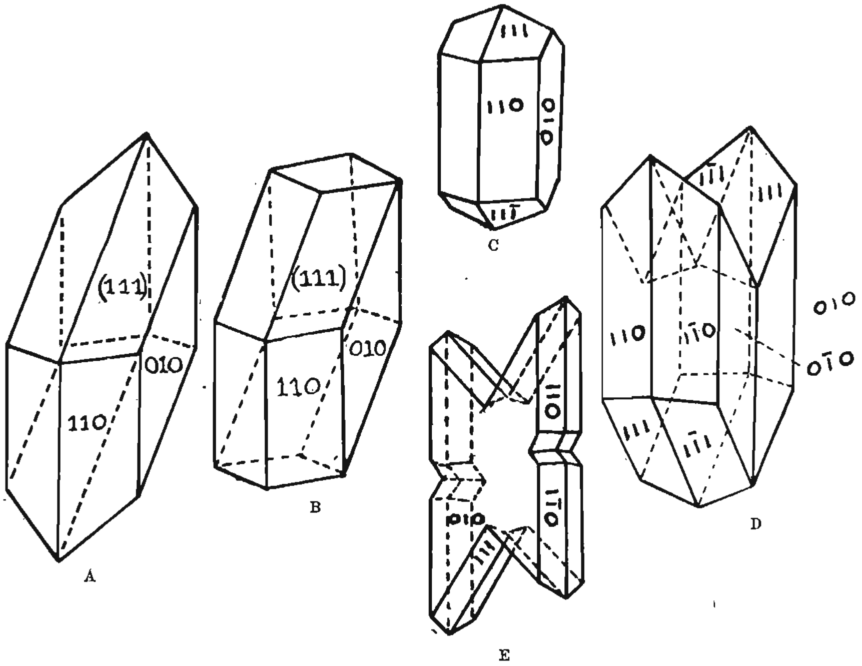

FIG. 2,A, B, C, D, E.—Diagrams of gypsum crystals. D shows the common method of twinning. Courtesy Illinois State Museum.

Selenitic gypsum, which consists of masses of crystals so intergrown as to lose their individual outline, forms solid beds in Oklahoma[5] and Texas.[6] Veins of selenite from eight to twenty feet thick and extending for half a mile along the strike of the gypsum beds which they cut are reported as occurring in Nova Scotia.[7] Selenite crystals, usually in rosettes or clusters

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[5] Gould, Oklahoma Geol. Survey, Bulletin No. 11, p. 6.
[6] Dumble, E. T., Selenite at Loma Blanca. Mineral Industry, Vol. XXIV, p. 378.
[7] Cole, L. H., Gypsum in Canada. Canada Dept. Mines, Mines Branch, No. 245, p. 190, 1913.

are often found scattered through massive gypsum and anhydrite. An example of this intergrowth is shown in figure 3.

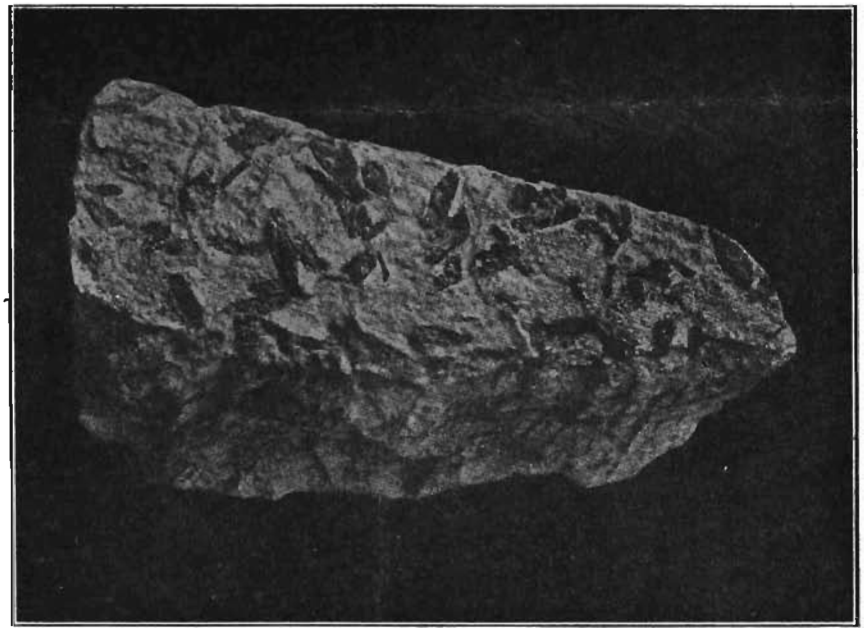

FIG. 3.—Selenite crystals imbedded in gypsum. In a similar manner gypsum crystals are often surrounded by fine grained anhydrite. Canadian Mining Journal.

Such occurrences may be noted in the anhydrite of Centerville, Iowa. Some beautiful crystals from the Centerville mine are illustrated in Plate II.

Satin spar

Satin spar is gypsum that has been deposited from solution along cracks and crevices and in cavities, and has taken the form of long slender crystals. Deposition took place along both edges of the crevice and the pressure created by the growing crystals has been sufficient in many cases to develop a crack several inches across, which the satin spar mass completely fills. Veins of satin spar from twelve to eighteen inches wide are reported as occurring in marls in Nova Scotia.[8] Satin spar is generally white in color and has a silky luster. The beautiful rosettes of gypsum lining the walls in certain parts of Mammoth cave are like satin spar in their origin and nature. Satin spar is illustrated in figures 4 and 5.

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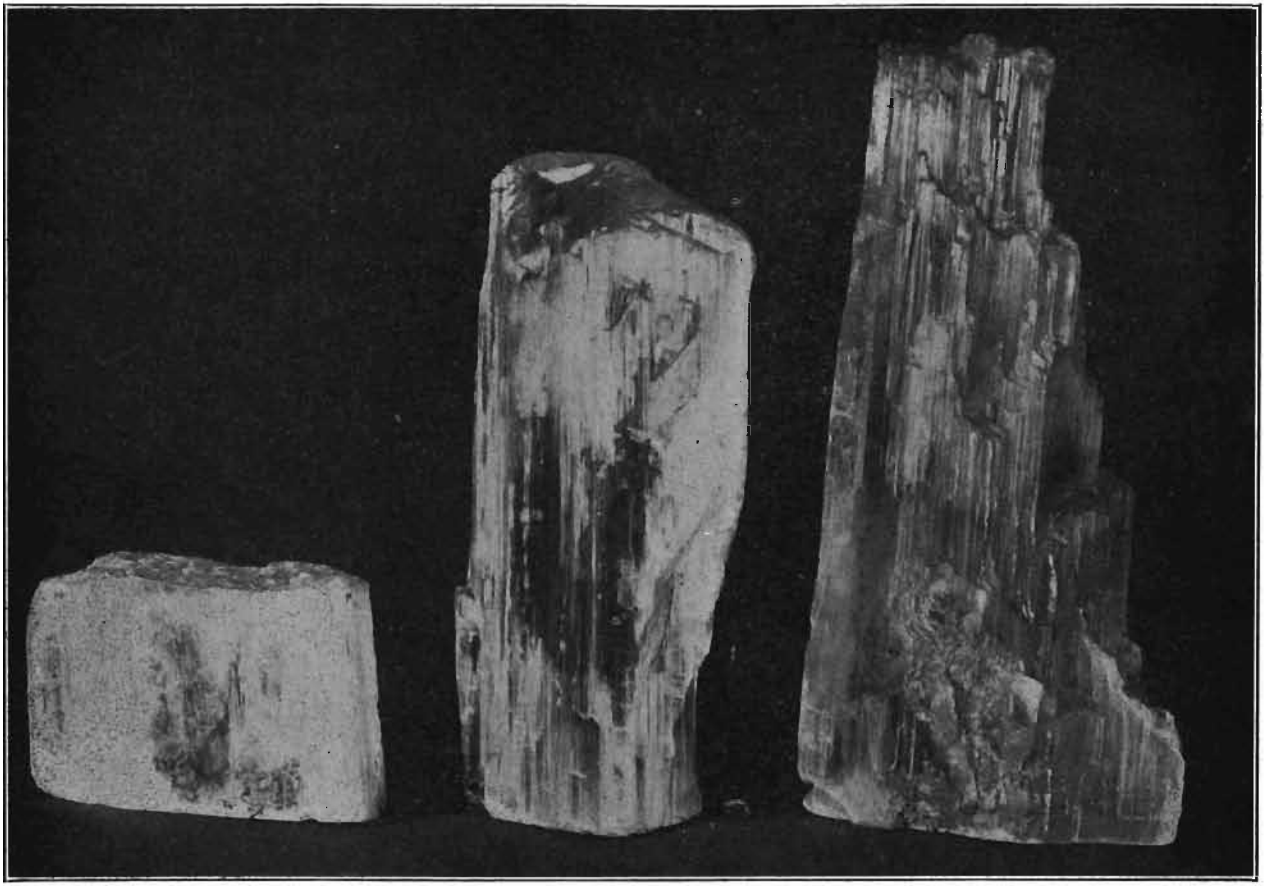
[8] Cole, L. H., Op. cit., p. 210.



Selenite crystals from Centerville, presented to Iowa Geological Survey by Scandinavian Coal Co. Crystalline forms are only partly developed. Cleavage specimens of great beauty, ten inches or more in length were found in the cave in the gypsum mine at Centerville.

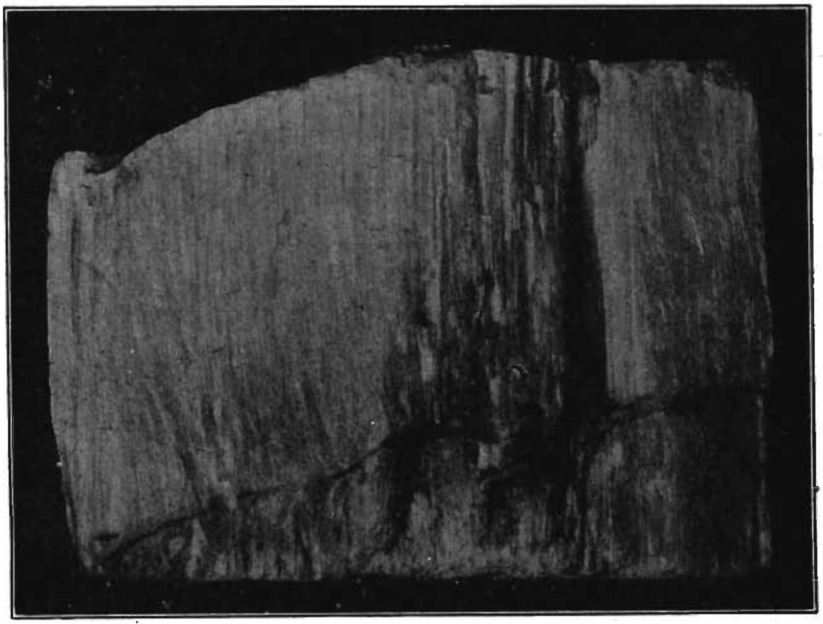


FIG. 4.—Satin spar, or fibrous gypsum. In many gypsum producing localities satin spar is found abundantly as veinlets and in veins up to two or three inches in thickness, in the associated clays. The figure shows the parting that is commonly present, indicating crystalline growth in opposite directions, from an originally small crack carrying mineral in solution, outward, or from the sides of an open fissure, inward. Courtesy U. S. Geological Survey.

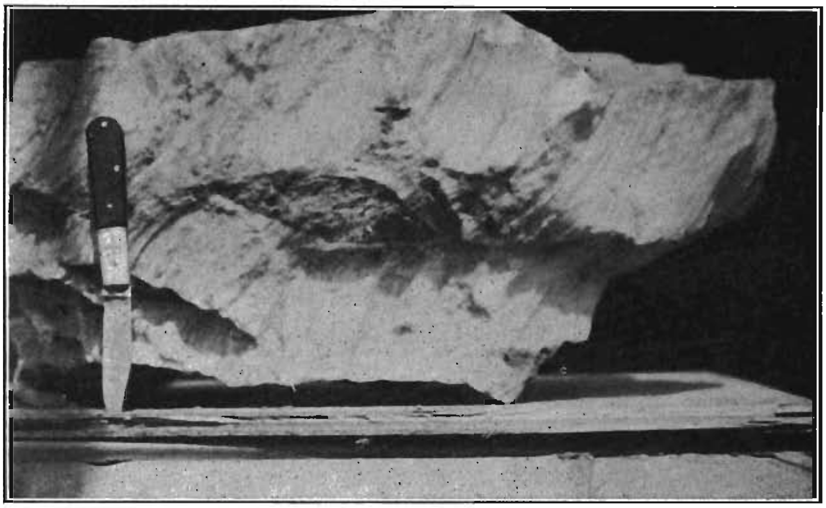


FIG. 5.—Satin spar with clay inclusion. Explained by supposing a fractured zone in the clay traversed by mineralized waters. The growing crystals enlarged the cracks and surrounded portions of clay included between the cracks. Photo by Wilder.

Rock gypsum

Massive or rock gypsum occurs in large bodies, in some localities, over extensive areas and in beds that attain a thickness of a hundred feet. It furnishes most of the gypsum that is used for industrial purposes. It presents a considerable variety in color, texture and structure. Pure white gypsum is common, though grayish white is more abundant, while browns and grays and more rarely pink may be noted. From coarsely crystalline it ranges downward to fine granular in texture. In structure it may show distinct bedding planes along which it breaks easily, or it may occur as a compact body lacking in bedding and jointings. The distinct bedding of the Fort Dodge gypsum is one of its striking characteristics and aids greatly in winning the mineral in the mine and quarry.

Alabaster

Alabaster is massive gypsum crystalline in texture and white in color, which is used to some extent for statuary and vases and for ornamental slabs where hardness is not essential.

Flour gypsum and seed gypsum are descriptive terms given by Winterbottom[9] to extensive deposits in South Australia. Flour gypsum is fine granular mineral, purer than the American variety known as gypsite, which is described in a later paragraph. Seed gypsum is coarsely granular, and apparently is like the gypsum sands about Alamogordo, New Mexico.

Gypsite

Gypsite consists of small detached crystals of gypsum scattered through fine clay or loam so abundantly that they form eighty to ninety per cent of the entire mass. It occurs as extensive surface deposits in several of the western states, and is of considerable economic importance.

Chemical composition

Considered chemically, gypsum has for its formula $CaSO_4 2H_2O$. When it is pure the various constituents give the following percentages by weight:

Gypsum ($CaSO_4 2H_2O$)	Lime sulphate ($CaSO_4$)	Lime (CaO)	32.6
		Sulphur trioxide (SO_3)	46.5
	Water H_2O		20.9
			100.0

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[9] South Australia, Department of Chemistry, Bulletin No. 7, Gypsum and Plaster of Paris

Some typical analyses of hand samples, selected by F. W. Clarke, Chief Chemist, U. S. Geological Survey, are given below.[10]

Type analyses

A. From Hillsboro, New Brunswick. Analysis by George Steiger.
B. From the Western Plaster Works, Alabaster, Michigan. Analysis by George Steiger.
C. From east of Cascade, Black Hills, South Dakota. Analysis by Steiger.
D. From Rico-Aspen mine, Rico district, Colorado. Analysis by W. F. Hillebrand.
E, F. From Nephi, Utah. Analysis by E. T. Allen. Some anhydrite must be present.

	A.	B.	C.	D.	E.	F.
SO_3	46.18	46.18	45.45	45.07	48.14	39.53
CO_2	------	------	.85	1.54	.65	7.73
Cl	trace	.03	------	------	trace	.04
SiO_2	------	------	.10	.51	------	------
TiO_2	------	------	------	trace	------	------
Al_2O_3	.10	.08	.12	.03	------	.14
Fe_2O_3			------	.09	------	
CaO	32.37	32.33	32.44	32.49	35.29	38.46
SrO	------	------	------	.10	------	------
MgO	trace	.05	.33	.92	trace	.24
Na_2O	.10	.14	------	trace	------	.07
K_2O			------	------	------	.19
H_2O	20.94	20.96	20.80	19.67	15.88	12.69
Insoluble	.10	.05	------	------	------	.45
Organic matter	------	------	------	present	------	------
	99.79	99.82	100.09	100.42	99.96	99.54

Analyses of gypsum from a number of other localities appear in the following table, and with them analyses of two samples of gypsite.[11]

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[10] U. S. Geol. Survey, Bulletin 419, p. 307.
[11] U. S. Geol. Survey, Mineral Resources of the United States 1906, p. 1069, Burchard, Ernest F., Gypsum and Gypsum Products.

ANALYSES OF GYPSUM AND GYPSITE

	Silica (SiO_2)	Alumina (Al_2O_3 and iron oxide (Fe_2O_3)	Lime carbonate ($CaCO_3$)	Magnesium carbonate ($MgCO_3$)	Lime sulphate ($CaSO_4$)	Water (H_2O)
1	0.40	0.19	0.25	0.35	78.10	20.36
2	.05	.08		.11	78.51	20.96
3	.68	.16	Not det.	Not det.	78.08	20.14
4	.10	.70			79.26	19.40
5	.10	.10			78.55	20.94
6	.11		1.07		78.42	20.43
7	3.62	.45	4.09	.34	71.94	19.87
8	9.73	.78	4.32	Trace	68.29	16.88

1 Gypsum from Blue Rapids, Kansas
2 Gypsum from Alabaster, Michigan
3 Gypsum from near Sandusky, Ohio
4 Gypsum from Saltville, Virginia
5 Gypsum from Hillsboro, New Brunswick
6 Gypsum from Baddeck Bay, Nova Scotia
7 Gypsite from Gypsum City, Kansas
8 Gypsite from Salina, Kansas

A number of analyses of Oklahoma gypsum appear below:[12]

	A	B	C
Calcium sulphate	74.45	77.38	63.82
Calcium carbonate	4.25		4.86
Magnesium carbonate	.84		.14
Magnesium sulphate		.83	
Water	18.61	20.78	16.43
Oxides of iron and aluminum	.61	.67	.69
Silica and insoluble residue	1.02	.41	13.95

A. From vicinity of Cement, Oklahoma.
B. From ledge four miles west of Weatherford.
C. Gypsite near Cement, Oklahoma.

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[12] Oklahoma Geol. Survey, Bulletin No. 11, p. 179, 185, 187.

The average composition of the ‘run of mine’’ New York gypsum as given by Merrill,[13] is as follows:

	1	2	3	4	5	6
SiO_2	.51	1.03	.40	2.93	8.31	4.00
Al_2O_3	1.19	.41	2.97	1.92	4.53	1.74
Fe_2O_3	.79	1.27	.77	1.10	1.34	1.11
CaO	30.62	30.74	30.76	26.27	21.50	29.36
MgO	1.20	2.01	1.53	8.29	7.20	2.81
SO_3	43.59	42.39	43.78	33.83	30.47	35.79
CO_2	1.02	2.20	2.80	11.02	9.50	6.38
H_2O	20.52	18.19	17.53	14.87	14.53	17.93
	99.44	98.24	100.54	100.23	97.38	99.12
Gypsum calculated	93.74	91.27	94.26	72.84	65.49	77.06

1. Akron, Erie county.
2. Oakfield, Geneseo county.
3. Oakfield, Genesee county.
4. Garbutt, Monroe county.
5. Lyndon, Onondaga county.
6. Lyndon, Onondaga county.

Two analyses from Colorado and from Wyoming, quoted by Grimsley, are interesting.[14]

	ASPEN DISTRICT, COLORADO	RED BUTTES, WYOMING
Silica and insoluble material	1.46	4.50
Iron and alumina oxides	---- ----	1.27
Lime sulphate	69.26	64.22
Lime carbonate	5.96	15.74
Water (calculated)	21.50	14.00
Magnesium carbonate	1.32	---- ----

ANALYSES OF MICHIGAN GYPSUM[15]

	A	B	C	D
Silica and insoluble material	1.28	1.18	.55	.19
Iron and aluminum oxides	1.82	1.87	trace	---- ----
Lime sulphate	79.98	76.02	77.76	77.93
Lime carbonate	1.95	2.57	1.86	1.25
Water	19.00	19.00	20.28	20.32
Magnesium carbonate	trace	---- ----	---- ----	---- ----

A. Alabastine quarry, Grand Rapids; B. English Shaft, Grand Rapids; C. Alabaster, Michigan; D. St. Ignace.

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[13] Bulletin New York State Museum, Vol. III, p. 81, 1893.
[14] Geol. Survey of Michigan, Vol. 9, p. 146.
[15] Geol. Survey of Michigan, Vol. 9, pp. 153-154.

ANALYSES OF GYPSUM FROM NEAR CASCADE SPRINGS, SO. DAK.[16]

Lime (CaO)	32.44
Magnesia	.33
Alumina	.12
Silica	.10
Sulphuric anhydrite (SO_3)	45.45
Carbon dioxide (CO_2)	.85
Water (H_2O)	20.80
	100.09

ANALYSES OF GYPSUM FROM MONTANA

	1	2	3
CaO	32.5	33.02	33.10
Al_2O_3	.3	---- ----	---- ----
Fe_2O_3	trace	---- ----	---- ----
SiO_2	.2	---- ----	---- ----
SO_3	46.3	45.93	45.94
H_2O	20.8	21.04	20.96

1. Gypsum from Red Buttes, U. S. Geol. Survey Bulletin No. 285, p. 405.
2. Gypsum near Bowler, U. S. Geol. Survey Bulletin No. 285, p. 314.
3. Gypsum near Kibbey, American Geologist, 1905, pp. 104-113.

Iowa Analyses of the gypsum of Fort Dodge and Centerville, Iowa, are discussed at length in Chapter VII.

Australia Analyses of flour and seed gypsum from Lake Fowler, Yorke Peninsula, South Australia, are particularly interesting.[17] The physical conditions under which these deposits occur are described in Chapter II.

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[16] Steiger, George, U. S. Geol. Survey, Bulletin 223, p. 78; Bulletin 697, p. 248.

[17] Dept. of Chemistry, South Australia, Bulletin No. 7, p. 22.

	SEED GYPSUM 1	SEED GYPSUM 2	FLOUR GYPSUM 3	FLOUR GYPSUM 4
Lime, CaO	31.75	33.00	32.30	32.30
Sulphuric Anhydrite, SO_3	44.90	44.45	43.60	44.90
Water, Combined, H_2O	20.20	20.10	19.60	20.10
Water, Moisture, H_2O	0.20	0.20	1.10	nil
Carbon Dioxide, CO_2	0.15	1.50	1.50	1.10
Aluminum and Ferric Oxide	0.20	0.20	trace	0.10
Insoluble	2.00	0.14	1.10	1.15
Organic Matter	0.40	0.40	0.70	0.35
Equivalent gypsum content— $CaSO_4 2H_2O$	96.85	95.60	93.70	96.30
Specific gravity	2.3			

The gypsum of the Paris basin contains from ten to twenty per cent of calcium carbonate and according to Dammer and Tietze[18] "also silica in a soluble form so that calcined gypsum from this material sets decidedly harder."

The water of crystallization which appears in all analyses of gypsum is given off either wholly or in part when the mineral is heated, and the products derived from gypsum by heating or calcination have valuable properties which are discussed in later chapters.

ANHYDRITE

Anhydrite is a mineral closely related to gypsum chemically and in point of origin. Gypsum under certain conditions is changed into anhydrite while under other conditions the opposite transformation takes place. Chemically, anhydrite is gypsum without water of crystallization and has for its formula simply $CaSO_4$.

Its hardness is 3 to 3.5 in the Mohs scale, or about that of ordinary limestone. In mining where gypsum and anhydrite occur together, the greater hardness of anhydrite must be considered in selecting equipment. The miners easily recognize the greater weight of anhydrite, which has a specific gravity of 2.9 as compared with 2.3 for gypsum.

Hardness and weight

Anhydrite is generally white, with a bluish or grayish tinge.

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[18] Die Nutzbaren Mineralien, II, p. 67.

Color, texture and composition

In rare instances it is red. Its texture is commonly fine granular, though fibrous masses and orthorhombic crystals with three good cleavages are found. Chemically pure anhydrite contains 58.8 per cent SO_3 and most anhydrite will show 54 to 56 per cent SO_3, the impurities present being usually the same that are found in gypsum.

Structure

Anhydrite is found in distinct beds, and in some cases it occurs as lenses in gypsum. Crystals of gypsum are frequently found scattered throughout anhydrite, giving the latter mineral a porphyritic texture.

CHAPTER II

DESCRIPTION OF IMPORTANT DEPOSITS OF GYPSUM IN THE UNITED STATES AND IN FOREIGN COUNTRIES

Within the United States there are numerous deposits of gypsum of sufficient size to render them commercially important. They occur in New York, Virginia, Ohio, Michigan, Iowa, Missouri, Kansas, Oklahoma, Texas, Montana, South Dakota, Wyoming, Colorado, New Mexico, Arizona, Utah, Oregon, Nevada, California and Alaska. A peculiar deposit in Florida is of scientific interest but has not proved of commercial value. To the north of the United States valuable deposits are found in Nova Scotia, New Brunswick, Ontario, Manitoba and British Columbia.

In Europe there are notable deposits in England, France, Germany, Switzerland, Russia and Italy. Asia, Africa and Australia possess gypsum areas which will be briefly referred to in subsequent pages.

The gypsum deposits of the United States are shown on Plate III. Brief descriptions follow, arranged alphabetically with reference to the states and territories in which the deposits occur.

Alaska

E. F. Burchard states[19] that "the only extensive gypsum deposit known in southeastern Alaska is operated by the Pacific Coast Gypsum Co., and is situated in the eastern part of Chicagof Island, about a mile from Iyoukeen Cove. The limits of the deposit have not yet been ascertained. At the surface the deposit is covered with gravel except near the shaft house, and no footwall nor hanging wall has been encountered in the mine workings. Several solution channels filled with gravel more or less cemented have been encountered in mining. The gravel is of the same character as that in the bed of Gypsum Creek. The gravel-filled channels extend below the 160-foot level. One channel has been tunneled for 35 feet without being cut through. Thin dikes of basaltic rock cut the gypsum beds, and a vein of anhydrite ranging in thickness from 6 inches to more than 10 feet has been encountered in the lower work-

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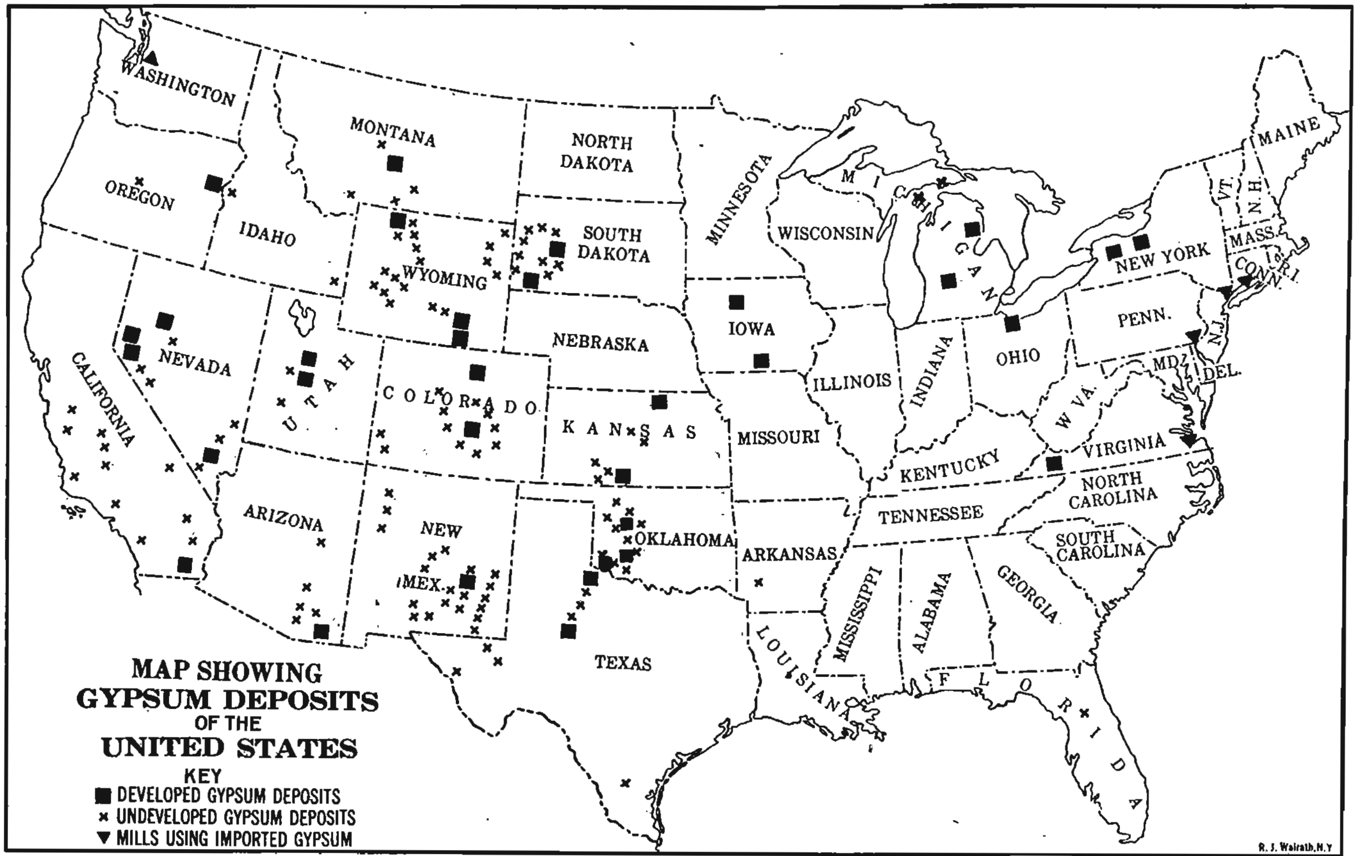
[19] U. S. Geol. Survey, Mineral Resources 1913, Part II, p. 363. Also Gypsum Deposits of the United States, Bulletin 697, p. 47, 1920.



Map showing the location of gypsum deposits and gypsum mills in the United States.

ings. This anhydrite is much harder to drill than the inclosing gypsum, and it is left in the mine. The gypsum is generally of a light bluish-gray color, although some is white, and occurs in massive beds, which dip 30°-60° NE. The main body of gypsum is of a high degree of purity.

The mine shaft is 315 feet deep. The first level is at 75 feet and the second at 160 feet. The general trend of the gypsum deposit is in a direction slightly north of west, and the levels extend for 750 feet east and west and 270 feet north and south, with the shaft near the middle of the exploited area. Altogether the underground workings are reported to measure probably 1 mile. Overhand stoping is the method employed in mining, and considerable broken gypsum rock is stored in the stopes.

The gypsum is hoisted to rock bins of 1,200 tons capacity, from which it is dumped into tramcars and drawn by a steam locomotive to the wharf. Shipments of crude gypsum are made by barges to Tacoma, Wash., where the material is calcined and manufactured into wall plaster of various grades in the company's plaster mill.

Adjoining on the east the claims now being worked for gypsum by the Pacific Coast Gypsum Co. and extending to the shore of Chatham Strait are other claims which have been located on reported deposits of gypsum."

Arizona

Gypsum deposits of considerable extent occur in Arizona, but on account of their remoteness from markets, and the abundance of gypsum in adjoining states, they are not extensively developed. The only mill and mine in the state is located at Douglas, operated by the Arizona Gypsum Plaster Company. A buff colored gypsite is used, which is hauled five miles by tram to Douglas.[20]

According to R. W. Stone there are indications of a ten foot bed in Land county about one mile west of the town of Land, a station on the El Paso and Southwestern Railroad.

In Mohave county W. T. Lee[21] found extensive beds of gypsum and gypsiferous clays in Virgin Valley, while Stone states that thick ledges of excellent gypsum are reported to occur in South Mountain and Quail Canyon fifteen miles south of St. George.

A large amount of gypsum was shipped before 1914 from the

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[20] Stone and others, Gypsum Deposits in the United States: U. S. Geol. Survey, Bull. 697, p 49, 1920.

[21] U. S. Geol. Survey, Bull. 352, p. 26, 1908.

town of Winslow in Navajo county to California points. On account of increased freight rates shipments have been discontinued. The bed is from four inches to four feet thick and averages eighteen inches in thickness. The mineral was hauled to Winslow on tram cars.

Stone states that in the Empire mountains in Pima county there occur two beds of gypsum, each fifty feet thick and separated by a thin bed of limestone.

W. P. Blake reported[22] that gypsum occurred in the Santa Catalina mountains north of Tucson, and was calcined for local use. Stone,[23] in 1919, could not locate any quarry or mine answering to Blake's description. Eight miles northeast of Tucson pits eight to ten feet deep have been sunk to a bed of gypsum four and one-half feet thick.

Near Feldman in Pinal county a thirty foot bed of good gypsum occurs but the distance from the railroad makes it of doubtful commercial importance.

Arkansas

Gypsum is found in Pike and Howard counties, Arkansas.[24] The thickest exposure is in Plaster Bluff southwest of Murfreesboro in Pike county, sixty-five feet above Little Missouri river. A single bed ranging from ten to fourteen feet in thickness is pure saccharoidal gypsum, with some thin seams of satin spar, and as much as three feet of interbedded clay in its lower part. The thickest layer of gypsum is at the top of the bed and measures four feet. Gypsum not exceeding three feet thick is found as far west as Messers creek in Howard county. In Arkansas the occurrence of gypsum is so restricted that the gypsum has practically no commercial value, although it could be produced in a small way for purely local use.

California

The more important deposits of gypsum in California lie south of San Francisco Bay. Considerable interest is being taken in these deposits and California promises to become an important gypsum producing state. In 1919 the Pacific Coast Gypsum Company was operating a plant at San Francisco, and the United States Gypsum Company one at Amboy.

At Point Sal, Santa Barbara county, and at Palmdale, Lang,

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[22] Gypsum Deposits of Arizona, U. S. Geol. Survey, Bull. 223, pp. 100-101, 1904. Also Bull. 697, pp. 49-56.

[23] Gypsum Deposits of the United States, U. S. Geol. Survey, Bull. 697, 1920.

[24] Gypsum Products, their Preparation and Uses: Bureau of Mines, Technical Paper 155.

and Castaic in Los Angeles county gypsum deposits have been worked.[25] In the Palen mountains and Maria mountains between the Colorado and Mohave deserts, there are extensive deposits of rock gypsum, and gypsite deposits are numerous.

Deposits are known to occur[26] in the counties of Fresno, Ventura, Kings, Monterey, Kern, San Luis Obispo, Santa Barbara, Los Angeles, San Bernardino, Riverside, and Orange. They are generally shallow and of the variety known as gypsite, although there are some extensive exposures of rock gypsum, as at Tecopa and in the Palen and Maria mountains.

Gypsum has been quarried in Fresno county, at Coalinga and Mendota; Kern county near Fellows, Mohave, McKittrick, and Bakersfield; Los Angeles county at Palmdale and Castaic; Monterey county, King City; Riverside county, Corona; San Bernardino county, Amboy; and Ventura county, Fillmore.

The more important gypsum beds of Colorado are found along the eastern part of the Rocky mountains.[27] At Loveland Colorado the gypsum is interbedded with siliceous limestones and red marls. It varies from seven to twenty-eight feet in thickness and is compact and of a drab-gray color.

Near Morrison on Bear creek are local beds of unknown thickness, while at Deer creek, eight miles southeast of Morrison, they are twenty feet thick. A gypsum bed is conspicuous in the Garden of the Gods, near Colorado City, and at Canyon on the Arkansas. There are important deposits of gypsum in southwestern Colorado, to the east of the La Sal mountains, in the area drained by the Rio Dolores.

The gypsum quarried at Loveland analyzes from 92 to 99 per cent hydrous calcium sulphate and its age is Permian.

In 1919, gypsum was calcined at Arkins, west of Loveland and at Portland. It was quarried at Stone City in Pueblo county for use in Portland cement.

R. D. George[28] describes important deposits which occur in Larimer, Jefferson, Douglas, El Paso, Pueblo, Fremont, Custer,

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[25] Stone and others, Gypsum Deposits of the United States: U. S. Geol. Survey, Bull. 697, 1920.

[26] Stone, R. W., Gypsum Products, their Preparation and Uses: Technical Paper, 155, Bureau of Mines, p. 51.

[27] Siebenthal, Bulletin 285, U. S. Geol. Survey, pp. 401-404. Stone, R. W., Technical Paper 155, Bureau of Mines, p. 53.

[28] George, R. D., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, pp. 87-94, 1920.

Huerfano, Chaffee, Park, Rio Blanco, Garfield, Eagle, Pitken, Montrose, San Miguel and Dolores counties.

Florida

Gypsum has been reported in Florida from time to time, and a brief description of the best known occurrence was given by Dr. David T. Day in the 20th Annual Report of the United States Geological Survey, Part 6. In a personal letter to the writer Dr. F. H. H. Calhoun gives additional information in regard to the Florida occurrence.

"This deposit is evidently formed from springs. It lies on the surface of the ground in masses from 6 to 12 feet deep; in other places of the area it is covered by an overburden in places as deep as 3 feet, the deposit itself in this situation being from 3 to 7 feet in thickness.

The composition of the gypsum is rather variable; in some places it is nearly pure gypsum and in other places it contains as high as 22½ per cent calcium carbonate. The material is in form of powder, in some places grading into a more granular structure.

This deposit is probably the same one visited by Dr. Day, but he evidently did not see the best exposures. The material first appears in Sec. 23, T. 20, R. 21, as a huge mound from 6 to 10 feet thick. It has an average length of 150 yards and an average width of 60 yards.

North of this large deposit, which occurs on what is known as Soapstone Island, the deposits become thinner and less continuous. It might be best described as a swell or saucer type. This type continues for some 200 yards and then gradually gives place to the type of deposit on Bear Island described by Day. The deposits on Bear Island consist of isolated mounds of gypsum from 6 to 100 feet in diameter and probably average 3 to 4 feet in thickness. I estimate that the deposit on Soapstone Island contains about 35,000 tons, the adjacent deposit about 70,000 and that on Bear Island probably as much, but so scattered as to make quarrying difficult. I found very little evidence that these mounds were connected under the surface. Further north about 5 miles east of Inverness more deposits are found, but in these the type is different. It lies beneath the surface covered with an overburden from a few inches to several feet in thickness. The deposit itself, I believe, would not average more than 3 feet and is not continuous. This deposit extends south some 2 or 3 miles."

Gypsum occurs in Washington county,[29] Idaho, in the bluffs

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[29] Burchard, E. F., Mineral Resources of U. S., 1910, p. 13.

Idaho

overlooking Snake River, about ten miles northeast of Huntington, Oregon, which is the nearest town. Short tunnels and prospect pits have shown that the material consists of lenticular masses of rock gypsum banded with grayish and greenish material, possibly chloritic, and indicate thicknesses ranging from six to twenty feet or more. The hill slopes are too steep and there is too much stripping necessary to render extensive open quarrying practicable, but the material can be obtained by mining. A railroad that connects with the Oregon Short Line at Huntington passes down the Oregon side of Snake river within 2,000 feet of the gypsum outcrop, and near enough for the rock to be carried across the river on an aerial cableway. The deposits here apparently are of the same series that occur on the Oregon side of Snake river, a few miles farther south. The Washington county gypsum deposits are held by the Northwest Gypsum Plaster Company of Huntington, Oregon.

Iowa Gypsum deposits of Iowa in Webster county about Fort Dodge and at Centerville in Appanoose county are fully described in Chapters IV and V.

Kansas Kansas possesses highly important beds of rock gypsum, and a number of deposits of gypsite, or secondary gypsum. The area in which gypsum is found appears on the map shown in Plate XIII of the publication cited below.[30]

The more important centers are the Blue Rapids area, the Gypsum City area, and the Medicine Lodge area, as pointed out by Grimsley.[31]

From an examination of a map of west central United States with the gypsum deposits indicated thereon, it will be seen that if the northeast line of the Kansas deposits is extended it will strike the Fort Dodge area in Iowa, and if it is continued to the southwest it will strike the extensive deposits of Canadian river in Oklahoma and Indian Territory and Texas.

The Kansas gypsum is of Permian age, the beds in the northern part of the state belonging to the lowest portion of the Permian, while those farther south are higher. Both gypsum and gypsite are found within the state, the former in very extensive

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[30] U. S. Geol. Survey Bull. 223, p. 54; also Bull. 697, Pl. XVII, p. 112.

[31] Gypsum Deposits of the United States, U. S. Geol. Survey Bull. 223. See also Bull. 697, pp. 112-120.

beds and presenting very favorable conditions for development. Near Blue Rapids the bed is nine feet thick; near Gypsum City six to fourteen feet; at Dillon eighteen feet and in the Medicine Lodge area from three to twenty feet. The quality of the gypsum is good, and certain brands of plaster of Paris made in Kansas are well received for the finer uses by the building trade.

Gypsite is found at a few points. It is generally found in low ground in areas limited to a few acres, and in thickness from three or four feet to eighteen feet. Gypsite makes an excellent wall plaster with less expense for treatment than in the case of rock gypsum and for this reason Kansas gypsite beds have been extensively developed, but many of the deposits have been exhausted, and each year more reliance is placed on the rock gypsum deposits for the maintenance and expansion of the industry.

Louisiana

According to Stone[32] thick beds of gypsum have been encountered in deep drill holes in Louisiana at St. Charles, Calcasieu Parish, associated with sulphur, and at Pine Prairie, St. Laudry Parish. Gypsum occurs also at Rayburn's salt works, Bienville Parish.

The gypsum of Louisiana is not developed and on account of its position and the salts and minerals that are associated with it, there is little likelihood of its becoming important economically.

In connection with the oil domes in Louisiana extensive deposits of gypsum occur but under conditions that render it improbable that they will ever be of economic importance. These deposits are considered in Chapter III, in connection with the origin of gypsum deposits.

The principal gypsum areas of Michigan are[33]: (1) in the vicinity of Grand Rapids near the western side of the Lower Peninsula, and (2) at Alabaster, north of Saginaw bay on Lake Huron.

Michigan The deposits occur in a formation which outcrops around the interior coal basin. At Grand Rapids there is an

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[32] Gypsum Industry in 1913, U. S. Geol. Survey, Mineral Resources of United States.

[33] Stone, R. W., Gypsum Products, their Preparation and Uses; Bureau of Mines, Technical Paper 155, p. 55.

upper ledge six feet thick separated by one foot of shale from a lower ledge twelve feet thick; about forty feet below the latter bed there is a twenty-foot bed of gypsum and a few feet above this thick bed another deposit several feet thick, making four beds which have been utilized. Several thinner beds are not used. At Granville, five miles southwest, two ledges eleven and fourteen feet thick are separated by four feet of limestone. The gypsum is very pure and is taken from quarries and underground workings.

At Alabaster an extensive exposure of gypsum twenty-three feet thick has been worked back from its original outcrop on the shore of Lake Huron for more than a quarter of a mile, the quarry now being very large. A ten-foot bowlder-clay cover is stripped and the rock is blasted from a horseshoe-shaped face. The bottom of the quarry is about fifteen feet above the lake level. Several thin beds underlie the quarry within a depth of ninety feet. Gypsum has been found in a number of wells in northern Arenac county and southeast Ogemaw county; in Mackinac county near Point Aux Chenes, seven miles west of St. Ignace, and in the vicinity of St. Martin's bay.

Seven plants were operated in 1921 in Michigan, six being near Grand Rapids and one at Alabaster.

Montana

Developed gypsum beds occur in Montana in Cascade, Jefferson and Carbon counties. According to W. H. Weed[34] the gypsum occurs interbedded in a series of red and green shales with limestones carrying Mississippian fossils. The rocks have been folded by mountain forming uplifts and lie at steep angles, or more nearly horizontal a mile or more away from the mountains.

Deposits are reported near Millegan in Cascade county, and have been mined intermittently at Riceville and Goodman. The gypsum at these points is not continuous but occurs in lenses and in places contains clay and sandstone partings.[35]

In 1898 gypsum was quarried and milled near Monarch, but the mill was burned in 1900, and not rebuilt. Near Kibbey there

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[34] Weed, W. H., Gypsum Deposits of the United States: U. S. Geol. Survey Bull, 223, p. 74; Bull. 697, pp. 131-138.

[35] Stone, R. W., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 132.

is a good body of gypsum but it is located several miles from the railroad.

In Fergus county the gypsum bearing formations completely encircle the Big Snowy mountains, and beds of good material occur. Near Heath, where the United States Gypsum Company has prospected extensively, gypsum fourteen to sixteen feet thick is reported. A considerable area is underlain with an eight foot gypsum bed. At Hanover gypsum occurs at the top of the Carboniferous section. A seven foot bed is worked by the Three Forks Portland Cement Company, while thinner beds occur in the same locality.

In Jefferson county a small deposit has been developed just east of Lime Spur, by the Three Forks Portland Cement Company for use in its mill at Trident.

In Carbon county a ten foot bed at Bridger was developed for use in a plaster mill at that point but the mill has been idle for some years.

N. H. Darton[36] reports three beds of gypsum, five, sixty and fifty feet thick in the Red Valley on the Crow Indian Reservation. They are fifteen miles from a railroad and therefore remain undeveloped.

Other deposits are reported in Madison county and at Hunters Hot Springs on Yellowstone river.

The more important gypsum deposits in Nevada occur in two widely separated areas,[37] one in the western part and one in the southern part of the state.

Nevada

The western area lies in Humboldt, Washoe, Lyon and Mineral counties. The southern area lies in Clark and Lincoln counties. In both areas the gypsum is of exceptional purity and for that reason it has been developed to some extent, for shipment to rather remote points. Quarries are in operation at Lovelock, Mound House, Ludwig and Arden, and plaster mills are operated at Moapa and Arden. Considerable quantities are shipped to cement mills in adjoining states.

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[36] Darton, N. H., Geology of the Big Horn Mountains: U. S. Geol. Survey, Prof. Paper 51, p. 38, 1906.

[37] Jones, J. C., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 139, 1920.

New Mexico

Very extensive beds of exceptionally pure gypsum occur in New Mexico. In at least sixteen counties workable deposits have been found.[38]

On account of their remoteness from important markets these beds are not extensively developed. The gypsum of the Manzano group begins in northcentral New Mexico and thickens southward. These beds probably are Jurassic in age and the gypsum occurs in massive beds reaching a thickness of 100 feet. In the northern part of the state, above the Wingate sandstone and overlain by a thin bedded sandstone, a thick bed of gypsum outcrops on the sides of the Nacimiento and Landia mountains.

In Otero county, west of Alamogordo, wonderful white gypsum sand hills are found. They extend twenty-eight miles from north to south and in width range from six to fifteen miles. These deposits are ten to thirty feet high with an average thickness of twenty feet. Much of the material is snow-white. The origin of these gypsum hills is considered in Chapter III.

In 1919 mills were in operation at Acme, Chaves county; and Oriental, Eddy county. From time to time attempts have been made to develop the gypsum sands near Alamogordo, but transportation difficulties have proved too great to be overcome.

New York

The rocks of the Salina stage of the upper Silurian, which contains the workable gypsum of New York,[39] have for many years been studied along a belt extending without interruption from Albany county on the east to the Niagara river on the west, and thence into Ontario.

The Salina in New York is largely made up of shales. In the upper shale beds gypsum occurs in abundance, while salt is found in the middle of the series. An impure limestone caps the shales in the central and western part of the state while irregular bands of limestone occur within the shales. Except for a few feet near their base the shales are without fossils.

Underneath an argillaceous magnesian limestone known as the Bertie, which extends from Niagara river to Fayetteville, or somewhat beyond the center of the state, lies the Camillus

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[38] Darton, N. H., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 161, 1920.

[39] Gypsum Deposits in New York, by D. H. Newland, New York State Museum, Bull. 143, 1910.

shale in which are found the workable beds of gypsum. These shales contain no fossils though one or two species have been found in thin bands of interlayered limestones. The gypsum deposits are seamed with shales which divide them into separate beds. The gypsum is present in regularly stratified beds which range from a few inches to five feet or more in thickness. It occurs in well defined lenses. The edges of these lenses have been broken by erosion and solution so that often large isolated masses of gypsum are found.

Small and irregular masses of gypsum are found in Herkimer and Madison counties but at present they are of no economic importance. Onondaga county contains important beds which are developed in the vicinity of Fayetteville and Jamesville. In Cayuga county the Salina series is well represented but the gypsum, while present in quantity, is low-grade, showing only eighty per cent hydrous lime sulphate.

Farther west, in Seneca and Wayne counties, the gypsum continues to be of low grade and is not abundant. Core drilling in Ontario county has shown beds of gypsum of good quality, but no developments of consequence have resulted.

The Bertie limestone covers the shales and gypsum in the next county to the west, Livingston, and there are no outcrops of gypsum and its presence would have to be determined by drilling.

In Monroe county gypsum of value is confined to the single township of Wheatland but within this area there are important developments in the vicinity of Wheatland.

Decidedly the most important developments in the state are in Genesee county, about the town of Oakfield, and just across the county line to the east, in Niagara county, about the town of Akron. Within this area some of the most important mills in the country are located. The gypsum that is worked is limited in thickness, averaging four feet, but is of good quality and is well located with reference to important markets and transportation. In 1921 New York ranked first in the production of gypsum. Two mills were located at Fayetteville where gypsum hauled from neighboring quarries was ground for agricultural purposes. The Cayuga Gypsum Company in Cayuga county, prepared crude gypsum for use in Portland cement and in agriculture. In Monroe county important plaster mills are located at Garbutt and Wheatland. The most important area is the Oakfield-Akron district in Genesee county, where four very large plaster mills furnish the greater portion of the state's output of gypsum. Up to 1920 approximately 9,000,000 tons had been mined in the state, approximately 7,000,000 tons having been taken out since 1890.[40]

Newland states[41] that "developments within recent years indicate that deposits of high-grade rock (over 90 per cent) are quite limited and are particularly confined to the western section of the Salina formation, in Erie and Genesee counties. Contrary to the opinion frequently expressed, the deposits do not extend to any great distance to the south of the outcrop on the dip of the formation, but thin out or change to the anhydrous condition as they reach a depth of more than 100 feet. The gypsum thus is the result of surface conditions which prevail through a very restricted horizon. This feature, together with the thinness of the bed indicates a rather meagre supply of the higher-grade material in western New York."

The gypsum beds of Ohio that are of commercial importance are found in Ottawa county, on the north and south shores of Ohio Sandusky bay. The beds north of the bay are near the town of Port Clinton, while those south of the bay are within two miles of Castalia. The beds range in thickness from three to seven feet. They belong to the Monroe formation of the Silurian system.

Professor Edward Orton[42] gives the following typical section:

		FEET
Drift clays, level of bay, 8 feet below surface		12-14
No. 1.	Gray rock carrying land plaster	5
	Blue shale	½
No. 2.	Bowlder bed carrying gypsum in separate masses, embedded in shaly limestone	5
No. 3.	Main plaster bed	7
	Gray limestone in thin courses	1
No. 4.	Lowest plaster bed, variable	3-5
	Mixed limestone and plaster, bottom of quarry, water enters here in quantity	

"The beds are not even and horizontal but are found in waves or rolls, the summits of which rise five to eight feet above

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[40] Newland, D. H., and Leighton, H., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, pp. 187-217, 1920.

[41] Mineral Industry, McGraw-Hill Book Co., Vol. xxviii, p. 333.

[42] Geol. Survey Ohio, Vol. 6, p. 698.

the general level. Sections like the one given here will yield 50,000 tons of plaster to the acre.

The bed marked No. 1 in the section is a mixed deposit of shale and plaster that has hitherto been rejected but which has recently been found fully available for grinding into a dark colored land plaster. It has been lost by erosion in much of the territory already worked, and is not commonly counted among the valuable resources of the quarry.

No. 2 is one of the interesting divisions of the section. Scattered through the calcareous shales, there are balls of gypsum, concretionary in form and probably in character, varying in diameter from six to twenty-four inches. For a long time it was thought that they were of inferior value, and they were ground into land plaster, but recently it has been found that the present product of the quarries can be derived from these same plaster balls. The gypsum yielded by them when they have been carefully freed from their shaly envelopes proves to be of the whitest and purest sort, such as is used as terra alba."

Bownocker[43] states that "although the area underlain by gypsum is large, it seems probable that the deposit is too thin or at too great depth to be mined except along or near the lake shore west of Sandusky, and even there only two comparatively small areas have been actually tested."

In 1919 three mills were in operation, two at Gypsum, and one at Port Clinton. The mill at Castalia has run intermittently. Although the deposit of gypsum at that point is good, water conditions in the mine are difficult to overcome.

Oklahoma

The gypsum of Oklahoma is Permian in age and is found in the "Red Beds," which extend from Texas through western Oklahoma into Kansas. The mineral is found in beds of rock gypsum which in places reach a thickness of sixty feet, and in the form of gypsite.

The gypsum beds occupy three areas:

1. A line of gypsum hills resulting from the outcrop of the Blaine formation. Here, according to Linder,[44] three beds occur, the Shimer, the Medicine Lodge and the Ferguson. The gypsum is selenitic in all three beds, and the texture coarsely crystalline. The gypsum belt extends from the north across

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[43] Bownocker, J. A., Gypsum in Ohio; U. S. Geol. Survey Bull. 697, pp. 218, 219.

[44] Linder, L. C., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 225.

Harper, Woods, Major and Blaine counties, and dies out in Canadian county in the central-western portion of the state.

2. The important deposits in the second area occur in Custer and Washita counties. Here the gypsum is of the massive rock form and in places reaches a thickness of fifty feet. The area extends into Dewey county on the north and into Caddo, Grady, Comanche and Stephens counties to the south, but in these counties the deposits are of limited quantity and doubtful value. Considerable gypsite has been worked out in Caddo county, and an undeveloped deposit of some size is reported near Indianapolis.

3. The third area lies in the extreme southwestern portion of the state in Beckham, Greer, Jackson and Harmon counties. Here well defined beds occur, and at some places four and five beds, most of them of considerable thickness, are found. In addition gypsite deposits, particularly in Jackson county, are of considerable value.

The quantity of gypsum in Oklahoma is very great and it is developed to a considerable extent though the distance of the deposits from important markets is a serious handicap.

In 1919 mills were located at Southard, Eldorado, Homestead, Cement and Acme.

Oregon

Near the middle point of the eastern boundary of Oregon gypsum is developed on a ridge which forms the divide between Burnt and Snake rivers. The mineral occurs in lenses ranging from ten to forty feet thick. Some of these lenses are composed of white crystalline gypsum of good quality, while others are of doubtful value on account of impurities.[45] A mill has been erected at a point named Gypsum.

Gypsite is reported to occur in Crook county, where it is said to be more than fifteen feet thick and to require no stripping.

Pennsylvania

No gypsum deposits of commercial importance occur in Pennsylvania but in the deep well at Erie gypsum in considerable quantities is reported in the Salina formation just below the 1700 foot level.[46]

Important and fairly accessible beds of gypsum occur in the

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[45] Stone, R. W., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 236.

[46] Geol. Survey of Ohio, 4th Series, Bulletin 18, p. 414.

South Dakota

Black Hills, South Dakota. The structure of the Black Hills is that of a great dome, with the older crystalline rock in the center and more recent strata tilting away from the central mass. The Spearfish formation, which is probably of Triassic age, forms a ring around the Black Hills and gypsum is present at most places in this formation.[47] The gypsum ranges in thickness from a fraction of an inch to thirty feet. Two thick beds of gypsum occur near Minnekahta, with several beds from two to six feet in thickness. Between Minnekahta and Hot Springs gypsum outcrops as far east as Erskine station. Gypsum has been milled in the vicinity of Black Hawk, Rapid City and Hot Springs, though the mills at the latter points are not now in operation. The mill now operating at Black Hawk is using gypsite as raw material. From Tilford to Sturgis gypsum outcrops almost continuously and at Sturgis the bed is ten feet thick.

At present in addition to the mill at Black Hawk, a mill utilizing both rock gypsum and gypsite is in operation at Piedmont.

Texas

The gypsum deposits of Texas that have, up to the present time, been developed commercially, occur in connection with clays, sands and limestones of Permian age, which lie east of the Staked Plains in Texas and extend northward from the Texas and Pacific Railway across Oklahoma and Kansas.[48] The gypsum for the most part occurs massive and in beds varying from a few inches to twenty feet in thickness. They extend over a very considerable area and the total amount of gypsum available is almost beyond computation. In the same region occur extensive deposits of gypsite which are extensively developed.

In addition to the Permian deposits of Northern Texas there are others which Dumble regards as of equal, if not greater extent and value. These occur between the Guadalupe mountains and the western scarp of the Staked Plains in the valley of Pecos river. The Castile gypsum outcrops in a belt between the Delaware mountains and Rustler hills which has an average

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[47] Hutton, C. H., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 240, 1920.

[48] Mineral Industry, Vol. IV, pp. 375-380.

width of fifteen miles. It is of the massive white granular variety. Locally selenite is abundant. Its thickness ranges from sixty to over three hundred feet.

Large deposits of gypsum occur in the Malone mountains, which lie just south of the Southern Pacific line between El Paso and Sierra Blanca.

Another, and a rather remarkable occurrence of gypsum is found in the southern coastal region of Texas, in the neighborhood of Falfurrias. Here occur extensive deposits of gypsite and the most extensive beds of massive selenite that have ever been discovered. The thickness of the deposit is unknown, but Dumble reports it as over 1000 feet thick. This deposit seems to be related, as to origin, to the salt and oil domes of the coastal plains, with which extensive beds of gypsum are often found. The gypsum deposits in the vicinity of Falfurrias are within a reasonable distance of transportation. The terminus of the San Antonio and Arkansas Pass Railroad is only six miles away, and Sarita on the St. Louis, Brownsville and Mexican Railroad is only fourteen miles distant.

The remarkable deposits of gypsum encountered in deep drilling in the salt and oil domes of southeastern Texas are referred to on page 125, in Chapter III. Gypsum 600 feet thick was found at Spindletop and an equal thickness at High Island. In 1919 two mills were operating at Acme and one at Plasterco.

Utah

There are several important gypsum deposits in central and southern Utah.[49] The most important development is at Nephi, where a fully equipped mill secures its raw material from a highly inclined ledge of gypsum 400 feet high and 250 to 300 feet thick. At Levan in Juab county a somewhat similar deposit was utilized several years ago, but the mill at present is not in operation.

Gypsum outcrops almost continuously from Nephi southward in Sevier valley and at Sigurd in Sevier county two mills are in operation. At least three beds, somewhat broken by erosion and faulting, occur in this locality. Their thickness ranges from ten to fifty feet.

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[49] Stone, R. W., and Lupton, C. T., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 261, 1920.

Stone[50] describes an interesting deposit of gypsum in Millard county as follows: "About eight miles west of Fillmore gypsum occurs in deposits of three types—gypsiferous clay, gypsum sand, and loose crystals. The gypsiferous clay covers an oval area approximately three by five miles in extent. Gypsum sand dunes occur in two areas, one of them a mile long and a third of a mile wide, the other an irregular area approximately half a mile square. Mounds of loose small crystals cover an area two miles long and half a mile wide." These accumulations of wind blown material are remarkably pure and contain about 450,000 tons.

Other important but undeveloped gypsum deposits are found in Iron county where a bed 200 feet thick outcrops for several miles. In Emery and Wayne counties along the west side of the San Rafael Swell there are extensive beds of good rock gypsum. In Washington county several beds of gypsum, from five to fifteen feet in thickness, occur.

Virginia

A very restricted area in Washington and Smyth counties, in southwest Virginia, contains extensive deposits of gypsum that are commercially of considerable importance, and are of more than ordinary interest from a scientific point of view. The gypsum is associated with shales and limestones of Mississippian age and is found only near the point of contact of these rocks with a great overthrust fault which has brought Cambrian dolomite over the Lower Carboniferous strata. This fault, according to G. W. Stose,[51] has been traced through into the Rome fault which he states has been shown to have a displacement of five miles at Rome, Georgia. The gypsum occurs in huge masses of irregular shape and in various positions, surrounded by red and gray shales. Enclosed in the gypsum are irregular masses of dolomite and shale.

The peculiar nature of the deposit has given rise to a great deal of divergent speculation in regard to the origin of the gypsum and the salt which is in places associated with it. Eckel[52] attributed them to ordinary salt pan conditions. Stose regarded them as secondary deposits formed by ascending waters moving

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[50] Stone, R. W., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 268, 1920.

[51] Stose, G. W., U. S. Geol. Survey Bull. 530, p. 20.

[52] Eckel, U. S. Geol. Survey Bull. 213, p. 406.

along the fault, which dissolved gypsum and salt disseminated through shales and limestones of the Mississippian formation.

Two gypsum mills are in operation in Virginia and the state is fourth in its annual output of gypsum. Its importance as a gypsum producing center lies in the fact that gypsum is not found in any other state in the southeast.

Wyoming

The gypsum of the Bighorn Basin, Wyoming, was described by C. A. Fisher[53] in 1905, and more recently by C. T. Lupton, D. D. Condit and R. W. Stone.[54] Beds of workable gypsum occur in the upper part of the Chugwater formation, and about one thousand feet stratigraphically lower down, in the Embar formation. The beds differ in thickness and number, and evidently were not deposited in continuous sheets but rather as lenses in isolated bodies of water along the margin of a former sea. At one point in the Chugwater formation the gypsum appears in a single bed ranging from forty-two to seventy-four feet in thickness, while at other points from six to eight relatively thin beds are exposed. Gypsum of the Chugwater formation is found near Stucco, Graybull, Hyattsville, Tensleep, Bigtrails, Thermopolis, and on Kirby creek.

In the Laramie district, according to C. E. Siebenthal,[55] the heaviest developments of gypsum rock are found along the foot of the north slope of Red Mountain. He gives the following section taken from this locality:

	FEET
Red gypsum rock nearly pure	6
Red shale	35
Gypsum	3
Red shale	10
Gypsum	4
Reddish shale	55
Banded gypsiferous limestone	5
Red sandy shale	88
Gypsum, massive	67
Fossiliferous limestone	1

This basal limestone is everywhere crowded with fossils which represent only a few species and are of Upper Carboniferous age. A mile south of Red Buttes station a bed fifteen feet thick has been quarried since 1890. At Laramie extensive deposits

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[53] Contributions to Economic Geology, U. S. Geol. Survey Bull. 285, p. 313, 1905.

[54] Stone, R. W., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 295. 1920.

[55] Siebenthal, C. E., Contributions to Economic Geology; U. S. Geol. Survey Bull. 285, pp. 404-406, 1905.

of gypsite have been developed. Branson describes the gypsum in the Lander region[56] as ranging from a few inches to forty feet in thickness and maintaining a thickness of a few feet for long distances along the outcrop. The thick deposits in some localities extend for a mile, and contain only a few partings.

Other deposits are reported from the Rawlins uplift, Freezeout Hills, Grand Canyon of the Platte, Black Hills, and Medicine Bow, Shirley, Seminoe, Ferris, Rattlesnake, Bighorn, Absaroka, Prior, Wind Run, Gros Ventre and Salt Creek mountains.

In 1919 two mills were in operation at Laramie and a third at Red Butte. A small mill at Basin, Big Horn county, calcines limited amounts of plaster for the manufacture of gypsum blocks. These blocks are all used locally and on account of the semi-arid climate, have proved satisfactory for exterior walls.

GYPSUM IN CANADA

The deposits of gypsum in Canada are very extensive and valuable. Many of them are at or near tide water and therefore come in direct competition with American gypsum along the coast. The accompanying map, Plate IV, shows the location of Canadian deposits and the districts that are under development.

The provinces producing gypsum, in the order of their production are Nova Scotia, New Brunswick, Manitoba and Ontario.

Canadian production by provinces for the year 1912 is given below:

	Tons
Nova Scotia	376,082
New Brunswick	82,757
Manitoba	66,500
Ontario	53,119

Canadian production in 1920 was as follows:

Nova Scotia	260,661
New Brunswick	49,405
Ontario	74,707
Manitoba	45,371

The production in 1920 was restricted by the high ocean freight rates that prevailed during that year, which interfered

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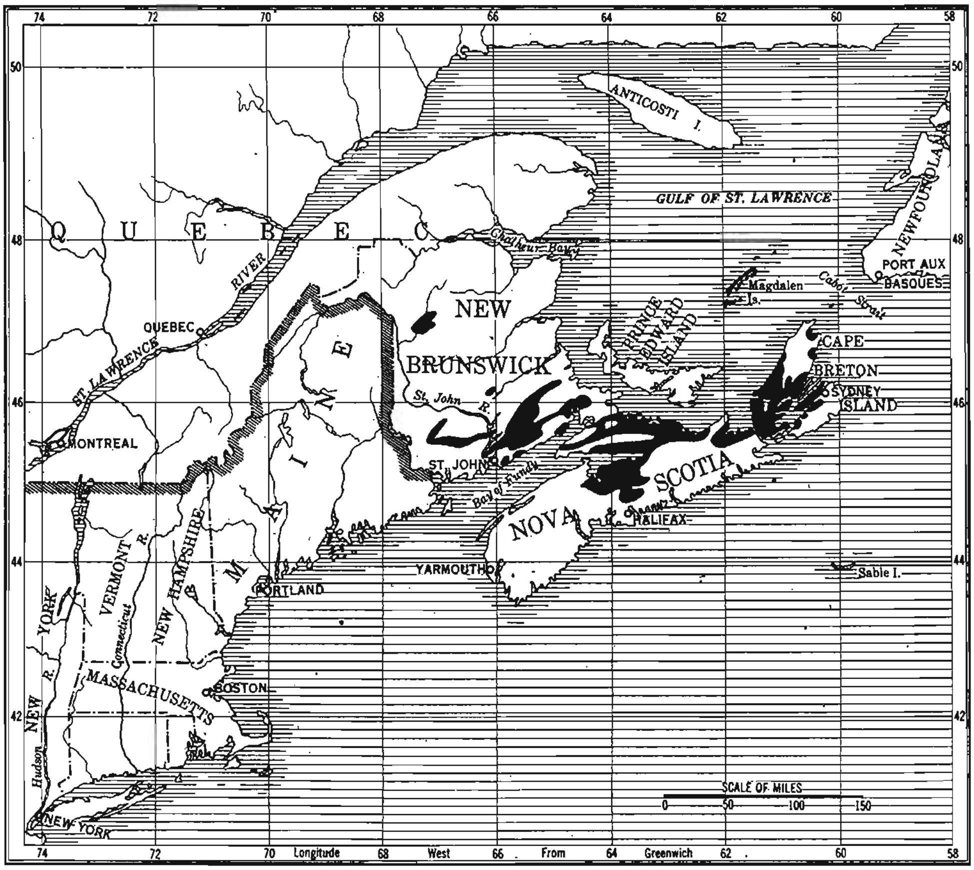
[56] Bull. Geol. Soc. America, Vol. XXVI, No. 2, p. 222.



Map showing the gypsum bearing formations of Nova Scotia and New Brunswick. Gypsum is present only in limited portions of these areas, shown as black on the map.

with the normal movement from the maritime provinces to American coast cities.

Nova Scotia

In Nova Scotia extensive deposits of economic importance are found in the following districts or counties[57]: Inverness and Victoria; Gypsborough and Antigonish; Pictou, Halifax and Colchester; Hants; and Cumberland. The gypsum is found in beds, associated with anhydrite and belongs to the Lower Carboniferous series. Some of the beds have a thickness of 100 feet.

New Brunswick

Extensive gypsum beds occur in New Brunswick, and furnish large quantities of alabaster from which the higher grades of plaster of Paris are made. As in Nova Scotia, the gypsum belongs to the Lower Carboniferous measures. The principal deposits are found in the south of the province in the counties of King, Albert, and Westmoreland. In the northern part of the province there is a single occurrence in Victoria county.

Ontario

In Ontario beds of the same age and character as those in New York occur and have been developed to some extent, at York and other points in the vicinity of Grand river. The bed is four and one-half feet thick. While the bed extends over a considerable area the amount of water that is encountered at many points is a serious hindrance to development.

Quebec

In the province of Quebec gypsum occurs in the Magdalen islands, in the Gulf of St. Lawrence, and is like the Nova Scotia gypsum in age and physical characteristics. The principal deposits of economic importance are on Grindstone, Altright, Amherst and Entry islands.

Manitoba

Manitoba possesses several deposits of gypsum. In the vicinity of Lake St. Martin exposures occur throughout an area of eight square miles. A mill has been erected at this point. In the southern part of the province, about eighteen miles east of Dominion City, a deposit of pure white gypsum is reported to have been found by drilling, at a depth of 325 feet. Gypsum occurs in the province of Alberta, at Bear Rock Mountain, a few miles west of Fort Norman.

In British Columbia, about twenty miles north of Kamloops

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[57] Gypsum in Canada, by L. H. Cole, Canada Dept. of Mines, No. 245.

and on the east bank of Thompson river, a large deposit can be traced for a long distance along the mountain side. Another extensive deposit occurs about eleven miles east of Grand Prairie. Gypsum deposits have been developed near Merrett, a town on a branch of the Canadian Pacific Railway.

British Columbia

The following quarries are operated in the Maritime Provinces of New Brunswick and Nova Scotia by American capital for the furnishing of raw gypsum to American mills[58]:

Newport Plaster, Mining & Manufacturing Co. (Ltd.), Avondale, Nova Scotia, J. B. King & Co., New York.
Wentworth Gypsum Co. (Ltd.), Wentworth, Nova Scotia, J. B. King & Co., New York.
Hillsborough Plaster Quarrying & Manufacturing Co. (Ltd.), Hillsborough, New Brunswick, J. B. King & Co., New York.
Rock Plaster Corporation, Walton, Nova Scotia, Rock Plaster Corporation, New York.
Newark Plaster Co., McKinnon Harbor, Nova Scotia, Newark Plaster Co., Newark, N. J.
Albert Manufacturing Co., Hillsborough, New Brunswick, Newark Plaster Co., Newark, N. J., interests and others.
Windsor Gypsum Co. (Ltd.), Newport Station, Nova Scotia, Higginson Manufacturing Co., Newburgh, N. Y.

Shipments from these quarries constitute practically all of the raw gypsum imported in the United States.

The following quarries are operated by Canadian capital for Canadian use only:

Windsor Plaster Co. (Ltd.), Windsor, Nova Scotia.
Iona Gypsum Co. (Ltd.), Iona, Cape Breton, Nova Scotia.
Ontario Gypsum Co. (Ltd.), Caledonia and Carson, Ontario.
Manitoba Gypsum Co. (Ltd.), Winnipeg, Manitoba.

Following is a list of manufacturing plants operating in Canada:

Small mill at Windsor, Nova Scotia, operating but one kettle for a local market.
Iona Gypsum Co. (Ltd.), at Brador Lakes, Cape Breton, Nova Scotia, a two-kettle plant, shipping its product locally and to points on St. Lawrence river.
Albert Manufacturing Co., Hillsborough, New Brunswick, affiliated with the Newark Plaster Co., Newark, N. J., United States. A four-kettle plant, which ships plaster of

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[58] Statement of J. C. Seguine, representing the firm of J. B. King & Co., at Tariff hearings in Washington on January 11, 1921.

Paris in barrels to a limited extent to points on the Atlantic seaboard, the major portion of its output being for Canadian consumption.

Ontario Gypsum Co. (Ltd.), Caledonia, Ontario. It supplies raw gypsum largely to Canadian cement plants. It also supplies calcined gypsum for the manufacture of gypsum blocks to the Ebsary Gypsum Co., (an American-owned corporation) for Canadian consumption only.

Manitoba Gypsum Co. (Ltd.), Winnipeg. Output distributed in Canada.

None of the foregoing plants (data on Manitoba Gypsum Co. lacking) manufacture plaster board or plaster block.

MEXICO, CUBA AND SOUTH AMERICA

Mexico

According to Manuel Rangel[59] gypsum occurs abundantly in the Cretaceous formation of Banderas Campana and the Sierrita Hills of the Mapimi districts. What is called "gypsum" (geso) in Tejamen, Avilez, San Jose des Canas, Mezquital and other places is only lime carbonate having the appearance of limy alabaster.

In a personal letter which accompanied two samples of gypsum, one of which contained considerable sulphur, two Mexican localities were discussed as follows:

"The darkest sample comes from a deposit in the vicinity of Iguala (a station of the Cuernavaca Branch of the Mexican Central R. R.). The other two are from a deposit near Axochiapam, a station on the Matamoros Branch of the Interoceanic R. R.

Both deposits are practically inexhaustible, but the exploitation of them is not cheap on account of their distance from the railroads. We get the gypsum from Iguala at $5.00 Mex. Cy. per ton (2,240 Lbs.) f.o.b. at Iguala and the freight from Iguala to Mexico City is $4.00 per ton."

Gypsum and sulphur occur at Conejos, north of Torreon. The sulphur is separated by melting with steam and both minerals are utilized.

South America

Gypsum in abundance is reported in Argentine, in the Cordilleras near Aconcagua,[60] but its inaccessibility renders it of no commercial importance.

Cuba

According to the American Consul General at Havana the most extensive deposits in Cuba and the only ones exploited to date are in and around Caibarien. Other deposits are reported near Matanzas.

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[59] Eng. and Min. Jour., July 30, 1921.

[60] Dammer u. Tietze, Die Nutzbaren Mineralien, Vol. II, p. 78.

GYPSUM IN EUROPE[61]

Remarkably pure white gypsum in large quantities occurs in the Hartz mountains, in rocks of Permian age (Zeckstein formation). Important producing localities are Osterode, Nord- Germany hausen, Sangerhausen, Stoller, Ellrich and Ilfeld. In Thuringia gypsum in commercial quantities occurs at Eisenach, Erfurt, Altenstein and in the neighborhood of Oberellenbach. The gypsum in Thuringia belongs to the lower Trias. Figure 6 shows a quarry in a deposit at Krolpa.

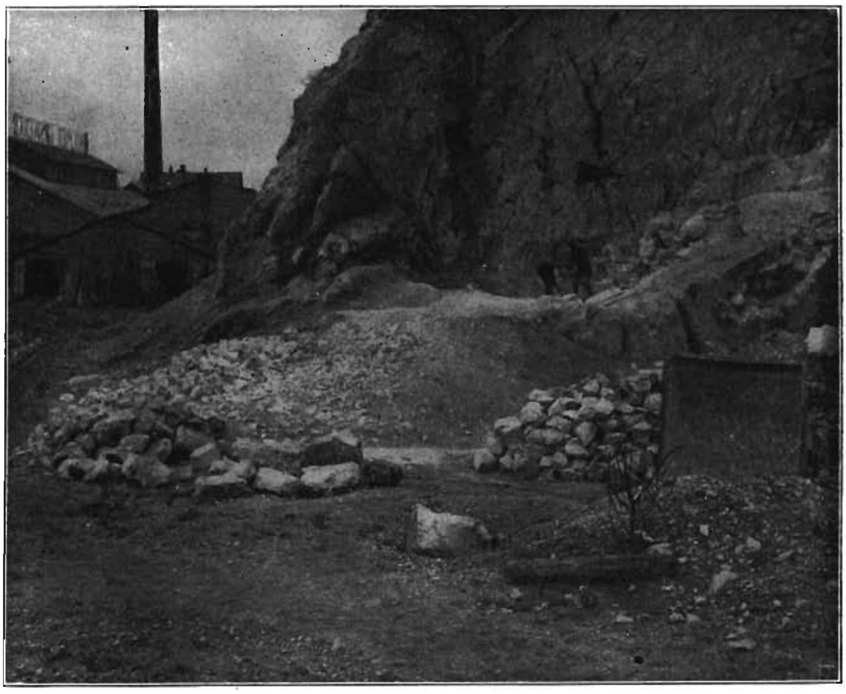

FIG. 6.—Gypsum quarry at Krölpa, Germany.

Gypsum of Triassic age occurs in Saxony in the vicinity of Eisleben and deposits of the same age are found at Luneburg, Segeberg, Lübtheim and Sperenberg. In Hesse gypsum of Triassic age occurs at Stottunheim and Reichelsdorf, and the extensive deposits along the Neckar river are of the same age. In Alsace gypsum of upper Triassic age occurs at Bergheim, Reichenweier, Balbronn and Waltenheim.

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[61] Die Nutzbaren Mineralien, Dammer und Tietze, II.

In Wurtemberg, Triassic gypsum is extensively developed at Grailsheim and occurs at a number of other points. In the Bavarian Alps gypsum occurs at Tegersnee, Langgries, Oberau, Partenkirchen, Fussen, Pfronten and Hohenschwangau.

Austria

Gypsum in large quantities occurs about Salzburg, Austria, and at Groden in Tyrol. In Czecho-Slovakia, Kaaden is an important locality, and in the Carpathians, Wieliczka. The Vienna basin, in the Bruhl district, is productive, as are certain points in Siebenburgen.

Switzerland

Gypsum is found at Bex and Ehendingen in Aargau, Switzerland, the last point yielding fine alabaster. There are extensive gypsum quarries near Ponterliers.

France

The Paris basin of France has long been famous for its gypsum and for gypsum products as is shown by the fact that calcined gypsum is everywhere known as plaster of Paris. The most important producing points in this basin are Mont Martre, Pantin, Belleville, Samois and Enghein where the gypsum occurs in three horizons interbedded with clay. The upper bed of gypsum is the most extensive and usually the thickest, reaching sixty-five feet at Mont Martre. The gypsum of the Paris basin contains lime carbonate up to 10 or 12 per cent.

England

The more important gypsum deposits of England occur in Cumberland, Nottinghamshire, Staffordshire, Derbyshire, and Westmoreland. The gypsum in these localities is of Upper Triassic age. Gypsum occurs also in Sussex and Lincolnshire. The British plaster mills are located in the towns of Newark, Nottingham, Carlisle and New Biggin.

Russia

The gypsum of Russia is of Devonian, Permian, Triassic and Tertiary ages. In the province of Archangel it occurs near the mouth of Pinega river; in the province of Livland near Adsel, Palzmar, Treppenhof, Schoneck, Allasch, Pullandorf, Stubbensee, Kengeragee, Schlockhof, Kemmen and in Pawasser. The central gypsum region extends from Stubbensee and Riga, through Stopinshof, Kengeragge, Dahlen and Kuchholm, in a southerly direction to Kurland. The most important producing points are Stopinshof and Pawasser. The gypsum occurs in beds which on account of bituminous content are yellow to dark blue in color. The thickness of the beds averages from three to five feet, and in places is as much as seven feet. In the province of Kurland gypsum is found in the neighborhood of Schlampen, Ekkendorf, Tackum, Randen, Leuten, Weggen, Eckhof, Goldengen, Appriken, Kalnezeem, and in the vicinity of Schonber, Baldohin and Dunshof. In the province of Pleskauski the gypsum industry is extensively developed at Dubniki and Drosdowa. A number of other localities are mentioned by Dammer and Tietze,[62] who refer to an article by Sodoffsky (in Zeitschrift fur prakt. Geol., 1904, 411).

Spain Spain possesses valuable gypsum deposits in Catalonia, Aragon and Andalusia, the last named province producing alabaster.

Italy The mountains of Tuscany yield gypsum in the vicinity of Castellina and Chiusdino. It occurs in lenses of white or agate-like banded alabaster. Gypsum occurs included in limestones of the Upper Triassic at Cornocchio, Roccastrada, and Chiauciano. It occurs also in connection with sulphur springs at San Fillippo and Campiglio d'Orcea. Gypsum is found in connection with the sulphur deposits of Girgenti.

GYPSUM IN ASIA

Gypsum in great masses is reported at Anna, India, and in Asiatic Turkey. It is quarried in the vicinity of Damascus and Aleppo,[63] and in Turkestan, near Krasnowodsk.

Persia In Persia and the Near-East, gypsum is in many cases associated with oil seeps.[64] On the north of the road from Mossul to Bagdad oil seeps from gypsum beds at a number of points. Oil springs exist in the vicinity of Kifri about 150 kilometers northwest of Bagdad, where beds of gypsum yield quantities of salt, sulphur and petroleum. On the Euphrates in the vicinity of Hit the natives by crude methods obtain about 2500 tons of asphaltic oil a year from a series of gypsum beds in layers up to two meters thick intercalated with sandy clays. In western Persia, about 150 miles west of Shustas, seepages from

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[62] Dammer u. Tietze, Die Nutzbaren Mineralien.

[63] Eng. and Min. Jour., Nov. 26, 1921.

[64] Edmund M. Speicher's review of "Die Turkisch-Persischen Erd oeloorkommen," by Schwerr, Published in Eng. and Min. Jour., Aug. 14, 1920.

beds of light yellow loam rich in sulphur and gypsum yield small quantities of oil.

China Gypsum has been developed near Hankow, China. The raw material has for the most part been sold to Japanese for export.

GYPSUM IN AUSTRALIA

South Australia contains gypsum deposits of considerable magnitude. These occur in the hundred of Warrenben, at Marion Bay; in the hundred of Melville, on Yorke Peninsula; and in the hundred of Gordon, on the Murray Flats.[65]

The deposits at Lake Fowler, Yorke Peninsula, are of considerable extent and take the form of sand hills up to sixty and eighty feet in height. These hills are composed entirely of gypsum. The upper six to nine feet consist of fine "flour" gypsum, which differs from the American gypsite in its greater purity. Chemical analysis shows that it contains 43 to 44 per cent SO_3. The lower part of the hills consists of coarser material, locally called "seed" gypsum, which shows an equally good percentage of SO_3.

In the hundred of Warrenben, near Marion Bay, the gypsum is in the form of a lake deposit from six inches to four feet in thickness, and is free from overburden. In the winter months there is a considerable quantity of water in the lake and quarrying operations are confined to the summer when the lake is practically dry. The gypsum layer breaks clean from the limestone floor underneath it, which makes a good bottom for shoveling.

In the hundred of Gordon the gypsum occurs in a bed three or four feet thick, and is in the form of flour gypsum.

GYPSUM IN AFRICA

Africa The pyramids of Egypt bear witness to the ancient use of gypsum as plaster, and the word alabaster is derived from a state in upper Egypt. At present gypsum is found at Wadi Gerrani, not far from Memphis, and in the vicinity of ancient Hermopolis. Recently a quarry has been opened about forty miles southeast of Alexandria. The bed differs in thick-

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[65] South Australia Dept. of Chemistry, Bull. No. 7, 1917.

ness from one and one-half to nine feet and extends over a considerable area and is supposed to contain one and a half million tons.

In Tripoli, Tunis and Morocco there are numerous occurrences of gypsum, some of them of considerable extent. The age of the beds is reported as Triassic.

The cement factories of the Union of South Africa secure a scant supply of gypsum from irregular segregations in certain valleys in the arid districts of Natal and Orange Free State.[66] The output is about 100 tons a month, valued at £300.

THE GEOLOGICAL AGE OF THE MORE IMPORTANT GYPSUM DEPOSITS OF THE WORLD

FOREIGN		AMERICAN
	PLEISTOCENE AND RECENT	
		Florida[1]
		Utah[2]
		(Dunes in Millard County)
		New Mexico[3]
		Alamogordo
		California[4]
		Lake deposits
	PLIOCENE	
Austria[5]		
Wieliczka		
and		
Siebenbürgen		
	MIOCENE	
		Idaho[6]
		California[7]
	OLIGOCENE	
Transylvania[8]		
Carpathian Mts.		
Germany[9]		
Sperenberg		
France		
Montmartre[10]		
Upper Alsace[11]		

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[1] Calhoun, F. H. H., Mineral Industry for 1917

[2] U. S. Geol. Survey Bull. 697, p. 269

[3] U. S. Geol. Survey Bull. 697, p. 163

[4] U. S. Geol. Survey Bull. 697, p. 58

[5] Credner, Geologie, p. 699-700

[6] U. S. Geol. Survey Bull. 697, p. 100

[7] U. S. Geol. Survey Bull. 697, p. 84

[8] Geikie, Text Book of Geology, 3d. Ed., p. 856

[9] Credner, Geologie, p. 679

[10] Credner, Geologie, p. 675

[11] Dammer u. Tietze, II, p. 67

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[66] So. Afri. Min. Jour., Aug. 10, 1918.

EOCENE

None

CRETACEOUS

- Arkansas[12]
- Colorado[13]

JURASSIC

- Utah[14]
    - Sigurd
- New Mexico[15]

TRIASSIC

- Germany[16]
    - Hanover, Anstadt
    - Erfurt, Thuringia
    - Lothringen Neckar
    - Ellrich
- England[17]
    - Devonshire
- Russia[18]
    - Archangel
- Tunis[19]

- South Dakota[20]
    - Black Hills
- Arizona[21]
- Wyoming[22]

PERMIAN

- Germany[23]
    - The Hartz
    - Stassfurt, Sperenberg
- Austria[24]
    - South Tyrol
- Russia[25]

- Iowa[26]
    - Fort Dodge
- Texas[27]
- Kansas[28]
- Oklahoma[29]
- South Dakota[30]
    - Black Hills
- Colorado[31]
    - Larimer and Douglas counties
- Wyoming[32]
    - Big Horn Mts.

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[12] U. S. Geol. Survey Bull. 697, p. 57

[13] U. S. Geol. Survey Bull. 697, p. 87

[14] U. S. Geol. Survey Bull. 697, p. 268 and 275

[15] U. S. Geol. Survey Bull. 697, p. 163

[16] Dammer u. Tietze, II, p. 66

[17] Giekie, Text Book of Geology, 3d. Ed., p. 866

[18] Dammer u. Tietze, II, p. 58

[19] Dammer u. Tietze, II, p. 70

[20] U. S. Geol. Survey, 21st Ann. Report, Part IV (Darton)

[21] U. S. Geol. Survey Bull. 223, p. 101

[22] U. S. Geol. Survey Bull. 697, p. 295

[23] Credner, Geologie, pp. 503-511

[24] Giekie, Text Book of Geology, 3d. Ed., p. 853

[25] Giekie, Text Book of Geology, 3d. Ed., p. 853

[26] Iowa Geol. Survey, Vol. XII, p. 111

[27] 3d. Ann. Report Texas Geol. Survey, p. 212

[28] Geol. Survey of Kansas, Vol. V

[29] U. S. Geol. Survey Bull. 697, p. 4

[30] U. S. Geol. Survey, 21st Ann. Report, Part 4 (Darton)

[31] U. S. Geol. Survey Bull. 697, p. 87

[32] U. S. Geol. Survey Bull. 223, p. 85

- New Mexico[33]
    - Mesa Lucero
    - East of Socorra
    - Phillips Hills
    - Sacramento Mts.

CARBONIFEROUS

- Colorado[34]

MISSISSIPPIAN

- Michigan[35]
    - Alabaster
    - Grand Rapids
- Nova Scotia[36]
- Virginia[37]
- Montana[38]
    - Carbon county
    - Madison county
- Iowa[39]
    - Centerville
- Nevada[40]
    - Lovelock

DEVONIAN

- Russia[41]
    - Baltic Provinces

SILURIAN

- Russia[42]
    - Baltic Provinces

- New York[43]
- Ohio[44]
- Michigan[45]
    - St. Ignace
- Iowa[46]
    - Grinnell

CAMBRIAN

- India
    - Punjab Salt Range[47]

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[33] U. S. Geol. Survey Bull. 697, pp. 164-170
[34] U. S. Geol. Survey Bull. 697, p. 87
[35] Geol. Survey of Michigan, Vol. V (1881-93), Part II, pp. 14-30
[36] Min. Resources of Canada, 1897, pp. 105-111
[37] U. S. Geol. Survey Bull. 697, p. 285
[38] U. S. Geol. Survey Benton Folio, p. 6
[39] U. S. Geol. Survey Bull. 697, p. 8
[40] U. S. Geol. Survey Bull. 697, p. 147
[41] Geikie, Text Book of Geology, 3d. Ed., p. 789, also Dammer u. Tietze, II, p. 68
[42] Geikie, Text Book of Geology, 3d. Ed., p. 789
[43] N. Y. Geol. Survey, Vol. III, No. 15, p. 550
[44] Geol. Survey of Ohio, Vol. VI, pp. 691-702
[45] Geol. Survey Mich., Vol. I (1869-73), Part III, pp. 913-915
[46] Iowa Geol. Survey, Vol. XXI, p. 581. Gypsum at depth of 1010 to 1030 feet.
[47] Geikie, Text Book of Geology, 3d. Ed., pp. 787-789

CHAPTER III

ORIGIN OF GYPSUM AND ANHYDRITE

Early students of the subject, including Dana, who wrote particularly of the gypsum in New York, believed that gypsum was generally derived from limestone by the action of sulphurous waters resulting from the oxidation of pyrite and other sulphides. After Ochsenius, in 1877, published the results of his studies of sea water, belief gradually centered about the idea that most gypsum deposits have been formed directly from sea water under conditions favorable to evaporation, which resulted in a concentration of its saline contents.

Early opinions

More recently A. W. Grabau[68] pointed out difficulties in connection with the direct evaporation theory. E. B. Branson[69] came to the support of the direct evaporation, or "salt pan" theory, with a "modified bar" hypothesis, which assumed a second or inner basin in which the brine reached the gypsum depositing stage. The views of these writers are presented somewhat at length later in the chapter.

In 1910 F. L. Hess[70] grouped gypsum deposits in four classes.

Recent classifications

1. Efflorescent deposits
2. Periodic lake deposits
3. Interbedded deposits
4. Veins

R. W. Stone[71] adopted a similar classification for gypsum deposits derived from solution. He further adds

5. Deposits produced by alteration
6. Deposits produced by disintegration and mechanical reaccumulation.

The classification given below, based upon origin, will be followed in this chapter.

1. Deposits, generally disseminated, and seldom of economic

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[68] Grabau, A. W., Principles of Stratigraphy, p. 350; also Bull. Geol. Soc. America, Vol. 24, pp. 496-498.

[69] Bull. Geol. Soc. America, Vol. 26, p. 235

[70] Hess, F. L., Reconnaissance of the Gypsum Deposits of California, U. S. Geol. Survey Bull. 413, 1910.

[71] Gypsum Deposits of the United States, Bull. 697, U. S. Geol. Survey, 1920

importance, formed directly by evaporation of sea water.

2. Concentrations, accomplished by moving waters, of gypsum disseminated through sediments.
   - a. in inland lakes
   - b. on the surface
     1. by springs
     2. as efflorescence, concentrated further by winds and streams
   - c. in fissures, cavities, and as replacements.
3. By alteration
   1. of carbonates
   2. of anhydrite
   3. of calcium-bearing minerals in igneous rocks by ascending sulphides.

DEPOSITION FROM SEA WATER

Gypsum is deposited with other salts on the evaporation of sea water, which contains three and one-half per cent of mineral matter of the following sorts and percentages:[72]

		PER CENT TOTAL SALTS	PER 1000 PARTS WATER
Nature of salts in sea water	Chloride of sodium	77.758	27.213
	Chloride of magnesium	10.878	3.807
	Sulphate of magnesium	4.737	1.658
	Sulphate of calcium (gypsum)	3.600	1.26
	Sulphate of potassium	2.465	.863
	Carbonate of lime	0.345	.123
	Bromide of magnesium	0.217	.076
		100.000	35.000

The order of deposition of salts from sea water with incresse in density of the brine is shown in the following table compiled by Grabau:[73]

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[72] Encyclopedia Brittanica.

[73] Principles of Stratigraphy, p. 349

TABLE SHOWING THE SEPARATION OF SALTS FROM SEA WATER

Density of the sea water or of the mother liquor at 12.5°C. (Baume scale)	Specific gravity (after Clark)	Volume after evaporation and crystalization. Liters	SEPARATION AT THE SUCCESSIVE DENSITIES IN GRAMS								
			Sesquioxide of iron, Fe_2O_3	Calcium carbonate, $CaCO_3$	Calcium sulphate, $CaSO_4 \cdot 2H_2O$	Sodium chloride, NaCl.	Magnesium sulphate, $MgSO_4$	Magnesium chloride, $MgCl_2$	Sodium bromide, NaBr	Potassium chloride, KCl	Total precipitated
1	2	3	4	5	6	7	8	9	10	11	12
1.0258	1.0258	1.0000	....	....	....	....	....	....	....	....	....
1.0506	1.0500	0.5330	0.0030	0.0642	....	....	....	....	....	....	0.0672
1.0820	1.0836	0.3160	....	trace	....	....	....	....	....	....	trace
1.1067	1.1037	0.2450	....	trace	....	....	....	....	....	....	trace
1.1304	1.1264	0.1900	....	0.0530	0.5600	....	....	....	....	....	0.6130
1.1653	1.1604	0.1445	....	....	0.5620	....	....	....	....	....	0.5620
1.1786	1.1732	0.1310	....	....	0.1840	....	....	....	....	....	0.1840
1.2080	1.2015	0.1120	....	....	0.1600	....	....	....	....	....	0.1600
1.2208	1.2138	0.0950	....	....	0.0508	3.2614	0.0040	0.0078	....	....	3.3240
1.2285	1.2212	0.0640	....	....	0.1476	9.6500	0.0130	0.0356	....	....	9.8462
1.2444	1.2363	0.0390	....	....	0.0700	7.8960	0.0262	0.0434	0.0728	....	8.1084
1.2627	1.2570	0.0302	....	....	0.0144	2.6240	0.0174	0.0150	0.0358	....	2.7066
1.2874	1.2778	0.0230	....	....	....	2.2720	0.0254	0.0240	0.0518	....	2.3732
1.3177	1.3069	0.0162	....	....	....	1.4040	0.5382	0.0274	0.0620	....	2.0316
Total precipitated..........................			0.0030	0.1172	1.7488	27.1074	0.6242	0.1532	0.2224	....	29.9762
Remainder in mother liquor.........			....	....	....	2.5885	1.8545	3.1640	0.3300	0.5339	8.4709
Sum total of salts..........................			0.0030	0.1172	1.7488	29.6959	2.4787	3.3172	0.5524	0.5339	38.4471

The following diagram (figure 7) presents in a general way the relation of deposition to density of salts common to sea water.

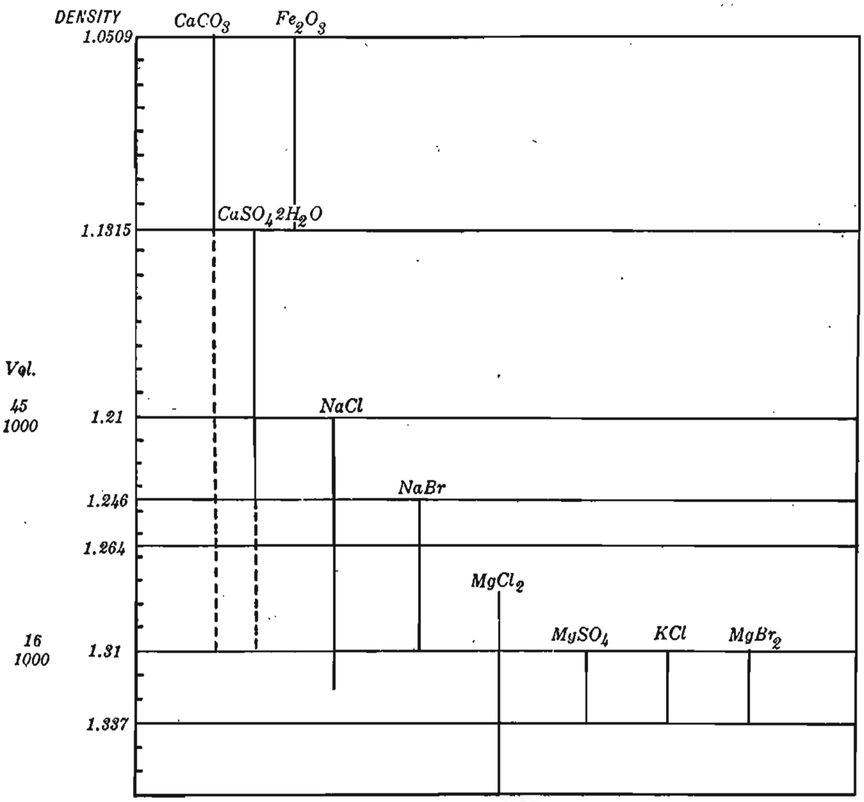

FIG. 7.—Sketch showing the order of precipitation of salts from sea water with increase in density.

Three-fourths of the gypsum is deposited between the densities of 1.1315 and 1.21, or when the volume of the water has been reduced from 80 to 92 per cent. The remaining one-fourth of the gypsum is deposited with the salt but constitutes so small a part of the whole that the commercial value of the salt is not appreciably lowered. The normal order of deposition on evaporation from sea water, beginning with the first precipitates, which will occur, of course, at the bottom of the deposit, is:

Deposition of salts from sea water

1. Limestone with limonite ($CaCO_3$ and $2Fe_2O_3–3H_2O$).
2. Gypsum $CaSO_4$. $2H_2O$ (with a small percentage of limestone).
3. Sodium chloride (common salt) NaCl (with some gypsum and traces of limestone).
4. The bitter salts ($MgSO_4$, $MgCl_2$, NaBr).

Karabugas gulf

When deposits resulting from the evaporation of sea water are under consideration attention is generally called to Karabugas gulf on the eastern border of the Caspian sea, by way of illustration. This gulf is separated from the Caspian by a long and narrow bar, save for a narrow and relatively shallow channel through which a stream of salt water from the Caspian constantly flows to compensate for the evaporation within the gulf. It is stated that this current carries 350,000 tons of salt into the gulf daily. The density of the water is, of course, steadily increasing and has already reached the point where certain salines are deposited. Gypsum crystals are formed near the margin of the gulf, while toward the center sodium sulphate is deposited, though only in the winter months, for at summer temperatures the water is not saturated as regards sodium sulphate. It is not saturated at any natural temperature for common salt, sodium chloride, and this substance remains in solution.[74] Two analyses of the salts contained in the waters of Karabugas gulf, quoted by Clarke, appear as A and B in the table below.

	A	B	C
Cl	53.32	50.26	55.29
Br	.06	.08	.188
SO_4	17.39	15.57	7.69
CO_3	--------	.13	.20
Na	11.51	25.51	30.59
K	1.83	.81	1.10
Rb	.06	--------	--------
Ca	--------	.57	1.19
Mg	15.83	7.07	3.72
	Salinity 28.5 per cent	Salinity 16.39 per cent	Salinity 3.3 to 3.7 per cent

For purposes of comparison the mean of seventy-seven analyses of the salts contained in sea water collected by the Challenger Expedition appears under C.[75] Quoting Grabau[76] "This gulf further illustrates the enormous destruction of organisms due to the intense salinity, a destruction that would render all

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[74] Clarke, F. W., The Data of Geochemistry: U. S. Geol. Survey Bull. 616, p. 166, 3d Ed. This gives reference to a number of original sources.

[75] U. S. Geol. Survey Bull. 616, p. 123.

[76] Principles of Stratigraphy, p. 354.

salt deposits of such a gulf highly fossiliferous. Andrussow calls attention to the large number of fish which are carried across the bar into the Karabugas, where they perish. Their carcasses float about as long as the water flowing into the gulf moves them, after which they either sink to the bottom or are driven onto the shore.

"Among other organisms killed in the saline waters of this gulf **Cardium edule** should be mentioned. This eurybaline organism abounded in the gulf before it reached the stage at which sulphates were deposited. The shells of this species occur in enormous numbers on the shores of the Karabugas."

Nile delta salt pans

Gypsum is deposited, according to Grabau,[77] in connection with natural salt pans in the Nile delta. These salt pans extend along the coast "and owe their salt to flooding from the Mediterranean and the rapid evaporation due to the desert climate of the coast. The salt is covered by wandering sand dunes, which when they reach a great thickness become filled through efflorescence with crystals of gypsum three to five cm. long. These unite into heads one to four meters broad and from one-half to one meter in thickness.

Red Sea salinas

"On the borders of the Red sea are a number of salinas. One west of Amfila Bay on the Abyssinian border lies below sea level, and is surrounded by a wall of gypsum. The streams flowing from the East Abyssinian mountains into this depression evaporate, adding their contribution to the saline deposits. At Allolebod, on the southern coast of the Red Sea, the deposits in the natural pans show regular interstratification by layers of gypsum similar to the annual rings of the Stassfurt salt. These layers mark the periodic inundations of the salt pans."

Difficulties of evaporating basin theory

The great thickness of some occurrences of gypsum and salt must be considered in connection with any theory offered to explain their origin. The combined series at Stassfurt amounts to more than 1000 feet and that at Sperenberg to more than 3000 feet. To yield even fifteen feet of gypsum, the average thickness in the Iowa field, an immense amount of water of the composition of ordinary sea water must have been evaporated. A cubic foot of gypsum weighs 140 pounds and the amount of gypsum in a cubic foot of sea water today is three-fiftieths of a pound, so that 2,333.3 cubic feet of sea water are required to yield one cubic foot of gypsum.

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[77] Principles of Stratigraphy, p. 355.

If the sides of the containing basin were vertical the depth of the water necessary to produce fifteen feet of gypsum must have been 34,986 feet. If the average thickness of the Webster county gypsum be taken as fifteen feet, and the gypsum area regarded as thirty square miles in extent, nearly thirty trillions of cubic feet (29,270,220,000,000) of ordinary sea water must have evaporated in the deposition of the gypsum beds.

Branson's hypothesis

Branson[78] has proposed a "modified bar hypothesis" to account for thick deposits of gypsum free from salt. By this hypothesis he aims to supply the receiving basins with highly concentrated waters instead of normal sea water. He says, "In the drying up of a large interior sea the waters might come to lie in separate basins if the bottom were uneven. Evaporation over the full expanse of the interior sea might be rapid enough to decrease the depth and area in spite of the inflow of some stream, but when considerable areas of bottom had become exposed the total evaporation would have become less and the inflow nearer to the rate of evaporation. Assuming that isolated basins would be found, separated by low barriers and that the main streams would empty into the marginal basins, the inflow might be sufficient to cause these basins to overflow and supply the inner basins, that had no direct stream connections, with highly charged waters as fast as their own waters evaporated. As beds of gypsum 10 feet in thickness are widespread. a depth of water great enough to contain the salt of sea water evaporated to deposit them must be assumed, and the evaporation must not be carried beyond nine-tenths of the original amount if the salt is to remain in solution. The depth of a basin for 10 feet of gypsum would have to be at least 1400 feet and possibly 1500."

Branson accounts for beds of gypsum reaching great thickness, by supposing that currents shifted unconsolidated gypsum and deposited it in the deeper or quieter basins. He supposes that after the water has deposited its gypsum an inflow of water from one or more of the stream fed border basins causes the basin to overflow into a more remote basin where evaporation brings the water to the salt depositing stage.

Deposition of thick beds of relatively pure gypsum directly from sea water is attended with many difficulties. To secure such a result a considerable number of pecular conditions must

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[78] Branson, E. B., Bull. Geol. Soc. America, Vol. 26, No. 2, June, 1915, p. 235.

be operative at the same time. There is no point on the earth's crust where all of the necessary conditions exist today. It is true that some gypsum is being deposited today from sea water. Cases have been cited as in Karabugas gulf; the Nile delta salt pans; and the Red Sea salinas. In all of these instances, however, the gypsum is very impure, or consists merely of thin bands or detached crystals scattered through silt.

The lime carbonate problem

If any extensive and practically pure beds of gypsum are to be regarded as direct deposits from sea water, some disposition must be made of the lime carbonate which is present in sea water. If sea water is evaporated in the laboratory the lime carbonate is deposited, partly before the gypsum and partly with it, as illustrated in figure 7.

E. B. Branson[79] points out that "if the waters were widespread in the beginning, about half of the limestone might be deposited over the wider area, as more than half of the $CaCO_3$ precipitates when the volume of sea water is reduced about fifty per cent." Branson states that he has not seen limestone immediately below the gypsum at any place in the Red Beds of Wyoming. There is no limestone immediately below the gypsum in Webster county, Iowa, though the lower six inches of the gypsum contains some calcium carbonate. A twenty foot bed of gypsum like that at Fort Dodge should have nearly a foot and a half of limestone below it if the evaporation all took place in a restricted basin.

It is probable that a considerable amount of the lime carbonate would be precipitated near the point where the water of the outer basin began to mingle with the denser brine of the inner basin. There would, however, be a considerable lime carbonate contamination throughout the basin.

Stieglitz and atmospheric equilibrium

The carbon dioxide of the atmosphere is an important factor influencing the solubility of calcium carbonate. This fact must be kept in mind in considering the deposition of gypsum directly from sea water. Julius Stieglitz[80] in a very interesting discussion entitled The Relations of Equilibrium between the Carbon Dioxide of the Atmosphere and the Calcium Sulphate, Calcium Carbonate, and Calcium Bi-

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[79] Branson, E. B., Bull. Geol. Soc. America, Vol. 26, No. 2, p. 235, 1915.

[80] Stieglitz, Julius, in Contributions to Cosmogony and the Fundamental Problems of Geology, Carnegie Institute, p. 236, 1909.

carbonate of Water Solutions in Contact with It, concludes that for an ideal condition, if the natural waters of the earth were supposed to contain only lime salts, that is the sulphate, carbonate and bicarbonate, in equilibrium with the carbon dioxide of the atmosphere, then by evaporation they would deposit first, as is now the case, until the solution became saturated with gypsum, all the calcium carbonate in solution in excess of the amounts given in table 5 in columns 3 and 5; depending on the partial pressure of the atmospheric carbon dioxide. When the solution becomes saturated with gypsum this will, by continued evaporation, crystallize out, but no matter whether it is deposited in the same locality as, or in some other locality than, the first great deposit of calcium carbonate, the gypsum must inevitably be continuously contaminated with some calcium carbonate, varying from 0.3 to 2.85 per cent according to the partial pressure of the carbon dioxide in the atmosphere within the limits given.

TABLE 5

CO_2 atmosph.	$CaSO_4$ grams	$CaCO_3$ grams	$CaSO_4$ moles	$CaCO_3$ moles	$CaCO_3$ per cent
0.00003	2.07	0.006	0.0152	0.00006	0.30
.0003	2.07	.019	.0152	.00019	0.90
.003	2.07	.059	.0152	.00059	2.89

Professor Stieglitz further continued his studies by considering the influence on the deposition of calcium sulphate, of the presence in the solution of other sulphates and of sodium chloride. He concludes

1. that if the natural waters of the earth were supposed to contain only lime salts, that is the sulphate, carbonate and bicarbonate, in equilibrium with the carbon dioxide of the atmosphere, and if the average partial pressure of carbon dioxide in the atmosphere were the same as at present (0.0003 atmosphere) by evaporation the gypsum would be precipitated with contamination of 0.9 per cent of calcium carbonate.

If the carbon dioxide were reduced to one-tenth the amount in the present atmosphere—a condition hardly conceivable—the gypsum would still be precipitated with contamination of calcium carbonate, though the amount would be reduced to 0.3 per cent.

If the carbon dioxide were increased to 10 times the amount in the present atmosphere, the calcium carbonate contamination would increase to 2.85 per cent.

2. The presence of other sulphates which might be found in sea water would increase the calcium carbonate contamination of the gypsum.

3. An increase of temperature, by decreasing the coefficient of absorption of carbon dioxide would possibly be a favorable factor in the formation of pure gypsum by evaporation of sea water. Such increase in temperature, however, would probably be associated with an increase in the amount of carbon dioxide in the atmosphere and as has been noted, an increase in the carbon dioxide content of the atmosphere means a rapid increase in calcium carbonate contamination of the gypsum.

4. The presence of large amounts of sodium chloride (about 8 to 25 per cent) would have a tendency to reduce the calcium carbonate contamination.

Professor Stieglitz calls attention to Usiglio's work on Mediterranean water where calcium sulphate began to be deposited when the water reached the density of 1.13, which corresponds to a chloride content of 17 per cent. This concentration, Stieglitz states, was reached in Cameron's experiments for solution 7, from which, going to solution 8, gypsum would be obtained with about 0.8 per cent of carbonate.

5. "Even if the great mass of an excess of calcium carbonate in a solution were deposited first in some other locality before the point of saturation for gypsum were reached, the requirements for equilibrium would be such as to hold carbonate in solution and to make the question of the place of deposit of the excess of carbonate in the first instance one of no moment."

As a result of Stieglitz' work it seems necessary to draw the conclusion that it is very unlikely that gypsum that contains less than nine-tenths of one per cent of calcium carbonate, was formed under salt pan conditions.

Inasmuch as there are many published analyses of gypsum which contain less than nine-tenths of one per cent of calcium carbonate it seems necessary to take such deposits out of the salt pan class, or else to suspect that the analyses were not made with sufficient care with reference to calcium carbonate. In some cases there is ground for suspecting the accuracy of the analyses. Recent analyses of the Fort Dodge, Iowa, gypsum, for instance, show sufficient calcium carbonate to permit the supposition that they were deposited from sea water, though earlier analyses had shown no carbonate.

Analyses of a great many interesting and important deposits remain, however, that record no lime carbonate, and unquestionably some of these analyses were carefully made and fairly represent the bed as a whole. This list of carbonate-free deposits contains those in

- Arizona
  - Douglas
  - Empire Mountain
- California
  - Amboy
  - Palmdale
- Florida
  - Penasoffkee
- Iowa
  - Centerville
- Kansas
  - Kling
  - Medicine Lodge
- Montana
  - Great Falls
  - Armington
  - Boulder
- New Mexico
  - White Sands of Alamogordo
- Oklahoma
  - Cement
  - Southard
- Utah
  - Levan
  - Nephi
- Wyoming
  - Red Buttes

Certain portions of the gypsum in Virginia and at Medicine Lodge, Kansas, contain lime and magnesium carbonate, while other portions seem to contain no carbonate.

DISSEMINATED GYPSUM

The preceding pages have been devoted to gypsum deposits, usually disseminated, resulting from the evaporation of seawater in more or less detached basins. There are other sources for the gypsum that is found in limited quantities in a great many sedimentary rocks.

Disseminated gypsum from connate waters

Grabau has called attention to the "connate" waters in sedimentary beds. He regards these oceanic waters, imprisoned when the sediments were laid down, as the chief source of material for saline deposits.

It is highly probable that along the shores of the ancient oceans gypsum was deposited more or less continuously, in small quantities, with all classes of sediments. Waves rolling up the beach saturate the sands with brine which later evaporates, leaving the salts. Beach sands today contain more or less salt and gypsum and the amount that they retain depends upon their protection from leaching. The salt leaches out readily, while considerable quantities of the gypsum may remain.

Much gypsum has been formed by the action of sulphurous waters circulating through sediments that contain calcium carbonate.

Disseminated gypsum by chemical reaction

The shales of nearly every geological horizon in numerous and widespread localities contain individual crystals and rosettes of selenite produced by the action of iron sulphate derived from the oxidation of pyrites, on lime carbonate. Selenite so derived is particularly abundant in the Mississippian, Pennsylvanian and Cretaceous shales.

CONCENTRATION OF DISSEMINATED GYPSUM

Waters flowing over or through sediments containing disseminated gypsum dissolve the gypsum and under certain conditions redeposit it in concentrated form. Arid regions present conditions favorable for such concentration. If the moisture of the region is sufficient to permit of intermittent streams, both the surface water and the springs feeding them will be heavily charged with salts. These streams, which may be perennial in their lower courses, generally empty into a detached basin.

The water of the river Jordan gives the following analysis:[81]

	PER CENT
Sodium chloride (common salt)	.35
Magnesium chloride	.03
Calcium chloride	.07
Calcium sulphate (gypsum)	.04
Water	99.50

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[81] Bischof, Chem. and Phys. Geology, Vol. I.

The Dead Sea

The waters of the Dead Sea are largely the result of concentration by evaporation of this water. Quoting Bischof:[82] "In spring when the streams are turbid with the particles of carbonate of lime and clay, mere mechanical deposits take place, for at this period, when large masses of water are carried into the Dead Sea, and the saline solution is thereby diluted, while at the same time the evaporation is but slight, no common salt is deposited. During the ensuing warmer months the chemical deposition of common salt and carbonate of lime takes place. Should the stream become turbid at this season in consequence of continued rain, deposits are formed which contain a less amount of common salt. In this way there must arise a constant alternation of different irregular layers of greater or less thickness. All these layers must contain gypsum since in a water which contains so much chloride of magnesium as is present in the Dead Sea, gypsum as we shall subsequently see, is dissolved with difficulty."

Great Salt Lake

Great Salt lake is but a remnant of the much larger Lake Bonneville, which was fresh and was drained by a stream flowing into Snake river. The streams flowing into Great Salt lake carry considerable quantities of mineral in solution, as is shown by the following table:[83]

	A	B	C	D	E	F	G
Cl	2.68	32.36	35.54	34.76	5.38	23.21	13.73
SO_4	5.76	8.16	26.54	30.68	2.87	5.65	9.25
CO_3	52.68	21.53	2.67	trace	52.57	33.68	40.00
Na }	4.49	20.54	26.13	23.04	3.74	11.31	8.37
K }						4.16	4.19
Ca	23.69	10.12	7.59	10.26	24.19	16.05	18.19
Mg	6.86	4.76	1.53	1.26	7.15	5.94	6.27
SiO_2	3.84				3.69		
$AlFe_2O_3$		2.53			.41		
Total	100	100	100	100	100	100	100
Salinity, parts per million	185	637	892	1090	243	444	455

A. Bear river at Evanston, Wyoming.
B. Bear river at Corrine, Utah.
C. Jordan river at intake of Utah and Salt Lake canal.
D. Jordan river near Salt Lake City.
E. City Creek, Utah.
F. Ogden river at Ogden, Utah.
G. Weber run at mouth of canyon.

Clarke adds: "All of the waters tributary to Great Salt Lake, so far as they have been examined, contain notable quantities of carbonates, which are absent from the lake itself."

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[82] Ibid, p. 397.

[83] Data of Geochemistry, U. S. Geol. Survey Bull. 616, p. 156.

The present salinity of the lake is high, the specific gravity being 1.1 and its saline content, varying with the seasons from 14 to 22 per cent, is distributed as follows, as shown in five analyses[84]:

Sodium chloride	90.7	79.1	65.9	81.3	80.5
Potassium chloride			14.1		
Magnesium chloride	1.1	9.9	8.9	6.7	10.3
Sodium sulphate	8.2	6.2	8.1	8.5	5.4
Potassium sulphate	-----	3.6		2.6	2.4
Calcium sulphate	-----	.6	1.5	.9	1.4
Chlorine (in excess)	-----	.6	1.5	-----	-----

In these analyses the absence or the very small content of calcium, both as sulphate and carbonate, is remarkable. Analyses of the fresh waters tributary to the lake show that the lake could accumulate its total content of calcium in eighteen years while the accumulation period for the chlorine would be 34,200 years[85]. Manifestly the lake is disposing of much of the calcium as fast as it is received. Deposits of tufa occur on the old Bonneville, Intermediate and Provo shore lines, on their weathered faces, and a few feet below their crests. It is absent in sheltered bays and most abundant on points that were especially exposed to wave action. Calcereous oölitic sands are now forming along certain parts of the shore of Great Salt lake ‘‘between the delta of the Jordan and Black Rock, where it constitutes the material of a beach, and is drifted shoreward in dunes.’’[86] Of the three important fresh water tributaries of Great Salt lake, the water of Utah lake is characterized by sulphate of lime, over 60 per cent of the total solids held in solution by it consisting of this salt, while the waters of Bear river and City creek are characterized by carbonate of lime.’’[87] Strictly speaking, in the last case, as commonly when carbonate of lime is in solution, the lime is in the form of the bicarbonate. During the process of aeration caused by the beating of the waves against the shore carbon dioxide is given off and the lime, reduced to calcium carbonate, is deposited.

The oölitic sands may be ascribed to the action of plants which have the power of withdrawing carbon dioxide from soluble calcium bicarbonate, which would cause the precipita-

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[84] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Monograph I, p. 254.

[85] Idem, p. 256.

[86] Idem, p. 169.

[87] Idem, p. 207.

tion of the insoluble carbonate.[88] Deposits of calcareous tufa and oölite are particularly abundant near the mouths of streams which convey carbonate of lime to the lake and possibly the lime carbonate is wholly withdrawn from the inflowing water before it has an opportunity to mingle with the more remote waters of the lake.

The Bessarabian coast of the Black Sea furnishes an example of salt deposits in bays slightly connected with the ocean and fed from the landward side by rivers. From the Danube to the Dnieper the rivers before emptying into the ocean expand into lakes which are separated from the sea by natural dams. Under ordinary circumstances the water flows into the sea through an opening in the dam, while during storms the water of the sea enters the lakes. Three of these lakes become partly dry every summer and deposit salt which in places amounts to a layer a foot thick.[89] This salt is used for commercial purposes. The calcium sulphate of the river water and of the sea water which is driven in during storms must also be deposited, but the quantity being small readily escapes notice.

The difficulties in the way of accumulations of practically pure gypsum in stream fed inland basins are, in general, the same that interfere with accumulations of gypsum from sea water. It is conceivable that differential solution might give rise to inflowing streams carrying no salt in quantity except gypsum. It is impossible, however, to cite instances where extensive beds of gypsum are today forming in this way.

Spring deposits

The gypsum deposits of Florida have been formed in recent geological time and according to R. W. Stone are due to the action of springs.[90] The great masses of gypsum found in the "domes" of Louisana and Texas are regarded by G. D. Harris[91] and some others as the work of water moving upward along fissures. It is supposed that the gypsum was originally disseminated through beds located below the present accumulations.

F. L. Hess in his report of the gypsum deposits of Cali-

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[88] Russell, Lakes of North America, p. 76.

[89] Bischof, Vol. I, p. 392.

[90] Stone, R. W., Gypsum Deposits of the United States: U. S. Geol. Survey Bull. 697, p. 95, 1920.

[91] Bull. Louisiana Geol. Survey No. 7, 1908.

fornia describes a deposit of gypsum, sulphur and hydrocarbon, which is locally known as the "oil bubble".[92] He states that "the mound is formed by the evaporation of water carrying gypsum in solution and clay probably being brought to the place by winds. The excessive dryness of the surrounding country makes it seem probable that the water comes from a considerable depth, rising through the Tertiary gypsiferous sandstones."

According to G. W. Stose the gypsum deposits of Virginia were probably derived from calcareous-argillaceous sediments which contained disseminated gypsum. He believes that this gypsum was dissolved by underground waters which circulated along the fault that lies close to the gypsum deposits, and was later deposited in concentrated form at higher levels.

Deposits by ascending waters and seepages

The domes of the gulf coast are built up of immense masses of gypsum and salt, with which in some instances oil and sulphur are associated. Although there is diversity of opinion as to the origin of these domes many believe that the gypsum and salt have been deposited in the domes by waters moving upward along fault planes.

In Persia and the Near East gypsum is in many places associated with oil seeps.[93] The association of gypsum with oil and bituminous shales may be the result of the action of sulphur, which is usually associated with hydrocarbons; or it may merely indicate that the same seepage conditions that bring the oil to the surface have been instrumental in concentrating and depositing gypsum.

Satin spar veins

In many gypsum fields the associated shales and clays are banded with satin spar seams. These may follow the bedding of the clays or may run in various directions. These satin spar zones unquestionably are secondary concentrations. They occur in massive gypsum, and the gypsum of the Fort Dodge area shows, on careful examination, numerous fine bands of satin spar parallel to the bedding. From such zones of infiltration the gypsum has often crystallized, crowding back the surrounding clays until bodies of gypsum of considerable extent have resulted.

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[92] Hess, F. L., U. S. Geol. Survey Bull. 413, p. 15.

[93] For a more complete report of occurrences of this nature see paper by the writer in Bull. Geol. Soc. America, Vol. 32, No. 4, pp. 385-394.

In many arid regions gypsum appears as an extensive efflorescence. The delicate crystals so formed are later broken off and heaped up by the winds till they form immense dunes, or gypsum hills. The best known deposits of this type are the "White Sands" of Alamogordo, New Mexico. Many millions of tons of remarkably pure gypsum occur in these hills, which would be of the greatest commercial importance if they were nearer to important markets. Similar deposits occur in Australia and in Utah.

Efflorescent gypsum deposits

Gypsum dunes

GYPSUM PRODUCED BY ALTERATION

Ochsenius published his conclusions in regard to deposition of salts from sea water in 1877. Previous to that time gypsum was generally regarded as an alteration product, derived from limestone. Sulphurous waters are abundant and their ability to convert limestone into hydrated lime sulphate has long been recognized. Numerous instances of gypsum deposits which have been formed in this way have been reported.

From limestone

An interesting case at Spatsum, British Columbia, is described by L. H. Cole[94]. Gypsum-bearing rocks occur on the hills forming the west bank of Thompson river. Cole says that "the surface material consists of badly disintegrated masses of mica schists, limestones and shales with frequent nodular lumps of white gypsum of varying size. After passing through this altered material, which has been highly recemented, the tunnel cuts through a band of very pure massive white gypsum which proved by analysis to be almost a theoretically pure gypsum. This band, however, was only 5 feet wide with very light gray or white highly altered hydro-mica schist together with some altered limestone for the hanging wall."

O. M. Knode of the United States Gypsum Co. visited the spot and found a tunnel forty feet long driven into a bed of crystalline limestone. The whole face of the tunnel was moist and slimy from a deposit of sulphur and gypsum. Analyses of the rock along the sides of the tunnel gave from 12 to 100 per cent gypsum.

Grabau[95] in his latest work, returns to the older view of Dana and ascribes the New York gypsum to the action of sulphurous waters on limestone.

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[94] Cole, L. H., Gypsum in Canada, pp. 95, 96.

[95] Text Book of Geology, Part I, p. 246.

W. G. Matteson, in a valuable paper recently presented to the American Institute of Mining Engineers,[95a] reviews the earlier work in connection with salt dome structure and concludes that the domal materials were "deposited relatively near the surface directly from solutions of secondary origin and character." So far as the gypsum is concerned he says that "it appears most likely that the original domal materials consisted only of limestone, probably in the form of travertine, and salt, the gypsum being the result of the conversion of the limestone through the action of sulfuric acid and hydrogen sulfide-bearing waters and gases."

Gypsum from anhydrite

A. J. Rogers,[96] after reviewing the more important anhydrite deposits of the United States, arrives at the conclusion that many, if not most, of the important gypsum deposits have been formed by the hydration of sedimentary anhydrite. Some important anhydrite beds are probably not sedimentary, and Rogers' statement is rather broad. It emphasizes an aspect of the situation, however, that generally has been overlooked. The Virginia gypsum and the important deposits about Windsor, Nova Scotia, seem to have been derived from anhydrite. In the light of recent drilling Newland[97] is inclined to the opinion that the more important deposits in New York were originally anhydrite.

ORIGIN OF THE FORT DODGE GYPSUM

If the Fort Dodge gypsum is regarded as the residue left after the evaporation of a body of sea water, originally widespread but eventually concentrated within a few square miles, it is necessary to account for the absence of the limestone and salt that would be associated with gypsum precipitated by such a process. It is possible that after reaching the density required for gypsum deposition, some diversion took place and the water failed to deposit its salt. Such an interruption in the natural course of events would come if there were a great inflow of fresh water; if the brine by some change in surface elevation should be drawn off to deposit its salt elsewhere; or if an

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[95a] Transactions American Institute Mining & Metallurgical Engineers, Vol. LXV, pp. 295-322, 1921.

[96] School of Mines Quarterly, Columbus Univ., Vol. XXXVI, January, 1915, p. 141.

[97] Mineral Industry, 1920, Vol. 28, p. 333.

oceanic connection should be established or an existing connection enlarged so that the brine would be diluted.

If salt were deposited at Fort Dodge it might easily have been removed by preglacial erosion. The absence of salt therefore is not in any way a definite factor in determining the origin of the gypsum.

The absence of limestone beneath the gypsum is more difficult to explain if the gypsum is regarded as the result of the direct evaporation of sea water. The earlier pages of this chapter make it plain that there should be a foot or two of limestone below the gypsum, since sea water that will deposit fifteen feet of gypsum necessarily contains enough lime carbonate to make a bed of this thickness. There is no limestone anywhere beneath the gypsum at Fort Dodge. The lower six inches of the gypsum contains lime carbonate in varying amounts, possibly up to 25 per cent. The gypsum itself contains from one to two per cent of lime carbonate. The amount of carbonate in the gypsum, however, is not sufficient to account for the lime carbonate in sea water of sufficient volume to deposit fifteen feet of gypsum though it is sufficient to satisfy equilibrium requirements.

It seems more probable that the Fort Dodge gypsum represents the concentration of gypsum by streams flowing over and through the St. Louis limestone and Coal Measure shales. Certain layers of the St. Louis limestone contain 2.46 per cent of gypsum while some gypsum is present in practically all of this limestone.[98] The Coal Measure shales about Fort Dodge abound in crystals of selenite as do the marls of the Ste. Genevieve. These limestones, shales and marls formed the surface of the region when the gypsum was deposited. On account of its solubility streams crossing these beds would readily dissolve the disseminated gypsum. See page resulting in efflorescence may have been a contributing factor. Some lime carbonate would be dissolved also. The greater portion of this probably was deposited locally as in the case, already cited, of the tufa deposits on the shores of Great Salt lake.[99]

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[98] Iowa Geol. Survey, Vol. XII, p. 184.

[99] For further discussion of the origin of the Fort Dodge gypsum see Chapter V.

ORIGIN OF THE CENTERVILLE GYPSUM

The Centerville gypsum is associated with more or less anhydrite. The deposit is made up of remarkably pure gypsum; gypsum and anhydrite; and practically pure anhydrite. It resembles in these respects the well known gypsum deposits about Windsor, Nova Scotia. It does not occur in definite layers and there are no distinct laminae. The original mineral may have been anhydrite, and the hydration of that portion which is now in the form of gypsum may have taken place either before or after the overlying beds were laid down.

The published analyses of the Centerville gypsum show no calcium carbonate. The probabilities are that the anhydrite, which was later in part altered to gypsum, was formed by alteration of limestone.

ORIGIN OF ANHYDRITE

From solutions of rather high concentration of the more soluble salts, calcium sulphate is more apt to be deposited in the anhydrous form. If the temperature is somewhat high anhydrite instead of gypsum may be deposited from less saline solutions.[100] D. H. Newland interprets the work of Van't Hoff as follows:[101]

"Van't Hoff and his associates, in their experimental work on the minerals of the Prussian potash deposits, found that solutions of calcium sulfate, when evaporated in open containers, and therefore under atmospheric pressure, deposit gypsum or anhydrite according to the temperature reached at saturation. Up to 66° C. gypsum separates, above that limit anhydrite; however, if the solution contains other salts, the boundary temperature for gypsum-anhydrite will be lowered. In the presence of sodium chloride, anhydrite begins to form at 30° C. and the gypsum deposited below that temperature will, in contact with a solution saturated for sodium chloride, change into anhydrite. In the evaporation of sea water, the crystallizing point of anhydrite is 25° C.

"From these data, it appears that the deposition of gypsum and anhydrite at atmosphere pressures is not simultaneous, but each substance crystallizes during a separate range of tempera-

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[100] See summary of the work of Van't Hoff and Meyerhofer, by Cameran, F. K., and Bell, T. M., Calcium Sulphate in Aqueous Solutions: U. S. Dept. Agr., Bureau of Soils Bull. 33, p. 9, et seq., 1906.

[101] From a paper by D. H. Newland, presented in September, 1921, at the Wilkes-Barre meeting of the American Institute of Mining Engineers.

tures, which is lower for gypsum than for anhydrite. Therefore, in the evaporation of marine and saline lake waters, which undoubtedly were the sources of most of the calcium-sulfate deposits, it would appear that the prevailing precipitate is likely to be anhydrite rather than gypsum, for such waters contain salts that must lower the boundary temperatures within the range of those ordinarily reached in dry climates.''

If the figures given above are correct, a temperature of 77° F. (25° C.) for the gypsum solution at the time that saturation was reached, would result in a deposit of anhydrite instead of a deposit of gypsum, assuming that the solution was originally sea water.

In the preceding pages the difficulties in the way of direct deposition of either gypsum or salt from sea water have been discussed although the possibility of such direct deposition is admitted.

Newland's theory

Newland further argues that on account of the increase in volume that accompanies the transformation of anhydrite into gypsum, pressure lowers the temperature of dehydration whenever the released water has a chance to escape. He draws the inference that gypsum becomes unstable under conditions of moderate temperature and permanent load, while anhydrite as is generally known is the unstable form under atmospheric pressure and average surface temperatures. He finds confirmation of his opinion that in many cases anhydrite must be regarded as the original mineral in the conditions existing in western New York. ''Where the deposits may be followed from the outcrop under an increasing cover in the direction of the dip, anhydrite begins to appear at 150 feet or less and within the next hundred feet becomes the predominant mineral.''

Udden's theory

According to J. A. Udden[102] extensive beds of anhydrite in Texas have been formed by the dolomitization of limestone, as a result of a reaction between magnesium sulphate in the circulating solutions and the calcium carbonate in the original sediment.

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[102] Udden, J. A., The Deep Boring at Spurr: Bull. Univ. of Texas, No. 363, p. 67.

CHAPTER IV

GENERAL DESCRIPTION OF THE IOWA GYPSUM AREAS

THE FORT DODGE AREA

Early geological work

Some of the earliest geological work undertaken in Iowa was carried on in Webster county. Des Moines river crosses the gypsum area and gives excellent exposures of the glacial drift and the underlying beds. Naturally the water courses determined the routes of the pioneer students of geology for they combined means of transportation with the best opportunities for observation. The position of the area in the state is shown in figure 8.

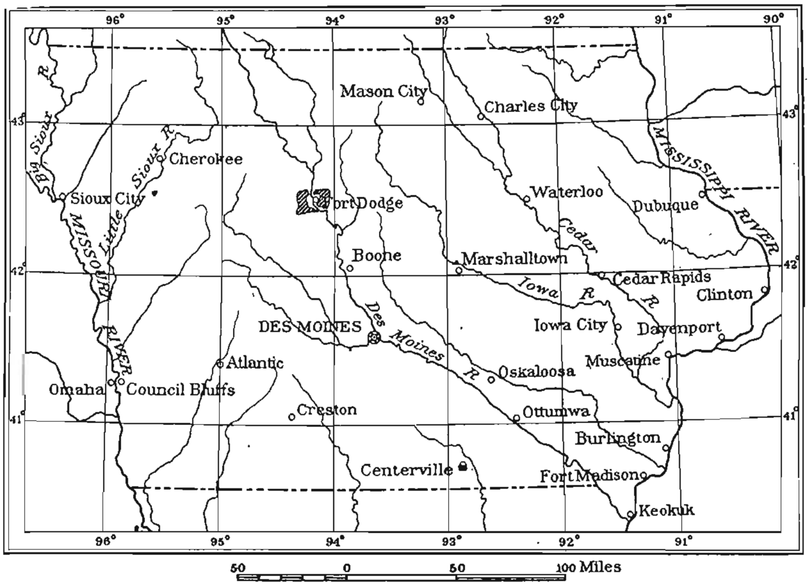

FIG. 8.—Map showing the location of the Fort Dodge and Centerville gypsum fields. Courtesy of U. S. Geological Survey.

Owen

In the year 1849 David Dale Owen[103] made a hurried trip up Des Moines river, noticed the gypsum in Webster county, made certain deductions in regard to its age and called attention to the abundance of the vegetation within the gypsum area.

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[103] Geology of Wis., Iowa and Minn., p. 126, Philadelphia, 1852.

Worthen

In 1856 Worthen visited the region and came to the conclusion that the gypsum does not lie conformably on the Coal Measures.

Hall
McGee

James Hall[104] in 1858 and W J McGee[105] in 1884 investigated the stratigraphic relationships of the gypsum and contributed to the discussions in regard to its age.

White

Webster county was included in the investigations of C. A. White and in his annual reports of 1868 and 1870 he referred to its coal and gypsum.[106] He laid stress on the economic significance of the gypsum and urged that it be developed so that the state might furnish stucco and land plaster at least in quantities sufficient to meet its own requirements.

Keyes

In 1893 Charles R. Keyes[107] reported quite fully on the gypsum area. He considered the position and extent of the deposit and its stratigraphic relationships. He emphasized the value of the gypsum and described the quarrying and milling methods at that time in use. His opinion as then expressed, as well as his later views in regard to the age of the gypsum will be considered at some length in chapter V.

Wilder

In his report on the Geology of Webster county Frank A. Wilder[108] discussed somewhat at length the age and origin of the gypsum about Fort Dodge and devoted some time to the technique of the industry which had advanced considerably in the eight years that had elapsed since Keyes' report was issued.

Keyes' later papers

In recent years Keyes[109] has put forward the theory that the Fort Dodge gypsum is associated with faulting on a large scale. He ascribes its preservation and its rather abrupt termination on the north to this cause.

General location

The city of Fort Dodge lies nearly in the center of the Webster county gypsum field. Along Soldier creek, which roughly bounds the city on the north, are numerous outcrops of gypsum, while along both banks of the Des Moines, which runs through the city, historic exposures occur. Fort

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[104] Geology of Iowa, Vol. I, p. 142, 1858.

[105] Tenth U. S. Census, Vol. C., Building Stones, p. 258, Washington, 1884.

[106] First Annual Report, State Geologist, pp. 26-27, 1868; Second Annual Report, pp. 135-140, 1868; Geology of Iowa, Vol. II, p. 293 and pp. 254-256.

[107] Iowa Geological Survey, Vol. III, pp. 259-304, 1893.

[108] Iowa Geological Survey, Vol. XII, pp. 63-235, 1901.

[109] Keyes, Chas. R., Controlling Fault Systems in Iowa, Iowa Academy of Science, Vol. XXIII, pp. 103-112.

Dodge is located somewhat northeast of the center of the state, and is well supplied with railroads, which offer unusually good transportation facilities. The Fort Dodge mills can compete favorably with Grand Rapids, Michigan, in the Chicago markets. They are nearer Milwaukee, St. Paul, Minneapolis and Duluth than any other producing point. To the south they meet Kansas and Oklahoma competition in St. Louis, and the distance is somewhat greater than from Centerville. To the west, Omaha, Council Bluffs and Sioux City are nearer to Fort Dodge than they are to the gypsum mills in the Black Hills of South Dakota. It is not surprising that the Fort Dodge gypsum field has become one of the most important in the country.

Markets

The extent of the gypsum area must be determined by exposures along the Des Moines and its tributaries, by well records and by drilling. Throughout the region the mantle of glacial drift is heavy and contains many gravel beds which are excellent water pockets, and in consequence only a limited number of wells penetrate the drift and enter the underlying formations. Natural exposures of gypsum may be seen on the left bank of Lizard creek one-fourth mile above its mouth; at intervals for two miles along the lower course of Soldier creek; along Two Mile creek, and the little stream directly opposite whose course is followed by the interurban railway. The best known exposures are, of course, along the river, from the mouth of Soldier creek south nearly to the town of Kalo. Away from the streams the position of the gypsum beds must be determined by prospect holes and by well drilling. Areas close to the railroad and near the gypsum mills, like sections 27, 28, 29, 31, 32, 33, and 34, Cooper township, have been prospected by core and churn drilling. Not all of the records of this work are available but many of these records will be found in chapter V. Holes drilled for wells throw considerable light on the position of the gypsum beds, and the information that it has been possible to secure in this way has been presented in chapter V also, as well as on the geological map.

Size and shape

In general it may be said that the Fort Dodge gypsum beds extend in a northeast-southwest direction; that the average width of the area is three miles and the probable length is seven miles. Des Moines river cuts through the gypsum area however, and by erosion and solution the river with its tributaries has removed the gypsum from at least three square miles of the area outlined above, and it is possible that five or six square miles must be subtracted from the gypsum area on account of the stream's activities. The amount of preglacial erosion can be determined only by actual drifting in the gypsum beds and by drilling. The older maps indicate an additional area of eight or ten square miles within which gypsum may occur. Its presence or absence here can be determined only by careful drilling and as the localities are somewhat distant from a railroad very little prospecting has so far been undertaken.

THE CENTERVILLE FIELD

Location of Centerville field

The Centerville field, which will be described somewhat more fully in chapter V, is located near the southern boundary of the state, in Appanoose county. It is fortunately located with reference to gypsum-consuming markets, and in this respect enjoys advantages equal to the Fort Dodge district. While it cannot reach the Minnesota and Wisconsin markets as readily, it is nearer to Missouri, the city of St. Louis and the large cement mills about Hannibal. The mining conditions at Centerville have not proved particularly difficult. The gypsum field is near the center of Iowa's most important coal field and is within reach of hydro-electric power from the Keokuk dam. The location of this field is shown in figure 8, page 131.

Extent of Centerville field

The extent of the Centerville field is not known. As the gypsum lies at a depth of 550 feet its presence must be determined wholly by drilling.

Discovery of Centerville gypsum

In the fall of 1910 the Scandinavian Coal Company located the gypsum at Centerville, while prospecting for coal near that town. Shortly thereafter two additional test holes were put down. One of these was located 1,200 feet southwest of the "Discovery hole", and went to a somewhat greater depth, 563 feet, but found no gypsum, the other, located

1,700 feet northwest of "Discovery hole", found 18 feet of gypsum beginning 572 feet below the surface.

Some additional drilling has been undertaken during the last two or three years but the results are not available for publication.

CHAPTER V.

STRATIGRAPHY OF THE IOWA GYPSUM AREAS

The formations that are found in the Fort Dodge gypsum area, and their geological relationships are given in the following table.

GROUP	SYSTEM	SERIES	STAGE	FORMATION
Cenozoic	Quaternary	Recent		Tufa, humus, alluvium
		Pleistocene	Wisconsin	Drift, gravel
			Kansan, Aftonian (?)	Drift, Gumbotil
Paleozoic	Permian (?)		Fort Dodge	Gypsum, red shale and sandstone
	Carboniferous	Upper Carboniferous or Pennsylvanian	Des Moines	Coal, sandstone, shale
		Lower Carboniferous or Mississippian	Ste. Genevieve	Marl and limestone
			St. Louis	Limestone, sandstone, shale

Information on which this table is based was gathered from exposures along Des Moines river; and along Soldier, Lizard, and Two Mile creeks; as well as from well records and drill holes sunk in searching for gypsum and coal.

Exposures and well data for the area will first be presented in order to set before the reader the field data in full and enable him to criticise more intelligently the deductions that are made later, when in appropriate sections, the various formations are separately considered.[111]

EXPOSURES ALONG SOLDIER CREEK

Particular interest has for many years centered about the valley of Soldier creek, a small stream that flows into the Des

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[110] This chapter has been prepared by James H. Lees and Frank A. Wilder. Lees is largely responsible for the sections and the description covering the Ste. Genevieve, and has assisted in collecting and checking all data in connection with the Fort Dodge beds.

[111] On the topographic map localities are indicated by numbers which correspond to numbers in the text at the description of the locality.

Moines from the northeast in the north part of Fort Dodge. Several explanations for the peculiar relationship existing between the St. Louis limestone, the gypsum and the Coal Measures shales have been offered, the most recent being Keyes' hypothesis of faulting on a large scale.[112] An airplane view of lower Soldier creek valley is shown in figure 9.

FIG. 9.—Airplane view of part of Des Moines river valley and the lower portion of Soldier creek valley. The viaduct referred to in the text is plainly shown. Courtesy of Fort Dodge Commercial Club.

Kohl's Brewery Section. No. 1 on map

The section at the mouth of Soldier creek near the end of the ridge that separates the valley of Des Moines river from Soldier creek valley, and known as the "Kohl Brewery" section is of considerable historic interest. The old brewery long ago disappeared though portions of the foundation walls still stand to identify the spot. When studied by the writer in 1902 the section to be seen was as follows:

		FEET
9.	Gravel, fresh, clean, well water-worn, containing much limestone	5
8.	Drift, slightly oxidized, unleached	28
7.	Gravel, rusted, many decayed fragments, showing only at certain points along bluff	2
6.	Sandstone, soft, friable, buff-colored, though at points not far away it is white and heavily bedded	5
5.	Shales, argillaceous, sandy layers alternating	5
4.	Sandstone, buff, friable	2
3.	Shale, gray	2
2.	Thin bands of gypsum and shale	7
1.	Gypsum, massive (exposed)	11

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[112] Controlling Fault Systems in Iowa: Iowa Academy of Science, Vol. XXIII, p. 103.

At present about thirty feet of red, buff and gray shales are exposed at this point, capped by a two foot bed of white sandstone. Near the base of the shale a three inch layer of gypsum appears, which probably corresponds to one of the bands referred to in No. 2 in the section above. The massive gypsum shown in No. 1 is now covered by wash from the slope.

This description agrees substantially with that of Keyes in 1893.[113] Keyes then added that "this exposure of over fifty feet of stratified rocks appears to lie in a depression in the Coal Measures, since a short distance to the north bituminous shales rise to a level considerably higher than the top of the section."

In a recent paper[114] Keyes accounts for the depression that he and others have noted by postulating a fault which depressed the gypsum series forty feet.

The sandstone bed in the Kohl Brewery section apparently is a part of an arenaceous zone that outcrops about 100 yards farther west in a cut of the Minneapolis & St. Louis Railroad and in a nearby mound isolated by the cuts of the Illinois Central Railroad and the Minneapolis & St. Louis Railroad.

At the north end of the first viaduct over Soldier creek a heavy mass of drift extends from the upland to the bridge level. Below the drift is found:

			FEET
Viaduct section. No. 2 on map	3.	Red shales and shaly sandstone	15
	2.	White sandstone	3
	1.	Red and gray shale	35

All of the shales and sandstones of this section have been correlated by all students of the section with the Fort Dodge beds. They are exposed within five feet of the creek level.

About 100 feet above the viaduct there is an exposure of red shales and red and gray, heavy bedded sandstone which rises thirty feet or more above the water. The sandstone is not of uniform hardness, some parts being quite soft. Crystals of celestite (strontium sulphate) in nodular masses, some of them a foot in diameter, occur in the shales. This section is illustrated in figure 10.

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[113] Gypsum Deposits of Iowa: Iowa Geol. Survey, Vol. III, p. 273, 1893.

[114] Iowa Academy of Science, Vol. XXIII, p. 109.

Just below the plant of the Fort Dodge Culvert and Iron Works, in the bluff which forms the north bank of the creek, the following section appears:

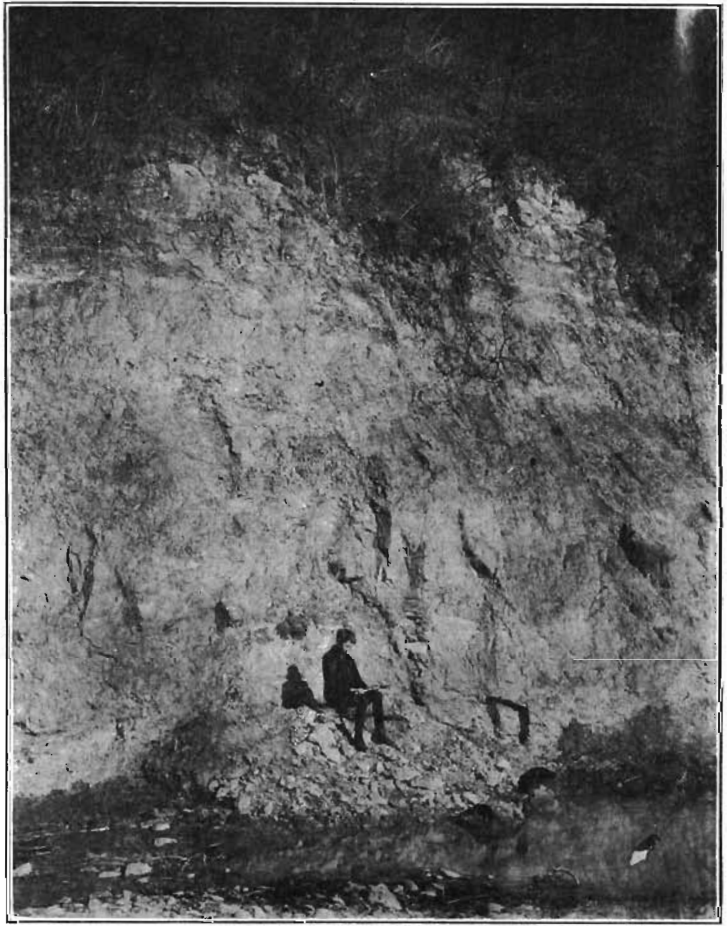

FIG. 10.—Shales and sandstones near lower viaduct over Soldier creek. Photo by Lees.

Iron Works section. No. 3 on map

		FEET	INCHES
8.	Drift		
7.	Green marl	10	
6.	Crystalline limestone		3
5.	Lithographic limestone	1	
4.	Gray marl	1	
3.	Sandstone, gray, soft streaks	7	
2.	Gray sand		10
1.	Brown limestone	3	

This section with the exception of No. 8 (drift) and the possible exception of No. 7 (green marl) is correlated with the St. Louis, which exhibits similar characteristics at typical exposures elsewhere in the county.

About 100 yards farther up stream occurs a similar section which is repeated a short distance beyond, at the stone bridge.[115]

Stone bridge section. No. 4 on map

		FEET	INCHES
6.	Drift and gravel		
5.	Shale, black, thinly laminated	10	
4.	Lithographic limestone	2	
3.	White sandstone	6	
2.	Lithographic limestone		6
1.	Brown limestone	6	

Aside from the drift and the shale all the members of this section are to be regarded as belonging to the St. Louis.

About 150 feet north of the stone bridge red and blue-green clay shales appear in a small gully and red clay shales appear at creek level only fifty feet farther on. About 600 feet farther on, where the creek approaches the railroad, black clay shales are exposed at stream level.

The pit of the Hawkeye Clay Works, about one-fourth mile above the stone bridge, in section 19, Cooper township, shows:

Hawkeye Clay Works. No. 5 on map

		FEET
7.	Drift	
6.	Gypsum (scattered blocks)	3
5.	Shale, black in lower half, upper half red, gray, etc.	40
4.	Shale, black and gray, sandy	6
3.	Shale, black	2
2.	Sandstone, fine, gray and yellow	4
1.	Shale, black, laminated, to creek	20

Aside from the drift and the gypsum the members of this section plainly belong to the Coal Measures.

Old lime kiln

At the upper end of the brick yard is an old lime kiln. Across the creek and 100 feet to the north limestone is exposed in a low dome rising three feet above the water, and this body of rock doubtless furnished the material that was used in the old kiln. Above the limestone occur red and green shales similar to those above the stone bridge farther down the stream. In both cases the bright shales may be referred to the Des Moines beds. Only 100 yards farther up

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[115] Most of the sections given in this chapter are taken from field notes made by Lees after a visit to all the localities with Wilder. Subsequently Lees visited the localities again and confirmed the earlier observations and correlations. The Soldier creek sections were checked three times by Lees and Wilder during as many consecutive summers.

stream the limestone disappears and its place is taken by black shales.

Gypsum near railroad bridge. No. 6 on map

Just above the first steel railroad bridge, which is about one-fourth of a mile beyond the brick yard, gypsum appears near water level, and 180 yards farther up it rises from water level twelve feet and is covered with thirty feet of dark red shales in which are streaks of bluish sandstone. This outcrop is shown in figure 11.

FIG. 11.—Gypsum on Soldier creek. Photo by Lees.

Gypsum at second steel bridge. No. 7 on map

At the second steel railroad bridge, opposite the south end of the cemetery the gypsum extends below water level and rises eighteen feet above the surface of the water. As in other exposures, it is overlain by red and blue sandy shales.

A little farther upstream and just beyond the viaduct leading to the cemetery, black shales appear along the creek for several hundred yards, while near the third railroad bridge close to the line between sections 9 and 16, Cooper township, the shales are much lighter in color.

The Haviland pit. No. 8 on map

The last known important exposure of the shales and sandstones of the Fort Dodge beds is at the Haviland pit, now abandoned, 125 yards above the third steel railroad bridge. Here at least twenty feet of red sandy shales is to be seen, with a four foot ledge of gray rather hard sandstone about the middle of the pit. Evidently these red sandy shales rest on a very irregular surface of black and red fissile clay shales of the Des Moines stage, for these are exposed in a nearby ditch at a level just below the floor of the pit, and at several nearby points along the creek sandy and clayey shales alternate at similar levels.

In his report on Webster county the writer stated that the repeated changes of the strata at water level of Soldier creek, from limestone and its associated sandy beds; to gypsum with its associated sandy shales; and from either of these to black clay shales of the Coal Measures, can be accounted for only by a pronounced unconformity between the St. Louis limestone series and the overlying Coal Measures (the Des Moines stage of the Pennsylvanian) and an unconformity between the gypsum series (Fort Dodge beds) and the beds that underlie it. At some points on Soldier creek these underlying beds belong to the St. Louis stage and at others to the Des Moines. The St. Louis limestone projects well up through the black shales at numerous points. The gypsum and shales of the Fort Dodge beds were deposited in a rather broad valley which was cut through the Coal Measures shales at numerous points while at others there was left only a relatively thin body of the black shales to separate the gypsum from the St. Louis limestone.

EXPOSURES ALONG DES MOINES RIVER NORTH OF SOLDIER CREEK

Pit of Fort Dodge Brick and Tile Works. No. 9 on map

The clay pit of the Fort Dodge Brick & Tile Works deserves very careful consideration in connection with the study of all the formations that occur within the gypsum area. In view of the fact that sections from this pit are given by various writers, and because there have been various stages of development and abandonment in the pit itself conditions will be described with considerable detail.

As early as 1902, what may be called the main southern part of the pit had been developed and abandoned, and the main effort toward winning clay had extended toward the north. At that time, however, on the extreme southern end of the pit, well down the river valley slope, some work was being done and the pit then showed the section given by Wilder.[116] This part of the pit had been abandoned, with the exception noted, probably on account of the excess of sand in the shales in the upper part of the face of the pit. Keyes and Wilder both gave sections of the north end of the pit where, in spite of the fact that the pit has receded many feet in a northerly direction, the section has not changed in any material way since 1902. Wilder's section was published in connection with a discussion of the Pleistocene of Iowa and did not differentiate the shales underlying the till, classing them all as Coal Measures.

Keyes analyzed the shales somewhat more carefully[117] and his section is given below.

		FEET
9.	Till, ashen, with pebble bands	15
8.	Shale, blue, yellow and variegated	18
7.	Sandstone, gray, massive	2
6.	Shale, black and gray with coal seams	11
5.	Shale, white (fireclay)	2
4.	Shale, light colored and variegated	15
3.	Shale, dark colored, partly hidden at base	25
2.	Sandstone, coarse, conglomerate, ferruginous	1
1.	Limestone, gray	30

This same section as seen and carefully measured by Lees and Wilder in 1917 showed:

		FEET
7.	Drift, yellow	4
6.	Drift, gray or ashen	23
5.	Shale, pink, gray, purple, yellow, mottled	12
4.	Sandstone, gray, massive	12
3.	Shale, black	12
2.	Shale, gray, its surface sloping and sharply defined from the black shale above	12
1.	Shale, green, smooth, soapy feel	2

In the floor of the pit green-gray marls are exposed. This floor is twelve or fifteen feet above the river, which is located a hundred feet to the west. At the water's edge a foot or two

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[116] Iowa Geol. Survey, Vol. XII, p. 129, 2d section.

[117] Iowa Acad. Science, Vol. XXIII, p. 109, 1916.

of limestone are exposed, and Keyes' section of the clay pit is to be taken as a composite for he shows thirty feet of limestone in the clay pit section.

Lees, in 1918, by digging, exposed a portion of the covered south end of the old pit, and exposed red and gray sandy shale which he correlated with similar shales of the Fort Dodge beds. A pit foreman reported finding a gypsum block above the clay shales in 1917 and Lees and Wilder found about a ton of gypsum at the base of the pit in the summer of 1921 with material that had slid down from higher levels. Later in the same year Lees observed several small fragments of gypsum and red and pink sandy shale which had come down into the pit with the slump.

The two feet assigned by Keyes as the thickness of the gray massive sandstone is evidently an error in field notes, for the thickness is twelve feet. His white shale or fire clay (No. 5) could not be identified in 1917.

There are at least six exposures of the sandy shales of the Fort Dodge beds between the old Kohl Brewery exposure and the pit of the Fort Dodge Brick and Tile plant. The demonstrated continuity of these beds is important, since the hypothesis has been advanced that due to faulting the Fort Dodge beds have been cut out in this locality. Instead of a fault there seems to be evidence of an erosion basin which rises to the north from Kohl's Brewery to the tile pit, about forty feet in fifteen hundred feet of horizontal distance.

Along the river two hundred yards north of the pit the sandstone ledge outcrops at about the same level as at the pit and below it are twenty feet of dark shale. Under the shale is a ledge of yellow sandstone about seven feet thick. Limestone spalls may be seen at the water's edge and upstream a hundred yards farther a limestone ledge rises a foot above low water level.

Excavations at the east end of the dam not far from here gave the following section:

			FEET
No. 10 on map	5.	Drift	
	4.	Green shale with selenite crystals	3
	3.	Sandy shale	4
	2.	Sandstone, light gray	5
	1.	Limestone, above water level	8

The excavation at the west side of the dam was seen by Lees at a time when it was considerably below water level. He reports:

			FEET
No. 11 on map	4.	Limestone	?
		water level	
	3.	Limestone	8
	2.	Green shale	3
	1.	Fine-grained green sandstone	6

Continuing up the east bank of the river, alternating exposures of dark shales, sandstones of the Coal Measures, and limestones are found at water level to the northern border of the county.

In 1918 Lees[118] located an interesting exposure on the west side of the river near the dam. This was found in a ravine which opens into the Des Moines valley from the northwest. Just above its mouth this ravine shows:

			FEET	INCHES
No. 12 on map	6.	Coal Measures shales	20	
	5.	Red clay shale	10	
	4.	Light gray shale, richly fossiliferous	7	
	3.	Hard yellow to gray shale	1	6
	2.	Green-gray clay	1	6
	1.	Dark red clay	3	

The shale members of this section with the exception of No. 6 have on fresh exposure a striking starchy texture which breaks down to marly texture on exposure. In this they resemble the shales exposed on Lizard creek in a section which occurs almost a mile due west. The fossils in the shales of zone 4 are the same as those determined for the Lizard creek section and set out on page 146.

LIZARD CREEK SECTIONS

Lizard creek, flowing from the west, empties into the Des Moines half a mile above the mouth of Soldier creek, which joins the parent stream from the east. Good natural exposures occur along its banks and greatly aid in determining stratigraphic problems in the northeastern portion of the gypsum area.

Limestones show along both banks of the stream and underlie the flat between the Illinois Central railroad and the creek. On the left bank of the creek ten or twelve feet of gray sand-

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[118] Iowa Acad. Science, Vol. XXV, p. 599, 1918.

stone appears above the limestone. About 500 yards above the mouth of the creek on this side is one of the old clay pits of the Fort Dodge Clay Works. This plant is at present dismantled. It is located on the right bank of Des Moines river just below the mouth of Lizard creek. Clay was secured from two pits; first in the bank of the river back of the kilns, and later six hundred yards away on the left bank of Lizard creek. The location of these pits, and of other localities described above is shown on the topographic map, numbers 13 and 14.

Fort Dodge Clay Works

North pit. No. 13 on map

The clay pit on the left bank of Lizard creek furnished the material for the Fort Dodge Clay Works twenty years ago. The section as now seen is somewhat obscure at certain points due to slides, but the following is approximately correct.

		Feet
8.	Drift	30
7.	Gypsum	6
6.	Shale, very dark, fissile	7
5.	Shale, nature obscure on account of slumping	10
4.	Shale, red, green and gray, some bands having a pronounced starchy texture	20
3.	Gray marl, with fossils	20
2.	Sandstone	2
1.	Limestone, to water level	10

Fossils from zone 4 of the section given above, collected by Lees and identified by Thomas are listed below:

Spirifer pellaensis (Weller)
Pugnoides ottumwa (White)
Girtyella indianensis Girty
Composita trinuclea (Hall)
Orthotetes kaskaskiensis (McChesney)
Clionolithes n. sp.
Spirorbis n. sp.
Crania (unidentified)
Liopora?
Trilobite, imperfect pygidium

Professor Thomas comments on this collection as follows: "The Orthotetes is larger, judging from the fragments, than any described under the name I have suggested but otherwise tallies in every way. The two first named species are the most abundant and they are the index fossils of the Ste. Genevieve. Girtyella is common in this formation elsewhere, but we got only one specimen."

A short distance farther up Lizard creek, on the right bank in the center of section 24, Douglas township, the following composite section was developed from water level of the creek up through the cut on the Illinois Central railroad, and published on the report on Webster county.[119] The fossils were identified by Professor Calvin.

		FEET
5.	Coal Measures covered by slope wash	30
4.	Fossil-bearing marl, *Spirifer littoni* Swallow, *Pugnax ottumwa* White, *Seminula subquadrata* Hall, *Dentalium* sp., abundant	6
3.	Marl, gray, without fossils, containing many small selenite crystals	40
2.	Sandstone, yellow, moderately hard, showing little lamination, calcareous	2
1.	Limestone, slightly folded, in definite layers, average thickness of largest eight inches, in places brecciated, though not showing a layer that is brecciated throughout, as in exposures in Des Moines river north of Fort Dodge	17

Other exposures up Lizard creek will be presented in the description of the Ste. Genevieve formation.

DES MOINES RIVER SECTIONS BELOW LIZARD CREEK

South pit.
No. 14 on map

The main clay pit of the Fort Dodge Clay Works was actively operated when the report on Webster county was published and an excellent opportunity to study conditions at this important point then existed. The section recorded is given below:

Section in the Pit of the Fort Dodge Clay Works:

		FEET
3.	Drift, yellow, unleached, lower part a little darker than the upper	35
2.	Red sandy shale with occasional thin bands of sandstone	10
1.	Gray Coal Measures shales, containing numerous fossils of ferns and lepidodendrons. A few iron nodules and crystals of selenite present. Separated from red shales above by sharp line of unconformity. Along the line of separation there is a layer of gumbo, one foot thick	30

The following statement was made:

"No. 2 includes the red shales found in so many places above the gypsum. These red sandy shales are so characteristic and are associated so conformably with the gypsum that they may safely be regarded as of the same age as the gypsum. The occurrence of the light colored, calcareous sandstone free from fossils with these red shales is also significant."

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[119] Iowa Geol. Survey, Vol. XII, pp. 78-79.

It is worth noting here that the relations between the Coal Measures and the Fort Dodge beds are the same on this side of the Des Moines valley as they are in the east bluff, namely that the contact surface rises to the north. In the south pit the Fort Dodge beds come down within about forty-five feet of the river; in the north pit, across Lizard creek, the gypsum lies seventy feet above the water.

Between Lizard creek and the viaduct crossing to West Fort Dodge, there are few exposures. On the west bank of the river, at the foot of the bluff below the Country Club there are abandoned drift mines from which coal was taken not many years ago. These pits are directly opposite the city of Fort Dodge and a little below the mouth of Soldier creek. They are about fifteen feet above water level. Just above them lies an eighteen inch fossiliferous limestone ledge, which appears in a number of places within the next two miles down the river.

The first gypsum showing down the river below Soldier creek is found at the Bradshaw Clay plant, in the northeast quarter of section 32, Cooper township, on the east bank of the river and in the edge of the city of Fort Dodge. The section here is as follows:

Bradshaw Clay pit. No. 15 on map

		FEET	INCHES
9.	Drift	5	
8.	Red sandy clay	12	
7.	Blocks of gypsum, in a yellow clay (unconformity, sharp contact)	4	
6.	Black shale	20	
5.	Dark gray limestone, fossiliferous	1	6
4.	Black coaly shale		10
3.	Black shale	3	
2.	Fire clay	1	
1.	Dark gray shale	20	

The surface of the black shale, No. 6 in section above, forms a sharp contact with the red clays and gypsum just above it.

About one hundred yards above the Bradshaw pit, in the east bank of the river there is an exposure of ten to twelve feet of black and dark red clay shale that dips strongly to the north. About one-third of the distance from the Bradshaw pit to the Chicago Great Western viaduct sandstones are exposed in a little ravine, and these beds dip strongly to the south.

On the west side of the river about two hundred yards south of the Chicago Great Western viaduct is an abandoned brick yard which shows the following section:

		FEET
3.	Drift	
2.	Dark red and gray clay shales with red sandstone, blocks of reddish limestone with brachiopods, orthoceras and corals	5
1.	Black shales	20

The Plymouth Gypsum Company's mine on the west bank of the river, in southwest quarter of section 31, Cooper township, shows a yellow sandstone overlying the gypsum. At the old clay pit near the mouth of the ravine in which the Plymouth mine is located, at a level about five feet below the level of the gypsum three hundred yards farther up the ravine, occurs an eighteen inch ledge of dark gray fossiliferous limestone. The fossil content of this ledge is the same as that of the similar ledge in the Bradshaw pit across the river and of the old clay pit described above as located on the west side of the river near the the Chicago Great Western viaduct.

Plymouth Gypsum Company's mine.
No. 16 on map

About two miles farther down stream the Fort Dodge, Des Moines and Southern electric railroad crosses the river and ascends to the upland on the west side through a ravine which gives interesting exposures. At the mouth of the ravine the railroad cuts through a spur in the bluff and, following up from water level so as to include this cut, the following section is developed:

Interurban exposures.
No. 17 on map

		FEET
6.	Sod	
5.	Gypsum	1
4.	Red and varicolored shales with sandy layers	30
3.	Black shale rising nearly to track level	20
2.	Black limestone band	1
1.	Black shale	30

For some distance up the ravine the red shales show a thickness of twelve to thirty feet. Above the red shale and six inches below the gypsum, which may be seen overlying it at various points, there appears a red or gray fossil-bearing conglomerate one foot to two feet thick. The pebbles are for the most part limestone. This conglomerate is shown in figure 13, page 169.

A generalized section of this ravine may be described as follows:

		Feet	Inches
8.	Drift	0-30	
7.	Gypsum	10-15	
6.	Clay		6
5.	Conglomerate	1-2	
4.	Red clay	12-30	
3.	Gray sandstone	6	
2.	Gray sand	2	
1.	Black shale	30	

The gray sandstone (No. 3) and the conglomerate are not constant, and it will be noted that they do not show in the section given for the mouth of the ravine. On the other hand they appear again across the river in the Vincent clay pit as shown below.

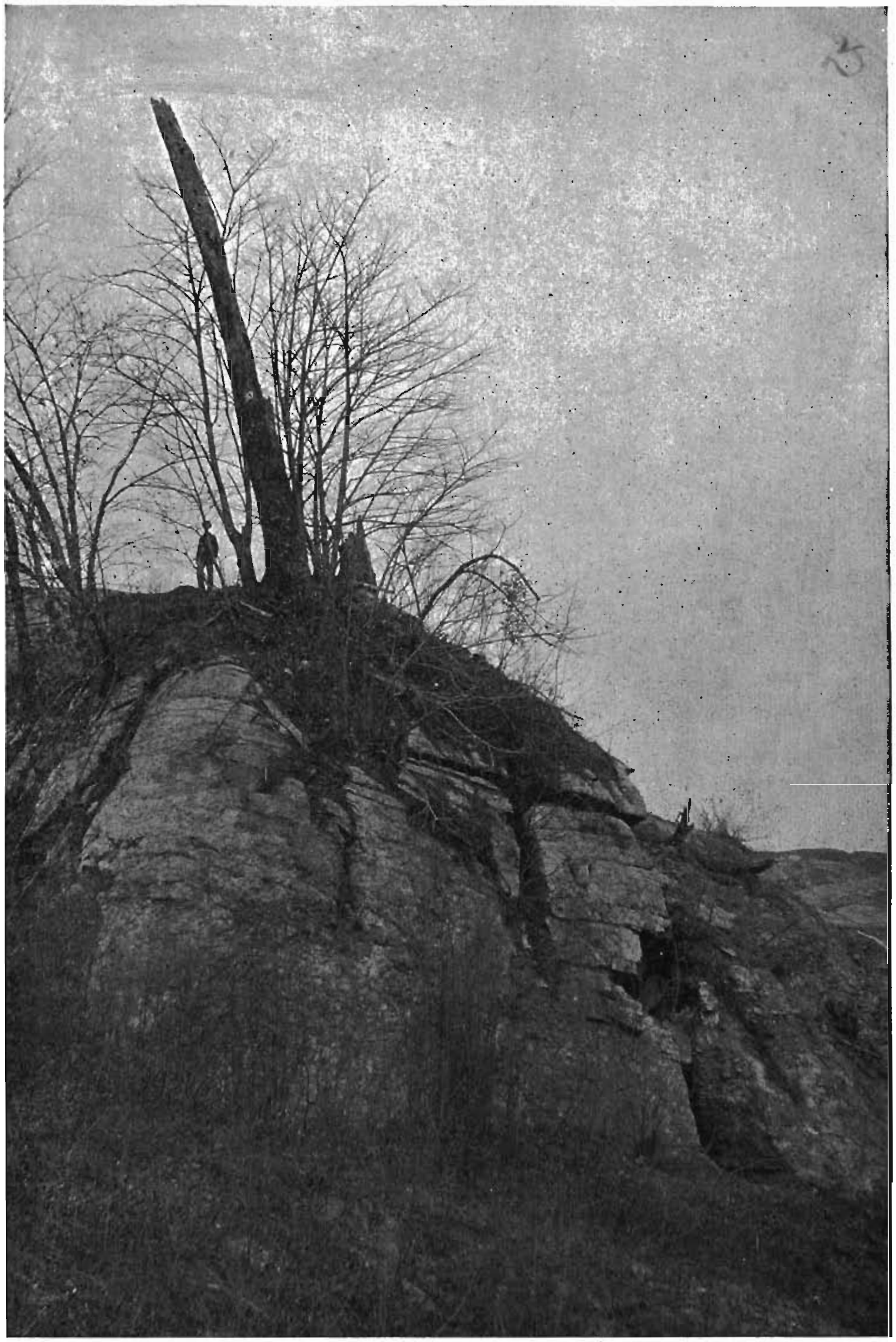
FIG. 12.—Gypsum at the Vincent Clay pit, exposed by hydraulic stripping, described somewhat fully in the text. Photo by Lees.

Vincent Clay pit. No. 18 on map

The plant of the Vincent Clay Products Company is located near the center of section 6, Pleasant Valley township, and the pit gives the following section:

VINCENT CLAY PIT SECTION

		Feet
9.	Drift	0- 8
8.	Gypsum	0- 6
7.	Red and gray conglomerate	0- 1½
6.	Varicolored clays darker toward base	15-20
5.	Gray sandstone, hard in places, elsewhere soft	10-15



Gypsum outcrop near Des Moines river. Jointing and bedding are both shown.

4.	Varicolored sandy shales, not so bright as No. 6, above	6
3.	Black finely fissile shales, rather sharply set off at contact from 4	15
2.	Limestone	1½
1.	Black shale, exposed	6

The gypsum at this pit is shown in figure 12, which shows well its extremely irregular surface.

Gypsum Hollow exposures. No. 19 on map

At the mouth of Two Mile creek, better known as Gypsum Hollow, immediately south of the Vincent pit, twenty-five feet of red shales with one foot of gypsum above are exposed on the west wall of the valley. A few yards farther up one foot of conglomerate appears under the gypsum, and five feet of black laminated clay shows under the red clays. The red clays are black toward their base but are not as well laminated as typical Coal Measures clays. One hundred yards up the ravine the gray sandstone (No. 5 in the Vincent clay pit section) appears. It is six feet thick, dips a little to the north, and is overlain by red clays above which in places some gypsum occurs.

For nearly a mile up Gypsum Hollow, gypsum is exposed at intervals and there are numerous old quarries from which material to operate two mills, long since dismantled, was secured during the nineties. Plate V shows an outcrop of gypsum in this vicinity. The last exposure to be seen in going up the valley is an old opening which shows three to four feet of dark red sandy shale and soft sandstone. Below these beds is the gypsum, several feet of which is shown. The upper surface of the rock, which is laid bare over an area several rods in extent, is marked by solution channels and low domes two to three feet in diameter and a foot or less in height. These are shown in figure 27 on page 205.

Gilmore Portland Cement Company's pit. No. 20 on map

About two hundred yards down the east wall of Des Moines valley from the mouth of Gypsum Hollow is the pit from which the Gilmore Portland Cement Company gets the shale for its plant at Gilmore City. The section is as follows:

		FEET
5.	Gypsum	6
4.	Bright clay shale	6
3.	Dark clay shale	6
2.	Limestone	0-2
1.	Gray shale	7

The limestone, No. 2, is two feet thick on the sides of the pit nearest the river, but disappears entirely twenty-five feet farther east.

River exposure. No. 21 on map

In the river about one-half mile east of this point along the east bank, one-fourth mile below the Minneapolis and St. Louis railroad bridge in Pleasant Valley township, the southwest quarter of section 5, the marls of the Ste. Genevieve may be seen rising a few feet above water level. They are characterized by the same fossils that are found in these beds on Lizard creek and listed on page 146. Below the marl a few feet of limestone appears. The entire exposed area of limestone and marl does not include more than ten acres.

Johnson Brothers clay pit. No. 22 on map

Continuing down the river from Gypsum Hollow on the west bank to the southwest quarter of section 5, Pleasant Valley township, the clay pit of Johnson Brothers gives the next series of exposures. The section is as follows:

		Feet
4.	Gravel	4-10
3.	Clay, dark gray, noncalcareous	½- 1½
2.	Gypsum	0- 4
1.	Shale, black above, red and gray below, sandy	20

The bed of the pit is a limy shale which contains some pyrite nodules.

An old pit just south of the one in present use was opened in light colored red, gray, and purple sandy shales with concretions and fossils of Stigmaria, Lepidodendron, etc. These shales differ from those over the gypsum and doubtless belong to the Coal Measures series.

Pit of Plymouth Clay Products Company. No. 23 on map

About one-fourth mile farther down the river is the pit of Plymouth Clay Products Company. No gypsum is found here but twenty-five feet of red and gray shale like that in the old (south) Johnson pit, is exposed. It shows a strong dip to the west.

The light colored sandy shales can be traced with ease to the ravine which joins the river valley one-fourth of a mile farther south (in north of southwest quarter of section 8, township 88 north, range 28 west). On the north side of this ravine, which is about thirty-five feet deep, the light colored shales are very conspicuous, while on the south side, two hundred feet away, they are replaced at least in part by dark Coal Measures shales. A few feet of light gray shale overlies the dark shale. At the level of an abandoned clay pit on the north side, which shows the bright shales, there is an abandoned drift which evidently was a prospect for coal. About two hundred yards up this ravine the dark Coal Measures shales are exposed under a few feet of the light colored shales and a heavy sandstone ledge appears up the ravine. This seems to be a part of the sandstone ledge that has been described as occurring at various points farther up the river.

Ravine exposure. No. 24 on map

The sandstone just referred to outcrops in the sides of the ravine known as Craig's Hollow, two-thirds of a mile farther south and about an equal distance north of Kalo, in the northern part of section 18. No gypsum is seen in Craig's Hollow nor are any of the bright shales found here. About twenty feet below the sandstone, and in the bed of the creek at places, a black limestone ledge appears, which coincides with a similar ledge already described from numerous points farther to the north.

Craig's Hollow

From Craig's Hollow to Kalo and thence to the south only Coal Measures shales are found, with the exception of certain exposures of St. Louis limestone in the bed of the river below Kalo and the mouth of Holiday creek.

Holiday creek is the largest tributary of the Des Moines in the southern part of the gypsum area. Flowing nearly south it crosses two sections in Cooper township and two in Pleasant Valley township, and in section 10 of the last named township it has cut into the indurated rocks, but there are no exposures of gypsum or associated beds. In this section nothing but Coal Measures shales appear. If the Holiday creek depressions were deep enough to reach the formations beneath the drift in section 3 just to the north, there is every reason to believe that the gypsum series would be exposed, since gypsum has been found in shafts and wells as will be set out later.

Holiday creek

A small ravine on the left bank of the river, in the southeast quarter of section 5, Pleasant Valley township, is cut through gypsum for half a mile. About eight feet of gypsum is exposed. The heavy bed of gray sandstone, so consistently reported in exposures on both sides of the river from the Vincent pit south, appears in the ravine, and in places is in contact with the gypsum, while at other points it is separated from the gypsum by ten to fifteen feet of shale.

Gypsum in ravine. No. 25 on map

The black limestone found in the Vincent clay pit (No. 2 of section) about thirty feet above water level rises to the east and in the northern part of section 5, Pleasant Valley township, it is sixty or seventy feet above the river.

DATA FROM DRILL RECORDS

The structural information given by exposures described above is supplemented by information obtained in shaft sinking, and in prospect and well drilling. Keyes in his paper in 1894 reported wells as follows:

Well on Webster County Poor Farm. No. 26 on map

"Southwest of Fort Dodge and from one and one-half to two miles from the river, several drill holes have been put down in the vicinity of the county poor farm. The well on the poor farm (Tp. 88 N., R. XXIX W., Sec. 3, SW. qr., NE. ¼), passed through seventeen feet of gypsum at a depth of eighty-three feet. The record is as follows:

		FEET	INCHES
23.	Soil	2	
22.	Clay, yellow	13	
21.	Clay, blue	47	
20.	Sand	1	6
19.	Clay, "hard pan"	19	4
18.	Gypsum	17	
17.	Shale, blue, "soapstone"	6	2

In July, 1922, Thorpe Bros., well drillers of Des Moines, submitted to Dr. Lees the log of a well recently drilled by them on the Webster County farm. This record is given verbatim below. The absence of gypsum at about eighty feet, and its presence at three hundred sixty to three hundred eighty-seven, is remarkable, so remarkable indeed as to cast doubt on the accuracy of the record.

THICKNESS		DEPTH
2 ft.	Soil	2 ft.
20 ft.	Yellow Clay	22 ft.
63 ft.	Blue Clay	85 ft.
35 ft.	Yellow Clay	120 ft.
46 ft.	Red Clay	166 ft.
2 ft.	Lime rock	168 ft.
7 ft.	Shale	175 ft.
10 ft.	Lime rock	185 ft.
18 ft.	Shale	203 ft.
36 ft.	Lime rock	239 ft.
36 ft.	Lime and streaks of shale	275 ft.
41 ft.	Hard lime rock	316 ft.
24 ft.	Green shale	340 ft.
20 ft.	Hard lime rock	360 ft.
27 ft.	Gip rock	387 ft.
118 ft.	Solid lime	505 ft.

		FEET	INCHES
16.	Limerock, black	2	
15.	Coal		9
14.	Fire clay	1	6
13.	Shale, light colored	1	4
12.	Coal	1	3
11.	Sandstone	4	
10.	Shale, black	4	2
9.	Coal		3
8.	Fire clay	1	
7.	Sandstone, white	4	6
6.	Shale, with limestone bands	34	6
5.	Shale, light colored	5	
4.	Shale, blue	4	
3.	Limestone, or hard calcareous shales	6	5
2.	Shale, blue	21	2
1.	Limestone (penetrated)	40	

One mile to the north, the Craig Coal Company has prospected at the head of what is known as Elkhorn ravine (Tp. 89 N., R. XXIX W., Sec. 36, SE. qr., NW. ¼). Sixteen feet of gypsum was found at a depth of seventy-six feet. A third layer one foot thick exists just above the main mass and is separated from it by seven inches of clay or shale.

Cooper township, Section 33. No. 27 on map

‘‘Southeast of Fort Dodge, a couple of miles, a number of borings have been made to the east of the head of ‘gypsum hollow’, showing from fifteen to twenty feet of gypsum at a depth of about fifty feet. One of the holes made in township 89 north, range 28 west, section thirty-three (SE. qr., SW. ¼) showed the following succession of strata:

		FEET	INCHES
22.	Soil	6	
21.	Clay, yellow and blue	14	
20.	Shale, red and yellow	6	
19.	Gypsum	16	10
18.	Shale	1	6
17.	Sandstone, white	2	
16.	Sandstone, brown	1	
15.	Shale, reddish	2	
14.	Shale, yellow	2	4
13.	Shale, dark colored	14	6
12.	Fire clay	3	1
11.	Shale, black	3	
10.	Coal	1	10
9.	Sandstone	3	
8.	Shale, light colored	2	2
7.	Shale, black		3
6.	Sandstone	1	
5.	Shale, black	4	
4.	Fire clay	1	6
3.	Shale, black	3	
2.	Sandstone, soft		4
1.	Limerock, black (penetrated)		3

There were other holes drilled on the same quarter section, each giving practically the same sequence of strata.

Pleasant Valley township, Section 4 No. 28 on map

"Two and one-half miles to the southeast, on the Holiday farm and near by (Tp. 88 N., R. XXVIII W., Sec. 4, SE. qr.), four holes have been put down. Gypsum was struck at depths varying from 50 to 125 feet, the variation in depths being due largely to the differences in altitudes of the surface. In the two holes farthest north the gypsum was nine to twelve feet thick. Hole number 3 was near the center of the quarter section indicated:

		Feet	Inches
11.	Soil	2	
10.	Clay, yellow	17	
9.	Clay, blue	25	6
8.	Shale, red	2	6
7.	Gypsum	12	
6.	Shale, black	5	6
5.	Coal	2	
4.	Fire clay	4	6
3.	Shale, gray	5	6
2.	Sandstone	16	
1.	Shale, black	1	

Northwest of Kalo, for a distance of one mile, numerous prospect holes have been put down by various coal companies. Near the center of section 7, township 88 north, range 28 west, the gypsum is fifty-eight feet from the surface, and only one foot thick. South of this point no gypsum has been reported, though a large number of drill holes have been put down much below this level.

Five miles northeast of Fort Dodge on the Groebner farm (Tp. 89 N., R. XXVIII W., Sec. 12), a well eighty feet in depth gave this section:

		Feet
4.	Soil	2
3.	Clay, yellow above, blue below	50
2.	Shale, red, sandy	26
1.	Gypsum (penetrated)	4

In the Flattery well, which is about one mile east of the Groebner place (Tp. 89 N., R. XXVII W., Sec. 7, SE. qr., SW. ¼), the same bed was encountered at a depth of forty feet, and fifteen feet of gypsum penetrated."

Wilder in 1902[120] obtained the following additional well and drill data:

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[120] Iowa Geol. Survey, Vol. XII, pp. 105-108, (Webster County).

WELL DATA FOR CENTRAL AND NORTHERN WEBSTER COUNTY

TOWNSHIP	SECTION	AUTHORITY	DEPTH IN FT.	STRATA PASSED THROUGH. THICKNESS IN FEET.
Newark	Sec. 27, Sw. ¼	Schmaker	126	Drift and blue clay, below which was gypsum.
Newark	Creamery at Vincent	Schmaker	80	Drift, 66; gypsum, 14.
Newark	Sec. 32, Nw. ¼	J. J. Meyer	118	Wholly in drift.
Badger	Sec. 25, Nw. ¼	J. J. Meyer	130	Drift, 70; sandstone, 4; clay, 25; sandstone, 30.
Badger	Sec. 31, Sw. ¼	J. J. Meyer	96	Drift, 80; sandstone, 16.
Badger	Sec. 31, Nw. ¼	J. J. Meyer	110	Wholly in drift.
Badger	Sec. 34, Sw. ¼	J. J. Meyer	-----	Depth not known, entered sandstone under drift.
Badger	Sec. 29, Nw. ¼	J. J. Meyer	70	Drift, 68; sandstone, 2.
Badger	Sec. 22, Sw. ¼	J. J. Meyer	120	Drift, 100; sandstone, 20.
Badger	Sec. 34, Sw. ¼	J. J. Meyer	125	Drift, 55; sandstone, 8; soft sandstone, 40; clay, 2, sandstone, 20.
Badger	Sec. 11, Sw. ¼	J. J. Meyer	120	Drift, 90; sandstone, 30.
Badger	Sec. 14, W. ½	J. J. Meyer	140	Drift, 90; sandstone, 50.
Badger	Sec. 17, Sw. ¼	J. J. Meyer	100+	Drift, 100; ent'd sandstone.
Badger	Sec. 22, Nw. ¼	J. J. Meyer	144	Drift, 80; sandstone, 4; red clay, 60.
Badger	Sec. 20, Nw. ¼	J. J. Meyer	118	Drift, 100; hard sandst'e, 18.
Badger	Sec. 16, Sw. ¼	Lappint	108	Wholly in drift.
Badger	Sec. 33, Nw. ¼	Lappint	70	Drift, 50; limestone, 20.
Badger	Sec. 33, Nw. ¼	Lappint	120	Wholly in drift.
Badger	Sec. 20, Sw. ¼	Lappint	113	Drift, 50; sandstone, 6; clay, 50; sandstone, 7.
Badger	Sec. 20, Sw. ¼	Lappint	116	Drift, 60; sandstone, 6; clay, 20; limestone, 30.
Badger	Sec. 32, Se. ¼	Lappint	120	Drift, 80; red clay, 40; sandstone.
Badger	Sec. 33, Sw. ¼	Lappint	90+	Drift, 90; stopped in sandst.
Badger	Sec. 34, Sw. ¼	Lappint	68	Drift, 50; sandstone, 1; limestone, 17.
Colfax	Sec. 18, Sw. ¼	Lappint	50	Drift, 49; enter gypsum 5 in.
Colfax	Sec. 17, S. ½	Lappint	158	Drift, 90; shale, 61; limest'e.
Colfax	Sec. 8, Sw. ¼	Lappint	83	Drift, 60; gypsum, 23.
Colfax	Sec. 9, Nw. ¼	J. J. Meyer	132	Drift, 125; sandstone, 7.
Colfax	Sec. 7, Nw. ¼	J. J. Meyer	106	Wholly in drift.
Cooper	Sec. 4, Ne. ¼	Lappint	67	Drift, 40; red clay, 20; limestone, 7.
Cooper	Sec. 9, Nw. ¼	Lappint	90	Drift, 85; limestone, 5.
Cooper	Sec. 12, W. ½	Lappint	75	Drift, 60; sandst'e, 4; gyps.
Cooper	Sec. 33, Ne. ¼	Craig Coal Co.	42	Drift, 26; gypsum, 16.
Cooper	Sec. 23, Sw. ¼	Lappint	125	Drift, 120; limestone, 5.
Cooper	Sec. 23, Sw. ¼	Lappint	81	Drift, 70; sandstone, 2; gypsum, 9.
Cooper	Sec. 26, S. ½	Lappint	101	Drift, 100; limestone, 1.
Cooper	Sec. 26, Nw. ¼	Lappint	80	Drift, 60; gypsum, 20.
Cooper	Sec. 34, Sw. ¼	Lappint	72	Drift, 47; gypsum, 25.
Cooper	Sec. 28, Se. ¼	J. J. Meyer	78	Drift, 57; gypsum, 21.
Cooper	Sec. 8, Nw. ¼	J. J. Meyer	70+	Drift, 70; sandstone.
Cooper	Sec. 16,	J. J. Meyer	87	Drift, 75; sandstone, 4; clay, 4; sandstone, 4.
Cooper	Sec. 10, Nw. ¼	J. J. Meyer	100	Drift, 80; sandstone, 20.
Douglas	Sec. 36, Se. ¼	Craig Coal Co.	109	Drift, 76; gypsum, 18.
Douglas	Sec. 11, Se. ¼	J. J. Meyer	150	Drift, 136; sand, 14.
Washington	Sec. 12, Ne. ¼	Lappint	95	Drift, 50; sandstone, 45.
Otho	Sec. 7, center	Keyes' report	-----	Drift, 57; gypsum, 1.
Elkhorn	Sec. 25, Sw. ¼	Lappint	70	Drift, overlying sandstone.
Elkhorn	Sec. 6, N. ½	Lappint	120	Drift and Coal Measures. No gypsum.
Clay	Sec. 8, Nw. ¼	Rasmusson & Stone	296	Drift, shale and 50 feet of limestone.
Elkhorn*	Sec. 32, Se. ¼	Rasmusson & Stone	252	Shale & 12 feet of limestone.

* Other wells of which records were obtained in Elkhorn township, were shallow and did not go through the drift.

RECORDS OF PROSPECT HOLES

Pleasant Valley township, southeast ¼ Section 4.

		FEET	INCHES
9.	Soil	3	
8.	Yellow clay	16	
7.	Blue clay	30	
6.	Red shale	4	
5.	Shales	30	
4.	Rock (undet.)	1	10
3.	Shale	9	
2.	Coal	2	7
1.	Black jack		8

On the same quarter section:

		FEET	INCHES
6.	Soil	2	
5.	Yellow clay	17	
4.	Blue clay	25	6
3.	Red shale	2	6
2.	Gypsum	12	
1.	Shale	5	6

Douglas township, section 36, southeast ¼ (on what is known as the Bassett farm).

		FEET	INCHES
14.	Soil	2	
13.	Yellow clay	8	
12.	Blue clay and sand	36	
11.	Red sandy shale	30	
10.	Gypsum	1	
9.	Yellow shale		7
8.	Gypsum	17	7
7.	Shale	15	6
6.	Rock (undet.)	1	3
5.	Sandstone		6
4.	Coal		5
3.	Fire clay	5	1
2.	Shale	1	
1.	Brown sandstone	1	6
		119	9

On the southeast ¼ of section 6, Otho township, on which were located the mines that supplied the Duncomb Plaster Mills, ten prospect holes gave the following records:

No. 1. 46 feet, all in drift
No. 2. 50 feet in drift and shale, 10 feet gypsum
No. 3. 45 feet in drift and shale, 15 feet gypsum
No. 4. 50 feet in drift and shale, 7 feet gypsum
No. 5. 50 feet in drift and shale, 4 feet gypsum
No. 6. 41 feet in drift and shale, 11 feet gypsum
No. 7. (In a hollow) 6 feet of drift, 11 feet gypsum
No. 8. 38 feet drift and shale, 6½ feet gypsum
No. 9. 54 feet drift and shale, 12 feet gypsum
No. 10. 45 feet drift and shale, 20 feet gypsum

Lees reports that an old mine shaft in the northwest quarter of section 3, Pleasant Valley township, went through about four feet of gypsum and that Mr. M. A. Hughett's barn well in the southwest quarter of section 36, Cooper township, went through a little gypsum, but the house well only 150 feet away encountered no gypsum.

Cemetery well

J. J. Meyer in drilling a well in the cemetery, Cooper township, section 17, penetrated a considerable body of gypsum. This is not surprising in view of the excellent exposures along Soldier creek, a little to the south.

Record of prospect holes drilled for gypsum in southwest quarter, section 27, Cooper township, Webster county, for W. J. Carter.

	FEET		FEET
No. 1		No. 6	
drift	55	drift	49
gypsum	20	red clay	3
No. 2		gypsum	21
drift	47	No. 7	
gypsum	23	drift	49
No. 3		red clay	1
drift	47	(record not clear)	6
gypsum	23	gypsum	21
No. 4		No. 8	
drift	48	drift	49
gypsum	24	red clay	5
No. 5		gypsum	21
drift	44		
red clay	3		
gypsum	23		

Hole No. 9 near the center of south line of northwest quarter, section 27, went from drift directly into Coal Measures clay. Near the northwest corner of this section twelve feet of gypsum was found in a well, and twenty-three feet of gypsum was located in a well in the southeast corner of the same quarter section.

In the south half of the northwest quarter of section 26, Cooper township, seven drill holes gave an average of twenty-two feet of gypsum. From two to five feet of red clay (Fort Dodge beds) occurs above the gypsum in most instances, and above this the drift averages about fifty feet thick.

Mr. C. H. Crutchman has drilled eighty-two holes on his farm in the west half of section 27, Cooper township, and found conditions quite like those reported above in the drillings for W. J. Carter in the same section. The thickness of the gypsum ranges from twenty-four feet, eleven inches, to two feet. It is generally covered by three to six feet of red clay (Fort Dodge beds) and lies beneath forty to fifty feet of drift.

Other well data listed by sections follow:

North half of northeast quarter of section 28, Cooper township, gypsum reported by C. H. Krutchman.

North half of southeast quarter of section 22, Cooper township, eight feet of gypsum reported by C. H. Krutchman.

Middle quarter of south half of section 24, Cooper township, gypsum reported in well by F. H. Pingel, thirteen feet found, with well ending in gypsum.

Northeast quarter of section 30, Cooper township, gypsum reported by F. H. Pingel.

Southwest quarter of section 36, Cooper township, gypsum reported in well by Mark Hughett.

Southwest quarter, section 19, Colfax township, no gypsum known, though wells penetrated to ninety-five feet and to one hundred and sixty-eight feet (H. Scharf).

Northeast quarter of section 30, Colfax township, wells over one hundred feet deep located no gypsum (J. F. Hogan).

Northwest quarter of section 29, Colfax township, wells eighty feet deep located no gypsum (E. T. Stake).

Southwest quarter, section 20, Colfax township, two wells one hundred feet deep, no gypsum (J. J. Hogan).

Northeast quarter, section 20, Colfax township, well one hundred and twelve feet deep, no gypsum (P. Ledeh).

Southwest quarter, section 29, Colfax township, well one hundred and fifty feet deep, no gypsum (Dr. J. W. Kime).

Reports are conflicting in regard to the finding of gypsum in the stockyards well at Industry.

Middle of south line of section 12, Cooper township, four or five feet of gypsum reported in eighty foot well (John Grebner).

Southeast quarter, section 11, Cooper township, well one hundred and thirty-five feet deep showed no gypsum (James Coughlin).

Southwest quarter, section 36, range 28 west, township 89 north, five holes from seventy to one hundred and six feet deep gave no gypsum, Coal Measures shales coming in directly under the glacial drift (Mr. Hughett's farm).

Cooper township section 8, N. E. ¼.
Well eighty-eight feet deep struck no gypsum.

Cooper township section 35, N. E. ¼
Five feet of gypsum was found in a well.

Cooper township section 2, S. W. ¼
No gypsum found in a well seventy feet deep.

Colfax township, section 5, middle of south line
Well eighty feet deep struck no gypsum.

Colfax township section 9, N. W. ¼
Well seventy-five feet deep struck no gypsum.

Colfax township section 9, S. W. ¼
Well 147 feet deep struck no gypsum.

Colfax township section 16, N. E. ¼
Well eighty feet deep struck no gypsum.

Colfax township section 9, The Gus Ming well,
90 feet deep struck no gypsum.

Colfax township section 21 N. E. ¼ of the N. W. ¼
Well sixty feet deep struck no gypsum.

Colfax township section 20 N. E. ¼
Well 160 feet deep struck no gypsum

Colfax township section 17, middle of north line
Well 160 feet deep struck no gypsum.

Colfax township section 19, well on middle of north line 180 feet deep struck no gypsum.

ST. LOUIS LIMESTONE

The limestone reported frequently in the earlier part of this chapter as occurring in localities along the river and along Soldier and Lizard creeks, has been consistently and without exception referred to the St. Louis stage of the Mississippian series. At certain points the St. Louis limestone is overlain by a sandstone layer and this in turn by marls. An interesting section of this sort may be seen a short distance above the mouth of Lizard creek.

Lizard creek section

		Feet
4.	Fossil-bearing marl	6
3.	Marl, gray, without fossils, containing many selenite crystals	40
2.	Sandstone, yellow, moderately hard, calcareous	2
1.	Limestone, slightly folded, in definite layers, in places brecciated	17

The first or lowest member of this series represents the St. Louis while Nos. 2, 3, and 4, though formerly regarded as belonging to the St. Louis, are now referred to the Ste. Genevieve.

Typical section

A typical section for the St. Louis in Webster county is found just at the northern edge of the gypsum area, on Des Moines river, in Cooper township, section 7, the southwest quarter.

		Feet	Inches
13.	Sand	5	
12.	Limestone layer	1	
11.	Limestone layer with persistent band of flint one inch thick	1	2
10.	Limestone layer	2	6
9.	Limestone layer	1	
8.	Limestone layer	1	
7.	Limestone, at some points massive and at others showing layers slightly distinguishable	4	
6.	Limestone layer, light color		1
5.	Limestone layer	1	
4.	Limestone layer	1	
3.	Sandstone in places containing a flint band one inch thick		6
2.	Limestone layer	1	6
1.	Sandstone, to water's edge	1	6

STE. GENEVIEVE

Directly above the St. Louis limestone at three or four points in the district under discussion lie beds of fossil-bearing marl and between them and the limestone is a sandstone layer, which lies unconformably on the limestone. Earlier reports describing the Fort Dodge gypsum area classified these marls and sandstones with the St. Louis. Weller and Van Tuyl[121] have recently pointed out the faunal similarity of these marls to the Pella beds in the southeastern part of Iowa.

Nickles and Bassler[122] and subsequently Weller,[123] pointed out the Ste. Genevieve affinities of the Pella, and there is substantial ground for referring the fossil-bearing marls described on pages 146 and 154 to the Ste. Genevieve.

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[121] Iowa Acad. Science, Vol. XXII, p. 241.

[122] U. S. Geol. Survey Bull. 173, pp. 166 and 188.

[123] Jour. Geology, Vol. XVII, p. 278, 1909.

The following quotation from the paper of Weller and Van Tuyl[124] is interesting in this connection:

> "In his report on the geology of Lee county Keyes described a fine-grained, compact limestone at the top of the St. Louis formation, resembling lithographic stone in texture. Gordon reported a similar limestone characterized by **Spirifer littoni** (**Spirifer pellaenis** Weller) and **Pugnax Ottumwa** at the same horizon in Van Buren county. Bain subsequently recognized this member in Keokuk county and named it the Pella because of its typical development at the town of this name in the neighboring county of Marion. This name has been adopted by Savage in his geology of Henry county and by Miller in the Marion county report. Until 1900, when Nickles and Bassler referred the Pella to the Ste. Genevieve upon the basis of its bryozoan fauna, the St. Louis age of the formation was accepted without question. Weller subsequently pointed out the Ste. Genevieve affinities of the Pella fauna in 1909, and recent field studies have now likewise demonstrated that the Pella is formationally distinct from the underlying St. Louis, it being separated from that formation by a disconformity and by a characteristic basal sandstone in every Iowa locality which has come under observation.
>
> "**Areal Distribution.**—In general, the exposures of the Pella beds in Iowa are confined mainly to the southeastern part of the state. In the belt of Mississippian rocks, which extends northwestward from this region, the higher formations of the system are concealed by the Coal Measures, except for locally exposed areas in Story, Webster and Humboldt counties, where the overlying beds have been removed by erosion. Little is known as to the extent of the Pella in this direction, but the finding of a good Pella fauna by Wilder in certain marls overlying the St. Louis limestone in Webster county indicates that the Pella seas extended at least as far northward as Fort Dodge."

The exposures of the St. Louis and Ste. Genevieve along the river above Fort Dodge, along Lizard creek and near Kalo, are shown on the geological maps.

Exposure near Kalo

The exposure near Kalo is one-fourth mile below the Minneapolis and St. Louis railroad bridge, about half a mile below the Vincent Clay Works, in Pleasant Valley township, section 5, the southwest quarter. Here the marl with typical brachiopods occurs above the St. Louis limestone, which

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[124] Iowa Acad. Science, Vol. XXII, p. 241.

appears in the river bed. Half a mile farther down stream in section 8, the northeast quarter, the limestone appears for a thousand feet along the river. Above five feet of solid stone an equal thickness of marl is found.

The exposures along the lower course of Lizard creek have been described in the earlier part of this chapter. Shales and marls of the Ste. Genevieve that occur farther up the creek are described by Lees as follows:[125]

North Lizard exposure. No. 29 on map

"About four hundred yards above the junction of North and South Lizard creeks, on the east bank of North Lizard, there is an exposure of the gray-green shale which rises twenty-five or thirty feet above the stream. Over this shale lies fifteen to twenty feet of red shale. At several horizons in the gray-green shale there are harder limy bands which contain large numbers of fossil brachiopods. The contact of the red shale with the gray is quite sharp and lies just above a layer of fossiliferous yellow limestone.

Douglas township outcrops.

"The next exposures on this fork, and so far as is known to the writers the last ones, are a group five miles up the valley and in the southeast quarter of section 8, Douglas township, about one-fourth mile below the Minneapolis and St. Louis railroad bridge, on the north bank of the stream. Here a small tributary ravine has been cut through six feet of yellow and green shale, below this through five feet of red and green shale, beneath which is exposed two feet of gray sandstone or sandy limestone, then five feet of shaly material beneath which in turn two feet of green shale is seen above the stream level. Just down the main valley a few rods is an exposure of ten feet of yellow and brownish red clay shale, under which is six feet of red shale which lies on gray sandstone which rises six feet above the creek. The red shales of these exposures are for the most part true clay shales, although some are finely sandy. Lithologically they are the equivalent of the red shales overlying the fossiliferous gray-green marls seen in the abandoned clay pit and elsewhere upstream as far as the exposure just above the forks. None of the beds at this locality yielded any fossils nor were there found any of the nodular limestone bands which are the fossiliferous members of the exposures farther downstream. Black shales probably Coal Measures are said to be present in the valley walls. Along the ravine to the north there are exposed at intervals for nearly one-half mile pink

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[125] Iowa Acad. Science, Vol. XXV, pp. 601, 616, 1918.

and gray clay shales which rise at least twenty feet above the water."

PENNSYLVANIAN SERIES

DES MOINES STAGE

The productive Coal Measures of Iowa belong to the Des Moines stage of the Pennsylvanian series. The Des Moines beds underlie the drift in most of the central and southern part of Webster county, the principal exception being the area where the gypsum with its associated shales, known collectively as the Fort Dodge beds, intervenes.

Nature of Coal Measures

The Coal Measures consist of shale, coal, sandstone, with thin beds of argillaceous limestone and limonite. The shales are fissile, in many cases arenaceous, and generally free from lime. They differ in color from very dark gray to yellow. Sections showing beds of shale belonging to the Des Moines stage appear in several of the earlier pages of this chapter. These beds are fairly constant in their physical characteristics and their presence has always been recognized within the district under consideration. In this region they are in every way distinct from the members of the Mississippian series, which they invariably overlie unconformably, except at points where the Des Moines beds were removed prior to the deposition of the Fort Dodge beds, where, of course, the Fort Dodge beds themselves rest on the Mississippian. In the southern part of the area under consideration two rather constant features of the Des Moines beds are of special aid in studying structural problems. There is the bed of gray sandstone which, at the Vincent clay pit; at the entrance to the depression leading to the Plymouth mines; along the river and along the Interurban railway track, lies about twenty feet below the gypsum, though at one or two points the gypsum lies directly on it. Secondly, there is the thin bed of fossiliferous limestone that generally lies about twenty feet below this sandstone. A typical section through the Fort Dodge beds and Coal Measures to the St. Louis limestone is given on page 157 where a drill hole in Cooper township, section 33, is recorded. The record of the well in Elkhorn township, section 3, given on page 156 is very similar.

PERMIAN

FORT DODGE BEDS

The gypsum is so characteristic that it is easily recognized wherever it occurs. The highly colored shales associated with the gypsum are quite definite in their nature and very little if any confusion has arisen in their classification. Where they are associated with the gypsum their identification is generally easy. At a few points an element of uncertainty arises from the fact that the Coal Measures shales are locally rather highly colored.

Character of Beds

The heaviest body of the bright shales associated with the gypsum is found at the north abutment of the Soldier creek viaduct. Here fifty[126] feet of the pink-red shales with characteristic sandy streaks is exposed.

In 1916 Lees noted a conglomerate in the ravine followed by the Fort Dodge, Des Moines and Southern railroad, on the west side of the river in Pleasant Valley township, section 6, the southwest quarter, and Elkhorn township, section 12, the northeast quarter. A generalized section of this ravine is given on page 150. It shows ten or fifteen feet of gypsum separated by six inches of clay from a conglomerate layer one to two feet thick. This conglomerate is illustrated in figure 13. The conglomerate rests on a bed of red clay twelve feet thick beneath which are gray sandstones and shales. The conglomerate forms the basal member of the Fort Dodge beds. Since this conglomerate contains fossils and no other fossils have been found in the Fort Dodge beds, it has received careful study.

Lees' paper[127] discussing this conglomerate is quoted below.

A New Basal Conglomerate.—During the prosecution of field study of the gypsum for the Iowa Geological Survey the writer found immediately beneath the gypsum in several places a basal conglomerate which has not heretofore been described in reports on the region. The locality where this conglomerate is best developed is in a ravine on the west side of Des Moines river opposite Two Mile creek about three miles south of Fort Dodge. The Fort Dodge, Des Moines and Southern railway

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[126] Keyes in Iowa Acad. Science, Vol. XXIII, p. 108, reports: "75 feet of the pink shales which directly overlie the gypsum," at this point and it may be assumed that he saw the section under exceptionally favorable conditions at the time of excavation of the viaduct. Drift apparently has washed down over part of the exposure to which he refers.

[127] Iowa Acad. Science, Vol. XXV, pp. 587-591.

extends along this ravine and has exposed the conglomerate in some of its cuttings. In the lower part of the ravine the gypsum is seen to be on the black or dark colored Coal Measures shales. In places the contact is direct while in other places about six inches of clay, evidently residual, intervenes. Perhaps one-half mile up the ravine there is exposed beneath the gypsum a reddish or grayish conglomerate one to two feet thick. The pebbles are mostly limestone, fairly well smoothed by attrition, and are rather small, the larger ones being not much over an inch in diameter. Under the conglomerate lie the shales of the Des Moines stage locally colored red or lighter shades. At other places near by the conglomerate outcrops immediately beneath the drift. The gypsum either has been removed by erosion or solution or was not deposited. The significant feature about this conglomerate, however, is its fossil content, and this it is which makes it of peculiar value in relation to the gypsum. Professor Thomas of the Department of Geology of the State University visited the gypsum region with the writer on a later trip and a number of fossils were collected from the conglomerate. Mr. Thomas after studying this collection and comparing it with type forms wrote as follows:

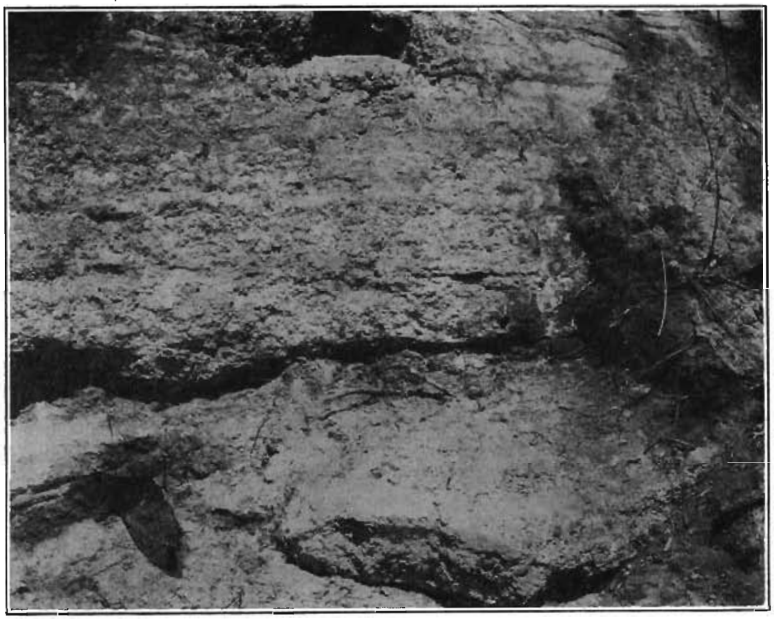

FIG. 13.—Conglomerate which appears at the base of the Fort Dodge beds in the ravine which is followed by the Fort Dodge, Des Moines and Southern railroad on the west bank of the river. This conglomerate contains the only fossils ever found in the Fort Dodge beds.

"The basal conglomerate fauna is very evidently of Missourian age although I am not ready to say so unequivocally since so many Pennsylvanian forms have a habit of continuing on into the Permian. I have compared the unquestionably identified species with Pennsylvanian and with Permian lists and all point to the former rather than to the latter. Not a trace of anything Mesozoic occurs in the material. Some of the specimens show evidence of wear as from rolling but they do not seem to have been transported far. Here is the list:

Squamularia perplexa (McChesney).
Pugnax osagensis (Swallow).
Fusulina secalica Say=F. cylindrica Fischer.
Productus cf. longispinus Sowerby.
Rhombopora lepidodendroides Meek?
Zaphrentis (unidentified).
Stem segments and plates (?) of unknown crinoids.

"The Rhombopora has suffered from wear so that the characteristic markings, if they were ever present, are rubbed off. There is no question about the Fusulina. I sectioned a few, they are as good specimens as one could wish for."

The nearest known rocks of Missouri age are in Carroll, Crawford, and Monona counties. In former time the northward extent undoubtedly was greater. Cretaceous rocks are present only a few miles to the west of Fort Dodge in Calhoun and Pocahontas counties. In spite of the softness of these rocks fossils certainly could be transported as far as the gypsum region and in fact they are found in the drift at considerable distances from the original strata. There are no known strata in northwestern Iowa west of Webster county intermediate in age between the Missouri and the Cretaceous. The presence of Missouri life forms in the conglomerate of the gypsum region proves it to be of post-Missouri age, while the entire absence of fossils of Cretaceous or later age argues strongly for a post-Missouri-pre-Cretaceous age for the conglomerate and for the associated gypsum and the shales and sandstones which in some localities overlie it.

Doctor Sidney L. Galpin of the Department of Geology of Iowa State college informs the writer that a similar fossiliferous conglomerate underlies the gypsum beds of Kansas, which are well known to be of Permian age.

The other locality where this conglomerate was found is at the pit of the Vincent Clay Products Company at Shady Oaks station on the Fort Dodge, Des Moines and Southern railway. This is at the mouth of Two Mile creek on the east bank of Des Moines river directly opposite the ravine in which the previously described outcrops occur. Here the conglomerate is absent from some places while at others it is a foot or a foot and a half thick. It is red and gray and most of the pebbles are less than one-half inch in diameter. Parts of the conglomerate are really a coarse sandstone. Fossils were found in streaks and pockets of the coarser materials.

A noteworthy feature in this pit as well as in several others is the fact that the upper few feet of the Coal Measures shales just under the gypsum is highly colored, red, blues, purples, and light grays predominating. These lighter colors grade into black below. Whether this lighter coloration is inherent in the shales or is due to the chemical action of the dissolved gypsum as it percolates downward is not clear.

GEOLOGICAL AGE OF THE FORT DODGE GYPSUM

Aside from the fossil evidence in the conglomerate just described there is no new light on the geological age of the Fort Dodge beds. The writer assigned these beds to the Permian in his report on Webster county[128] and the statements there made still seem to hold good, though in the light of present knowledge less emphasis should be laid on aridity as a factor governing gypsum deposition. They may be quoted here:

> The fact that the gypsum and the red shales lie unconformably on the Coal Measures is good ground for believing that if they belong to the Paleozoic era they were formed near its close, during the Permian. The Permian beds of Kansas, Indian Territory and Texas, which contain quantities of gypsum, are so highly and so characteristically colored that they are known as the "red beds". These red beds like the red shales and gypsum of Iowa are nearly destitute of fossils, due probably to the fact that the climatic conditions favoring deposition of gypsum were hostile to organic life. Aridity is the climatic characteristic most essential for great deposits of gypsum, and the redness of the sandstones and shales usually accompanying gypsum deposits of all ages and localities may fairly be assumed to be an effect of climate, direct or indirect, on the iron content of the soil. All of these considerations, namely, the arid climate that prevailed during the Permian, shown by great gypsum deposits associated with red shales occurring in both Europe and America, and the striking resemblance which the series bears to the Permian only 300 miles to the west, carry great weight. The Iowa series might reasonably be interpreted as an outlier of the Permian of Kansas and Indian Territory. During the long interval between its deposition and that of the drift which now protects it erosion had an abundant oppor-

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[128] Iowa Geol. Survey, Vol. XII, pp. 111-114.

tunity to remove the Permian from the intervening territory. The gypsum was doubtless protected by heavy beds of the red shales, for had it been exposed long it must have yielded to the solvent and erosive action of water.

It is possible to refer the gypsum to the Triassic or to the Cretaceous. Like the Permian, the Triassic of the west is red and contains large deposits of gypsum, notably those of the Black Hills. Known outcrops of Triassic strata occur only far to the west of the area under consideration, much farther west than the most eastern exposures of recognized Permian in Kansas. While this fact favors a reference of the Iowa gypsum to the Permian rather than the Triassic, the fact that the Permian of Kansas rests conformably on the Coal Measures while the gypsum of Iowa does not, throws a certain amount of weight the other way.

The claims of the Cretaceous have been considered in previous reports on the region.[129] Reference to the geological map of Iowa shows that Cretaceous deposits are present throughout the greater part of northwestern Iowa and that they approach within thirty miles of Webster county, at Auburn in Sac county, where they appear as chalk. The Cretaceous in Iowa consists of sandstone of the Dakota stage, and shales, limestone and chalk of the Colorado stage. Sandstone, shales and limestone have yielded abundant fossils which definitely fix their age. Other things being equal, it would be somewhat more natural to regard the Webster county gypsum series as an outlier of the Cretaceous than of the Permian which is farther away, yet the distance is not so great as to render a correlation with the Permian in any degree improbable if the preponderance of other evidence favors such a view. A review of Cretaceous climatic conditions is first of all necessary, for if aridity is a more striking characteristic of the Permian than of the Cretaceous, the Cretaceous age of the gypsum can hardly be established. The Dakota sandstone is in places red, but this color does not everywhere prevail and it does not characterize the Cretaceous shales and limestones in any degree. The Dakota sandstone abounds in fossils, as does the limestone of the Colorado stage, in which Inoceramus labiatus is found in great numbers. The Benton shales, while not so rich in fossils as is the limestone. contain Ostrea congesta, Prionocyclus wyomingensis and other species, none of which are brackish water forms. They contain also some selenite, but in view of the fossil contents of the shales it is probable that the selenite was not formed by precipitation from concentrated brine at the

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[129] Iowa Geol. Survey, Vol. III, p. 290.

time that the shales were laid down, but is due to subsequent chemical reaction in which sulphuric acid, generated perhaps from iron pyrites, converted part of the lime carbonate of the shales into the sulphate. In barrenness of fossils, in color and in association with gypsum the red shales which accompany the Iowa gypsum resemble the Permian of Kansas much more than they do the Cretaceous shales of Iowa. The presence of chalk in Sac county, close to what must have been the Cretaceous shore, indicates that for a time sediments from land were at a minimum and organic sediments unmixed with land waste were able to accumulate near the shore. This would indicate an absence of the barren surface usually attending aridity, or the absence of elevation, or both, so that climatic conditions favoring deposits of gypsum are not implied by the chalk of the Cretaceous. Regions devoid of rainfall are characterized by windstorms of great violence capable of transporting much earthy material as dust and carrying it out to sea where it would ultimately be deposited. The arid regions of America are subject to brief but violent rain storms during which erosion is vigorous on the surface barren of vegetation. Low land surfaces covered with an abundant vegetation are most favorable for pure chemical and organic accumulations in the neighboring seas. The great purity of many gypsum deposits presents a difficulty for this very reason, for the land must have been barren during the concentration of the sea water and conditions favorable for dust storms seem likely to have prevailed. Microscopic examination of the Iowa gypsum reveals particles of sand scattered through the gypsum, probably by wind, but the total amount is small, amounting to about one per cent of the whole.

STRUCTURAL PROBLEMS CONNECTED WITH THE FORT DODGE BEDS

Unconformities

The structural feature that stands out most prominently and which has been emphasized by every student of the Fort Dodge beds, from Worthen in 1856 on to the present, is the pronounced unconformity that exists between Fort Dodge beds and the Coal Measures.

The unconformity between the Mississippian beds (Ste. Genevieve and St. Louis) and the Coal Measures also is a striking phenomenon. The relationship existing between the Mississippian, the Coal Measures, and the Fort Dodge beds was shown by Keyes in a diagram that has become a classic[130] and is reproduced as figure 14.

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[130] Iowa Geol. Survey, Vol. III, p. 269. Second annual report, 1893.

The curious variations in the strata seen along the bed of Soldier creek, described earlier in this chapter, are accounted for by the uneven floor of the Mississippian on which the Coal Measures were laid down by the erosion to which the Coal Measures were subjected prior to the deposition of the gypsum.

FIG. 14.—Keyes' diagram showing relationships between the St. Louis limestone, the Coal Measures and the Fort Dodge beds.

Fort Dodge Basin

The Fort Dodge beds seem to have been laid down in an oval basin whose longer axis extended from northeast to southwest. The proof of the existence of this basin is found in the relationships of the Fort Dodge beds to the underlying formations in the restricted area within which these beds lie, which relationships have been set out fully earlier in this chapter. They are shown graphically in the sections on Plate VI.

Keyes' earlier views

Keyes' later hypothesis

Keyes in 1895[131] regarded the gypsum as a basin deposit, laid down in a long estuary extending from northeast to southwest, in the Cretaceous (Niobrara) sea. In a recent paper[132] Keyes postulates a remarkable series of faults in the Mississippi Valley region and in the series introduces faults in the Fort Dodge region which he believes explain the position of the gypsum and its preservation from erosion. He regards the gypsum as of Miocene age though it is not clear on what grounds this correlation is made.

Fort Dodge beds in Tile Pit section

He finds evidence of faulting in the Soldier creek exposures and particularly between Kohl's brewery section at the mouth of this creek and the Fort Dodge Brick and Tile pit section

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[131] Iowa Geol. Survey, Vol. III, pp. 285-290.

[132] Iowa Acad. Science, Vol. XXIII, pp. 103-112, 1916.

on the river one-fourth of a mile farther north. Keyes finds no sign of Fort Dodge beds in the Tile pit and accounts for it by assuming a fault that passed between the pit and the bluffs near the mouth of Soldier creek. Gypsum and its associated pink shales, probably in place or nearly so, have been found in the Tile pit and the Fort Dodge shales are found in at least six places between the mouth of Soldier creek and the Tile pit. The difference in elevation, perhaps fifty or sixty feet, is not more than can be readily accounted for by basin conditions or by slight folding, when it is remembered that the localities under consideration are fifteen hundred feet apart.

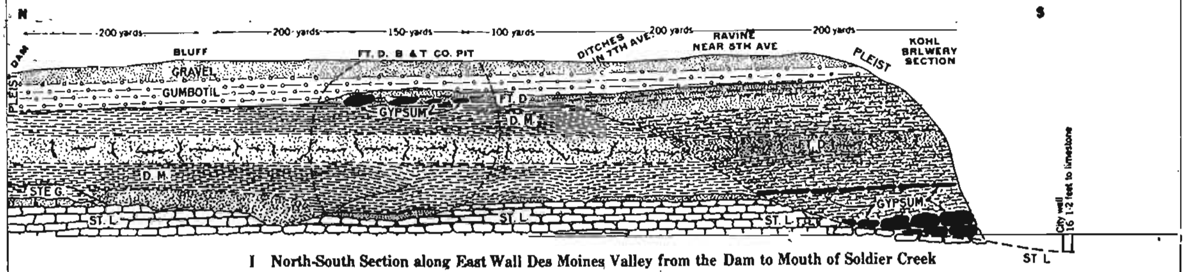
Fort Dodge beds in Clay Works section

The Fort Dodge beds certainly are present in the old pit at the abandoned Fort Dodge Clay Works, across the river and a little above the mouth of Soldier creek; and they are present in the north pit of the same plant a thousand feet up Lizard creek, on its left bank. At both of these points the Fort Dodge beds are considerably above the same beds as shown at the old Kohl brewery section and their elevations correspond rather well with the same beds in the Fort Dodge Brick and Tile pit. If a fault running northeast to southwest and in the general direction of Soldier creek is needed to explain the difference in elevation between the Fort Dodge beds at the mouth of Soldier creek and in the Tile Company's pit, there is apparently the same need of postulating another fault running at right angles to the first one, and in the general direction of the river, to account for the difference in elevation between the Fort Dodge beds in the Kohl brewery section and in the Fort Dodge Clay Works pit.

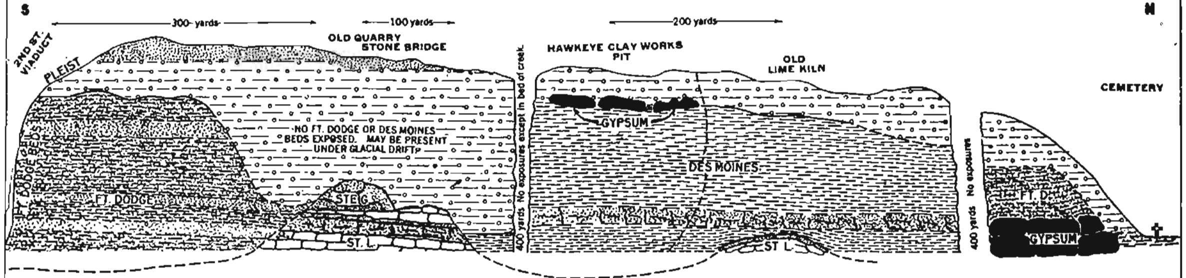
A basin probable

It seems simpler to assume a basin whose sides rise gradually to the north and to the west as well. If Keyes' hypothesis of an east-west, or a northeast-southwest fault were correct, the St. Louis limestone on Lizard creek should be considerably higher than the limestone along Soldier creek, and along the river south of Soldier creek. While the surface of the St. Louis limestone is irregular, as has been shown, it is no higher on Lizard creek than on Soldier creek or along the river.

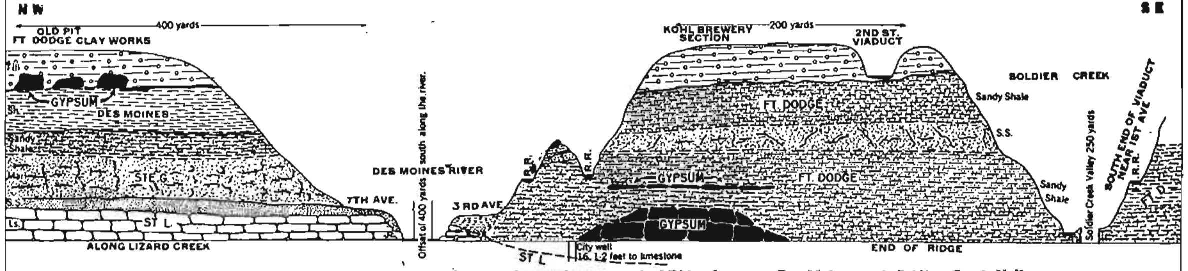
The stratigraphic peculiarities of the Soldier creek basin, set



I North-South Section along East Wall Des Moines Valley from the Dam to Mouth of Soldier Creek



II North-South Section along West Wall of Soldier Creek Valley from 2nd Street Viaduct to the Cemetery.



III Northwest - Southeast Section down Lizard Creek Valley and across end of Ridge between Des Moines and Soldier Creek Valleys

Sections Drawn By James H Lees

Cross sections along Des Moines valley and Soldier and Lizard creeks.

out in detail in the first part of this chapter, are all readily explained by the two unconformities which are so apparent to all students of the region.

The gypsum in the old pit of the Fort Dodge Clay Works on Lizard creek, and at the cemetery north of Soldier creek, lies north of the fault line postulated by Keyes. The inference that is naturally drawn from his paper is that the gypsum is confined to the area south of this fault line, whereas gypsum outcrops on Lizard creek north of the line he has drawn, it appears as large blocks in the pits of the Hawkeye Clay Works in Soldier creek valley and of the Fort Dodge Brick and Tile Company in Des Moines valley and it is reported in well drillings north of Fort Dodge. It has been exposed also in ditches on the Hawkeye Highway along the west wall of Des Moines valley opposite the Fort Dodge Brick and Tile Company's pit.

ORIGIN OF THE GYPSUM

In chapter III the conclusion is reached that beds of commercial gypsum are not all alike as to origin. The evidence presented also leads to the belief that secondary concentration has played a much larger role than has generally been assigned to it. Gypsum has in many cases been deposited in limited quantities in clays, shales and limestones, and subsequently dissolved and concentrated in basins by ground water.

Possible source of the gypsum

The marls of the Ste. Genevieve, the limestones of the St. Louis, and the shales of the Coal Measures in Webster county contain gypsum in considerable quantities. On weathered exposures of the shales and marls at numerous points selenite crystals can be gathered in abundance.

Analyses of the St. Louis limestones and interbedded shale from the mouth of Lizard creek give[133]

	PER CENT
Upper layer, 2 feet	
Carbonate of lime	88.75
Sulphate of lime	00.28

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[133] Analyses by Lundteigen, Peerless Portland Cement Co.

Next layer, shale, 2 feet	
Carbonate of lime	53.25
Sulphate of lime	2.46
Next layer, 2¼ feet	
Carbonate of lime	88.75
Sulphate of lime	00.17

The conditions that would give rise to beds of gypsiferous shales, marls or limestones occur a dozen times to one occurrence of conditions that make possible by primary deposition beds of commercial gypsum.

The following analyses of Ste. Genevieve shales from the banks of Lizard creek in section 8 of Douglas township, Webster county, however, show no gypsum.

CONSTITUENT	PER CENT	PER CENT
Silica (SiO_2)	73.99	78.35
Water at 105°C.	1.67	2.91
Water from 105° to red heat	4.19	3.54
Alumina (Al_2O_3)	17.70	14.00
Iron Oxide (Fe_2O_3)	.90	.60
Calcium Oxide (CaO)	1.66	.50
Total	100.11	99.90

Analyst: F. S. Mortimer.

On the other hand the Mississippian marls along Des Moines river above Fort Dodge, near the site of the dam, contain large quantities of gypsum crystals. The Mississippian in many localities in the United States and elsewhere contains extensive deposits of gypsum, and it would not be remarkable if it furnished material for concentration under conditions that existed in the Permian.

The Fort Dodge beds may represent a remnant of gypsiferous beds laid down in Permian time and the gypsum may have been disseminated through Permian shales which connected the Iowa area with Permian areas in Kansas.

The concentration of disseminated gypsum is greatly aided in arid climates by efflorescence. The soil water is constantly rising to the surface carrying with it mineral matter with which it has come in contact. On the surface the water evaporates and the mineral is deposited, to be caught up by the winds to make dunes, or to be redissolved by the next rain and carried to some nearby basin or to some stream which ultimately bears it to the ocean.

The possibility that the Fort Dodge gypsum was deposited in an arm of the ocean under conditions like those described in chapter IV as existing at certain points along the Caspian sea may be admitted. At the same time the probabilities are that the gypsiferous beds of the Ste. Genevieve, the St. Louis and the Coal Measures furnished material which was reworked by ground waters, and redeposited after the manner of the gypsum lakes of Australia described in chapter IV.

EXTENT OF THE FORT DODGE GYPSUM BEDS

In his report on Webster county the writer stated that[134]

"The well data and records of prospect holes neither positively confirm nor deny the suggestion of Keyes that the gypsum extends on from the Fort Dodge region through the southwestern part of the county and connects with the chalk deposits that are found near Auburn in the southeast corner of Sac county. In the southwestern part of the county most of the wells do not go through the drift and few positive data in regard to the formations under the drift were attainable. Gypsum was not definitely reported by any well driller farther west than the Bassett and the Poor farms, two miles west of the river. Evidences of gypsum as far west as Moorland and Callender are too uncertain to make it wise to extend the gypsum area to those towns. A prospect hole drilled for F. J. Deischmidt just east of Moorland by the Jasper county Coal Company in search of coal is said to have penetrated gypsum. The parties who possessed primary knowledge of this prospect hole have died and it is impossible to corroborate the report. North and east the gypsum area may now be extended beyond the limit which was definitely known when Keyes made his report. At Vincent gypsum was reported by those who drilled the creamery well. A number of reliable persons examined the material brought up by the bucket and pronounced it gypsum. In order to verify as far as possible these statements water from this well, which was said to stop just below the gypsum, was analyzed with these results:

Calcium oxide	226 pts. per million
Sulphur trioxide	302.5 pts. per million
Equal to calcium sulphate	528.5 pts. per million

"The high percentage of calcium sulphate, one part in two

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[134] Iowa Geol. Survey, Vol. XII, p. 108.

thousand, would indicate the existence of gypsum in the neighborhood."

In 1917 an effort was made to verify the statements in regard to the creamery well but the creamery had long ceased to exist and even the existence of a well that passed through the glacial drift was questioned. The analysis of the water from this well, however, was actually made with results as stated.

Gypsum is reported in two wells in the northeastern part of Colfax township, in sections 8 and 18 (see table on page 159). These wells are four miles away from Vincent, but they lend a little support to the reported occurrences in the vicinity of that village. Recent well data from other points in Colfax township render doubtful the accuracy of these records. While the area mapped as probably containing gypsum, and published in the report on Webster county, may be correct, a more conservative estimate is shown on the map that accompanies this report. The Fort Dodge beds probably underlie an area twenty-five or thirty miles in extent. Perhaps not more than half of this area will prove productive, on account of preglacial erosion which has channeled the gypsum deeply along the river and the larger creeks.

Duration of gypsum supply

The average thickness of gypsum that can be mined for plaster in the Fort Dodge field is ten feet and the estimated yield per acre is 20,000 tons after allowing sufficiently for gypsum left as roof and pillars.

The output of the Fort Dodge district is now about 500,000 tons a year. This means that gypsum is annually removed from twenty-five to thirty acres.

Assuming that the output remains at the present level, the gypsum supply in the Fort Dodge region probably is sufficient for more than two hundred years. If the production continues to increase in the ratio that it has increased during the last twenty years[135] the supply will be exhausted in one or two generations. It is hardly probable that the rate of increase of recent years will be maintained. An annual average gain of 10 per cent is perhaps conservative. This means an output of a million tons in 1931 and two million tons in 1941. After

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[135] From 100,000 tons to 500,000 tons, or 500 per cent.

twenty years, more or less, when gypsum products have been fully applied to the many fields for which they are adapted, the curve of increase will flatten and conform to the curve which represents the increase in population.

The Fort Dodge field can probably sustain an output of two million tons a year for seventy-five years.

THE CENTERVILLE FIELD

Deep drilling near Centerville in Appanoose county during the fall of 1910 revealed an interesting deposit of gypsum at that point.[136]

The Scandinavian Coal Company put down a test hole with a core drill to a depth of 550 feet and between 537 and 547 feet found five feet each of gypsum and anhydrite. A study of the log of this drill hole has resulted in the following classification of the formations penetrated.

GROUP	SYSTEM	SERIES	STAGE	FORMATION
Cenozoic	Quaternary	Pleistocene	Kansan drift	
Paleozoic	Carboniferous	Pennsylvanian	Des Moines	Henrietta limestone shale Cherokee shale coal limestone
		Mississippian		limestone shale sandstone gypsum anhydrite

The detailed record of this hole follows:

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[136] A new Gypsum Deposit in Iowa: U. S. Geol. Survey Bull. 580E, pp. 59-64, 1914.

Driller's log of hole of Scandinavian Coal Co., Centerville, Iowa

	Thickness Ft.	Thickness In.	Depth Ft.	Depth In.
Filled ground	3	0	3	0
Yellow clay	28	0	31	0
Limestone	1	0	32	0
Limestone with shale	8	0	40	0
Soft blue shale (banded)	10	0	50	0
Soft blue shale	14	0	64	0
Limestone	3	0	67	0
Sandy shale[a]	21	0	88	0
Old workings	4	0	92	0
Fire clay	2	0	94	0
Limestone	1	6	95	6
Soft clay shale	1	6	97	0
Dark shale	9	0	106	0
Gray shale	7	0	113	0
Fossiliferous shale	1	0	114	0
Black shale	3	0	117	0
Gray shale, very soft	2	0	119	0
Gray shale	13	0	132	0
Black shale	2	6	134	6
Soft clay shale	15	6	150	0
Shaly sandstone	38	0	188	0
Sandstone	1	0	189	0
Black shale	2	0	191	0
Coal		2	191	2
Gray shale	8	2	199	4
Black shale		8	200	0
Coal	1	0	201	0
Limestone	1	6	202	6
Soft clay shale	7	6	210	0
Clay shale		10	210	10
Limestone	2	0	212	10
Black shale	2	10	215	8
Black shale	9	2	225	2
Limestone	4	0	216	0
Coal		10	226	0
Fire clay	1	0	227	0
Clay shale	2	0	229	0
Soft blue shale	3	0	232	0
Soft clay shale, gray	1	6	233	6
Blue shale	3	6	237	0
Black shale	1	4	238	4
Soft clay shale, gray		8	239	0
Blue shale	3	0	242	0
Blue shale with bands of red shale	1	6	243	6
Blue shale	3	8	247	2
Black shale	4	6	251	8
Coal	1	8	253	4
Black shale		8	254	0
Gray shale	6	0	260	0
Black shale	4	0	264	0
Clay shale	8	0	272	0
Gray shale	13	0	285	0
Sandy shale	4	6	289	6
Sandstone	2	6	292	0
Black shale	2	0	294	0
Blue shale	6	0	300	0
Gray shale	5	0	305	0
Sand shale	2	0	307	0
Red and blue shale	8	6	315	6
Blue shale	4	6	320	0
Black shale	0	6	320	6
Gray shale	3	9	324	3
Black shale	1	0	325	3
Coal		2	325	5
Black shale		6	325	11
Sandy shale	15	3	341	2
Coal	1	5	342	7
Sandy shale	4	5	347	0
Sandstone	5	0	352	0
Gray shale	3	9	355	9
Black shale	2	9	358	6
Gray shale	6	0	364	6
Dark shale	2	6	367	0
Gray shale	5	0	372	0
Black shale	9	0	381	0
Sandstone	7	0	388	0
Sandy shale	2	0	390	0
Black shale	3	0	393	0
Gray shale	12	6	405	6
Black shale		10	406	4
Coal (A)		8	407	0
Gray shale	4	0	411	0
Blue shale	4	0	415	0
Coal (B)		3	415	3
Blue shale	3	9	419	0
Clay shale	2	0	421	0
Gray shale	6	0	427	0
Red and gray shale	2	0	429	0
Gray shale	1	0	430	0
Clay shale	2	0	432	0
Gray shale	7	0	439	0
Shaly limestone	6	0	445	0
Limestone	14	0	459	0
Lime shale	9	6	468	6
Sandstone	8	6	477	0
Limestone		6	477	6
Lime shale	6	6	484	0
Limestone	16	0	500	0
Conglomeration of sand and limestone	6	0	506	0
Limestone with spots of shale	17	0	523	0
Limestone	14	0	537	0
Anhydrite, compact	5	0	542	0
Gypsum, white, crystalline	5	0	547	0
Limestone, dolomitic, buff	2	3	549	3
Green shale		9	550	0

This log has been interpreted as follows:

Correlation of log of Scandinavian Coal Co.'s hole at Centerville, Iowa

	Feet
Quaternary: Drift	31
Carboniferous:	
Pennsylvanian: Des Moines group:	
Henrietta formation: Limestones and soft blue shales	36
Cherokee shale: Blue, gray, and black shale, sandstone, several thin seams of coal, and some limestone	372
Mississippian: Chiefly limestone, lime shale, shaly limestone, some sandstone, gypsum and anhydrite	111
	550

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[a] The driller's logs of holes 2 and 3 show no shale on top of the old workings of the Mystic bed; the roof is limestone.

The geology of the region is presented fully in the report on Appanoose county by H. F. Bain, published by the Iowa Geological Survey.[137] Except in the deeper valleys the region is covered with Kansan drift. The drift rests on rocks of the Des Moines stage of the Pennsylvanian series. The upper part of the Des Moines contains the Mystic coal which is one of the most extensively developed beds in Iowa.

Geology of the region

The rocks below the Pennsylvanian are not exposed in Appanoose county and are known only from drill records. The deepest of the three deep holes put down for water at Centerville gave the following section:[138]

Record of deep well at Centerville, Iowa

	FEET
Quaternary: Drift	90
Carboniferous:	
Pennsylvanian: Shales, coal and coaly shale, and a few thin seams of limestone	436
Mississippian: Chiefly limestones and shales	574
Devonian: Limestone and shales	260
Silurian: Limestones, shales, and sandstones	180
Ordovician: Dolomites, limestones, sandstones, and shales	955

This well reached a depth of 2,495 feet and no gypsum was recorded. The log of one of the other deep wells, however, states that at a depth of 600 feet, 15 feet of white sand was found. The material reported as white sand may have been gypsum or anhydrite. This well is located more than half a mile northeast of the test hole in which gypsum was first discovered.

Deep well at Centerville

Shortly after the discovery of gypsum at Centerville, two additional core drill holes were put down. One was located 1200 feet southwest of the original hole and at a somewhat lower elevation. The hole reached a depth of 563 feet, which brought it twenty or thirty feet below the level of the bottom of the gypsum already known. No gypsum was found. A third hole was drilled 1700 feet northwest of the original hole and here nineteen feet of excellent gypsum was found, beginning at 572 feet below the surface. Recently additional drill-

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[137] H. F. Bain, Geology of Appanoose County: Iowa Geol. Survey, Ann. Rept., Vol. V, pp. 378-394.

[138] Iowa Geol. Survey, Ann. Rept., Vol. XXI, p. 937.

ing has been done, but the results are not available for publication.

The limestone directly above the gypsum is highly crystalline and very porous. The thickness varies from fourteen to twenty feet. It presents numerous flat cavities partly filled with calcite crystals.

The characteristics of the Centerville gypsum are described in chapter IV. The deposit seems to have been originally anhydrite, part of which has altered to gypsum. In turn the anhydrite was probably derived from limestone by the action of sulphurous waters.

CHAPTER VI

HISTORY OF THE GYPSUM INDUSTRY

Egypt

The use of gypsum in the arts is recorded in the earliest monuments of civilization. Its value was known to the pyramid builders of Egypt and to artists who wrought during the eighteenth (1580-1350 B. C.) and later dynasties. Hydraulic gypsum mortar was used in the Pyramid of Cheops* (see chapter XIX) and this mortar is hard and its bond with

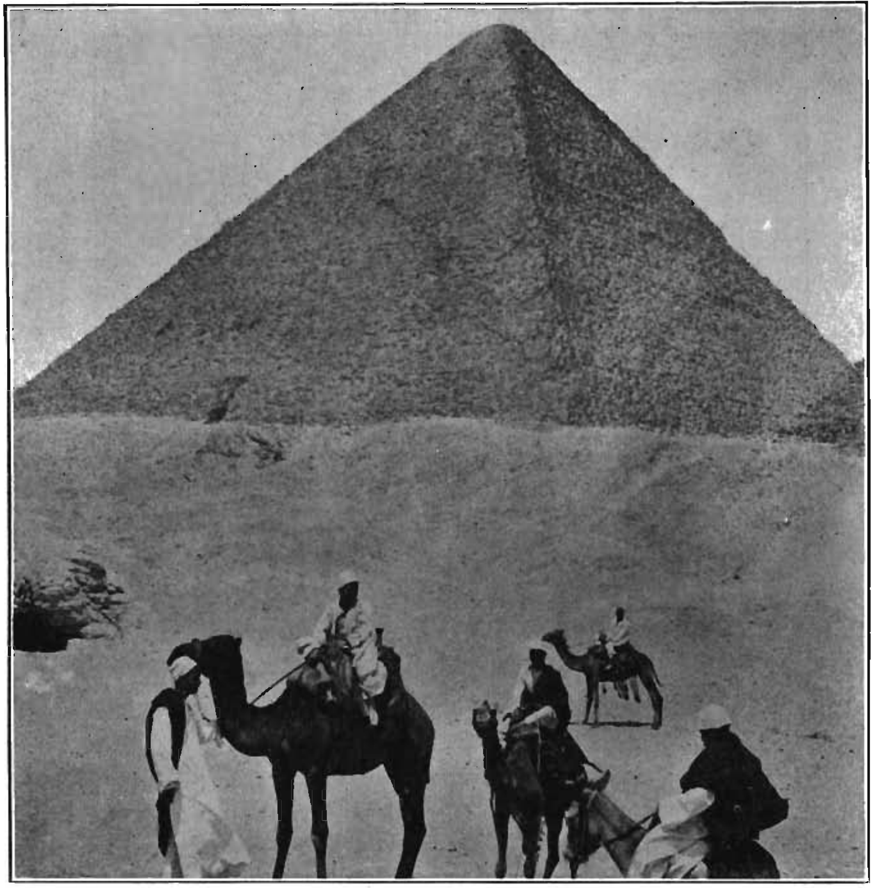

FIG. 15.—Pyramid of Cheops. Hydraulic Gypsum was found in certain portions of this structure and has endured to this time. Copyrighted by and republished through courtesy of Keystone View Co.

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* Based on statements in das Kleine Gipsbaubuch des Deutschen Gips—vereins and in Pedrotti's Der Gips und seine Vervendung.

the massive blocks of stone is perfect to this day. A view of this pyramid is shown in figure 15.

Hydraulic gypsum is admirably adapted to exterior uses, and its calcination requires no delicate control of temperature. In this fact may be found the reason for the extensive use of hydraulic gypsum far in advance of other forms of gypsum mortar. The use of calcined gypsum (plaster of Paris) however was not unknown to the Egyptians and to the Greeks. At the capital city of Amenophis IV, Achet-aton (now Tell el Amarna), excavations have brought to light the studio and workshop of Thuthues,[139] who with his associates calcined gypsum, and made plaster of Paris models and masks. Analyses of objects found in this workshop show that they are composed of 57 per cent gypsum and 31 per cent lime.

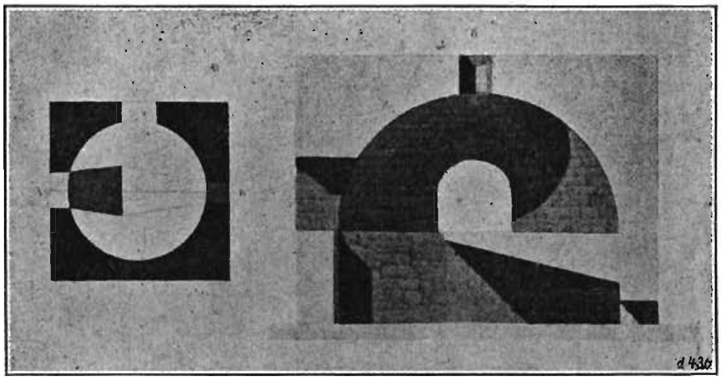

FIG. 16.—Ancient Egyptian calcining oven. From Bericht Deutschen Gipsverein, 1914

Theophrastus records that plaster casts were first made by Lysistratus but the Greeks made very little use of gypsum in their art.

Greece

The use of hydraulic gypsum was known to the Romans and this material served them well in many important and enduring structures. Alabaster was highly valued by Greeks and Romans and the ancients in general for vases, ornamentation and the lighter forms of statuary. The Romans esteemed gypsum also as a fertilizer.

Rome

Hydraulic gypsum formed the mortar used in medieval

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[139] Report of the 14th Assembly of the German Gypsum Association, 1914. An address by Prof. Dr. F. Rattigen, Berlin.

times in the construction of German castles and fortresses. In the vicinity of gypsum quarries, hydraulic gypsum was used exclusively in mortar making. On the southern border of the Germany Hartz, in Thuringia, in Luneberg, Legeburg and elsewhere are found interesting relics[140] of the days of chivalry which are enduring monuments to the worth of gypsum for exterior construction. The beautiful ruins of the monastery at Walkenreed, the ancient cathedral of Bardowiek, the remnants of the walls of Luneburg, Nordhausen and other cities in the Hartz mountains show how gypsum mortar has withstood a trying climate for hundreds of years, and how age has seemed merely to intensify the bond between the gypsum plaster and the stone blocks that compose the ancient structures.

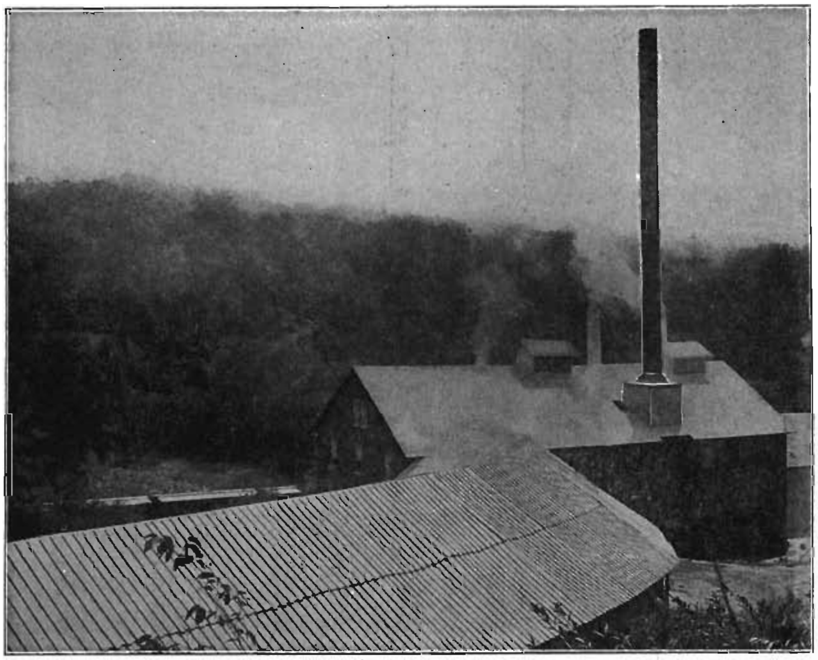

FIG. 17.—Lower mill of Iowa Plaster Association as it appeared in 1902. It has since been completely dismantled.

Gypsum was early valued as a fertilizer, and before and after the revolution was extensively used in agriculture. Benjamin Franklin, by word and pen and example urges the use of gypsum on the farm. His famous object lesson, showing the America value of gypsum as a fertilizer, is familiar to everyone who has read anything about the life and work of the great

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[140] Das Kleine Gipsbaubuch. Published by the German Gypsum Association, Berlin, 1912.

philosopher. He applied ground gypsum to a clover field in the form of large letters with the result that the words "Land Plaster Used Here", could be read for miles in the leaves and greener growth that resulted from the application of the gypsum. Thousands of tons of gypsum, at first imported from Nova Scotia and later quarried in New York state were used annually in the colonies and in the early days of the republic.

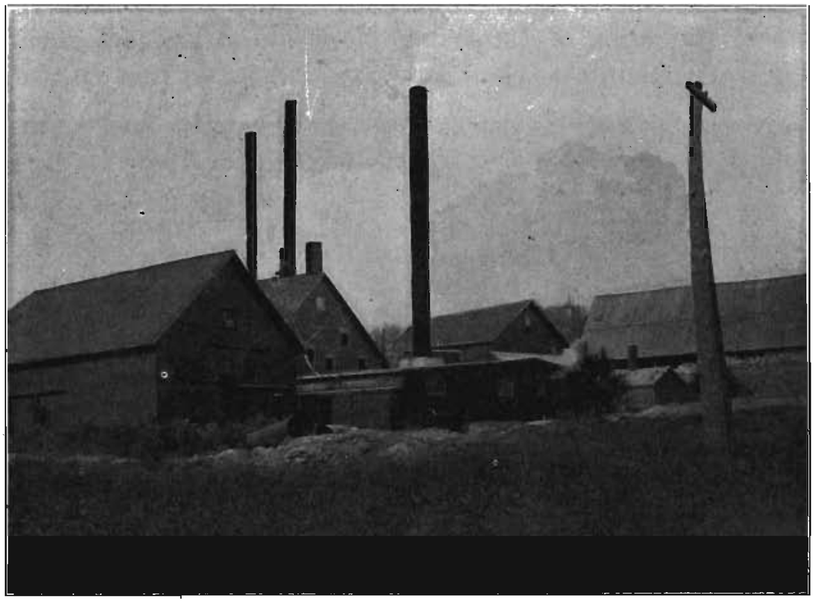

FIG. 18.—The Blandon Gypsum mill, as it appeared in 1902. It was torn down shortly after that date.

As the settlements moved westward, the gypsum deposits of Ohio, Michigan, and Iowa were in turn discovered and developed first for land plaster and subsequently for the manufacture of structural plasters. The development of the land plaster industry is illustrated by the production in the Grand Rapids district of Michigan.[141]

From 1842 to 1850	500 tons a year
From 1850 to 1860	2,000 tons a year
From 1860 to 1864	3,000 tons a year
From 1864 to 1868	8,000 tons a year
In 1869	12,000 tons a year
In 1870	12,000 tons a year

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[141] Geol. Survey of Michigan, Vol. IX, p. 47.

There are no figures available for the country as a whole, but as far as is known, the production of land plaster in New York and Ohio was equal to that of Michigan, and considerable quantities were ground in Iowa, while the use of Nova Scotia mineral along the coast, begun in colonial times, was continued and extended. The history of the use of gypsum as a fertilizer is considered somewhat at length in chapter X.

The calcining of gypsum for plastering purposes began in America about 1835 and from a small beginning in New York state, it gradually developed in every gypsum locality where population was sufficiently dense to offer a market for plastering material.

FIG. 19.—Mill of the Cardiff Gypsum Plaster Co. as it appeared in 1902. At that time this mill was new. It was the first mill located on the prairie and demonstrated that gypsum mining as well as stripping was practical about Fort Dodge.

The primitive gypsum mill consisted of a corn mill and a cauldron kettle. A little later the grinding was done in burr stones, and kettles with an extra heavy cover and capable of holding two or three barrels, were used.

Kettles with two flues were used in New York and from that state the idea was imported into Michigan in 1871 by Freeman Godfrey, one of the pioneers in the gypsum industry in that state.

Calcining introduced

The same years that witnessed the introduction of calcined gypsum for plastering purposes, saw the beginning of the decline in its use in agriculture.

FIG. 20.—Mill of the Plymouth Gypsum Co. near Fort Dodge. Courtesy of Plymouth Gypsum Co.

The reasons for this decline are threefold. First, the rapid growth in the demand for calcined plasters absorbed the attention of the gypsum producers and they made no study whatever of the underlying scientific principles that make gypsum valuable on the farm. Second, competition from potash, nitrate and phosphate fertilizers arose, and agricultural experts recognized the merits of these new fertilizers. Third, land plaster had produced wonderful results but on land where it had been used continuously for years in time it failed to give results of earlier years. The new fertilizers on the other hand on these lands proved very helpful. Chemical analyses of plants, seeds, fruits, and stems, as made at this time aided in obscuring the issue. They showed the reasons why the potash and phosphate were valuable, by demonstrating their presence in the plant tissue, but the high percentage of sulphur present in many plants was volatilized and hence never recorded. So the idea

Other fertilizers displace gypsum

Reasons for decline of land plaster

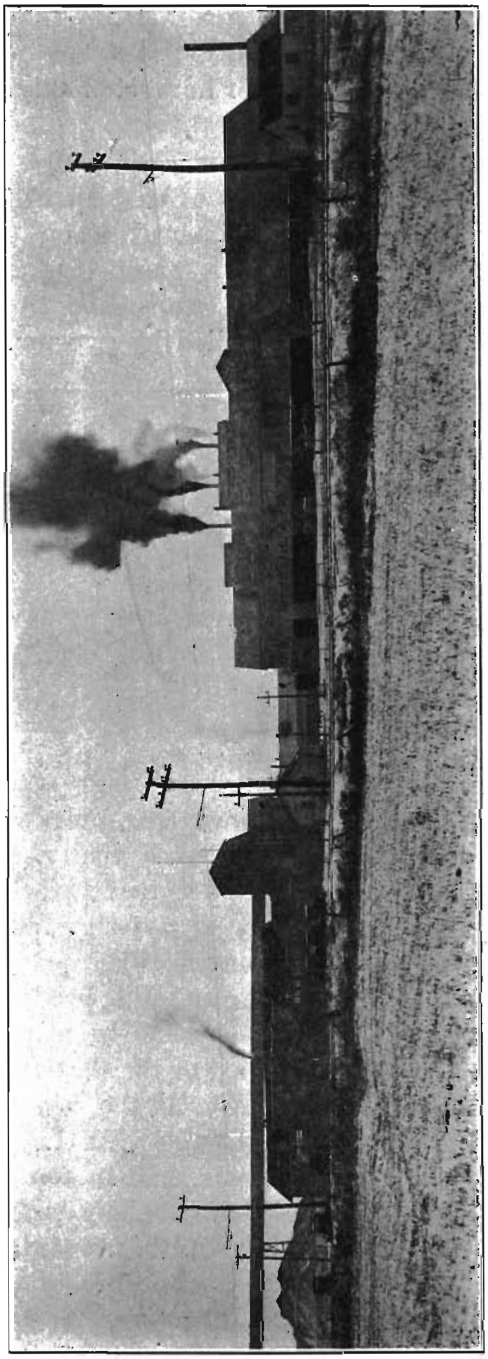

FIG. 21.—Mill of the American Cement Plaster Co., Fort Dodge. Courtesy of the Beaver Board Co.

arose that gypsum was merely a stimulant and furnished no plant food. A stimulant was a bad thing on general principles and all forms of lime were so regarded for a considerable period. The saying that "lime makes the parent rich and the child poor" is quite universally accepted as true.

Revival of land plaster

The revolution in favor of lime compounds began with lime carbonates primarily because they were soil sweeteners, though gradually the recognition of calcium as a plant food was extended.

The use of gypsum as a fertilizer survived in a few localities simply because experience showed that nothing else took its place. The crop that particularly held for land plaster a place in agriculture was the peanut. This legume, like all the members of the family, is a heavy consumer of sulphur and when gypsum was not used the kernels did not fill out and the farmer harvested only a crop of empty shells or pops.

In chapter X the recent history of gypsum in agriculture is set out. This modern period may be thought of as beginning with the publishing by the Wisconsin Experiment Station of Bulletin 14, which showed that sulphur is a plant food as essential as phosphorus for many important crops, and that sulphur in the best and cheapest form is supplied by gypsum.

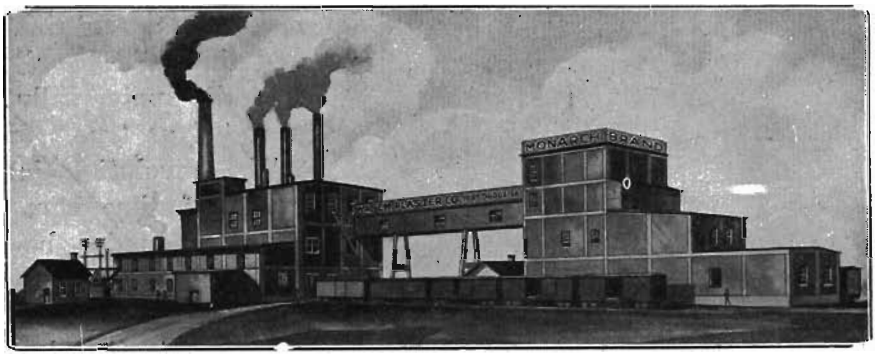

FIG. 22.—Mill of the Wasem Plaster Co. near Fort Dodge. Courtesy of Wasem Plaster Co.

Progress of gypsum plasters

The use of calcined gypsum for interior plastering purposes made rapid and permanent progress. It filled a real need by furnishing a substantial wall surface that favored rapid construction and the freedom of gypsum from dampness was recognized as a great aid to good health.

At first the calcining methods were crude and the product difficult for the plasterer to handle. Improvement in manufacturing processes and greater skill on the part of the plasterer have developed hand in hand. The increase in the use of gypsum plasters is best shown in the table in Chapter XXII.

Gypsum blocks

The writer in 1902, described[142] the processes then in use in Germany for making gypsum blocks. This phase of the gypsum industry had advanced considerably in that country when the first steps toward making blocks were taken in America. Once successfully made and introduced to the

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[142] Iowa Geo'. Survey, Vol. XII, p. 198-202.

building trade, however, the use of blocks has increased rapidly.

The gypsum board, as that article is understood in American trade, is purely an American product. Of the two types of gypsum board recognized by the trade, namely plaster board and wall board, the plaster board was first developed.

Plaster board is intended as a base coat, to be covered with one or two coats of plaster. In other words it takes the place of lath and the first coat of plaster. It was first introduced to the trade about fifteen years ago and has met with a favorable reception on the part of architects, underwriters and owners.

Gypsum board

Gypsum wall board was perfected about five years ago to meet the demand for a substantial ready made wall, that could be put in place by simple methods. The various composition boards had left much that was to be desired. Their fire hazard was great, and expansion and contraction with warping developed unsightly surfaces. The satisfactory showing made by gypsum wall boards on buildings constructed for war purposes in 1917 and 1918 greatly stimulated this phase of the industry.

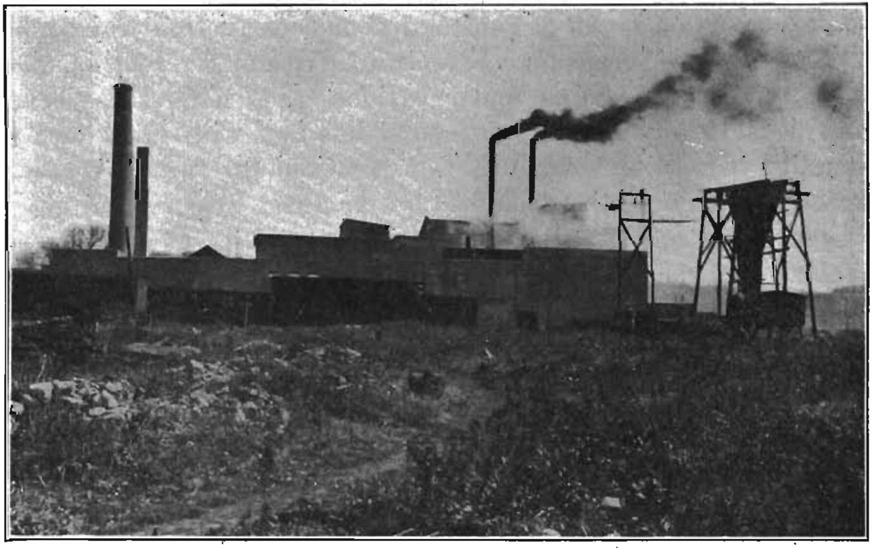

FIG. 23.—Mill of the Iowana Plaster Co. near Fort Dodge. Courtesy of Rock Products.

The properties of gypsum boards, methods used in their manufacture, with specifications and standards are considered at length in Chapter XVII.

Hydraulic gypsum

Gypsum calcined at high temperatures, as has already been noted, was used as mortar by the ancients and was the common mortar used in Europe at points where gypsum was easily won, during the middle ages. The same material is still used extensively for mortar in Europe. It is used also, almost to the exclusion of the Portland cement and lime mixture in vogue in America, for exterior stucco. It is more commonly used for flooring in Germany than Portland cement, and its use for flooring purposes and for exterior stucco is increasing.

The German "Estrich"

Structural gypsum

While the American gypsum industry has not taken advantage of obvious opportunities to enter important fields with hydraulic gypsum it has developed two interesting and important types of roof and floor construction which use calcined gypsum. Structural gypsum for roofing and flooring purposes, going under various trade names, has been on the market about ten years, and has met with favor and a steadily increasing demand. Construction for war purposes greatly stimulated the demand for structural gypsum and gave ample opportunity to demonstrate its flexibility as a building material, as well as its strength, low conductivity and fire resistance.

European and American types of structural gypsum are considered at length in Chapter XVIII.

HISTORY OF THE GYPSUM INDUSTRY IN WEBSTER COUNTY

Mills in Gypsum Hollow

The first gypsum mill in Webster county was erected in 1872 at the head of Two Mile creek, better known as Gypsum Hollow, close to the track of the Illinois Central railroad. The founders of the gypsum plaster industry in Iowa were Captain George Ringland, Mr. Webb Vincent, and Mr. S. T. Meservey. At this time calcined gypsum was used only as plaster of Paris, and for mixing with lime for finish coat in plastering. In 1878 small quantities of gypsum plaster for base coat work were put on the market. Plasterers accustomed to lime mortars only did not quickly comprehend the technique of gypsum plasters, but gradually they became familiar with

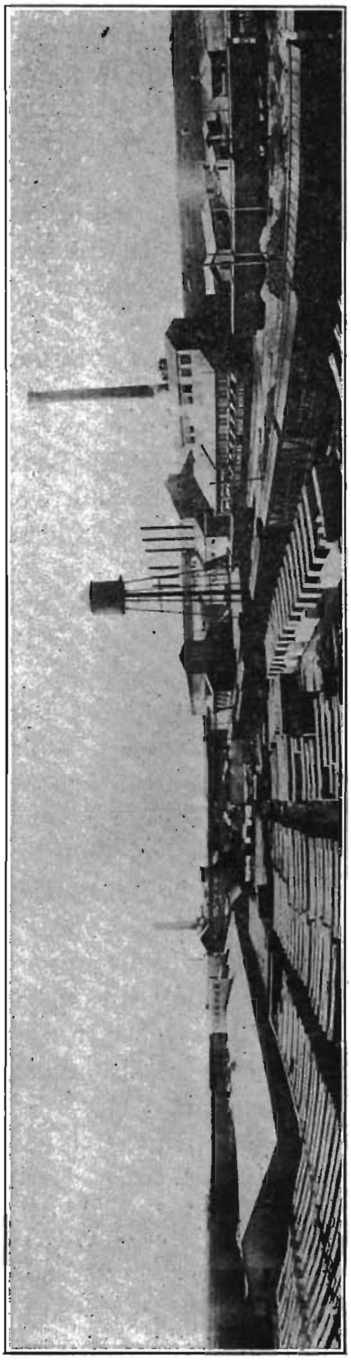

FIG. 24—Mill of the United States Gypsum Co. near Fort Dodge. Gypsum blocks stacked in the foreground. Courtesy of U. S. Gypsum Co.

their manipulation. The growth of the industry progressed steadily as is shown by statistics given in Chapter XXII. In 1882 the second mill was erected, at a point half way down Two Mile creek or "Gypsum Hollow". This mill is shown in figure 17. Three years later the Blandon mill, shown in figure 18, was erected on the river bank below Fort Dodge. The interests controlling these three mills later consolidated and formed the Iowa Plaster Association. The Duncombe was built a little later at the mouth of Two Mile creek and secured most of its gypsum from a quarry on the opposite side of the river. These four mills secured gypsum by stripping at points where the gypsum was exposed along the river and Two Mile creek.

The Blandon mill

In 1899 the Cardiff Gypsum Company sank a shaft through the glacial drift to the gypsum and erected a mill on the open prairie. Figure 19 illustrates this mill. The success of this venture led others to follow the example thus set. In 1900 the Mineral City mill

The Cardiff mill No. 30 on map Mineral City and Crawford mills

was erected, and this was followed soon after by the Crawford mill.

The United States Gypsum Company No. 31 on map

In 1902 the United States Gypsum Company was organized and took over the mills of the Iowa Plaster Association, the Blandon, the Mineral City and the Crawford mills.

The Waterloo mill

Waterloo, Iowa, capital put up the next mill, which was commonly known as the Waterloo mill. It was taken over by the United States Gypsum Company. It burned not long afterward and was not rebuilt.

The Plymouth mill, No. 32 on map

The Plymouth mill was erected about 1905 and has continued to operate as an independent mill.* A view of this mill is given in figure 20.

Iowa Hard Plaster Co. No. 33 on map

The Iowa Hard Plaster Company was organized by Butler and Ryan, and built a mill which was later sold to the American Cement Plaster Company. Figure 21 shows how modern this mill is at the present time.

Acme Cement Plaster Co.

Mr. Ward built the next mill which he soon sold to the Acme Cement Plaster Company. Several years later this mill burned and was not rebuilt.

The Wasem mill No. 34 on map

The Wasem Plaster Company was organized about ten years ago and has been a steady producer since that time. Its first mill was burned in 1918, and another more nearly fire proof structure was erected as promptly as possible on the same site. The present mill is shown in figure 22.

Iowana Company No. 35 on map

In 1920 the mill of the Iowana Company was begun and was completed during the following year. This mill and the Plymouth mill obtain their gypsum from a drift mine on the west side of the river, the rock being transported by overhead tram. A view of the Iowana mill is shown in figure 23. The Iowana mill uses the method of making plastic gypsum which is discussed on page 176 and in Appendix VII.*

The older mills taken over by the United States Gypsum Company were later dismantled and activities were concentrated at the Mineral City plant which was enlarged till it became one of the largest in the United States. A view of this mill is shown in figure 24.

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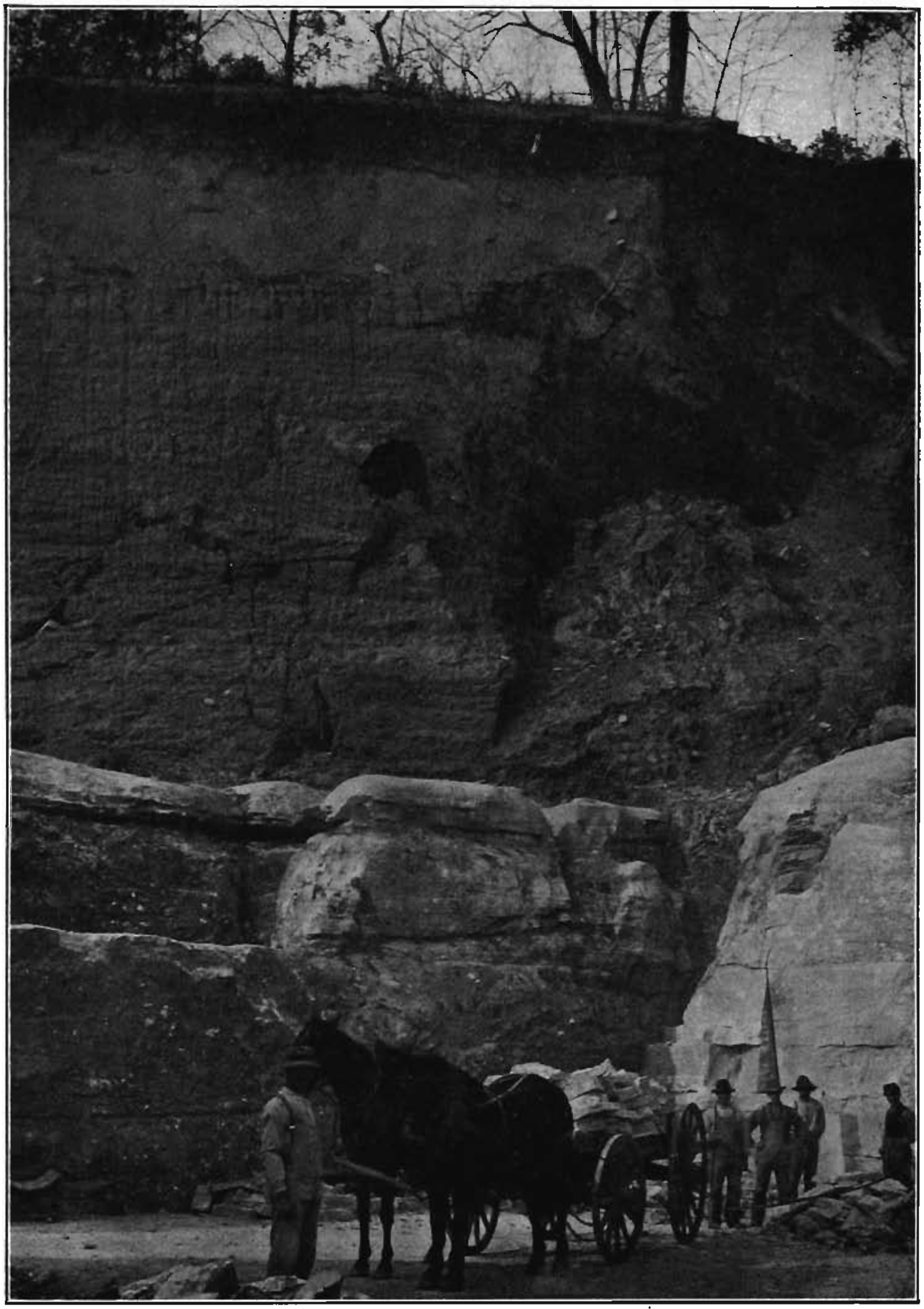
* Since this text was written the Plymouth and Iowana mills have been taken over by the Universal Gyspum Company, a corporation organized for the purpose of operating mills in all the more important gypsum centers.



Quarry that furnished gypsum for the lower mill of the Iowa Plaster Co. in Gypsum Hollow, as it appeared in 1902. The overburden is glacial drift. Note the solution channels and the bedding and jointing, which aid in quarrying and mining.

At present the following companies have each one mill in operation. They are listed in the order in which they began operations in the Fort Dodge field:

Cardiff Gypsum Plaster Company.
United States Gypsum Company.
Plymouth Gypsum Company.*
American Cement Plaster Company.
Wasem Plaster Company.
Iowana Plaster Company.*

HISTORY OF CENTERVILLE GYPSUM FIELD

In 1910 the Scandinavian Coal Company discovered gypsum in the course of prospecting which it undertook near the town of Centerville in Appanoose county. Additional drilling proved the presence of gypsum in the region in commercial quantities and in July, 1912, a shaft was started. This shaft was completed in September of the following year. Considerable quantities of water were encountered in the shaft and no further work was done till 1917. At that time the water was cut off successfully and a two kettle mill was erected, and is now in operation. The mill is illustrated in figure 25.

FIG. 25.—Mill of Centerville Gypsum Co., Centerville, Iowa. Courtesy of Centerville Gypsum Co.

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* Taken over by the Universal Gypsum Company in 1922.

CHAPTER VII

PHYSICAL AND CHEMICAL CHARACTERISTICS OF IOWA GYPSUM

THE FORT DODGE BEDS

Bedding

The Fort Dodge gypsum is distinctly bedded, the layers ranging from two inches to a foot in thickness and separated by traces of clay. The easy parting along bedding planes is a distinct advantage in mining Fort Dodge gypsum. The nature of this bedding is distinctly shown in Plate VII and in figure 26, which shows a mine interior, and also in figure 27, a view of a house in Fort Dodge which was built of gypsum. Several gypsum buildings are still standing in the "Mineral City". The Fort Dodge gypsum bed, taken from top to bottom, has certain well defined characteristics,

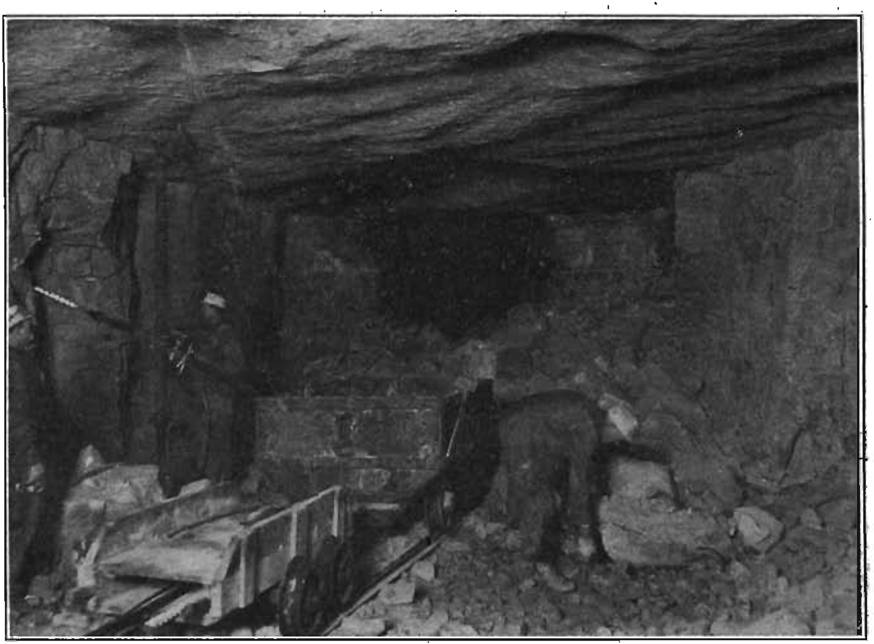


FIG. 26.—Room in the mine of the American Cement Plaster Co. at Fort Dodge. Courtesy of the Beaver Board Co.

"Ledges"

and as a result the face of the quarry or mine is divided into "ledges" by the miner. The group of layers making a "ledge" may be recognized in mines separated by

FIG. 27.—A house in Fort Dodge, built of gypsum. Photo by Lees.

a considerable distance. The following subdivisions are commonly recognized in the Fort Dodge area.

		FEET
5.	Upper rock, varying in thickness on account of differences in loss due to erosion and solution	3–12
4.	Six foot ledge	6
3.	Hard ledge	4
2.	Eighteen inch ledge	1½
1.	Bottom ledge	5

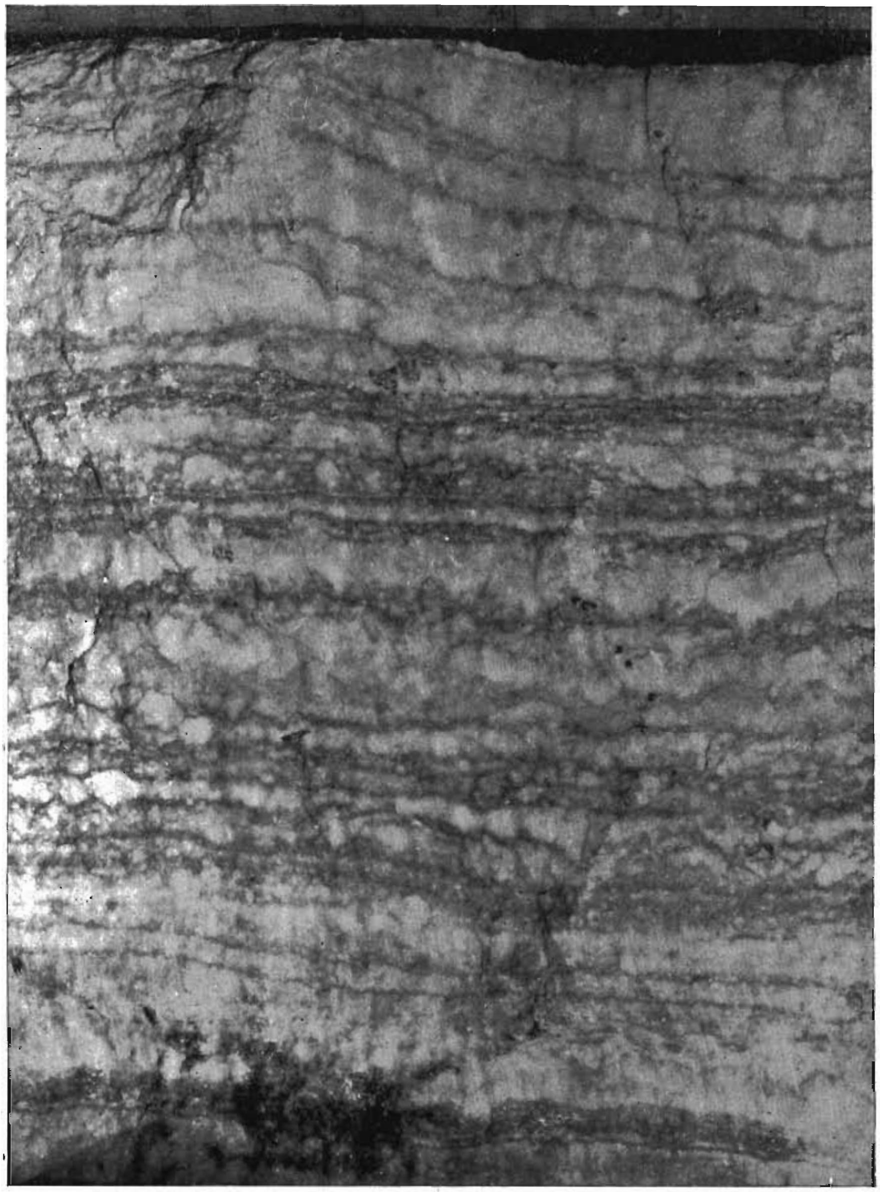
Lamination

Lamination lines are suggested by streaks with a green-gray tinge which parallel the bedding. These alternate with white lines. The structure is shown in Plate VIII. The material in each one of these bands seems to have crystallized at one time and each band represents a period of some sort. Their average thickness is about one-third of an inch and if they represent annual deposits, the interval required to deposit the gypsum can be simply and quite accurately determined. A foot of gypsum would represent thirty-six to forty years and assuming thirty feet for the original thickness of the beds, 1200 years would suffice for their accumulation. It is quite probable that rapid deposition took place during the hot dry summer period, when the mineral in solution was concentrated due to evaporation and to limited flow into the basin. During the winter, with conditions reversed, crystallization doubtless stopped, and the water became slightly clouded with earthy matter so that the first deposit of the summer was slightly gray in color.

Expansion peculiarities

Many observers have wondered at a peculiar phenomenon in connection with the top layer of the gypsum exposures where the mineral has been stripped and subjected to heat and rain for some time. Such conditions occur at a number of points along Two Mile creek, better known as Gypsum Hollow. Some of the upper layers of gypsum have been arched up till small circular or elliptical domes are formed. The walls of these domes are six or seven inches in thickness. See figure 28 for an illustration of this phenomenon.

FIG. 28.—A dome in Fort Dodge gypsum. The top of the dome, which appears in the foreground, has been broken. Photo by Lees.



Fort Dodge gypsum showing its banded structure.

As the Fort Dodge gypsum contains no anhydrite it is not possible to explain the expansion by assuming that the mineral has taken on additional water. The explanation probably lies in the fact that the gypsum is slightly pervious and hence mineral dissolved in rain water is carried into the body of the rock and crystallizes out around already existing crystals, increasing their size, with the resultant expansion and doming of the layers.

Cause of domes

The conditions for these processes have been particularly favorable since the old quarries were stripped and then abandoned, but might have taken place at any time in the past when the gypsum was not protected by overlying impervious beds.

Lees has photographed and described the exceedingly irregular solution surface of the gypsum which may be seen from time to time in the Vincent clay pit, as follows (see also figure 29):

Solution surfaces

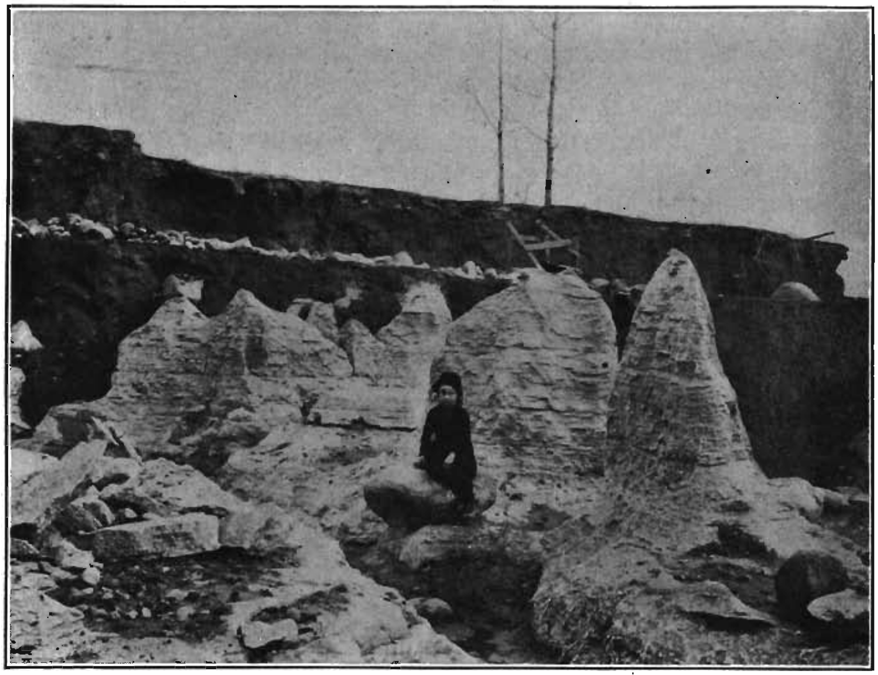


FIG. 29.—Pinnacles, resulting from solution of gypsum, exposed by hydraulic stripping, Vincent Clay pit. Photo by Lees.

"The overburden of drift at the Vincent clay pit is removed by hydraulicking. The gypsum, which here has a maximum thickness of about seven feet, is then broken up and removed. In the fall of 1917, quite a large area had been cleared of drift and a remarkably irregular surface of the gypsum was revealed. From its nature it is evident that the irregularity was caused by aqueous solution or erosion rather than by ice erosion. Sinuous winding channels have been cut almost through the gypsum bed as the accompanying views show. What was apparently a larger channel extended almost the entire length of the stripping. Pinnacles and towers and walls of fantastic design have been carved in the solid rock and a most picturesque miniature topography has been formed. Potholes or pothole-like cavities have been dissolved out where we may imagine that the tiny torrents dashed and swirled or the slowly percolating waters of a bygone day seeped among the rocks and clays that formed the surface of that time.

"There is little evidence to show the age of this solution surface. In some places gray drift fills the hollows in the gypsum while yellow oxidized till extends across hollows and eminences alike, without curving down at any point. In one place an oxidized band bends up over the gypsum mound. There is no indication of slumping or settling of drift into the hollows as the gypsum was dissolved away. If all of the drift here is Wisconsin, as it seems to be, its condition and position would seem to indicate that the solution was accomplished mostly in pre-Wisconsin (Peorian) time at least, and it might, of course, be earlier than that. The illustrations show that the pebble band and the humus zone extend, for the most part, in uniformly straight lines parallel with the surface of the ground. The fact that this locality is on the upper slope of the valley wall makes escape of the ground water easy and would permit of relatively rapid passage of these waters through and over the rock. This condition might point to a more recent date for the formation of this surface. At the same time similar topographic conditions have prevailed since the valley was formed in post-Kansan (Yarmouth) time so that similar opportunities for solution have been offered for a long period of time."

The ice could never have overridden these soft and tender pinnacles without obliterating them. As the material filling the crevices is normal drift it cannot be said that outwash material filled the irregularities, and that the ice subsequently rode over the gypsum pinnacles which were packed, as it were, and protected from breakage. There seems to be only one explanation, and that is solution in post-Wisconsin time. The Wisconsin ice probably removed the overlying shale that protected the gypsum from solution, and may have scoured away more or less of the gypsum. The oxidation of the yellow till which Lees speaks of as often extending over hollows and eminences in the gypsum alike, must be subsequent to the formation of these solution phenomena. The pebble bands and humus zone also, which run for the most part in uniform straight lines parallel with the surface of the ground, are developments more recent than the solution channels, but may easily have been developed within very recent times.

The Fort Dodge gypsum is remarkably pure calcium sulphate with water of crystallization ($CaSO_4\ 2H_2O$). At the base of the gypsum there are six inches of quite impure mineral. The rest of the bed is quite uniform and of a consistently high quality. The earlier analyses by Patrick made a distinction between the upper part of the bed and the lower five feet. These analyses indicated for the upper part of the bed, a mineral almost chemically pure.

Chemical composition

The analyses of the lower part of the bed, while showing that it was inferior to the upper part, nevertheless showed it to be purer than most of the commercial gypsum of the country. They are given below.

Earlier analyses

	UPPER LAYER[143]	LOWER LAYER[144]
Calcium sulphate	78.44	76.28
Water of crystallization, calculated	20.76	20.72
Insoluble matter	.65	2.92
	99.85	99.92

The absence of calcium carbonate in these analyses as well as in analyses made by other investigators in various fields, raised the question as to whether gypsum could be deposited from sea water, without some measurable amount of calcium carbonate being deposited with it. A negative conclusion was reached by Stieglitz, whose work in this connection is briefly reviewed in Chapter III.

Analyses of Fort Dodge gypsum made for this report at

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[143] Analysis by G. E. Patrick, Iowa Geol. Survey, Vol. II, p. 291.

[144] Analysis by J. B. Weems, Iowa Geol. Survey, Vol. XII, p. 110.

Recent analyses

the chemical laboratories of the State University of Iowa, and given below, show easily measurable quantities of calcium carbonate (limestone) and it is quite probable that in other cases a thorough search for the carbonate will result in its discovery.

STATE UNIVERSITY OF IOWA
DEPARTMENT OF CHEMISTRY
ANALYSES OF GYPSUM FROM FORT DODGE[145]

(I) *PLYMOUTH GYPSUM COMPANY*

	PER CENT	CALCULATIONS	PER CENT
Calcium oxide	31.24	Gypsum	92.91
Sulphur trioxide	43.21	Limestone	1.77
Water	19.42	Silica	2.23
Iron and alumina	3.25	Iron and alumina	3.25
Silica	2.23		
Carbon dioxide	.78		100.16
	100.13	Calcium sulphate, anhydrous	73.47

(II) *AMERICAN CEMENT PLASTER COMPANY*

	PER CENT	CALCULATIONS	PER CENT
Calcium oxide	31.90		
Sulphur trioxide	44.95	Gypsum	96.65
Water	20.06	Limestone	0.70
Iron and alumina	1.55	Silica	1.28
Silica	1.28	Iron and alumina	1.55
Carbon dioxide	.31		
			100.18
	100.05	Calcium sulphate, anhydrous	76.43

Another sample collected near Fort Dodge by Doctor Lees and analyzed by Marquis and Jennings gave:

	ANALYSIS "A" PER CENT	ANALYSIS "B" PER CENT	ANALYST
SiO_2	1.81	1.70	Marquis
Al_2O_3 Fe_2O_3	.85	.90	Marquis
CO_2	.55	.59	Jennings
CaO	32.42	32.14	Jennings
MgO	--------	--------	
Total H_2O	19.94	20.04	Jennings
SO_3	44.73	44.77	Jennings
	100.30	100.14	

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[145] Samples collected by Doctor Lees from the working faces of the mine, in such manner as to secure an average sample for the working face.

THE CENTERVILLE GYPSUM

PHYSICAL PROPERTIES

Color and partings

The Centerville gypsum is white, free from the colored bandings so characteristic at Fort Dodge, and lacks partings and bedding planes.

Texture

In texture it varies from coarse crystalline to fine granular. Portions of it are saccharoidal and distinctly friable.

Associations

It is, in places, closely associated with anhydrite and the appearance of the mass in such cases is somewhat mottled, due to the light blue color of the anhydrite which is surrounded by the whiter gypsum. Considerable bodies of the gypsum will doubtless be found that are entirely free from anhydrite, and it is quite likely that it will prove practical on a commercial scale to separate the gypsum from the anhydrite, and to use each grade of mineral for purposes for which it is adapted. A view of the mine face is shown in figure 30.

FIG. 30.—A view in the mine of the Centerville Gypsum Co. Courtesy of Centerville Gypsum Co.

CHEMICAL COMPOSITION

With the exception of a few inches near the bottom of the bed the Centerville gypsum, where free from anhydrite, is remarkably pure. The following analyses are by Jennings:

	ANALYSIS 1 PER CENT	ANALYSIS 2 PER CENT
CO_2	.76	.79
SO_3	45.92	45.80
Al_2O_3 Fe_2O_3	.28	.26
CaO	32.11	32.42
MgO	.18	.17
Total H_2O	20.06	20.02
	99.31	99.46

Analyses[146] of a sample which from the variation in its hardness and color was easily recognized as a mixture of gypsum and anhydrite gave the following:

	ANALYSIS 1 PER CENT	ANALYSIS 2 PER CENT
CO_2	1.76	1.69
SO_3	52.60	52.54
SiO_2	traces	traces
Al_2O_3 Fe_2O_3	.62	.61
CaO	36.32	36.70
MgO	2.09	2.12
Total H_2O	5.61	5.58

A sample which had the typical glassy luster of pure anhydrite, as well as the fine grain and light blue color, nevertheless on chemical analysis was found to contain over 3 per cent of water of crystallization. Probably small quantities of gypsum will be found in all of the Centerville anhydrite.

Analyses made under the direction of Prof. S. W. Beyer of the Iowa State College gave the following results[147]:

	GYPSUM		ANHYDRITE		
	1	2	1	2	3
Sulphur trioxide (SO_3)	46.56	45.65	54.12	55.29	54.45
Lime (CaO)	33.37	32.76	40.20	40.67	39.58
Loss on ignition	20.03	20.75	6.62	4.66	5.13
	99.96	99.16	100.94	100.62	98.16

Caves

An interesting development at Centerville was the discovery of a cave in the gypsum. This opening, which is, of course, an old water channel, is twenty feet wide, fifty feet long and seven feet high.

It was, when found, lined with beautiful crystals of selenite, some of them of unusual size. These are well illustrated by Plate II, p. 69.

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[146] By Jennings.

[147] U. S. Geol. Survey Bull. 580-E, p. 64. Also Iowa Geol. Survey, Ann. Rept., Vol. XXI, p. 24.

CHAPTER VIII

TECHNOLOGY OF GYPSUM AND GYPSUM PLASTERS

Winning of gypsite

The loose, granular, and somewhat impure form of gypsum known as gypsite, commonly lies on or near the surface and is placed in the mill by simple methods. The material may be excavated with shovels, either hand or steam, or with wheel scrapers. No explosives are necessary, and as a rule deposits that require much stripping are not worked. The gypsite is loaded directly into cars, carts or wagons, which are dumped into proper mechanical appliances for delivering it to the kettle bins or to a dryer.

Quarrying gypsum

A considerable percentage of the gypsum of commerce is taken from quarries. Twenty years ago very little gypsum was mined, as there were ample exposures, generally along rivers and creeks, with a relatively small amount of overburden. This was true in the Grand Rapids and Fort Dodge fields, and is still true in the Alabaster, Michigan, field and at many points in the west. As the work progressed, however, and the quarry faces receded into the upland, the stripping became more and more arduous, and quarrying gave place to mining.

Drilling, hand

Drilling in quarries may be carried on by hand and by steam, compressed air, and electricity. The softness of the mineral favors hand drilling, and up to ten years ago this was the method commonly employed. After stripping, churn drill holes were sunk to a depth in keeping with the face of the quarry and the breaking properties of the gypsum, and these holes, after being loaded, were discharged by fuse or battery.

Drilling, steam and air

Any of the numerous machines designed for drilling vertical holes may be used in a gypsum quarry. At least twice the footage per hour may be obtained in gypsum that is secured in limestone with the same equipment.

Explosives

Both dynamite and black powder are used in quarrying and mining gypsum. When dynamite is used, a low nitro is preferred for the conditions that generally prevail.

For underground work the room and pillar method is generally employed. This system is used in the Iowa fields, at Grand Rapids, Michigan, Oakfield, New York, and in general at all points where the beds are of moderate thickness and pitch. In the Virginia field stoping methods are employed. Figure 31 shows a typical room in a Fort Dodge mine. The pronounced bedding and jointing of the Fort Dodge gypsum greatly aids in the breaking of the mineral, and the amount of mineral won per unit of explosive compares favorably with that of any mining field in the country. In the Oakfield, New York, district the gypsum is keyed in by irregularities in roof and floor and breaking is somewhat difficult in consequence. The texture of the rock differs in different mines, and in some cases differs in different rooms in the same mine. The amount and kind of explosive that give the best results will depend in some measure on the texture of the mineral.

Mining methods

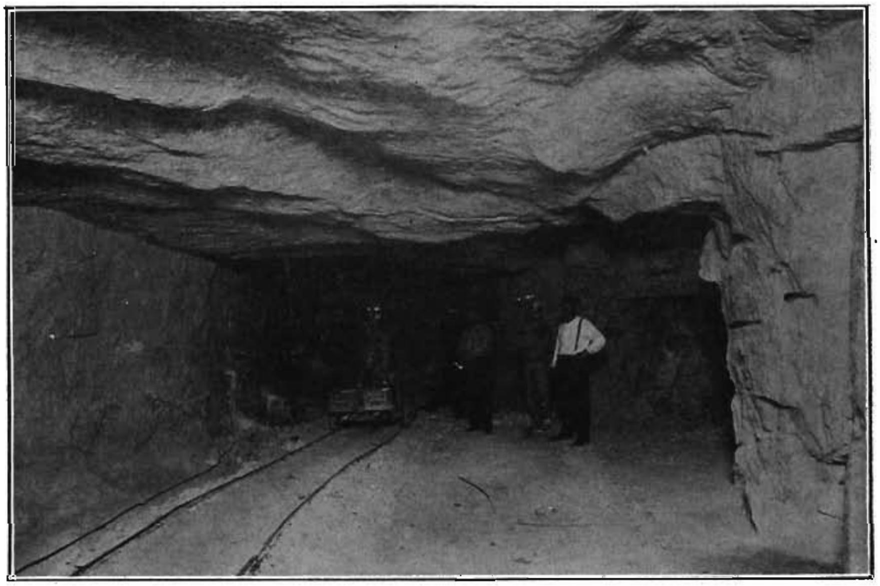


FIG. 31.—A portion of the mine of the Plymouth Gypsum Co. Courtesy of Plymouth Gypsum Co.

Gypsum generally makes a good mine roof. Its crushing strength is fairly high, as has been shown in Chapter I, and the proper relationship between room and pillars may be easily determined by estimating the overburden. If the surface is not too valuable, it is customary to rob the roof and pillars after the manner common in coal mines.

The great solubility of gypsum renders mud seams and water courses even more common than in limestone and in the Fort Dodge field these mud seams present the only unfavorable mining feature.

The amount of water encountered in the Fort Dodge mines is moderate. In the shaft of the Centerville mine a considerable flow was encountered when the shaft was sunk, coming from the limestone that lies just above the gypsum. This was successfully cut off, however, and no serious trouble from water has since been encountered.

Crushing

The gypsum after coming from the mine passes directly to the crusher. In some mills it goes through "grizzlies" on the way to the crusher. These consist of a series of bars which permit the finer material that does not need crushing to fall through. The fines pass directly by spiral or belt conveyor to bins for pulverizing. The lump going over the grizzly falls into the crusher which is usually either a jaw crusher, a gyratory or a large cone crusher. In one mill large rolls of the Edison type are used, and are reported as operating successfully. A common type of crusher is shown in figure 32.

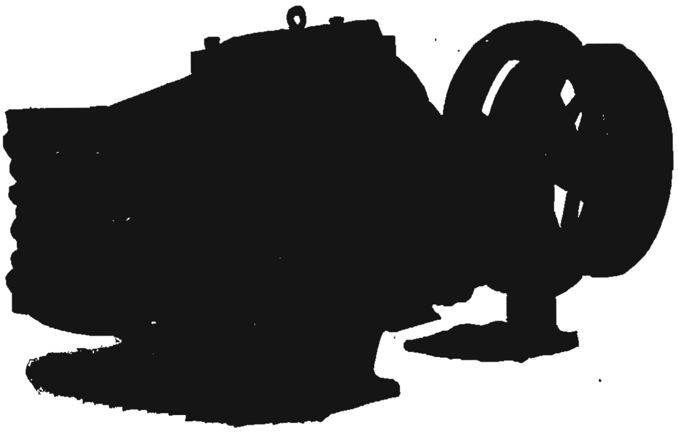


FIG. 32.—Jaw crusher of the type often used in gypsum mills. Courtesy of the Ehrsam Mfg. Co.

The criticism usually passed on both gyratories and rolls in connection with the crushing of gypsum grows out of the tendency of the mineral to "gum up", that is, to adhere to the metal at the points where the pressure is applied. If the gyratory or the rolls are sufficiently large, however, this criticism has no great weight.

As a rule only one coarse crusher is installed and this machine has capacity to meet the output demanded of the mill. Some crushers have a capacity of fifty or more tons an hour while in the smaller mills a machine that will reduce twenty tons in an hour is ample. From the coarse crusher it is a common and a desirable practice to pass the material over or through magnetized surfaces, to take out iron in the form of mine spikes, wedges and other mining tools, which

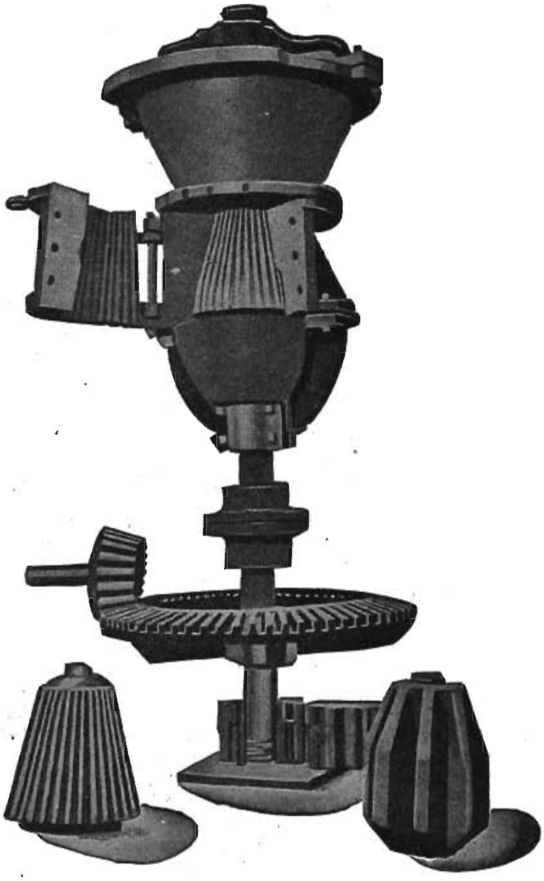


FIG. 33.—Cone crusher or cracker which is commonly used in gypsum mills to further reduce the product coming from the jaw crusher. Courtesy of New York Geological Survey.

are often shoveled into the mine cars with the finer gypsum and make serious trouble if they reach the "nipper" or "cracker," as the fine crusher is called. In a few mills where very large gyratory, or cone crushers are used, the crushing is completed in a single operation.

The fine crusher is in the essentials of its construction like an immense coffee mill. Its capacity is usually equal to that of the coarse crusher whose operation it follows. Within a corrugated shell made in the form of two funnels, the lower one inverted and bolted to the upper, are two corrugated cones, the upper one coarse, and the lower one reversed in position with fine corrugations to match those on the sides of the inverted funnel-like shell within which it revolves. The nipper, or cracker, as the crusher is called, may be driven from above or below by bevel gear. There are a number of advantages in the upper drive, the main one being the fact that the gears are out of the way of the dust that commonly leaks through the nipper, at times in considerable quantities. Figure 33 shows a common form of cracker. The gypsum on leaving the cracker is of walnut size or smaller. The material fed to the cracker from the crusher varies in size with the size of the installation, the large jaw crushers allowing fragments six or eight inches in diameter to fall through. These are easily crushed in the nipper, which must, of course, correspond in size with the crusher.

Drying

In many mills it is customary to pass the gypsum through a dryer before attempting to pulverize it. The need of a dryer depends largely on the amount of pore filling or hygroscopic water that is present in the gypsum. If the mineral contains much free moisture the cost of fine grinding is greatly increased on account of the large amount of power required and the reduction in the capacity of the machine. Most of the heat given to the gypsum in the dryer is retained till the mineral reaches the kettles and shortens the time required for calcining. The contraction of the kettle bottom is reduced also by charging it with warm dry material. Several dryers on the market are suitable for use with gypsum which does not present any special peculiarities in connection with the drying problem except that of the dust. Gypsum dust from the dryer represents a considerable waste if it is not saved.

For fine grinding a variety of methods are used. In some plants gypsum from the nipper or dryer passes directly to burr mills. The burrs may be of American or imported stone. Grinding on burr mills produces rounded particles, which is desirable as compared with angular fragments produced by certain types of disintegrators. The low first cost of the burr mill is in its favor, but its upkeep is expensive as the stones must be dressed often by skilled workmen if a uniformly fine product is secured. Their power consumption is high if very fine grinding is required. Figure 34 shows one of the burr mills in the plant of the Centerville Gypsum Company.

Grinding, burr mills

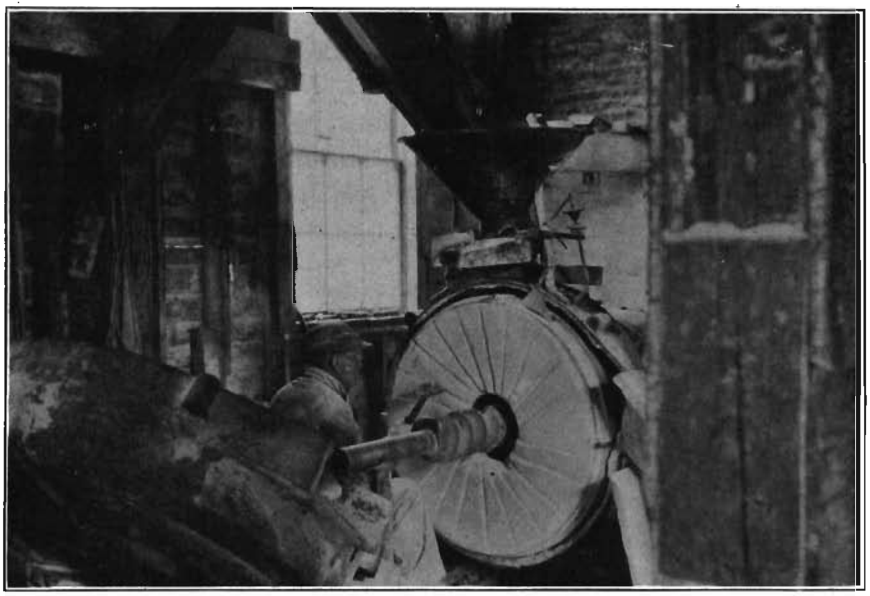


FIG. 34.—Burr mill of the type commonly used in Iowa plaster mills for fine grinding. Courtesy Centerville Gypsum Co.

A modification of the burr mill is found in the vertical and horizontal emery mills which are used to some extent in pulverizing gypsum. In these mills blocks of emery are skillfully set in a cement matrix, and on account of the superior hardness of the emery these mills require less

Horizontal emery mill

attention than those using burr stones. A sectional view of one of these emery mills is shown in figure 35.

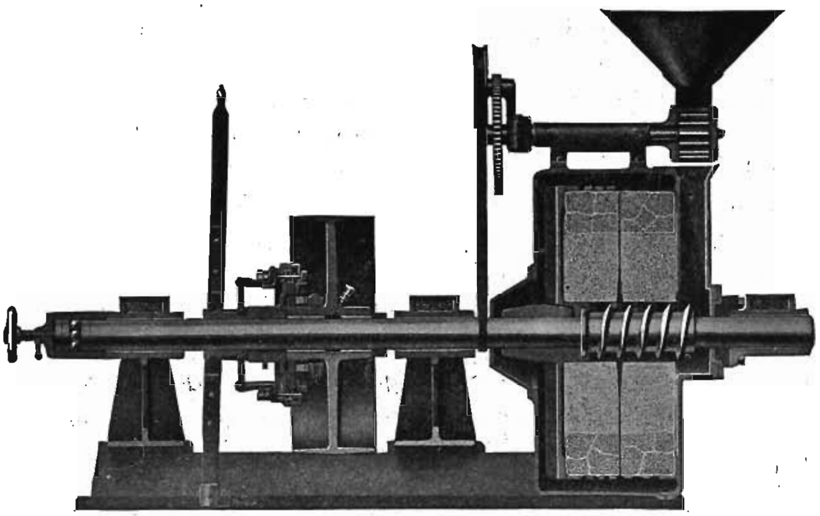


FIG. 35.—Vertical emery mill. Often used for fine grinding of calcined gypsum. Courtesy New York Geological Survey.

For some years disintegrators of various makes were used

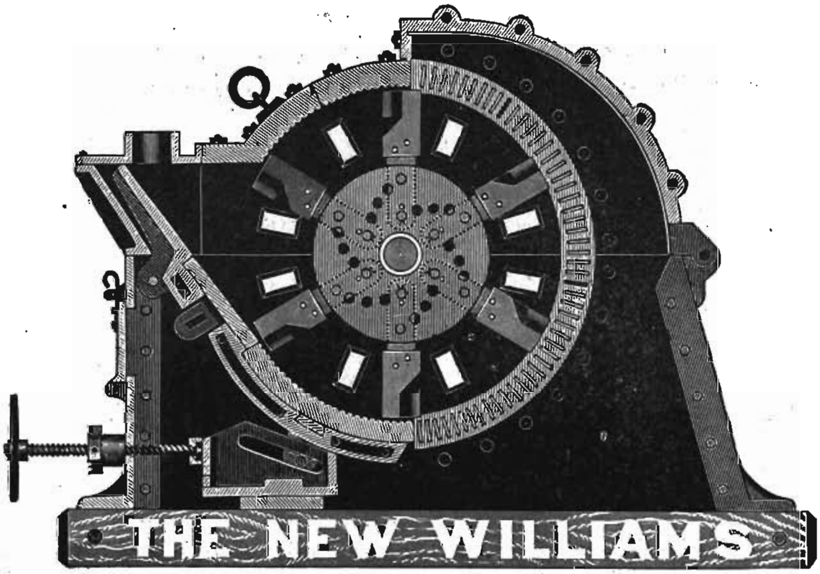


FIG. 36.—A hammer mill. Several mills of this type are on the market and they are sometimes used in gypsum mills for initial crushing and grinding. Courtesy New New York Geological Survey.

Disintegrators

with a fair degree of success. Machines of this type reduce the gypsum to a fine powder by means of rapidly revolving hammers, striking by centrifugal force. A cross section of one of these machines is shown in figure 36. The fragments produced by the disintegrator seem to be angular, and do not give the same good working qualities to the plaster that are secured by the rounded particles turned out by the old burr mills. The capacity of the disintegrator, however, is very large, the first cost is not excessive and the power required per ton of finished product is low.

Because they desire to take advantage of the good features of the disintegrator and at the same time to secure a finer product than it can deliver and one containing rounded instead of angular particles, some plaster producers pass the product of the disintegrator over screens, sending the material that passes through the screen to the kettle bins for calcination and returning the tailings to burr or emery mills for grinding.

Screens

Screens are used also where all of the grinding is done on burr or emery mills, to secure a finer product, and in this case the tailings are either returned to the mill doing the primary grinding or pass on to other burrs which grind finer than the first. Rotary screens have not proven wholly satisfactory for this purpose on account of the tendency of the gypsum to clog the perforations, and vibratory screens of some type are generally preferred.

The chart shown as Plate IX gives a typical flow sheet for a gypsum mill.

Roller mills

During the past five years roller mills have found great favor with many gypsum producers, because certain types, at least, of these machines yield a large amount of very fine material in a single operation. They are particularly advantageous if the gypsum contains any hard impurity which injures the faces of the stones in burr and emery mills. On this account, for example, roller mills of various types have found special favor in the Ohio field where in some portions of the gypsum beds chert in limited quantities is present.

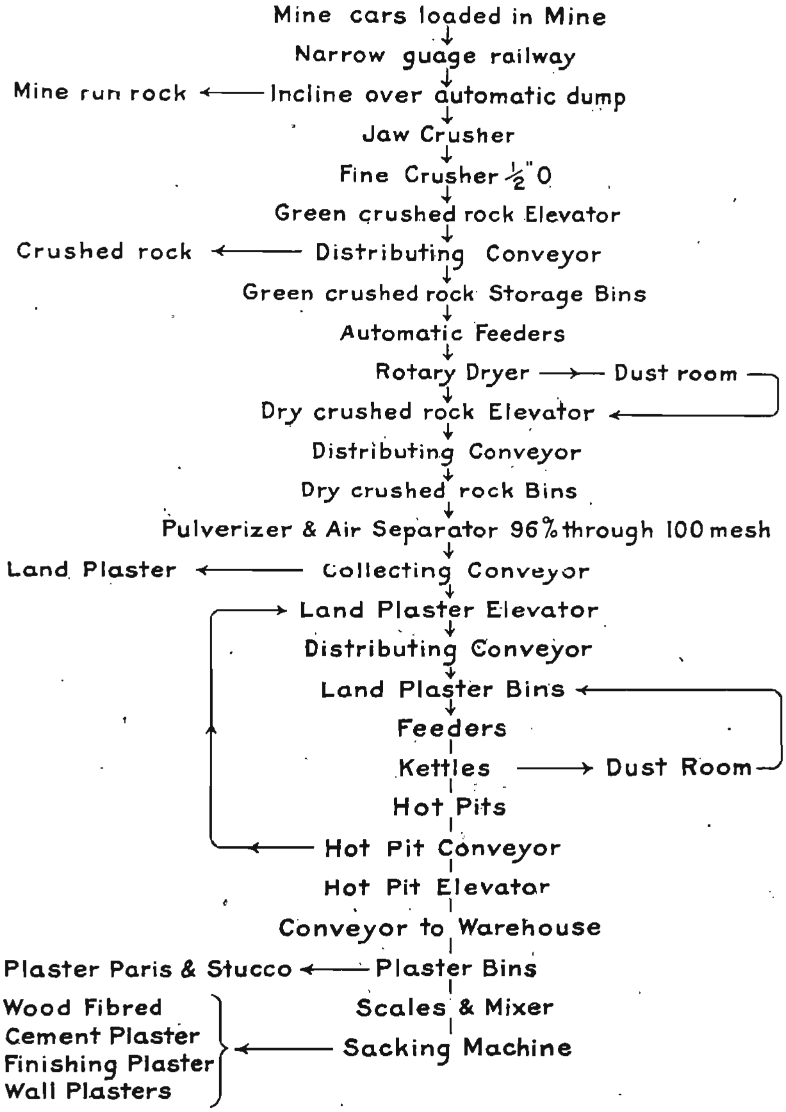
The principle in most roller mills used for grinding gypsum involves roll crushing in one way or another, with air separation. There are on the market roller mills from which the fines are taken by screens, but they are not generally acceptable for gypsum because the spaces clog too easily, whereas with air separation the large fan carries the fines readily to the collecting chambers where simple adjustments permit the operator to return to the mill for regrinding any portion that is below the standard of fineness that he has adopted.

The horsepower required for roller mill grinding in standard machines is one horse power per ton of gypsum ground each twenty-four hours, the gypsum being reduced so that 90 per cent will pass a hundred mesh screen.

Plate X shows a type of roller mill in common use for grinding gypsum. Four or five heavy rolls are suspended from a central shaft and when this shaft is rotated the rolls by centrifugal force press against a broad steel ring. The gypsum is mechanically fed to the machine and by properly arranged blades or scrapers is kept crowded against the steel ring on which the rolls press while rotating. A strong air current produced by a large fan carries away the fines to a collector where the coarser particles are separated and are returned to the mill for regrinding, while the gypsum of approved fineness passes on to the kettle bins.

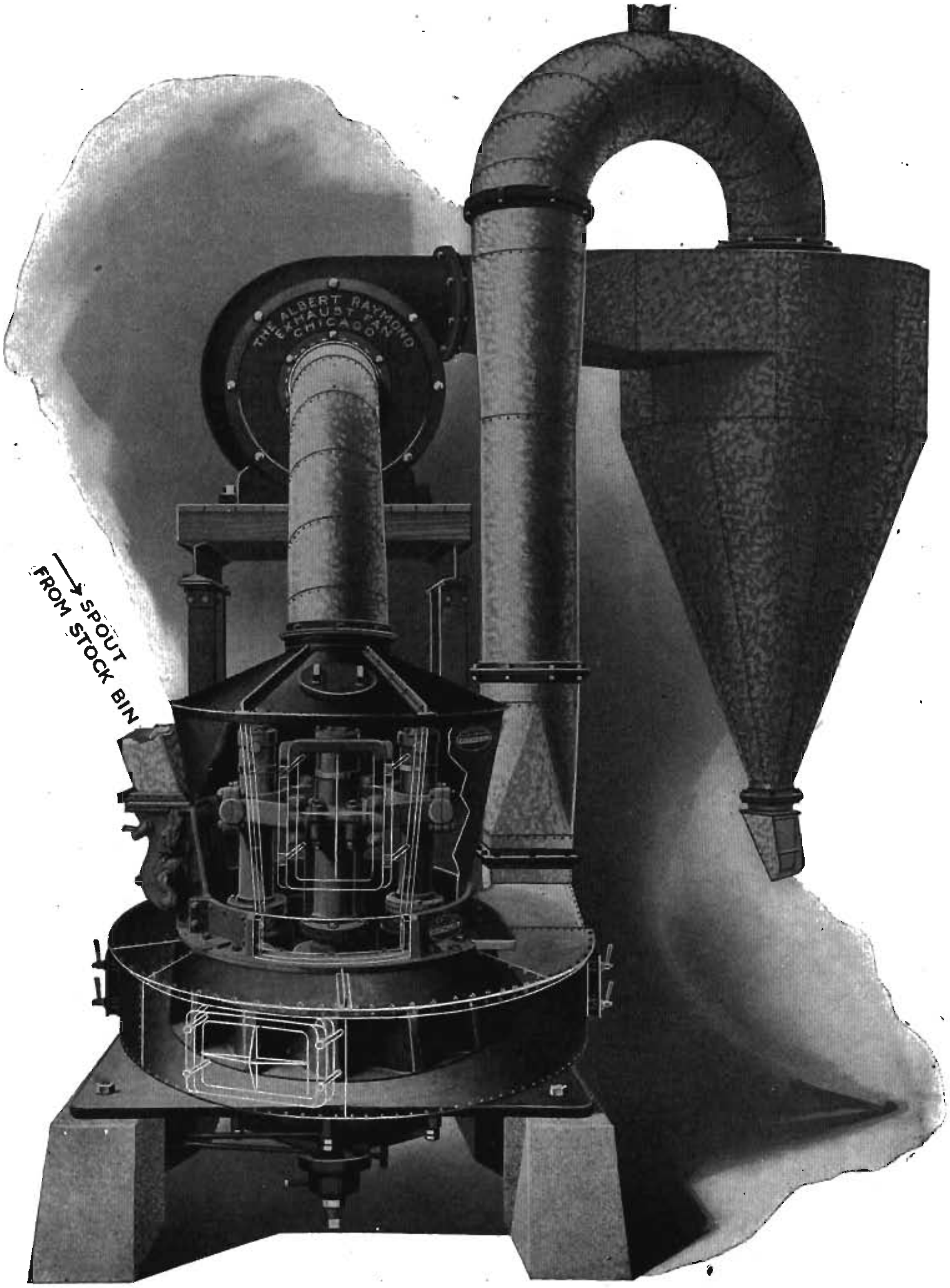
Fineness

The tendency in the gypsum industry during the past fifteen years has been toward finer grinding. This has been in response to the demand of contractors for a plaster that would carry more sand and on the part of plasterers for plaster that could be applied with the least effort. During the summer of 1918 and the fall of 1921 Fort Dodge plasters were secured on the market and tested for fineness by the Department of Engineering at Iowa State University. In the determination of fineness Tyler standard screen scales, shaken by a Tyler Ro-Tap Sieve Shaker, were used. The report on the 1918 tests follows.



Notes: Crusher capacity 30 Tons per Hour
Dryer " 40 " " "
Elevating & Conveying Machinery 45 Tons per Hour
Calcining capacity finished Mill 20 " " "
Loading capacity:
Crushed rock 30 Tons per Hour
Unfibred Goods 30 " " "
Fibred Goods 22 " " "

Flow sheet of a typical gypsum mill. Courtesy of Department of Mines, Canada.



A roller mill with air separator of the type used in many gypsum mills for fine grinding. Courtesy of Raymond Bros. Impact Pulverizer Co.

SIEVE ANALYSIS

Screen No.	Size of Mesh in inches	N		O		P	
		Per cent Retained	Per cent Passing	Per cent Retained	Per cent Passing	Per cent Retained	Per cent Passing
14	.046	0.0	100.0	0.0	100.0	0.0	100.0
20	.0328	1.0	99.0	0.0	100.0	0.0	100.0
48	.0116	7.5	92.5	1.5	98.5	5.5	94.5
65	.0082	13.0	87.0	6.0	94.0	10.5	89.5
100	.0058	24.0	76.0	20.5	79.5	23.5	76.5
150	.0041	40.0	60.0	34.0	66.0	40.5	59.5
200	.0029	51.0	49.0	50.0	50.0	51.5	48.5

Q		R		S		T	
Per cent Retained	Per cent Passing	Per cent Retained	Per cent Passing	Per cent Retained	Per cent Passing	Per cent Retained	Per cent Passing
0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
0.5	99.5	0.0	100.0	0.0	100.0	0.0	100.0
5.0	95.0	6.0	94.0	5.0	95.0	14.0	86.0
10.5	89.5	11.0	89.0	10.0	90.0	21.5	78.5
27.0	73.0	31.5	68.5	25.0	75.0	33.0	67.0
50.5	49.5	51.0	49.0	39.5	60.5	44.5	55.5
65.0	35.0	60.5	39.5	48.5	51.5	55.5	44.5

The plasters used in the tests just described were all wall plasters, as distinguished from plaster of Paris and finishing plasters, and they are more fully described below:

LABORATORY DESIGNATION	MATERIAL
N	Wood fibred plaster, Fort Dodge
O	Keene's Cement
P	Finish coat, Fort Dodge
Q	Unfibred plaster, Fort Dodge
R	Cement plaster, Fort Dodge
S	Cement plaster, Fort Dodge
T	Cement plaster, Fort Dodge

The fact that the Fort Dodge district is grinding finer today than it did fifteen years ago is shown by comparing the figures given above with those published in the Geology of Webster county in 1902.[148]

The following tests for fineness of calcined plaster were made by Prof. A. Marston in the summer of 1900, from material purchased in the market. The sieves used were calibrated by standard methods, and the terms, No. 74, No. 100 and No. 200 mesh, stand definitely for the diameters given below. The average diameters of the largest particles passing these sieves are as follows:

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[148] Iowa Geol. Survey, Vol. XII, p. 162.

No. 74 .... 0.229 millimeters = .00901 inches
No. 100 .... 0.115 millimeters = .00452 inches
No. 200 .... 0.069 millimeters = .00271 inches

KIND	PER CENT PASSING MESH		
	No. 74	No. 100	No. 200
Gypsum from Stucco Mills, Ft. Dodge, Iowa	68.3	60.0	44.0
Stucco from Ft. Dodge Plaster Co., Ft. Dodge, Iowa	71.9	66.2	49.3
Baker Stucco, Kansas	72.9	58.3	39.5
Kallolite Stucco, Cardiff Gypsum Plaster Co., Ft. Dodge, Iowa	69.1	63.8	50.2
Baker Plaster, Kansas	68.2	58.7	28.2
Mineral City Wall Plaster, Ft. Dodge, Iowa	72.1	65.4	49.1
Oklahoma Cement Plaster Co., Okarche, Oklahoma Ter.	77.8	70.2	51.3
Flint Wall Plaster, Iowa Plaster Association, Ft. Dodge, Iowa	72.4	64.2	48.1
Acme Wall Plaster, Acme, Texas	74.6	69.2	56.6
Kallolite Wall Plaster, Cardiff Gypsum Plaster Co., Ft. Dodge, Ia.	70.8	65.5	53.5
Stonewall Plaster, Ft. Dodge Plaster Co., Ft. Dodge, Iowa	72.4	66.1	54.0
Duncomb Wall Plaster, Duncomb Stucco Co., Ft. Dodge, Iowa	63.8	57.8	43.6

Another interesting series of fineness tests was made in the laboratories of the State University of Iowa in 1918, most of the samples used being the finer forms of calcined plaster. The material was milled at various points in the United States, and in the series are two samples of wall plaster from mills outside of the state.

SAMPLES. The fourteen samples on which these tests were performed were, with one exception, obtained from the manufacturers. Hereafter, reference to these samples will be made by their laboratory numbers which were as follows: A, B, C, D, E, F, G, H, I, J, K, L, M, and X.

FINENESS. In the determination of fineness Tyler standard screen scales, shaken in a Tyler Ro-Tap Sieve Shaker, were used. The sieves were placed in the machine in the order of size, the coarsest on top. Fifty grams of the material were placed on the top sieve and shaken for twenty minutes. The residues on each sieve and in the pan at the bottom were then weighed and percentages were calculated. The following table shows the percentage retained on the different sieves for each sample:

PERCENTAGES RETAINED

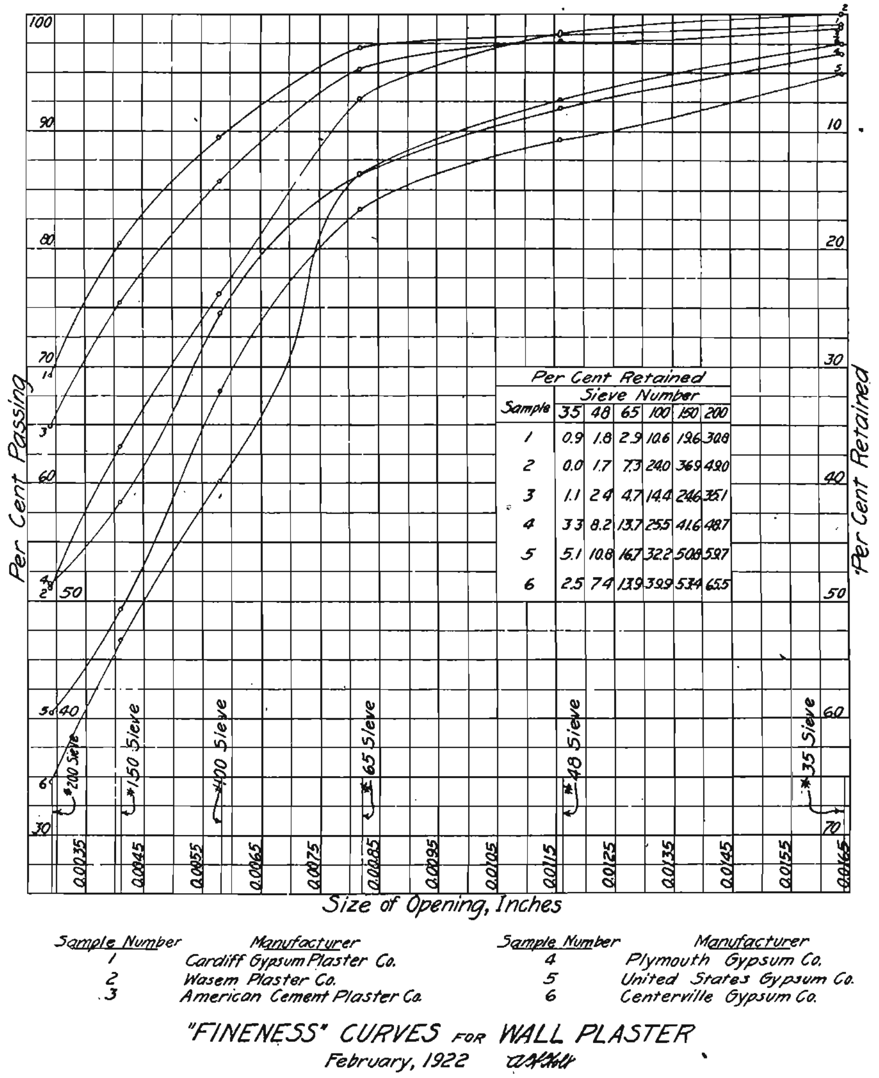
SAMPLE	SIEVE NUMBER				
	No. 48	No. 65	No. 100	No. 150	No. 200
A	2.9	2.9	8.7	16.0	14.1
B	0.2	1.9	6.3	20.7	21.1
C	0.4	0.2	1.9	18.3	25.4
D	2.5	0.8	15.4	40.1	16.3
E	0.7	0.6	5.1	26.2	26.3
F	0.5	0.2	1.1	10.0	26.7
G	4.4	3.0	7.6	7.7	10.1
H	10.0	8.1	14.1	19.1	15.7
I	1.1	2.7	11.3	14.1	12.2
J	0.2	0.2	2.4	44.5	14.2
K	0.2	0.4	4.9	38.4	13.3
L	4.7	6.3	11.5	10.0	7.8
M	4.6	3.4	9.7	21.7	9.5
X	0.1	0.5	2.0	4.4	5.5

The fourteen samples shown above may be described as follows:

LABORATORY NUMBER	DESCRIPTION
A	Plaster of Paris, Fort Dodge, Iowa
B	Structolite, Fort Dodge, Iowa
C	Moulding plaster, Blue Rapids, Kansas
D	Moulding plaster, Blue Rapids, Kansas
E	Moulding plaster, Southard, Oklahoma
F	Moulding plaster, Southard, Oklahoma
G	Wall plaster, Grand Rapids, Michigan
H	Wall plaster, Grand Rapids, Michigan
I	Stucco, Fort Dodge, Iowa
J	Moulding plaster, Fort Dodge, Iowa
K	Dental plaster, Fort Dodge, Iowa
L	Plaster of Paris, Fort Dodge, Iowa
M	Plaster of Paris, Fort Dodge, Iowa
X	Dental plaster, bought of local dealer at Iowa City

Fineness tests of 1922

In the autumn of 1921 another series of samples of wall plasters was collected by Mr. A. H. Holt of the Department of Civil Engineering of the State University of Iowa and was tested for fineness in order to secure the latest information regarding presentday practice in grinding gypsum. The data gained from these sieve analyses are incorporated in the following chart, figure 37. Each curve on the chart represents the results of three to six separate tests on each sample. Tests were continued until results seemed to make it a warranted conclusion that the curve to be plotted would fairly represent the sample.



Per Cent Retained						
	Sieve Number					
Sample	35	48	65	100	150	200
1	0.9	1.8	2.9	10.6	19.6	30.8
2	0.0	1.7	7.3	24.0	36.9	49.0
3	1.1	2.4	4.7	14.4	24.6	35.1
4	3.3	8.2	13.7	25.5	41.6	48.7
5	5.1	10.8	16.7	32.2	50.8	59.7
6	2.5	7.4	13.9	39.9	53.4	65.5

Sample Number	Manufacturer	Sample Number	Manufacturer
1	Cardiff Gypsum Plaster Co.	4	Plymouth Gypsum Co.
2	Wasem Plaster Co.	5	United States Gypsum Co.
3	American Cement Plaster Co.	6	Centerville Gypsum Co.

"FINENESS" CURVES FOR WALL PLASTER
February, 1922

FIG. 37.—Curves illustrating fineness of grinding of Iowa plaster. Prepared by Dept. of Engineering, State University of Iowa.

Plasticity and fineness

In a general way and within certain limits, the plasticity of plaster, one of its most important characteristics, is increased by fine grinding. The speed of set is also somewhat increased, and rather strikingly so if the fine grinding is done after calcining, as is the custom where certain types of rotary calciners are used. The following figure by Winterbottom,[149] figure 38, shows curves that record the setting time and rise in temperature of four sets of samples two samples in each set, one ground to pass a sixty mesh screen and the other to pass a hundred mesh screen. All of the samples were ground after calcining.

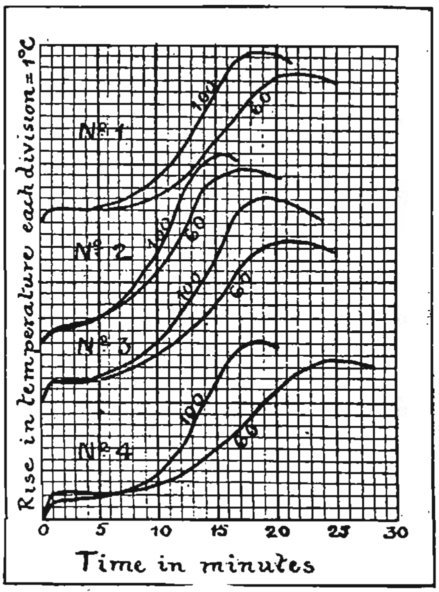


FIG. 38.—Effect of fine grinding on speed of set as shown by rise in temperature. The diagram illustrates four samples each ground after calcining to pass 60 mesh and 100 mesh screen. After Winterbottom.

Calcining

Calcining is the process of partly or completely dehydrating gypsum by heat. In chapter XII the nature of the products resulting from calcining gypsum at various temperatures is considered at some length. Two distinct groups of calcined gypsum products are recognized in the arts. The first and more important group consists of gypsum that has been calcined at temperatures not exceeding 400° F. The second group includes gypsum products resulting from calcination at high temperatures, that is from 1652° to 2552° F. (900-1400° C.).[150]

Most of the plaster of Paris and wall plaster made in America

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[149] Gypsum and Plaster of Paris, Bulletin No. 7 Dept. of Chemistry South Australia, 1917.

[150] See Chapter XII for high temperature calciners.

is calcined in especially constructed vertical cylinders called in the trade "kettles". Continuous rotary calciners are used in three or four American mills and are used to some extent in other countries. Kilns and ovens of unusual design are employed to produce special kinds of plaster of Paris in Germany, France and England.[151]

Kettle calcining

Most American gypsum mills calcine in kettles holding eight, ten, twelve or fifteen tons, those of ten tons capacity being most common. The kettle consists of a steel shell cylindrical in shape, eight or ten feet high and with the bottom arching up from six to twelve inches. The shell is made of steel from three-eighths to six-eighths inch thick and the bottom may be either cast iron or steel and varies in thickness from one inch to three inches. In some instances sectional bottoms of six pieces are used. A kettle shell and section of such a bottom are shown in figure 39.

FIG. 39.—Calcining kettle with stirrer, and portions of sectional bottom and lip ring. Courtesy New York Geological Survey.

Four flues are commonly present in each kettle, and they may

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[151] For description and illustrations of many of these kilns see "Der Gips" by V. Waldegg

be placed about eighteen inches from the bottom as shown in figure 39 or one pair may be so placed and the other pair twelve or fourteen inches above them, as shown in figures 40 and 41. The kettle shell is enclosed with fire brick leaving

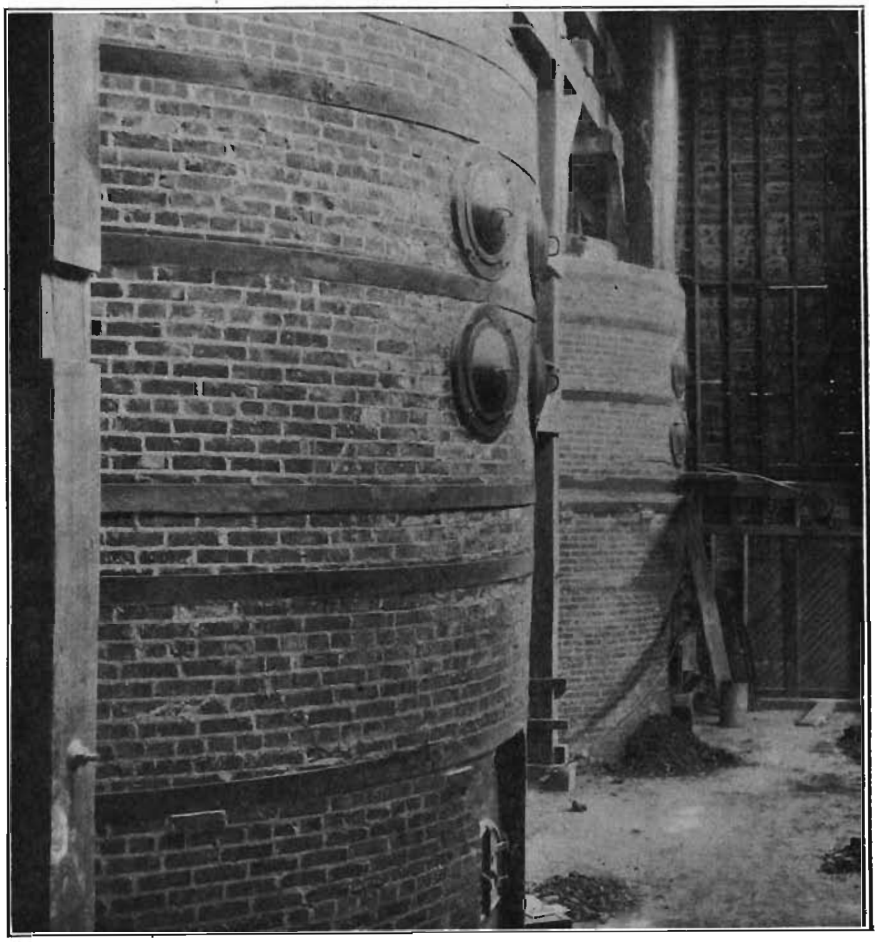

FIG. 40.—Exterior of calcining kettle showing the banded brick jacket and clean-out ports opposite flues. Courtesy Centerville Gypsum Co.

a space of six to fourteen inches between the brick and the shell itself. The kettle rests on a heavy cast "lip ring" a section of which is shown in figure 39. The lip ring is carefully protected by fire brick from direct exposure to the heat of the fire box. There is a space of four to seven feet between the grates and the fire box, and the whole design of the kettle

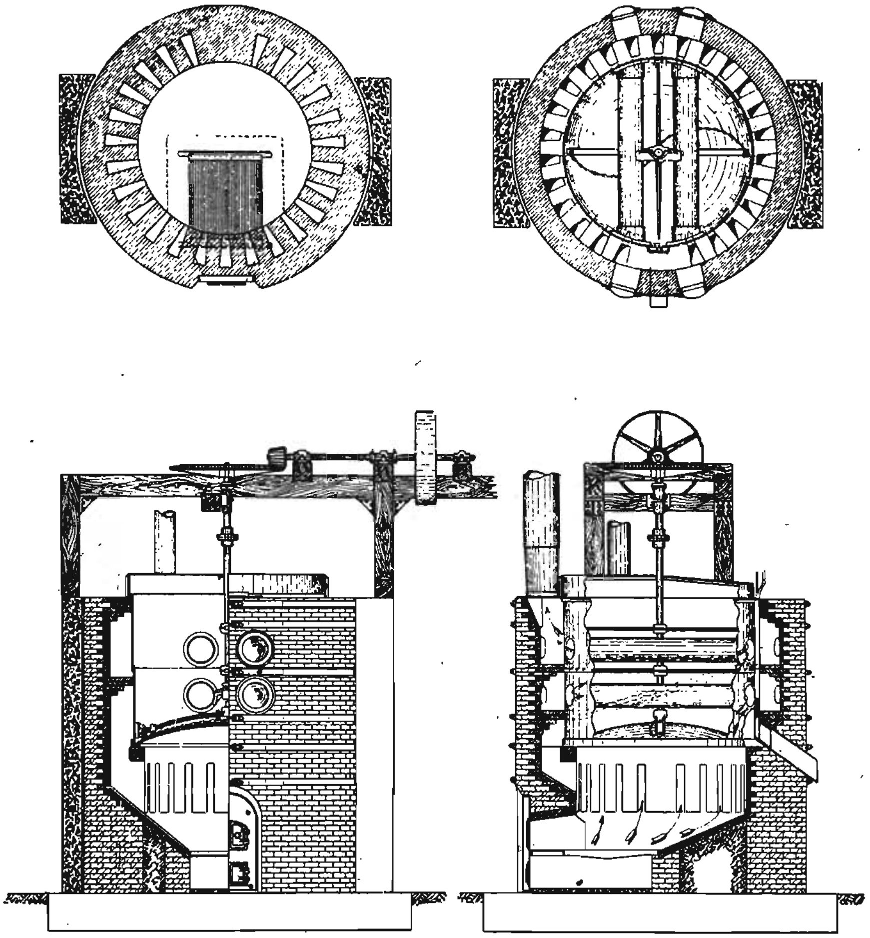

FIG. 41.—Diagram illustrating calcining kettle and setting. In figure in upper right hand corner note the two stirrers and chains dragging the bottom, attached to lower stirrer. Courtesy Ehrsam Mfg. Co.

is intended to distribute the heat on the sides and through the flues of the kettle so that the bottom shall not be exposed to excessive temperatures. The heat and furnace gases pass out through ports below the fire brick that protect the lip ring, into the space at the sides of the kettle. These ports are not directly opposite the flues, and baffles made of fire brick and placed between the steel shell and the outer brick wall, compel the heat and gases to wholly cover the lower sides of the kettle before they can escape through the flues and pass out to the stack. The stacks are high enough to secure a strong draft and there is a good deal of actual combustion between the side walls of the kettle, and in the flues. A high percentage of inflammable gas passes to the stack and is lost and from this point of view kettle calcining is not economical of fuel. Figure 41 shows a typical kettle setting. The vital point in a calcining kettle is the bottom. The greatest trouble in connection with the operation of a calcining kettle comes from leaking through the bottom, or at the contact of the shell and bottom with the lip ring. The difficulties in this connection have steadily increased as the gypsum has been more finely ground. Hot gypsum ground so that ninety per cent passes a hundred mesh screen, flows almost like water and will escape through very minute cracks. A small leak into the fire box will most effectually smother the fire. Steel bottoms do not crack as readily as cast iron, but they may buckle badly and pull away from the sides thus causing trouble as serious as cracking.

Suitable kettle coal

A free burning coal giving a long flame and plenty of gas for combustion about the sides and in the flues of the kettle gives better results than a coking coal which tends to focus the heat on the bottom.

Drafts should not be allowed to strike the hot kettle bottom and when the door is opened for firing it should be closed as quickly as possible. Because of these conditions gas, either natural or producer, and fuel oil make most excellent calcining fuels. They are easily regulated and the heat can be quickly increased or decreased as the kettle is charged or the contents drawn off into the hot pits.

Mechanical agitation

As gypsum is a poor conductor of heat mechanical agitation is necessary during the calcining process to prevent overheating of the material near the bottom, sides and flues and underheating of the more remote material. This agitation is secured by a sweep attached to a shaft that is pivoted in the kettle bottom and is driven by bevel gear above the kettle. To this sweep chains are attached which drag over the bottom and keep the plaster agitated. The life of a kettle bottom depends in part upon the success of the agitating devices in preventing the plaster from lying dormant on the bottom. A second sweep is attached to the shaft just above the flues. The great quantities of steam which are given off aid materially in agitating the mass in the kettles. In calcining gypsite scrapers are used on the sides as well as on the bottom of the kettle.

Fuel requirements

The amount of fuel required for power purposes in calcining gypsum for ordinary wall plaster (through the first settle) is about one ton of coal for twenty tons of gypsum calcined. One ton of coal is fired under the kettles for every sixteen tons of calcined plaster drawn from them.

First settle

The chemical changes that take place during the calcining of a kettle of gypsum are considered in chapter XII on the Chemical Nature of Calcined Gypsum. These chemical changes correspond to definite temperatures and are accompanied by certain characteristic manifestations. When the temperature reaches 262° F. (128° C.) steam begins to come off very rapidly, due to the breaking up of the molecules of water of crystallization. It is quite likely that the self recording therometers commonly used to register kettle temperatures will not run quite so high when the "first boil"—as this stage is called—begins, but as shown later in chapter XII, the material nearest to the heated surfaces has, at least in places, reached this temperature. The temperature of the kettle, which had been rising rapidly, now remains almost stationary, while the mass within the kettle "boils" violently. The length of time that the boiling at this stage continues depends on the size of the kettle and the vigor with which it is fired, but in average practice it ends in about forty-five minutes. The temperature begins to rise rapidly again and the plaster in the kettle becomes relatively quiet,—"enters the first settle."

It is the generally accepted opinion that wall plaster made from material drawn from the kettles during the first settle works more easily—is more plastic—than that made from material that has been further calcined. For wall plaster, therefore, the contents of the kettle are generally discharged when the temperature is between 330° F. and 340° F.

For certain purposes it is thought desirable to carry calcina-

Second settle

tion further. At 325° F. (163° C.) the gypsum begins to boil violently again, perhaps more violently than before. This continues for thirty or more minutes, depending on the size of the kettle and the vigor with which it is fired. Then the material becomes quiet and is drawn off as "second settle" plaster, at 390° F.

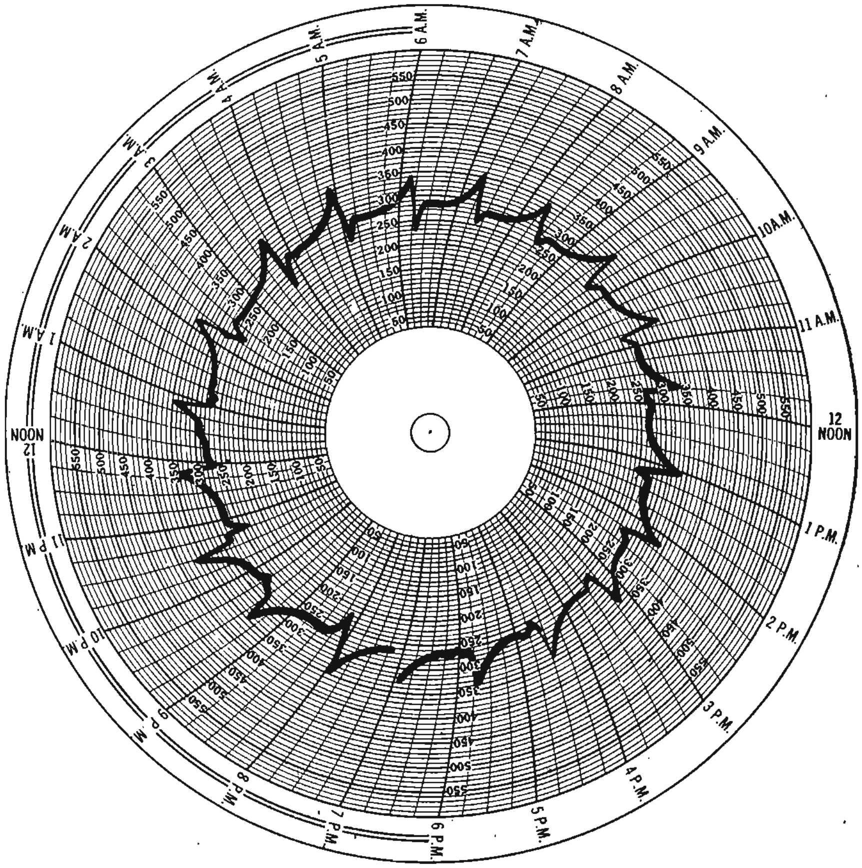

FIG. 42.—Chart from self-recording thermometer showing changes in temperature for twenty-four hours in calcining kettle. Described more fully in the text.

Uses of second settle calcined gypsum

As set out more fully in chapter XII second settle plaster lacks the fatty plastic nature of first settle material. The plasterer characterizes it as short working. It is preferred, however, for moulding, pottery and casting plaster on account of its greater density and strength.

Figure 42 shows a chart from a self recording thermometer for recording temperatures in a calcining kettle. The capacity of the kettle was ten tons, and it took, as the chart shows, twenty charges in twenty-four hours. It received, therefore, 200 tons in one day and delivered 168 tons of calcined plaster, allowing 16 per cent for shrinkage in calcining. The plaster was drawn at 340° F., but the thermometer ran up another ten degrees during the emptying of the kettle. The sharp downwards stroke in each curve represents the charge of cold gypsum with which the kettle was again filled. The line rises sharply each time till 270° F. is reached. The first boil is then fairly under way. It flattens out till this stage is concluded. The kettle was emptied each time just as the second boil started. The time required to calcine gypsite is very much longer than that necessary to calcine ground rock gypsum. If the gypsite has not first passed through a dryer, from six to eight hours may be needed to calcine a single kettle charge, consequently kettles with large capacity are commonly used in gypsite mills.

Calcining Gypsite

It is customary to install over each kettle a dust collector, with baffles so arranged that the dust will be retained without condensing the steam. This dust is finer and faster setting than the regular kettle product and it is either drawn off for uses in which these properties are not objectionable, or it is returned to kettle or hot pit in such a way that it is thoroughly mixed with the larger mass, as otherwise plaster with irregular set would result.

Dust collectors

The kettle is discharged through the wicket into the hot pit. It is highly desirable that this valve be tight and that no raw or partly calcined gypsum is allowed to leak into the hot pit, for raw gypsum acts as an accelerator and a plaster with uneven set would result. The hot pit is usually made of concrete, with one steeply sloping side so that the calcined plaster will run readily to the screw conveyor that extends along the lower side of the pit. The hot pit should be covered to exclude any dirt or raw gypsum, and to prevent the dust and steam, which come off in a cloud when the kettle is discharged, from escaping into the building. A flue from the pits through the roof to the open air is often built to dispose of the steam and prevent condensation in the hot pit. Figure

Hot pit

43 gives a cross section of a calcining mill which shows these details.

Cooling the plaster

Spiral conveyors and elevators between the hot pit and the bins above the packers serve the double purpose of aerating and cooling the plaster and transporting it to the point desired for further treatment.

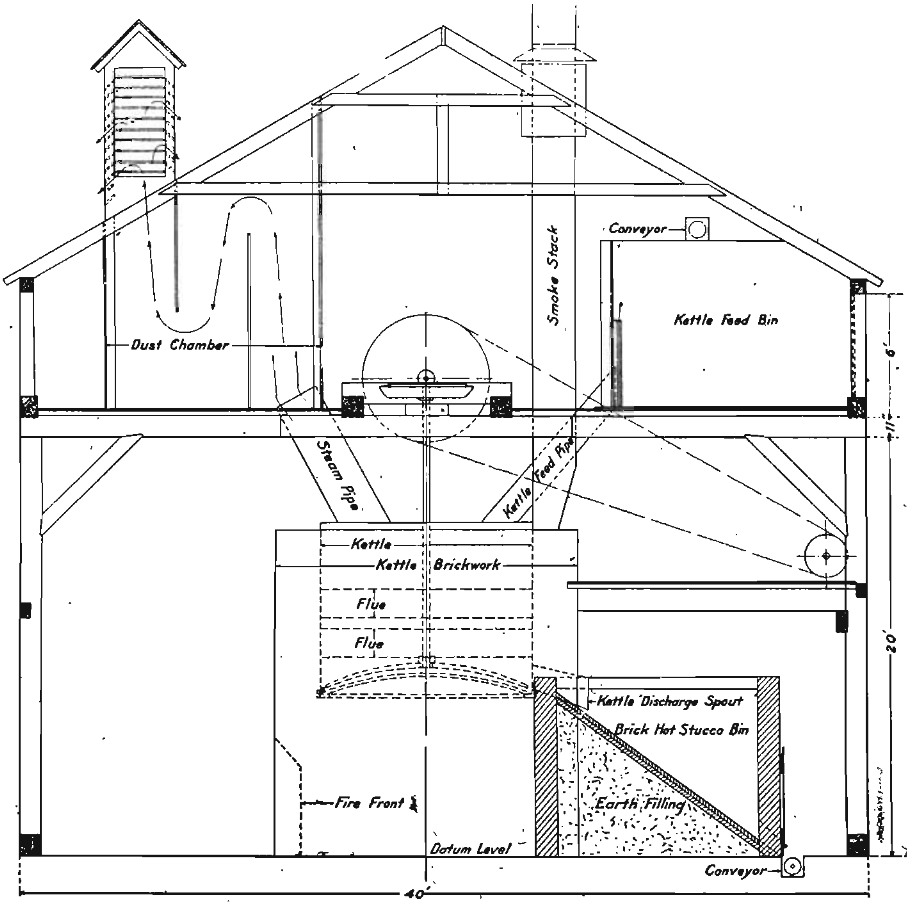

FIG. 43.—Cross section of calcining department of a gypsum plaster mill. Courtesy of Department of Mines, Canada.

Rotary calciners

Calcining in rotary kilns, which is the universal method employed for Portland cement, has made but limited headway in the gypsum industry. Numerous early attempts proved to be failures and the pioneers in the industry invariably came back to the kettle process.

In 1901 the writer[152] described a continuous calciner which he found in operation at Mannheim, Germany, as follows:

"The mill of the Rhenish Gypsum Company, located near Mannheim, is so interesting that it will be well to describe it rather minutely at this point in connection with its unique calcining machinery.

German type

"Mannheim is situated on the middle Rhine, fifteen miles northwest of Heidelberg. The works of the Rhenish gypsum industry are located in the village of Wildhof, about four miles north of the city. The plant is modern and fireproof throughout. The roof of the building is made of gypsum boards covered on the outside with asphalt, the inner walls are made of the same material, while the floors are made out of estrick gypsum. In this mill fine grinding of the gypsum is postponed till after calcining. When the material comes from the crushers and nippers it varies in size from the finest powder to fragments as large as an ordinary hickory nut. Varying thus in size, the material goes directly to the calciner.

"The calciner consists of a fire box with an automatic stoker, which is placed in front of and connected with a chamber containing a rotating cylinder. Above this cylinder is a chamber called the forewarmer, through which a spiral conveyor passes, from end to end. A pipe leads from the rotating cylinder to the forewarmer, and connects at the other end with the chimney. Connected with the fire box is a fan by which a forced draft is secured. In the figure this fan, instead of being connected with the fire box, is shown connected with the rotary cylinder. The fire box is heated to a high temperature, and the draft, forced by the fan, passes through the rotating cylinder, and then through the forewarmer. The gypsum is conveyed by bucket elevators from the crushers to a bin above the calciner and thence it flows under the influence of gravity into the forewarmer, through which it is carried by the spiral conveyor. It then falls directly into the rotary cylinder below. Shelves or buckets on the inside of this cylinder pick up the material and elevate it as the cylinder rotates. When the material nears the top the slant of the shelves is so great that it falls again to the bottom. This process of raising the gypsum and allowing it to fall is constantly repeated. The strong draft of hot air passing through the cylinder from the fire box strikes the gypsum as it falls from top to bottom and moves the fragments toward the rear with a velocity inversely proportional to their size. The coarser material moves more deliberately, and thus is exposed to the

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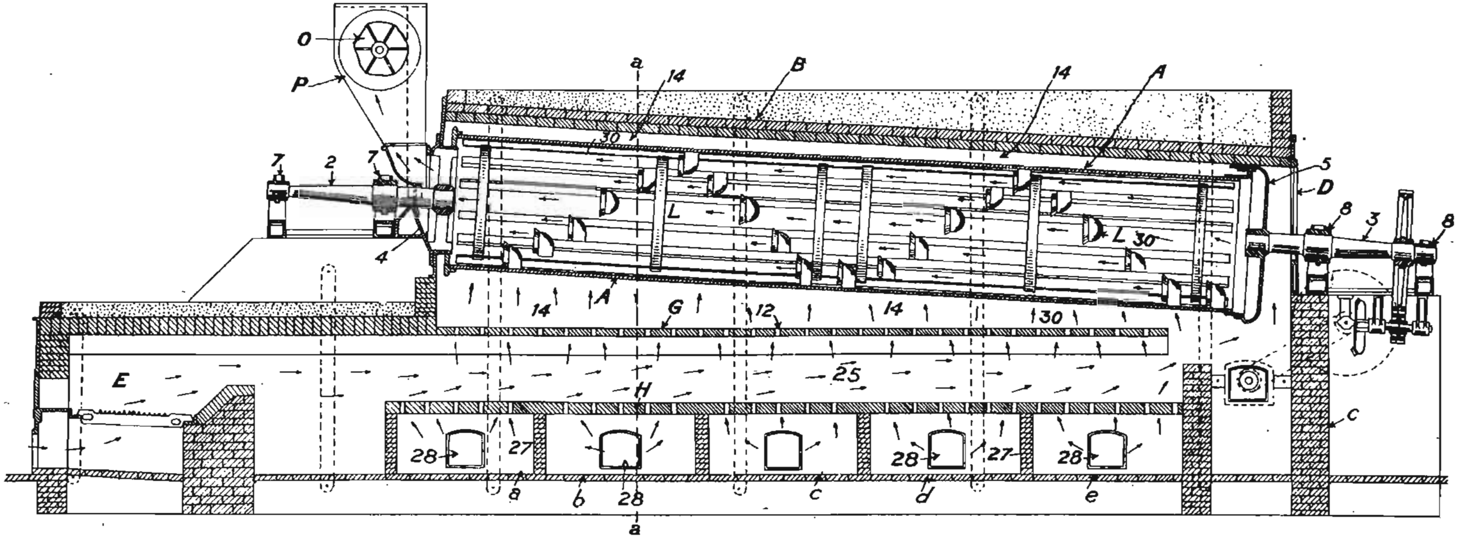
[152] Geology of Webster County, Iowa Geol. Survey, Vol. XII, pp. 213-215.

heat longer than the finer and more readily calcined particles. In this way, though the material entering the rotating cylinder varies greatly in fineness, the finer is not "dead burned" and the coarser is sufficiently calcined. All of the heat has not been exhausted from the air in passing through the rotary cylinder, and this is for the most part saved by forcing the air, after it leaves the cylinder, through the forewarmer. In this process the heat is so completely utilized that the air and furnace gases pass to the chimney with a temperature of only 80° C. Between the forewarmer and the chimney the dust chamber is situated. Here all of the finer particles are allowed to settle and the air passes on to the chimney practically free from dust. No gypsum was seen about the outside of the mills and the roof showed no trace of dust, while within everything was dust free except the grinding and sacking rooms. To calcine one ton of gypsum by this Mannheim method experience has demonstrated that on an average only 100 pounds of rather inferior bituminous coal is required. An automatic recorder indicates constantly the heat of the rotary cylinder, and this, with the mechanical stoker, insures an even temperature during the entire process of calcining. From the rotary cylinder the gypsum is again elevated to the floor above, and passes through a spiral conveyor which is surrounded with a water jacket. Here the gypsum is cooled and passed on to the sieves. That portion of the gypsum which does not need further grinding is separated by the sieves and the rest goes to the vertical mills."

The Cummer process

Three or four American mills use a calciner of the Cummer type. Plate XI illustrates this machine and figure 44 shows end elevation and section. It consists of a cylinder thirty or more feet long and five feet in diameter. It is slightly inclined and its weight is carried by trunnions. It is rotated by a gear drive attached to one end. The cylinder is inclosed with brick at sides and top, and by metal plates at the ends. Hot gases generated in a furnace fed by automatic stokers are mixed with air from ports beneath the rotating cylinder and this air enters the cylinder at the lower end and through specially designed funnels along its sides. The gypsum, which is generally crushed to pass a three-quarters inch ring, is fed into the cylinder from a hopper at the upper end. Longitudinal shelves on the inside of the cylinder carry the gypsum part way up with each rotation. In falling to the bottom the gypsum passes repeatedly through the hot gases and the



Rotary calciner, Cummer type, used in some gypsum mills. Courtesy of Department of Mines, Canada.

finer material is caught by the air current stimulated by a strong fan, and passes with the hot air to a dust room where it is gathered by a screw conveyor rotating at the bottom of the room. A recording thermometer notes accurately the temperature, which is controlled within rather narrow limits.

As originally constructed and as recommended by Mr. Cummer, the inventor of this device, the gypsum from the calcining cylinder passes to large bins where, shut off from the air, the calcining of the larger lumps which were not completely calcined in the cylinder, is completed. Some operators have found the use of such bins unnecessary and pass the gypsum from the calciner directly to grinding mills. It is probable that in these mills the calcining is completed, for they receive the gypsum hot from the calciner, and the grinding process itself develops some additional heat.

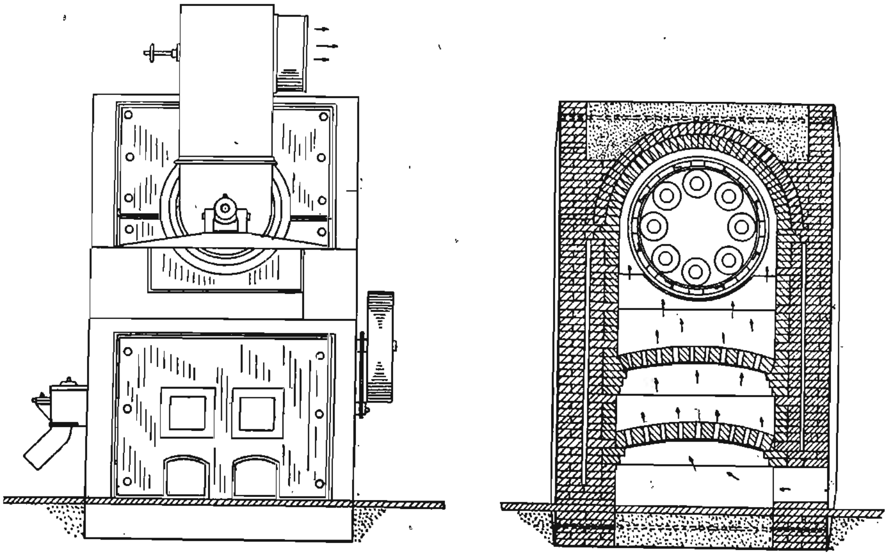


FIG. 44.—End view Rotary calciner. Cummer type. Courtesy Department of Mines, Canada.

Cement mill type rotary

In 1917 one gypsum producer broke away from kettle calcining and installed two rotary calciners each seventy feet long, like those used in making Portland cement.

Regrinding

When certain types of continuous calciners are used, all of the fine grinding is done after calcining, and the same types of grinding machinery that were described earlier in this chapter may be used.

Many mills grind to moderate fineness, and then screen the plaster after calcining and regrind the tailings.

Screens

A shaking or tapping screen is preferred to a rotating screen for classifying gypsum at any stage in its manipulation on account of the ease with which the screen clogs or gums up.

The setting time of plaster ground after calcining is shorter than that of plaster made from material ground before calcining. This is due to particles of raw gypsum in the center of the coarser fragments, which the regrinding brings to the surface and which act as accelerator.

Plastic gypsum

Attention has recently been called by Mr. Emley of the Bureau of Standards, to the possibility of making a very plastic gypsum by grinding in a closed mill after calcining. This important matter is set out in appendix VII. This process of regrinding seems to bring about an equalization of the water of crystallization in the calcined mass so that the final product is composed wholly of the hemihydrate. Its plasticity is remarkable so that it can be used as a finish coat without admixture of lime. It should be noted that this process of making plastic gypsum is in use at the Iowana mill at Fort Dodge.

Purpose of mixing

Materials mixed

Various ingredients are mixed with the calcined plaster in order to produce a substance best adapted for covering interior walls. The materials are added for two purposes; first, to aid the plasterer in applying the material to the wall; and second, to reduce the cost per yard of finished surface. Materials added to modify the physical properties of the plaster so as to simplify its application are, retarder; fibre, either hair or wood or sisal; hydrated lime and clay. Sand is added, either at the mill or on the job, to reduce costs.

Retarder

In order to give the workmen ample time to mix the plaster with sand and apply it to the wall a retarding substance is added at the mill. The nature of the retarders used is discussed in chapter XIX. The amount of retarder required depends on the nature of the material used for the purpose and on the nature of the plaster. Gypsite plaster requires little or no retarder. Calcined gypsum made from rock gypsum sets in fifteen or twenty minutes and it is customary to add retarder in sufficient quantity to slow the set to two hours, even after it has been mixed with sand, which has an accelerating tendency.

Fibre is added to give more adhesion to the plaster while it is being applied and to prevent its dropping off behind the lath. Any benefit derived from it is confined to the period of application, as the strength that it imparts to the plaster is very small and is not needed to supplement the strength of the calcined plaster. From four to six pounds of long fibred goat hair are commonly mixed through each ton of neat gypsum plaster. The goat hair is often supplemented by one or two pounds of sisal or similar vegetable fibre. Some producers use only cattle hair. Wood fibred plasters are commonly recommended for use without sand and are generally sold where sand is scarce and expensive. Thirty or forty pounds of shredded wood are used in each ton of plaster. Soft, non-staining woods are chosen for this purpose, bass, willow, poplar, buckeye and similar trees furnishing most of the fibre.

Fibre

The hair comes in compact bales and must be shredded before it can be mixed with the plaster. Two or three machines are on the market for this purpose. A central disc with projecting teeth is revolved rapidly near a stationary disc of similar construction and the matted hair is thrown into an opening near the center of the revolving disc and frayed between the stationary and revolving teeth till it is discharged by centrifugal force, in a loose condition, at an opening on the outer edge of the containing case.

Hair picker

A machine for shredding wood for mixing with plaster is much more elaborate and for its operation requires twenty to thirty horse power. The log cut to proper length and barked, is pressed against a set of saw toothed discs on a rapidly revolving shaft to which they are firmly keyed. The log rotates slowly and is held against the revolving discs with even pressure. In the same proportion that the diameter of the log decreases its speed of rotation is increased by a cone drive so that the length of the fibre remains fairly constant. The fibre is in many cases taken from the machine by a fan and delivered to a fire proof bin.

Wood fibre machines

In order to shred properly the wood must not be too dry. In another type of fibre serial blocks are clamped to a rotating disc and remain stationary while the disc slowly revolves and brings the blocks of wood in succession in contact with rapidly revolving knives which shred the wood with the grain.

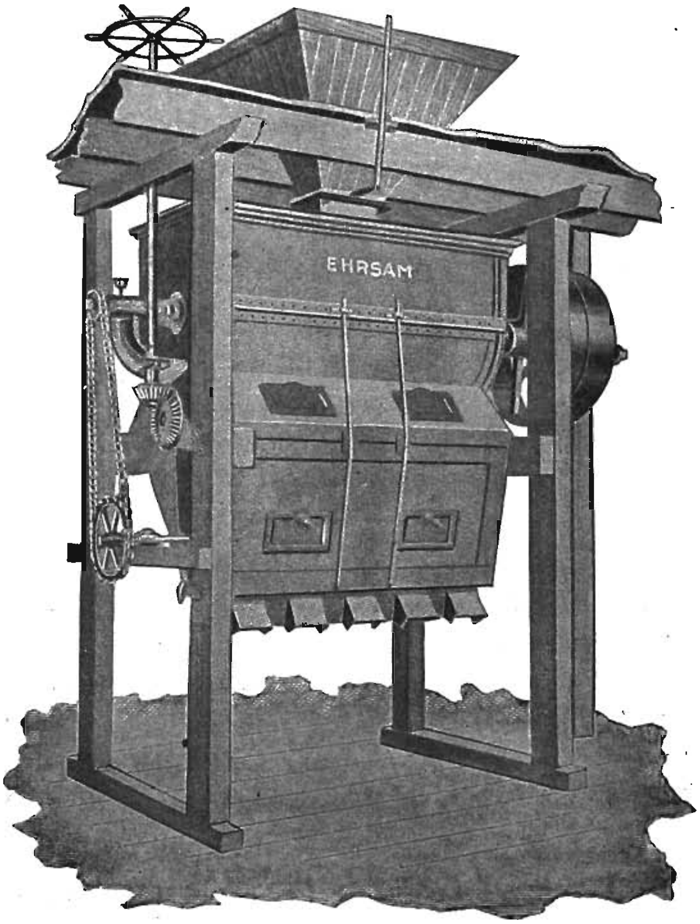


FIG. 45.—Plaster mixer. Courtesy Ehrsam Mfg. Co.

The purpose of this machine is to produce the maximum amount of long fibre.

Mixing

The ingredients in proper proportion are placed in a hopper over the mixer, which is usually built to take a charge of a ton. Some care must be taken when mixing wood fibre plaster, not to let the retarder come in contact with the damp wood for this results in the retarder sticking to the fibre, and small white spots of over retarded plaster appear when the plaster is applied on the wall.

In the mixer a series of blades attached to a revolving shaft secure a thorough mechanical mixing. The mixer may discharge into a sacker for hand tying or may be attached directly to a valve-packer. An illustration of one type of mixer in use at gypsum mills is shown in figure 45.

Automatic packing

Packing machinery is used almost universally in Portland cement mills and the same type of packer is used in some gypsum mills. On account of the fibre in gypsum plaster some modifications were found necessary in adapting the cement packer to wall plaster. The mouth of the plaster bag is securely closed while the bag is empty and the plaster is injected through a valve in one corner of the bottom and its loss is prevented by a flap which closes the opening under pressure of the contents of the bag. Figure 46 shows a packer of the type used in gypsum mills.

The plaster is generally conveyed to the car in truck loads

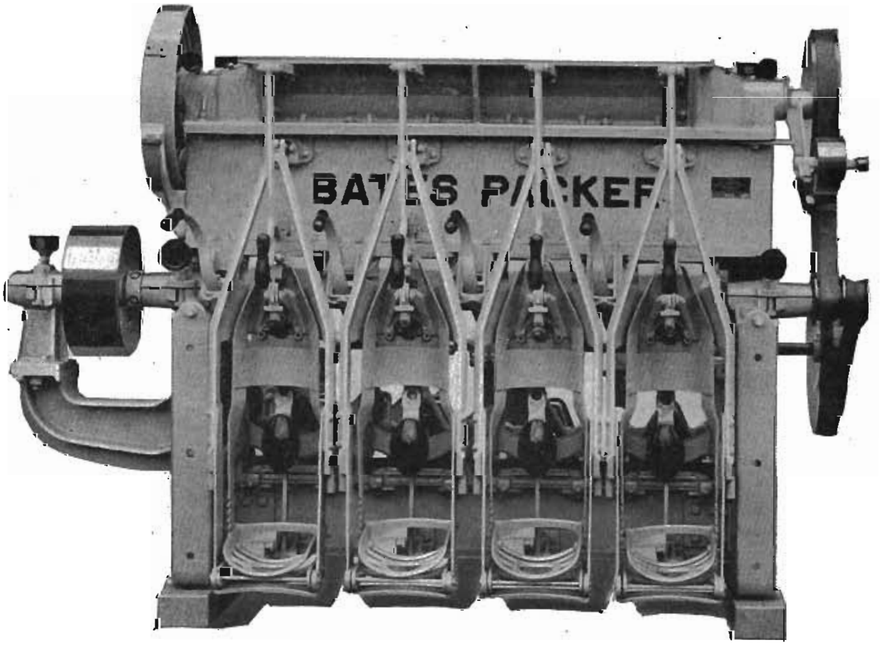


FIG. 46.—Automatic bag filler, packer and weigher. Courtesy Bates Valve Bag Co.

Loading and trucking

of five bags each. When paper bags are used care is taken to see that nails and projections that would tear the bottom bags are removed. Usually a layer of felt paper is placed on the car floor as additional protection and extra paper bags are placed in the car to replace bags that are broken in transit.

Bags

Calcined gypsum and plaster may be packed either in jute or paper bags. At present jute bags are more commonly used though there is a strong tendency toward the more extensive use of paper. Twelve ounce jute is commonly used though the light grades down to ten ounce are sometimes employed. The package usually holds 100 pounds, and the size of the bag to hold this amount varies with the fineness of grinding. When calcined gypsum is ground so that 90 per cent passes a 100 mesh screen, the size of the bag to hold 100 pounds should be 20 by 36[153] inches.

The plaster manufacturer usually includes the price of the jute bag with that of the plaster when it is sold, and redeems jute bags of his own brand when returned in good condition freight prepaid, within six months. The bag department where returned bags are cleaned and reconditioned is an important part of a plaster mill.

Paper bags

Where paper bags are used an extra strength is desirable. The size of the package is reduced to eighty pounds. Paper bags cost from a dollar to a dollar and a half per ton of plaster, are sold with the plaster and of course cannot be redeemed.

A chart showing fuel consumption and other items in the manufacture of calcined gypsum is introduced as Plate XII.

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[153] These figures represent the size of the average bag used by the industry. Where special regrinding processes are used a somewhat larger bag is sometimes required.

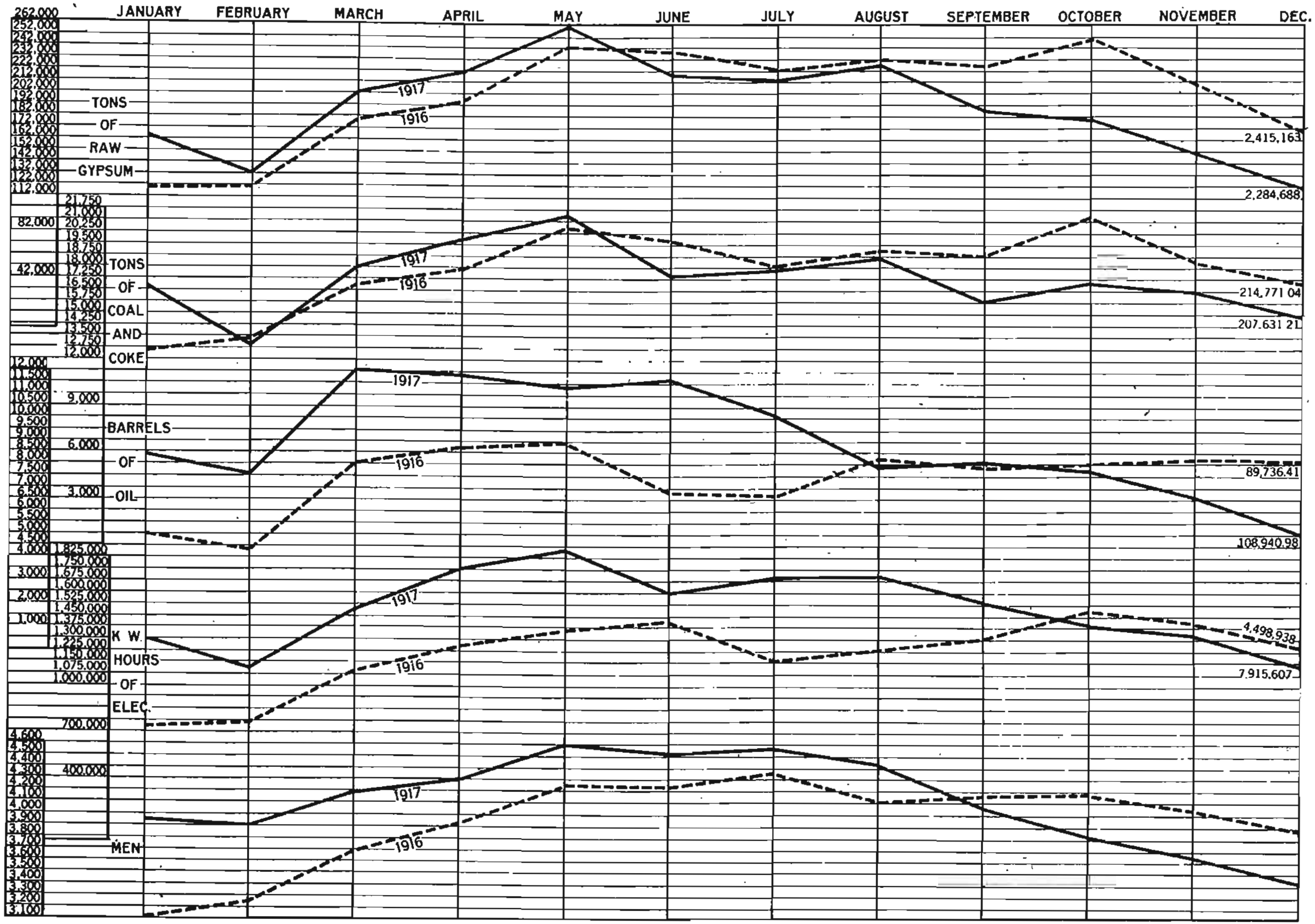

Diagram showing fuel and power consumption of the Gypsum industry in 1916 and 1917, with fluctuation in monthly output. Prepared by O. M. Knode of the U. S. Gypsum Co.

CHAPTER IX

USE OF GYPSUM IN PORTLAND CEMENT

Purpose

Gypsum, either calcined or crude is universally used as the retarding element in Portland cement. Cement should not develop its initial set in less than 45 minutes, nor its final set in less than ten hours.[154]

The sulphur trioxide (SO_3) is the active agent in the gypsum which renders it valuable as cement retarder. According to generally accepted conclusions, high alumina cements require more SO_3 to make them usable during the hot humid season than the low alumina and high iron-oxide cements; and further, the finer a cement is ground the more SO_3 is required to prevent it from setting too quickly.[155]

Limits

If sulphur trioxide is present in considerable quantities the strength of the cement is weakened. Standard specification limit the SO_3 in Portland cement to 2 per cent.

Forms used

Crude gypsum is generally used, on account of its cheapness as compared with calcined gypsum. The SO_3 content of the gypsum is generally specified in cement mill contracts. It is common practice to specify gypsum containing 42 per cent SO_3, though mineral carrying only 35 per cent SO_3 is at times used. When crude gypsum is used it is added to the clinker and ground with it.

Some cement chemists prefer calcined gypsum even though the cost per ton is twice that of the crude mineral. For this purpose the calcined gypsum is finely ground. It is added to the finished cement in very carefully measured quantities and is thoroughly mixed to insure uniform set.

Anhydrite

Anhydrous gypsum contains a higher per cent of SO_3 than is found in gypsum proper. Some chemists have no objection to the use of anhydrite as cement retarder, while some actually prefer it, as a ton of anhydrite contains more SO_3 than a ton of gypsum. Other cement chemists are not satisfied with the results that they have secured with anhydrite.

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[154] A. S. T. M. Standards, 1918, p. 504.

[155] P. H. Bates, Paper at A. S. T. M. meeting June 22, 1915.

Uniformity essential

The SO_3 content of the gypsum used in Portland cement must be fairly constant, or uneven set in the cement results. It seems probable that where trouble has resulted from the use of anhydrite, the cause is often to be found in the fact that the percentage of SO_3 was not uniform, rather than to the nature of the anhydrite itself. Anhydrite almost invariably occurs mixed with gypsum, and if it is used some care must be taken to see that the gypsum and anhydrite are so mixed by mechanical processes, that the SO_3 content is uniform throughout the entire mass.

Anhydrite and High Alumina Clinker

Experiments now being carried on by various cement companies, co-operating with Committee C-11 of the American Society for Testing Materials seem to indicate that clinker of a high alumina content and relatively low lime cannot be sufficiently retarded by the use of pure anhydrite.

Inasmuch as the magnesia (MgO) content of Portland cement is restricted to 5 per cent, gypsum for cement mill use should not contain any considerable amount of dolomite. This is a matter of no great importance, however, as both gypsum and anhydrite are seldom so intimately associated with dolomite as to make its presence in the gypsum a hazard.

Statistics given in chapter XXII show how extensive are the requirements of the cement industry. While the increase in the manufacture of Portland cement will hardly be as rapid during the next decade as in the ten years just past, there will be a steady expansion of the industry.

CHAPTER X

GYPSUM IN AGRICULTURE

HISTORICAL

USE IN EUROPE

The history of gypsum as a fertilizer dates back a little more than 150 years. The earliest use of gypsum in agriculture probably occurred in Wurtemberg, in southern Germany, but the first information published in regard to it came from the Economic Society of Berne, Switzerland.[156] Memoires de Societe Economique de Berne, in 1768, contain the first account of the use of gypsum on the farm. In response to a request for essays on the general subject "Description of the Different Kinds of Earth and Methods for Mixing Them to Render the Soil Fertile", Rev. J. F. Mayer of Kupferzell in Wurtemberg submitted a paper which was awarded first prize by the Society. This paper had in the form of an appendix a brief note on gypsum as a fertilizer which attracted great attention and led the Society to ask for more information, and in complying with this request Mayer stated:

Rev. J. F. Mayer's statement

"It is only two years since one has entertained the thought that a stone of which little account was taken, was nevertheless well suited to attract to itself the oil and salt of the air, and consequently suitable to be placed on the meadows and to enrich them. When it is found crude, it is reduced to powder, and after it is crushed it is placed on the meadows or upon sterile soils of whatever nature they may be. Over one acre one scatters eight fri (a measure 13 inches in diameter and 8 inches high) and this fertilizer furnishes the best forage and the best clover one can imagine. It has greater effect if calcined, but the best effect is obtained by adding to it two fri of wood ashes and eight handsful of salt, and the whole soaked in a half pail of manure water. Let these materials be well mixed, then let them lie eight days, after which having stirred them, one may spread them on the soils to be fertilized. Our people profit by it continually and the experience for two years has justified the first trials. As soon as

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[156] According to Grimsley, in Geol. Survey of Michigan, Vol. IX, p. 194. Grimsley acknowledges his indebtedness to Prof. Chuard of Lussanne, Switzerland, who placed in his hands a number of his papers on agricultural gypsum.

one is quite convinced, and one cannot conceive it otherwise, that all plants are composed of salt, oil, and earth, one will be as easily persuaded that gypsum flour scattered over wheat, oats, barley, and vegetables, ought to produce the same effect. The experiment has already been tried.''

The society of Berne decided to have these experiments repeated at a number of places, and the results of further experimentation conducted under its guidance were published in a memoir in 1771. In this memoir are important papers by N. H. Kirchbergner and M. Tschiffeli.

Kirchbergner's paper

Kirchbergner describes his experiments with clover, lucerne (alfalfa) and radishes and expresses his surprise at the marvelous results that he obtained with gypsum.

Tschiffeli's paper

Tschiffeli obtained results similar to Kirchbergner and like him found that legumes profited most from applications of gypsum. He further noted that, on wheat becoming weak in its growth at the first of June, gypsum applied liberally at a dry time resulted, after the first rain, in an almost miraculous growth and a good harvest.

USE IN AMERICA

In early American history Judge Richard Peters of Philadelphia and John Binns of Loudon county, Virginia, were staunch champions of gypsum as a fertilizer. Their names are perhaps not as well known in this connection as those of Benjamin Franklin, Robert Livingston and Edward Ruffin.

Judge Peters

Judge Peters' book seems to have been published in 1796 in response to a request from Washington for a statement of his experiments and experiences along this line. A second and revised edition was later published by Smith and Harris in Philadelphia.

The following interesting paragraphs appear therein:

''The prejudices for and against this manure are equally violant. In Germany, where this fossil has been longest known and used, opinions have been very opposite, and many of them very absurd and ridiculous. Witchcraft has been charged on those who used the plaister, but it has been said by some wonderfully wise people there, that it produced or attracted thunder and lightning. Petty princes made edicts against it, urged by the bigotry of its opponents and the unfounded German adage, ''That it makes rich fathers and poor children''. Peasants have however sown the plaister on their fields in the night.

“It is a capricious and whimsical substance. I have known it to produce no effect for four years, and then throw up a most astonishing vegetation. In field now in clover, I perceive it most luxuriant, where Indian corn hills were plaistered with no effect on the corn, four or five years ago. This is one among many instances I have had in my own fields, and have heard from other farmers of similar effects. May not this be accounted for by supposing that the operative principal in the plaister was an overcharge for the fermentable substances then in the earth, and that did not find enough of these substances to operate on till the time when it produced the vegetation here mentioned. According to these notions we may perhaps understand why all these manures which undergo the quickest decompositions, ought to be oftener applied than some others, which, not being susceptible, but of a very slow decomposition, such as chalk, lime, burnt and pounded bones, gyps, impart, during several years, the soil with prolific quality. I had not seen this essay when I gave an account of my experience of the plaister. But I am much confirmed, in some of my conjectures, since reading this production; and particularly in my opinion, that the plaister operates most powerfully, when in connection with animal or vegetable putrified or putrifying substances.

“Whatever be the cause, dew will remain on a part of a grass field plaistered, an hour or two in a morning, after all moisture is evaporated from the part of the same field not plaistered. I have also frequently seen this effect in my garden beds, which, if plaistered, will retain moisture in the driest season, when there is not the least appearance of it in those beds, whereon no plaister was strewed.”

Professor Crocker, in an historical sketch on gypsum as a fertilizer summarizes Peters' book as follows:

“Peters, as did several of those filling out the questionnaire, started with worn out lands and brought them to a high state of fertility by the use of gypsum in combination with stable or green manure. Peters especially found this combination desirable, speaking of the gypsum and manure as mutually supplementary. Peters says, ‘I have heard of none who have been more successful in the plaster system than Mr. Price and Mr. West. They have brought old worn out land to a remarkable degree of fertility and profit by combining the plaster with other manures. The gypsum was, however, the principal agent. As to the results in general my experience and theirs agree; but I think that I have proved that dung and plaster mutually assist each other.’ The greatest

Synopsis of Peters' book

effect was found on leguminous crops, especially red clover. The yield of the latter was often increased two or three fold. Gypsum also proved beneficial for flax, hemp, rape and other farm crops as well as garden plants and trees. It proved quite as beneficial on limed as on unlimed soil and on old as well as newer soils. American plasters were found as good as imported plasters. From his experience and questionnaire Peters concludes that plaster is of value on many types of soil but gives little if any response on heavy clays."

Judge Peters gives in his book a series of questions that he addressed to an intelligent farmer whose interest in gypsum had come to his notice, and a portion of this catechism is given below:

"Query 1st. How long have you used the plaister?

Answer. About eleven years, without disappointment in its effects.

Query 2d. What state was your land in when you began the use of it?

Answer. My land chiefly when I began to apply it, though naturally of the first quality, had been nearly a century under bad management, and tired down. I ploughed up about five or six acres, and dressed it with a rich earth about old buildings that grass had grown over, and rotted it down in itself, and applied about thirty loads to the acre, sowed it with winter barley, the spring following with clover, the next spring with Plaister of Paris; its product in grass was allowed to be equal to any that had anywhere been seen. I mowed it two summers, and have grazed it ever since, and the sod is now in good perfection. I redressed it last summer with plaister, and its stimulation very good: the sod is green grass, white clover with a mixture of red. This piece with a number of others, laid down in grass with different kinds of manure, and plaistered, will now feed as many cattle as acres, and from the effects of their droppings may be kept up continually. I have continued the application of plaister every year from my first using of it to the present, and its most beneficial use is on grass, if rightly managed on the previous dressing of other manure and its preparation; all which will require a system in itself to describe at large.

Peters' questions and answers

Query 3d. What quantity per acre have you generally used?

Answer. The quantity of plaister per acre, four and a half bushels, and the redressing about three bushels; but I would not recommend a second application when land has been mowed five or six years, without a light dressing of other manure.

Query 4th. What soils are the most proper for this manure?

Answer. The soils most proper for the plaister are warm, kind loamy ones; the land is generally deemed good wheat land; that will sink the water quick in winter, not too level, and land moderately hilly. Land that takes lime well, will the plaister.

Query 5th. Have you repeated the application of it with or without ploughing, at what intervals, and with what effect?

Answer. The repeated application of it has a good effect as I have mentioned above. It follows lime equal to any manure.

Query 6th. In consequence do you find that it renders the earth sterile after its useful effects are gone?

Answer. It does create something of sterility in five or six years by mowing; then it may, as above mentioned, be lightly dressed by dung or compost; about twelve loads to the acre, will make a new footing for the plaister. This quantity will promote a wheat crop.

Query 7th. To what products can it best be applied—grain and what kinds—grass and what kinds?

Answer. It is best adapted to grass and every kind of summer grain.

Query 8th. When is the best time to scatter it?

Answer. The time to strew it is in the spring, when vegetation is fairly abroad.''

John A. Binns

John A. Binns, in 1804, wrote a treatise on practical farming[157] and devoted nearly one-half of the book to a discussion of gypsum.

Professor Crocker thus sums up Binns' book:

''The following is a quotation from the preface of Binns' little book: 'Having been been frequently requested by several of my friends and acquaintainces as well as sundry persons from a distance to publish my experiences in farming generally, and more especially on the use of plaster of Paris; (the use of which has made my farm, from that of being tired down, or the natural soil entirely worn out, a rich and fruitful one) I have been induced to present them with the following pamphlet.' He speaks of raising the fertility of his first farm to a high level by the use of gypsum and later buying a second farm of exhausted fertility on which his neighbors said he would starve. This in turn was raised to a high state of productiveness by the same means. In time he induced his neighbors to use gypsum with the result that in a few years they doubled their corn yield and increased their wheat yield three to four fold. He speaks of the number and size of stacks

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[157] Published by John B. Colvin, Fredericktown, Md., 1803. 2d edition published by S. Pleasants, Richmond, Va., 1804, 83 pp., 35 devoted to gypsum.

being greatly increased and the grain in greater proportion. The granaries and mills of the community were glutted and threshing greatly delayed due to big yields. He states that if the use of land plaster continues for a few years the uplands of Loudon county will be as good as, or superior to, any river bottom for grain, hemp and tobacco and far better for clover.

"Binns' favorite way of applying the plaster was to roll the moistened seed in it before sowing. He supplemented this with applications placed on the hill or sown broadcast on the crop in the early spring with a total application scarcely exceeding two bushel to the acre per year. Plaster proved to be especially beneficial to the clovers; but it also greatly benefitted corn, wheat, rye, and blue grass. From his report one cannot determine whether the benefit on the non-legumes is due to direct action of gypsum or due to the increase of nitrogen in the soil by the greater growth of the legumes in the rotation. He emphasizes the fact that gypsum greatly reduces the ravages of the fly on wheat.

"Peters emphasizes the use of green manures and stable manures with gypsum, but Binns does not mention this although later in his book he does discuss the use of other manures. One can hardly explain his results and those of other farmers of Loudon county except by assuming the accumulation of organic matter and nitrogen on the farms due to the marked effect of gypsum on the growth of clovers in the rotation. This nitrogen and organic matter must of course find its way back to the soil as stable or green manure along with root residues if it is to accumulate on the land.

"Binns' explanation of the method of action of gypsum was fatal to a system of permanent fertility for he assumed that gypsum contained all the virtues of any manure. At best it increases the supply of only three essential elements, calcium and sulphur directly and nitrogen indirectly by favoring the growth of legumes. While it may increase the solubility of potash and perhaps other nutrients it will not increase their amount in the soil. Such a system of fertility must in time fail for it will not care for the general shortage of phosphorus and the occasional shortage of potassium."

Benjamin Franklin

Franklin's keen interest in every phase of scientific thought and experiment is shown by his investigation of gypsum, and perhaps the most familiar anecdote in connection with the early history of gypsum is the story of the field of clover where Franklin sowed with gypsum the words LAND PLASTER USED HERE, with the striking result that this clover grew so much ranker and greener than the rest, that the words could be easily read from distant points.

George Washington

Washington's particular contribution to this subject is found in the fact that he induced Peters to write and publish his experiences. Washington tried gypsum at Mount Vernon only once. The results were not very remarkable, and this is not strange since the crop to which application was made was oats, a crop that does not especially respond to a sulphur fertilizer.

Charles F. Grece

Charles F. Grece recorded his observation in the United States and Canada in 1819[158] in the Quarterly Review and speaks as follows:

> "This valuable manure, almost unknown though very easy to obtain, merits the attention of every farmer. There is scarcely a farm in the provinces but it might be applied to with advantage. The practice of nine years on the following soils and crops may suffice to prove its quality. On a piece of poor yellow loam I tried three grain crops without success, with the last which followed a hoe I laid it down with barley and the return was little more than the seed. The grass seed took very well. In the month of May of the following year I strewed powder of plaster at the rate of one minot and one pack to the arpent (acre). In July the piece of land being mowed the quantity of the grass was so great that it was not possible to find room to dry it on the land where it grew. The product was five large loads of hay to the arpent. It continued good for five years. I tried plaster on cabbages and turnips, but did not perceive any good effects. From the frequent trials of this manure on various soils it is evident that it is applicable to both light and strong soils for top dressing of succulent plants."

Ruffin

Edmund Ruffin, in his essay on Calcareous Manures,[159] speaks of gypsum as follows:

> "I do not pretend to explain the mode of operation by which gypsum produces its almost magic benefits; it would be equally hopeless and ridiculous for one having so little knowledge of successful practice, to attempt an explanation, in which so many good chemists and agriculturalists both scientific and practical

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[158] Vol. XXIII, pp. 147-150. 1820. Quoted by Grimsley in Geol. Survey of Michigan, Vol. IX, p. 196.

[159] Edmund Ruffin, An Essay on Calcareous Manures, XII, 242, 1832. J. W. Campbell, Petersburg, Va.

have failed. There is no operation in nature less understood, or of which the cause, or agent, seems so totally disproportioned to the effect, as the enormous increase of vegetable growth from a very small quantity of gypsum in circumstances favorable to its action. All other known manures, whatever may be the nature of their action, require to be applied in quantities very far exceeding any bulk of crop expected from their use. But one bushel of gypsum spread over an acre of land fit for its action, may add more than twenty times its own weight to a single crop of clover.''

USE OF GYPSUM IN ENGLAND

Fothergill In 1808 Dr. A. Fothergill of Philadelphia reported to the Board of Agriculture of Great Britain on the use of gypsum as a fertilizer in the United States. He stated that at that time Philadelphia alone imported from France and Nova Scotia each year 12,000 tons, and that in addition much American gypsum was used in the region adjacent to Philadelphia.

Smithe Smithe of Tunstall, Kent, England, wrote a prize essay, about 1805, setting out his experiments with gypsum. His findings, as summarized in a statement by Professor Crocker are strikingly in line with recent reports from the Oregon Experiment Station.

''Smithe, as did the American users, found it especially effective with leguminous forage crops,—sainfoin, clovers and alfalfa. He reports that the total value of crops of sainfoin was increased 45 per cent by the use of gypsum; cow-grass, 14 per cent; Dutch clover, 330 per cent; and red clover 237 per cent. Similarly the value of the seed was increased 300 per cent for Dutch clover and 325 per cent for red clover. Applications of gypsum after the first cutting of clover hay increased the seed of the second crop three fold. Smithe found that gypsum had little direct effect on the cereal crops. Indirectly, however it seemed to benefit the grain very materially. As he puts it the more clover was forced by the addition of gypsum the better the grain crop following the clover. In one case he got 86 per cent increase in wheat following gypsumed clover. This may be largely due to increased nitrogen fixation by the clover.

''Smithe applied about six bushels to the acre when seeding to the legume and followed with much lighter applications every second or third year afterwards. He recommends application in April or May, but gets very good results with seed production in clover, as mentioned above, by applying after the first crop is cut. Like most of the experiences with gypsum up to this time, he found that the greatest effect often appeared the second or third year after the application. This may be why Binns got such good results by rolling the seeds in the gypsum before planting. Such treatment insures close contact with the first roots put out by the plant. This delayed effect is still more marked with the very slightly soluble raw rock phosphates. Insoluble fertilizers in general should be mixed with the soil as thoroughly as possible by cultivation and otherwise to insure early maximum contact with the roots. In his answers to the questions of Sir John Sinclair, Smithe mentions seventeen users of gypsum to confirm his experiences. It seems that the use of gypsum as a fertilizer spread and became popular in the region of Tunstall, Kent, England, as it did about Binns' home in Loudon county, Virginia."

Johnson

Johnson, in addition to a prize essay on the subject has an article "Gypsum as a Manure" in his encyclopedia of agriculture which was published in 1842. Professor Crocker reviews Johnson's essay as follows:

"The following quotation is from Cuthbert Johnson's prize essay on Gypsum. 'There is perhaps no artificial manure so decided in its effect upon some soils, so readily obtainable by the farmer and so plentiful in this country (England) as gypsum. Its mode of action, too, is easily understood, for it acts as a direct food for some plants, is not what is sometimes called a stimulant.' He goes on to say that there are only five cultivated crops that contain gypsum in any sensible quantities and for which it is consequently a choice food; lucern, sainfoin, red clover, rye, grass and turnips. Gypsum as a top dressing helps these. He speaks of other crops that do not contain a trace of calcium sulphate and that farmers find are not helped by applications of gypsum. Johnson was probably more nearly right than most later writers in speaking of its main function as a "direct food", although he was wrong, due to crude chemical methods of the time, in assuming the absence of calcium sulphate from most plants. He also did not know a thing discovered much later, that sulphur is a building material for several essential organic compounds of plants and calcium for at least one. Besides calcium has other indispensable functions inside and outside the plant. Johnson also mentions the experiments of various farmers, largely confirmatory of the results of Mr. Smithe."

The fact stands out in bold relief before the reader of these pages recording early experimentation with gypsum that the crops which gave a remarkable response to gypsum fertilizer, were clover, alfalfa, and legumes in general; together with cabbage, radishes, turnips, and other members of the mustard family. Potatoes and onions also responded moderately.

The fact that the scientific explanation for these results was not known makes the uniformity of results all the more striking.

Wolff's erroneous analyses

When, about ten years ago, agricultural chemists checked on Wolff's analyses of plant seeds, leaves and stems, and discovered that, through using faulty methods he had overlooked most of the sulphur present in plants, the real explanation of the value of gypsum in agriculture was discovered and correct conclusions were promptly drawn.

In the interval various theories were advanced to account for the efficacy of gypsum, some of which have merit.

Storer's theories

In his Chemistry of Agriculture,[160] Storer called attention to the fact that all lime compounds, including gypsum, have a tendency to flocculate loose soils; that is, to collect the loose particles and give the soil more body. With a tough clay soil they have the opposite effect and break up such soils into finer particles.

GYPSUM AS AN INDIRECT FERTILIZER

In addition to the physical benefit derived from gypsum, Storer pointed out—and leading agricultural chemists since his time have confirmed his conclusions—that gypsum decomposes the double silicates in the earth, and puts in soluble form the potash bound up in these silicates. Storer expressed the chemical reaction in the following form:

$$\left.\begin{matrix} Al_2O_3 \\ CaO \\ K_2O \\ H_2O \end{matrix}\right\} x\ SiO_2 \text{ plus } CaOSO_3 \text{ equal} \ldots\ldots\ldots\ldots \left\{\begin{matrix} Al_2O_3 \\ CaO \\ CaO \\ H_2O \end{matrix}\right\} x\ SiO_2 \text{ plus } K_2OSO_3$$

The favorable action of gypsum on legumes was accounted for by the fact that they are heavy users of potash, and gypsum renders potash available.

As is generally known there are enormous stores of potash

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[160] Volume I, pp. 206-216, 1887.

present in most American soils, extremely sandy soils being about the only exception. This potash is much more abundant in the layer from twelve to twenty inches deep than in the six or seven inches nearest the surface. As a result of forty-nine analyses of typical soils in the United States, Professor Chester[161] found for the first eight inches of soil 13,400 pounds of potash. Doctor Olive estimates that if this potash is made available the supply is sufficient for 1000 wheat crops, counting 13.7 pounds removed per acre by an average fourteen bushel crop.

Abundance of potash in most soils

GYPSUM AS A DIRECT FERTILIZER

Hart and Peterson's[162] investigations, published in Wisconsin in 1911, first paved the way for a complete and satisfactory explanation of the behavior of gypsum when used as a fertilizer. They called attention to the errors in Wolff's analyses, and proved conclusively that many important crops consume as much sulphur as phosphate.

Wisconsin Bulletin 14

The authors sum up the results of their investigations in the following manner:

> "The sulphur content of a number of our common farm products has been determined and in agreement with other investigations the quantity is much larger than found by Wolff in the ash from such products.
>
> "The amount of sulphur trioxide removed by crops is considerable, being equal in the case of average crops of cereal grains and straws to about two-thirds of the phosphorus pentoxide removed by these crops; the grasses of mixed meadow hay remove quite as much sulphur as phosphorus, while the legume hays may approach, and in the case of alfalfa, even exceed in this respect. Members of the Cruciferae, as the cabbage and turnip, are heavy sulphur-using crops and may remove two to three times as much sulphur trioxide as phosphorus pentoxide. An average acre crop of cabbage will remove about 100 pounds of sulphur trioxide.
>
> "Normal soils are relatively poor in total sulphur trioxide; a limited number of analyses showed a percentage content of from 0.033 to 0.140; most of them contained less than 0.10 per cent. An acre foot will contain from 1,000 to 3,000 pounds

Wisconsin Bulletin No. 14 conclusions

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[161] Delaware Agr. Expt. Station, Bulletin 65. p. 51, 1904.

[162] Wisconsin Agr. Expt. Station Research Bulletin 14, 1-21, 1911.

of total sulphur trioxide. About the same quantity of phosphorus pentoxide will be found in an acre foot of normal soil. These results for sulphur trioxide are based on analyses made by the method of fusion with sodium peroxide. Determinations by extracting with hydrochloric acid or with nitric acid and bromine will not give the total sulphur content of soils.

Soils cropped for 50 or 60 years either unmanured or receiving but slight applications during that period have lost on the average 40 per cent of the sulphur trioxide originally present as determined by comparison with virgin soils.

"Where farm manure has been applied in regular and fairly liberal quantities the sulphur content of the soil has been maintained and even increased.

"The total sulphur trioxide precipitated at Madison, Wis., with the rain amounted in the five months of June to October, 1910, inclusive, to 11.7 pounds per acre. The annual amount may tentatively be placed at from 15 to 20 pounds.

"The losses of sulphur trioxide by drainage, based on the analysis of the drainage waters at Rothamsted, England, and on a yearly drainage of 10 inches, would amount to about 50 pounds per acre yearly.

"Even with much less loss by drainage it does not appear that the atmosphere can serve as a complete compensating factor for losses of sulphur trioxide which soils sustain through both cropping and drainage. The partial depletion of the sulphur of the soil by continued cropping without adequate fertilization is evidence in support of this view.

"From the data here presented it appears that for permanent and increased production of farm crops such systems of fertilization must be inaugurated as will supply to the soil from time to time, in addition to the elements now recognized as generally necessary,—namely, nitrogen and phosphorus,—a sufficient quantity of sulphur to meet the losses sustained by cropping and drainage.

"Such sources of sulphur are farm manures: the trade fertilizers, such as super-phosphate, ammonium sulphate and sulphate of potassium: and the socalled soil stimulant, gypsum or calcium sulphate."

Professor Shedd soon followed with two interesting bulletins[163] which confirmed for Kentucky soils the conclusions of

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[163] Relation of Sulphur to Soil Fertility: Kentucky Agr. Expt. Station Bulletin 188, 595-630, 1914. The Sulphur Content of Some Typical Kentucky Soils: Kentucky Agr. Expt. Station Bulletin 174, pp. 269-306, 1913.

Shedd in Kentucky

the Wisconsin experiments. In his analysis of thirty-one samples of tobacco leaves he found that all but two contained more sulphur than phosphorus, and in some cases the sulphur was nearly double the amount of phosphorus.

Brown and Kellogg

In Iowa Brown and Kellogg found that there was nearly twice as much phosphorus as sulphur in the surface rocks of important areas and they came to the conclusion that "all systems of permanent agriculture in Iowa which[164] leave the sulphur out of account would be incomplete and inefficient."

Oregon Bulletin 163

In 1919 Reimer published a bulletin[165] giving the results of years of careful experimentation in Oregon, which proved conclusively that sulphur must be classed as an exceedingly important plant food, and showed that in many cases all or most of the benefit derived from acid phosphate could be secured by using gypsum, and a fifty per cent saving be made. Most of the Oregon soils were found to be well supplied with phosphorus and deficient in sulphur. Agricultural gypsum therefore gave remarkable results, crops of alfalfa being increased from 200 to 500 per cent by the use of 200 pounds of gypsum to the acre. Figure 47 shows the effect of gypsum on alfalfa.

FIG. 47.—Effect of agricultural gypsum on alfalfa in Oregon. Crop from test plots of equal size, the larger pile showing result of agricultural gypsum while the smaller was from plot receiving no sulphur fertilizer. From Oregon Station Bulletin 163, Courtesy SOUTHERN GYPSUM CO., INC.

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[164] Sulfofication in Soils: Iowa Agr. Expt. Station Bulletin 18, pp. 49-111, 1914. Also Iowa Acad. Science, Vol. XXI, p. 17.

[165] Oregon Agr. Col. Expt. Station Bulletin 163, 1919, Corvallis, Oregon.

Description of a typical test plot follows, with Reimer's explanation of the plot:

FERTILIZER APPLIED AND YIELDS PRODUCED
PHOENIX CITY ADOBE SOIL. PLOTS 2 BY 8 RODS.
FERTILIZER APPLIED MARCH 9, 1915.

PLOT	APPLICATION		FERTILIZING CONSTITUENTS		YIELD IN POUNDS			
					1915	1916	1917	TOTAL
		Lbs.		Lbs.				
1	Check				227	450	736	1413
2	Gypsum	59.5	Sulfur	10.00	369	826	936	2131
3	Double superphosphate	40	Sulfur	9.70	361	418	607	1387
			Phosphorus	7.40				
4	Superphosphate	82	Sulfur	10.00	348	728	860	1936
			Phosphorus	7.40				
5	Check				159	260	544	963
6	Sulfur	10	Sulfur	10.00	216	478	676	1370
7	Sulfur	30	Sulfur	30.00	253	422	668	1363
8	Check				294	192	480	896

"Check plot 1 borders on a stream and the soil of this plot is better than that of the other plots. This accounts for the larger yield of plot 1. It would probably be better to ignore this check plot entirely. The fertilizers containing sulfur again produced large increases in yield. The gypsum plot produced a larger yield than the superphosphate plot, and these two plots produced considerably more than the two plots which received flowers of sulfur. The small amount of sulfur in the double superphosphate, amounting to only 9.7 pounds an acre, produced a large increase in yield, especially the first and second seasons. This shows that only a very small amount of sulfur is necessary to produce material increases in yield. The effect of the double superphosphate was barely perceptible the third season of the experiment."

Quite a different type of soil was tested in the plot described below:

FERTILIZER APPLIED AND RESULTS ON BARRON COARSE SAND
PLOTS 2 BY 5 RODS. FERTILIZER APPLIED MARCH 12, 1915.

PLOT	APPLICATION		YIELD IN POUNDS		
			1915	1916	TOTAL
		Lbs.	Lbs.	Lbs.	Lbs.
1	Gypsum	23.4	334	269	603
2	Check		158	149	307
3	Double superphosphate	16.5	265	228	493
4	Superphosphate	33.0	321	342	663
5	Check		194	162	356

"The gypsum, double superphosphate, and superphosphate produced very large increases in yield in this field. It is important to note that the small amount of sulfur in the double superphosphate, amounting to 5.7 pounds an acre, produced an increase of 186 pounds over the nearest check plot. It is also clear that this amount of sulfur is not sufficient to produce maximum yields on this soil, as shown by the larger increases produced by the larger amount of sulfur supplied to the gypsum and superphosphate plots."

Gypsum and nitrogen secreting bacteria

Professors Graves, Carter and others at the Utah Experiment Station have investigated the influence of gypsum and other salts on the production of nitrogen and on the growth of nitrogen fixing bacteria in the soil. They have found that gypsum greatly increases the growth of these helpful organisms. Of some twenty substances used in the tests gypsum was found most useful for increasing the nitrogen in the soil through bacterial activity, and the increase, as measured by their experiments, amounted to 97 per cent.

Gypsum fertilized alfalfa has greater feeding value

Gypsum increases the protein content in legume hays, alfalfa, clover and similar crops. Professor Peterson at Wisconsin found that land plaster more than doubled the protein in alfalfa. Reimer concluded that the feeding value of alfalfa hay from sulphur fertilized plots, without taking into consideration the increased yield, was sufficiently greater to pay for the fertilizer used.

Gypsum and root growth

Professor Reimer found that "the root system of alfalfa fertilized with gypsum and other sulphur fertilizers" is from two to three times as large as that of the unfertilized plants. The value of this larger root system is obvious.

St. John and Olson

In 1909 the Washington Agricultural Experiment Station began a study of Washington soils to determine the amount of sulphur present, and whether the beneficial results already recognized in that section of the United States as resulting from the use of agricultural gypsum, were due to its sulphur rather than its lime content. The results of their work are admirably presented in bulletin 165, of the Pullman Station.*

They consider that, "In a system of farming with legumes

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* Bulletin 165, An Investigation of Sulphur as a Plant Food. State College of Washington, Agricultural Experiment Station, Pullman, Washington, May 1921.

included in the rotation, it has been evident that applications of gypsum have caused very profitable increases in alfalfa. This increased yield has been due to the supplying of sulphur which has been utilized by the legumes in comparatively large quantities and showing, therefore, that sulphur has been a limiting factor in the production of alfalfa. Cereals require small quantities of sulphur compared with the quantity utilized by legumes, and about one-half as much sulphur as phosphorus.

"With increased yields such as have been obtained with the use of gypsum fertilizer, alfalfa growing has become more encouraging and may well be included in the rotation with cereals. On farms where alfalfa has been grown, it has been noted that better yields of wheat have been obtained and the wheat has been found to be of better milling quality. The soil has been rendered better physically and better water absorption and retention have been procured. The annual growing of cereals on land which has been in alfalfa, in place of the two crops in three years or one crop every two years as with

FIG. 48.—Alfalfa roots showing benefit of gypsum fertilization. Large plant with well branched root system from plot fertilized with gypsum which supplied sulphur at the rate of 100 pounds to the acre. The small plant with long slender unbranched root system was from test plot which received no gypsum. Oregon Agr. College Experiment Station Bulletin 163. Courtesy Southern Gypsum Co.

the fallow system, has to be considered as an indirect benefit due to the growing of a legume such as alfalfa.

"QUALITY OF ALFALFA AND CROPS FOLLOWING: The darker green color noted in the alfalfa grown on the gypsum treated plots is also observed in the cured hay when compared with hay obtained from adjoining untreated plots.

FIG. 49.—Field showing effect of agricultural gypsum on clover. The dark streaks on each side show the heavy growth of the clover where gypsum was applied. On the light streak where no gypsum was applied the growth was very scant. From U. S. Department of Agriculture, Bureau Plant Industry, circular 22. Courtesy Southern Gypsum Co.

This difference in color adds to its merchantable value, and generally the highest colored hays are sold for the best price.

"The protein content of alfalfa grown on gypsum and acid phosphate treated land has been found to be higher than that in alfalfa obtained from adjoining untreated plots. The protein found in the alfalfa obtained from the gypsum treated plots was 30 per cent and that from the acid phosphate treated land was 17 per cent higher than that found in the alfalfa grown on the check plots. Similar relations have been found in farmers' lots of alfalfa. Land which has been in alfalfa has been improved both physically and chemically."

A PERMANENT AND ECONOMICAL SYSTEM OF SOIL FERTILITY

Nitrogen

Nitrogen, one of the most important, and certainly the most expensive form of plant food to purchase in chemical form, is effectively and cheaply supplied to the soil indirectly by the use of gypsum.

The legumes, as is generally known, are the hosts of nitrogen-secreting bacteria, and the legumes respond tremendously to a sulphur fertilizer like gypsum. Moreover the gypsum has a very stimulating effect on the nitrogen-gathering or nodule-forming bacteria of red clover roots, as shown by Pitz of Wisconsin[166] and others. Figure 49 shows the results of using gypsum on clover land.

Potash

Potash, which is abundant in most soils, and which, in insoluble form is present even in the first six inches of surface soil equal to the needs of hundreds of years, is made soluble without waste in sufficient quantities by the reaction of gypsum on the potash silicates. This action is assisted by turning under a green crop occasionally.

Phosphate

Many soils are deficient in phosphate and this deficiency may be supplied most cheaply by the use of raw rock phosphate. The solubility of raw rock phosphate has been called in question by the champions of the more expensive acid phosphate. If the rock phosphate is finely ground, however, and as offered to the trade at present its mechanical condition is excellent, and especially if it is turned under with a green crop, like clover or beans, there is sufficient ground for believing it abundantly soluble. Indeed the Illinois system of agriculture as advocated by Hopkins[167] and as successfully practiced throughout that state, shows that rock phosphate is sufficiently soluble even though the precautions suggested above are not carefully observed.

Sulphur

The sulphur essential to the legumes which are the source of the nitrogen supply, and which contributes direct plant food to numerous crops, is best and most cheaply furnished by gypsum. Figure 50 shows the results of tests in use of sulphates on clover and rape.

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[166] Effect of Elemental Sulphur and of Calcium Sulphate on certain of the Higher and Lower forms of Plant Life. Jour. Agr. Research, Vol. 16, pp. 771-780, 1916.

[167] Soil Fertility and Permanent Agriculture. Ginn & Co.

Acid phosphate is expensive as compared with gypsum and raw rock phosphate.

Raw sulphur is effective, but it rapidly sours the soil and this tendency must be constantly checked by the use of lime.

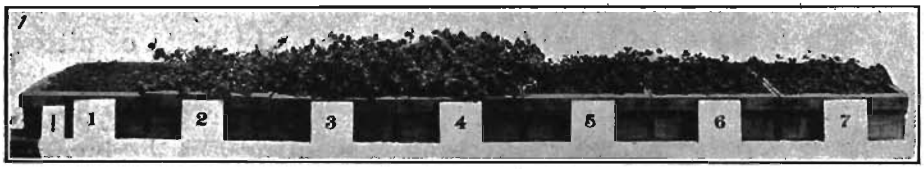

FIG. 50.—Clover showing effect of gypsum and other sulphates on growth, fertilized as follows: 1, check, 2, Nitrogen, Phosphate, Potash. 3, Nitrogen, Phosphate, Potash plus Sodium Sulphate. 4, Nitrogen, Phosphate, Potash plus Gypsum. 5, Sodium Sulphate only. 6, Gypsum only. 7, Sulphur. From Hart and Tottingham.

The sulphur must first be transferred into lime sulphate by chemical reaction in the soil, whereas gypsum, a neutral salt, is itself lime sulphate.

Except for garden plots and truck farms where the large returns per acre justify expensive mixed fertilizers, it is in the interests of economy and efficiency to fertilize through legumes, together with the natural rock fertilizers suitably ground; gypsum and rock phosphates.

Lime is essential also to keep the soil in an alkaline condition, which makes it congenial to most crops.[168]

Experiments by the United States Department of Agriculture show that gypsum has given remarkable increases in the yield of cotton.[169]

Gypsum as cotton fertilizer

The results are shown in the table given below. The following were the costs per ton of fertilizer used:

Nitrate of soda	$50.00
Sulphate of ammonia	62.00
Acid phosphate	14.00
Ground bone	26.00
Rock phosphate	9.00
Floats	8.00
Basic slag	12.50
Sulphate of potash	60.00
Bone black	22.00
Wood ashes	5.00
Gypsum	8.00
Marl	.50
Lime	6.00

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[168] For a synopsis of recent literature on gypsum as a fertilizer see special Bibliography covering Gypsum in Agriculture.

[169] U. S. Dept. of Agriculture, Bureau of Soils, Bulletin 62, p. 10.

The value of cotton in the table was taken at ten cents a pound. The test plots were usually one-tenth of an acre, and were distributed through North Carolina, South Carolina, Louisiana, Georgia, Mississippi, Alabama, Arkansas, and Texas. The greater part of the work was done between 1888 and 1893. The proportion of cases of success to cases of failure (number of tests over 110) was as ten to one.

RESULTS OF FERTILITY TESTS WITH COTTON SOILS

KIND OF FERTILIZER USED	TOTAL AREA	FERTILIZERS PER ACRE		AVERAGE CROP INCREASE PER ACRE		AVERAGE GAIN PER ACRE
		USED	COST			
		POUNDS	DOLLARS	POUNDS	DOLLARS	DOLLARS
Nitrate of Soda	73	160	4.00	64.0	6.40	2.40
Sulphate of Ammonia	17	128	3.97	58.2	5.82	1.85
Acid Phosphate	181	286	1.90	69.8	6.98	5.08
Ground bone	14	279	3.63	92.8	9.28	5.65
Rock phosphate	6	706	3.18	4.0	.40	3.58
Floats	25	201	.80	16.7	1.67	.80
Basic slag	4	230	1.42	1.0	.10	1.52
Boneblack	3	500	5.50	132.7	13.27	7.77
Muriate of potash	36	98	2.16	34.5	3.45	1.29
Sulphate of potash	6	112	3.36	21.2	2.12	1.24
Kainit	161	292	1.75	32.3	3.23	1.48
Wood ashes	3	1,667	4.17	68.0	6.80	2.63
Cotton-seed-hull-ashes	12	271	4.61	41.6	4.16	.45
Lime	3	1,333	4.00	33.3	3.33	.67
Marl	3	900	.23	19.0	1.90	1.67
GYPSUM	11	195	.78	197.4	19.74	18.96
Salt	1	200	.80	8.0	.08	.88
TOTAL	559		2.33	54.0	5.40	3.07

On page 13 of the same bulletin is the following table:

KIND OF FERTILIZER USED	TOTAL AREA	FERTILIZERS PER ACRE		AVERAGE CROP INCREASE PER ACRE		GAIN PER ACRE
		USED	COST			
		POUNDS	DOLLARS	POUNDS	DOLLARS	DOLLARS
Cotton-seed meal Kainit GYPSUM	4	(260) (347) (210)	6.17	233.0	23.30	17.13

The investigations of Kearney and Cameron[170] show that

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[170] Some Mutual Relations Between Alkali Soils and Vegetation: U. S. Dept. Agriculture Bulletin 71.

gypsum counteracts in a wonderful way the injurious effects of certain salts that are present in many soils. It is a veritable specific for black alkali, caused by the presence of sodium carbonate, as has been already pointed out. Magnesium sulphate, magnesium chloride, sodium sulphate, and sodium chloride are injurious to many important plants. In the presence of gypsum the endurable amount of these substances may be increased many times.

Neutralizing injurious salts

Kearney and Harter[171] experimented further and found that gypsum neutralizes the poisonous effects of salts. In the case of common salt or sodium chloride the resistance of the plant was increased as follows:

Lupine (white)	5 to 10 times
Wheat	5 to 10 times
Oats	9 times
Cotton (G. barbadense)	32 times
Beet	8 times

Similar beneficial results were secured with sugar cane in Hawaii. The use of gypsum to neutralize objectionable salts increased the yield of sugar 46 per cent.[172]

Hawaiian sugar

Remarkable results have been secured by the Cuban Agricultural Experiment Station.[173] The data given below were compiled by Dr. Mario Calvino.

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[171] Bulletin of Plant Industry, U. S. Dept. of Agr., No. 113.

[172] Experiment Station Hawaiian Sugar Planters Assn., Bulletin 11.

[173] Review of Agriculture: Commerce and Labor Official Organ. February, 1921, Havana.

TABLE NO. I

		(Quantities are per Caballeria)	
	Plot A Test Plot	Plot B	Plot C
Fertilizer used:			
Waste matter (*cachazas*)	....	26,840 Klgs.	26,840 Klgs.
Ashes	....	13,420 Klgs.	13,420 Klgs.
Calcium sulphate (gypsum)	....	....	5,368 Klgs.
Value of the fertilizer: Waste matter	....	$134.20	$134.20
Ashes	....	134.20	134.20
Gypsum	....	....	107.36
Total	....	$268.40	$375.76
Yield (*arrobas*)	63,784	94,000	177,952
Difference of yield as compared with the test plot (*arrobas*)	....	30,216	114,168
Value of this difference, figuring 10 *arrobas* of sugar cane at $7.50	....	$2,266.20	$8,562.60
Net gain, deducting the cost of the fertilizers	....	$1,997.80	$8,186.84
Difference of yield, comparing the plot which was treated with gypsum with the plot which was not (*arrobas*)	....	....	83,952
Value of this difference, figuring 100 *arrobas* of sugar cane at $7.50	....	....	$6,296.40
Net gain, deducting the cost of th gypsum	....	....	$6,189.04

NOTES:—The capital of $268.40 invested in waste matter and ashes produced in about 14 months $1,997.80 more than the test plot, or 744 per cent.

The capital of $375.96 invested in waste matter, ashes and calcium sulphate (gypsum), produced in about 14 months $8,186.84 more than the test plot, or 2,177 per cent.

The capital of $107.37 invested in gypsum produced in about 14 months $6,189.04 more than the plot fertilized with waste matter and ashes only, or 5,764 per cent.

(A caballeria equals approximately 33.33 acres).

(An arroba equals approximately 25.4 pounds).

Gypsum as manure preservative

Ground gypsum when sprinkled over stable manure, changes the volatile ammonium carbonate into the non-volatile ammonium sulphate. In this way it preserves the valuable nitrogen compounds which are otherwise lost. Gypsum also aids in checking the decomposition of the organic materials and humus in the manure piles. From two to four pounds of gypsum may be used with profit daily for each head of stock.

Anhydrite can be used satisfactorily for agricultural gypsum provided it is very finely ground. This finer grinding is necessary on account of the fact that it is less soluble than gypsum. It is higher in sulphate and if its limited solubility is overcome by fine grinding it can be used without hesitation in making agricultural gypsum.

CHAPTER XI

OTHER USES FOR RAW GYPSUM

In addition to the use of gypsum in agriculture, in the manufacture of Portland cement and calcined plasters, there are a number of places in the arts where gypsum plays an important part.

Terra Alba

Very white gypsum which has been ground and bolted through a 200 mesh screen is sold as a filler for paper and paint under the name of terra alba. In the making of paper its function is to close the pores and permit of a hard finish.

Flux

In certain processes gypsum is added as flux to galena concentrate. In Germany it is used similarly in the concentration of lead-copper matte in reverberatory furnaces. Large quantities are required in the smelting of certain nickel ores in New Caledonia. The gypsum in this case furnishes the sulphur necessary for collecting the metal into a matte and also acts as a base to counteract and slag the siliceous gangue.[174]

Insecticides

Finely ground raw gypsum as well as calcined gypsum is used to dilute arsenic poisons that are employed in combating insects. Hundreds of tons of gypsum are used annually for this purpose. A large percentage of this amount is used in fighting potato bugs. The following experiment was one of a series tried by the Department of Agriculture in their endeavor to find suitable methods to control this pest.

> "*Experiment No. 6*—This plat was treated with a mixture of Paris green and land plaster at the rate of 1 pound of Paris green to 50 pounds of plaster, the mixture being put in a coarse burlap bag and sifted over the plants by a negro laborer in the usual plantation manner, the amount of dust used being at the rate of 320 pounds per acre. The wind prevailing at the time carried a large part of the dust from the plat as it was applied, but the portion remaining was sufficient to thoroughly destroy the larvae by forty-eight hours afterwards. This mixture killed 90 per cent of the larvae during the first twenty-four hours, and is very effective in controlling the potato beetle."[175]

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[174] Stone, Bureau of Mines, Technical Paper No. 155, p. 38.

[175] U. S. Dept. of Agriculture, Bureau of Entomology, Bulletin 82, Part 1, p. 5.

Alabaster

The mineralogical term alabaster is applied to pure white, semi-transparent gypsum which is used for statuary and vases. Its softness renders it easier to work than marble but the same property renders it less durable.

Crayons

The common school crayon known as chalk is made from finely ground uncalcined gypsum. The gypsum, with a suitable binder, is molded under pressure.

Imitation marble

Numerous patents have been issued to cover processes of hardening gypsum blocks till they equal marble. Some ambitious attempts have been made to establish a gypsum industry along this line. The processes are often successful but inasmuch as not one of the numerous attempts has survived under actual business conditions, it may be assumed that the cost of the processes is too great to permit of competition with marble and similar natural stones.[176]

Sulphuric acid

Numerous patents have been issued for extracting sulphuric acid from gypsum and during the war it is stated that Germany depended largely on gypsum for her supply of this essential. Our own country during the last months of the war took initial steps, at Grand Rapids, toward securing sulphuric acid from this source.

When calcium sulphate is treated in an open tube it decomposes at 1200° C., the products being CaO and SO_3[177]. When it is mixed with molecular proportions of silica the temperature of dissociation is 1005° C. While these temperatures are high they are within the range of those used for Portland cement and the process apparently has commercial possibilities. Certain patents issued in connection with these processes are described in the annual report of the Iowa Geological Survey for 1901 (Vol. XII, pp. 155-156) and others are reviewed in Bulletin No. 7 of the Department of Chemistry of South Australia (pp. 155-157).

Miscellaneous uses

Raw gypsum is used in the manufacture of rubber goods, and phonograph records. With other substances it enters largely into the composition of certain kinds of buttons. It plays a useful part in certain methods for filtering oils.

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[176] For description of some processes see Geol. Survey of Michigan, Vol. IX, p. 206.

[177] H. O. Hoffman, Journal Society of Chemical Industry, p. 333, 1912.

POSSIBLE FUTURE USES

Dry spray

Considerable attention has been called to the possibility of widely extending the use of dry spray for orchard use and for fighting boll weevil. Finely ground gypsum seems to be an admirable filler for this purpose. The readiness with which it can be ground to pass 200 mesh, and the fact that it is not injurious to eyes, lungs or skin, are important properties to consider in this connection.

CHAPTER XII

CHEMICAL CHARACTERISTICS OF CALCINED GYPSUM

Natural forms

As set out in chapter I there are two natural forms of calcium sulphate, the hydrated form with chemical formula $CaSO_4\ 2H_2O$, correctly called gypsum, and the anhydrous variety $CaSO_4$ known as anhydrite.

Extensive beds of gypsum exist in our own country and elsewhere, free from anhydrite. Anhydrite also is found occasionally that is free from the water of crystallization which characterizes gypsum. As a rule, however, anhydrite shows on careful analysis, some water of crystallization, and this chemical test, easily confirmed by microscopic examination, establishes the fact that there is present in each case an intergrowth of the two minerals.

Artificial forms

When gypsum is subjected to heat, a variety of chemical forms may result depending on the temperature to which the gypsum is exposed and the duration of the exposure.

Existing confusion

For over a century the various substances resulting from the partial or total dehydration of gypsum have been the subject of chemical study and a considerable volume of technical literature has grown up around them. Davis[178] in 1907, said that in spite of the work of such well known chemists as Lavoisier, Marignac, Le Catalier, Van't Hoff, and others, the confusion that exists on this subject is without parallel in inorganic chemistry. In 1916 L. A. Keene[179] was obliged to reiterate this statement, although in the meantime important articles on the subject had been published by Desch, Blake, Hursh, Rohland and Glasenapp.

Importance of thorough investigation

Inasmuch as progress in the technology of gypsum plasters is largely dependent on a correct understanding of the chemical characteristics of calcined gypsum it is essential that any treatise on gypsum that aims to serve the industry, must present all of the information available on this subject.

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[178] Journal Society Chemical Industry 1907, p. 727.

[179] Journal Physical Chemistry 1916, p. 701.

It must be kept in mind that certain physical characteristics of plaster, and notably plasticity, are as essential as tensile strength. Plasticity, as well as tensile strength, is dependent on the conditions that govern the calcining process. Only recently have attempts been made to consider and measure plasticity scientifically, and nothing has been published which sets forth the reasons for the relationship between plasticity and calcining temperature.

Chemists overlook physical properties of plaster

HISTORICAL SKETCH

Our knowledge of the chemical characteristics of gypsum dates back to the work of Lavoisier in 1765. He determined its solubility; that the mineral was a chemical salt; the nature of the acid and the base; and the presence of the water of crystallization. He called attention to the fact that overburned gypsum will not set in water, and that the setting of plaster of Paris is a simple process of crystallization, in which process the plaster of Paris builds into its structure the water of which it had been robbed by heat.[180]

Lavoisier

Payen in 1830[181] published a paper giving results of experimental work which amplified somewhat the earlier work of Lavoisier. He found that gypsum began to calcine at a temperature of 80° C. (187° F.) in a current of dry air, and the process continued rapidly as the temperature was raised. He noted that gypsum calcined at 200° C. (392° F.) hydrated slowly, and that gypsum calcined at 300°-400° C. (572°-752° F.) loses the power of taking on water of crystallization.

Payen

Berthier in 1840 demonstrated that the commercial plaster of Paris of his day contained from 3 to 8 per cent of water, and this corrected an error of Lavoisier who had reported that all of the water of crystallization was driven off in the calcining process.

Berthier

In 1883 Le Chatelier[182] published the results of investigations which were of great practical importance. He noted that the plaster of Paris of his day contained some 7 per cent of water, and that the decomposition of gypsum in the cal-

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[180] Acad. des Science, Compt. Rend., Paris, 1765.

[181] Chimie Industrielle 1830.

[182] Acad. des Sci., Compt. Rend., 1883.

cining process took place in two very distinct periods of time. **Le Chatelier** He treated a measured quantity of gypsum gradually in a paraffin bath, recording the temperature every five minutes. He found that the temperature did not rise uniformly, but that there were two periods at which it remained nearly stationary. After rising rapidly to 110° C. (227° F.) it then rose more slowly to 120° C. (248° F.), stood stationary for some time at 128° C. (262° F.) then went on more rapidly to 140° C. (284° F.), from this point the temperature moved slowly to 163° C. (325° F.) where there was a second stop, which was not as long as the first. W. A. Davis plotted the curve shown in figure 51 from these experiments, using the time as abscissa and the temperature as ordinates.

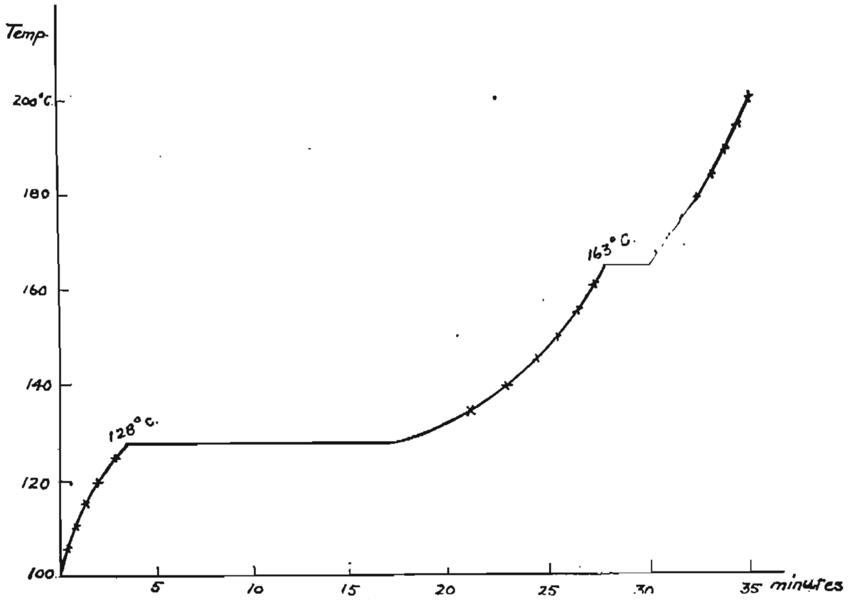

FIG. 51.—Temperature gradient for the decomposition of gypsum. Courtesy New York Geological Survey.

Le Chatelier concluded "that these two halts in the rise of the thermometer were brought about by the absorption of heat which accompanied the elimination of the water. They indicate the existence of two hydrates having different temperatures of decomposition."

Further experimental work of Le Chatelier determined exactly the chemical formula of the half hydrate.

Glasenapp in 1908[183] classified gypsum plasters as follows:

Glasenapp's Classification

Sets with water, owing to formation of crystals.	107°C (224°F) hemihydrate 107°C (224°F) to 170°C (338°F) mainly hemihydrate 170°C (338°F) to 200°C (392°F) more or less dehydrated hemihydrate. Sets rapidly with water to form the hemihydrate. (The soluble anhydrite of Van't Hoff and others. F. A. W.) 200°C (393°F) to 250°C (482°F) contains small quantity of H_2O, sets slowly, at first with formation of hemihydrate. 250°C (482°F), contains traces of H_2O, sets very slowly	Plaster of Paris
Set slightly or not at all[184]	400°C (752°F) to 700°C (1292°F) anhydrous gypsum, practically dead burned. 700°C (1292°F) to 800°C (1472°F) beginning of formation of flooring gypsum.	
Set slowly with water without alteration of form[184]	800°C (1472°F) flooring plaster with crystal form of the granular anhydrite. 900°C (1652°F) to 1000°C (1832°F) flooring gypsum with full development of granules. 1000°C (1832°F) to 1400°C (2552°F) flooring plaster with granules of increased size and hardness and rising content of basic sulphate.	

Calcined gypsum, when pure, and when composed entirely of hemihydrate ($CaSO_4 \frac{1}{2}H_2O$) consists of 93.8 per cent of calcium sulphate and 6.2 per cent water. As actually manufactured the hemihydrate forms the greater part of calcined gypsum, but mixed with it there may be small amounts of

1. raw gypsum.
2. soluble anhydrite, or No. 1 anhydrite.
3. dead burned gypsum, or No. 2 anhydrite.
4. natural anhydrite or No. 4 anhydrite.

Raw gypsum should not be present unless fast setting material is desired, for raw gypsum speeds the set and wall plaster made from calcined gypsum containing some raw material requires more retarder and is apt to be irregular in set.

"First settle" calcined gypsum

Calcined gypsum intended for use in wall plaster is calcined to a temperature of approximately 320° F. (160° C.). It has passed through the first boil which takes place at 262° F. (128° C.) and is just ready to enter the second boil which begins at 325° F. (163° C.) (See Fig. 51.) It contains a small amount of soluble anhydrite.

In addition to the hemihydrate, there are considerable quan-

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[183] Journal Society Chemical Ind. 1908, p. 858.

[184] When treated with alum solution set owing to formation of crystals.

tities of soluble anhydrite, and some dead burned gypsum in second settle calcined gypsum. The nature of the second settle product is considered at length in chapter VI.

"Second settle" calcined gypsum

Soluble anhydrite was first recognized by Van't Hoff, who formed it directly by heating gypsum in a vacuum over sulphuric acid, without the intermediate formation of the hemihydrate. In the ordinary calcining processes hemihydrate is first formed and this is converted to soluble anhydrite on further heating.

Soluble anhydrite

Soluble anhydrite is very soluble in water and very unstable. It readily takes moisture from the atmosphere and returns to the hemihydrate. To determine its presence, material must be taken directly from the kettles as they are discharged, and kept in air tight containers till analyses can be made.

The nature of gypsum calcined at high temperatures is considered in chapter XIX.

THE SETTING OF CALCINED GYPSUM

The generally accepted theory to account for the set of gypsum plasters was first propounded by Le Chatelier. He pointed out that when water is added to calcined gypsum a certain portion of it promptly goes into solution. Gypsum itself is very soluble, and the hemihydrate is at least five times as soluble as gypsum. When water is added to calcined gypsum, therefore, it very quickly becomes supersaturated with reference to gypsum and crystals of that substance begin to form. Only a portion of the hemihydrate actually goes into solution. Other portions of the hemihydrate serve as nuclei about which the crystals of gypsum grow. These crystals interlock and the whole mass is firmly bound together by them. If too much water is added the spaces between the crystalline centres is so great that the interlocking is imperfect or completely prevented, and in consequence the plaster is weak or does not set up at all.

Setting of gypsum plaster

Grimsley[185] assumes that a certain amount of raw gypsum in the calcined gypsum is necessary to start the crystallization.

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[185] Kansas Geol. Survey, Vol. V, p. 167.

Without question raw gypsum greatly accelerates the setting action, but microscopic examination of calcined gypsum shows that material free from raw gypsum sets satisfactorily for wall plaster purposes. Indeed the manufacturer of gypsum wall plasters is exceedingly careful to exclude every trace of raw gypsum from the calcined plaster that he uses for making wall plaster.

CHAPTER XIII

PHYSICAL PROPERTIES OF CALCINED GYPSUM[186]

In the strictest sense calcined gypsum is a fine powder, and its more important physical properties are its color, fineness, and weight.

It is the custom to ascribe to calcined gypsum the properties which it possesses when mixed with various degrees of water to form a paste, and in this form its more important properties are, its setting time; plasticity; and expansion.

It is customary also to speak of the properties of the hard masses resulting from the setting of calcined gypsum pastes as the properties of calcined gypsum. The more important of these properties are tensile, compressive, and adhesive strength; hardness; and conductivity of heat and sound.

In this chapter the properties of calcined gypsum will be considered in all three of these aspects. Before taking up the properties of calcined gypsum pastes and of the solids resulting from the setting up of these pastes it will be necessary to consider at some length the question of the consistency of these pastes since the physical properties of pastes and resulting solids vary with the percentages of water added to the calcined gypsum.

Color

The color of calcined gypsum is dependent on the color of the mineral used in its manufacture and on the fineness of grinding. Inasmuch as gypsum varies widely in color, there is a wide range in the color of the calcined product. Color is not an important property of gypsum that is used in making plaster for base coats, nor is it essential for many of the purposes for which it is used in the arts. A pure white gypsum is often desired for finishing plaster and for moulding plaster. Certain beds of Nova Scotia gypsum have been preferred for the manufacture of finishing plaster. During the world war, the United States

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[186] It is understood that the term calcined gypsum is applied to gypsum calcined under 400° F. with the formation of the hemi-hydrate or soluble anhydrite; and that the terms hydraulic gypsum and Keene's cement are applied to the products of calcination at higher temperatures.

was thrown upon its own resources and the genuine merit of certain beds of gypsum located in the Western States was recognized. Calcined gypsum made from these gypsum beds has as light a color and is in every way as suitable for the highest grade of finishing plaster, as the imported article.

Fineness

The fineness of calcined gypsum is entirely a matter of grinding and the standards are largely determined by the demands of the trade. For certain purposes very finely ground material is desired. Fineness of grinding is discussed somewhat at length in chapter VIII which deals with the Technology of Calcined Gypsum.

Weight

The weight of calcined gypsum is largely dependent upon the fineness to which the material is ground. As set out in chapter I calcined gypsum, ground so that 90 per cent passes a 100 mesh screen, when loose weighs from fifty to sixty-five pounds per cubic foot, and when well shaken down or taken from bins where it has been stored for some time, from sixty-five to seventy-five pounds per cubic foot.

NORMAL CONSISTENCY

In order that the setting time and tensile strength of different calcined gypsums may be accurately compared, it is essential that the different specimens be mixed with water to the same consistency. If samples of calcined gypsum from each of the sixty-five mills in the United States are taken, it will be found that when like amounts of water are added, the consistency of the resulting pastes will differ more or less for every sample. In consequence of this fact it is generally felt that an accurate method for establishing a "normal" consistency is the most important step in the standardizing of methods for testing the strength and setting time of calcined gypsum.

German method for determining normal consistency

The German Gypsum Assn. some years ago adopted a rather simple, but not very accurate method, for bringing samples of calcined gypsum whose physical properties were to be compared, to a common, or normal consistency. Their directions are as follows: "Place in a glass vessel 100 cc. of water. To this water add gypsum by hand till it ceases to sink; that is, till the water surface disappears and a thin dry layer of gypsum remains visible for a period of 3 to 5 seconds. All of the gypsum necessary should be added in 1½ to 2 minutes. While adding the calcined gypsum neither the glass nor the paste should be touched, jarred, or stirred in any way. The glass containing the paste is now weighed and the ratio of the dry material to the water (100 cc.) is recorded as the normal consistency."

Determination of normal consistency at Iowa City

In connection with tensile strength tests conducted for this report by Messrs. Holt and Holmes, of the Department of Engineering, Iowa State University, the question of normal consistency was necessarily considered, and the following method was used: "In the determination of normal consistency 300 grams of plaster were poured upon a measured quantity of water, the mixture stirred to an even consistency, formed into a ball with the hands, and pressed by one hand into the larger end of the rubber ring (specified by the Committee on Uniform Tests of Cement of the

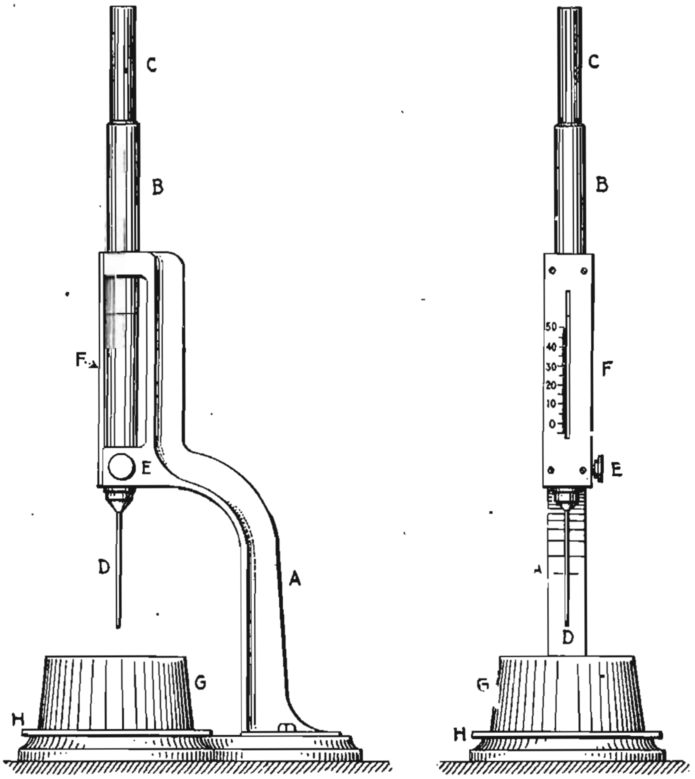


FIG. 52.—Vicat needle. Courtesy of American Society for Testing Materials.

American Society of Civil Engineers) held in the other hand and through the ring so as to completely fill it with paste, leaving the surface flush at the larger end. The ring is then placed on its larger end on a glass plate, and the excess paste at the smaller end removed and the surface smoothed off with a trowel. The paste, confined in the ring, resting on the plate, was placed under the rod of the Vicat needle (see figure 52), the larger end of which was carefully brought in contact with the surface of the paste, the scale read, and the rod quickly released. The paste was assumed to be of normal consistency when the rod (or cylinder) settled to a point ten millimeters below the original surface in one minute after being released. In order to avoid inconsistent results from setting of the plaster the whole operation should be completed within three minutes from the time the calcined gypsum is put in the water. It was found that the method gave a very definite and positive method of determining normal consistency, in that the use of a quantity of water one per cent greater than that required for normal consistency permitted a settlement of the rod far exceeding ten millimeters; while the use of one per cent less than that required for normal consistency resulted in a settlement decidedly less than ten millimeters."

Samples of calcined gypsum tested in this manner for normal consistency gave the following results:

SAMPLE	TRADE NAMES	PER CENT OF WATER
A	Plaster of Paris, Ft. Dodge	58
B	Structolite	48
C	Moulding Plaster, Blue Rapids	55
D	Moulding Plaster, Blue Rapids	56.5
E	Moulding Plaster, Blue Rapids	52
F	Moulding Plaster, Blue Rapids	49
G	Moulding Plaster, Grand Rapids	40
H	Moulding Plaster, Grand Rapids	55
I	Stucco, Fort Dodge	56.5
J	Moulding Plaster, Fort Dodge	46.5
K	Dental Plaster, Fort Dodge	41
L	Plaster of Paris, Fort Dodge	56
M	Plaster of Paris, Fort Dodge	55
	Dental Plaster (unknown)	45.5

Southard viscosimeter

An apparatus for testing normal consistency has been devised by Mr. Geo. L. Southard and is known as the Southard viscosimeter. The instrument is shown in figure 53 and may be briefly described as follows:

The apparatus consists of a brass cylinder of 2-inch bore with a circular disk flange flush with its upper end. The screw actuating the piston is five-eighths inch in outside diameter, one-fourth inch pitch, right-hand square threads one-sixteenth inch deep. The top of the brass disk flange is etched with concentric circles which vary in diameter from 6 cm. up to 28 cm. by increments of 2 cm.

When in position for use the brass flange is to be maintained in a true horizontal position.

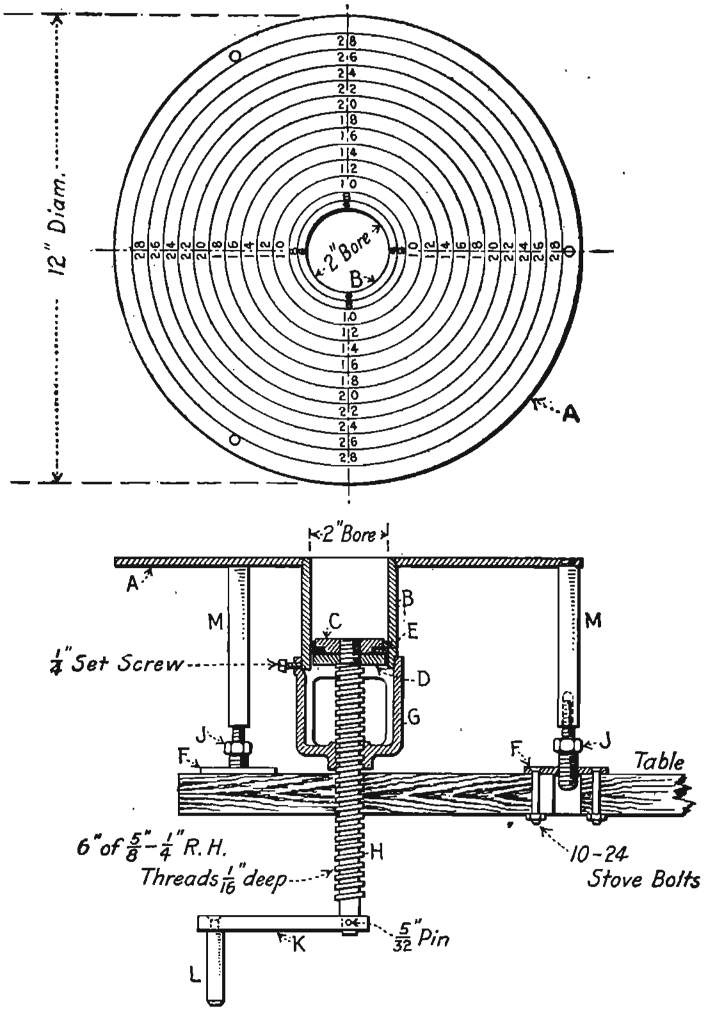
To prepare this viscosimeter for use see that the piston, cylinder walls and top of plate are clean. Then by turning the crank, bring the top of the piston exactly flush with the top of the plate. Then by reverse cranking make ten complete turns, which will lower the piston to a point 2½ inches below the top of the plate. Next proceed to prepare the sample of dry calcined gypsum, adding to it and mixing with it thoroughly in the dry state, 0.1 per cent of retarder. Then make a mixture of at least 300 grams total of this retarded calcined gypsum and water. Add the retarded calcined gypsum to the water, allowing it to soak two minutes. Then stir vigorously to an even fluidity for one minute. Then immediately pour this mixture into the well in the center of the plate of the viscosimeter, filling the well just flush with the top of the plate. Then immediately turn the crank at the bottom of the viscosimeter ten turns at the rate of one turn per second. The upward motion of the piston will cause the mixture to overflow into a circular patty, it being understood that the top face of the circular disk of the instrument is to be adjusted and maintained in a true horizontal plane. Next take the average of the quadrant readings on the concentric lines on top of the plate.

A mixture is of normal consistency if with this operation it gives a circular patty averaging 9.7 cm. in diameter. The normal consistency shall be expressed as the number of cubic centimeters of water required to be added to 100 grams of the plaster under test in order to make the mixture of normal consistency.

Field method for normal consistency

The committee of the American Society for Testing Materials, having in its charge gypsum and gypsum products, recommends the following simple method for determining normal consistency in the field, and reports that fairly accurate results are obtained thereby.

"The apparatus shall consist of a piece of brass tubing 2 inches in inside diameter and 4 inches long, and a piece of



A, $\frac{3}{16}$" Hard Brass Plate Scale Disk.
B, 2" Ex. H. Seamless Brass Tube Cylinder.
C; Brass Piston Top.
D; " " Bottom.
E; Leather " Packing.
F, $\frac{3}{16}$" x 1" Flat Bar Steel Support Plate.
G; Brass Cage (Open on two Sides).
H; $\frac{5}{8}$" Hard Brass Piston Screw.
J; $\frac{1}{2}$" Hex. Brass Support Stud.
K; $\frac{3}{8}$" x $\frac{3}{4}$" C. R. S. Screw Lever.
L; $\frac{3}{8}$" Diam. C.R.S. Lever Handle.
M; $\frac{1}{2}$" Diam. C.R.S. Support Rod.

FIG. 53.—Southard Viscosimeter. Courtesy American Society for Testing Materials.

plate glass about 8 inches square. The brass tubing shall be cut off true and square at the ends, and to the exact length.

Thoroughly wet the cylinder and glass plate by immersion in clean water. Set the cylinder on end on top, and in the center of, the glass plate.

"Prepare a dry sample of calcined gypsum by adding to it and mixing thoroughly, in a dry state, 0.1 per cent of retarder by weight. Next make a mixture of this retarded calcined gypsum and water of sufficient quantity to slightly more than fill the cylinder. The mixture shall be made by adding the retarded calcined gypsum to the water, allowing it to soak for two minutes. Now stir vigorously to an even fluidity for one minute, and at once pour this mixture into the cylinder so as to completely fill it level with the top.

"Immediately raise the cylinder from the glass with a quick, straight and upward motion so as to withdraw it from the stucco mass within. This act will allow the stucco and water mixture to leave the cylinder, assuming a coneshaped circular patty upon the glass plate.

"The normal consistency is a mixture which will give a circular patty averaging 9.7 cm. in diameter, and shall be expressed as the number of cubic centimeters of water required to be added to 100 g. of the plaster under test in order to make the mixture of normal consistency."

SETTING TIME

Definition The period required for calcined gypsum to harden is called its setting time. For practical purposes two stages in the hardening process are recognized and should be carefully distinguished.

Initial set Calcined gypsum, after being mixed with water, can be manipulated freely for a certain period without reducing its ultimate tensile strength. When the point is reached where further manipulation measurably reduces the tensile strength it is said to have taken its initial set.

Final set When the material has further hardened so that it cannot be worked conveniently with a trowel it has taken on its final set. The time of final set does not correspond with the point of maximum tensile strength, which is arrived at many days later.

Determination of setting time Inasmuch as the value of calcined gypsum for many purposes is largely dependent on the length of time it can be conveniently manipulated the determination of final set is very important. The determination of initial set is of less importance, for practical tests show that the loss in tensile strength resulting from the manipulation of calcined gypsum plaster for some time after initial set has taken place, is not serious. In the case of gypsum wall plasters, initial set probably takes place in a majority of instances, before the plaster is applied to the wall. The strength method for determining initial set is exceedingly laborious, as a great many briquettes must be broken if accuracy is desired. The German Gypsum Association has adopted a simple empirical method, according to which the material is said to have taken on its initial set when a knife that is passed through it leaves a clean cut. The paste which has been mixed with water to normal consistency is poured on a glass plate and at frequent intervals a knife blade is passed through it. When the edges of the cut cease to flow together the initial set is recorded.[187]

Determining initial set

It is very desirable that a common standard for final set be agreed upon, so that comparisons may be accurately made. Many methods are in use which give widely divergent results. Mr. Emley has considered at some length the problems involved in determining the time of set of calcined gypsum and has suggested methods for use in determining final set. His paper is presented at length in appendix IV.[188] Extended experiments were conducted by Mr. Emley to determine the relative merits of the "Vicat needle", and the "rise of temperature" methods for determining final set.

Determination of final set

Heat is generated by the process of hydration which constitutes the setting process of calcined gypsum. Mr. Emley found that the point of maximum temperature occurred considerably after the gypsum had taken on its final set (defining final set as the time after the material is no longer workable). His conclusion from his experiments was (see appendix IV) that the measurement of the temperature rise is useless for determining the time of set.

Rise of temperature method

Mr. Emley's experiments led him to the conclusion that the use of the Vicat needle was the most satisfactory method of determining final set, and he outlines the following method of procedure: "Determine first the

Vicat needle method

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[187] See Appendix IV for a more complete statement.

[188] Warren E. Emley, Measurement of the Time of Set of Calcined Gypsum: Transactions American Ceramic Society, Vol. XIX, 1917.

normal consistency using the Southard instrument, as recommended by Sub-Committee 4 of Committee C-11, A. S. T. M. Determine from this the amount of water which must be added to 100 grams of the sample to produce a paste of normal consistency. In a perfectly clean porcelain casserole, put three times this amount of distilled water, weigh out 300 grams of the sample and transfer to a clean sheet of glazed paper. Also provide a clean glass stirring rod about ⅛ in. diameter. When the second hand of a watch points to zero, transfer the sample from the paper to the casserole. This should be done as quickly as possible without splashing, and should not take more than two seconds. Let the plaster soak quietly until the second hand again reaches zero, when the mixture is to be stirred vigorously by means of the stirring rod for one minute, by which time the mass should be homogeneous.

"At the end of the second minute, this mixture should be poured into the mold for the Vicat needle. At one minute intervals, the needle is allowed to sink into the paste. Eventually there will be found a time when the needle will not penetrate clear to the bottom. The time elapsed between the time when the sample was added to the water and the time when the needle no longer penetrates to the bottom is recorded as the time of set.

"The sample, water, casserole, and mold shall be at a temperature of not less than 20° C., nor more than 25° C., at the beginning of the experment.

"The Vicat needle and the mold are described in the standard specifications for cement—1915 Yearbook, A. S. T. M., page 359. The mold is made of hard rubber, and it will be found difficult to remove all traces of set plaster from it without scraping, which might cause injury. To overcome this, the mold should be prepared for use by dipping it in melted paraffin. This will prevent adherence of the plaster to a great extent, and the mold can be cleaned thoroughly and easily by heating it very gently."

The German method

The method for determining final set adopted by the German Gypsum Association is wholly empirical. A paste made according to their established rules for normal consistency, is allowed to harden till pressure by the finger shows that the set has advanced considerably. From that time at intervals of one minute shavings about 2 mm. (about one-tenth of an inch) thick are cut off. When, with the knife blade moving fairly fast, the shavings come off grainy and brittle, the final set is said to have been reached.[189]

FACTORS GOVERNING TIME OF SET

Setting time and consistency

The discussion of normal consistency, necessarily introduced before the consideration of setting time, has already brought out the fact that the amount of water used in mixing is an important factor in the setting time of calcined gypsum. Householder[190] sums up a series of experiments in the curve shown in figure 54. The time of set was determined by the methods proposed by Mr. Emley and quoted above.

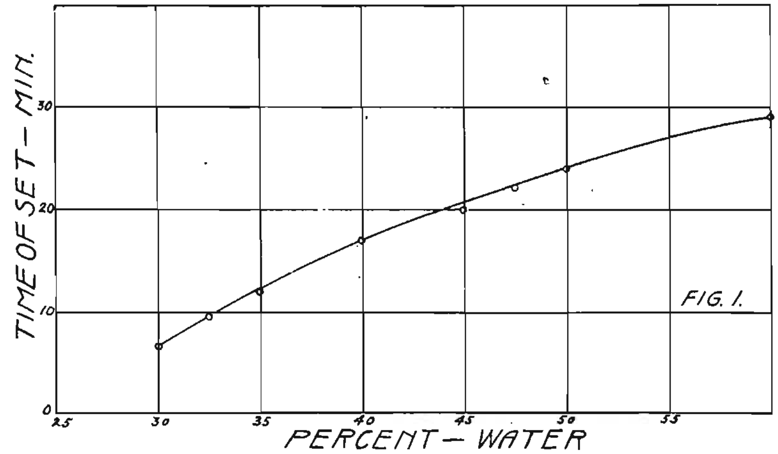

FIG. 54.—Diagram showing relationship between per cent of water used and setting time of calcined gypsum. Courtesy Journal of Ceramics.

Calcining and set

Imperfectly calcined gypsum, that is, calcined gypsum containing some raw material, sets much faster than gypsum that has been properly carried to either the first or the second settle. Gypsum reground after calcining sets faster than material not reground, according to tests by Winterbottom.[191]

The explanation probably lies in the fact that the tailings that are reground contain fragments that are not calcined to

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[189] For a more complete statement including the German method of obtaining normal consistency, see appendix III.

[190] Some factors influencing the time of set of calcined gypsum. Paper given in full in appendix V.

[191] D. C. Winterbottom, Dept. of Chemistry, South Australia, Bulletin No. 7, p. 104.

the center, and the process of regrinding releases some raw material.

Certain impurities act as a retarder. This is notably true of colloidal clay that makes up 15 to 25 per cent of a calcined gypsum made from gypsite. The retarding effect of this clay is so great that very little retarder need be added for wall plaster purposes. Admixture of a sharp sand speeds the set of calcined gypsum, while a loamy sand may actually retard it.

Impurities and setting time

In general it may be said that substances that furnish nuclei about which the gypsum in solution can crystallize act as accelerators, and that materials that interfere with the interlocking of the growing crystals have a retarding influence. These matters are further considered in chapter XX on Retarders and Accelerators.

Agitation of calcined gypsum paste hastens its set. Householder has shown by diagram the accelerating effects of stirring and these diagrams are given in appendix V.

Stirring

PLASTICITY

In connection with calcined gypsum and similar substances, the word plasticity is given a meaning somewhat more restricted than in common usage. The dictionary defines plasticity as "that property of matter by virtue of which it can be molded into shape and will retain that shape". The lime section of the American Society for Testing Materials proposes that "Plasticity is that property of a material or combination of materials by virtue of which it deforms continuously and permanently during the application of force".

Definition

Plastering materials and clays, obviously, to be plastic must be combined with water, and their behavior when moving under pressure will indicate their plasticity.

A calcined gypsum paste is highly plastic if, when forced through an orifice, it presents a continuous, clean, unbroken surface. A plastic plaster is neither sticky nor sandy. It feels soft and velvety and a trowel passes over it as over an oiled surface.

The ability to take on and hold water in the face of the absorptive competition of the background is an essential characteristic of a plastic plaster.

The plasticity of plasters made from calcined gypsum is a highly important property, and the subject will be considered further in chapter XV where gypsum plasters are considered.

The question of plasticity is presented further and in an instructive way in appendix VII where the specifications for the Emley patent for making plastic gypsum are set forth.

Hardness

Surfaces made from ordinary gypsum plasters used neat or with suitable sand not in excess of two parts by weight to one of plaster, are abundantly hard for all the usual structural demands. Until recently the hard surface given by gypsum plasters has been somewhat reduced by the necessity of mixing hydrated lime with the finish coat to secure the necessary plasticity. With the new processes for making plastic gypsum, however, a pure gypsum finish becomes possible. Where surfaces of unusual hardness are required Keenes cement, a standard gypsum product, may be used. Special processes for hardening gypsum surfaces are described in chapter XXI.

Compressive strength

The compressive strength of calcined gypsum depends upon the amount of water used in mixing; the temperature of calcination; the dryness of the material; and the purity of the material.

Second settle calcined gypsum (gypsum calcined at 385° F.) gives a block of higher compressive strength than first settle calcined gypsum. When mixed with water to normal consistency its compressive strength is about 2000 pounds per square inch. The compressive strength of first settle material is about one-half as great. This subject is considered somewhat at length in connection with structural gypsum in chapter XVIII.

Heat conductivity

Gypsum is a poor conductor of heat. This important property adds to its value in every one of the many forms in which it is used as a building material. While its low conductivity is a valuable characteristic of gypsum plasters, it is an even more important property of gypsum blocks and boards. This property makes it a remarkably good material for use in roofs and floors.

"Compared with other commonly used fireproof materials, a gypsum roof construction 3 inches in thickness will save about 125 sq. ft. of radiation (or 290 lineal feet of 1¼ inch pipe) or from three to four tons of coal for heating per year, for each 1,000 sq. ft. of roof area so covered. These figures are based upon test information submitted by Prof. G. F. Gebhardt, Armour Institute of Technology, and Prof. R. C. Carpenter, Cornell University. Professor Gebhardt's tests give the following in terms of B.T.U. transmitted per hour per degree difference in temperature through different thicknesses of gypsum and concrete.[192]

	B. T. U.	
THICKNESS—INCHES	GYPSUM	CONCRETE
0.250	.667	.780
0.500	.575	.770
0.750	.503	.757
0.875	.476	.750
1.000	.455	.745
2.000	.314	.706
3.000	.242	.670
4.000	.196	.635"

Gypsum posseses a peculiar virtue as an insulating material for protecting columns and beams of wood or metal from the high temperatures that develop during a conflagration. This property grows out of the fact that the gypsum must be deprived of its water of crystallization before its temperature can be made to rise above that required for its dehydration, 105° C. (221° F.). In figures 55 and 56 it has been proven on a large scale as well as in laboratory tests, that a protective coat of two inches of gypsum will protect steel against the temperatures that develop in severe conflagrations.

Commenting on the experiments of which the diagrams shown as figures 55 and 56 are a partial illustration, Hull[193] says:

"It is found that the length of time required to reach 600° C. at depths of 1½ and 2½ inches does not vary greatly in the clay and concrete specimens. This is not remarkable when it is considered that in materials of high conductivity, heat is more free to pass on to the interior, whereas, in materials of low conductivity it "banks-up" near the exposed surface. It is seen, however, that the denser clays, and the gravel and cinder concretes, make comparatively poor showings in this

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[192] Marani, Blue Book, Gypsum Industries Association.

[193] Hull, W. A., Comparison of Heat-Insulating Properties of Materials used in Fire Resistive Construction: Proceedings American Society for Testing Materials, Vol. XVII, Part II, 1917.

respect, and that the limestone concretes make a slightly better showing than the other concretes. The gypsums are found to be distinctly better than the clays and concretes in this respect."

In another series of experiments Hull[194] demonstrated the insulating effect of gypsum on concrete columns. He says:

"In order to determine the effect of additional insulation on a square gravel concrete column, one of these, No. 27, was plastered with 1 inch of a gypsum plaster, known as wood fibre plaster. This material contains no sand but has a wood filler. It was selected for this purpose on the assumption that such a material would give better thermal protection than a gypsum plaster containing sand. This plaster was reinforced with light expanded metal of the same grade and applied in

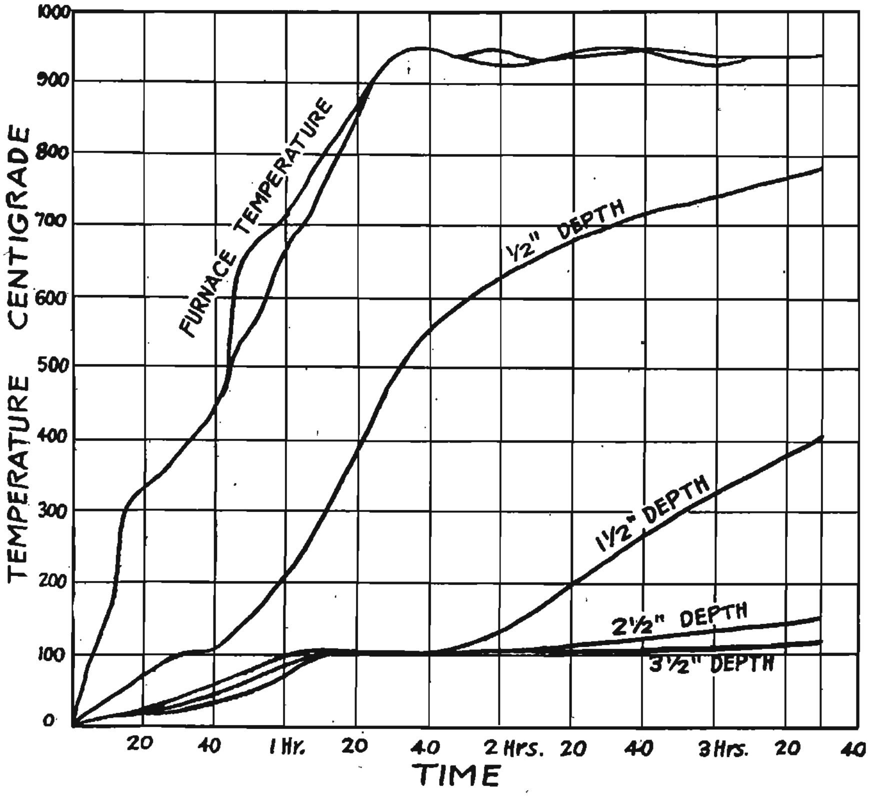

FIG. 55.—Diagram illustrating slow increase in temperature in protective coating of calcined gypsum, covering steel pillar. This is to be compared with figure 56 which gives temperature rise in pebble concrete under similar conditions. After Hull, Bureau of Standards.

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[194] Hull, W. A., American Concrete Institute, Vol. XIV, 1918.

the same way as that used on the round columns referred to in the preceding paragraphs.

"It will be seen that the ultimate strength of this column, at the end of the four-hour fire test, was slightly more than three times the average strength of the two columns of the same kind which had no plaster. In this case, as in the preceding one, a comparison of the temperature attained in the plastered and in the unplastered columns shows the important thermal effect of the additional insulation. In the unplastered square columns, a relatively small part of the protective covering spalled off in the fire test and the lower temperature attained at the center of the plastered column is to be credited largely to the thermal insulation of the plaster."

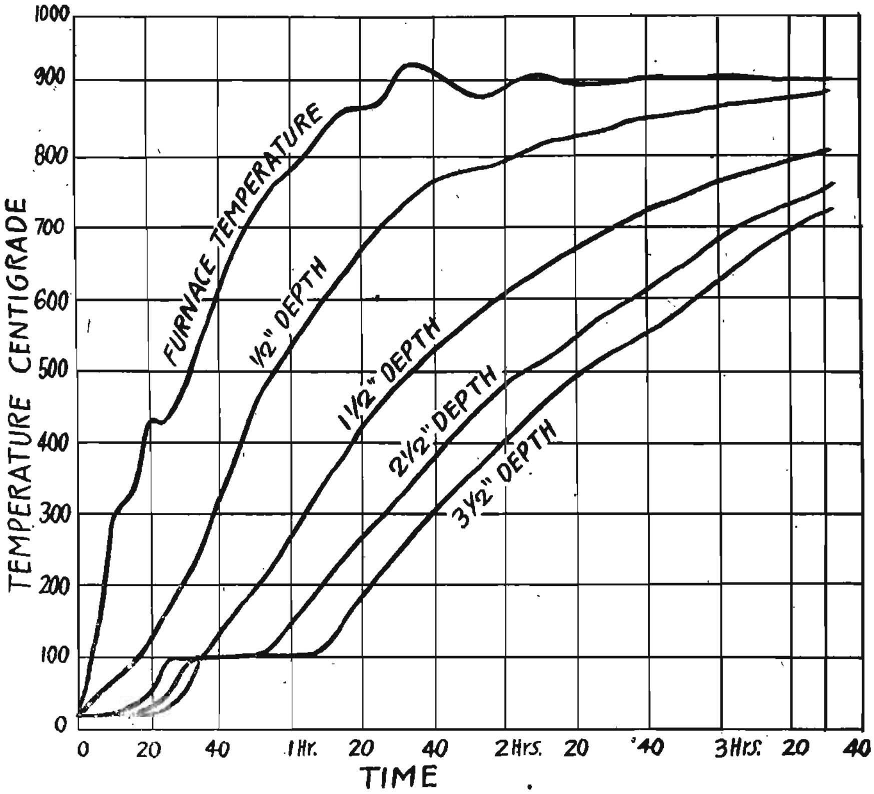

FIG. 56.—Diagram illustrating increase in temperature in pebble concrete. Shown for purpose of comparing with figure 55. After Hull, Bureau of Standards.

Gypsum products are unique in their lightness, a property which they enjoy without sacrifice of other essential characteristics required of a high grade, fire resisting building material.

A finished wall or partition of gypsum is 38 per cent lighter than a similar wall of the lightest competitive material.[195]

Structural gypsum weights 6½ pounds per square foot for each inch of thickness. This is about one-half the weight of average concrete.

This lightness means, in building construction, a saving in concrete and steel in footings and supporting members and a saving in labor required for erection.

TENSILE STRENGTH

The tensile strength of calcined gypsum is an expression of its ability to withstand a direct pulling strain. The instruments used in testing tensile strength are the same that are employed for this purpose in testing Portland cement, and there are several standard machines on the market. Figure 57 shows the details for a briquette and figure 58 shows a gang mold in which briquettes are made.

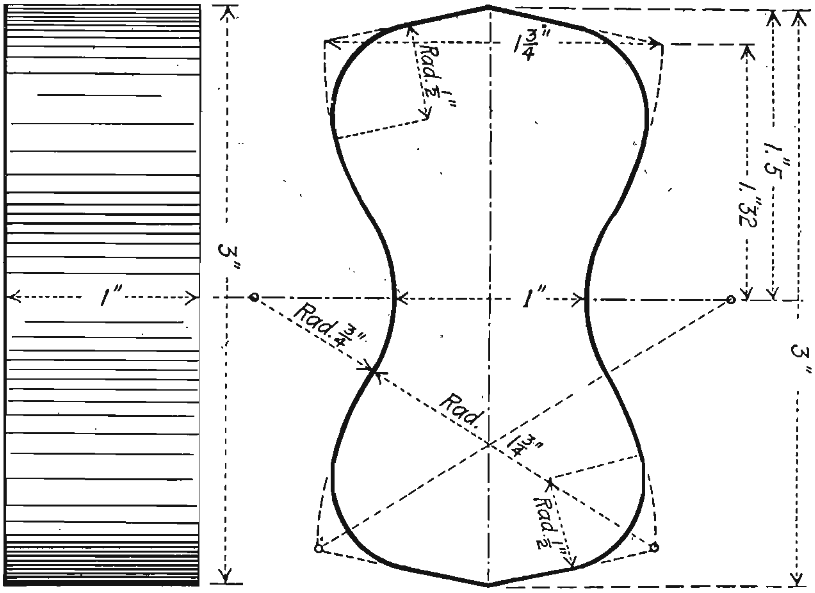

FIG. 57.—Standard Briquette used in testing tensile strength of calcined gypsum. Courtesy American Society for Testing Materials.

The tensile strength of calcined gypsum varies with the

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[195] Marani, in Blue Book, Gypsum Industries Association.

Dependent on various conditions

amount of water used in mixing; the age of the briquettes; the purity of the mineral used; the fineness of grinding; and the extent to which the calcined gypsum has been exposed to moisture before mixing. Other accidental factors sometimes interfere with a correct calculation of tensile strength. Flaws or blow holes of course cause weakness. If the briquettes are dried at too high temperatures, or freeze before becoming dry, they are weakened.

Preliminary to the devising of a method of determining normal consistency a series of tensile strength tests were run at the laboratory of the State University of Iowa and varying percentages of water were used in mixing the calcined gypsum. On this point the report of Messrs. Holt and Holmes reads as follows:

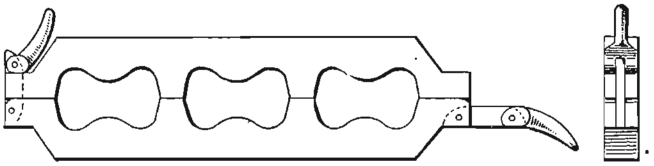

FIG. 58.—Gang mold for making briquettes. Courtesy of American Society for Testing Materials.

> ''From each sample five briquettes were made with each of the following percentages of water: 35, 40, 50, 60, 70, and 80, by weight. 35 and 80 were chosen as the limiting percentages because 35 per cent gave, with most of the samples, a mix somewhat drier than it is practicable to handle; and 80 per cent gave a mix which in some cases was so wet that water drained from the moulds, causing shrinkage of the briquettes. These briquettes were tested at the age of seven days. The results of the tests are summarized in the following table, each number stated being the average of the strengths of five briquettes:

SAMPLE	35 PER CENT	40 PER CENT	50 PER CENT	60 PER CENT	70 PER CENT	80 PER CENT
A	251	242	278	177	158	191
B	177	258	235	172	142	101
C	197	189	174	146	120	105
D	145	139	194	169	162	142
E	190	180	160	142	109	84
F	184	207	174	215	146	100
G	141	197	161	148	123	112

Sample	35 Per cent	40 Per cent	50 Per cent	60 Per cent	70 Per cent	80 Per cent
H	257	263	275	228	185	173
I	221	179	208	129	139	136
J	229	243	206	145	128	114
K	249	223	209	151	123	113
L	182	153	145	131	111	90
M	197	162	135	113	119	87
X	494	449	373	350	261	200
	3114	3084	2927	2416	2026	1748
Average	222	220	209	173	145	125

"Comparing the results shown in this table with those which follow under the heading "Tensile Strength", it will be noticed that these tests of seven-day briquettes show strengths much lower than those there stated. The reason for this is that the briquettes for these preliminary tests, with the exceptions of those from Sample "X", were stored in a too closely confined space, where the moisture produced by evaporation so retarded the setting of the plaster and softened it as to prevent the briquettes from attaining the strength shown by those properly stored. It was assumed, however—and the validity of the assumption was shown by later tests—that since all these briquettes were (with the exception noted above) made and stored under the same conditions they would furnish a fair comparison of the results to be obtained by use of the different percentages of water.

"From this summary it is seen that the drier the mix the stronger the briquettes. There is, however, only a slight difference in strength between the 35 per cent and the 40 per cent briquettes."

Tests made at Ames for the Iowa Geological Survey in 1902 showed that for calcined gypsum as then ground and calcined (second settle) maximum tensile strength was secured with 30 to 35 per cent of water.

Age of briquettes

In connection with its report on Webster county the Iowa Geological Survey[196] published the results of laboratory work by Marston which included tensile strength tests of numerous samples of calcined gypsum, the briquettes being broken at intervals of 1, 7, 28, and 220 days.

Typical briquettes made from Ft. Dodge material as well as from calcined gypsum from Texas and Kansas are tabulated below.

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[196] Iowa Geol. Survey, Vol. XII, p. 228.

	STRENGTH PER SQUARE INCH AFTER			
	1 Day	7 Days	28 Days	220 Days
A	226	204	329	274
B	219	188	379	288
C	211	184	375	335
D	131	170	483	386
E	192	224	348	359
F	107	128	333	193
G	227	236	468	405
H	181	195	465	283

Messrs. Holmes and Holt report on carefully made tests for tensile strength of calcined gypsum as follows[197]:

"The method of mixing the plaster and water to form a paste from which to make the briquettes was the same as that used whenever plaster and water were mixed for any of the tests, and was as follows:

"The measured quantity of water was placed in the mixing dish, which had previously been wiped clean and dry. The plaster, which had been passed through a number 20 sieve, was turned into the water and the mixture stirred with a spoon to an even consistency. The paste was then placed in the moulds as quickly as possible, pressed in firmly with the thumbs, and the surface smoothed off with a trowel. It was found in many cases that the surface could be made smoother by allowing the paste to set up somewhat before removing the excess, when the latter could be shaved off with a trowel.

"As soon as the briquettes were set sufficiently to permit, they were removed from the moulds and stored on shelves in such a manner that there was free circulation of air around and between them. It was found that the storage of specimens in a confined space or in contact with each other caused an appreciable softening, supposedly from dampness produced by evaporation, and a resultant decrease in strength.

"At the proper age the briquettes were broken in an Olsen cement testing machine, provided with A. S. C. E. standard roller clips as specified for cement testing. It was found that a large percentage of the breaks occurred where the rollers of the clips gripped the briquettes, and not in the one-square-inch cross section. The gypsum briquette is softer than one of cement or cement mortar and the rollers cut into it, causing the "clip break". This would seem to indicate a need of a clip of different design for gypsum briquette testing.

"The results of the tension tests of neat plaster (or gypsum)

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[197] The samples are the same that are referred to on pages 295 and 296 by the same letters.

briquettes are summarized in the following tables. As in the similar tables previously given, each number represents, in pounds, the average of the strengths of five briquettes."

	24 Hours			7 Days		
Sample	35 Per cent	Normal Consist'cy	80 Per cent	35 Per cent	Normal Consist'cy	80 Per cent
A	176	175	104	439	322	235
B	264	247	128	359	406	245
C	225	185	112	422	355	236
D	163	173	147	163	379	278
E	187	173	104	460	363	124
F	241	212	124	457	386	239
G	204	269	159	343	502	......
H	178	219	157	200	391	274
I	201	142	95	409	322	216
J	202	258	114	472	422	234
K	278	270	104	495	459	218
L	220	162	97	321	349	211
M	216	139	94	392	358	248
X	317	239	121	469	400	229

	28 Days			12 Weeks					
Sample	35 Pct.	N. C.	80 Pct.	35 Pct.	40 Pct.	50 Pct.	60 Pct.	70 Pct.	80 Pct.
A	469	308	228	386	419	345	314	278	231
B	528	424	223	499	479	383	314	257	247
C	517	370	212	530	435	416	351	262	205
D	425	384	268	460	433	386	323	244	197
E	439	350	205	475	454	378	311	231	199
F	488	414	238	480	498	323	305	248	199
G	392	438	372	377	435	331	292	272	237
H	272	375	240	168	516	409	380	294	235
I	501	326	201	465	414	337	271	213	165
J	464	383	229	503	447	380	307	263	217
K	480	418	199	491	453	378	333	245	209
L	468	326	200	415	444	371	289	269	217
M	466	313	204	441	444	307	289	209	156
X	475	396	218	487	497	381	332	230	198

Tensile strength and age of the calcined gypsum

Numerous tests have demonstrated that the strength of calcined gypsum is not lessened with time, if the calcined gypsum is kept perfectly free from moisture. Under ordinary conditions, however, some moisture is absorbed by the calcined gypsum, and there is a tendency in material that has been stored for some time toward fast setting, as well as a slight loss in strength.

Tensile strength and age of briquettes

It has been noted that briquettes made from calcined gypsum reach their maximum strength in about thirty days and then recede slightly. Their strength becomes stationary after twelve months, and averages three-fourths the strength shown at thirty days.

Additional data on compressive and tensile strength are given in appendix I where a paper by Emley and Faxon reviewing work done at the Bureau of Standards is presented.

Adhesion

The only adhesion tests that have been reported were made by Marston for the Iowa Geological Survey, in 1901, and published, with other tests of calcined gypsum, in connection with the report on Webster county.[198] As they are of considerable interest they are repeated here.

	STRENGTH PER SQ. IN. AFTER		
KIND	1 DAY	7 DAYS	28 DAYS
Fort Dodge "Stucco"		87	133
Fort Dodge "Stucco"		45	115

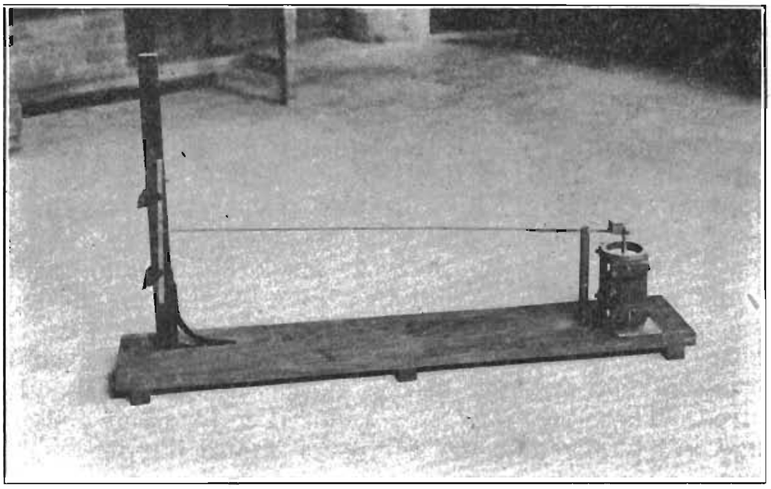

FIG. 59.—Instrument devised by Department of Engineering, University of Iowa, for testing expansion of calcined gypsum while setting.

Expansion and contraction

Tests to demonstrate change in volume in calcined gypsum while setting, were made at Iowa City by Messrs. Holt and Holmes and their report follows. The let-

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[198] Iowa Geol. Survey, Vol. XII, 1901, pp. 224-225.

ters refer to samples of the same material described on page 298.

"For determining the percentage change in volume of the plaster while setting the apparatus shown in the accompanying cut (figure 59) was used. It consists essentially of a cast-iron cylinder, open at both ends and of known capacity, in which the paste under test is held. For convenience in removing the set plaster this cylinder was made in two halves, held firmly together by four bolts. During the test, the cylinder, containing the paste, rests on a glass plate. On the surface of the paste rests a disk, or piston, one-eighth inch smaller in diameter than the interior diameter of the cylinder. This piston is attached to the shorter end of a lever, the longer end of which terminates in a pointer which moves over a scale graduated to hundredths of an inch. The length of the longer lever arm being ten times that of the shorter, a movement of the pointer of 0.01 inch indicates a movement of the piston of 0.001 inch. The strength of the cast-iron cylinder is such that all change in volume is forced to take place in a vertical direction, causing a movement of the piston, which is magnified at the pointer by the ratio of the lever arms and is measured on the graduated scale. A light pressure of the piston on the paste is maintained by proper adjustment of a counter-weight.

Change in volume while setting

"In determining the change in volume, pastes of normal consistency were used. An amount of plaster sufficient to make the quantity of paste required to fill the cylinder to within half an inch of the top was mixed with the proper amount of water. The paste was placed in the cylinder a little at a time, each small quantity being lightly tamped in with a stick so as to compact the mass and remove air-holes. The piston was then brought to a firm bearing on the surface of the paste with the pointer against the scale, and an initial or zero reading made. Thereafter readings were made at intervals of five minutes, or less if the rapidity of the change required. These readings were reduced to terms of percentage change in volume and the curves of figure 60 plotted therefrom.

"Further tests were made with some of the samples to determine whether the change recorded was actually proportional to the volume of the mass under test. The tests were made exactly as above except that a cylinder of paste of one-half the height was used. The results obtained were, in quantity, almost exactly one-half those obtained from the full-sized cylinders, indicating the same percentage change."

Of the thirteen samples tested twelve show expansion and one shows contraction. This erratic sample (H) was taken from material supposed to be identical with C. Several of the samples show an initial contraction though an ultimate expansion.

Plasters made from calcined gypsum are remarkably good non-conductors of heat. This property makes them especially valuable for roof construction, where they serve to keep out exterior heat, and to retain heat generated within. Their fire resisting properties are of the highest value. Calcined gypsum will stand a long exposure to intense heat with little rise in temperature, due to the fact that its water of crystallization must be drawn off before it is possible for its temperature to rise above 360 to 400° F.

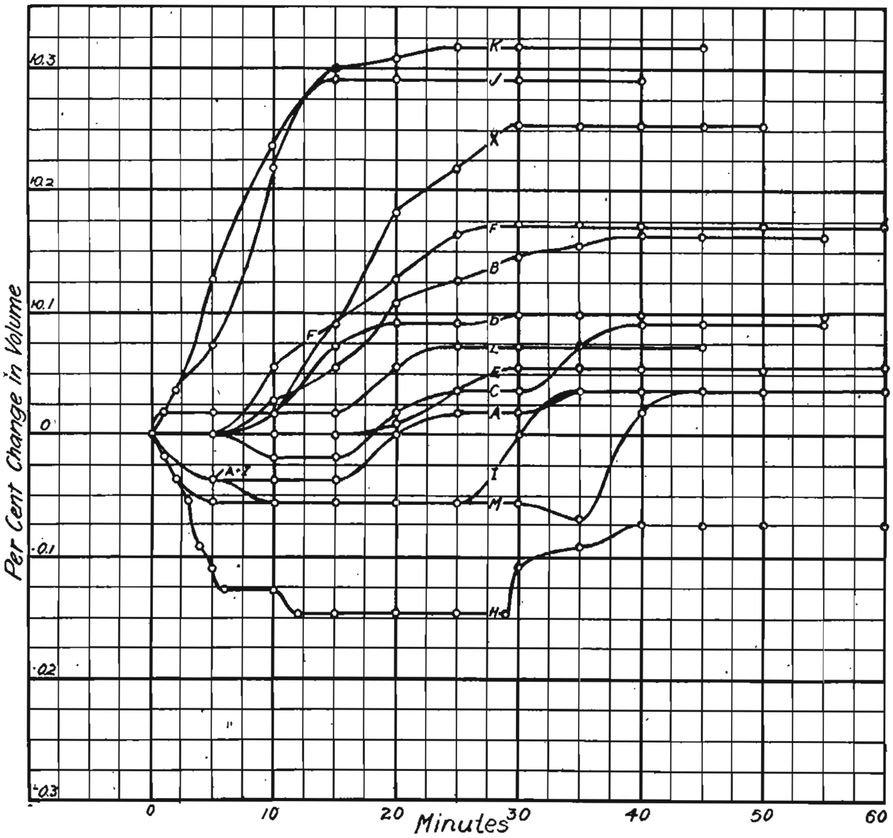

FIG. 60.—Diagram illustrating expansion of calcined gypsum while setting.

Conductivity, heat

This subject will be considered more fully in the chapters treating of structural gypsum, gypsum blocks, and wall plasters.

Conductivity, sound

Advocates of lime plasters have frequently made the assertion that walls made of gypsum plasters do not deaden sound as effectively as does the material whose cause they champion. Their statements, however, do not seem to be borne out by careful tests. Inasmuch as these tests have been made in connection with gypsum plasters and plaster block the question of sound conductivity will be reserved for later chapters.

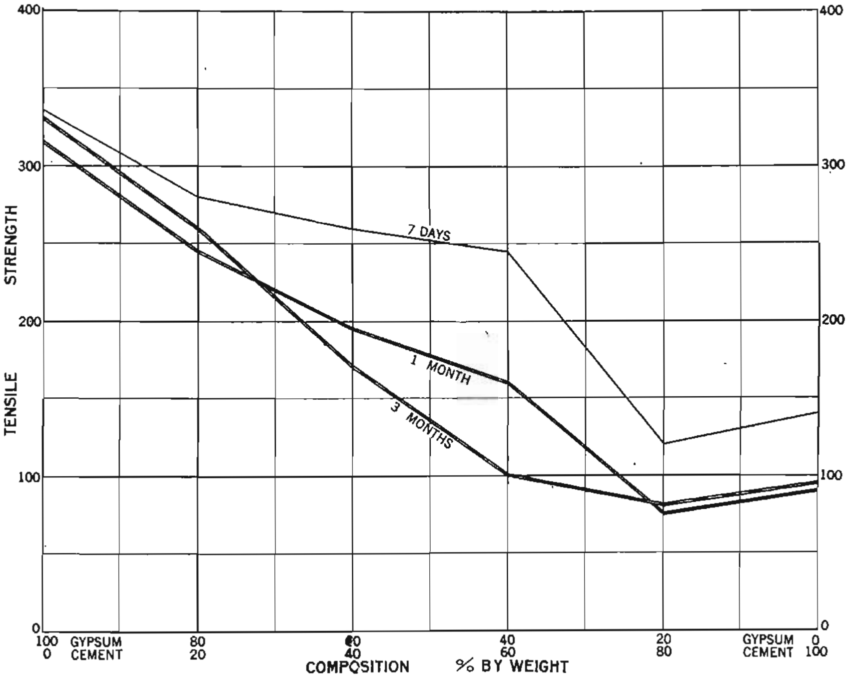

FIG. 61.—Diagram illustrating the tensile strength of mixtures of calcined gypsum and Portland cement in varying proportions. Courtesy of Bureau of Standards.

GYPSUM AND PORTLAND CEMENT

Tensile strengths

Some interesting tests of the tensile strength of gypsum and Portland cement were recently made by the Bureau of Standards and the results are shown in the curve given in figure 61. With this diagram the Bureau of Standards submits the following letter of explanation:

DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
WASHINGTON

July 10, 1920.

Dr. F. A. Wilder,
Southern Gypsum Company,
North Holston, Va.

(Subject: Curve for publication)

Dear Sir:

Complying with your request of the 30th, we take pleasure in enclosing herewith curves showing tensile strength of various proportions of gypsum and Portland cement. You are authorized to use these curves in your forthcoming monograph provided that they are accompanied by a qualifying statement which is also enclosed. It is understood that you will give due credit to the Bureau.

Respectfully,
S. W. STRATTON,
Director

"The tensile strengths of mixtures of gypsum and Portland cement are illustrated by the accompanying curve. It is to be noted that this curve shows the briquettes made of neat cement are weaker than those made of neat gypsum. While this statement can hardly be vouched for as a general conclusion, being based on only one series of experiments, it does not seem so improbable when all of the factors are taken into consideration. The consistency used is the standard prescribed for testing gypsum (9.7 by the Southard viscosimeter). Material of this consistency can be readily poured, and the mixtures were thus much wetter than is usual in tests of Portland cement. The briquettes were removed from the molds as soon as they were hard enough to handle, and immediately exposed to the air in the room for storage. This too is opposed to the usual practice of storing cement briquettes in a damp closet or under water. These two factors make the cement appear unusually weak, but the strengths found may possibly approach more nearly to those actually attained in practice than would have been the case, had the cement been tested in the usual way."

CHAPTER XIV

USES OF CALCINED GYPSUM

Calcined gypsum is often called stucco. The whiter varieties are called, in connection with certain trades, plaster of Paris.

The most important use for calcined gypsum is found in the manufacture of interior plasters. Perhaps four-fifths of all the gypsum calcined in America is used for plastering purposes. Gypsum plasters possess important advantages in this connection over other materials. First, their great hardness is an important and valuable characteristic. Almost as important is the fact that they set up in a few hours and the work of carpenters and finishers follows closely after the plasterers. Their period of drying is limited to a few days and this is of great importance, since certain kinds of mortar require weeks to dry out, and the house is untenable during this long period or is occupied at a positive risk to health.

Interior plasters

The nature of gypsum wall plasters and rules for their manipulation are considered in chapter XV.

Some Portland cement chemists prefer calcined gypsum to raw gypsum for retarding the set of their product. Calcined gypsum of course has a higher content of SO_3 and consequently less of it is required to produce the desired retarding effect. The mill price, however, is usually twice that of raw gypsum while the amount needed is only a few per cent less. Where excessive freight rates are involved in getting the raw gypsum to the cement mill, there might be economy in using the calcined product. The reason for its use in preference to raw gypsum, however, must be found in something besides economy, for mills that use calcined gypsum are not, as a rule, handicapped by high freight rates on gypsum. The reason for its use apparently lies in the belief that a more uniform product is secured.

For cement retarder

When calcined gypsum is used in retarding cement it is mixed carefully with the cement just before packing.

Gypsum blocks

Considerable quantities of calcined gypsum are used in making gypsum blocks for use in constructing partitions and roofs. Blocks and roof panels are considered at length in chapter XVI.

Plaster boards

The use of calcined gypsum in the making of plaster boards is increasing rapidly. These boards are of two types, one intended to take the place of lath and the first coat of plaster, and to be plastered over; while the other, after nailing to the studs, gives a finished wall when nailheads and cracks are covered by wooden strips or otherwise concealed. This type is called "wall board" to distinguish it from "plaster board", which is intended for a plaster base. These articles are considered at some length in chapter XVII.

Poured gypsum roof and floor

In chapter XVIII an interesting and important type of roof construction is discussed. This is the poured gypsum roof and floor. As is there pointed out the material used for these purposes in America must not be confused with hydraulic gypsum which is extensively used for flooring in Europe.

Plate glass industry

Many thousands of tons of calcined gypsum are used annually in connection with the plate glass industry. The glass is embedded in gypsum paste preparatory to polishing, and is held by a gypsum matrix during the polishing process.

The strength required for this purpose is not great and the set gypsum is crushed, ground and recalcined. Some fresh mineral is added each time, however, to give greater life to the plaster.

For plate glass purposes, material free from grit is required and this is secured by using gypsum of great purity, or by exceedingly fine grinding.

Insulation

Mixed with asbestos, calcined gypsum is extensively used as a pipe and boiler covering. It is used to fill the space between the walls of fire proof filing cabinets and safes.

A patent has recently been issued for a process of insulation with calcined gypsum, which consists of the addition when dry of chemicals which give off gas in the presence of water. The gas bubbles develop a spongy texture favorable for insulation.

Considerable quantities of calcined gypsum are required for

Pottery molds

pottery and terra cotta molds. This gypsum is usually calcined to the second settle, is short working and dense. Up to 1916 most of the potteries insisted on having material made from Nova Scotia gypsum, but when this supply was cut off by the war, it was found that some beds of domestic gypsum gave equally good results.

Statuary

The use of plaster of Paris for making casts and for reproducing works of art, ancient and modern, is familiar to all. Relief maps and scientific models are made of the same material.

Surgical uses

Plaster casts are commonly used for holding broken limbs in place while the bone is knitting. During the war hundreds of tons of domestic plaster of Paris were used in making orthopedic bandages. Open mesh bandages are passed through a tray containing plaster till the meshes of the fibre are filled. They are then rolled while dry and laid away for use.

When applied the rolls are soaked in water ten minutes and then unrolled and wound firmly about the injured limb till a closely knit strong splint is produced.

Scagliola

Marble columns, wainscoatings and balusters are made by treating gypsum with various chemicals which harden and color it till it is very difficult to distinguish from marble. The methods used are presented in chapter XXI.

Dental plaster

An exceedingly fine, fast setting plaster is used in making dental molds.

Cold water paints

Plaster of Paris, finely ground and properly colored is sold in small and large packages for tinting interior walls and ceilings. It is said that forty tints can be made from three colors, red, white, and blue, by mixing with the white plaster. Five pounds of the powder will cover fifty square yards of wall surface.

Exterior stuccoes

In temporary exposition buildings plaster of Paris mixed with excelsior and known as "staff" is employed in large quantities. The surfaces of the great buildings at the fairs of Chicago and St. Louis were covered with staff and the striking statuary groups were built up out of the same material. Nearly 30,000 tons of calcined gypsum were used by a somewhat different process, for exterior plastering at the Panama-Pacific Exposition.[199]

Miscellaneous

Calcined gypsum is used in marble setting, in making corn cob pipes, in the heads of matches, in taxidermy and for imbedding fragile material for transportation. It furnishes the mold in which rubber stamps are cast, and is used for some sorts of metal casting.

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[199] For a full statement see Wall Surfaces of Panama-Pacific Exposition, by A. W. Markwart, Rock Products and Building Materials, Nov. 22, 1918.

CHAPTER XV

COMPOSITION AND PROPERTIES OF GYPSUM PLASTERS;[200] THEIR MANIPULATION AND SPECIFICATIONS FOR THEIR USE.

The composition of gypsum plasters differs somewhat, to make them fit for different purposes and varying conditions. The base for all gypsum plasters is, of course, calcined gypsum. Various substances are added to this base, and the following types of gypsum plasters are developed:

Kinds

Neat gypsum plaster, often, but unfortunately, called cement plaster.
Gypsum wood fibre plaster.
Ready mixed gypsum plasters.

All of these plasters contain retarder and fibre of some sort.[201]

NEAT GYPSUM PLASTER

Composition of neat gypsum plaster

Nature and purpose of fibre

Purpose of other ingredients

Neat gypsum plaster is intended for mixing with sand at the point where it is applied to the wall. Ordinarily it contains at least 85 per cent of calcined gypsum, the remainder being hydrated lime, ground clay, asbestos, retarder and fibre. From four to six pounds of goat or cattle hair is used in each ton of plaster. In addition some manufacturers use one or two pounds of manila or sisal fibre. The purpose of the fibre is to hold the plaster together while it is being applied and to prevent it from dripping from the keys that are formed behind the lath. The addition of other ingredients is for the purpose of plasticity, which aids in applying the plaster. The fibre does not add measurably to the ultimate strength of the plaster and is not needed for this purpose. The ingredients added to give plasticity are used sparingly, so that the tensile strength and hardness are not impaired.

The amount of sand that may be mixed with neat gypsum

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[200] Hydraulic or slow setting gypsum plaster and Keene's cement are treated in Chapter XIX.
[201] For the nature of retarders see Chapter XX.

plaster depends upon the quality of the sand and the nature of the background. Standard specifications adopted some years ago by the plaster manufacturers association stated that six, ten-quart buckets of clean sharp sand might be used with a sack (100 pounds) of plaster for a lath background. This represents proportions of two to one by weight. For brick, gypsum block or terra cotta side walls, the proportions of sand may be increased to three to one.

Proper amounts of sand

Loamy sand, while making a plaster that works nicely, will give a soft wall if used in the quantities permissible for a sharp, silica sand.

Suitable sand

The best sand consists of a mixture of moderately coarse and moderately fine grains. A good plastering sand is one which when dry will pass an eight mesh sieve and 80 per cent will be retained in a forty-eight mesh sieve.

Cement plasters are retarded to give from two to six hours working time. Some local sands seriously affect the set of plasters, some accelerating and some retarding them. Clean, sharp sand, and particularly sand having a trace of salt, will accelerate the plaster, while a muddy or loamy sand acts as a retarder. In a similar manner the water used in mixing may disturb setting conditions. It is sometimes necessary to specially retard plasters at the mill for certain markets, by using more or less than standard amounts of retarder, to meet local conditions.

Setting time

Gypsum plasters may be applied to the background selected in three coats; in two coats; or in a single coat.

Coatings

The best grade of work is three coat work. These three coats or layers are called:

First or scratch coat
Second or browning coat
Third or finish coat.

The scratch coat is made somewhat richer than the second or browning coat and should not contain more than two parts sand by weight. This gives a strong key and a better bond than will be possible if more sand is used.

Composition of scratch coat

If good sand is available three parts to one of plaster, by weight, may be used for the second or browning coat.

Composition of browning coat

Composition of trowel finish

Where a trowel or smooth finish is desired, a mixture of lime putty and calcined gypsum is used, the proportions varying with the season of the year. Standard proportions are 75 per cent by volume of lime putty to 25 per cent by volume of calcined plaster.

Sand finish

A sand or rough finish is composed of the following by volume:

Lime putty	1 part
Sand	3 parts

These ingredients are thoroughly mixed. Before applying mix six to nine parts of this mixture with one part of calcined gypsum.

GYPSUM WOOD FIBRE PLASTERS

Composition

Wood fibre plasters contain at least 80 per cent by weight of calcined gypsum, and not less than 1 per cent of a non-staining shredded wood. The remainder may be composed of hydrated lime, ground clay, asbestos, sand, or substance of a similar nature; and retarder. From thirty to forty pounds of shredded poplar, linn, willow, or buckeye wood are used to the ton of plaster.

Wood fibre plasters are intended for use where sand is scarce or expensive, or where unusual toughness and a measure of flexibility is desired. They are intended to be used without admixture of sand and are especially convenient for patch work.

Since they are prepared for use without sand, less retarder may be used than for those kinds intended for use with sand, since most sand has an accelerating influence on gypsum plasters. Ordinarily four or five pounds of commercial retarder to the ton will keep the plaster in proper working condition for two hours, which gives ample time for mixing and applying.

READY MIXED GYPSUM PLASTERS

Considerable quantities of plaster are shipped from some gypsum mills with sand already added. In some of the larger cities mixing plants take the calcined gypsum in car lots and mix it with sand for the local trade. It is not economical to ship sanded plasters any considerable distance, for if local sands are not suitable for mixing, it is generally cheaper to use wood fibre plasters.

TENSILE STRENGTH

Methods of testing

The apparatus and technique for testing gypsum plasters are the same that are employed in testing calcined gypsum, and they have been described in chapter XIV.

The same factors control the tensile strength of gypsum plasters that control the strength of calcined gypsum, and additional factors are found, of course, in the ingredients added to calcined gypsum for wall plaster purposes.

Effect of retarder on strength

Inasmuch as retarder must be added to calcined gypsum in the manufacture of all sorts of gypsum plasters, its effect upon tensile strength is of more than ordinary interest and has been carefully studied. Inasmuch as the common commercial retarders hold back the set of the plaster by forming a film between the gypsum crystals growing[202] around nuclei from gypsum in solution it is apparent that retarders may have a tendency to cut down tensile strength. Ample tests show, however, that the tensile strength of plasters is not materially reduced by retarders, till the amount of retarder used reaches seventeen or eighteen pounds to the ton of plaster. Conditions which call for use of more than fifteen pounds of retarder to the ton of plaster are very unusual and in general terms it may be said that in the ordinary manufacture of gypsum plasters, the retarder used does not reduce its strength.

Effect of other ingredients on strength

Ingredients added to increase plasticity and improve working qualities generally have less bonding value than the calcined gypsum, and therefore tend to some extent to reduce tensile strength. This is true of clays, kaolins and hydrated lime.

Sand, of course, is mixed with plasters in quantities sufficient to reduce the strength of the mixed goods materially below that of neat plasters.

Tensile strength tests on sanded plasters were made at

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[202] See Chapter XX for the theory of retarders.

Ames[203] in 1901, the material used being secured in Kansas, and from the Fort Dodge district. The results were as follows:

	PROPORTION	STRENGTH		
		1 day	7 days	4 weeks
Average of 15 tensile tests (Kansas plaster)	1:1	87	320	368
Average of 15 tensile tests (Kansas plaster)	1:2	55	203	212
Average of 15 tensile tests (Kansas plaster)	1:3	35	148	145
Average of 15 tensile tests (Ft. Dodge)	1:1	104	303	362
Average of 15 tensile tests (Ft. Dodge)	1:2	61	233	242
Average of 15 tensile tests (Ft. Dodge)	1:3	39	132	139

Remarkably high tensile strengths are reported by Grimsley as the result of tests made at Washburn College.[204]

As to the consistency used in these tests, Mr. Grimsley says that "the proportion of water varied somewhat with the plaster used in the experiments. In the Kansas plasters for a stiff mixture, the water percentage varied from 26.3 per cent to 40 per cent for neat briquettes, and in sand mixtures (2 to 1) the water percentage varied from 12 to 14, and proportions were about the same in the Michigan plasters.

"The briquettes for the long time test were set on edge on glass and kept in a room of fairly uniform temperature till broken. The sand used was ordinary Kansas river sand screened through a sieve (No. 20) of 400 meshes and held on a screen (No. 40) of 1600 mesh, and carefully dried."

The results given below are the average of three to five briquettes:

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[203] Iowa Geol. Survey, Vol. XII, pp. 224-235, 1901.

[204] Geol. Survey of Michigan, Vol. IX, pp. 166-169, 1903-4.

KIND	PROPORTION	24 HRS.	1 WK.	1 MO.	6 MOS.	1 YR.
Kansas	Neat	255	386	553	430	370
Oklahoma	Neat	229	460	525	543	441
Kansas	1:2	117	351	375	364	278
Oklahoma	1:2	91	318	410	366	293
Grand Rapids	Neat	366	429	461	426	
Grand Rapids	1:2	125	412	302	344	

Iowa City tests

Messrs. Holt and Holmes, at Iowa City,[205] determined the tensile strength of calcined gypsum when mixed with three parts of sand. Inasmuch as the material was not ibred or retarded it was not, strictly speaking, gypsum plaster. The results, however, are probably correct for a 1:3 plaster mixture, for the fibre and retarder do not measurably affect the tensile strength of the plaster.

"Another series of tension tests was made to determine the best percentage of water to use in making 1:3 mortar briquettes. From each of six samples five briquettes were made with each of the following percentages of water: 25 per cent of the normal consistency determined for the given sample (same amount of water that would have been used for the plaster without the sand), 30 per cent, 35 per cent and 40 per cent or normal consistency. These briquettes were broken at the age of seven days. The results of the tests are summarized in the following table, each number stated being the average of the strengths of five briquettes.

SAMPLE	PERCENTAGE OF NORMAL CONSISTENCY OF PLASTER			
	25	30	35	40
B	249	328	280	272
D	189	253	238	240
F	152	225	249	258
I	154	187	197	182
J	182	281	252	255
X	218	261	304	222
	1144	1535	1520	1429
Average	191	256	253	238

"From this summary it is seen that 30 per cent of the normal consistency of the plaster gave the best results, and this con-

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[205] For full report see page 295.

sistency was adopted for use with all other mortar briquettes made.

"*Tensile Strength.*—1:3 Mortar. The method of mixing the material for the mortar briquettes was the same as that used for the neat briquettes, except that the weighed quantities of plaster and standard Ottawa sand were thoroughly mixed dry before being put into the water.

"The method of placing the mortar in the moulds, the storage, and the method of breaking were the same as for the neat briquettes.

"The results of the tests are summarized below:

	ALL OF NORMAL CONSISTENCY	
SAMPLE	7 DAYS	28 DAYS
A	......	195
B	328	266
C	......	......
D	189	227
E	......	217
F	152	247
G	......	141
H	......	301
I	154	197
J	182	264
K	......	190
L	......	196
M	......	179
X	218	256"

Minimum tensile strength

Plaster for scratch coat mixed two parts of sand by weight to one part plaster should have a tensile strength of not less than 100 pounds to the square inch. Most gypsum plasters sanded in these proportions have a tensile strength of 200 to 300 pounds.

Plaster for browning coat in which three parts of sand to one of plaster, by weight, may be used should have a tensile strength of not less than 75 pounds. This figure is easily exceeded by all standard makes of gypsum plasters.

Compression

Neat gypsum plasters have a compressive strength ranging from 1000 to 1700 pounds per square inch. In a general way the compressive strength of gypsum plasters varies with their tensile strength, but the variation is somewhat irregular.

Adhesion

Adhesion tests for gypsum plasters, conducted in the same manner as were the adhesion tests for calcined gypsum described in chapter XIV, were carried on at Ames in 1901, with results as shown below:

KIND	PROPORTION	1 DAY	1 WEEK	4 WEEKS
Ft. Dodge	1:1	33	93	51
Ft. Dodge	1:2	21	31	54
Ft. Dodge	1:3	6	10	20
Kansas	1:1	27	58	48
Kansas	1:2	16	16	21
Kansas	1:3	----	----	7

BASE OR BACKGROUNDS FOR GYPSUM PLASTERS[206]

GROUNDS

Method of Setting Grounds

Wood lath

"For wood lath, the total nominal thickness including lath and plaster shall be ⅞ inch for three-coat dry-scratched or set-scratched work, and ¾ inch for two-coat work.

Wire or metal lath

"For wire or metal lath, the total nominal thickness including lath and plaster shall be ⅞ inch for three-coat dry-scratch or set-scratch work.

Gypsum plaster board

"For gypsum plaster boards, the total nominal thickness including boards and plaster shall be ⅞ inch for three-coat dry-scratch or set-scratch work. In no case shall the thickness of the plaster on the surface of the boards be less than ½ inch.

Gypsum plaster blocks

"For gypsum plaster blocks, the grounds shall be set ⅜ inch in thickness.

Brick

"For brick, terra-cotta and cement walls, the grounds shall be set ⅝ inch in thickness.

APPLICATION

Three-Coat Work, Dry-Scratch

Three-coat work, dry-scratch

"Three-coat work, dry-scratch plaster, when used on wood lath, wire or metal lath, brick, terra-cotta, masonry, gypsum plaster blocks, or plaster boards, shall be applied as specified below:

First coat

"Apply first or scratch coat (with hair or fibre) well rubbed in, and scratch well with ordinary plasterer's scratcher and allow to become "bone dry" before applying second coat.

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[206] The paragraphs under the headings Base or Backgrounds; grounds; applications; General Precautions; Work and Workmanship, were prepared by Sub-Committee 2 of Committee C-11 of the American Society for Testing Material, Mr. D. L. Haigh, chairman, but were not published in the report of that committee, due to the Society's general ruling against prescribing methods for applying and erecting materials.

Second coat

"Apply second or browning coat (with or without hair or fibre), using enough to fill out to the grounds and to make walls straight and plumb. Rod and darby to a rough surface making angles and corners true, and allow to become "bone dry" before applying third or finishing coat.

Note.—The first or scratch coat may be used as a second or browning coat and this custom is generally followed particularly in country work, as it avoids the necessity of shipping more than one material.

Third coat

"If trowel or smooth finish is to be used, apply trowel or smooth finish and trowel to a smooth hard finish, free from trowel or brush marks or other imperfections.

"If sand float or rough finish is to be used, apply sand float or a rough finish and bring to an even granular sand-float finish, free from cat-faces or other imperfections.

Note.—For first-class work, minimizing cracking, staining and other imperfections, three-coat dry-scratch work gives the best results.

Only three-coat, dry-scratch work should be used on metal lath. It is not advisable to apply the second coat on metal lath until the first coat has become thoroughly dry.

Three-Coat Work, Set-Scratch

Three-coat work set-scratch

"Three-coat work, set-scratch plaster, when used on wood lath, brick, terra-cotta, masonry, gypsum plaster blocks, or plaster boards, but not on the wire or metal lath, shall be applied as specified below:

First coat

"Apply first or scratch coat (with hair or fibre) and follow as soon as this sets firmly with second coat.

Second coat

"Apply second or browning coat (with or without hair or fibre) using enough to fill out to grounds and to make walls straight and plumb. Rod and darby to a rough surface, making the angles and corners true, and allow to become thoroughly set for third or finishing coat.

Third coat

(a) "If trowel or smooth finish is to be used, apply trowel or smooth finish and trowel to a smooth hard finish, free from trowel or brush marks or other imperfections.

(b) "If sand float or rough finish is to be used, apply sand float or rough finish and bring to an even granular sand-float finish, free from cat-faces or other imperfections.

Note.—Three-coat set-scratch work is more liable to have cracks and show staining from wood lath, but in so far as strength is concerned it is equally as good as three-coat, dry-scratch work.

Two-Coat Work

Two-coat work

"Two-coat work, when used on wood lath, brick, terra-cotta, masonry, gypsum plaster blocks or plaster boards, but not on wire or metal lath, shall be applied as specified below:

First coat

"Apply first or scratch coat (with hair or fibre), using enough to fill out to grounds. Rod and darby to straighten, and allow to become "bone dry" before applying second or finishing coat.

Second coat

(a) "If trowel or smooth finish is to be used, apply trowel or smooth finish and trowel to a smooth hard finish, free from trowel or brush marks or other imperfections.

(b) "If sand float or rough finish is to be used, apply sand float or rough finish and bring to an even granular sand-float finish, free from cat-faces or other imperfections.

Molded Work

Molded work

(a) "*Solid Cornices and Molding.*—All solid cornices and molding shall be blocked out with browning or second base coat of gypsum plaster to within ¼ inch of the finished surface and allowed to set for finishing coat. The finished moldings shall be run and composed of lime putty with calcined gypsum added at the building by the mechanic, in the proper proportion to secure a good working material and a satisfactory hard finish.

(b) "*Furred and Lathed Cornices.*—To all furred and lathed cornices the scratch coat of gypsum plaster shall be applied and scratched and allowed to set thoroughly. It shall then be blocked out with browning or second gypsum plaster to within ¼ inch of the finished surface, and allowed to set for the finishing coat. The finished moldings shall be composed of lime putty with calcined gypsum added at the building by the mechanic, in the proper proportion to secure a good working material and a satisfactory hard finish.

Note.—In all run-work moldings applied over furred or lathed surfaces, the finished surface should be not less than one inch from the furring.

Ornamental Work

Ornamental work

"All ornamental plastering in the form of molding or case pieces of varying design to be placed on cornices or moldings in place, shall be thoroughly keyed and securely fastened to the prepared surfaces of cornices or moldings. There are many acceptable methods employed to fasten or key the ornamental molded pieces to the surfaces but special care should be exercised to secure a proper key in attaching solid moldings to the prepared surfaces.

Finish Coats

Finish coats

"The finish coats shall be run to guide lines and made straight, level and plumb, with all arrises true and sharp.

(a) "Trowel-finish coats shall not be over ⅛ inch thick, and shall be troweled down true and smoothed with metal trowels and water brush to a polish free from defects and brush marks.

(b) "Sand-float finish coat shall be floated true with cork float to a sand finish free from defects.

Interior, Wire or Metal Lath and Furring

"Studs, joists, rafters, furring and similar support shall be spaced not to exceed 16 inches on centers. Where greater spacing of supports is necessary special types of ribbed lath, or special supporting construction, shall be provided.

Supports

"Place the metal lath horizontal upon the supporting members, securing same with staples spaced not over 8 inches apart and driven home. Or, the supporting members may be furred out with three-sixteenths inch round rods secured with staples spaced not to exceed 8 inches, and the metal lath applied as hereinbefore stated.

Setting

"The metal lath sheets shall be lapped not less than ½ inch, end to end. All metal lath and furring shall be wired with tie wires not less than once between adjacent supports. Sheets shall be started not less than 4 inches from corners and shall be bent around the corners in such manner that no joints shall occur at any corner. Lath upon ceilings shall be bent down to extend not less than 4 inches upon all wall surfaces.

Lapping and wiring

"Staples used for securing metal lath or furring shall be not less than 1-inch No. 12 gage. Staples used for securing three-sixteenths inch furring rods shall be not less than 1½ inch No. 12 gage. All wiring used between supports shall be done with not less than No. 18 gage tie wire.

Staples and tie wires

Gypsum Plaster Board

"Studs, joists, rafters, furring and similar supports shall be accurately spaced 12, 16 or 18 inches on centers, and shall be in proper alignment. The standard spacing of 16 inches is recommended.

Supports

"All boards shall be spaced ¼ to ⅜ inch apart on all sides.

Spacing

"Lay boards parallel to the run of the supports. Horizontal joints on walls, and joints at right angles to ceiling joists, shall be broken at each board by starting each alternate tier with a half or a quarter sheet. On wood stud partitions, vertical joints shall not occur on the same studs on both sides of the partition.

Setting

"To cut plaster board to suit requirements, score both sides

Cutting and break against a straight edge. If sawing is preferred, provide firm platform, support board close to where cut is made, and saw.

Nailing "Plaster boards shall be nailed directly to the supports. Nails shall be spaced not to exceed 6 inches on centers for walls and 4 inches on centers for ceilings. First nail entire middle of board, then follow by nailing all outer edges. No portion of any plaster board shall have less than a ¾ inch bearing upon the supports to which it is nailed.

Nails "The nails used shall be 1¼ inches No. 11½ gage wire nails with flat heads of not less than ⅜ inch.

Grounds "Grounds shall be secured by nailing through the plaster boards to the supporting members, and shall not be less than ⅞ inch in nominal thickness. This thickness includes the thickness of the ⅜ inch plaster board.

Precaution "Do not sprinkle or wet gypsum plaster boards before the application of plaster.

Gypsum Wall Boards

Supports "Studs, joists, rafters, furring and similar supports shall be accurately spaced 12, 16, 18 or 24 inches on centers and shall be in proper alignment. The standard spacing of 16 inches is recommended.

Spacing "Gypsum wall boards shall be closely butted at all joints and corners or shall be spaced not less than ¼ inch where joint filler is to be used. In butt-joint work provision shall be made for boards to overlap the full thickness of the board at all internal and external angles.

Setting "Lay boards parallel to the run of the supports. Provide headers for nailing at all ends of wall boards; every joint and edge shall be supported by a firm backing to nail to. Ceilings shall be covered first and all ceiling boards shall lap beyond the face of the wall boards the full thickness of the board.

Cutting "To cut wall boards to suit requirements, score both sides and break against a straight edge. If sawing is preferred, provide firm platform, support board close to where cut is made, and saw from face side of the board always.

Nailing "Wall boards shall be nailed directly to the supports. Nails shall be spaced not to exceed 3 inches at all edges and 9 inches elsewhere. Where joints are to be covered with battens the nailing may be spaced not to exceed 6 inches at all points. First nail entire middle of board, then follow by nailing all outer edges. Wall boards shall have a bearing of not less than ¾ inch upon all supports to which they are nailed. Nails securing the edges shall be driven ⅜ inch from the edge of the board.

"The nails used shall be 3 penny, common or fine wire flathead nails.

Nails

"Grounds are not necessary. Headers or plates shall be placed between studs behind the wall boards in order to provide a backing and nailing surface to secure base boards, chair rails, moldings and similar interior finishes.

Grounds

GENERAL PRECAUTIONS

"Precaution should be taken to see that all materials are mixed in clean, tight boxes, with clean, fresh water, and that all tools are kept clean. If a machine mixer is used it should be properly cleaned at frequent intervals.

Mixing boxes and tools

"All material shall be applied before it has commenced to set. Re-tempered material shall not be used.

"In the use of neat material which requires sand to be added, the neat material and sand shall not be mixed and allowed to stand before the addition of the water.

Mixing

"The temperature of all buildings being plastered during cold weather shall be kept above freezing during the time of plastering. Extreme forced heat shall be avoided.

Heat

Note.—In cold weather it is always better to have all or part of the permanent heating system in operation before starting to plaster. Avoid the use of salamanders, coke pots or other temporary heating appliances or local drying, to keep the plastered surfaces free from coal-smoke stains.

"While plastering, windows shall be in place, or other closures provided, as a protection against strong winds, and that ventilation may be controlled. Openings shall be kept sufficiently open to allow the escape of dampness. Drying and ventilation is governed by the time of year and weather conditions.

Drying and ventilating

"Gypsum plaster shall not be subjected to freezing temperature weather within 36 hours after application. If frost should get into any coat of plaster, the coat shall be free from frost and in good condition before application of the next coat.

Frost

WORK AND WORKMANSHIP

"The contractor shall furnish all material and labor for the completion of the plaster work, as hereinafter specified.

Work included

"All surfaces of walls, columns, piers, partitions and ceilings (including all furred and lathed surfaces), and in all interior exposed surfaces, terra-cotta, gypsum plaster blocks, gypsum plaster boards, hollow brick, rough brick and concrete, throughout shall be plastered as specified under "Application".

Distribution

"All plastering throughout the building shall be carried down to the floor, unless otherwise specified by the architect.

Workmanship

"The contractor shall do all necessary jobbing and patching after other mechanics, and finish up after them, at any and all times as required by the architects.

Jobbing and patching

"It shall be the duty of the contractor to properly protect all work, and he shall be liable for damage done to the same and have it properly repaired or replaced as the architect may direct.

Protection of work

"The contractor shall remove all refuse at any and all times, as directed by the architect, and have the entire building, including glass, clean at completion."

Refuse

CHAPTER XVI

GYPSUM BLOCKS FOR FLOORS, WALLS, AND ROOFS

Definition

In this chapter it will be understood that the term plaster block is applied to a construction unit made of calcined gypsum, which is delivered to the job ready for erection. It is a factory made article, in distinction from slabs or blocks poured at the point of erection. Blocks so made are considered under Structural Gypsum in chapter XVIII.

Historical

Gypsum blocks were introduced in Europe and particularly in Germany, during the latter part of the last century. The industry as it was developed in Germany in 1902 was described in an appendix to the report on Webster county, published by the Iowa Geological Survey, in volume XII.

About the year 1900 American manufacturers in the vicinity of New York City, stimulated by small importations of gypsum blocks from Germany, which were well received by the building trade, began the manufacture of blocks in America. By the year 1904 the American gypsum block industry was on a sound footing, as shown by the elaborate display of gypsum blocks at the St. Louis exposition in that year, and the interest on the part of the building trade in these exhibits.

Composition of

Gypsum blocks consist of not less than 95 per cent gypsum by weight, and 5 per cent or less of nonstaining wood fibre. First settled calcined gypsum is used ordinarily in their manufacture.

Types of

Gypsum blocks as used in nonbearing partitions are best known to the building trade. Closely related to the partition block is the furring block, which is merely a partition block split through the center.

Gypsum blocks, generally reinforced, are used in roof construction. These blocks may be made at the factory, or poured on the job. The larger and heavier units are generally used, and as these are usually poured on the job, gypsum roof blocks will be considered under Structural Gypsum in chapter XVIII.

GYPSUM PARTITION BLOCKS

Structure, size and weight

Gypsum partition blocks are either solid or partly hollow, depending on their thickness and the load they are intended to carry. Sizes from two and one-half to five inches may have single rows of core holes. The six and eight inch sizes have two rows of core holes. Sizes and weights are shown in the table below.

SIZES AND WEIGHTS OF STANDARD GYPSUM TILE

Size	Ceiling height feet	Weight tile per sq. ft., lbs.	Weight mortar in joints per sq. ft., lbs.	Weight plaster 1 side per sq. ft., lbs.	Total weight plastered 1 side per sq. ft., lbs.	Weight plaster 2 sides per sq. ft., lbs.	Total weight plastered 2 sides per sq. ft., lbs.
1½ inch split 1½" by 12" by 30"	Furring	4.5	1	3	7.5	6	10.5
2 inch split 2" by 12" by 30"	Furring	6	1	3	9	6	12
2 inch solid 2" by 12" by 30"	10	9	1	3	9	6	15
3 inch hollow 3" by 12" by 30"	13	10	1.2	3	13	6	16
3 inch solid 3" by 12" by 30"	15	12.5	1.2	3	15.5	6	18.5
4 inch hollow 4" by 12" by 30"	17	12	1.63	3	15	6	18
5 inch hollow 5" by 12" by 30"	25	15	2.04	3	18	6	21
6 inch hollow 6" by 12" by 30"	28	17	2.45	3	20	6	23
8 inch hollow 8" by 12" by 30"	40	23	3.26	3	26	6	29

Manufacturing methods

Gypsum partition blocks are either hand molded or machine made. The hand molded block is equal in quality to the machine made article. Economies growing out of the application of elaborate machinery to the manufacture of gypsum blocks have not been very great, and in consequence the machinery used is relatively simple.

Hand made blocks are molded on rubber mats. A frame with height equal to the thickness of the block desired is used to hold the plaster mixture. Calcined plaster which has been mixed with fibre and water till it has the consistency of thick soup, is poured into the frame, which is so constructed that it can be easily detached from the contents of the frame as soon as it has set. The calcined plaster is not retarded and the hardened block can be removed from the frame a few moments after pouring.

Machines for making blocks are all elaborations of the simple principles illustrated in the cut below.

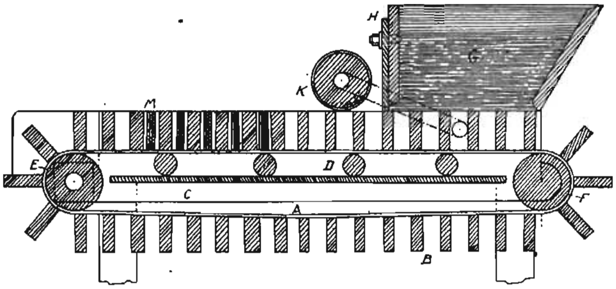

FIG. 62.—Diagram illustrating one of the methods of making gypsum blocks by machinery.

Wooden cores, tapered so that they may more easily be removed after the block hardens, are inserted in the frame before the calcined gypsum paste is poured. When hollow blocks are made various mechanical appliances may be used to force out these cores after the block has hardened.

Mixing

In the case of gypsum boards considerable care must be taken in the mixing of the paste, for the intergrowth of crystals into the chip board seems to take place most efficiently during the earliest stages, and "peelers" may result if mechanical mixing is carried too far. In the making of gypsum blocks it is not necessary to exercise the same degree of care in the mixing, but crystallization, which is accelerated by agitation, must not go too far in the hopper or the block will lack strength. Hand made blocks often have a greater crushing strength than machine made blocks for this reason.

Advantages of gypsum blocks

Fire Protection.—Gypsum block has received the full approval of the Underwriters laboratories for use in nonbearing partitions, stairways and elevator enclosures in fireproof building construction. Tests conducted at Armour Institute of Technology show that gypsum blocks have 40 per cent greater resistance to heat conduction than other standard materials tested.[207] Figure 63 shows the use of gypsum blocks for this purpose.

An important fire proofing feature is their freedom from expansion and contraction during great changes in temperature. The Bureau of Standards has found that:

FIG. 63.—Gypsum blocks used as fireproofing. Courtesy of V. G. Marani.

> "The contraction of a block under load is about one-thousandth of an inch per two pounds per square inch load. This is when the block is tested on edge which is the usual method of laying it, and applies to loads from zero to seventy pounds per square inch. The expansion with heat is about .00001 inches per degree Fah. This applies to temperatures from 32° to 100° Fah. For higher temperatures the expansion is considerably greater. The change in moisture content from bone dry to saturated is accompanied by an expansion of one-thousandth of an inch per inch."

Light Weight.—Gypsum blocks are from 30 to 35 per cent lighter per square foot than any other structural material of a

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[207] Marani in Buildings and Building Management, April, 1919.

similar nature and of equal thickness. This greatly reduces the load on columns, girders and all supporting members, and permits the use of steel with less cross section. The Statler Hotel, Cleveland, for instance, required 450,000 square feet of partitions. By using gypsum blocks a saving of 2,418 tons in dead weight was made.[207]

Noncondductor of Sound.—Tests described in chapter XVII show that gypsum blocks are 60 per cent more effective as a nonconductor of sound than other types of standard partition material.

Economy.—As has been noted gypsum blocks permit economy in connection with steel supporting members. Time and labor are saved through rapid construction made possible by the large units used. The surface presented by a finished partition of gypsum blocks is much truer than that offered by other tile surfaces, and a saving of 10 to 25 per cent in plaster is effected in consequence.

In remodeling a building where gypsum block partitions are used the cost is relatively small. A carpenter's saw may be used to cut through the partitions, and a large percentage of the gypsum blocks themselves can be salvaged.

"*Strength*[208]—The Chicago Board of Fire Underwriters' test of June 22, 1910, made at the Chicago laboratories, on 18 full-size three inch gypsum partition tile, selected at random from 50 samples, showed an average crushing strength of 12,603 pounds to the tile, or over an average area of 90.2 square inches. The average crushing strength was 139.7 pounds. As the weight of this tile is about 0.28 pound per square inch on bedding surface, a nonbearing partition of gypsum would have to be about 500 feet high before it would crush of its own weight."

The following specifications are generally agreed on by manufacturers of gypsum blocks:

Specifications for setting gypsum blocks

Partitions shall be set in at least ½ inch bed of mortar and started on the tile or concrete floor which shall first be swept clean.

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[208] Marani, V. G., in Rock Products and Building Materials, Dec. 22, 1919, p. 48.

Blocks shall be set plumb and straight with joints broken regularly. All joints shall be at least ½ inch thick. The top course of blocks shall be securely wedged to the ceiling with mortar.

Reinforcement over openings.—Where the rough bricks do not extend to the ceiling the partitions over all openings three feet or less in width shall have reinforcement consisting of a strip of metal lath three inches, four inches, or six inches in width, depending on the thickness of the block, laid in the first horizontal mortar joint above the opening. This lath shall extend at least six inches beyond each side of the opening and be well imbedded in mortar.

For openings three feet or more in width, two or more blocks shall be laid end to end and a half inch rod laid in the lower core hole, and this core hole shall then be filled solidly with plaster and allowed to set thoroughly before being placed in the wall.

Mortar.—All blocks shall be laid up in gypsum mortar containing not more than three parts of sand by weight to one part of gypsum plaster. Do not use Portland cement or lime plaster.

Underwriters specifications.—In approving of gypsum block for fireproof buildings in July, 1916, the Underwriters Laboratories laid down the following specification:

"Partitions built of these blocks shall have the blocks set on noncombustible foundations and laid with staggered joints in properly tempered gypsum plaster containing not to exceed three parts of sand, and shall be coated on each side with the same material, fibred with hair or wood, at least ½ inch in thickness and are standard for use as nonbearing corridor and room partitions in office buildings, hotels, apartments and buildings of like class of fire-resisting construction, and acceptable for use at enclosures to vertical communications in such buildings where standard enclosures are not required, and when the partition heights do not exceed the following:

Nominal or Trade Size of Block	Maximum Height of Non-Bearing Partition
2 inch, solid	10 feet
2½ inch, cored	10 feet
3 inch, cored	13 feet
4 inch, cored	17 feet
5 inch, cored	20 feet
6 inch, cored	30 feet
8 inch, cored	40 feet

GYPSUM FURRING BLOCKS

Gypsum furring blocks are generally made by sawing four inch blocks the long way. The hollow space prevents dampness. They are held in place by metal ties inserted in the wall every twelve inches.

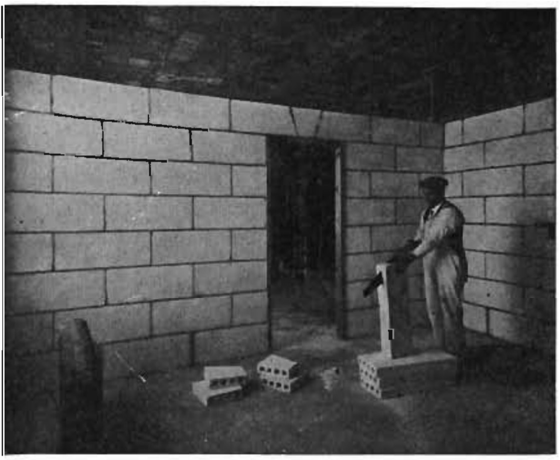

Fig. 64.—Sawing a four inch block for furring. Courtesy Beaver Board Co.

For free standing furring two inch hollow blocks are commonly used, which are attached to the wall by anchors or ties. The furring is laid up in mortar like that specified for gypsum blocks. Figure 64 illustrates the use of four inch block for furring by sawing it longitudinally.

CHAPTER XVII

GYPSUM PLASTER BOARD AND GYPSUM WALL BOARD

GYPSUM PLASTER BOARD

Definitions

Gypsum plaster board consists of two or more layers of fibrous binding material and one or more layers of gypsum. It is used chiefly as a base coat for plaster and in this capacity takes the place of lath and the first coat of plaster.

Gypsum wall board is an incombustible material which gives a finished surface for interior walls, partitions and ceilings. It consists of two outside layers of fibrous binding material and a core of gypsum which may contain a small amount of filler.

Composition

While plaster boards differ slightly as placed on the market by different manufacturers, the following specifications, prepared in 1919 by a committee of the Gypsum Industries Association for the Building Material Division of the War Industries Board, present fairly the nature of plaster board:

Two ply board

"The fibrous binder shall consist of two outer layers of chip board of the following specifications:

(a) "*Caliper.*—Each ply of chip board shall caliper not less than .025 inch—subject to manufacturer's normal variation of not more than 10 per cent, excepting in cases of boards where the chip board on plastering side is keyed on by means of a mechanical bond when chip board of not less than .020 inch may be used—subject to manufacturer's normal variation of not more than 10 per cent.

(b) "*Finish.*—The finish of the chip board may be plain chip, filled news, or any finish of equal strength.

(c) "*Weight.*—One thousand square feet of chip board shall weigh not less than the following:

.020 Chip Paper Minimum weight 60 lbs.
.025 Chip Paper Minimum weight 75 lbs.

(d) "*Strength.*—The puncture test (Mullen test) shall not be less than 50 per cent (Mullen test points) of the weight per thousand square feet.

Two, three and four ply boards

"The fibrous binder shall consist of two outer plies (and may contain one or more inner plies) of wool felt interposed and cemented together with a core or cores of gypsum.

(a) "*Caliper of Felt.*—Outer layers to be not less than No. 18 felt (18 lbs. per 480 sq. ft.), inner layers not less than No. 15 felt (15 lbs.per 480 sq. ft.). Manufacturer's variation in paper of not more than 10 per cent shall be permissible.

"*Core of all Boards.*—The core shall consist of calcined gypsum mixed with water to handling consistency, to which may be added not to exceed 10 per cent by weight of sawdust or other fibre, intimately mixed with the calcined gypsum.

"*Dimensions of Finished Boards.*—Standard boards shall be

32 inch by 36 inch or
24 inch by 32 inch.

"Boards may be ¼ inch undersize to allow for structural variations and to provide for a plastering key. Provided however that not to exceed 5 per cent what is known as ½ and ¼ boards (of same quality as full sized boards) accumulated in manufacture may be included in each shipment.

"*Thickness of Board.*—The boards shall be not less than ⅜ inch in thickness. This thickness shall be determined as follows: 32 boards when piled flat shall measure not less than 12 inches.

"*Plaster Board Less Than ⅜ Inch in Thickness.*—¼ inch and five-sixteenths inch boards are produced by board manufacturers and are only recommended in cases where economy is of greater importance than the more perfect fire protection afforded by use of the thicker board.

"*Weights of Boards.*—One thousand square feet of ⅜ inch board shall weigh not less than 1700 pounds.

"*Finished Product.*—The finished boards shall comply with the following: (a) the edges shall be folded, molded, cut or perforated-break. (b) The core shall be of sufficient thickness throughout the board to make the product conform to specifications. (c) The finished product shall present a suitable surface for plastering and when shipped from the manufacturer's plant shall be free from cracks or breaks except that 2 per cent shipment may consist of boards with breaks not exceeding one-half of 1 per cent of the total area of a single board.

'*Physical Characteristics.*—The boards when shipped must be dry, true and straight excepting that boards with not more than two inch warp may be shipped. The chip board binder must adhere firmly to the core."

A remarkable bond between the fibrous binder and the calcined gypsum develops during the hardening of the gypsum. A certain amount of the saturated gypsum solution penetrates the fibre and crystals form which penetrate the fibre and interlock with the material in the gypsum layers.

Impregnation of binding material

The same conditions develop when plaster is applied to gypsum plaster board, and a fine bond, more reliable even than the keys formed when lath are used, results. Figure 65 shows cross section of gypsum plaster board magnified to reveal this impregnation.

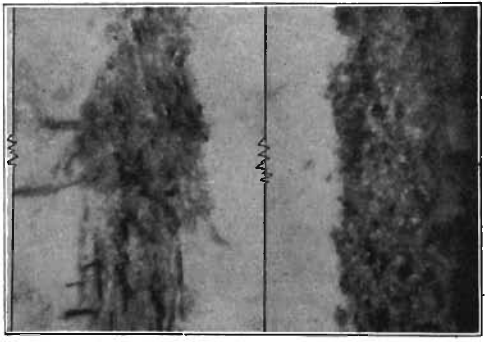

FIG. 65.—Cross section of plaster board magnified to show the penetration of the pulp board by the gypsum. Courtesy of United States Gypsum Co.

Marani[209] describes tests made to determine the adhesion of plaster to gypsum plaster board. As shown in figure 66 an average sample of plaster board was covered with gypsum plaster in which hooks for attaching a weight were cast. By ordinary testing methods the weight attached to these hooks was gradually increased till the point of rupture was reached. The material tested and the results obtained are more fully described as follows:

Adhesion of plaster to plaster board

Gypsum plaster board lath	⅜ inch thick
Area of plaster board lath (5 inches by 4 inches)	20 sq. inches
Area of plaster coat (3 7/16 inches by 2 11/16 inches)	9.19 sq. inches
Thickness of plaster coat	½ inch
Total load to produce parting of plaster coat from plaster board	115½ lbs.
Total load at rupture, per square inch	12.57 lbs.
Factor of safety, assuming weight of ½ inch plaster coat at 3 pounds per square foot (approximate)	600

"The gypsum plaster board of this test consisted of two

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[209] Marani, V. G., Construction, Sept. 1916, pp. 161-164.

layers smooth chip binder and one intermediate layer of gypsum, making up the full thickness of the board. The rupture was in the parting of the smooth chip binder itself, the plaster board and plaster coat remaining uninjured."

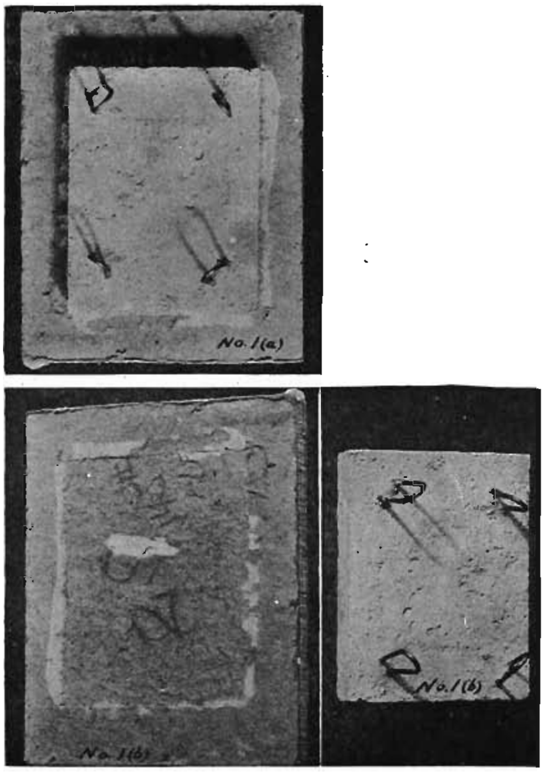

FIG. 66.—Photograph showing method of preparing specimen of plaster board for the adhesion tests described in the test. No. I (a) specimen before weights were attached. No. I (b) after bond between plaster and board was broken. Courtesy U. S. Gypsum Co.

Fire resisting properties

Gypsum plaster boards are approved on a parity with metal lath in most large cities, and such approval is set out in the provisions of the building codes of the National Board of Fire Underwriters in 1915 and 1916. As a fire resistive material gypsum plaster board is recommended by:

Construction Division of the Army.
The U. S. Bureau of Mines.
National Board of Fire Underwriters' Codes.
New York State Department of Labor.

Industrial Commission, Ohio.
Building Department, Milwaukee, Wisconsin.
Building Department, Cincinnati, Ohio.
Building Department, New York City.
Building Department, Chicago, Illinois.
Chicago Board of Underwriters.
New England Fire Insurance Exchange.
Kansas State Architects Specifications.
New York State Architects Specifications.

The fire test described below was conducted by the Building Department of the City of Detroit on January 2, 1920:[210]

"The furnace consisted of a small enclosure of fire brick with an opening on the top capable of testing samples about 10x10 feet in position as for ceiling construction.

"Temperature. The temperature was maintained, as nearly as possible, at 1700 degrees Fah. and was recorded by electric pyrometer readings.

"Samples. Plaster board, 10 by 10 feet, ¼ inch thick and plastered with about ⅜ inch of sanded gypsum plaster in the proportions of about 1 part of gypsum plaster to 2½ parts fine sand by volume. These proportions were determined by crumbling and washing a portion of the plaster, allowing it to settle in a test tube in water. On the top of the unexposed face of the sample (the face not exposed to the furnace fire) there was placed a piece of 2 by 4 inches studding.

SAMPLE NO. 1

TIME	DEGREES FAH.	REMARKS
1:47 P. M.	1650	Test started
1:58 P. M.	1700	
2:03 P. M.	1700	Unexposed face of board hot to the touch
2:06 P. M.	1700	Paper on unexposed face begins to char
2:11 P. M.	1610	Wood, 2″ by 4″ on unexposed face begins to char
2:47 P. M.	1700	
3:02 P. M.	1700	Board begins to check
3:17 P. M.	1700	Signs of failure
3:31 P. M.	1700	Test stopped

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[210] Reported by V. G. Marani, who was present as representative of the Gypsum Industries Association.

SAMPLE NO. 2

Time	Degrees Fah.	Remarks
3:32 P. M.	1700	
3:54 P. M.	1700	Unexposed face of board hot to the touch
3:56 P. M.	1700	Paper on unexposed face begins to char
3:59 P. M.	1700	Temperature on unexposed face about 440 degrees Fah.
4:04 P. M.	1700	Board begins to check
4:18 P. M.	1700	Wood, 2″ by 4″, on unexposed face begins to char
4:20 P. M.	1700	Test stopped

Gypsum plaster board is valuable as a sound deadener. Professor P. D. Woolworth[211] of Lewis Institute, Chicago, in tests made in 1914, found that a plaster board containing four laminations of fibrous binding material was 3½ times more sound proof than wood lath plastered to the same standard grounds as was the plaster board. Sound tests

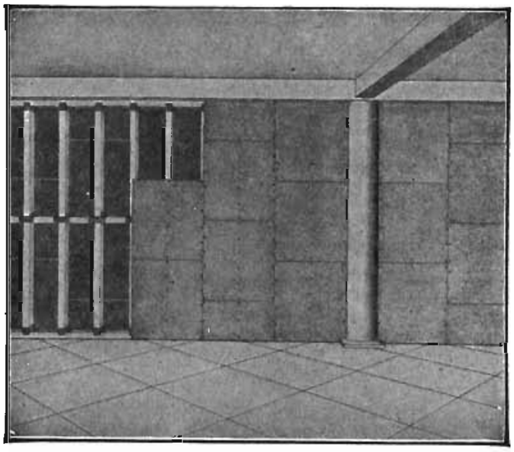

FIG. 67.—Placing plaster board on gypsinite studding. Courtesy Oklahoma Geological Survey.

More recent tests by Professor Watson, show that gypsum boards and plasters are remarkable for their ability to prevent the transmission of sound through partitions. Watson's tables show that as sound absorbers gypsum boards and gypsum plasters are slightly more effective than lime plasters, and make plain the fact that to prevent reflected sound carpets

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[211] Marani, in Construction, Sept., 1916, p. 165.

and tapestries must be employed. His conclusions lead decisively to the fact that gypsum boards and plasters are desirable materials from the standpoint of acoustics.

Directions for application

Studding and Joists.—Set studding and joists straight and true, 16 inches from center to center.

Spacing of Boards.—Boards must be spaced not less than 1/4 inch apart at all horizontal or other joints which do not come on studs or joists. See figure 67 for method of application.

All vertical or other joints coming on the studs or joists may be butted tight, or spaced not to exceed 3/8 of an inch apart.

Nailing.—Place the branded side of board against the face of the support. Nail the boards directly to studding, furring or joists. Nail center of boards first, then the outer edges.

The nails used, to be 1 1/4 inch, 11 1/2 gauge, seven-sixteenths inch head wire nails, spaced not more than four inches apart with each nail head driven home firm and tight.

Joints must be broken at right angles with the nail studs and the ceiling joists, which shall be accomplished by starting every other course with a half board.

Perpendicular joints on the opposite side of partitions must not occur on the same stud as on first side, but shall come on the next stud.

Cutting.—Boards to be cut to size with a saw, or scored both sides and broken across a straight edge.

Grounds.—Grounds shall be 7/8 inch in thickness. Wherever practical, the grounds shall be placed on the face of the plaster board and securely nailed to the studs through the board.

Grounds shall be applied directly to the surface of the board after the board is in place.

Grounds shall be nailed to the studs or joists through the boards, and shall be not less than 7/8 inch in thickness which shall include the thickness of the 3/8 inch plaster board.

MORTAR.—To be any "Standard" brand of gypsum cement plaster, gypsum wood fibre plaster, or gypsum sanded wall plaster.

Mixing.—Gypsum cement plaster shall be mixed with dry clean sharp sand screened through a six mesh screen (avoid quicksand) in the proportions of not more than two parts of sand to not less than one part of gypsum by weight.

Gypsum wood fibre plaster may be used with the addition of water only, or mixed with equal parts by weight of dry, clean, sharp sand, screened through a six mesh screen (avoid quicksand).

Gypsum sanded wall plaster shall be used with the addition of water only.

To mix gypsum plasters with sand, place in raised end of mortar box, first a layer of sand, then a layer of plaster. Hoe dry from raised end of mortar box to the other, then back again, working sand and plaster thoroughly together until the mortar is of uniform color. Put water in lower end of the box and hoe the plaster into the water, mixing thoroughly to proper consistency for application.

Gypsum wall plasters which do not require the admixture of sand on the job, shall be mixed by placing the plaster in the raised end of the mortar box, hoeing it into the water in the lower end of the box, mixing thoroughly to proper consistency for application.

Note.—In ordering gypsum sanded wall plaster, specify that it is for use on gypsum plaster board.

Application.—Do not wet plaster boards before applying the mortar.

First work plaster well into joints, forming perfect keys, and follow immediately with base coat, filling out to grounds. Darby to a straight and even surface. To receive the finish coat, darby lightly, and leave surface rough, and use water sparingly.

FINISHING COATS.—To be any ''Standard'' brand of ''Lime putty gauged with gypsum'', ''prepared white trowel finish'' or ''gypsum sand float finish''.

Mixing.—Lime Putty Gauged with Gypsum (plaster of Paris), shall be prepared (as in general practice) by making a two foot ring of lime putty, height of ring to be about six inches. Fill in center of ring with water to a depth of about four inches. Sift gypsum finishing plaster (plaster of Paris) into the water, allow to settle a few minutes, mix to creamy consistency and then mix the lime putty and plaster to a uniform paste.

The mixture should be composed of three parts of lime putty to one part of gypsum finishing plaster (plaster of Paris) by volume.

Prepared white trowel finish and gypsum sand float finish shall be used with the addition of water only, and shall be mixed in a suitable mortar box used exclusively for this purpose.

Place material in raised end of mortar box with water in lower end. Hoe the material into the water, allowing it to soak without further hoeing for at least ten minutes, then mix thoroughly to a smooth and even consistency.

Application.—All finishing coats shall be not less than 1/8 inch in thickness, shall be run to guide lines and made straight and level and plumb, with all arrises true and sharp.

Gypsum prepared white trowel finish shall be applied to a thoroughly dry base coat, and shall be applied in three coats. First coat shall completely cover the surface using material as thin as possible, grinding it thoroughly into the base coat. Allow this coat to draw for a few moments to avoid blistering. Second coat shall be applied perfectly level, and the thin coat shall be applied with material as thin as can be handled to fill in cat faces and imperfections.

After the finish has drawn a few moments, trowel it to a smooth surface, brushing lightly with a damp brush.

Gypsum sand float finish shall be applied after the base coat has set firm and hard, but while still green, and within twelve hours after the base coat is applied, lay on with trowel, using cork, carpet or felt float, working the material to a smooth surface free from cat faces, defects and brush marks. For floating, use as little water as possible, applying same with a damp brush.

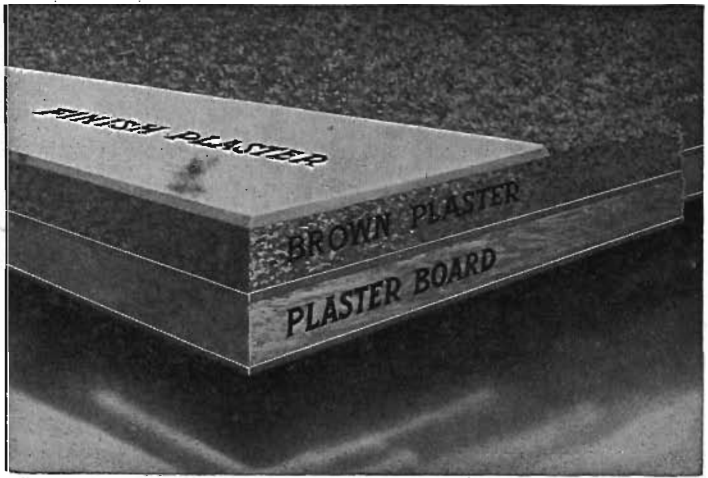

FIG. 68.—Plaster board and plaster coatings. Courtesy Beaver Board Co.

Lime putty finish shall be applied in the usual manner, troweled down perfectly true, with metal trowel and water brush to a smooth surface free from defects and brush marks. Figure 68 gives a cross section of plaster board covered with standard plaster coatings and figure 69 illustrates the use of plaster boards on ceilings together with gypsum block partitions.

GYPSUM WALL BOARD

Gypsum wall board is an incombustible material for interior walls, ceilings, and partitions, consisting of two layers of **Definition** fibrous binding material on the outside of a core of gypsum. In distinction from plaster board, gypsum wall board furnishes a finished surface, and is not intended to serve as a base for plaster. A sectional view of wall board is presented in figure 70.

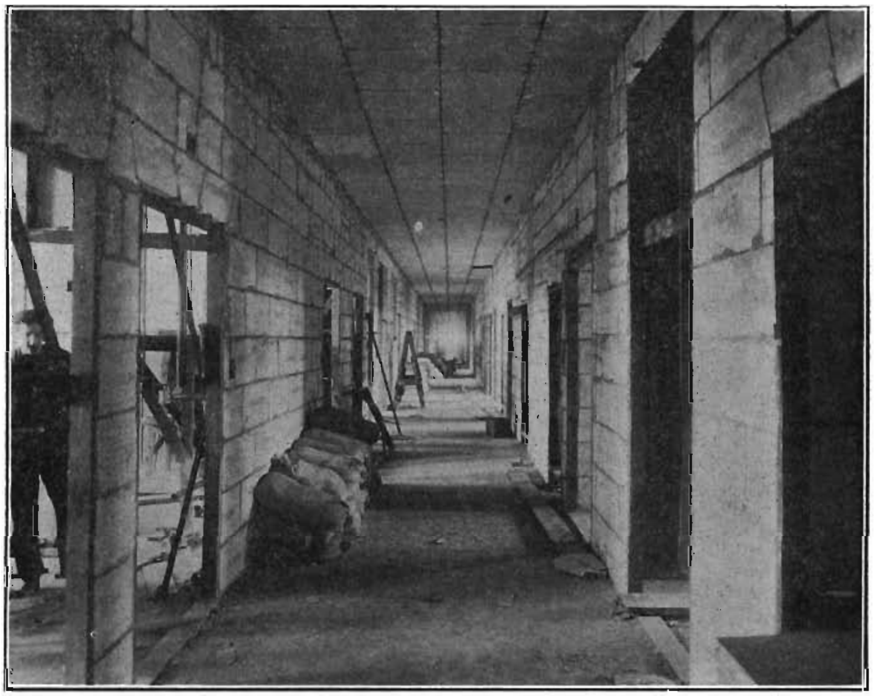

FIG. 69.—Plaster board ceilings and gypsum block partitions. U. S. Government Hospital, Maywood, Ill. Courtesy V. G. Marani.

The following specifications[212] show the nature of gypsum **Nature of wall boards** wall board, as well as the various materials entering into its composition.

"*FIBROUS BINDER.*—The fibrous binder shall consist of two outer layers of chip board of the following specifications:

Caliper.—Each ply of chip board shall caliper not less

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[212] Prepared for the Building Materials Division of the War Industries Board, by the War Service Committee of the Gypsum Industries Association, O. M. Knode, Chairman.

than .030 inches—subject to manufacturer's normal variations of not more than 10 per cent.

Finish.—The finish of the chip board may be plain chip, filled news, or any finish of equal strength.

Weight.—One thousand square feet of chip board shall weigh not less than 90 lbs.

Strength of Binders.—The puncture test (Mullen test) shall be not less than 50 per cent (Mullen test points) of the weight per thousand square feet.

Core of Boards.—The core shall consist of calcined gypsum mixed with water to handling consistency, to which may be added not to exceed 10 per cent by weight of sawdust or other fibre intimately mixed.

Dimension of Finished Boards.—Length, 3 feet and 4 feet with nominal width of 32 inches; length, 8 feet, 9 feet and 10 feet with nominal width of 32 and 48 inches.

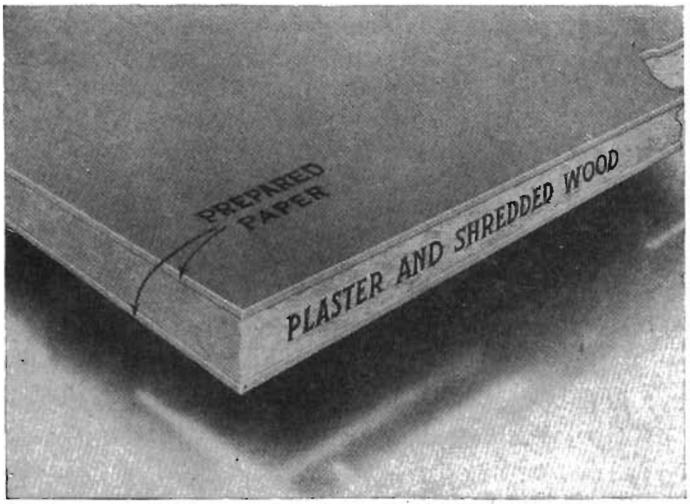

FIG. 70.—Section of gypsum wall board. Courtesy of Beaver Board Co.

In the process of manufacture boards 4 feet, 5 feet, 6 feet, and 7 feet in lengths, by 32 inches and 48 inches are produced in limited quantities.

Boards may be ¼ inch under-size in the narrow dimension to allow for structural variations and unequal stud spacing.

Thickness of Boards.—Boards shall be not less than ⅜ inch in thickness. This thickness shall be determined as follows: 32 boards when piled flat shall measure not less than 12 inches. In determining the thickness in the above method, no boards shall vary more than three sixty-fourths of an inch over or under size.

Weight of Boards.—One thousand square feet of 3/8 inch in thickness Wall Board shall weigh not less than 1700 lbs.

Wall boards less than 3/8 inch in thickness, namely 1/4 inch and five-sixteenths inch are produced by manufacturers and are recommended only in cases where economy is of greater importance than the more perfect fire protection afforded by use of the thicker board.

Finished Product.—

Edges.—The edges shall be folded, molded, cut or perforated-break.

Core.—The core shall be of sufficient thickness throughout the board to make the product conform to these specifications.

Surface.—The exposed or outer face of boards shall present a surface suitable for use with, or without, additional decoration. When shipped from the manufacturer's plant all boards shall be free from cracks or breaks.

Physical Characteristics.—The board when shipped must be dry, true and straight, excepting that boards with not more than two inch warp may be shipped. The chip board binder must adhere firmly to the core.

Advantages of gypsum wall board

Gypsum wall board is the only form of wall board on the market that has fire resisting features. Its value in this connection is recognized by the underwriters. Gypsum wall board itself will not burn even at high temperatures and is capable of withstanding great heat for a long period of time without breaking down. It thus presents an effective barrier to the spreading of fire.

Gypsum wall board does not shrink, expand, warp or buckle, and for all situations where a type of construction more flexible than a plastered surface is desired, it offers greater advantages than any other form of construction material. It may be applied and decorated in the same way that any of the numerous forms of wall boards are treated.

MANUFACTURE OF GYPSUM PLASTER BOARD AND WALL BOARD

The methods used in manufacturing gypsum plaster board and wall board are quite similar. Since wall board gives a finished surface, while plaster board is covered with plaster, it is essential that wall board be uniform in thickness and attractive in color. These properties are not so essential in plaster board. It is necessary to have thickness sufficient for strength, but the fact that some plaster boards are somewhat thicker than others does no harm.

A satisfactory bond between paper and gypsum matrix is the great essential in both types of boards. As has been stated, while the gypsum core or matrix is setting there is an actual growth of gypsum crystals within the fibre of the chip board, due to the penetration of the chip board by water saturated with gypsum. The chip board must not be sized enough to prevent moderately prompt water penetration. On the other hand if the chip board takes up water too quickly it loses its stability and tends to wrinkle.

Bond between chip board and the gypsum

The chip board is delivered in large rolls and the gypsum paste, made by mixing slightly accelerated calcined gypsum and water either on the lower sheet of chip board or in a mixer, is spread out between the layers of paper as the plastic mass passes between rollers. The edges are either molded, trimmed with saws or made true by folding the edge of the lower sheet of the chip board under the edge of the upper sheet.

The edge

The plaster board is allowed to run out on a traveling belt till the plaster has set sufficiently to make it possible to handle the boards without breaking. It is then either cut into appropriate lengths by knives or saws, or perforated so that the sheet can be broken to size.

After the plaster in the board has hardened so that the board may be handled conveniently the boards are placed in a dryer and subjected to moderate heat, to remove the surplus water in the chip board. The temperature must not reach a point which would deprive the gypsum of any of its water of crystallization. Steam radiators are commonly used to furnish the heat, though in some instances carefully regulated direct heat obtained by burning coke in a furnace attached to the dryer, is employed.

Drying

CHAPTER XVIII

STRUCTURAL GYPSUM

Definition

Nature of structural gypsum

When gypsum is used in roofs, floors and pillars, it is often spoken of as structural gypsum.[213] For these purposes the compressive strength of gypsum, which is relatively unimportant in connection to its other uses, becomes a matter of prime importance. That gypsum possesses a compressive strength which makes it useful in floor and roof construction has been recognized only in recent years. The other properties of gypsum which make it an admirable material for roofs and floors were better known.

The compressive strength of gypsum depends upon the amount of water used in mixing; the method of calcining; the dryness of the material and the purity of the mineral.

Mr. Willis A. Slater, in the Laboratory of Applied Mechanics, University of Illinois, carried out an elaborate series of tests in accordance with a comprehensive plan, and worked out formulae for the guidance of engineers who use gypsum for structural purposes.[214]

Professor Slater's summary of his tests follows:

(1) "The rate of drying of gypsum after setting took place was nearly constant until about 87 per cent of the excess water had been evaporated. For 6x12-in. cylinders this required about 20 days. Evaporation of the remaining 13 per cent required about 20 days more. This was at ordinary temperatures and humidities. With the temperature raised to 100 degrees F. and relative humidity at about 0.50, the drying time was reduced to 7 days or less for complete dryness.

(2) "The weight of hydrated first settle gypsum per cubic foot was about the same as that of hydrated second settle gypsum. The weight of dry hydrated gypsum decreased with an increase in the amount of water used in mixing. The calcined gypsum required was about five-sixths of the weight of the dry hydrated gypsum resulting, regardless of the amount of water used in mixing.

(3) "The attainment of the maximum compressive strength

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[213] Gypsum calcined at high temperatures for flooring is considered in Chapter XIX.

[214] W. A. Slater and J. J. Whitacre, Tests of Plain and Reinforced gypsum specimens: Journal of the Western Society of Engineers, Vol. XXIV, No. 7, September, 1919.

of gypsum appears to depend upon the amount of drying out rather than upon the age. Increase in strength with age is apparently due to increased drying with age. Small specimens (3x6-in. cylinders) dried at 100° F. showed a temporarily high strength as soon as they were dry. This strength soon fell to about the same as that of specimens dried at ordinary temperatures or of larger specimens dried at the same temperature. The permanent strength of second settle dry specimens made from gypsum mixed at standard consistency and having 0.1 per cent retarder seemed to be about 1900 to 2000 pounds per square inch, whether dried at 100° or 70°, regardless of the size of the specimen.

(4) "When mixed without retarder at standard consistency the strength of the first settle gypsum when dry was about two-thirds that of second settle gypsum, whether the storage was at 70° or at 100° F.

(5) "The compressive strength fell off regularly and rapidly with an increase in the percentage of water used in mixing. For second settle gypsum, 100 per cent dry using 0.1 per cent retarder, the range in strength found was from 2400 to 400 lb. per sq. in. when the water varied from 35 per cent to 53 per cent.

"For first settle gypsum about 50 per cent dry, using no retarder, the range in strength was from 760 lb. per sq. in. to 140 lb. per sq. in. when the water varied from 35 to 60 per cent.

Slater's tests

"A portion of the difference in strength between the second settle and first settle gypsum is undoubtedly due to the fact that the first settle gypsum was only about 50 per cent dry.

(6) "Under certain conditions the use of retarder caused a decrease in the strength of the gypsum. For the conditions most likely to be met in practice the use of not more than 0.1 per cent retarder is likely to cause only a slight loss but under certain storage conditions it may even cause an increase in the strength.

(7) "The tensile strength of gypsum seems to be from, say 300 to 800 lb. per sq. in. The earlier beam tests indicated that no cracks occurred in the gypsum until the stress in the reinforcement was very high. This was, to a certain extent, true for the later beams, but was less marked than in the earlier investigations. The combination of a high tensile strength with a low modulus of elasticity would be expected to bring about this kind of a result. A part of the difference in behavior may be due to the fact that the earlier beams were not as dry at the time of testing as were the later ones.

(8) "Only a small amount of exposure of dry hydrated

gypsum to very moist air was sufficient to reduce the strength of gypsum considerably—but additional exposure even to the extent of soaking the specimen in water had relatively slight effect on the strength.

(9) "The use of hydrated lime up to about 4 per cent of the weight of the gypsum caused a marked decrease in the amount of corrosion of the imbedded bar and in the bond strength with steel bars. With larger amounts of lime there was little additional effect on either the bond strength or the amount of corrosion.

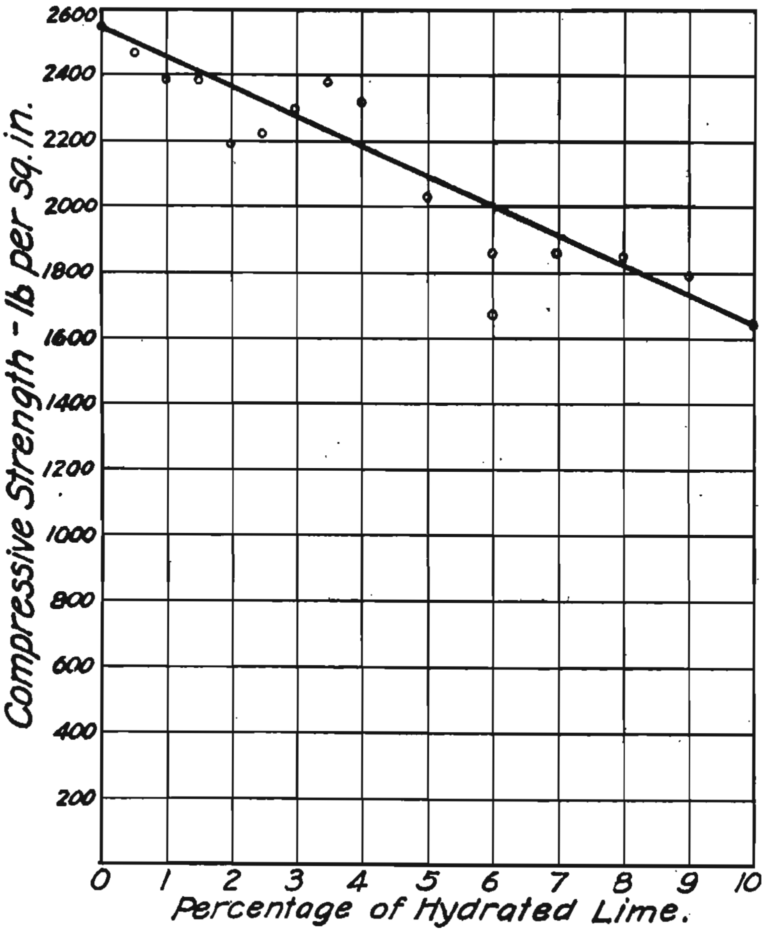

FIG. 71.—Effect of addition of hydrated lime on compressive strength of calcined gypsum. Courtesy of Society of Western Engineers.

"The tests indicated a loss of about 3½ per cent of the compressive strength of the gypsum for each one per cent of hydrated lime used. This is true up to ten per cent of the total weight of lime and gypsum. Ten per cent was the largest amount of lime used. Results of the tests are shown graphically in figure 71.

(10) "Corrosion of the reinforcement in roofing tiles which had been in use for four years was negligible where the gypsum had been kept reasonably dry. Where the gypsum had been continually saturated for a considerable time the corrosion was important.

(11) "Second settle gypsum from various mills showed a good degree of uniformity in compressive strength.

(12) The tests of the T-beams indicate that the same principles which are used in the design of reinforced concrete beams are applicable to the design of reinforced gypsum beams.

(13) "Under conditions comparable with those which existed in these tests and where stripping and bond failure are eliminated failure by diagonal tension in beams without web reinforcement does not seem likely to occur when the shearing stress is 80 lb. per sq. in. or less.

(14) "Anchorage of reinforcing bars by means of semicircular hooks at the ends was fully as effective as the use of plates attached to the ends of the bars for anchorage.

(15) "In a test made to determine the effectiveness of anchorage the end plate came into action early in the test. Shortly after the beginning of the test the proportional part of the total tension carried by bond began to decrease and the proportion carried by anchorage increased until at about two-thirds of the maximum load slightly more than one-half of the total tension was resisted by bearing against the anchor plate. From then until failure the proportion carried by bond was nearly constant. It is possible that under some conditions a larger proportion would have to be carried by the anchor plate. The largest average bond stress found for this beam was about 120 lb. per sq. in. and this occurred at the maximum load.

(16) "An upward deflection amounting usually to about 3-16 in. and in certain cases to as much as ¼ in. was found in the beams previous to testing them. An expansion of the gypsum during the setting or drying process took place and the restraint of this expansion on the reinforced side of the beam seems to be responsible for the upward deflection. It was ascertained that the most of the expansion occurred soon after the first set had taken place and at the end of 24 hours the expansion generally was larger than at any time later."

A valuable report on Design of Reinforced Gypsum Beams, by Professor Slater, appears as appendix VIII.

First settle gypsum has been used successfully for roofs and floors though its compressive strength is not equal to the second settle product.

Gypsum carrying impurities sufficient to affect its compressive strength may be used for flooring and roofing provided the cross section of the slab is figured somewhat more liberally, to allow for any difference in strength. For any rock gypsum now in commercial use the increase in the section required to balance such impurity would be small.

Advantages of structural gypsum

Conductivity.—As gypsum is an exceedingly poor conductor of heat, it has an important advantage over other substances used in making roofs and floors. A gypsum roof slab as ordinarily made shows a heat loss per square foot per hour, for each degree difference in temperature of .4 B. T. U. as compared with 1.2 B. T. U. loss for an equal thickness of cinder concrete and 2.0 B. T. U. loss for an equal thickness of stone concrete. These figures justify the statement that where a gypsum roof is used instead of cinder concrete, between latitudes thirty-nine and forty-two there is a saving of 10 per cent in the initial cost of the heating plant, and a saving of 20 to 25 per cent in the cost of fuel. These savings are of course greater if comparison is made with stone concrete, and are still greater as compared with clay tile.

These figures showing relative nonconductivity are as favorable to gypsum if summer conditions, instead of winter conditions, are under consideration. The gypsum roof is cool, and lofts may be used with comfort where gypsum is the roofing material which would be intolerable otherwise.

Gypsum roofs are free from condensation or "sweating", which is an important consideration in industrial buildings where the air is moist from any cause.

Fire Resistance.—Because gypsum is a poor conductor of heat, gypsum roofs and floors are remarkably resistant to fires. This has been considered to some extent in chapter XVII.

An important fact that deserves special mention is found in the protection given by gypsum roofs and floors to the structural steel that carries the weight of the building. At a temperature of only 800° F. steel loses 10 per cent of its strength, and at 1700° F. it loses 50 per cent of its strength. It is exceedingly important, therefore, that in fireproof buildings, where the contents of the building may create high temperatures, the steel be given ample protection.

Lightness.—Gypsum roofs and floors are lighter than any other form of fireproof construction. Certain types of poured roof do not weigh over twelve pounds per square foot for average purlin spacing, ready for finish or water proof surfacing. A four inch poured slab weighs but sixteen pounds per square foot. Precast roof blocks have the following weights:

TYPE	LENGTH, INCHES	THICKNESS, INCHES	WIDTH, INCHES	WEIGHT PER SQUARE FOOT, LBS.
Solid	30	3	12	13
Hollow	30	4	12	14
Slabs	48 to 72	5	15	14 to 16

The thirty inch blocks, either solid or hollow, are set in T iron sub-purlins and save 40 per cent in steel over clay block tile construction.

Elasticity.—Gypsum roofs and floors are more elastic than concrete structures and the vibrations from machinery or other causes do not develop cracks which are often troublesome where a less resilient construction material is used.

Nonconductor of Sound.—Tests quoted in chapter XVII verify the statement that gypsum floors are excellent nonconductors of sound. For this reason gypsum floors are especially commended for hotels, apartment houses and educational institutions.

Rapidity of Construction.—The rapidity with which gypsum sets makes rapid construction possible. The forms or centers from poured units can be removed in twenty or thirty minutes. In the case of a poured roof or floor the resulting surface is sufficiently strong to be used at once and within an hour provides a working floor that may be safely used under the loads for which it was designed. In the case of precast gypsum roof blocks, on account of the large size of the unit and its lightness, construction is rapid.

In the case of poured floors and roofs the gypsum generates considerable heat while setting and it is possible to proceed with the work even when temperatures are considerably below freezing.

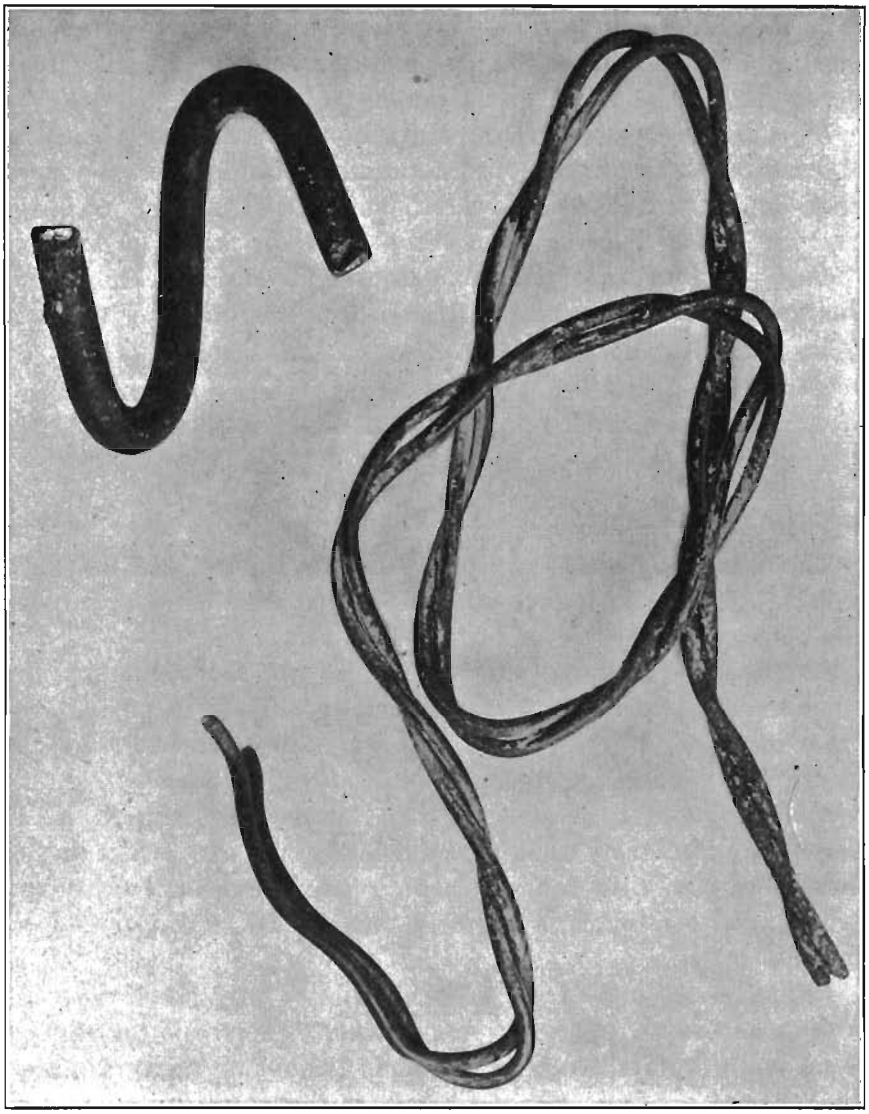

FIG. 72.—Showing excellent condition of steel reinforcing imbedded in calcined gypsum for fifteen years. Hammerstein Theater. Courtesy V. G. Marani.

Strength.—As has been shown in the paragraph on compressive strength and as is more fully set out in appendix VIII where the computations of Professor Slater are given at length, gypsum can be easily and amply reinforced to give the strength desired for any roof and floor construction. Where roof slabs or blocks, either precast or poured on the job, are used ample strength for all needs is easily secured.

Durability.—The steel reinforcement used in structural gypsum is remarkably free from corrosion. Wires which have been imbedded in gypsum for fifteen years have been examined repeatedly and, aside from a thin film of initial rust that always forms when a wet substance touches metal, the steel is as bright as when installed.

Mr. Marani[215] describes an interesting investigation of the gypsum floor in Hammerstein's Theater as follows:

> "In the year 1911 the sub-committee on engineering subjects of the Joint Committee of City Departments of New York City, while investigating the subject of corrosion, caused the cutting into of a gypsum floor slab in the roofing and upper floor system of Hammerstein's Victoria Theater, Seventh Avenue and Forty-second street, New York City, for the purpose of examining the imbedded steel. Both the twisted wire cables and the I beams showed only initial rusting and that the rusting had not progressed, the committee being favorably impressed with the condition of the steel.
>
> "Subsequently in the summer of 1915, this theater building was torn down. "S" hooks, which were used as anchors for the reinforcing cables, though not previously coated in any manner, showed no signs of progressive corrosion, the same being true of the galvanized, twisted cables. The accompanying illustration (figure 72) shows this hook and a section of the cables as they were taken from the building. (This matter will be found carefully set forth in an affidavit made by Samuel G. Webb, and registered Bronx County, No. 4, Bronx Register, No. 606. Certificate filed in New York County, No. 11, New York Register, No. 6036.)

GYPSUM ROOF CONSTRUCTION

Historical

Gypsum has been used as a roofing material in America since 1898. Sufficient time has elapsed, therefore, to demonstrate its durability. The list of important office buildings in New York City, covered with gypsum roofs, in-

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[215] Marani, in Construction, September, 1916.

cludes a fair percentage of the more important structures in that city, while the number of gypsum roofs on industrial, apartment and office buildings in that city runs into the hundreds.

Canada seems to have been a particularly favorable field for the installation of gypsum roofs, probably on account of the fact that they can be poured, or put in place in freezing weather, and under conditions that make the use of concrete impossible.

In Europe gypsum roof and floor work is of an altogether different nature, as gypsum calcined at high temperatures, as described in chapter XIX is employed entirely for these purposes.

Types

The poured roof

Gypsum roofs are of two types; the poured roof, and the roof slab. Although advocates of each type claim for it superior advantages local conditions will probably decide the question when choice must be made between them. Both systems adequately meet all requirements for fire protection, durability and economy. The principle involved in the poured roof is that of the suspension bridge. Steel cables properly paced, carry the entire load with an ample margin for safety, to which factor of safety may be added the compressive strength of the gypsum roof deck.

Cables composed of galvanized wires are carried over the tops of the beams or purlins and are secured to purlins or walls by strong hooks, bars, or anchors. The cables are laid parallel to one another and at intervals of from one to three inches, varying according to spans and loads. The cables pass under an iron bar midway between the purlins which causes a uniform deflection in the cables. Forms are placed about an inch below the round iron bar which crosses the center of the cables. When the gypsum paste is poured on this form till it stands about one-half inch above the tops of the purlins, the slab has a thickness of about three inches.

The gypsum paste consists of calcined gypsum and water, with planer shavings or shredded wood, preferably of some non-staining sort. The percentage of water used in mixing is a highly important factor, for, as has already been shown, the compressive strength of the slab depends upon this, more than upon any other single factor. Over the gypsum slab a layer of ordinary slag roofing is commonly poured. A variety of water proof compounds may be substituted for the slag cement any of which will successfully keep water from the gypsum slab, which is essential.

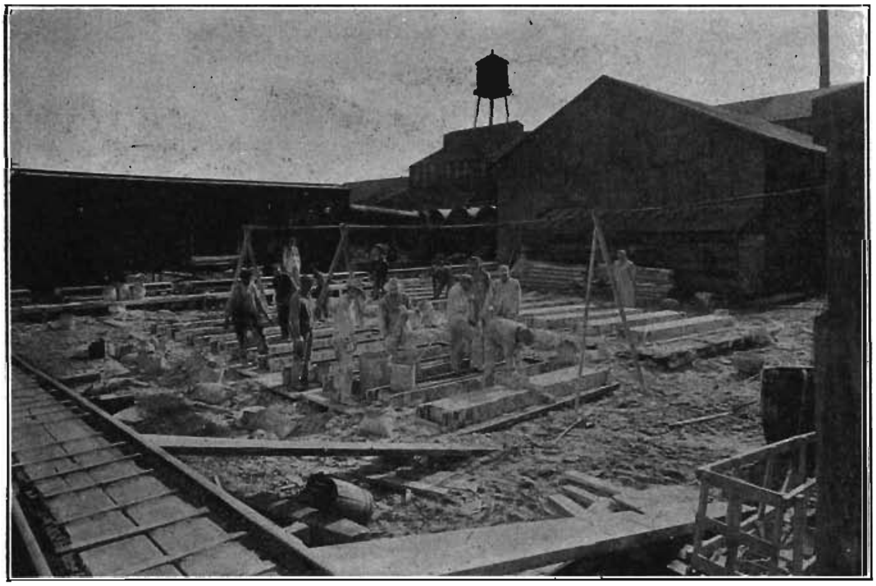

FIG. 73.—Making large roof tile on the job. Courtesy V. G. Marani.

The government in awarding contract for the navy yard at Norfolk made a thorough investigation of the poured gypsum roof and its report[216] is very favorable to this type of construction. This report is reproduced as appendix VI and to this the reader is referred for much valuable information.

Roof Block Construction.—Factory made blocks, reinforced, but otherwise like gypsum partition blocks are used in roof construction. The tendency, however, is to use larger units, moulded on the job, such as blocks ten feet long which extend from truss to truss and eliminate the T irons ordinarily used in roof construction. Figure 73 shows how these units are made and figures 74 and 75 illustrate the method of laying and surfacing a tile roof. Tests of these blocks made twenty-

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[216] Bulletin 25, Public Works of the Navy, Washington, 1917.

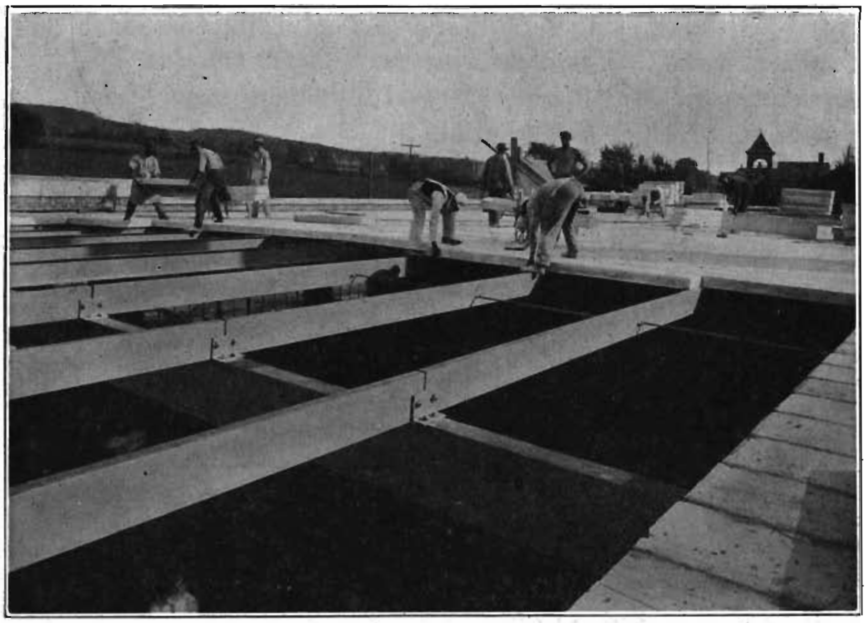

FIG. 74.—Laying precast gypsum roof tile on purlins. Courtesy United States Gypsum Co.

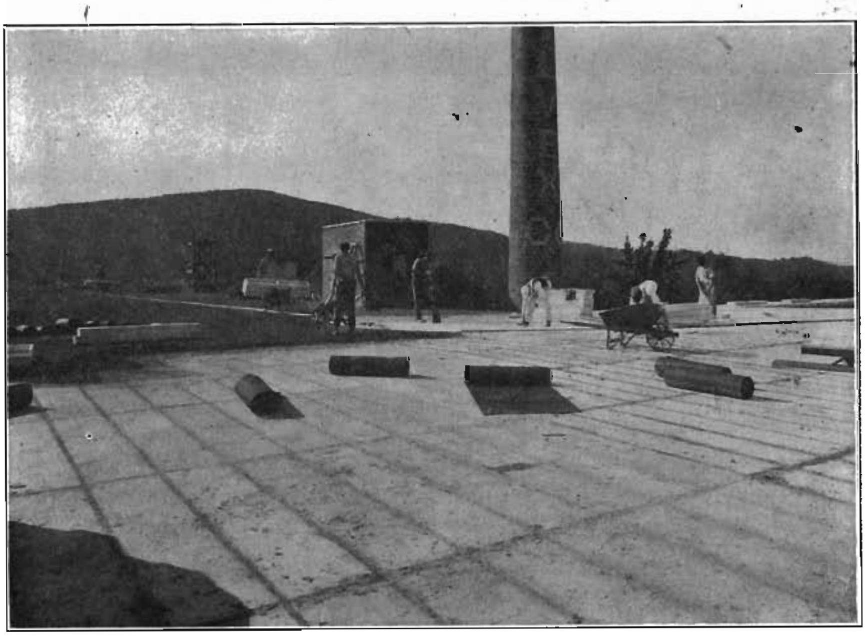

FIG. 75.—Surfacing a gypsum tile roof. Courtesy United States Gypsum Co.

four hours after pouring showed them to be capable of carrying a uniformly distributed load of two hundred pounds per square foot.

GYPSUM FLOORS

The same types of construction used for roofs are appropriate for floors in fireproof buildings. In addition to these a gypsum floor tile or filler for use in reinforced concrete floor construction is popular. These floor tile or domes are light, and permit of long floor spans. They have solid ends which reduce the loss of concrete at the joints when concrete is poured. The bottom of these tile makes an excellent surface for the plaster of the ceiling formed by the floor.

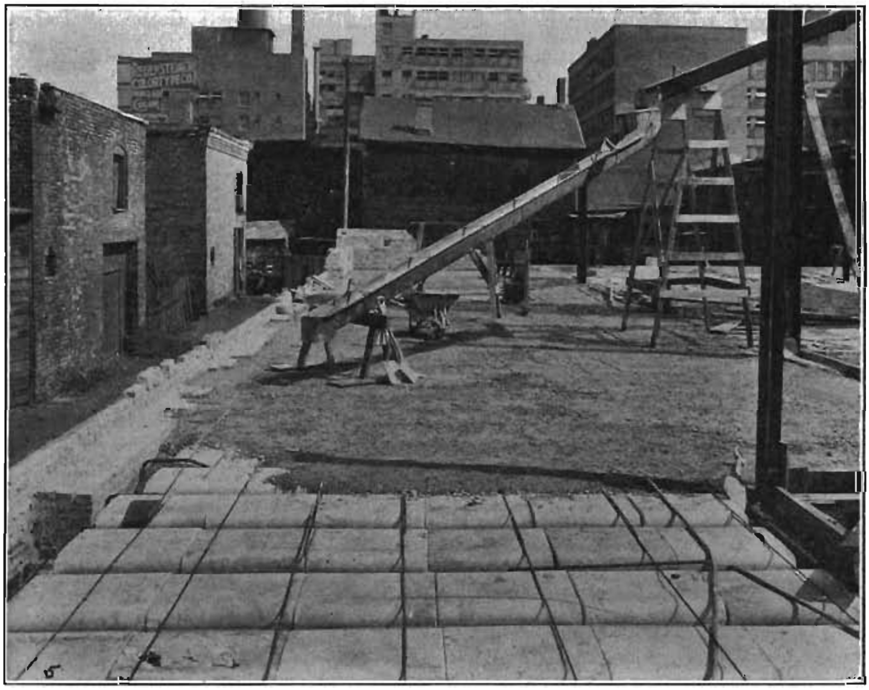

FIG. 76.—Gypsum floor tile showing conduits, and surfacing of same with concrete. Castle Hotel, Omaha. Courtesy V. G. Marani.

Floor tile of this type are spaced twenty-four inches on centers and are about one-half the weight of clay tile. They are illustrated in figure 76.

CHAPTER XIX

HYDRAULIC GYPSUM AND KEENE'S CEMENT

An English term is needed to cover gypsum which has been calcined at high temperatures and in consequence has not merely been dehydrated but has lost a portion of its sulphur through oxidation.

Definition

Calcined gypsum is a term that may well be confined to gypsum calcined at moderate temperatures, and which retains a portion of its water of crystallization or so quickly takes on water from the atmosphere (as in the case of soluble anhydrite) that it is in the hemi-hydrate form when it reaches the market. It then becomes a synonym for stucco and plaster of Paris.

Dead burned gypsum is a term which satisfactorily covers gypsums dehydrated between the temperature used in making calcined gypsum (400° F. or 190° C.) and the temperature at which partial oxidation takes place (1652° F. or 900° C.).

In Germany the term Estrich (which means flooring) is applied to gypsums calcined at the temperatures last named, because it possesses properties which make it peculiarly valuable for flooring purposes.

The German "Estrich"

Inasmuch as ordinary calcined gypsum is used extensively and successfully in America as a flooring material, it does not seem wise to use the term "flooring" as the descriptive adjective which designates the gypsum product resulting from high temperature calcination.

The term hydraulic gypsum has been used to describe this product, and inasmuch as it correctly describes one of its important attributes and is free from confusing associations it is recommended for use in this connection.

Hydraulic gypsum is calcined by heating lump gypsum in an oxidizing flame to a temperature of 900° C. (1652° F.) to 1300° C. (2372° F.). The gypsum at these temperatures is at a red heat. Higher temperatures are in no way harmful and produce a somewhat better product, but they are expensive and hard to attain.

How calcined

Glasenapp[217] made a series of microscopic studies of gypsum calcined at various temperatures up to 900° C. and beyond, and found that the structure that definitely characterizes hydraulic gypsum does not develop until 900° C. is reached. These studies coincide with pyrometric tests which show that the minimum furnace heat required for the manufacture of hydraulic gypsum is about 900° C. When burned at higher temperatures the gypsum sets harder and more quickly, both desirable properties.

Hydraulic gypsum from anhydrite

Glasenapp[218] states that anhydrite may be used successfully as raw material for the manufacture of hydraulic gypsum provided it is heated to sufficiently high temperatures (1400° C. and above).

Chemical nature of hydraulic gypsum.

Next to the point as to the proper temperature required for burning hydraulic gypsum, it is necessary to stress the fact that it must be burned under oxidizing conditions. In other words, the heat must be applied in such a way that, during the later stages of the burning process, an excess of free oxygen is present. Some of this oxygen will, at the high temperature prevailing, combine with a portion of the sulphur present as calcium sulphate ($CaSO_4$) and go off with the furnace gases as SO_2. There will be left in consequence a certain amount of calcium oxide (CaO), ranging from 4 to 10 per cent.

Glasenapp[219] gives the following table which shows the increase in the amount of calcium oxide present in hydraulic gypsum, with increase of the temperature used in burning.

TEMPERATURE IN CENTIGRADE	$CaSO_4$	CaO
800	96.93	2.73
1100	95.88	3.58
1400	88.20	11.40

If the gypsum is left at 1400° C. for a considerable time the percentage of calcium oxide will be considerably in excess of the figure given above.

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[217] Glasenapp, M., Plaster, Overburnt Gypsum and Hydraulic Gypsum. Translated by Dr. W. Michaelis, Jr. Cement and Eng. News.

[218] Bericht uber die XVI Haupt Versammlung des Deutschen Gipsverein, Ann. 2, Marz. 1914, p. 110.

[219] The Manufacture of Hydraulic Gypsum and other Gypsum Products. Translated by Michaelis, p. 29.

The hardening of hydraulic gypsum is not due, primarily, to the growth of gypsum crystals from solution, as is the case with calcined gypsum. According to Glasenapp[220] "hydraulic gypsum hydrates principally without changing its form, without crystallizing because it is unable to form an oversaturated solution. This explains the necessity of densifying the mortar during the early stages of its hardening, by tamping it. The particles are thus forced together more closely". The hydration apparently causes a growth and expansion of the particles till one particle adheres to its neighbor by a sort of concretional growth, quite different from the structure of interlocking crystals. The calcium oxide also slowly takes on carbon dioxide and sets after the manner of burnt lime.

Theory of set

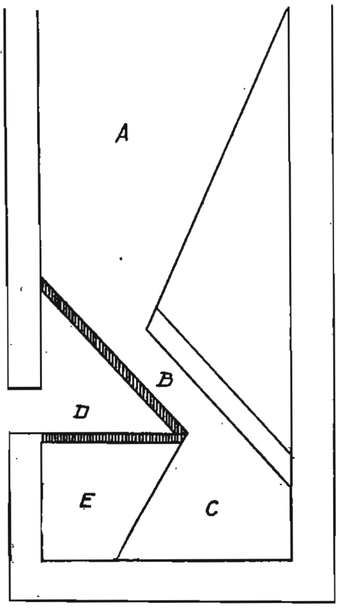

FIG. 77.—Diagram showing arrangement of kiln for burning hydraulic gypsum.

Burning of hydraulic gypsum

Hydraulic gypsum is produced extensively in Germany. It is there burned in a simple kiln not unlike the old style kiln. Lump mineral is dumped into the top of the kiln (figures 77 and 78), and is exposed to intense heat generated in the fire box. The red hot mineral is, from time

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[220] The Manufacture of Hydraulic Gypsum, p. 36.

to time, drawn out from the bottom of the kiln, where it is thoroughly exposed to the oxygen of the air. After the kiln has become thoroughly heated the carbon is completely oxidized and there is no smoke. The operation is continuous, or intermittent, as best suits the convenience of the operator in drawing out the heated mineral.

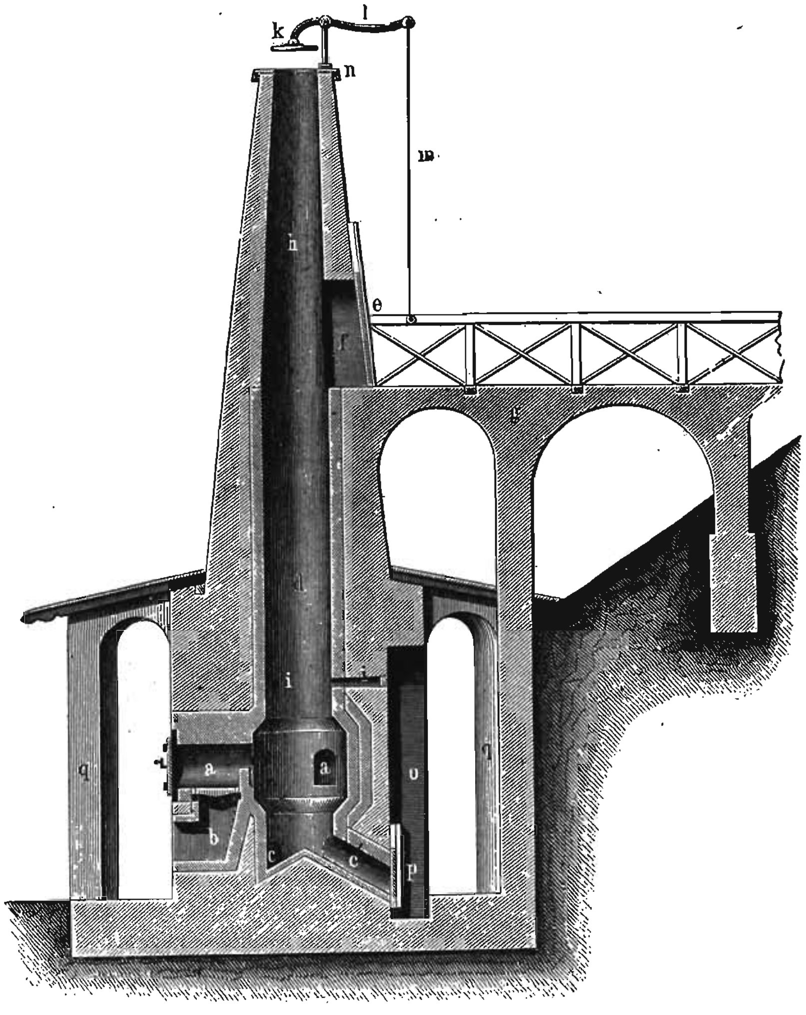

Fig. 78.—Cross section of one type of kiln for burning hydraulic gypsum (Estrick). After Von Waldegg.

The whole process is extremely simple and no delicate control of temperature is necessary.

As in lime kiln practice it is not practical to burn the fines because they choke the draft in the kiln. In Germany the fines are used for calcined gypsum or for agriculture and the lump is reserved for burning in the hydraulic gypsum kiln.

Grinding

After burning, hydraulic gypsum is coarsely ground as it gives the best results when only a small percentage of the whole passes the hundred mesh sieve.

PROPERTIES AND MANIPULATION OF HYDRAULIC GYPSUM

The following is a free translation of a pamphlet published in 1914 by the German Gypsum Association[221] and the illustrations are taken from the same source.

Properties of hydraulic gypsum

Specific gravity

"As already mentioned above hydraulic (flooring) gypsum is a highly calcined gypsum, that is, the gypsum rock is heated to a bright heat, say from 800° to 1000° C., in kilns of various construction. Burning at high temperatures results in the slow setting of the water-gypsum paste which, on completion of the setting stage, shows a very great hardness. After setting, hydraulic (flooring) gypsum resists an occasional exposure to moisture, and the specific gravity is greater than that of ordinary calcined gypsum. Hydraulic gypsum weighs from 900 to 1200 grams per liter, while calcined gypsum weighs from 650 to 850 grams per liter.

"Since calcined gypsum must be manipulated in a manner altogether different from hydraulic gypsum, it is clear at once that failures are bound to result if these varieties of plaster are mistaken for each other or are used in the wrong place.

ADVANTAGES OF HYDRAULIC GYPSUM FLOOR

Fire protection

"A floor made of hydraulic gypsum has remarkable advantages over other floor compositions. Due to the absence of joints in the one piece gypsum floor many a destructive fire is prevented. If a fire starts on a given floor the gypsum floors prevent its spreading upward or downward, and in addition protect the lower floors against the destroying action of water.

A non-conductor

"The one piece gypsum floor does not readily deteriorate owing to its hardness. It is cool in summer and warm in winter. Vermin like moths and mice cannot find a shelter in it and being free from joints and cracks it does not furnish a gathering place for dust. Gypsum floors are highly suitable for houses and hotels. In these places the

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[221] Die Verwendung Von Estrichgips im Bauwesen, und seine richtige verarbeitungsweise. Verlag den Tonindustrie—Zeitung. Berlin, IV. W. 21.

floors will be covered with rugs or linoleum. Gypsum floors possess a considerable amount of elasticity and walking on them is noiseless. The penetration of dust and bacteria is impossible and in consequence gypsum floors are excellent for hospitals, schools and public buildings.

"In the laying of gypsum plaster floors it must be borne in mind that considerable experience is required in order to secure the best results. In all cases it is recommended that the gypsum flooring be handled as a distinct and separate item in the contract and that the gypsum flooring be not tied in with other plaster and stucco work.

"As a rule it is the custom of the flooring-plaster manufacturers to have the casting of plaster floors done by special workmen skilled in this line of work or else to sublet it to contractors who specialize on the laying of gypsum floors and consequently are in position to execute the work properly.

"In the laying of gypsum floors care must be taken to secure a proper background. A wooden base will prove satisfactory provided it is covered with asphalt paper or something of a similar nature; or with a layer of dampened gravel sand or coal ashes, at least 3 cm. (1.2 inches) thick. Before the plaster is poured the dampened underlayer must be levelled and rammed tight. If the gypsum floor is to be poured upon concrete or brick these must be wet down well, for otherwise the water needed for the hardening of the gypsum floor will be too rapidly absorbed by the dry background and the floor will lack hardness.

Application of floor gypsum

"As in the case of cement floors or any composition floor, the rooms where gypsum floors have been laid should be protected from draughts and low temperatures.

"Usually there is spread upon the underlayer a top layer of flooring plaster from 3 to 5 cm. (1.2 to 2 inches) in thickness. In the construction of a gypsum floor hydraulic gypsum should always be used and never the ordinary calcined gypsum. The latter will fail utterly to meet the requirements as to hardness and too much stress cannot be laid on the necessity of avoiding all confusion in regard to the kind of gypsum plaster suitable for flooring.

"As in the case of other cast-floor materials, the mixing of the gypsum plaster requires the attention of a careful workman. The best mixing box consists of a rectangular box of sheet iron, about 1.5 m. (4.5 feet) long and .7 m. (2.5 feet) high. This should be well braced with bar or angle iron and provided with handles.

"In a box of this size thorough mixing is possible, whereas in a smaller box it is difficult. The box is first filled with water and the gypsum plaster is slowly added till it stands above the level of the water. It is best to shake the shovel steadily, letting the dry plaster slowly spill into the water. After a while, when the water has soaked the plaster mass thoroughly, it is thoroughly stirred and worked, and no lumps should be allowed to form. The ordinary beater used in slaking lime is used for mixing the gypsum plaster with water. For large rooms it is well to have two mixing boxes, a fresh batch being mixed in one while the contents of the other is being poured.

FIG. 79.—Mixing the hydraulic gypsum.

"Figure 79 shows at the right a surface bounded by lath and covered with dampened sand, which is to be covered with flooring plaster. The sand layer is well sprinkled with water, brought to level and tamped. At the left of figure 79 the preparation of the plaster is shown. From a bag held open by one of the workmen the other takes the plaster with a shovel and shovels it into the box of a wheelbarrow which is used here as a mixing receptacle and is half filled with water. The shovel is constantly agitated as can be clearly seen in the picture. A still better method consists in taking the plaster from the bag by hand and in letting it run through the fingers under constant agitation of the hand.

"While the plaster paste is being spread on the floor it is necessary that the material in the mixing box be stirred frequently. If this is not done the water will separate from the mortar, and it may happen that the water content of the first third of the batch will be normal, the second third deficient in water; while the last third will contain too much water. Under these circumstances the floor does not set or harden properly.

"The pouring requires a sufficiently dampened underlayer as otherwise the flooring plaster loses its moisture too rapidly and does not attain the desired hardness. Care also must be taken to make the sand layer, which has been tamped with the rammer, as level as possible and to avoid deep depressions therein. This is necessary in order to obtain a layer of plaster of uniform thickness, which, on being struck after hardening, will emit a uniform sound throughout the entire surface. A well constructed floor emits a clear sound after setting, the height of the sound being indicative of its hardness. If the sound indicates a hollow space this means that, at this point, the plaster has not been tamped enough or is not flush with the underlayer.

"The plaster is generally poured with an ordinary sheet bucket. High-grade flooring plaster should remain soft hours and hours, during which time part of the water first sweats out at the surface and is afterward again slowly absorbed. The pasty mortar is spread on the underlayer in a uniform thickness of 3 to 5 cm. (1.2 to 2 inches) after which it is straightened out.

FIG. 80.—Pouring the hydraulic gypsum.

"Spreading is effected by means of an ordinary straightedge, which, in order to increase its durability, is reinforced with a galvanized iron sheet along one edge. After some experience the workman learns to spread the plaster with the aid of a single template, on the outer edge of the area to be covered, and relies on the free edge of the freshly poured plaster for the inner edge. It is good practice to provide the outer edge of the first coat portion with indentations in order to effect a better junction of the sections. Figure 80 illustrates this method of procedure.

"Figure 80 shows how the plaster mortar is poured from a bucket by one of the workmen and how it is spread out with a trowel by another.

"Figure 81 illustrates the leveling of the mortar with a straight edge. The straight edge in this case rests on both sides on templates and is drawn to and fro till a level surface is secured.

"After the plaster floor has become hard enough so that only a slight impression is left on making an imprint with the thumb, the operation of tamping the plaster layer is started. During this operation the workman stands on a plank in order not to injure the still unhardened floor. Various sorts of rammers or iron tamps are used. The most suitable form consists of a long plate provided with an upright plate which enables the workman to tamp the floor without having to bend down too much. The floor is tamped as long as water appears on its surface. After this the tamped surface is rubbed with an ordinary rubbing board and then smoothed down with a flexible steel trowel. After these operations the floor is left untouched for a time and protected from drying too rapidly. When the weather is unusually dry and the outside temperature high the floor should be sprinkled with pure water from a watering

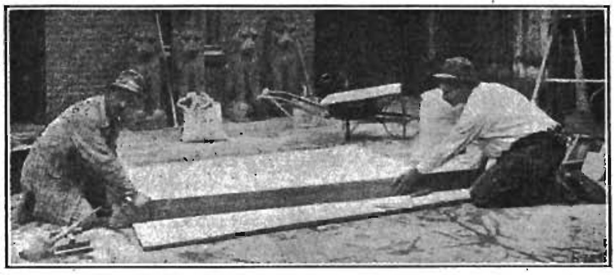

FIG. 81.—Bringing hydraulic gypsum to a true surface.

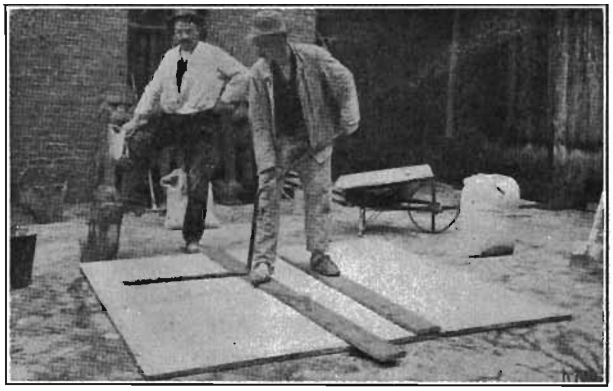

FIG. 82.—Tamping the hydraulic gypsum floor.

can once or twice at intervals of two or three days. Draughts should be avoided and to this end windows and doors should be kept closed.

"Figure 82 shows how the cast floor is tamped after the flooring plaster has passed through the first hardening stages. The workman is standing on two boards in order not to damage the still fresh plaster.

"Figure 83 shows the smoothing down of the tamping operation with rubbing board and trowel. The workman is shown holding in the left hand the rubbing board by means of which the first smoothing is accomplished. The steel trowel in his right hand is used for giving the finishing touch.

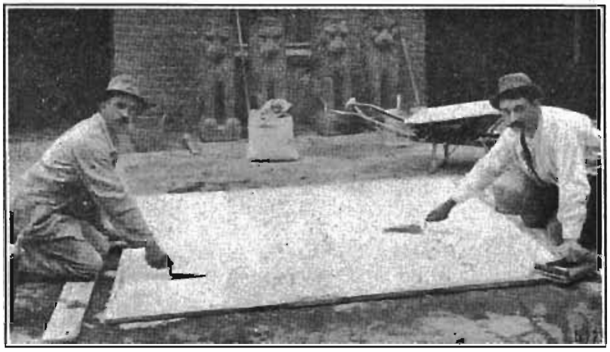

FIG. 83.—Smoothing hydraulic gypsum floor with trowels.

"After all of these operations have been completed, the floor is left untouched for some days as it attains to maximum hardness only after ten to fourteen days.

"If for reasons of economy other material is mixed with the flooring plaster these admixtures should not amount to more than one-third of the volume of the plaster. For this purpose clean sharp sand may be added, or calcined, preferably ground and weathered slag. The mixing of these ingredients must be thorough to insure uniform hardness. Generally it is preferable to use pure flooring plaster. If other material is to be added the contractor should consult the manufacturer of the flooring plaster and secure his advice as to the nature of the material that may best be added under existing conditions.

"The process described above may be called the casting process. Another method has of late been used which we shall call the ramming method.

"In the ramming method one volume of flooring plaster is intimately mixed while dry with one to two parts by volume of sharp sand or suitable slag. Then the mass is uniformly dampened by sprinkling while it is being turned with a shovel, like cement concrete. By this method much less water is used than is required in the casting process. The underlayer must be moistened. In case the underlayer is of a sort that strongly absorbs water (dry cement concrete, plaster floor, etc.) more water should be used in the mixing. The mortar is spread out like cement concrete in a layer of 3 to 4 cm. (1.2 to 1.6 inches) and thoroughly tamped till water appears on the surface.

"In order to smooth down the surface the concrete plaster is coated with dry flooring plaster by means of a screen, immediately after the completion of the tamping operation, after which it is rubbed down to a smooth finish.

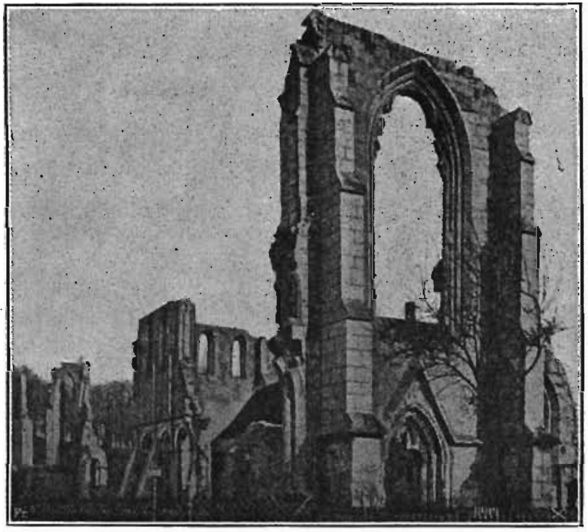

FIG. 84.—Medieval cloister of Walkenreed. The walls were laid in hydraulic gypsum mortar. After Von Waldegg.

"A floor made in this way will harden and dry rapidly. After two or three days it is ready to support the weight of a person walking on it. It is a good plan to cover the surface with moistened sawdust for one or two days more in order to prevent too rapid drying.

"The advantage of the tamping process lies in the fact that little water is required, which favors the rapid drying and hardening of the floors, and eliminates the danger of cracks from air draughts. (If hydraulic gypsum ever becomes popular in America as a flooring material this process undoubtedly will be used as it permits the use of concrete mixers and gives a floor that can be used two or three weeks sooner than is possible by the "casting process". F. A. W.)

"The floor should not be covered with linoleum for six or eight weeks in order that it may completely harden. Bubbles are also apt to form under the linoleum which will injure the fabric.

"In case the plaster floor is to be used without a linoleum cover the best procedure is to soak it with linseed oil, after which it may be given a coating of oil-paint after the manner of an ordinary wooden floor. It will be found that the floor maintains its good condition for years without showing appreciable signs of wear.

"A floor made strictly according to these rules will never expand, nor will it develop cracks. It will always be solid, warm, and show a high resistance to wear.

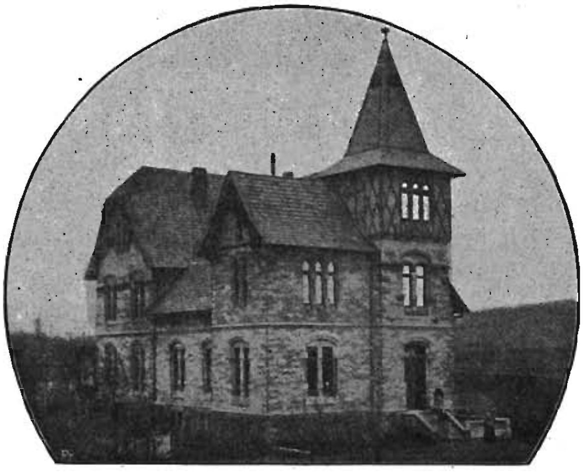

FIG. 85.—Modern German building in which hydraulic gypsum was used for floors and as mortar for walls. After Von Waldegg.

"The good properties of the cast plaster floor are more and more being recognized by architects and contractors. As shown by the long list of notable buildings appended to this pamphlet, it enjoys a wide reputation in all parts of the country. (Figures 84 and 85 afford illustrations of the use of estrich gypsum in ancient and modern buildings. F. A. W.)

"In order to illustrate the manipulation of flooring plaster with the greatest clearness the figures have been taken in open outside places as interior illumination would have been difficult. The floor section as shown in the picture is bounded by lath bars and should be considered as merely a sample. In closed rooms the plaster floor is laid by starting in one of the corners."

KEENE'S CEMENT

Composition

Keene's cement consists of "dead burned gypsum" (that is gypsum heated to 500° to 600° C. or 900° to 1100° F.) to which the property of quick setting is restored by the use of certain salts which act as positive catalysers. Authorities differ somewhat in their description of this material and it is probable that the treatment given to gypsum under this name is not always the same. According to E. C. Eckel[222] Keene's cement is made by calcining lump gypsum to a red heat; treated with a 10 per cent solution of alum; reburned to a dull red heat and then ground. Redgrave and Spachman[223] describe the process similarly stating also that borax may be used instead of alum. Strictly speaking, however, when borax is used the term Parian cement should be applied to the product.

American

R. W. Stone[224] says that it is reported that most of the producers of so-called Keene's cement in this country calcine lump gypsum in stationary kilns, grind it to a very fine powder, and add a small amount of powdered borax and other chemicals. The mixture is not recalcined and is marketed as American Keene's Cement. Mixtures of aluminum sulphate and sodium sulphate are doubtless employed to give the burned gypsum proper setting properties.

English

Keene's cement as originally made in England,[225] was produced by burning lump gypsum at a temperature only high enough to produce the hemi-hydrate ($2CaSO_4,H_2O$), soaking the lumps in a solution of alum, aluminum sulphate or borax, and recalcining at 500° C. (932° F.), after which the lumps were ground. Instead of lumps, ordinary finely ground calcined gypsum may be used. In this case the calcined gypsum is mixed with the alum solution and the hardened masses are broken up and burned on a vertical or a rotary kiln at temperatures from 900° to 1400° F.

A patent issued to John C. Best in 1919, and owned by Best

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[222] Eckel, E. C., Cements, Lime and Plasters, 1st ed., p. 77, 1905.

[223] Redgrave, G. R., and Spachman, Calcareous Cements, 2d ed., p. 273, 1905.

[224] Stone, R. W., Gypsum Products, their Preparation and Uses: Technical paper 155, Bureau of Mines, p. 47.

[225] Encyclopedia Brittanica, 11th ed., Vol. 5, p. 658.

Brothers, Keene's Cement Company, Medicine Lodge, Kansas, covers the following methods:

> "The market product known as the superfine grade of Keene's cement and generally used for the manufacture of artificial marble or scagliola has heretofore been produced in the following manner:
>
> "A standard grade of Keene's cement is mixed with water, permitted to set, being at that time molded into blocks of suitable size. These blocks are then recalcined substantially as was the original gypsum. After this second calcination the blocks are crushed and ground to produce the superfine product.
>
> "I have discovered that this same product may be more simply and cheaply prepared by initially burning the gypsum at a temperature higher than would ordinarily be employed for the production of a standard grade of Keene's cement. I prefer to carry out this burning or calcining operation in a rotary internally-fired kiln of the type used in the Portland cement industries, conducting the process so as to obtain a temperature of 1200° to 1400° F. of the burnt product issuing from the nose-ring of the kiln. The time of passage of the material through the kiln under these temperature conditions should be approximately one hour.
>
> "As an accelerator, catalyst or setting agent for this material I employ a neutral salt, such as neutral potassium sulphate, in the proportion of 1 per cent by weight. The entire product should be ground to 150 mesh.
>
> "This product prepared in this manner is very slow setting, has no effect upon colors, takes a very high polish, and is perfectly suited for the uses to which the superfine grade of Keene's cement is put, that is particularly for artificial marble or scagliola."

Rotary kilns

In a patent issued on March 8, 1921, to William Hoskens and by him consigned to Best Brothers, there are described[226] certain difficulties which developed in the use of a rotary kiln growing out of the presence of small quantities of lime carbonate in the gypsum. The product swelled in the mold, was deficient in tensile strength and density, and markedly porous. These difficulties, it is claimed, may be overcome by any one of three methods:

"1. By the addition to the burnt product of a quantity of

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[226] Rock Products, Vol. XXIV, No. 9, pp. 36-37, April 23, 1921.

hydrate of lime, for example, 0.2 to 0.5 per cent, although any proportion greater than this may be used.

''2. By the use of a setting agent more strongly acid than the potash-alum which is commonly employed; for example, by the use of potash sulphate, containing 0.25 per cent free acid.

''3. By grinding the burnt product to an unusually fine state of subdivision, for example, 150 mesh.

''Based upon the foregoing, it is my conclusion that in the calcining of the gypsum in the manner described, the lime content thereof suffers a peculiar modification, which I assume to be surface calcination, perhaps accompanied by surface sintering, fluxing, or fusing, these results being explainable by reason of the very high flame temperature in the kiln and the opportunity which is necessarily given for overburning of the surfaces of the particles.

''It is my belief that by reason of this surface modification of the lime content of the burnt product, the acid constituent of the setting agent, as for example, potash-alum, reacts with the calcium compounds much more slowly than would normally be the case, so that the reaction is still incomplete and carbon-dioxide is still being liberated when the material has set so far as to prevent its escape. By virtue of this continuing reaction during the period of setting, the cement is therefore caused to puff and become porous. As before stated, this difficulty may be entirely overcome by speeding up the reaction of the acid constitutent of the setting agent with the lime content of the cement, which acceleration may be accomplished in any one of the three ways mentioned. The action being properly accelerated, the evolution of carbon dioxide ceases while the cement remains so nearly fluid as to permit the free escape of the liberated gas.

''By the process described I am therefore able to produce from gypsum a dehydrated product suitable for use in the production of Keene's cement by a rotary kiln calcining method, which is highly desirable from an economic standpoint and superior to the stationary kiln method heretofore required.''

According to Von Waldegg[227] the solution commonly used in making Keene's cement (which is also known as marble cement, MacLean's cement, alum cement, and in France as Cement Anglais) consists of seventy-seven to eighty-three grams of potash alum to a liter of water. Hot water is generally used as the solubility of alum is greatly increased thereby.

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[227] Der Gips, by Edmund Heisinger von Waldegg, p. 240, Leipsig, 1906.

In addition to its greater hardness Keene's cement is valued because it takes a high polish, and will to some extent withstand exposure to the elements.

Properties of Keene's cement

Parian cement is made like Keene's cement and differs only in the fact that a borax solution is used instead of alum. In making the solution ninety-one grams of borax are used for each liter of water.

Parian cement

Mack's cement consists of hydraulic gypsum to which 0.4 per cent of sodium sulphate (Na_2SO_4) or potassium sulphate (K_2SO_4) has been added. This cement is unusually hard and durable, sets quickly and bonds well with the background to which it is applied.

Mack's cement

CHAPTER XX.

RETARDERS AND ACCELERATORS

RETARDERS

A great many substances have been used to retard the set of calcined gypsum and of gypsum plasters. Any material that will temporarily interfere with the growth and interlocking of the gypsum crystals as they form from solution; or will take up temporarily part of the water and later release it; will act as a retarder.

Clay as retarder

The setting time of calcined gypsum is lengthened by the presence of clay. Colloidal clays in particular act as effective retarders. Gypsite plasters, which contain from 10 to 20 per cent of clay, require little in the way of additional retarder.

Organic matter

The ancients used dried blood to retard the set of calcined gypsum. Sugars and syrups in small quantities may be used in an emergency. Pulverized glue is an effective retarder. Two pounds of glue may be dissolved in forty gallons of water. Use this glue-water in proportions so that three ounces of glue are added to one hundred pounds of plaster, if an hour of additional setting time is desired. As an emergency retarder citric acid may be similarly used.

Standard retarders

Commercial retarders for gypsum plasters are manufactured by several companies. The ingredients used and the method of preparation are generally the same. The raw materials consist of cheap hair or leather scraps; caustic soda, and lime.

Amount of retarder used

The amount of standard retarder used in different kinds of gypsum plasters may vary from one to fifteen pounds per ton of plaster. Gypsite plasters require very little retarder other than the colloidal clay that is present in the raw mineral. Wood fiber plasters for use without sand require only three or four pounds of retarder; while plasters intended to be mixed with three parts of sharp sand, for use on brick or terra cotta, may require eight or ten pounds of retarder.

Plasters intended for mixing by machine are retarded heavier than other plasters, for it is difficult to keep the mixer clean, and additional retarder is required to overcome the accelerating effect of particles of set plaster.

Retarder and the seasons

Chemical action of all sorts is hastened by heat, and the set of calcined gypsum is hastened somewhat when the material and water are warm. On the other hand, the retarder dissolves more completely and its action is more effective when water and plaster are warm. In consequence less retarder may be used during the summer months. Some care is necessary during these months, for if the plaster is over retarded, in warm weather dry-outs will result, due to atmospheric absorption of the water in the plaster before crystallization has taken place.

Treatment of over retarded plaster

Over retarded plasters may be treated with any of the accelerators described in later paragraphs in this chapter and brought to proper setting time. If they have been spread on the wall before their tendency to slow set is discovered, they will set up perfectly if kept moist with spray pump or brush. A weak solution of zinc sulphate,—three or four ounces to a pail of water,—applied with a spray or brush will remedy soft spots due to premature drying.

The effect of retarders on the strength of plasters has been considered in chapter XV.

ACCELERATORS

Nature of accelerators

Substances which will serve as nuclei about which crystallization may start will speed the set of gypsum plasters. Certain other substances also hasten crystallization directly.

Raw gypsum as accelerator

Dried mortar

Raw gypsum is a powerful accelerator but it is not recommended for this purpose, for its effect in other ways is generally regarded as unsatisfactory. Calcined gypsum which has set up and after drying has been ground, is the form of accelerator usually furnished by gypsum producers. Eight or ten ounces of this material, to the 100 pound sack of plaster will speed the set about an hour. This accelerator should be dry mixed through the plaster and sand.

Three ounces of zinc sulphate dissolved in water will speed the set of a 100 pound bag of ordinary plaster about an hour.

Zinc sulphate Dissolve about two pounds of commercial zinc sulphate in an ordinary fifty gallon barrel of water, and mix this with the water used in gauging the plaster; the same solution applied with a spray pump or brush is useful in bringing back normal hardness to plaster that has dried out before setting.

Alum Alum may be used as an accelerator in the same manner recommended for zinc sulphate. Slightly more alum will be required to the bag of plaster to produce the same degree of acceleration.

Portland cement and lime A few pounds of Portland cement or hydrated lime may be added to each sack of plaster as an emergency accelerator.

Effect of accelerators in plaster Any of the accelerators that have been mentioned when used in the limited quantities required for the purpose of acceleration, will not injure the quality of the plaster. The accelerator manufactured by the plaster producers is the most convenient form for use, but it is not always to be found in the dealer's stock as calls for accelerator are not frequent.

CHAPTER XXI.

THE HARDENING AND COLORING OF GYPSUM AND CALCINED GYPSUM

Various methods have been used to raise the hardness of gypsum. Many of these methods are successful from a technical point of view and works of art made from gypsum have been given the hardness of marble. The impulse to efforts along this line has grown out of the fact that gypsum is relatively soft and in its natural state can be carved easily. Its crystalline structure is beautiful and in some localities the coloring and the banding of the mineral are very pleasing. After it has been given the form desired, it can be hardened so that it is as durable as marble. The hardening processes at the same time generally reduce the solubility of the gypsum. The processes generally involve partial or complete dehydration of the gypsum and its immersion in the hardening substance. United States patent 549,151 may be cited as an example.

Hardening gypsum

"This invention relates in part to processes for treating gypsum rock to impart to it a hardness and polish resembling marble; but my object is to produce a product not only superior to marble in hardness and fineness of surface, grain and luster, but resembling in colors and in general appearance the different varieties of chalcedony, such as onyx, agate, etc. To this end the crude gypsum rock is first shaped in any desired form and configuration by carving, sawing, planing, etc., and this is then freed from the water constituting one of its constitutent elements, next colored in accordance with the desired effect and then it is treated to the action of hardening chemical solutions, all as more particularly set forth below. Beautiful onyx, agate, etc., effects can be produced, in accordance with the tastes and desires, in statuary, furniture ornamentations, and the like, and in finishing of rooms, using the material in lieu of marble or woodwork. By my treatment the colors are made to appear as if a constitutent part or element of the rock in its native condition and formation, and the condition of the product, as stated, is superior in hardness and finish to either marble or chalcedony.

"To carry my process into effect, the gypsum rock from the mines, having been given the desired configuration, as stated, is submitted to the drying action of hot air for twelve hours (more or less) until all the moisture has been eliminated. The material is now calcium sulphate, porous from surface to center, and capable of absorbing sufficient chemical solution to produce the desired effect of the rock and colors. To the surface of the dehydrated rock is now applied the mineral colors—such as, for an illustration, solution of copper nitrate and aqua ammonium, or a solution of a sulphate of iron, nitric acid, and potassium sulpho-cyanide or other mineral colors. After coloring, the rock is immersed in a solution of aluminium sulphate ($Al_2(SO_4)_3$) for about fifteen hours or until the pores of the rock are completely filled. The material is then removed and exposed to the open air for a few hours at a low temperature and then polished."

Hardening calcined gypsum

Where just enough water is added to calcined gypsum, (most conveniently in the form of steam) to meet the demands for chemical combination, and the moist mass is submitted to hydrostatic pressure, the resulting mass is unusually hard and dense. In Germany forms so made are used in connection with the molding of roof tile and similar articles.[228]

Surface hardening

Where very hard waterproof surfaces are desired surfaces and objects made of calcined gypsum may be washed with linseed oil, paraffin, stearic acid, or combinations of these. The surfaces to be hardened are carefully dried and warmed and then immersed or otherwise covered for three or four minutes in melted paraffin or stearic acid. When paraffin is applied it should be heated to 60° C. (140° F.) while stearic acid should be heated to 85° C. (185° F.). The surface should then be rubbed with a soft brush or flannel.

Various substances may be mixed with calcined gypsum to give it greater hardness. For this purpose calcined borax (fifty parts of calcined gypsum to one of borax) was one of the first substances used.

Hardening by mixing chemicals

Oxides of magnesium, aluminum or zinc, mixed with a thin solution of phosphoric acid are said to impart to calcined gypsum great hardness and a porcelain-like polish.[229]

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[228] Von Waldegg, Der Gips, p. 388.

[229] Von Waldegg, Der Gips, p. 364.

One hundred parts of calcined gypsum may be mixed with twenty parts of magnesite. Gypsum paste is made by adding water in the usual proportions and the objects made therefrom are soaked in a solution of zinc sulphate. Iron sulphate may be used instead if a golden brown color is desired.

The German texts (see bibliography) may be consulted for a great variety of formulae for hardening objects made from gypsum, as well as for processes by which gypsum surfaces may be rendered impervious to water. Von Waldegg in addition gives methods for coloring gypsum objects and for cleaning gypsum plaster surfaces.

Coloring wall plasters

Emley and Faxon have devised methods for coloring wall plasters by staining the wood fibre that is often used in them.[230] As stated by them "the process consists briefly of dyeing the fibre the desired color with analine dyes, mixing it with the other ingredients, applying the plaster to the wall in the usual way, and then, after the plaster has set, removing its surface in such a way as to expose the colored fibre." For a more detailed statement of methods of procedure, the reader is referred to the text of the government report.

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[230] Bureau of Standards, Technologic Paper No. 181.

CHAPTER XXII.

STATISTICS

Gypsum mined in the United States in 1920 totaled 3,130,305 short tons. The highest previous record was in 1916, when the mine output reached 2,757,730 tons. The gain, therefore, over any previous year was considerable. Compared with 1919 the increase was more than 700,000 tons. All the more important producing states showed gains in output. Gains were general for all forms of gypsum products.

CRUDE GYPSUM MINED IN THE UNITED STATES (*a*)*

	1918	1919	1920	1921
STATE	Quantity Mined (Short Tons)	Quantity Mined (Short Tons)	Quantity Mined (Short Tons)	Quantity Mined (Short Tons)
Iowa	327,927	421,279	571,895	350,247
Kansas	54,958	78,479	130,044	92,526
Michigan	286,768	339,125	382,212	408,224
New York	531,038	591,153	780,295	712,665
Ohio	199,456	251,259	277,899	363,905
Oklahoma	126,208	114,313	135,279	209,201
Texas	157,388	176,607	220,157	232,806
Wyoming	41,877	51,079	57,732	38,927
Nevada	(*c*)	91,756	143,929	178,275
Other States (b)	331,395	305,113	429,700	464,208
	2,057,015	2,420,163	3,129,142	3,050,984

(*a*) R. W. Stone, U. S. Geol. Surv. (*b*) Includes Arizona, California, Colorado, Montana, New Mexico, Oregon, South Dakota, Utah, Virginia. (*c*) Included with "Other States."

CRUDE GYPSUM MINED IN THE UNITED STATES (a)*

(Tons of 2000 lbs.)

1885	90,405	1897	288,982	1909	2,252,785
1886	95,250	1898	291,638	1910	2,379,057
1887	95,000	1899	486,235	1911	2,323,970
1888	110,000	1900	594,462	1912	2,500,757
1889	267,769	1901	633,791	1913	2,599,506
1890	182,995	1902	816,478	1914	2,476,465
1891	208,126	1903	1,041,704	1915	2,447,611
1892	256,259	1904	940,917	1916	2,756,630
1893	253,615	1905	1,043,202	1917	2,696,226
1894	239,312	1906	1,540,585	1918	2,057,015
1895	265,503	1907	1,751,748	1919	2,420,163
1896	224,254	1908	1,721,829	1920	3,129,142
				1921	3,050,984

(a) Statistics of the U. S. Geol. Surv.

TOTAL VALUE OF CRUDE AND CALCINED GYPSUM

1908	$4,075,824	1913	$6,774,822	1918	$11,470,854
1909	5,906,738	1914	6,895,989	1919	15,727,907
1910	6,523,029	1915	6,596,893	1920	24,542,512
1912	6,563,908	1917	11,116,452	1920	24,533,065
1911	6,462,035	1916	7,959,032	1921	23,700,290

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*From Mineral Industry, Vol. 29, p. 340.

Named in the order of tonnage produced the leading states rank as follows: New York, Iowa, Michigan, Ohio, Texas, Virginia, Nevada, Oklahoma, Kansas. The same order will hold for values, with the possibility that Virginia and Texas might exchange places. Virginia's position is not set out by itself in the federal statistics in view of the fact that there are only two producers in the State. The output of each of these plants is considerably above that of the average, taking the gypsum mills of the country as a whole.

*Gypsum produced and sold in the United States, 1920 and 1921, by States.**

STATE	Number of plants reporting	Total quantity mined (short tons)	Sold without calcining				Sold calcined		Total value
			Agricultural gypsum		For Portland cement, paint, and other purposes		Quantity (short tons)	Value	
			Quantity (short tons)	Value	Quantity (short tons)	Value			
1920									
Iowa	6	571,895	41,404	$161,838	69,435	$252,593	321,400	$4,008,534	$4,422,965
Kansas	3	130,044	(*a*)	(*a*)	(*a*)	(*a*)	78,347	864,334	968,298
Michigan	6	382,212	12,092	54,050	61,750	214,918	261,499	3,252,060	3,521,028
Nevada	4	143,929	(*a*)	(*a*)	13,043	32,123	105,280	1,036,158	1,100,261
New York	8	780,295	15,510	67,862	255,567	919,641	387,856	5,451,426	6,438,929
Ohio	3	277,899	(*a*)	(*a*)	8,474	35,707	220,903	2,122,223	2,161,038
Oklahoma	4	135,279	(*a*)	(*a*)	(*a*)	(*a*)	69,924	772,749	816,768
Texas	5	220,157	(*a*)	(*a*)	16,900	47,961	164,956	1,391,382	1,439,491
Wyoming	4	57,732	(*a*)	(*a*)	(*a*)	(*a*)	43,384	410,599	410,724
Other States[b]	18	429,700	*c* 38,437	*c* 274,175	*c* 136,648	*c* 504,327	250,935	2,658,405	3,253,563
	61	3,129,142	107,443	557,925	561,817	2,007,270	1,904,484	21,967,870	24,533,065
1921									
Iowa	6	350,247	26,364	98,311	58,293	135,727	216,930	2,688,662	2,922,700
Kansas	3	92,526	(*a*)	(*a*)	28,566	89,792	50,663	574,601	665,164
Michigan	5	408,224	26,558	98,139	84,119	271,046	240,648	2,942,911	3,312,096
Nevada	4	178,275	(*a*)	(*a*)	15,538	45,477	132,837	1,471,960	1,533,037
New York	9	712,665	20,081	84,283	186,223	610,235	418,695	5,715,703	6,410,221
Ohio	3	363,905	2,645	13,493	4,344	15,179	263,879	3,163,265	3,191,937
Oklahoma	3	209,201	(*a*)	(*a*)	72,087	238,494	99,923	1,046,844	1,289,226
Texas	4	232,806	(*a*)	(*a*)	10,709	33,068	183,159	1,732,463	1,765,600
Wyoming	5	38,927	....	....	(*a*)	(*a*)	24,244	222,960	224,258
Other States[b]	20	464,208	*c*29,318	*c*196,676	*c*78,079	*c*336,091	165,873	1,874,910	2,386,051
	62	3,050,984	104,966	490,902	537,978	1,775,109	1,796,851	21,434,279	23,700,290

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[a] Included under "Other States."

[b] Alaska, Arizona, California, Colorado, Montana, New Mexico, Oregon, South Dakota, Utah, and Virginia. Includes also a small quantity sold by warehouses and not elsewhere accounted for.

c This figure includes also output of States entered as "([a])" above.

*Cottrell, K. W., U. S. Geol. Survey, Mineral Resources of the U. S., 1921, pt. II, p. 90.

*Gypsum produced and sold in the United States, 1916–1921, by uses.**

Year	Sold without calcining											
	For Portland cement			As agricultural gypsum			For other purposes			Total		
	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton
1916	[a] 454,112	[a] $607,995	$1.34	81,879	$167,136	$2.04	[a] 11,128	[a] $15,299	$1.37	547,119	$790,430	$1.44
1917	[a] 526,881	[a] 867,123	1.65	84,366	230,808	2.74	[a] 12,748	[a] 26,439	2.07	623,995	1,124,370	1.80
1918	[a] 403,635	[a] 974,283	2.41	64,571	255,716	3.96	[a] 1,986	[a] 6,553	3.30	470,192	1,236,552	2.63
1919	[a] 470,267	[a] 1,332,637	2.83	39,978	185,566	4.64	([a])	([a])	....	510,245	1,518,203	2.98
1920	541,901	1,941,057	3.58	107,443	557,925	5.19	19,916	66,213	3.32	669,260	2,565,195	3.83
1921	[a] 537,978	[a] 1,775,109	3.30	104,966	490,902	4.67	([a])	([a])	....	642,944	2,266,011	3.52

Year	Sold calcined														
	As plaster of Paris, wall plaster, Keenes cement, etc.			For dental plaster			To glass factories			As boards, tile, and blocks, and for other purposes			Total		
	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton
1916	1,677,081	$6,884,960	$4.11	661	$8,766	$13.26	11,537	$28,839	$2.50	116,535	$246,037	$2.11	1,805,814	$7,168,602	$3.97
1917	1,531,535	8,873,176	5.79	991	7,672	7.74	13,808	72,558	5.25	131,056	1,038,676	7.93	1,677,390	9,992,082	5.96
1918	1,174,359	8,483,633	7.22	([b])	([b])	....	13,567	84,928	6.26	[b] 140,343	[b]1,665,741	11.88	1,328,269	10,234,302	7.70
1919	1,393,141	11,809,624	8.48	([b])	([b])	....	14,677	96,561	6.58	[b] 188,202	[b]2,303,519	12.24	1,596,020	14,209,704	8.90
1920	1,578,360	15,723,372	9.96	1,731	27,440	15.85	15,637	125,441	8.02	308,756	6,091,617	19.73	1,904,484	21,967,870	11.53
1921	[c]1,603,844	15,870,289	9.89	([c])	([c])	....	([c])	([c])	....	193,077	5,563,990	28.82	1,796,851	21,434,279	11.93

[a] A small quantity of paint material and of gypsum sold for other purposes included with gypsum sold for Portland cement.
[b] Some dental plaster included with boards, tile, etc.
[c] Dental plaster and plaster sold to glass factories included with plaster of Paris, etc.
* U. S. Geol. Survey, Mineral Resources of the United States.

PRODUCTION OF GYPSUM IN IOWA

	Short Tons	Value
1889	21,789	$ 55,250
1890	20,900	47,350
1891	31,385	58,095
1892	12,000	28,500
1893	21,447	55,538
1894	17,906	44,700
1895	25,700	36,600
1896	18,631	34,020
1897	29,430	64,900
1898	24,733	45,819
1899	75,574	296,220
1900	184,600	561,588
1901	125,000	562,500

PRODUCTION OF GYPSUM IN IOWA—Continued

Year	Crude Gypsum Mined	Sold Crude				Sold Calcined				Total Sold		No. Producers Reporting	Year
		To cement mills etc.		As land plaster		As Hard Wall Plaster		As Plaster of Paris, Stucco, Boards, etc.					
	Tons	Tons	Value	Tons	Value	Tons	Value	Tons	Value	Tons	Value		
1902	143,632	600	$ 900	2,000	$ 3,000	100,314	$ 290,242	17,865	$ 43,593	120,779	$ 337,735		1902
1903	166,713	703	1,534	2,098	9,227	87,397	411,503	30,306	100,744	120,504	523,008	8	1903
1904	145,359	2,013	4,223	933	1,816	94,811	399,281	19,540	64,112	117,297	469,432		1904
1905	179,016	4,867	9,357	2,723	2,723	119,252	558,992	4,566	17,983	131,408	589,055	6	1905
1906	286,857	9,862	15,414	3,751	6,922	146,526	551,162	Included in Hard wall plaster		160,139	573,498	8	1906
1907	251,874	17,272	24,837	1,562	4,278	153,965	656,268	9,000	45,000	181,799	730,383	7	1907
								Plaster Paris incl. in wall plaster					
1908	240,270	19,816	27,061	1,128	2,087	158,043	535,540	Plaster Paris incl. in wall plaster		179,987	564,688	7	1908
1909	319,577	18,452	11,466	9,676	14,633	188,389	629,503	Plaster Paris incl. in wall plaster			655,602	6	1909
1910	322,713	31,532	38,683	6,159	8,312	202,131	816,989	28,801	79,865	267,623	943,849	6	1910
1911	354,204	11,032	14,465	incl. under cement mills		195,274	777,095	34,616	80,192	240,922	871,752	6	1911
1912	411,186	42,443	40,824	incl. under cement mills		223,756	708,198	49,360	96,606	315,559	845,628	6	1912
1913	456,031	43,300	35,285	3,757	10,266	252,719	942,198	80,636	170,190	385,414	1,157,939	5	1913
1914	480,404	52,934	45,566	12,251	14,920	265,619	1,109,570	69,446	151,401	400,250	1,321,457	5	1914
1915	495,860	59,823	48,508	12,086	11,422	256,063	1,057,546	78,994	160,652	406,966	1,278,128	5	1915
1916	522,293	47,923	40,869	12,923	18,428	373,416	1,437,498	Included in Wall plaster		434,262	1,496,795	5	1916
1917	461,864	50,818	80,488	14,194	30,253	323,987	1,700,691	Included in Wall plaster		388,999	1,811,432	5	1917
1918	327,927	47,173	122,325	10,546	37,823	159,322	1,225,924	58,846	560,342	275,897	1,946,414	5	1918
1919	421,279	66,619	222,672	2,405	8,760	208,829	1,754,815	55,827	651,197	333,680	2,634,444	6	1919
1920	571,895	69,435	252,593	41,404	161,838	219,107	2,328,744	102,293	1,679,790	432,239	4,422,965	6	1920
1921	350,247	58,293	135,727	26,364	98,311	133,717	1,346,452	83,213	1,342,210	301,587	2,922,700	7	1921

PRODUCTION OF CRUDE GYPSUM IN THE PRINCIPAL COUNTRIES (a)*

(In metric tons)

Year	Algeria (b)	Canada (g)	France (b)	Germany (c)		Greece	India	United Kingdom	United States
				Baden	Bavaria				
1903	41,550	285,242	1,998,804	29,423	30,894	94	(d)	223,426	945,286
1904	48,375	309,133	1,957,802	26,984	22,766	393	3,937	237,749	853,546
1905	34,743	395,341	1,378,145	28,823	46,247	185	4,877	259,596	982,625
1906	27,950	378,904	1,377,429	25,643	50,763	70	(e) 5,000	228,627	1,397,480
1907	26,400	431,286	1,316,567	29,153	48,975	70	(e) 5,000	239,285	1,564,061
1908	25,500	346,436	1,750,562	35,217	51,314	Nil.	(e) 5,000	231,980	1,694,155
1909	36,250	398,290	1,655,672	36,621	51,630	191	17,588	242,832	f)2,042,286
1910	60,625	481,941	1,980,804	41,078	54,397	249	13,759	259,648	f)2,158,756
1911	61,502	470,381	2,110,520	42,408	60,390	1,263	11,115	281,111	f)2,112,770
1912	54,414	524,892	2,150,900	51,777	57,114	127	21,383	247,724	f)2,269,296
1913	50,413	577,442	1,726,379	49,767	....	2,245	25,362	242,341	f)2,357,752
1914	....	463,375	....	....	32,993	639	22,639	269,637	f)2,247,246
1915	....	430,752	....	....	28,459	1,648	22,926	251,209	f)2,220,458
1916	....	311,092	....	....	26,124	356	16,826	222,814	f)2,500,815
1917	....	305,120	....	....	21,035	44	16,952	175,800	f)2,446,016
1918	....	138,155	....	....	23,330	....	17,016	181,612	f)1,865,622
1919	....	278,454	....	....	33,692	....	28,774	223,545	f)2,223,547
1920	....	398,501	....	....	....	....	33,551	291,598	f)2,838,758
1921	....	324,122	....	....	....	....	30,672	....	f)2,768,588

(a) From official reports of the respective countries, except the statistics for the United States. (b) A part of the product is reported as plaster of Paris. In converting this into crude gypsum it has been assumed that the loss by calcination is 20 per cent. (c) Prussia is a largo producer of gypsum, but there are no complete statistics available. The output in 1910 was 22,042 tons. (d) Statistics not available. (e) Estimated. (f) U. S. Geol. Surv. (g) Tonnage shipped.

* Mineral Industry, Vol. 29, p. 346.

APPENDIX I.

RESULTS OF TESTING GYPSUM PRODUCTS[231]

BY W. E. EMLEY AND C. F. FAXON[232]

In an effort to write standard specifications for gypsum, many difficulties have been encountered. Probably the greatest source of confusion was the attempt to adopt verbatim the standard methods of test which were in use in the examination of other similar materials. Experience showed the futility of this procedure, and finally compelled the invention of new methods of test, designed especially for gypsum. After considerable deliberation and experiment, a number of methods of test were finally agreed upon and adopted as tentative.[233]

It then developed that no one had had enough experience with these new methods to be able to predict what numerical results they would give. For example, take the tensile strength. This property of gypsum was pretty well known when measured by any one of several different methods. The method adopted, however, introduced certain innovations, so that no one could foretell just what tensile strength a given sample of material would have when tested by this new method.

Obviously some information about these numerical results was essential, in order that specifications could be intelligently written. It would be absurd to specify a tensile strength of 300 pounds per square inch, and then discover that either all or none of the gypsum on the market met the requirement.

Accordingly the Bureau of Standards undertook to test a number of commercial samples. This article is a compilation of the results obtained. The tests were carried out on 43 samples, made by three different manufacturers. Of these, 25 were shipped to us direct from the factory, packed in air-tight glass containers; 8 came direct from the factory, in the usual commercial package; and 10 were obtained from dealers.

While an attempt was made to follow the methods of test

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[231] Reprinted from the Journal of the American Ceramic Society, Vol. 3, No. 12, December, 1920.

[232] Published by permission of the Bureau of Standards.

[233] American Society for Testing Materials, C-26-19T.

cited above, certain changes and additions were found advisable and were accordingly made. A brief description of the methods is as follows:

1. *Chemical Analysis.*—Lime, sulphuric anhydride, carbon dioxide, and loss on ignition, were determined by the usual methods of chemical analysis.[234] These constitutents were then combined as follows: The amount of lime required to combine with the carbon dioxide was found by multiplying the per cent carbon dioxide by 56/44. The per cent lime present as carbonate was deducted from the total per cent lime. The per cent water was found by subtracting the per cent carbon dioxide from the per cent loss on ignition. From the figures for lime, sulphuric anhydride, and water, the maximum possible content of calcined gypsum ($CaSO_4.\frac{1}{2}H_2O$) was calculated, using the ratios 56:80:9. Usually two, and always one of these three ingredients was found to be in excess of these ratios. This was taken to indicate the presence of some foreign material, such as calcium hydroxide, magnesium sulphate, anhydrous calcium sulphate, etc.

2. *Normal Consistency.*—This is the number of cubic centimeters of water which must be added to 100 grams of dry material to produce a paste of standard "wetness." It was determined by means of the Southard viscosimeter,[235] the standard wetness being such that the final radius of the pat was 9.6 cms.

3. *Time of Set.*—This is measured by means of a Vicat needle, on material of normal consistency. It is the elapsed time from when the sample is added to the water to when the needle fails to penetrate to the bottom of the pat.

4. *Fineness.*—This is expressed as the per cent by weight of the material separated by six sieves of different meshes. The sieves used were the Nos. 8, 14, 28, 48, 100 and 200. In general, the material could be screened dry through Nos. 8 and 14, but had to be washed with kerosene in order to get clean separations on the finer sieves.

5. *Compressive Strength.*—Three cylinders, 2 inches in diameter by 4 inches high, were made of paste of normal con-

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[234] Hillebrand, Analysis of Silicate and Carbonate Rocks: U. S. Geol. Survey Bull. 700.
[235] A. S. T. M., C26-19T.

sistency. They were removed from the molds as soon as they were hard enough to handle (1 to 24 hours), stored in the air in the room for one week, and tested. The results are expressed as pounds per square inch.

TABLE I

Lab. No.	Trade name of material	Class
1	Unretarded gauging plaster	Calcined gypsum only
2	Molding plaster	
10	Unretarded gauging plaster	
11	Molding plaster	
19	Unretarded gauging plaster	
20	Molding plaster	
26	Stucco	
28	Molding plaster	
29	Reground stucco	
31	Stucco	
32	Stucco	
34	Plaster of Paris F	
35	Plaster of Paris FFF	
37	Windsor cement FFF	
43	Potters plaster	
Ave.		
3	Retarded gauging plaster	Calcined gypsum plus retarder
4	Cement plaster, unsanded, not fibered	
12	Retarded gauging plaster	
13	Cement plaster, unsanded, not fibered	
21	Retarded gauging plaster	
22	Cement plaster, unsanded, not fibered	
38	Ready finish	
41	Superfine Windsor cement	
Ave.		
5	Cement plaster, unsanded, fibered	Calcined gypsum plus retarder plus fiber
16	Retarded fibered cement plaster	
23	Fibered cement plaster	
27	Fibered plaster	
33	Fibered plaster	
36	Windsor cement, neat	
Ave.		
6	Wood fiber plaster to be used with sand	Calcined gypsum plus retarder plus wood fiber
7	Wood fiber plaster	
14	Wood fiber plaster to be used with sand	
15	Retarded wood fiber plaster	
24	Wood fiber plaster to be used with sand	
25	Wood fiber cement	
30	Wood fiber plaster	
39	Windsor cement for concrete	
42	Wood fiber plaster	
Ave.		
9	Ready mixed brown coat	Calcined gypsum plus retarder plus sand
18	Ready mixed brown coat	
Ave.		
8	Ready mixed scratch coat	Calcined gypsum plus retarder plus fiber plus sand
17	Ready mixed scratch coat	
40	Brown mortar	
Ave.		

TABLE 2

	CHEMICAL ANALYSIS					
	FOUND				CALCULATED	
LAB. NO.	CAO	CO_2	SO_3	LOSS ON IGNITION	CALCINED GYPSUM	CONSTITUENTS IN EXCESS
1	37.60	4.21	48.73	10.40	83.50	$SO_3.H_2O$
2	37.20	4.22	49.00	10.70	82.40	$SO_3.H_2O$
10	34.80	12.53	36.80	16.20	48.77	$SO_3.H_2O$
11	35.28	11.00	38.55	16.40	55.10	$SO_3.H_2O$
19	38.12	0.56	53.50	8.00	97.02	$CaO.H_2O$
20	38.24	.74	53.64	8.00	86.60	$SO_3.H_2O$
26	38.20	.10	54.00	7.60	97.88	$CaO.H_2O$
29	35.80	2.40	47.80	9.20	84.83	$SO_3.H_2O$
31	37.44	0.60	51.90	7.90	94.07	$CaO.H_2O$
32	37.10	4.10	48.70	10.60	82.54	$SO_3.H_2O$
34	38.00	1.00	51.65	7.53	93.65	$CaO.H_2O$
35	38.26	0.62	53.70	6.91	97.10	$SO_3.H_2O$
37	38.13	.53	53.80	6.94	97.00	$SO_3.H_2O$
43	38.90	.70	53.60	7.55	97.15	$CaO.H_2O$
Ave	37.41	2.89	49.98	9.44	87.02	
3	37.04	4.53	48.28	10.90	83.50	$SO_3.H_2O$
4	36.72	4.37	47.90	10.75	80.60	$SO_3.H_2O$
12	34.52	10.02	36.49	17.35	56.35	$SO_3.H_2O$
13	34.84	12.33	37.56	16.55	49.58	$SO_3.H_2O$
21	38.60	0.81	53.30	7.55	96.60	$CaO.H_2O$
22	38.28	.84	53.74	8.10	96.40	$SO_3.H_2O$
38	39.20	2.83	15.55	14.20	28.20	$CaO.H_2O$
41	35.72	15.20	35.90	20.05	42.38	$SO_3.H_2O$
Ave	36.86	6.37	41.09	13.18	66.70	
5	36.96	4.73	47.83	11.15	80.20	$SO_3.H_2O$
16	35.00	12.16	37.90	17.15	50.56	$SO_3.H_2O$
23	36.88	0.68	52.30	7.35	93.30	$SO_3.H_2O$
27	38.24	.40	53.90	7.90	97.68	$SO_3.H_2O$
33	37.70	.10	53.40	7.80	96.79	$CaO.H_2O$
36	36.88	1.40	48.50	8.18	87.95	$CaO.H_2O$
Ave	36.94	3.24	48.97	9.92	84.41	$CaO.H_2O$
6	36.92	4.36	48.52	10.70	81.20	$SO_3.H_2O$
7	37.00	4.41	48.59	10.50	81.25	$SO_3.H_2O$
14	34.96	12.64	37.32	17.35	48.86	$SO_3.H_2O$
15	35.12	11.90	38.10	17.40	51.70	$SO_3.H_2O$
24	38.20	0.74	53.64	7.90	96.47	$SO_3.H_2O$
25	38.08	.82	53.06	7.95	95.95	$SO_3.H_2O$
30	36.14	2.50	48.40	9.40	85.34	$SO_3.H_2O$
39	27.41	1.64	27.70	9.25	50.22	$CaO.H_2O$
42	35.40	1.31	46.40	8.60	84.10	$CaO.H_2O$
Ave	35.47	4.48	44.64	11.01	75.01	$CaO.H_2O$
9	18.20	10.86	13.49	13.10	11.27	$SO_3.H_2O$
18	25.60	15.70	13.68	17.80	14.50	$SO_3.H_2O$
Ave	21.90	13.28	13.58	15.45	12.88	
8	18.52	10.32	14.80	12.75	13.92	$SO_3.H_2O$
17	24.80	13.86	15.84	16.70	18.49	$SO_3.H_2O$
40	8.76	0.47	10.80	3.09	19.58	$CaO.H_2O$
Ave	17.36	8.22	13.81	10.85	17.33	

TABLE 3

	FINENESS						
LAB. NO.	On 8	8–14	14–28	28–48	48–100	100–200	THROUGH 200
1	....	0.1	0.1	0.9	3.9	15.4	79.6
2	....	......	.2	1.1	4.1	8.2	86.4
10	....	.1	.3	4.6	7.0	11.5	76.5
11	....	.1	.1	.3	0.7	6.8	92.0
19	....	.1	.3	3.0	24.0	26.7	45.9
20	....	......	.1	0.5	6.3	23.2	69.9
26	....	......	.3	4.0	15.6	29.7	50.4
28	....	......	.1	0.3	4.8	15.6	79.2
29	....	......	.7	3.8	8.5	20.3	66.7
31	....	......	.1	0.4	1.1	9.1	89.3
32	....	......	.2	1.3	3.1	8.2	87.2
34	0.3	0.7	2.5	8.8	16.4	11.1	60.2
35	....	......	......	0.2	9.3	13.4	77.1
37	....	......	......	.1	6.1	9.7	84.1
43	....	......	......	.3	4.9	13.2	81.6
Ave.	0.0	0.1	0.3	2.0	7.7	14.5	75.1
3	....	......	0.2	0.9	3.1	10.7	85.1
4	....	......	.1	1.3	4.1	12.4	82.1
12	....	0.1	.3	4.1	8.9	8.8	77.8
13	....	......	.1	0.2	1.2	4.7	93.8
21	....	......	.2	2.5	18.0	28.7	50.6
22	....	......	.3	2.2	18.6	21.5	57.4
38	....	......	......	0.2	2.6	7.7	89.5
41	....	......	......	1.7	14.1	10.3	73.9
Ave.	0.0	0.0	0.1	1.6	8.8	13.1	76.3
5	0.1	0.1	0.1	0.9	3.3	10.8	84.7
16	.1	.1	.1	.2	0.8	6.4	92.3
23	.1	.1	.2	1.7	14.8	21.9	61.2
27	....	......	.2	0.9	2.8	17.0	79.1
33	....	......	.3	1.5	4.8	28.7	64.7
36	0.1	0.4	2.3	13.5	16.8	9.6	57.4
Ave.	.1	.1	0.5	3.1	7.2	15.9	73.2
6	0.5	0.4	0.5	1.7	3.8	9.7	83.4
7	.7	.3	.3	1.7	4.0	10.7	82.3
14	.4	.2	.4	4.0	8.9	11.0	75.1
15	.4	.2	.4	3.7	8.6	9.5	77.2
24	.8	.5	.6	2.7	17.5	19.3	58.6
25	.4	.1	.4	2.6	19.5	22.6	54.4
30	.1	.2	1.2	3.5	9.7	22.4	62.9
39	1.5	4.2	7.5	16.0	17.5	6.6	46.7
42	0.3	0.6	1.1	8.5	23.5	9.4	56.6
Ave.	.6	.8	1.4	4.9	12.6	13.5	66.4
9	0.1	8.9	10.9	18.0	25.4	16.7	20.0
18	.8	21.2	21.6	10.8	11.4	3.8	30.4
Ave.	.4	15.0	16.2	14.4	18.4	10.2	25.2
8	0.2	10.3	11.3	12.8	21.2	13.7	30.5
17	3.6	30.0	12.8	6.5	10.0	4.4	32.7
40	0.5	5.3	10.2	31.4	26.0	8.0	18.6
Ave.	1.4	15.2	11.4	16.9	19.1	8.7	27.3

TABLE 4

Lab. No.	Compressive strength	Yield			Tensile strength	Normal consistency	Time of set
		Lbs. paste per cu. ft.	Lbs. dry material per cu. ft. paste	Lbs. set material per cu. ft.			
1	1460	106	64	76	254	66.1	21
2	1315	107	64	75	775	66.9	21
10	1700	113	77	88	333	46.6	12
11	1570	107	66	79	270	56.2	7
19	1105	101	58	68	244	73.2	11
20	1060	102	58	68	220	75.0	19
26	1550	113	74	82	413	53.0	14
28	1580	112	72	81	387	56.0	22
29	1956	114	77	89	357	48.0	16
31	1935	107	68	78	394	58.0	8
32	1875	110	72	83	444	51.8	12
34	2200	114	76	85	437	50.0	13
35	1630	111	69	79	280	60.2	9
37	2285	116	75	83	299	51.5	8:00
43	1720	92	57	78	270	61.0	9:00
Ave.	1665	108	62	80	325	58.2	13:00
3	1295	107	65	77	273	64.3	53:00
4	925	105	63	74	236	66.0	11:56
12	1420	111	76	87	290	46.2	2:54
13	630	112	74	85	218	51.9	17:23
21	1280	103	62	73	272	65.4	1:58
22	1000	103	62	73	262	65.0	13:07
38	145	93	50	54	37	85.5	1:00
41	1400	120	83	87	129	44.6	5:37
Ave.	1010	107	67	76	215	61.1	6:41
5	555	104	63	73	182	65.7	14:15
16	1100	110	73	80	254	51.2	25:24
23	1030	106	66	75	269	61.0	13:09
27	1730	107	69	81	379	55.5	6:34
33	1475	115	75	83	400	53.3	8:50
36	800	107	70	80	186	51.6	19:42
Ave.	1115	108	69	79	278	56.4	14:39
6	835	103	62	73	222	65.4	18:35
7	670	103	62	74	195	66.3	6:17
14	785	108	73	86	223	47.1	11:26
15	885	109	75	87	259	45.7	6:20
24	960	99	61	73	228	63.0	10:30
25	910	101	60	71	232	67.4	12:24
30	1480	104	70	85	372	48.6	9:10
39	275	115	75	78	73	53.0	3:10
42	710	107	69	81	120	53.7	4:45
Ave.	835	106	67	79	214	56.7	9:11
9	195	129	101	108	52	27.0	2:19
18	475	131	106	111	109	23.1	2:32
Ave.	335	130	103	109	80	25.0	2:30
8	200	126	98	104	53	29.0	1:52
17	865	130	106	112	198	22.2	4:51
40	180	120	95	103	37	25.8	3:27
Ave.	415	125	100	106	96	25.7	3:23

6. *Yield.*—The above cylinder molds were weighed empty, and immediately after filling. The cylinders were weighed just before they were tested. The amount of dry material in a given volume of paste was calculated from the figure for normal consistency. These data were used to calculate the weight per cubic foot of paste, the weight of dry material per cubic foot of paste, and the weight per cubic foot of set material.

7. *Tensile Strength.*—Three briquettes of the usual form were made of paste of normal consistency, stored in the same way as the compressive strength specimens, and tested when one week old. The results are expressed in pounds per square inch.

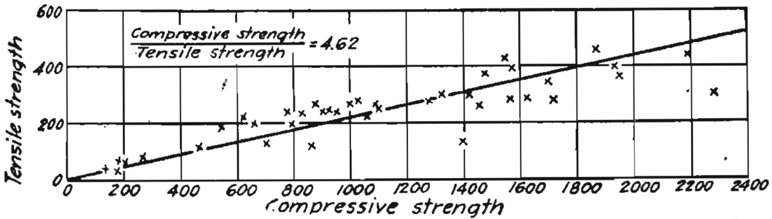

FIG. 86.—Diagram illustrating relationship between compressive and tensile strength of calcined gypsum.

The results of all of these tests are given in the accompanying tables. Owing to the extremely confusing nomenclature, no attempt has been made to group the samples according to their

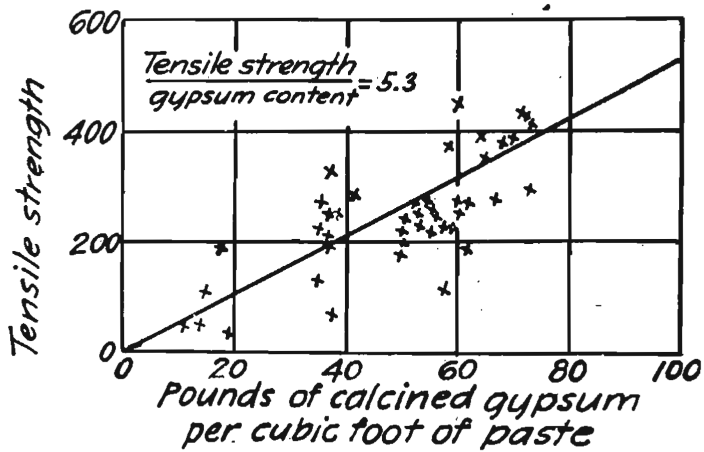

FIG 87. Diagram illustrating relationship between tensile strength and gypsum content.

trade names. They have been classified, instead, in accordance with their actual compositions.

Primarily, these data are intended to enable us to arrive at numerical values expressing the different properties of gypsum. These values are to be used in writing specifications for the material. Incidentally, the data may also be used in an attempt to correlate the various properties. Certain efforts along this line are indicated in figures 86 and 87, showing the relations between tensile strength and compressive strength, and tensile strength and gypsum content, respectively. Obviously the data permit and invite a great deal of this sort of calculation.

It seems that the present method of measuring time of set by means of the Vicat needle has been the subject of much criticism. To get more information on this point, the times of set of ten samples were measured by means of the temperature rise, and by direct observation. The results for one of these samples are given in figure 88. All of these results confirm those previously[236] obtained: that the temperature rise method is fundamentally unsound, and is misleading. The Vicat needle is endorsed. It gives results which are definite, which can be checked, and which indicate the time during which gypsum may be worked without injury.

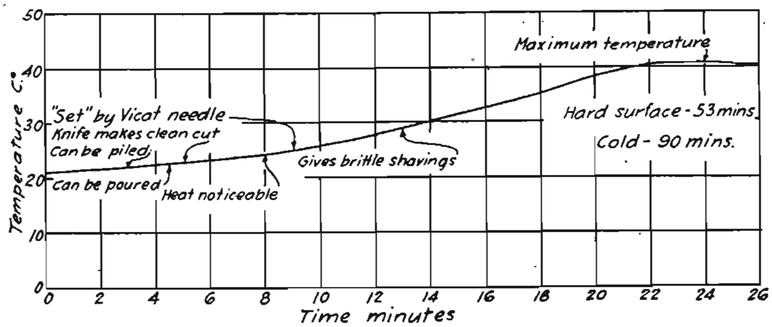

FIG. 88.—Diagram illustrating relationship between temperature and setting time of calcined gypsum.

The use of the Southard viscosimeter to measure normal consistency has also been criticized. The results obtained by means of this instrument are probably accurate within 1 per

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[236] Emley, Time of Set of Calcined Gypsum: Trans. Amer. Ceram. Soc., 19, p. 573, 1917.

cent, and can be readily checked by different observers. The machine is not portable, and its use is therefore confined to the laboratory. It was suggested that a cylinder mold two inches in diameter by four inches long could easily be carried in the pocket, and a "slump" test, using this mold, would measure consistency to a sufficient degree of accuracy. Accordingly, pastes of normal consistency (by the Southard viscosimeter) were made of 10 samples, and were tested by the slump method, using a two by four inch cylinder. It was found that the final diameter of the pat varied from 4¼ to 5½ inches for the different samples. It would seem, therefore, that the slump method is hardly accurate enough for a standard method, although it will probably give satisfaction when used for plant control.

We wish to acknowledge our obligations to Mr. H. A. Bright for the analytical work, and to Mr. L. A. Balser for assistance in making physical measurements.

BUREAU OF STANDARDS
WASHINGTON, D. C.

APPENDIX II

MICROSCOPIC EXAMINATION OF RAW OR CALCINED GYPSUM

BY DR. ESPER S. LARSEN[237]

Microscopic examination

13. The systematic microscopic examination of gypsum products offers no great difficulties to the specialist in petrography or microscopic mineralogy and any intelligent person could be taught certain routine tests that would apply to material whose constitutents are known and as few in number as are those in ordinary gypsum, just as a laboratory assistant can be taught to make simple chemical analyses. As in chemistry, such routine work should be controlled more or less by a trained microscopic mineralogist, as otherwise unexpected products or other difficulties may introduce serious errors in the results. The distinction under the microscope between substances depends on their optical and other crystallographic properties and accurate distinction requires skill if the substances have similar properties, and especially if they are in minute particles, or appear to have variable properties due to variable composition or submicroscopic inclusions. Ordinarily the microscope gives only qualitative results but rough quantitative estimates can usually be made very quickly, and for many determinations, as in the determination of anhydrite in gypsum, a fair quantitative estimate can be made. The greatest value of a microscopic examination is in checking the chemical analyses and in showing the state of combination of the radicals determined by chemical analyses.

Minerals in raw gypsum

14. The minerals most commonly found in raw gypsum are gypsum, quartz, anhydrite, calcite, and clay. In plaster of Paris calcined at about 170° C. the quartz and anhydrite remain unchanged as does the calcite for the most part, the clay loses some water and the gypsum changes to $CaSO_4.\frac{1}{2}H_2O$. If calcined at a higher temperature the gypsum changes

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[237] Published by permission of the Director of the United States Geological Survey.

to insoluble anhydrite or soluble anhydrite and some lime and calcium hydroxide may be formed from the calcite and the clay may be dehydrated.

The more important properties that aid in determining the minerals follow:

Gypsum

15. Gypsum ($CaSO_4.2H_2O$) is found in grains or prismatic crystals. Artificial crystals and small natural crystals are commonly lathlike and elongated parallel to c and with the flat face (010). Gypsum can be scratched with the fingernail. It has a very perfect cleavage (010). The indices of refraction are $\alpha = 1.521$, $\beta = 1.523$ and $\gamma = 1.530$. The double refraction is 0.009. The optic character is positive and the axial angle is 58°. The mineral belongs to the monoclinic crystal system and the optic orientation is $Y = b$, $x - c = 37\frac{1}{2}°$. Hence grains or crystals lying on the cleavage face are parallel to the plane of the optic axis and show large extinction angles. The low hardness, very perfect cleavage, indices of refraction, rather low birefringence, and large extinction angles readily distinguish gypsum from all other compounds found in gypsum products.

Quartz

16. Quartz (SiO_2) is one of the common impurities in gypsum and occurs chiefly in grains. It is the only product common in gypsum that is harder than glass and its presence can be determined from the fact that if a powder containing quartz is rubbed between two fragments of glass it will be "gritty", and will scratch the glass. Quartz has no cleavage. It is uniaxial positive and has indices of refraction appreciably higher than those of gypsum and lower than those of anhydrite ($\omega = 1.544$, $\varepsilon = 1.533$). It is distinguished from the associated minerals by its hardness and lack of cleavage, its indices of refraction, and its uniaxial positive character.

Calcite

17. Calcite ($CaCO_3$) is common in raw gypsum and is in many cases present in minute crystals or grains scattered through the clay or the gypsum. Less commonly it is in large grains. It is harder than gypsum but can easily be scratched with a knife. It is characterized by very perfect cleavages ($10\bar{1}1$) which gives rhombic cleavage pieces. Microscopically it is characterized by its very strong birefringence ($\omega - \varepsilon = 0.172$) giving rise to a white of the higher order in-

terference color for grains of normal thickness and to bright colored specks for the minute crystals. The ω index of refraction, shown on every grain, is 1.658, while ε, shown only on grains lying parallel to the crystal axis c, is 1.486. Calcite can be distinguished from the associated minerals by its perfect cleavage, its high interference colors and the high value for the index of refraction.[238]

Anhydrite

18. Anhydrite ($CaSO_4$) is common in natural gypsum and is usually found in grains of considerable size. It has a hardness near that of calcite. It is orthorhombic in crystallization and has a very perfect cleavage parallel to (010), and less perfect parallel to (100); thus cleaving into rectangular parallelopipeds. Its indices of refraction are considerably higher than those of gypsum and quartz and $\alpha = 1.570$, $\beta = 1.576$, $\gamma = 1.614$. Its birefringence is 0.044, and it therefore gives bright interference colors. It is optically −, and 2V = 74°. The optic orientation is X = c, Y = b, Z = a, and all cleavage fragments give extinction parallel to the other cleavages. It is easily distinguished from the associated minerals by its cleavages, its indices of refraction, its bright interference colors, and its parallel extinction.

Clay

19. Clay is a term applied to a group of hydrous aluminum silicates of which kaolinite is the commonest. The clay minerals are either amorphous or occur in very fine grains collected into aggregates or scattered through gypsum. They nearly all have a cloudy or dirty appearance under the microscope. Their optical properties are variable and their study requires a skillful optical mineralogist. Kaolinite has indices of refraction $\alpha = 1.561$, $\beta = 1.563$, and $\gamma = 1.567$. The clay minerals can usually be distinguished by their finely crystalline character and cloudy appearance; such material is for the most part intimately mixed with quartz, calcite, and other minerals.

Products in plaster of Paris

20. Plaster of Paris is made up mostly of $CaSO_4.\frac{1}{2}H_2O$ with some soluble anhydrite, lime, calcium hydroxide, quartz, anhydrite, calcite, and clay.

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[238] If calcite is imbedded in a liquid with an index of refraction of about 1.550, most grains when turned to extinction in one direction will show considerable relief (ω), but turned to the other extinction position will show little relief. Rare grains lying nearly parallel to the base will show lower interference colors and relief for all positions.

21. In ordinary plaster of Paris calcined at about 170° C. the gypsum grains have been dehydrated to $CaSO_4.\frac{1}{2}H_2O$ in an aggregate of very minute, fibrous crystallites which are intricately intergrown. These crystallites are in aggregates whose boundaries are those of the original gypsum crystals and the fibers tend to be orientated parallel to the crystallographic axis of the original gypsum. The mean index of refraction of the aggregate is about 1.54, which is a little higher than that of gypsum. The extinction is parallel and the elongation positive. The hemihydrate ($CaSO_4.\frac{1}{2}H_2O$) is characterized optically by its fibrous character, its parallel extinction, positive elongation, and mean index of refraction (1.54).

$CaSO_4\frac{1}{2}H_2O$

22. Soluble anhydrite ($CaSO_4$) forms by the dehydration of gypsum at a higher temperature than the hemihydrate. Like the hemihydrate it occurs in minute needles, intricately intergrown but its crystals show inclined extinction and have a mean index of refraction of 1.55. The double refraction is low, and the crystals give low order gray and white interference colors. Soluble anhydrite resembles the hemihydrate and insoluble anhydrite in its fibrous character but it has inclined extinction and a mean index of refraction of 1.55.

Soluble anhydrite

23. Insoluble anhydrite ($CaSO_4$) is found at temperatures between 200° to 500° C. It occurs as minute prisms, irregularly intergrown, thus resembling the hemihydrate and soluble anhydrite. Its optical properties are those of the mineral anhydrite with which it is probably identical. Just below the dissociation point the small needle crystallites reconsolidate, and the resulting crystal is comparatively large, agreeing with soluble anhydrite in all its optical properties. Insoluble anhydrite has a considerably higher mean index of refraction (1.587) than either $CaSO_4.\frac{1}{2}H_2O$ or soluble anhydrite.

Insoluble anhydrite

24. Lime (CaO) crystallizes in rounded, isotropic grains with a very high index of refraction (1.82) and is thus easily distinguished from all the other constituents.

Lime

25. Calcium hydroxide is probably amorphous and occurs in isotropic grains with an index of refraction of 1.58. Due to insufficient water during hydration, it may show a strained condition which manifests itself by very low

Calcium hydroxide

gray interference colors. Its index of refraction and isotropic character distinguish it and it is also recognized by White's calcium phenolate test.

Estimation of anhydrite

26. The quantitative estimation under the microscope of anhydrite in raw gypsum is especially important as the chemical analyses cannot be used to determine the amount of anhydrite, owing to the variable water content of natural gypsum and perhaps also of the clay minerals. The method recommended for this estimation will, therefore, be described in some detail and can be applied with slight modification for the estimation of other minerals.

Estimation by thin sections

27. The most accurate and probably the simplest method for determining anhydrite, or any other mineral that is in crystal grains of moderate size,—say over 0.1 mm. diameter—in a gypsum rock, is by grinding enough thin sections of the rock to represent a satisfactory sample and measuring the proportion of the mineral in the section by the Rosiwal method. Some of the objections to this method are:

Enough thin sections must be cut (from flat fragments about an inch square) to represent the material. This takes time and sections cost about 60 cents each.

Unless great care is exercised some of the harder minerals, such as quartz and anhydrite may tear out in grinding and lead to erroneous results.

Considerable skill is required to determine some of the mineral grains in the thin sections. The Rosiwal method is described in books on optical mineralogy.

Estimation of powder

28. A more practical method is to use a sample of the powder pulverized to about 100 to 200 mesh. The sample of the powder as charged to the kettles is satisfactory. The only equipment needed is a petrographic microscope, or even an ordinary microscope, a few object and cover glasses, and a liquid with an index of refraction of about 1.550.

Preparation of imbedding liquid

29. This liquid can be made by mixing by volume 77 parts of clove oil with 23 parts of cinnamic aldehyde. If kept in a carefully stoppered bottle this liquid will remain satisfactory for several years. Its index of refraction can be checked by immersing a little powdered quartz in

the liquid on a microscope slide and comparing the indices of refraction of the quartz and the liquid. To do this use a low power objective, shade one side of the field by sliding the finger or a card into the field below the substage condenser, or by tilting the mirror. The liquid has an index of refraction of about 1.550 if most of the quartz grains show a bright bluish white border on the shaded side of the field and a dark reddish gray border on the opposite side, while a few show rather dark blue on the shaded side and bright red on the opposite side. Its index is too high and more clove oil should be added if all the quartz grains show bright borders on the shaded side without much color. Its index is somewhat low and more cinnamic aldehyde should be added if most of the grains show a blue border on the shaded side and a red border on the bright side of the field. Its index is much too low if all the grains show dark borders on the shaded side of the field.

Estimation of anhydrite

30. To estimate the anhydrite, place a drop of the liquid (n equals 1.55) on an object glass, sprinkle from a knife blade a little of the sample in the drop of liquid and cover with a cover glass. Distribute the grains evenly by shifting the cover glass; place on the stage of the microscope fitted with a rather low power objective. The liquid should just fill the space between the two glasses, and the grains, as observed with the microscope should not be too close together. If they are packed closely together too much powder was used.

Shade one side of the field by sliding the finger or a card into the field beneath the substage condenser, or by tilting the mirror. All grains of gypsum will show a bright border on the shaded side of the field and a dark border on the bright side.[239] Quartz grains will show a faint bluish white to blue border on the shaded side. Clay will be in clouded aggregates which have dark grayish borders on the shaded side of the field and light grayish borders on the opposite side. Calcite grains can be distinguished by their strong birefringence, perfect cleavages, and by the fact that on revolving the stage of the microscope the grains nearly or quite disappear in some

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[239] With a strong condensing lens lowered below focus the borders will be reversed.

positions and stand out in marked relief in others. Most grains of anhydrite will show bright interference colors between crossed nicols and all will show a dark border toward the shaded side of the field and a bright border on the opposite side.

Each grain of anhydrite, and also of the other constituents can thus be quickly recognized and by counting grains and estimating sizes, remembering that a third dimension is normal to the microscope slide, an approximate determination of the proportion of anhydrite by volume can be made. To reduce to percentage by weight multiply by 1¼.

In practice it is usually true that the anhydrite grains are as large as the gypsum grains and there is no special tendency for the anhydrite to be either more or less abundant in the finer powder than in the coarse. This being true, the estimate is simplified from the fact that it is necessary only to consider the larger grains. To do this either ignore the fines in the microscope slide or, better, sift some of the sample in fine bolting cloth to get rid of the fines before mounting the sample. Sets of very small sieves can be purchased that are suitable for this purpose.

Accuracy of the method

31. The chief errors in the estimates are due to the difficulty in estimating sizes of grains, and the uncertainty in assuming that the proportion of anhydrite in the fines is the same as that in the coarser grains. Duplicate determinations should be made on different days by the same man checked to within ½ per cent for samples containing less than 5 per cent anhydrite and to within 1 per cent for samples with 10 per cent anhydrite. The actual accuracy of the determinations may be somewhat less.

Time required

32. In practice it is best to make measurements on several slides of the powder and to average the results. The time required to make a measurement is from a few minutes to an hour depending on the care taken and the number of slides examined.

More accurate modification

33. A more accurate estimate can be made by separating the anhydrite from a weighed amount of powder (1 to 10 g.) by a heavy solution weighing both the heavy and light portions of the powder and estimating the

anhydrite in both portions under the microscope as described in the preceding pages. If the separation has been carefully made the heavy portion should be made up chiefly of anhydrite. If any considerable amount of calcite is present it can be removed by hot dilute HCl. The light portion should contain very little anhydrite. Bromoform is about the most satisfactory heavy solution to use and if pure bromoform is found to be so heavy that anhydrite will not sink satisfactorily, its specific gravity can be reduced by adding a little carbon tetrachloride or benzol. On account of the large amount of fine material in the samples it is necessary to make a preliminary separation in a separatory funnel, drain off the heavy (settled) portion into another separatory funnel and to repeat the separation in both funnels by shaking the sample up in more liquid. Repeat the separation as many times as is necessary to get a clean separation. The use of heavy solutions in mineral separations is described in most text books on mineralogy and petrography.

This method should give more accurate results but it takes much more time.

APPENDIX III.

GERMAN METHODS OF TESTING GYPSUM

REGULATIONS FOR UNIFORM TESTING OF GYPSUM ADOPTED AT THE 13th ANNUAL MEETING OF THE GERMAN GYPSUM ASSOCIATION, (BERLIN NW. 21, DREYSESTRASSE 4) HELD FEBRUARY 15, 1911[240]

As a basis for the uniform testing of structural and stucco gypsum has been laid the determination of the following:

a) amount of "addition"
b) time of pouring
c) time of marking
d) fineness
e) tensile strength
f) bending strength

The amount of gypsum required for the above tests is from 4 to 5 kg., in accordance as the amount of gypsum used in making the pat is larger or smaller.

1. SCREENING

The gypsum to be tested is passed first through a sieve of 16 mesh per sq. cm., or 2mm. diameter of mesh, which causes the soft lumps, which often occur in gypsum, to break up, while the larger pieces of impurities are eliminated.

For this purpose it is most convenient to use a large sieve measuring 35x60x12 cm., as it allows not only the screening of the entire amount of the gypsum used for the test in one operation, but makes a thorough mixing of the material possible.

2. DETERMINATION OF THE AMOUNT OF "ADDITION"

By the "amount of addition" of gypsum is meant the amount of gypsum paste that can be poured.

For this determination is used a glass vessel of 60 mm. inside height, and 70 mm. inside diameter, which must be thoroughly dried for each test.

The weight of this glass is then carefully balanced off an

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[240] Translated for Keystone Plaster Co., and presented by courtesy of H. L. Brown.

exact table scale, of 4 to 5 kg. capacity (shot is best used for this purpose); next 100 grams (cub. cm.) of pure water, 15° to 20° C., are poured in or weighed, in such manner that no drops should fall on the upper part of the surface of the vessel, as otherwise, when the gypsum is being added, it may stick to the wet places, which may lead to errors. It is therefore best to measure off or weigh the 100 grams. or cub. cm. of water in a separate glass.

The glass is now set on a paper washer. The time of starting the addition of the gypsum is carefully noted, and the gypsum is added by hand until it ceases to sink, that is until the water level disappears, and a thin dry layer of gypsum remains visible for a period of 3 to 5 seconds. The duration of addition should be of 1½ to 2 minutes. While gypsum is being added, neither the glass, nor the paste should be touched.

The glass vessel is now weighed with the water and gypsum, and, after the amount of the water added, viz. 100 grams, is subtracted, the amount of gypsum added is obtained, which is the *amount of addition.*

The gypsum paste obtained in the determination of the amount of addition, should not be used for further tests, i. e. for the determination of the pouring and marking time.

3. DETERMINATION OF THE TIME OF POURING

By "time of pouring" of gypsum is meant the period of time which elapses from the time of the addition of gypsum (see par. 2) to the instant when gypsum ceases to be fluid enough to pour. To determine the time of pouring a *new* paste is made in accordance with the data on the amount of addition determined in paragraph 2. For this purpose a rubber hemisphere is used 12 cm. in diameter, over which is laid a square zinc sheet (16x16 cm.) with a circular opening 10 cm. in diameter.

The beginning of the period of addition of gypsum is again carefully noted, and the amount of gypsum, previously weighed, is uniformly added by means of a spoon, in about 30 seconds. The gypsum which may have fallen on the zinc sheet is carefully swept off into the rubber half-ball. After the zinc sheet cover is taken off, the paste is carefully stirred with the spoon, which should result in the breaking up any lumps that might have formed. The paste is then poured out on a glass plate (15x15 cm.), and, by lightly shaking the latter, allowed to form into a cake 5 to 7 mm. thick and 10 to 12 cm. in diameter.

At intervals of ½ minute cuts through the gypsum paste are made with a pocket knife. The knife must be thoroughly cleaned after each cut both in this case and in the tests for marking. When the edges showing the path of the cut cease to flow together of themselves, the time of pouring is considered to be concluded. This instant is recorded.

4. DETERMINATION OF "MARKING TIME"

By "marking time" of gypsum is meant the period elapsing from the addition of gypsum to the water in making the paste to the instant when the gypsum loses the ability to be marked or finished. To determine the marking time, the cake made during the determination of the pouring time is used. As soon as it has been established by pressing the paste with the finger that the mass is near the "marking time", at intervals of 1 minute shavings about 2 mm. thick are cut off. When, with the knife blade moving fairly fast, the shaving comes off grainy and brittle, the marking time is considered to be over, and the instant is recorded.

5. DETERMINATION OF FINENESS

100 grams gypsum are weighed on a small lever scale and passed through a dry sieve having a surface of 600 by 350 mm. and 900 mesh per sq. cm., that is 0.22 mm. diameter of mesh, until no more gypsum dust can be seen on a piece of black glazed paper laid below. The residue remaining on the sieve is weighed. Since 100 grams were used, the weight of the residue gives the percentage direct. Finely ground gypsum leaves residue from 0 to 10 per cent. Moderately fine gypsum leaves a residue of 10 to 20 per cent. Coarsely ground material leaves a residue of 20 to 30 per cent.

6. DETERMINATION OF TENSILE STRENGTH

For the determination of tensile strength twelve test-pieces (5 sq. cm. crosssection of rupture) are cast. Groups of six pieces are tested, one after one day, and another after 28 days, for tensile strength on the machines generally used in testing cement.

Preparation of the test piece for the tensile strength test.—The gypsum paste required is prepared in accordance with the data on the amount of gypsum addition obtained in paragraph 2. The amount of paste required for six test-pieces is obtained by adding to 400 cub. cm. of water having a temperature of 15° to 20° C., a fourfold amount of addition, and thoroughly stirring the mixture until all the lumps are broken up. If, e. g., the amount of addition determined in paragraph 2 was 160 grams, then 4x160, or 640 grams are to be added to 400 cub. cm. of water.

This paste, *constantly stirred,* is rapidly poured into a mold covered by white vaseline or wiped with a cloth impregnated with oil, the paste overrunning each mold by about 5 mm.

In quick setting types, with a period of setting of 2 to 3 minutes, only three test-pieces can be cast at a time, a double amount of addition being used per 200 cub. cm. of water.

After the lapse of the "marking time", the overrunning part is carefully cut off by laying the knife specially used for this purpose flat on the mold, and removing the excess of material by a seesaw motion of the knife. The surface of the test-piece is smoothed over by stroking it with the knife, but without applying any pressure. After the setting of the gypsum (i. e., after about half an hour), the test-pieces are described so as to make their recognition later on possible, taken from the molds, weighed and placed on triangular strips in a closed dry room having a temperature of 60 to 70° F. (15 to 20° C.) until they are old enough to be tested.

The best thing to be used for this purpose is a drying stand. Care should be taken that on none of its sides does the stand approach the walls nearer than 20 to 30 cm., so that the test-pieces will be on all sides surrounded by air, and may dry uniformly.

In order to introduce a uniform notation, the following is proposed:

In the first instance each gypsum test receives a running number—No. 1, 2, 3, etc.

As all tests are made after one and twenty-eight days, the test pieces which are due for test after one day, are marked with A, and those due for test after twenty-eight days, with C, the notation B being reserved for the exceptional test-pieces tested after seven days. If pieces are to be tested after eighty-four days and more, they are to be marked with letters D, etc. For denoting individual test-pieces, a number is added to the letter, so that the six pieces due for tests after one day, will be marked as A_1, A_2, A_3, A_4, A_5, and A_6. If the running number of the gypsums tested is 70, then the complete notation of the test-pieces will be as follows:

1 DAY	7 DAYS	28 DAYS	84 DAYS
$70A_1$	$70B_1$	$70C_1$	$70D_1$
$70A_2$	$70B_2$	$70C_2$	$70D_2$
$70A_3$	$70B_3$	$70C_3$	$70D_3$
$70A_4$	$70B_4$	$70C_4$	$70D_4$
$70A_5$	$70B_5$	$70C_5$	$70D_5$
$70A_6$	$70B_6$	$70C_6$	$70D_6$

This notation permits also one to recognize at once each test piece. For example, $35C_5$ will indicate that it is a test-piece No. 5 for gypsum No. 35, due for test in 28 days. By placing a fraction in front of the mark, the days of preparation of the test piece can be indicated. Thus, 7/4 70 A_1 shows that the test-piece was made on April 7 from gypsum No. 70, and shall be the first piece to be tested after one day.

7. DETERMINATION OF BENDING STRENGTH.

For the bending test twelve prisms, 16 cm. edge, and a square crosssection 4 by 4 cm., are prepared in a manner exactly similar to that of making the test-pieces for the tensile tests. Sets of six prisms each are tested, one after one day, and one after twenty-eight days. The test pieces are made in an iron mold divided into six parts, which can be easily taken apart, and is held by a single bolt. To make six test-pieces for the bending test, an elevenfold "amount of addition" is put into 1100 cub. cm. of water of 60 to 70° F. (15 to 20 deg. cent.). If, e.g., the "amount of addition" was found to be 150 grams, then 11 times 150, or 1650 grams are added to 1100 cub. cm. of water. The method of pouring is the same as that described in paragraph 6, but for finishing and smoothing the mold there is used a larger knife, 340 by 50 mm.

The test-pieces for the bending tests are marked also in the manner stated in paragraph 6, and placed on the same triangular strip drying stand.

For bending tests the Michaelis device is used (that is, the usual tensile test apparatus) which, instead of the usual grips, has on top a bow shaped piece with two edges 10 cm. apart, and below a little frame with a peg. The prisms are placed horizontally in the bow between the guides of the frame, and the iron peg of the lower frame is then set in. The bending tests are to be carried on in such a manner that the side of the prisms which was on top when it was made, that is, the side smoothed off, be on top in the bow. The weight of the cup and shot, multiplied by 11.7, gives the bending strength per sq. cm. Both in the tensile and bending tests the mathematical average of the six figures obtained in the series of six tests is taken (denoted by M, average, in German, *Mittel*).

In a letter from the Bureau of Standards the German method of testing gypsum for time of set is summed up as follows:

The German method of testing gypsum for time of set may be quoted from their specifications as follows:

> First—It is necessary to determine the amount of addition, which corresponds to our normal consistency. This is done by placing in a glass vessel 100 cc. of water. The vessel recommended is 70 mm. inside diameter and 60 mm. high and should, of course, be thoroughly cleaned and weighed before each test. To this water gypsum is added by hand until it ceases to sink, that is, until the water level disappears and a thin dry layer of gypsum remains visible for a period of 3 to 5 seconds. All of the gypsum necessary should be added in about 1½ to 2 minutes. During the addition neither the glass nor the paste should be touched, jarred, or stirred in any way. The glass containing the paste is now weighed and the amount of dry material which has been added is calculated and reported. To determine the "time of pouring," corresponding perhaps, to initial set, it is necessary to make up a new paste using the proportions of gypsum and water as just determined. This paste is made up in a rubber hemisphere 12 centimeters in

diameter, over which is laid a square zinc sheet 16 centimeters square with a circular opening 10 centimeters in diameter. The amount of gypsum, previously weighed, is added by means of a spoon in about 30 seconds. The gypsum which may have fallen on the zinc sheet is carefully swept off into the rubber half ball. After the sheet cover is taken off the paste is carefully stirred with the spoon to break up any lumps that might have formed. The paste is then poured out on a glass plate 15 centimeters square and by lightly shaking this the paste is allowed to form into a cake, 5 to 7 mm. thick and 10 to 12 centimeters in diameter. At intervals of ½ minute cuts through the paste are made with a pocket knife which must be thoroughly cleaned after each test. When the edges showing the path of the cut cease to flow together of themselves the time of pouring is considered to be concluded. Of course the first time reading is taken at the instant when the gypsum is added to the water. As soon as it has been established by pressing this cake of paste with the finger, that the mass is getting hard, at intervals of one minute, shavings about 2 mm. thick are cut off. When, with the knife blade moving fairly fast, the shavings come off grainy and brittle, the "marking time" is considered to be over.

APPENDIX IV

MEASUREMENT OF THE TIME OF SET OF CALCINED GYPSUM

BY WARREN E. EMLEY[241]

The time of set of calcined gypsum, or of a prepared wall plaster made therefrom is one of its most important properties. Pure $CaSO_4 \frac{1}{2} H_2O$ sets very rapidly. Commercially, however, the time of set is subject to variation, due to impurities in the gypsum, to the temperature of calcination or to the addition of retarder. Under these circumstances, it is impossible to use the time of set as a criterion by which to judge the purity or proper calcination of the material. The time of set of calcined gypsum is far more important: it is frequently the determining factor which governs the suitability of a given plaster for a given purpose. For example, a plaster should not begin to set too soon or its application would be a difficult matter; but having been applied, it should then set as rapidly as possible, in order not to delay the work. Obviously, any specification for calcined gypsum or wall plaster should cover the time of set. The writing of such specifications has been undertaken by Committee C-11 A. S. T. M., and as a necessary preliminary thereto, a standard method for measuring the time of set must be developed.

The time of set of any plaster is customarily divided into two periods, which may logically be differentiated as follows. For some time after the plaster has been mixed with water, it may be worked with impunity. Eventually, at the point of "initial set" it begins to harden. After this, any further working will destroy whatever bond has been formed, thus impairing the value of the finished product. Finally, the material will have undergone sufficient hardening so that it can no longer be worked, and is then said to have taken its "final set". With most plasters neither of these points is very sharply defined, so that it is deemed expedient to adopt some arbitrary means of determining them. For example, it would be

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[241] Republished from Transactions American Ceramic Society, Vol. XIX, 1917.

very difficult to decide just when a sample of Portland cement had set sufficiently so that it could no longer be worked. We can, however, determine when a needle of given dimensions will not penetrate it, and arbitrarily state that this shall be called the time of final set. To be acceptable, any such empirical designation must fulfill three requirements: (1) It must conform pretty closely to what is generally conceded to be the time of set of the material from both a scientific and a practical viewpoint. (2) It should be simple, so that the test will not be too costly. (3) It must be universally adopted.

The mechanics of the setting of calcined gypsum is so well known that it needs no explanation here. One point, should, however, be called to your attention: the tremendous effect of small amounts of foreign material in the water and sand. If a contractor in a certain locality desires a plaster which will set on the wall in from four to six hours, the manufacturer may give him a calcined gypsum which when mixed neat with distilled water will set in forty minutes. The manufacturer must thus be familiar with the qualities of sand and water in his markets and allow for them. Obviously, such anomalous conditions are not conducive to free intercourse, because if the above contractor asked a manufacturer who was unacquainted with local conditions for a gypsum plaster which would set in four hours, the material received would probably not fulfill his requirements.

Many methods of measuring the time of set of calcined gypsum have been suggested, and most of them are in use, with the result that it is difficult to find any two people who agree as to the time of set of a given sample. Recently a sample of plaster was thoroughly mixed and divided into five parts, which were sent to five different manufacturers. Each one determined the time of set by the method he is accustomed to use. The results varied from 16 minutes to 93 minutes. It is for the purpose of learning, if possible, which of the methods is best adapted to this material, that the present work was undertaken.

The methods in use may be grouped as follows: A—Methods based upon the measurement of the actual strength or hardness of the material at different time intervals. B—Methods based upon the measurement of some concurrent phenomenon such as the rise of temperature, or the expansion. C—Rule of thumb methods, which were originally devised for plant control, but have frequently found their way into specifications.

For the experimental work, a large sample of pottery plaster was mixed and stored in an airtight container until used. It was extremely lean and slow setting, and therefore very well adapted to the work. The experiments reported in a paper by Kerr[242] called attention to the necessity of using the same consistency throughout, if the results are to be at all comparable. Since the same quality of plaster was used for all experiments, uniform consistency could be obtained by keeping the proportions of water and plaster constant. It was decided to use a rather thin consistency so that small errors in weighing the materials would have no effect. The following procedure was maintained constant for all experiments: In a perfectly clean porcelain casserole, put 65 cc. of distilled water. At a definite noted time, which shall be designated hereafter as zero time, 100 grams of plaster was added to the water as quickly as possible. This was permitted to soak for one minute. Thus the sample was ready for use exactly two minutes after zero time. Extreme care was taken to see that all traces of set plasters were removed from the casserole and stirring rod after each experiment. The molds were cleaned thoroughly and then dipped in melted paraffine just before using. A stirring rod is to be preferred to a spatula or trowel for many reasons: its use precludes the possibility of chemical or electrical action; it is more easily kept clean; the plaster and water can be stirred into a homogeneous mass without the "working" effect which is necessarily attendant upon the use of a larger blade.

Under Group A, the first method to be examined is the strength measurement. This method is the only one which can be regarded as absolute rather than empirical. If a point of time can be found such that any further working of the sample beyond that point will cause a diminution of strength, that point is by definition the time of initial set. Unfortunately, the method is far too laborious, and the results too indefinite for general use, so that it is of value only for judging which

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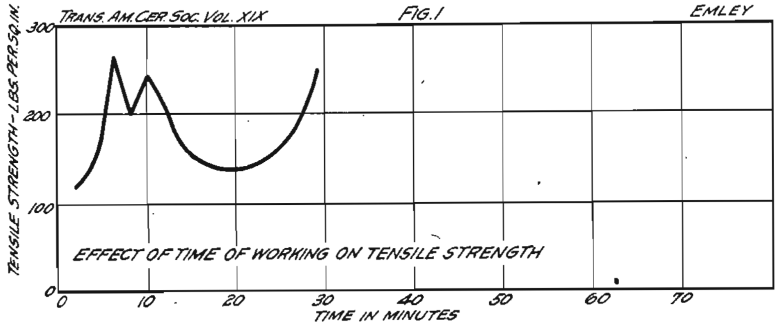
[242] Trans. Am. Cer. Soc. XVIII, 1916.

of the empirical methods comes nearest to the truth. The experiment was conducted as follows: A sample of plaster and water, mixed as above described, was permitted to stand



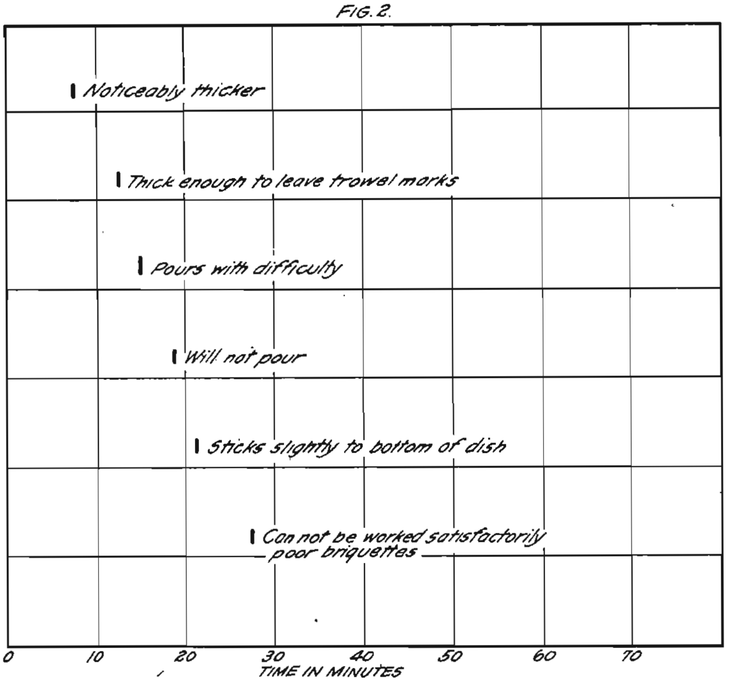
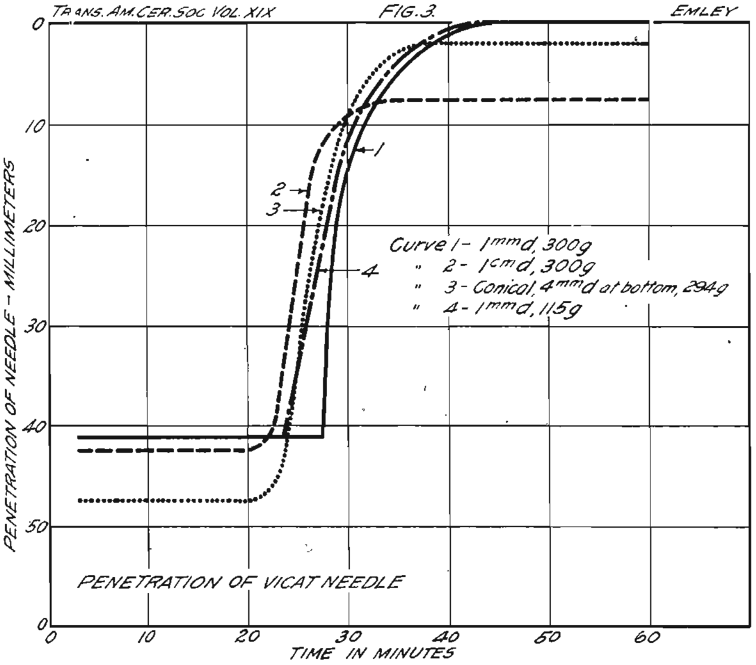


FIG. 89.—Effect of time of working on strength.
FIG. 90.—Stages in the setting of calcined gypsum with corresponding time intervals.

for X minutes. It was then reworked by mixing vigorously with a steel spatula, and cast into three briquettes. One hour after zero time, the briquettes were removed from the molds and put into a drying oven at 40° C. Twenty-four hours later, they were removed from the oven, and tested immediately. X was varied by one minute intervals from two minutes past zero time till the material was no longer workable. The results are shown in figure 89 and the remarks on the accompanying phenomena in figure 90. The immediate increase to a maximum is probably due to the thin consistency used; for the first four minutes, the plaster settled out of the mixture so rapidly that an undue proportion of it remained in the dish after the briquettes had been cast. This tendency becomes less marked as the plaster begins to thicken. For example, in the 5 minute sample the strengths of the three individual briquettes were 120, 206 and 317 pounds per square inch, indicating conclusively that the mixture was not homogeneous. The 9 minute sample showed strengths of 191, 212, 217, showing that the mixture had thickened sufficiently to keep the plaster from settling out. In view of these results, it is possible that the depression shown at eight minutes may be due to experimental error. The curve shows clearly that the time of initial set for this plaster is ten minutes, because if the sample is worked after this time, it loses strength. The time of final set is shown by figure 90 to be twenty-seven minutes. The plaster can be worked after this time but not satisfactorily; the briquettes made at twenty-eight and twenty-nine minutes had rough surfaces and were ragged and full of holes. Figure 89 shows that these last two samples were stronger than those preceding them. This is probably because the damp powders were packed into the molds with considerable force in an endeavor to make a presentable specimen.

The next four experiments were conducted to examine the "penetration method". The Vicat needle is 1 mm. in diameter, and weighs 300 grams. Curve 1 in figure 91 shows how far this needle will penetrate into the paste by its own weight after given intervals of time. It will be noted that this method shows no indication of any initial set at ten minutes. It shows very sharply and distinctly the point of final set at twenty-seven minutes. It shows also another rather indefinite point at about forty-five minutes, when the needle will make no impression on the surface of the plaster.

Curves 2, 3, and 4 in figure 91 were produced by changing the size, the shape, and the weight of the needle respectively. Apparently with these needles, the final set occurs in less time.



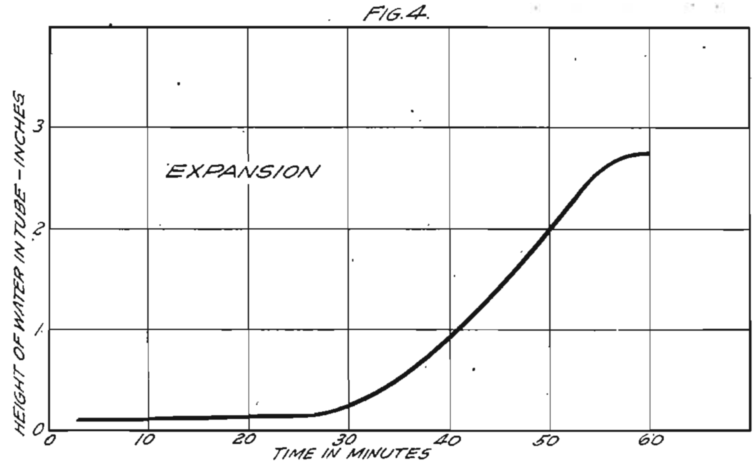


FIG. 91.—Diagram illustrating setting time of calcined gypsum.
FIG. 92.—Diagram illustrating rate of expansion of calcined gypsum while setting.

Figure 89 tells us that this is not so, and therefore the regulation Vicat needle (Curve 1, figure 91) is best adapted to the material. There is no indication of any initial set shown by any of them.

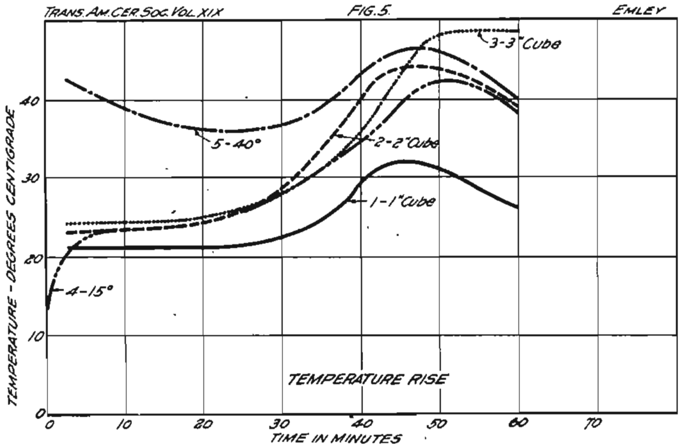
Under Group B there are two general methods, based upon expansion and temperature rise. We know that calcined gypsum expands as it sets, and a measure of the rate of expansion should therefore measure the rate of set. A thin walled rubber bulb was filled with water and placed in a small heavy metal can. The can was then filled with a sample of plaster and water mixed as above described. The cover was then screwed on until the plaster came out through two holes in it, so that the can was completely filled. Through one hole in the cover protruded the stem of the bulb, which was connected to a vertical glass tube. The other hole served to introduce a thermometer into the plaster. As the plaster expanded it squeezed the water out of the bulb and made it rise in the glass tube, where its height could be read. The thermometer was read simultaneously, and the height of the water corrected for the expansion due to heat. The final results are plotted in the curve, figure 92. This curve also shows no initial set. It shows the final set at twenty-seven minutes, but not so sharply and definitely as curve 3, figure 91.

Heat is generated by the chemical reaction which causes the set of gypsum. This causes the temperature of the mass to rise, and the rate of the rise of temperature should therefore be an indication of the rate of set. This method has been more widely used and more thoroughly investigated than any other, but it seems that one of the basic principles has been overlooked. The speed of any chemical reaction is either retarded or accelerated by an increase of temperature. Assuming that the method of manipulation is so refined as to prevent all loss of heat by radiation, then a large sample of plaster will generate more heat than a smaller one, but it will also have a larger quantity of material to heat. The final temperature will depend upon the balancing of these two factors. Without attempting to discuss whether a large sample will give a higher or lower temperature than a small one, we may be reasonably certain that the two temperatures will not be the same, even under ideal conditions. Practically, the sample is always subject to more or less loss of heat by radiation, so that the temperature as read really indicates the difference between the rate at which the heat is generated and the rate at which it is lost by radiation. Therefore the maximum temperature is a function of the shape and size of the specimen, the difference between the temperature of the specimen and that of the air and other similar factors which govern the radiation of heat. It is logical to assume that the absolute value of the temperature at any time will have some influence on the speed of the reaction, and therefore on the rate of set, at that time.

The curves 1, 2, and 3 of figure 93 show the effect of the size of the sample on the rate of temperature rise. They were made by inserting a thermometer in the center of a one inch, two inch, and three inch cube respectively. The molds were made of paraffined paper, and care was taken to keep the factors governing radiation as nearly constant as possible. It will be noted that curves 1 and 2 show maximum temperature at forty-five minutes, while the rate of set of the 3 inch cube is somewhat retarded. The size of the specimen evidently makes little difference, provided it is not too large. It is suggested that a good design would be a cylindrical specimen of such a size that the bulb of the thermometer would be equidistant from the surface. For example, if the bulb of the thermometer is ¾ in. long by ⅛ in. diameter, the specimen might be made 1¾ in. long by 1⅛ in. diameter, and then every point on the surface of the bulb would be just ½ in. from the surface of the specimen. A mold of this shape can be conveniently made by cutting a piece of paper of the required dimensions, dipping it in melted paraffin, rolling it to shape, and mounting it on paraffin on a glass plate.

Specimens of this shape were used in curves 4 and 5 in figure 93, which show the effect of variation of initial temperature.

Three points are to be noted from these five curves; (1) Initial set occurs before there is any noticeable rise of temperature. (2) At the time of final set, the temperature has begun to rise, but there is no sharp break in the curve to indicate a sudden change in the rate of reaction. (3) There is a well defined point of maximum temperature, which has frequently been called the time of set. If, however, we define final set as the time after which the material is no longer workable, this point of maximum temperature occurs considerably (with this plaster, eighteen minutes) later than the final set. It does not mark the completion of the chemical reaction,



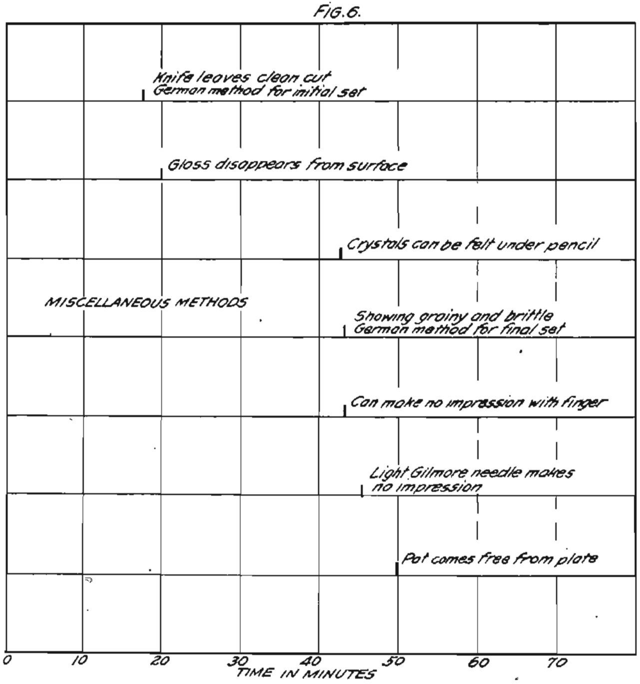


FIG. 93.—Curves illustrating temperature changes in calcined gypsum while setting.
FIG. 94. Diagram illustrating time intervals for initial and final set by various methods.

for we know that the specimen will continue to increase in strength for days. This point can be interpreted only as the time at which the reaction reaches its maximum velocity. The point is undoubtedly of scientific interest, but inasmuch as the plaster has long before ceased to be workable, it is difficult to see how this point can have any practical significance. Certainly it is a misuse of terms to call it the time of set.

Only one conclusion can be drawn from the above experiments: The measurement of the temperature rise is useless for determining the time of set.

In group C are included a number of empirical methods, the results of which are shown in figure 94. None of these requires any special explanation, except that the standard German method for measuring initial set is when the knife leaves a clean cut; and for the final set, when the shavings come off grainy and brittle. The number of methods in this group could be multiplied indefinitely, since almost everyone dealing with gypsum has a pet method of his own. The seven methods given were selected as being typical and since none of them shows the remotest connection with the time of set, either initial or final, it is hardly worth while to go further.

From the above discussion it seems reasonable to draw the following conclusions: (1) None of the methods examined is capable of indicating the initial set. (2) The ordinary Vicat needle, 1 mm. in diameter, weighing 300 grams, is eminently satisfactory for measuring the final set. (3) There is a third point, indicated by the temperature curves and by some of the methods in Group C., which is apparently the time of maximum velocity of setting. This point is of doubtful practical value.

Referring to figure 89, we find that when plaster is worked after it has taken its initial set, its strength is somewhat impaired. Fortunately, however, it does not seem possible to decrease the strength below ordinary practical requirements. That is, for most purposes for which gypsum is used, it could make little difference whether its tensile strength is 250 pounds per square inch or only 125. Indeed, experience leads one to believe that in most cases initial set has taken place before the application of the plaster has been completed. In other words, the working of a gypsum plaster makes no serious differences in its properties up to the time of final set when it can no longer be worked. From a practical view-point, therefore, the measurement of time of initial set is unnecessary, the final set only being of importance.

This interpretation of results may be objected to by one familiar with the testing of Portland cement. By such a one, the first break in curve 3, figure 91, would be taken as indicating the time of initial set, instead of the time of final set, as it has here been designated. In answer to this objection, it may be stated, first: The definition of either initial or final set, when measured by a penetration method, is purely empirical. There is, therefore, no particular reason for following the definitions adopted by the cement industry, when there is any advantage to be gained by deviating from them. Second; If it is accepted as logical that final set has occurred when it is no longer physically possible to work the material, then a comparison of figures 89, 90, and 91, will be convincing that the first break in curve 3, figure 91, corresponds to the time of final set.

Based on the above information, the following method is recommended for determining the time of set of calcined gypsum or of prepared plaster made therefrom. Determine first the normal consistency using the Southard instrument as recommended by Sub-committee 4 of Committee C-11, A. S. T. M. Determine from this the amount of water which must be added to 100 grams of the sample to produce a paste of normal consistency. In a perfectly clean porcelain casserole, put three times this amount of distilled water. Weigh out 300 grams of the sample and transfer to a clean sheet of glazed paper. Also provide a clean glass stirring rod about $\frac{1}{8}$ in. diameter. When the second hand of a watch points to zero, transfer the sample from the paper to the casserole. This should be done as quickly as possible without splashing, and should not take more than two seconds. Let the plaster soak quietly until the second hand again reaches zero, when the mixture is to be stirred vigorously by means of the stirring rod for one minute, by which time the mass should be homogeneous.

At the end of the second minute, this mixture should be poured into the mold for the Vicat needle. At one minute intervals, the needle is allowed to sink into the paste. Eventually there will be found a time when the needle will not penetrate clear to the bottom. The time elapsed between the time when the sample was added to the water and the time when the needle no longer penetrates to the bottom is recorded as the time of set.

The sample, water, casserole, and mold shall be at a temperature of not less than 20° C., nor more than 25° C. at the beginning of the experiment.

The Vicat needle and the mold are described in the standard specifications for cement—1915 Yearbook, A.S.T.M., page 359. The mold is made of hard rubber, and it will be found difficult to remove all traces of set plaster from it without scraping, which might cause injury. To overcome this, the mold should be prepared for use by dipping it in melted paraffin. This will prevent adherence of the plaster to a great extent, and the mold can be cleaned thoroughly and easily by heating it very gently.

APPENDIX V

SOME FACTORS INFLUENCING THE TIME OF SET OF CALCINED GYPSUM[243]

BY F. F. HOUSEHOLDER[244]

Introduction.—The time of set of calcined gypsum is one of its very important properties. Several methods for its measurement have been suggested and the chief ones have been tested and rated according to their merits.[245] However, no data resulting from thorough work on the relation of the time of set to the other physical properties are available. Obviously, this relation will depend upon the purity of the gypsum from which the plaster is made, the temperature at which it is calcined, and the amount of retarder or accelerator added. Experience shows that it depends also upon the cleanliness of the boxes or vessels in which the plaster is mixed, and the purity of the water used.

This preliminary note describes some tests made in order to determine the effect of varying the consistency of the mixtures, the time of stirring, the rate of stirring, and the temperature of the water used in mixing, on the time of set of calcined gypsum. The tests reported — although they may be of some value in themselves — were made as a guide in outlining further and more extensive tests on the physical properties of gypsum.

Preparation of Samples.—The same grade of plaster was used (without the addition of any retarder or accelerator) throughout the whole series of tests. A sample of 300 g. was made up in each case in a clean casserole. Each sample was stirred by means of a small spatula which was kept well polished. The plaster was added to the water as rapidly as possible (four to five seconds) without splashing or wasting and was allowed to stand undisturbed for one minute. It was

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[243] By permission of the Director, Bureau of Standards.

[244] Republished from the Journal of the American Ceramic Society, Vol. I, No. 8, Aug., 1918, pp. 578-583.

[245] Emley, Trans. Am. Ceram. Soc. 19, 573-584.

then poured (or was stirred as the test demanded and then poured) into the standard mold of a Vicat[246] apparatus. The mold was thoroughly cleaned before each test and was covered with a very thin coating of oil. The time of set was determined, as suggested by Emley,[247] by means of the standard Vicat needle.

Effect of Per Cent Water Added.—To determine the effect of the amount of water used in mixing the plaster on the time of set, samples containing 30, 32½, 35, 37½, 40, 42½, 45, 47½. 50 and 60 per cent of water, respectively, were made up and tested. A large number of tests on each mixture were made and the average results at each percentage were plotted. In figure 95 is shown the variation in the time of set with the amount of water used in the mixture.

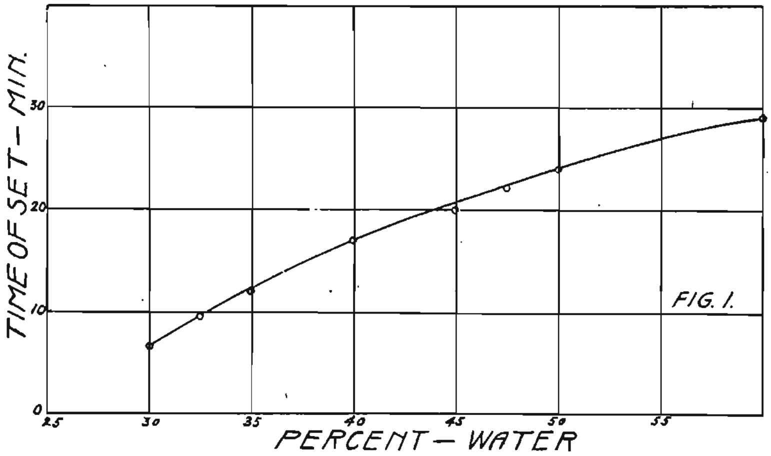

Fig. 95.—Diagram illustrating relationship between per cent of water used, and setting time of calcined gypsum.

The samples containing 30 per cent water were so stiff and viscous that much care and effort were required in introducing them into the mold. However, the time of set of the individual samples did not vary from the average by more than one-half minute. The sample containing 32½ per cent water was too viscous to mold satisfactorily, but gave fairly uniform values.

The curve (Fig. 95) shows a fairly uniform increase in the

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[246] 1915 Year Book. ASTM., p. 359.

[247] See page 578, Loc. cit., 19, 583-4.

time of set as the percentage of water was increased until about 45 per cent was reached. Thus the increase in time of set was less rapid — due to the fact that when the mixture was poured into the mold the plaster settled to the bottom and the excess water came to the top. A thin film of water came to the top of the 47½ per cent sample, and in the case of the 50 per cent sample, a layer of water 1-1.5 mm. deep formed, while with the 60 per cent sample, the water was 7 mm. deep at the top of the mold. Evidently, before any setting had taken place, the mixture was reduced to about 47 or 48 per cent and the further retardation probably was due, in part at least, to the fact that the plaster was under water. Also, the layer of water at the top of the mold increased the penetrating ability of the needle. These samples did not harden at the top — not even after the pouring off of the water and their removal from the mold. A day or two later the top could be brushed away with the hand. Considering the samples containing from 30 to 45 per cent water, an increase in the time of set from 6.5 minutes to 20 minutes, or approximately 300 per cent, is noted, while in the 45 to 60 per cent samples it increases from 20 minutes to 29 minutes or approximately 50 per cent.

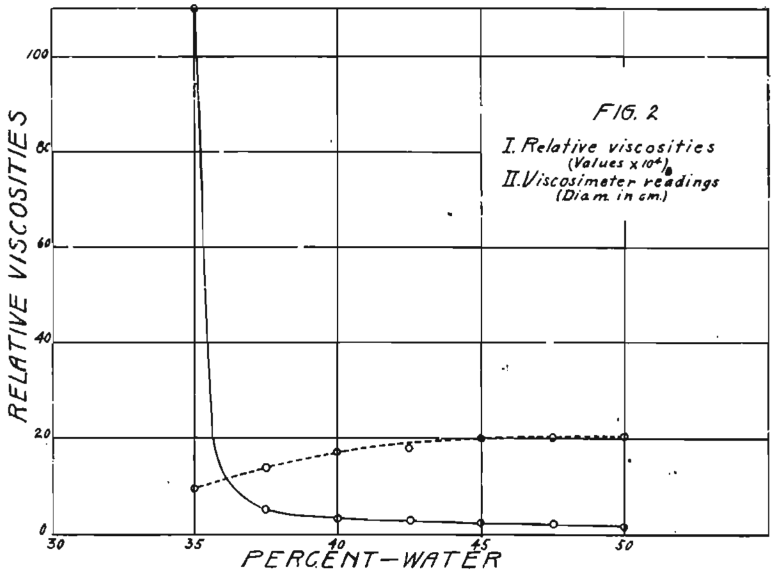

FIG. 96.—Described in text.

Viscosity Measurements.—The relative viscosities of each of the samples were determined by means of the Southard viscosimeter. The samples from 35 per cent up were placed in the viscosimeter and gave the results shown by the dotted curve (Fig. 96). Assuming that the "patties" were circular, the viscosity of a mixture would vary inversely as the square of the diameter of the "patty." The relative viscosities are shown by the solid curve (Fig. 96). A very marked decrease is noted between the water contents of 35 and 40 per cent but not much change is noted thereafter. The instrument used was not water tight and hence the 60 per cent sample was not tested. The shape of the viscosity curve would indicate that the viscosity very rapidly approaches that of water and probably reaches it before it crosses the 100 per cent abscissa. Lack of data makes it unsafe to judge where the two curves meet.

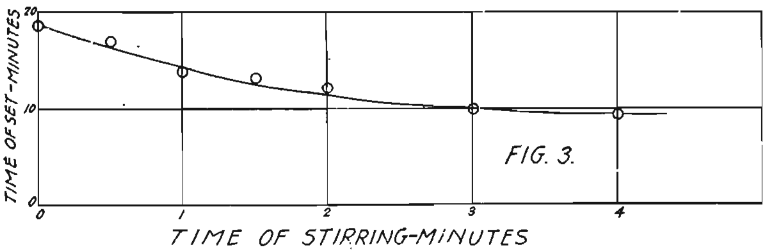

FIG. 97.—Diagram illustrating effect of stirring on time of set.

No extensive work has been published on the properties of gypsum solutions, although investigations along this line may lead to a more satisfactory definition of normal consistency. The immediate results obtained here indicate that decreasing the viscosity increases the time of set, but that the relation between the two is not a simple function.

Effect of Stirring.—In determining the effect of continued stirring, the samples used were mixed with 40 per cent water and each was stirred with a small spatula at the rate of four strokes per second. The calcined gypsum was added to the water and the mixture allowed to stand one minute, as before. The first sample was then poured immediately into the mold and the time of set determined. Each of the others was stirred at the same rate for 0, 0.5, 1, 2, 3, and 4 minutes respectively, and then poured into the mold. In figure 97 are shown the results of the tests.

Continuous stirring for four minutes decreases the time of set from 18.5 minutes (with no stirring) to 9.5 minutes or to almost one-half. The general shape of the curve would indicate that the time of set would not be very greatly decreased by a continuation of the stirring.

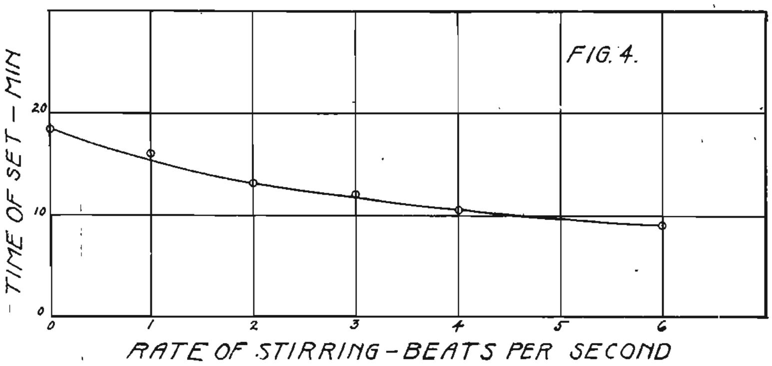

FIG. 98.—Diagram illustrating effect of rate of stirring on time of set.

In figure 98 is shown the effect of varying the speed of stirring of the same kind of samples on the time of set. The stirring was all done by hand and the speed varied from 0 to 6 strokes per second (each sample being stirred for one minute only).

Increased speed of stirring reduced the time of set. The shape of this curve is very similar to that of the curve shown in figure 97, although the decrease in the time of set is not so marked. The increased agitation of the mixture — either by increased stirring or by more rapid stirring — hastened the time of set. The first effect is probably to increase the rate at which the dry plaster takes up the water and goes into solution. The first crystal clusters formed are probably broken up and distributed throughout the mixture — thus becoming nuclei for further crystallization.

Effect of Temperature.—The effect of heating the water before mixing with the plaster was also tried out. The samples used for this purpose contained 40 per cent water and each was stirred at the same rate and for the same time as before. The data secured are less uniform than those secured in the foregoing experiments, but do not vary in any given direction. The conclusion reached is, that the temperature of the water has no appreciable effect on the time of set. The setting of calcined gypsum is always accompanied by the evolution of heat (pure $CaSO_4\ ½H_2O$ in forming $CaSO_4\ 2H_2O$ giving up about 3700 cal. per gram molecular weight). Heating would therefore tend to retard the process were it continued. On the other hand, the solubility of calcined gypsum tends to increase with a rise in temperature of the water — which probably would induce an acceleration of the process. Evidently from the results of this test, the two factors mentioned would about balance each other.

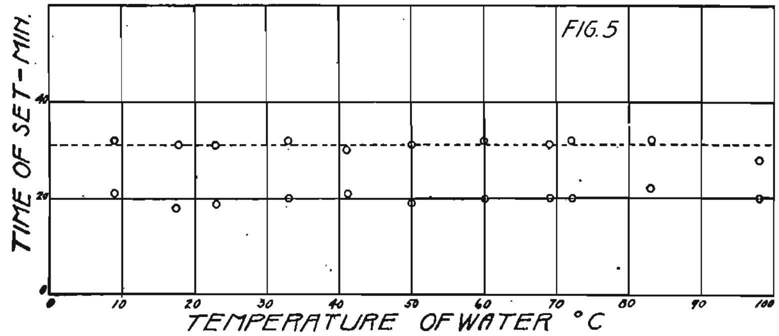

FIG. 99.—Diagram illustrating effect of temperature of water used in mixing on time of set. (Results would have been different had retarder been present in the calcined gypsum).

By the heavy curve (Fig. 99) is shown the time of set as determined by this test. The dotted curve shows the points at which the needle did not penetrate at all, or the time of hardening of the gypsum. The same regularity that is seen in the time of set is shown here.

CONCLUSIONS

(1) Increasing the proportions of water causes a decrease in viscosity, and an increase in the time of set of calcined gypsum.

(2) Vigorous and continued agitation, when mixing the calcined gypsum with the water, tends to decrease the time of set.

(3) The temperature of the water used in mixing has no influence on the time of set.

The above experiments were the outcome of the suggestions of Mr. C. A. Birdsley, Chief Engineer; P. H. Butler, Supt.; and J. A. Davis, of the Oakland Plant of the U. S. Gypsum Co. Acknowledgments are also due Mr. F. A. Kirkpatrick for many valuable suggestions in making the experiments.

APPENDIX VI.

GYPSUM COMPOSITION SLAB CONSTRUCTION FOR ROOFS AND FLOORS.[248]

The bureau has awarded contract No. 2264 for structural shop, navy yard, Norfolk, Va., on the basis of the roof slab being constructed of gypsum composition, because of the saving in weight of structural steel resulting from using a roof slab so much lighter than reinforced concrete, and also because of the anticipated saving from the reduction of heat losses through the relative nonconductivity of gypsum as against concrete. The unit cost of the gypsum slab complete for this project is 22.2 cents per square foot. In view of this being the first use of this material by the Bureau, the following report and record of test is published as being of particular interest to the corps.

REPORT ON INSPECTION OF INSTALLATION OF GYPSUM COMPOSITION SLAB CONSTRUCTION

(BY CIVIL ENGINEER GEORGE A. McKAY, U. S. NAVY)

As directed by Order No. 4234-93, dated September 13, 1916, I proceeded to Philadelphia and inspected installations of gypsum slab construction at the Midvale Steel Co.; Baldwin Locomotive Works, Eddystone; Remington Arms, Eddystone; Pennsylvania Ship Building Plant at Gloucester; and other installations.

The largest installation seen was at Eddystone, where there are built about 22 acres of roof covered with gypsum composition slabs. Certain of these slabs have been in use for as long as six years. All slabs inspected were installed in accordance with the table of spans, slab depths, and cable spacing, and represented standard construction of the Keystone Fireproofing Co. The superintendents of construction or their assistants at the different plants were interviewed, and all information gathered either by inspection or by interview was favorable.

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[248] Republished from Bulletin 25, Public Works of the Navy, pp. 20-37. Washington, 1917.

Particular attention was given to the work being installed on ordnance machine shop No. 7 Midvale Steel Co. The roof slabs were three inches thick, spans six feet three inches, reinforcement consisting of two No. 11 wires three inches on centers, wires being held down in the center of the span by one 5/8-inch round bar. This slab is designed for thirty pounds live load. Beam lengths were seventeen feet six inches, and the end panels were stiffened with three 1½-inch pipe struts and the center panels were stiffened with one 1½-inch pipe strut. In the end two panels, there was a six by six inch gypsum beam, six feet three inches long installed for further stiffening of the end slabs. The gypsum composition used contained 15 per cent by weight of wood chips and heavy broken shavings. The bulk of this wood filler, however, was considerable, so that in appearance, there was apparently much more wood filler than gysum. The gypsum and wood chips were first mixed dry by hand turning, similar to hand concrete mixing, on the ground; were then loaded into sacks, raised to roof by elevator, and transported to the site of the work where the mixture of gypsum and wood chips was again mixed in a box, water being added at the same time. The mixture was then immediately shoveled on the forms and screeded to proper elevation.

The company's force consisted of a total of seventy-five men, which force laid 7,500 square feet per day. There were about twelve men dry mixing, two men on hoist, and eight men for wet mixing and screeding. The remaining men were employed placing reinforcement and forms, stripping forms, and on miscellaneous work. Within fifteen minutes after a slab was poured, it was possible to step on same without leaving a footprint. A slab which had been poured at 9 o'clock had the form stripped at 11 o'clock. Seventeen men were then put on this slab in a space about 8 by 6¼ feet, which represented a live load about double that for which the slab had been calculated. The slab adjacent to the one loaded was without load. No defection was noticeable to the eye, and there was no apparent injury to the construction. At the time this first load was applied, the gypsum slab was so soft that it could be slightly compressed under the pressure of the thumb. The gypsum slab construction is quite elastic, and when compared to concrete is comparatively soft under foot, particularly so until it has thoroughly dried out, which takes about three weeks' time.

Through the courtesy of Civil Engineer L. M. Cox, U. S. Navy, public works officer, arrangements were made to have one of his assistants inspect certain floor installations in New York. The report of this inspection as forwarded by Mr. Cox is attached hereto. The advantages of gypsum slab construction are:

(a) The light weight of slab, thereby reducing dead loads and decreasing cost of steel foundations and piles.

(b) Quick construction, as forms can be removed in less than 24 hours, and roof covering can be placed in advance of the time required on concrete slabs.

(c) The material being a nonconductor decreases heat losses through roof, reduces coal consumption required for heating, and is free from condensation on the underside of the slab.

(d) The material has successfully passed several fire tests conducted by the bureau of buildings, New York City, and the Columbia University fire testing station at Brooklyn.

(e) There was a noticeable absence of cracks on all installations inspected, which is undoubtedly due to the elasticity of the material.

(f) The cost of maintenance and repair is low. The slabs are easily cut out where changes and construction are necessary; nails can be driven in the slab at any time.

This construction has the disadvantage that it is impracticable for the contractors to obtain wood chips which are free from oak and chestnut; and where these occur in the wood filler, brown stains are developed on the underside of the slab. Asbestos filler has been used in an effort to avoid this stain, but asbestos has been found unfit because of a chemical action which takes place which results in a white salt developing on the underside of the slab, which is more objectionable than the stain for the average installation. The slab is very porous, absorbs moisture freely, and when used for roofs must be waterproofed. The compressive strength of gypsum is diminished when the slab is wet, but it regains its strength in large part when it is redried. It is not considered that the decrease in strength of the slab when wet is sufficient to materially affect the strength of the structure when slabs are used for light loads and short spans.

The installation of gypsum is approved by building inspectors of several cities, among them being the cities of New York, Philadelphia, and Baltimore.

Letters requesting information concerning gypsum-slab installation were sent to the following companies:

The American Locomotive Co.
Baldwin Locomotive Co.
Montreal Light, Heat & Power Co.
Garvin Machine Co.
Norfolk & Western Railway.
Southern Railway.
Ingersoll-Rand Co.
Mr. John T. Wilson, Contractor.
Clinton & Russell, Architects.

All replies received (seven in number) were favorable. Information was particularly requested as to the length of time the system had been used; whether any trouble had been experienced from cracks due to irregular loading or vibrations; as to any deterioration in the slab where same had been exposed to moisture or rain; as to the effectiveness of the slab in decreasing heat losses and in preventing condensation, and as to whether the installation had been entirely satisfactory.

The method used by the Keystone Fireproofing Co. in figuring strength of slab, while not approved, appears to be safe for ordinary installations. It is believed that a method of analysis similar to that used for reinforced concrete construction would give results which would conform more nearly to those which actually occur in the installation. Calculation on the latter basis for a roof of spans and loading as specified for the structural shop showed that the slab should be four inches thick instead of 3½ inches thick as recommended by the manufacturers. It is also believed that a change in the system of tying down reinforcing cables, using two ½-inch round bars spaced about one-quarter of the span apart to hold down the cables instead of a single ⅝-inch round bar placed in the center of the span, would result in a material improvement in their construction.

Gypsum composition slabs are recommended for roof construction such as will be needed for the structural shop at Norfolk and also for light floor construction where no concentrated loads occur. Gypsum slabs are not recommended for floors having heavy concentrated loads, or for wide spans, that is, eight feet or over in width, nor for office floors or roofs where stains on the underside would form a serious objection.

The manufacturers claim that after a gypsum slab has thoroughly dried out, the underside can be coated either with calcimine or with plaster, and that further stains will not occur. This, however, has not been confirmed, as the installations examined were not so coated. It is considered probable that if the underside of a gypsum slab was plastered and again became wet, stains would develop through the plaster or calcimine.

REPORT TO CIVIL ENGINEER L. M. COX, U. S. NAVY, ON EXAMINATION OF GYPSUM SLAB FLOORS

The St. Nicholas Skating Rink.—This building has been in service for twenty-three years. The main floor, supporting the ice tank, consists of Metropolitan system type B slabs supported on steel beams five feet eight inches center to center. The basement floor below is occupied by ice-making machinery and small ice tanks. The rink was not in operation at the time of my inspection. Nails, pipes, and pipe hangers attached to the ceiling were all badly rusted, indicating severe moisture conditions. The tank above is insulated from the floor slab by twelve inches or more of material. Part of the ceiling is plastered. The underside of the floor slab, where exposed, is hard and sound. There is no sign of tension cracks in the ceiling. There are three or four small spots of porous material over the pumps, the gypsum probably not having filled the form. In one such spot I picked off enough of the gypsum to expose six of the steel cables and part of the ⅝-inch holding-down rod. The cables were entirely free from rust; there was a slight coat of rust on the ⅝-inch rod. A piece of gypsum knocked off a beam haunch with chisel and hammer showed a clean break, and sound, hard material. There has been little or no deterioration in the floor slabs of this building.

The Garvin Machine Co.—This building was erected over twenty years ago. It is an eight-story building, the floors above the second being occupied by machine tools driven by belts from overhead shafting. There is some vibration from the machines, but it is not severe. The bureau of buildings permits a live load of 220 pounds per square foot on the floors, which are Metropolitan system type B slabs between steel beams seven feet three inches center to center. However, there were local loads, such as piles of shafting, which I estimated at 400 pounds per square foot, and instances were frequent in which a heavy machine next to an aisle caused one panel to be fully loaded and the adjacent one unloaded. The floor slabs are to all appearances as good as new. There is no sign anywhere of cracking, flaking, or softening of the gypsum. The second-floor ceiling is plastered, elsewhere the ceilings were painted with a wash of plaster or cement. At one point two panels have been cut out and replaced. This was necessitated by the spilling of sulphuric acid over the floor, penetrating the cinder concrete fill and the gypsum slab. Employees of the Garvin Machine Co. stated that no work had been done on the ceilings as a whole since the company has occupied the building — about twenty-two years — except painting the plastered ceiling on the second floor.

At the office of the Keystone Fireproofing Co. I saw pieces of floor slab and steel taken from the Hammerstein Theater when that building was torn down, and from the overhang of the Ingersoll-Rand Co. building in Phillipsburg, N. J. The fireproofing was hard and sound; the steel showed only a little corrosion. The Hammerstein Theater had been in place nineteen years; the Ingersoll-Rand Co. building eight or nine years.

From the information I obtained, it appears that no repair or maintenance is required for Metropolitan system slabs at least for twenty years or more. In regard to alterations, costs were not obtainable, but it is probable that the gypsum and wood-chip composition is very much cheaper to cut than concrete. On the other hand, fastening the cables to the floor beams in existing work may be difficult. At 42 Broadway, New

York, a new stair well was cut; the cables in the adjacent panel were left untied, reliance being placed on the bond between the steel and the gypsum. The floor is apparently safe, but this procedure is, in my opinion, poor practice. The system is inapplicable to stairways.

In regard to appearance, the ceilings of the Garvin Machine Co. finished with a wash coat, the exact nature of which could not be ascertained, were gray in color and reasonably smooth and entirely satisfactory for a building devoted to manufacture. The untreated ceiling of the St. Nicholas Rink refrigerating room could not be recommended except where appearance is of no consequence whatever.

ARTHUR KRAUS, *Draftsman.*

REPORT ON LOADING TEST OF METROPOLITAN COMPOSITION FLOOR MADE BY THE U. S. BUREAU OF STANDARDS, NOVEMBER 14, 1916, AT 17th AND E STS. N. W., WASHINGTON, D. C.

DESCRIPTION OF TEST FLOOR

1. *Design of Metropolitan Floor.*—The design of this type of floor is based primarily upon the employment of steel cables placed in tension in the form of a series of suspension members. These suspension strands are so placed between I-beam supports that when a superimposed load is placed on the floor surface the resultant stress is transmitted through the tension of the cables to the I-beams on each side of the floor panel. The composition of calcined gypsum and wood chips which forms the body of the floor is intended to be used in direct compression merely to transmit the superimposed load uniformly to the steel cables.

2. *Construction.*—The test floor was constructed October 20, 1916 (warm day, partly cloudy, mean temperature 72°F.), according to details shown on Exhibit No. 1, (figure 100), which details were followed closely. As shown on the above noted exhibit, the structure consisted of five spans of Metropolitan composition floor, eight feet wide, supported by six 12-inch, 28½ pound I-beams, which beams rested in two 8-inch brick walls, placed twenty feet between inside faces. The floor was constructed only eight feet wide, in order to permit of lateral observation of the behavior of the floor under the test loading.

The floor as constructed differed from the customary type of

Metropolitan floor construction, in that there were placed in each panel two 1¼-inch diameter iron pipes seven feet five inches long at the one-third points of the eight-foot floor section, parallel with the cables, normal to the webs of the I-beams, and on top of the transverse ⅝-inch rod. These pipes were installed to give stiffness to the I-beams, in order to counteract any overturning effect produced by the pull of the cables on

EXHIBIT 1

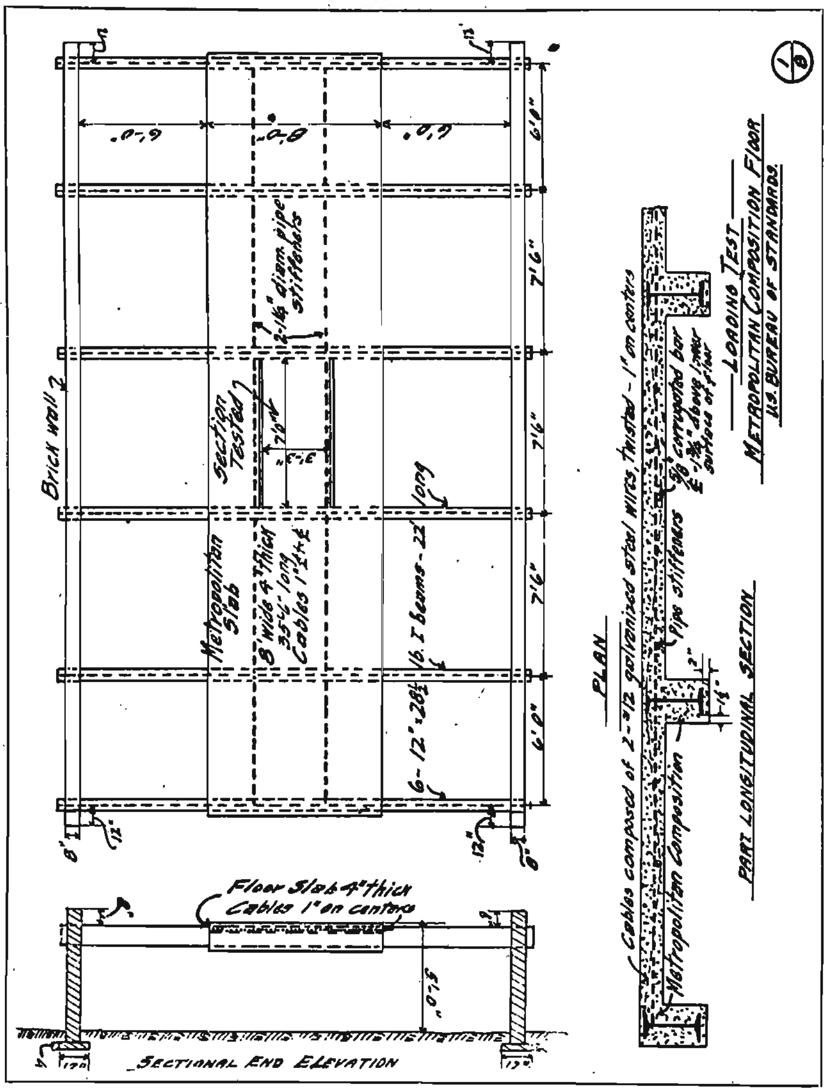


FIGURE 100

the top flanges of the I-beams. The builders' statement was to the effect that in the customary type of construction these pipes are not used, since the floor, being continuous for the full distance between the brick walls, gives the necessary stiffening or strut action.

Another exception to the customary installation consisted in the inability to place the cross rods in each panel as low as usually specified. Corrugated rods were used in place of the specified 5-8-inch diameter round rods (not obtainable at the time), and the corrugations had a tendency to cut the tie wires with which the cross rods were to be held down until the composition was placed. As a result of this difficulty the cross rods were placed with centers from 1¼ to 1¾ inches above the under surface of the floor slab instead of the specified distance of 1 inch. This misplacement of the cross rods shortens the effective depth of the cables below their points of suspension over the I-beams, and the builders state that the allowable live load is dependent directly upon this effective depth, and that consequently the slab as built, with the cross rod 1¾ inches above the underside of the floor, would have an allowable load of about 133 pounds per square foot instead of the specified 150 pounds per square foot.

The construction of the floor consisted of three operations, viz:

(a) Constructing the haunches or beam covering. This was effected by building forms around the webs and bottom flanges of all the I-beams and filling the forms with Metropolitan composition of a mushy consistency. This operation was completed in an hour, from 11 A. M. to 12 M.

(b) Stretching the cables and inserting cross rods, from 1 to 2:30 P. M. The cables were first stretched taut over the tops of the I-beams, being secured by S hooks of ¼ inch round steel to the outer edge of the top flanges of the two outermost beams. The center cross rod was then placed in each panel and brought down by means of tie wires to deflect the cables uniformly.

(c) Placing floor composition. Forms were built between the beams four inches below the top flanges and the composition of gypsum and wood chips was placed in these forms in a mushy condition and brought to a level of about ¼-inch above the top beam flanges.

The composition in the south panel was placed from 2:40 to 2:57 P. M. The balance of the panels were filled with the composition at an average rate of twenty minutes each. At 3:15 P. M. the south panel was firm enough to sustain a man walking on the surface, and from 3:17 to 3:25 all form work was removed from this section. At 3:30 P. M. 12 men of an average weight of 170 pounds stood in the center of the south panel, thus subjecting it to a load of about 85 pounds per square foot. The forms were removed from all sections of the floor by 4:35 P. M.

3. *Size of Test Panel.*—The section of the floor which was loaded for test consisted of a strip three feet four inches wide along the longitudinal center line of the center span, thus giving a section 7 by 3.33 feet supported at two ends. This size section was chosen because of the size of iron ingots available for producing the load. The loading material consisted of cast iron elevator weights approximately four by six by thirty-nine inches in size. A slot was made about ¾ inch wide on each side of the test slab the full depth of the floor in order to free the slab from any side friction on the balance of the floor.

4. *Age and Seasoning of the Test Slab.*—The floor was loaded for test November 14, 1916, the floor when tested being then twenty-five days old. The floor was constructed in the open air and seasoned through a period of rather cool weather with light rains for three days previous to the test. Tar paper shelters were used to protect the floor from precipitation and for a period of 4½ days previous to the loading of the slab the floor was heated with two salamanders under the center span. These salamanders maintained a temperature of 120 degrees F. under the structure.

5. *Loading the Floor for Test.*—The iron ingots described above were placed on the test slab at right angles to the slab center line in layers of ten weights each, producing load increments of approximately eighty pounds per square foot. Approximately twenty-five minutes to an increment were consumed in placing the load on the floor. The individual ingots were weighed and their respective weights recorded. Care was

taken to leave space between adjacent weights in each layer to avoid any arching action in the load. Four load increments were placed on the slab, producing a total load of 322 pounds per square foot, which was a little in excess of twice the original computed allowable working live load. Deflection measurements were made on the slab and the two supporting I-beams for each increment of load. The total load was then removed and at the end of thirty-five minutes measurements were again made to determine the recovery of the slab and the various members. The floor was next loaded to 726 pounds per square foot and deflection measurements were again made. This load of approximately five times the allowable live load was left in place seventeen hours until the morning of November 15, at which time the fatigue of the floor was determined. In an endeavor to destroy the slab the loading was continued to 1,040 pounds per square foot, and the resulting deflections noted. The total load was finally removed and the recovery of the slab again determined.

6. Instruments.—Determinations were made of the deflection of the slab at its center point, the deflection of the supporting beams, the settlement of the brick walls, and the stretch produced in various steel cables, figures shown in Tables I, II and III, Exhibit 2 (figure 101).

The deflectometer used at the center of the slab (point G on Exhibit No. 3, figure 102) consisted of an Ames dial gauge working between two steel rods. The dial was suspended vertically by an adjustable and graduated steel rod from the under side of a two by eight inch timber placed edgewise horizontally five feet above the center of the test slab. This timber was supported by two A frames twenty feet apart. The piston of the gauge worked in contact with the upper end of a vertical steel rod fastened by means of a flanged socket to the upper surface of the test slab at its center point. The dial was placed in compression with no load on the slab and when the load increments caused the floor to deflect, the pressure on the gauge piston was gradually released and the lowering of the center point of the slab was indicated on the dial.

The deflection of the supporting beams at their middle points was determined by measuring with an inside micrometer caliper between the under side of the bottom beam flange and the end of a steel rod held vertically in a steel tripod resting on a concrete platform 30 inches square built temporarily on the ground. These measurement points are shown at B and E on Exhibit No. 3 (figure 102).

EXHIBIT 2

TABLE I.

Superimposed Load lbs. per sq. ft.	Mean Wall Settlement Inches	Mean Beam Deflection Inches at Middle		Deflection of Slab Inches at Center	
		Indicated	Net	Indicated	Net
80	0.004	0.028	0.024	0.205	0.177
161	0.012	0.074	0.062	0.455	0.381
241	—	—	—	0.787	—
322	0.030	0.166	0.136	1.051	0.885
00 (Load Removed)	0.000	0.000	0.000	0.199	0.199
322	0.032	0.168	0.136	1.100	0.964
483	0.035 *	0.248 *	0.213 *	1.959	1.711
645	0.040 *	0.328 *	0.288 *	2.964	2.636
726	0.043	0.371	0.328	3.790	3.419
726 (17 hours)		0.373		4.920	4.547
1040				5.750	
00				3.690	

TABLE II.

Load lbs./sq. ft.	Wall Settlement in Inches					Deflection of Beams Inches at Middle		
	A	C	D	F	Mean	B	E	Mean
80	0.006	0.006	0.005	0.000	0.004	0.026	0.029	0.028
161	0.014	0.014	0.012	0.006	0.012	0.076	0.072	0.074
322	0.028	0.031	0.029	0.031	0.030	0.172	0.159	0.166
00	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000
726	0.040	0.045	0.041	0.045	0.043	0.398	0.344	0.371

TABLE III

Stretch in Cables on Spans of 20 Inches

Load lbs./sq. ft.		Span Numbers								
		1	2	3	4	5	6	7	8	9
80	Inches	0.0006	0.0008	0.0000	0.0016	0.0012	0.0026	0.0033	0.0027	0.0051
	%	0.0030	0.0040	0.0000	0.0080	0.0060	0.0130	0.0165	0.0135	0.0255
161	Inches	0.0036	0.0053	0.0020	0.0059	0.0039	0.0051	0.0063	0.0045	0.0126
	%	0.0180	0.0265	0.0100	0.0295	0.0195	0.0255	0.0315	0.0225	0.0630
322	Inches	0.0135	0.0175	0.0106	0.0159	0.0122	0.0135	0.0149	0.0131	0.0269
	%	0.0675	0.0875	0.0530	0.0795	0.0610	0.0675	0.0745	0.0655	0.1345
00	Inches	0.0042	0.0053	0.0020	0.0026	0.0006	0.0067	0.0016	0.0022	0.0051
	%	0.0210	0.0265	0.0100	0.0130	0.0030	0.0335	0.0080	0.0110	0.0255

* Values interpolated from Curves I & II

— LOADING TEST —
METROPOLITAN COMPOSITION FLOOR
U.S. BUREAU OF STANDARDS

3/8

FIGURE 101

The same type instrument was used to determine the settlement of the brick walls, measurements being made between the upper end of a similar vertical steel rod and the under side of the bottom flange of the beam at a point five inches in front of the inside face of the brick wall in each case. These measurement points are shown at A, C, D, and F on Exhibit No 3 (figure 102).

EXHIBIT 3

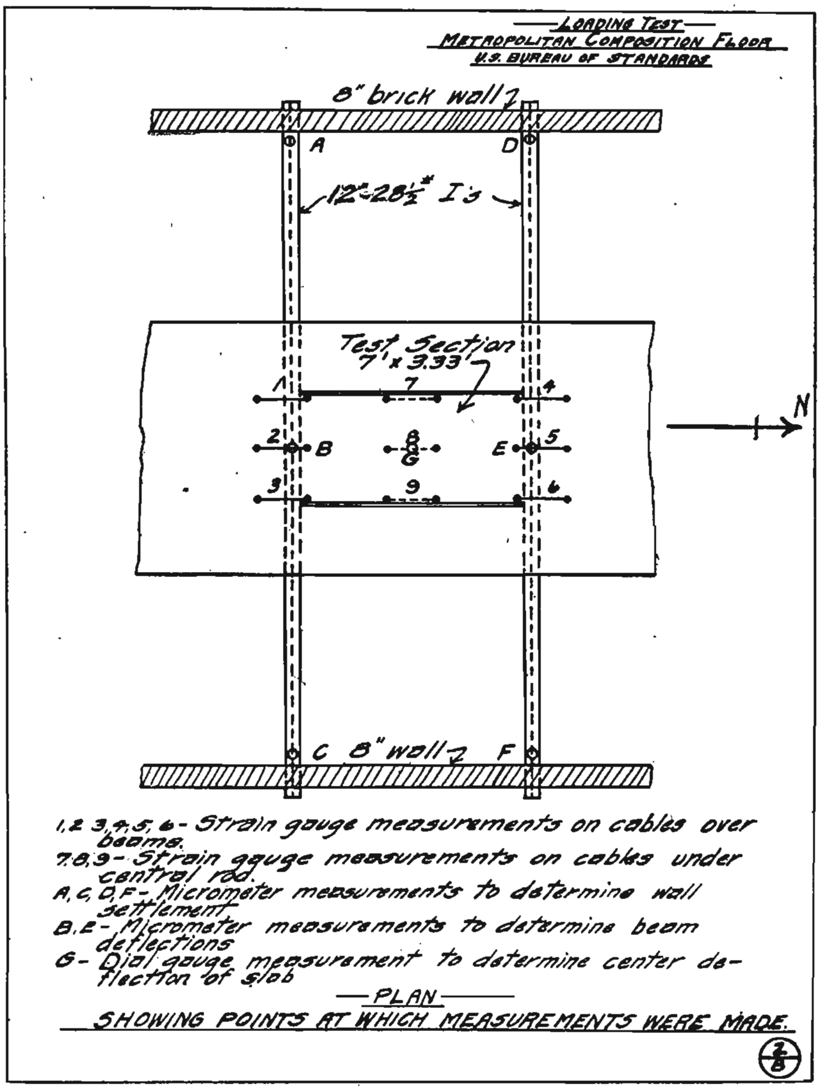


FIGURE 102

At points 1 to 9 inclusive, shown on Exhibit 3 (figure 102), determinations were made of the stretch produced in various cables. Holes were drilled in the composition to expose two points twenty inches apart on each of the cables measured. At

EXHIBIT 4.

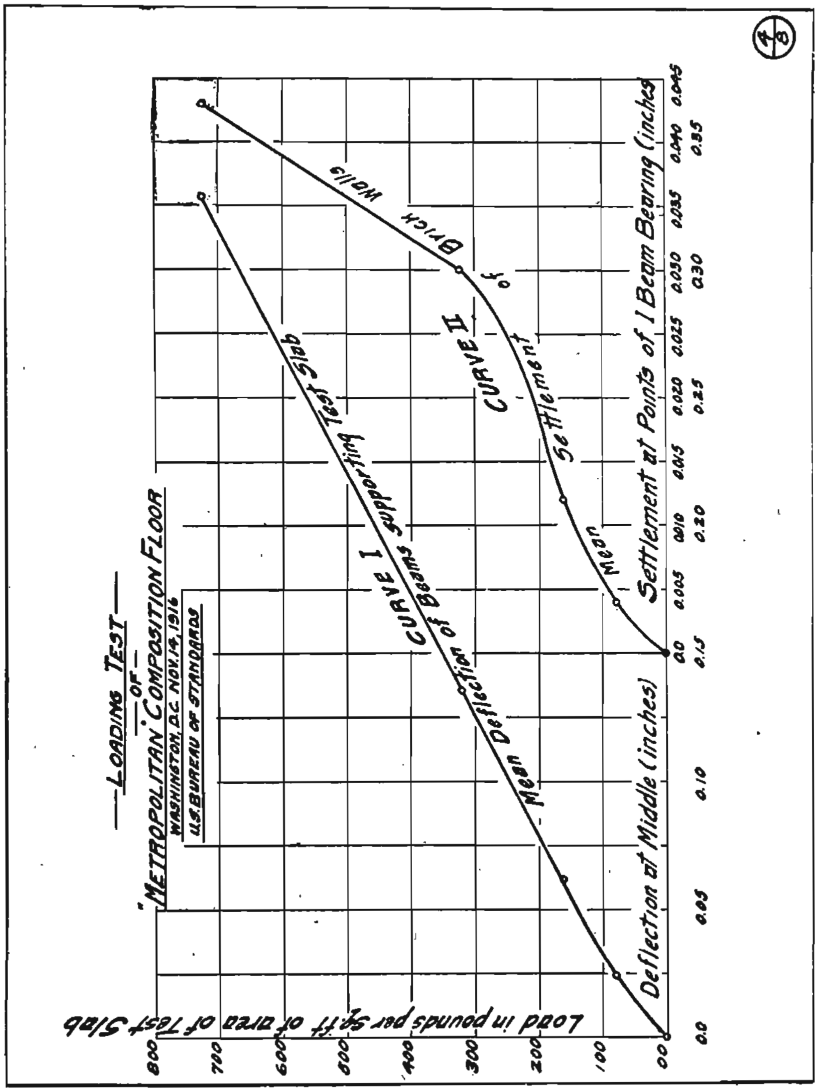


FIGURE 103

these exposed points double-screwed clips were attached to the cables. These clips were fitted with counter-sunk holes of size suitable to seat the points of a 20-inch Berry strain gauge, which instrument indicated the elongation between clips as the load was applied. These clips were so placed as to grip firmly both wires in each cable measured, thus assuring that the double wire acted as a unit.

EXHIBIT 5.

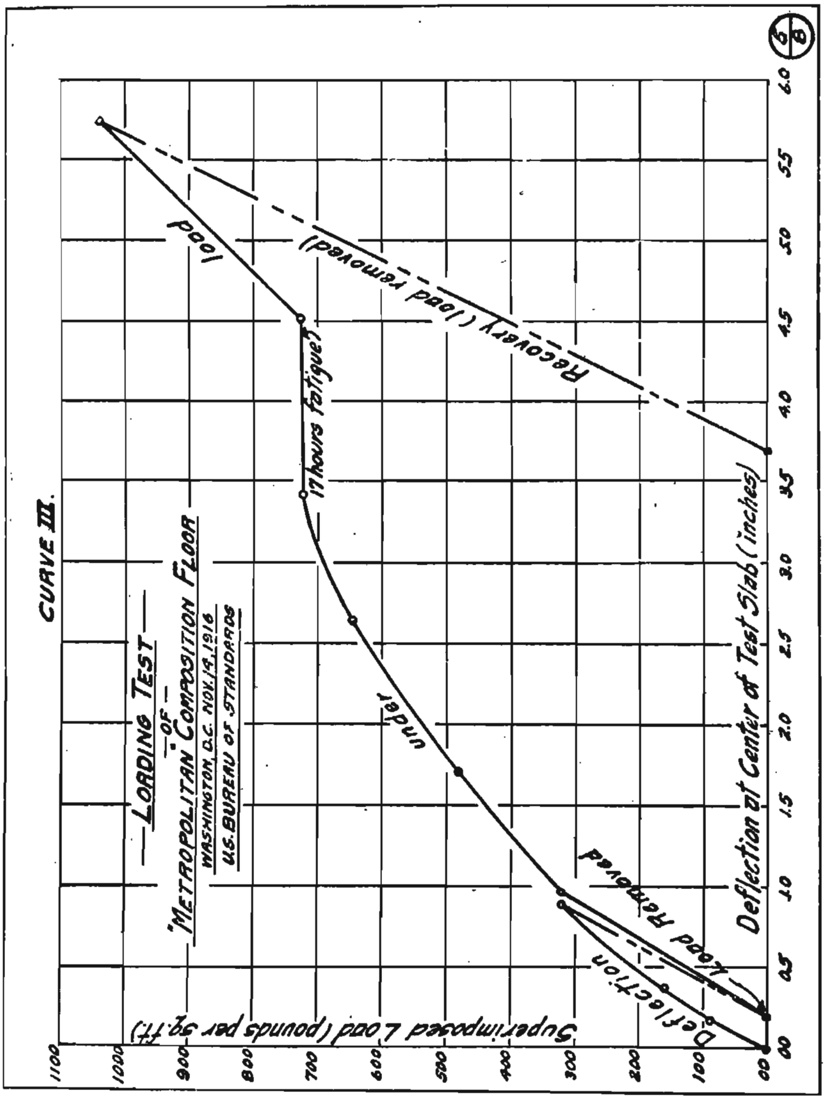


FIGURE 104

7. *Measurements of Deformation.*—As the various load increments were applied to the floor, determinations were made of the center deflection of the test slab, the middle deflection

of the two beams which supported the test section, the settlement of the brick walls at the points at which the supporting I-beams rested on the walls, and the elongation of the steel cables at nine points. The results of these measurements are shown in Tables I, II, and III, Exhibit 2 (figure 101).

In curves I and III, Exhibit 4 (figure 103), are plotted respectively the mean deflection of the supporting beams and the mean settlement of the brick walls. These values are used in making allowance for external influence in computing the net deflection of the floor from the values indicated by the deflectometer G.

The net deflection of the test slab is shown graphically in curve III, Exhibit 5 (figure 104). As indicated on this curve, at a load of 322 pounds per square foot, or somewhat more than double the allowable live load, the floor deflected 0.885 inch. When the load was removed and the floor allowed to stand free for thirty minutes, the floor returned to within 0.199 inch of its original unloaded position. Applying the load a second time caused a center deflection in the floor of 0.965 inch at a load of 322 pounds per square foot, which would seem to indicate a fatiguing action in the slab. With a load of 726 pounds per square foot, or approximately five times the allowable live load, the floor deflected 3.419 inches and leaving this load in place for seventeen hours caused a fatigue of 1.128 inches in the slab. Applying a load of 1,040 pounds per square foot deflected the floor 5.75 inches at the center. The steepness of curve III between these last two load points is probably attributable to the fact that at this stage of the loading the deflection of the floor was sufficient to lower the cables in the floor to a point where they were placed in practically direct tension and consequently the section of the curve mentioned above represents simply a tension deformation of the steel cables. When the total load was removed, the floor returned to a point 3.69 inches below its original unloaded position.

In curves IV (1 to 9), Exhibit 6 (figure 105), are shown the per cent elongation produced in the cables at six points spanning the supporting I-beams and at three points spanning the middle of the test slab. As shown on the curves, the stretch in the cables at the middle of the span was in general greater than at the points over the I-beams. This is especially noticeable in the early stages of loading.

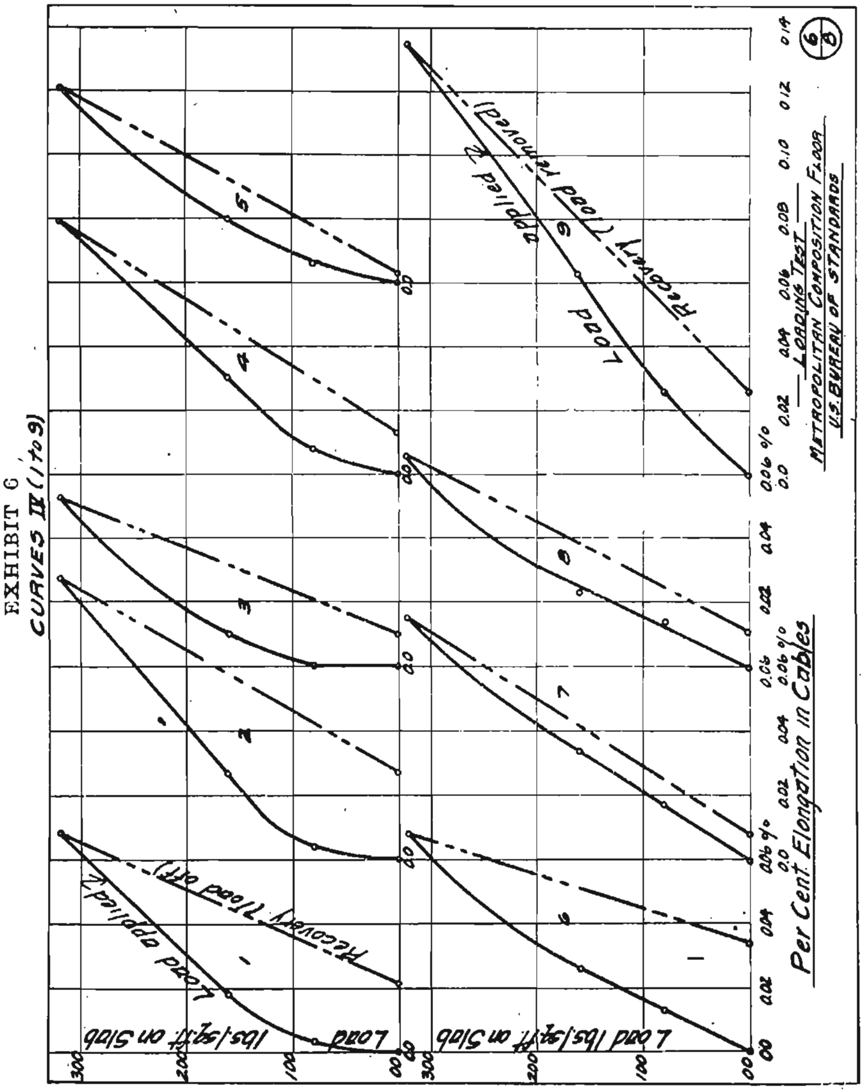


FIGURE 105

It could not be definitely ascertained as to whether spans 1, 7, and 4; 2, 8, and 5; and 3, 9, and 6 were in each case three spans on a common cable. However, these measurements were made on cables which were fairly representative of the wires at the three respective points. In curve 3 is a peculiarity in that no elongation was apparent for the first increment of

EXHIBIT 7

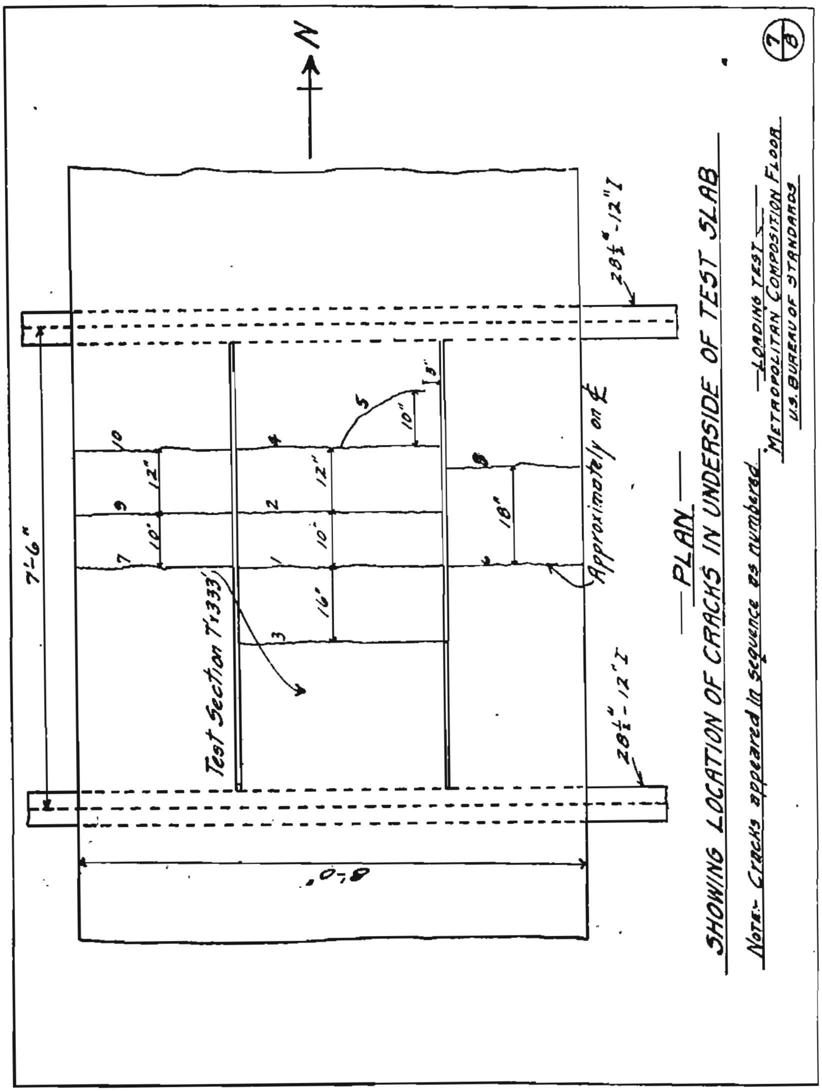


FIGURE 106

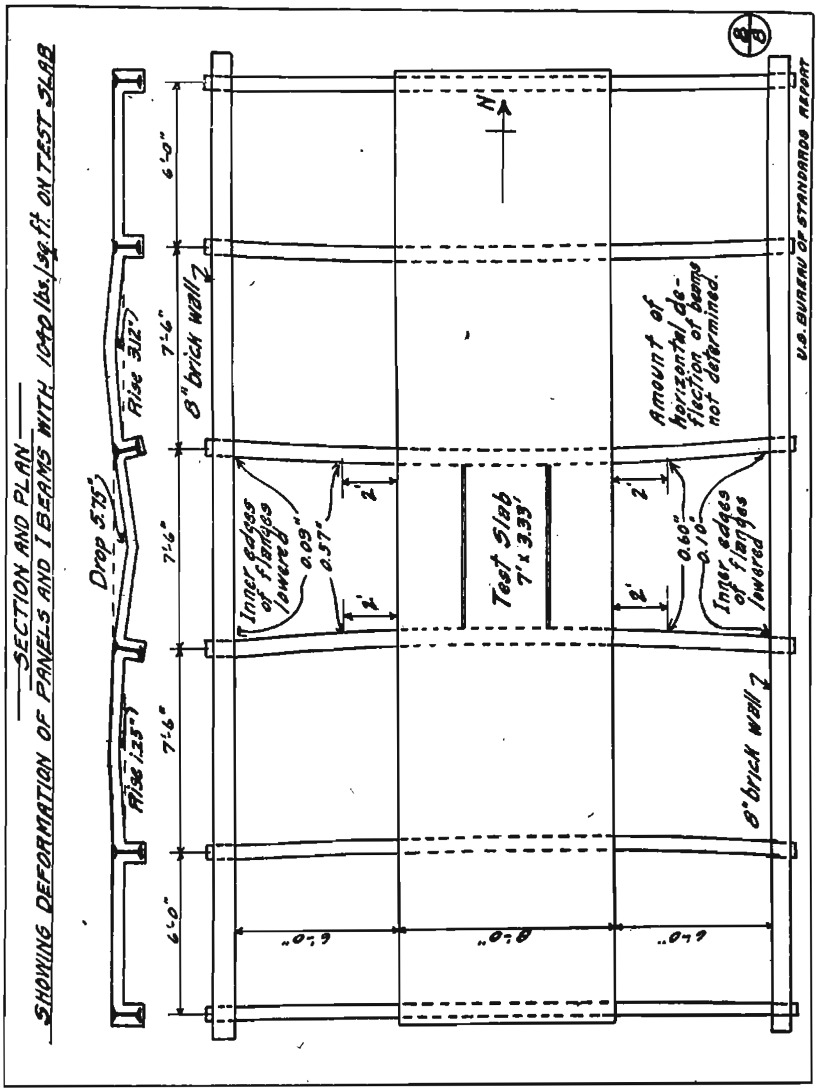
load. This may be due to the fact that some of the cables installed had slight irregularities or kinks in them. If this cable was in such a condition, it is evident that the kink would straighten out before direct tension would be noticeable in the span measurement.

8. Observations.—On Exhibit No. 7 (figure 106), are shown the location of cracks as they appeared in the underside of the floor. Cracks 1, 2, 3, 4 and 5 appeared as fine hair cracks at a load of 322 pounds per square foot. After the removal of this load the cracks closed and practically disappeared, showing considerable elasticity in the body of the floor. At a load of 726 pounds per square foot these three cracks opened about one-sixteenth inch and cracks 6 and 7 appeared as fine lines on the surface. After seventeen hours cracks 6 and 7 had opened about one-eighth inch, 1 to 5 had opened about three-eighths inch, and cracks 8, 9, and 10 had formed one-sixteenth inch open. When the floor was loaded with 1,040 pounds per square foot cracks 1 to 5 opened to five-eighths inch and cracks 6 to 10 about three-eighths inch.

There was very little spalling of material from the underside of the floor, and most of the cracks formed practically parallel to the I-beams. Although cracks 6 to 10 were not in the actual test slab, they are of interest in that they show presence of a thrust action along the upper surface of the floor on both sides of the test section. This thrust was due to the overturning of the beams, as shown on Exhibit No. 8 (figure 107).

With the load of 726 pounds per square foot in place for thirty minutes an arching action commenced in the two panels adjacent to the test section, the panel on the south rising three-eighths inch at its center and the panel on the north rising three-fourths inch at its center. After seventeen hours these distances increased to three-fourths inch and two inches respectively. With the load of 1,040 pounds per square foot in place, these rises increased to 1¼ inches and 3⅛ inches, as shown on Exhibit No. 8 (figure 107). These measurements were made with a steel scale and not by means of a micrometer caliper. The extreme end panels showed no arching action, although there was a slight horizontal deflection of the outside I-beams. The four inner I-beams suffered a more perceptible horizontal deflection, the south beams deflecting less than those to the north. After the removal of the total load the four outermost I-beams returned to practically their original straight condition, but the two beams supporting the test slab suffered a permanent distortion.

EXHIBIT 8



SECTION AND PLAN

SHOWING DEFORMATION OF PANELS AND I BEAMS WITH 1040 lbs./sq.ft. ON TEST SLAB

FIGURE 107

9. *Condition of Structure after Test.*—Two days after completion of the loading test sections thirty inches square were cut out from the center and ends of the test panel and from

the center of each of the other four panels. In the section taken from the test panel and the two adjacent panels there was no sign of the cables or cross rods having cut through the gypsum composition, the cross rods still being apparently the same distance above the bottom of the floor as when first measured, shortly after the floor was built. This was rather substantiated during the load test by the fact that when the cables in the panels adjacent to the test panel straightened horizontally under tension the slabs arched up, thus leaving the upper surface of the slabs in practically the same position relative to the cables and cross rods.

The cables in the various cut-out sections showed considerable rigidity or bond when jerked or shaken by means of a pair of pliers applied at alternate exposed sections three inches long, separated by sections three inches long, in which the cables were left covered with the composition. However, since, as noted above, there was an apparent horizontal tightening of the cables in the two slabs adjacent to the test panel there must have been a movement of the cables horizontally over the top flanges of the I-beams.

Laboratory tests are to be made of the ultimate crushing strength, the modulus of elasticity, and the bonding strength of the gypsum composition used in the floor.

Respectfully,
E. B. Rosa, *Acting Director.*

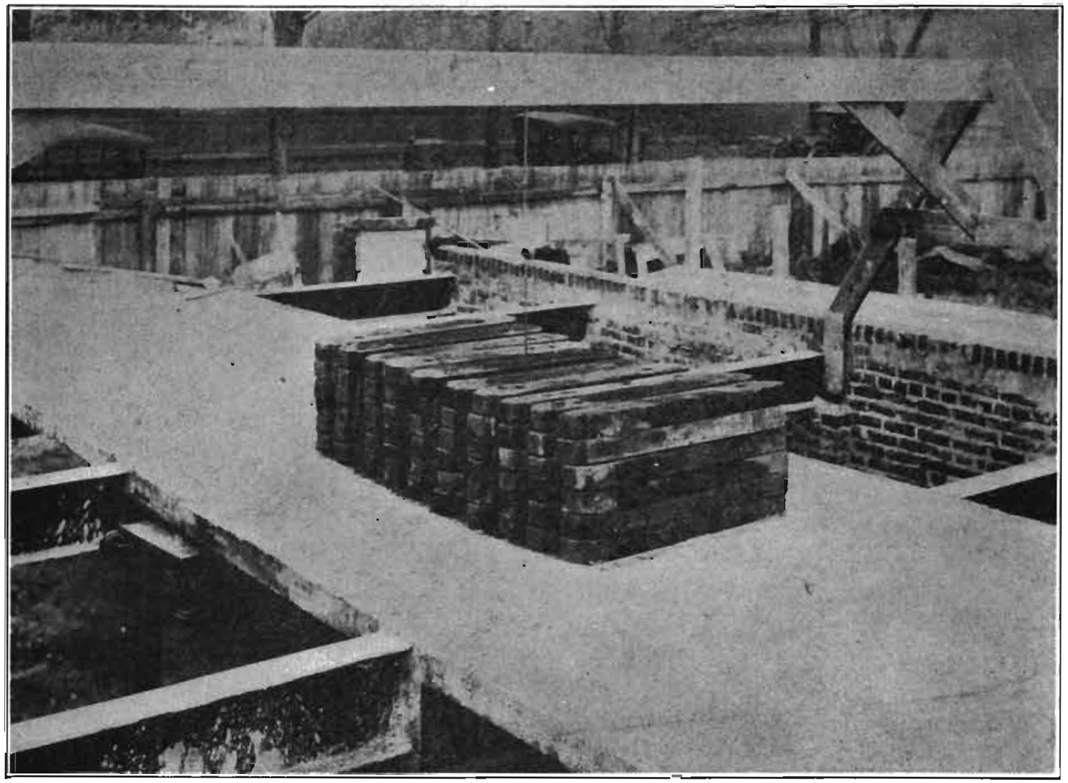


Photo showing the method of loading the gypsum roof in the tests described in text.

APPENDIX VII

EMLEY PATENT FOR PLASTIC GYPSUM

SPECIFICATIONS

To all whom it may concern:

Be it known that I, Warren E. Emley, a citizen of the United States, residing at Washington, in the District of Columbia, have invented new and useful improvements in the process of making plastic calcined gypsum, of which the following is a specification:

This application is filed under the Act of March 3, 1883, under the terms of which the applicant agrees that the invention described herein, if patented, may be used by the Government or any of its officers or employees in prosecution of work for the Government, or by any other person in the United States without the payment to him of any royalty thereon.

Calcined gypsum, or plaster of Paris, is a chemical compound of the formula $CaSO_4 . \frac{1}{2}H_2O$. It is of crystalline structure and sandy character. Because of this characteristic, calcined gypsum cannot be used alone for the white or finishing coat of plaster: the plasterer is not physically able to spread it. For the same reason, not more than two or three parts (by weight) of sand may be added to it in the preparation of the scratch or brown coats of plaster. This characteristic is described in the trade as "non-plastic".

It is quite possible to make a material sufficiently plastic for white coat work from calcined gypsum by the addition of other materials. It is known, for instance, that the addition of molasses, of certain other organic materials, or of loamy sand, will improve the plasticity of the calcined gypsum. In the 1919 Tentative Report on Gypsum Plasters, issued by the American Society for Testing Materials, it is stated that a neat gypsum plaster may contain up to 15 per cent of "hydrated lime, ground clay, asbestos, retarder, or fibre". In the 1920 report, this was changed to permit the addition of 15 per cent of "materials to control the working quality, setting time and fibering". It is general trade practice to add hydrated lime to calcined gypsum in the manufacture of neat gypsum plaster. In the 1919 report quoted above, it is recommended that plaster for white coat work be composed of 75 per cent lime putty and 25 per cent calcined gypsum. Practically all white coat plaster is composed of these two ingredients, although the proportions of them are variable.

If calcined gypsum is ground after calcination, one of two things may occur: If the grinding is not severe, the crystals will be reduced in size, but the sandy or non-plastic nature of the material will still remain. If the grinding is very severe, a chemical change can be made to occur, the water being actually ground out of the material. In actual practice, a buhr mill or tube mill is used for this grinding, and any water which is liberated is evaporated and carried off by the current of air passing through the mill. The resultant product is known as "soluble anhydrite". This is anhydrous calcium sulphate, but it differs from the naturally occurring anhydrite in that it has a great affinity for water. So great is this affinity that a few moments exposure to moist air is sufficient for it to recombine with enough water to change back to the original calcined gypsum. Because of this fact, and also because the soluble anhydrite is itself crystalline, the effect of this severe grinding is lost, and the product is still non-plastic. Commercial gypsum plasters consist mostly of calcined gypsum, with more or less soluble anhydrite and undecomposed gypsum.

I find that if calcined gypsum is ground severely so as to liberate the water, but in such a way that the water cannot escape, the resultant product has radically different properties. It is now plastic, rather than non-plastic. This can be proved by testing the material by means of the Carson blotter test as described in the Transactions of the National Lime Manufacturers Association, 1916, p. 175, or by means of a plasticimeter. It can be used alone as the white coat of plaster, and can be used with at least six parts (by weight) of sand for the scratch or brown coats. When compared with the original material, it will be found that it requires more water to mix it to a given consistency, that it sets more slowly, and that it will develop higher strength after setting. To use this material as a wall plaster, it will, of course, be necessary to retard it, using for this purpose the ordinary reagents which are used in the manufacture of wall plaster from calcined gypsum.

If it is not practicable to grind the calcined gypsum in such a way as to prevent evaporation of the liberated water, the same end can be attained by adding, either before or during the grinding, enough water to make up for the quantity evaporated, so that the final product will contain approximately one molecule of water to two molecules of calcium sulphate.

At a meeting of Committee C-7 on Lime, of the American Society for Testing Materials, held on January 12, 1821, directions were adopted for the use of the plasticimeter described in Bureau of Standards Technologic Paper No. 169, and for the calculation of "plasticity figures". It was also decided that a lime putty, to be satisfactory for finishing purposes (white-coat work) must have a plasticity figure of not less than 200.

This plastic calcined gypsum may be produced from substances other than calcined gypsum. The same end product will result if raw gypsum is ground in such a way that some, but not all, of its water is allowed to escape; or if the requisite proportion of water is ground into anhydrite, either soluble or natural.

Specifically, I find that if calcined gypsum is ground in a ball mill or similar sealed container, with such severity as to liberate the water of crystallization, the resultant product will be at least as plastic as "finishing" hydrated lime. This grinding may be either in addition to or in lieu of the usual grinding which is a part of the regular process of manufacture of calcined gypsum. The duration of the grinding, which determines the plasticity of the finished product, depends upon the quality (fineness) of the original material, and also upon the size of the mill. In a small laboratory mill, it required seven hours to produce one pound of material of the desired plasticity; in a larger mill, it required four hours for eighty pounds of material. I find that plastic calcined gypsum can be made by this method from calcined gypsum from any source, and that storage for four months does not cause any noticeable deterioration of its plasticity.

While it is true that in the academic sense all plastering materials, and even sand itself, have a measurable degree of plasticity, in the practical use of the word, a material is not considered plastic unless it has a certain minimum degree of plasticity. In the subjoined class the word "plastic" is taken to agree with the practical definition. That is to say, a material is plastic only when it can be used alone for the white coat of plaster. This degree of plasticity is readily ascertained by means of the Carson blotter test, or by means of the plasticimeter. When the latter instrument is used, the material is plastic only when the plasticity figure is greater than 200.

I claim:

1. The process of increasing the plasticity of calcined gypsum which comprises the grinding of the calcined gypsum and preventing evaporation of its water content.

2. The process of increasing the plasticity of calcined gypsum which comprises grinding the calcined gypsum in the presence of its water content.

3. The process of increasing the plasticity of calcined gypsum which comprises grinding the calcined gypsum to eliminate its water content only during the grinding operation.

4. The process of increasing the plasticity of calcined gypsum which consists in grinding the calcined gypsum to eliminate the water content during the grinding operation, preventing the escape of the said water content during the grinding step, and continuously keeping the above treated gypsum in contact with the water thus eliminated, ceasing the grinding operation, and permitting the water thus eliminated to be reabsorbed.

5. The process of increasing the plasticity of calcined gypsum which comprises grinding the calcined gypsum, with the addition, before the grinding operation, of enough water to make up for that lost by evaporation, during the grinding.

6. The process of increasing the plasticity of calcined gypsum which comprises grinding the calcined gypsum, with the addition, during the grinding operation, of enough water to make up for that lost by evaporation during the grinding.

7. A plastic calcined gypsum which is sufficiently plastic to be used without added ingredients for the white coat of plaster.

8. A plastic calcined gypsum which, when properly retarded, will give a plasticity figure of at least 200.

9. A plastic calcined gypsum having a plasticity figure of at least 200, the plasticity of which is not dependent upon the addition of any foreign material.

10. A plastic calcined gypsum having a plasticity figure of at least 200, the plasticity of which is not dependent upon the addition of lime.

In testimony whereof, witness my signature this day of February, 1921.

APPENDIX VIII.

TENTATIVE REPORT ON DESIGN OF REINFORCED GYPSUM BEAMS.[249]

The following recommendations are intended to apply to the design of simple beams of reinforced gypsum.[250]

It is assumed that:

1. The loads designed for are the weight of the structure and the static live loads.
2. The span length effective in causing moment is the distance between centers of supports.
3. Calculations will be made with reference to working stresses and safe loads for dry gypsum rather than with reference to ultimate strength and ultimate loads.
4. A plane section before bending remains plane after bending.
5. The modulus of elasticity of the gypsum is constant up to the ultimate load.
6. The ratio of the modulus of elasticity of steel to the modulus of elasticity of gypsum is 30.
7. In calculating the moment of resistance of beams the longitudinal tensile strength of the gypsum is neglected.
8. Initial stress in the reinforced gypsum due to the expansion or contraction of the gypsum is neglected. The cross-sectional area of gypsum effective in resisting the bearing pressure applied to it by the anchoring of the reinforcing bars is the projection of the anchor (either a hook or a plate) on a plane normal to the longitudinal axis of the beam.

It is recognized that the assumptions given are not entirely borne out by experimental data. They are given in the interest of simplicity and uniformity, and variations from exact condi-

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[249] Republished from
Proceedings of the American Society for Testing Materials,
Philadelphia, Penna.
Volume XIX, Part I, 1919.

[250] It is impossible within the scope of this report to give data on which the recommendations for design are based. The bibliography at the end of this report contains references to published literature supporting the report.

tions are taken into account in the selection of formulas and working stresses.

9. Reinforced gypsum as herein provided applies only to interior construction and to protected exterior construction.

10. Reinforced gypsum when used either in interior or protected exterior construction will be permitted to dry out as quickly as possible after hardening.

Tension and Compression.—The tensile stress in the reinforcement should not exceed 16,000 lb. per sq. in.[251].

The maximum compressive stress in a gypsum beam should not exceed 22 per cent of the ultimate compressive strength of the dry gypsum[252] to be used in the construction under consideration, when tested as a cylinder whose height is twice its diameter, and should not exceed 44 per cent of the ultimate strength of the gypsum when saturated[253] with water.

Modulus of Elasticity.—Results of tests indicate that the modulus of elasticity of dry gypsum is nearly constant up to the ultimate strength of the gypsum and that for saturated gypsum the stress-strain diagram approaches a parabola whose vertex is at the point representing the ultimate strength.

An approximate value of the modulus of elasticity for dry gypsum cast from a mixture of normal consistency is 1,000,000 lb. per sq. in.

Computations of stress in reinforced beams using such gypsum should be made on the basis of a ratio of $\frac{E_s}{E_g}=n=30$ for dry gypsum. No recommendation is made for beams using a gypsum mixture of other than "normal consistency." (See Tentative Methods for Tests of Gypsum and Gypsum Products).

Bond Strength, Bearing Strength, and Diagonal Tensile Strength.—Bond strength, bearing strength against anchor

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[251] This recommendation is the same as has been adopted by the Joint Committee on Concrete and Reinforced Concrete for tension in steel in reinforced-concrete beams. *Proceedings*, Am. Soc. Tst. Mats., Vol. XVII, Part I, pp. 202 ff. (1917).

[252] The term "dry gypsum" is used here to mean hydrated gypsum from which all water, except that which is combined as water of crystallization, has been evaporated. Drying the specimen to constant weight in air having a temperature of 70° F. and a relative humidity of 50 per cent will produce "dry gypsum." Committee C-11 will later prepare a specification to which reference will be made.

[253] The term "wet" or "saturated," as herein used, refers to hydrated gypsum which after being dried (as specified) has been immersed in water to complete saturation but not longer than one hour. (See Tentative Methods for Tests of Gypsum and Gypsum Products (Serial Designation: C 26–19 T) of the American Society for Testing Materials).

hooks or plates, and diagonal tensile strength of reinforced gypsum beams are so closely interrelated that they are discussed under one head.

Any provision which helps to prevent slipping of the reinforcing bars increases so markedly the diagonal tensile strength of a beam that mechanical anchorage at the ends of reinforcing bars should be used in all cases except those in which the bond stress and the diagonal tensile stress to be resisted are very small.

It may be assumed as a basis for design that when effective mechanical anchorage is furnished, the bond stress actually developed at any point along the bar is one-half of that computed on the basis of pure beam action, and that the remainder of the resistance is furnished by the truss action developed by anchoring the bars.

Test results on beams with anchored bars indicate that at the maximum load only about one-half of the tension in the reinforcing bars is developed by bond and that the remainder is developed by the anchorage of the bars.

It is recommended that the allowable working bond stress as computed by Eqs. 9 and 9 (*a*), given in percentage of the compressive strength of the hydrated gypsum to be used in the construction, be not more than 1 per cent in case mechanical anchorage is not furnished, nor more than 5 per cent in case mechanical anchorage, conforming with the requirements hereinafter stated, is furnished.

Test results indicate that truss action in the beam due to anchorage of the bars comes into existence early in the test. They indicate also that there is little difference in the effectiveness per square inch of the bearing area of the anchorage whether the anchorage be furnished in the form of U-hooks at the ends of bars or in the form of bearing plates rigidly attached at their centers to the reinforcing bars. Assuming that the effectiveness is the same for the two cases the average bearing unit pressure may be considered a measure of the value of the anchorage.

It is recommended that the allowable average bearing pressure to be used in determining the value of anchorage be taken as 40 per cent of the compressive strength of the dry hydrated gypsum to be used in the construction under consideration, or 80 per cent of the wet hydrated gypsum, and that Eqs. 10 or 11 be used for computing the bearing stress.

Test results have indicated a marked increase in the shearing strength of beams in which bars have been bent up for web reinforcement, over the strength of similar beams having no bars bent up.

It is recommended that the allowable working stress in shear, given in percentage of compressive strength of the dry hydrated gypsum to be used in the construction under consideration, be not more than 1.5 per cent for beams with no bent up bars but with or without mechanical anchorage at the ends of the bars, and 4 per cent for beams which have mechanical anchorage conforming to the recommendations in this report and which have bars bent up in conformity with the recommendations hereinafter specified.

In order that the working stresses in shear above named may be used in design:

(*a*) The angle Θ which the bent bar makes with the direction of the longitudinal axis of the beam should be not less than 18 nor more than 45 deg.;

(*b*) Except in cases of concentrated loading, one or more longitudinal reinforcing bars should be bent up at a section where the shearing unit stress is equal to or less than the allowable shearing stress for beams with no web reinforcement;

(*c*) In cases of concentrated loading where bending up of bars is necessary the distance between the load point and the first bend should not be greater than the depth of the beam, d;

(*d*) Proceeding from the point at which the first bar is bent up toward the end of the beam, other bars should be bent up at intervals not to exceed the distance s defined by Eq. 12.

(*e*) The distance from the last point of bending to the center of the support should be not greater than the distance s.

Between any section in the span and the section of zero shear the ratio of the total cross-sectional area of the bars bent up to the total cross-sectional area A_s should not exceed the value of $\frac{A_b}{A_s}$ given by Eq. 13 nor be less than the value given by Eq. 14.

One or more bars having a total cross-sectional area of not less than three-eighths of the total area, A_s, of the longitudinal reinforcement should extend throughout the length of the span in the bottom of the beam and these bars should have mechanical anchorage at their ends, except where the bond stress calculated by Eq. 9 is less than one per cent of the compressive strength of the gypsum.

The radius of bends except for U-hooks should be not less than $24a$.

The point of bending up is considered to be at the intersection of the axis of the inclined straight portion of the bar with the line parallel to the longitudinal axis of the beam and passing through the center of gravity of the longitudinal reinforcing area at the point of maximum moment.

NOTATION

The notation and equations used in computations for reinforced gypsum beams are the same as those recommended by the Joint Committee on Concrete and Reinforced Concrete to apply to corresponding terms and operations.[254] Modifications, additions, and omissions have been made where the two reports do not cover the same ground, but an attempt has been made to avoid conflict in the use of terms.

Definitions of all symbols used in the equations referred to and sketches illustrating their application are here given.

(*a*) *Dimensions and Angles.*

d = depth of beam to center of steel;
b = width of beam; for T-beams, width of flange;
b' = width of stem of T-beam;
jd = arm of resisting couple;
kd = distance from compression surface to neutral axis;
x = distance from section of zero shear to any section of the beam;
i = distance from section of zero shear to center of reaction of beam;
s = maximum allowable distance between points of bending up bars;

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[254] Loc. cit.

a = diameter of reinforcing bar;
h = width of U-hook;
o = perimeter of reinforcing bar;
Σo = sum of perimeters of all reinforcing bars in beam;
θ = the angle which the bent-up straight portion of the reinforcing bar makes with the longitudinal axis of the beam.

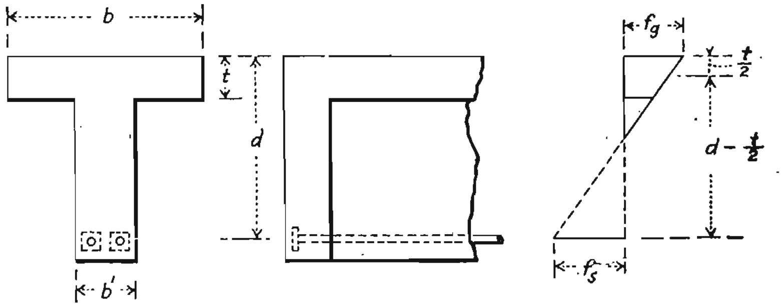

FIG. 108.

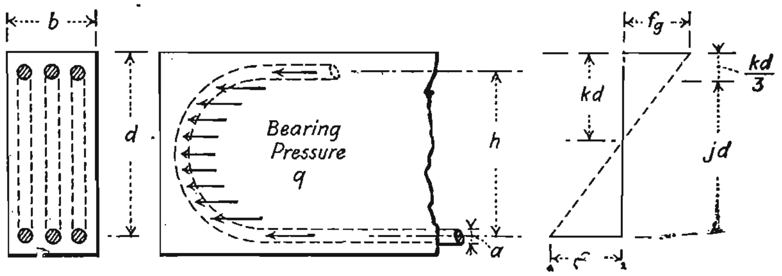

FIG. 109.

(b) *Areas.*
A_s = cross-sectional area of longitudinal reinforcement at point of maximum moment;
A_b = sum of cross-sectional area of bent-up bars between section of zero shear and any section at a distance x from the section of zero shear;
B = effective bearing area of anchor.

(c) *Moments, Stresses and Properties.*
M = bending moment or resisting moment;
f_s = tensile unit stress in steel;
f_g = compressive unit stress in gypsum;

f'_g = ultimate compressive unit strength of gypsum determined from 3 by 6-in. cylinders, or any other cylindrical test specimen whose height is twice its diameter;

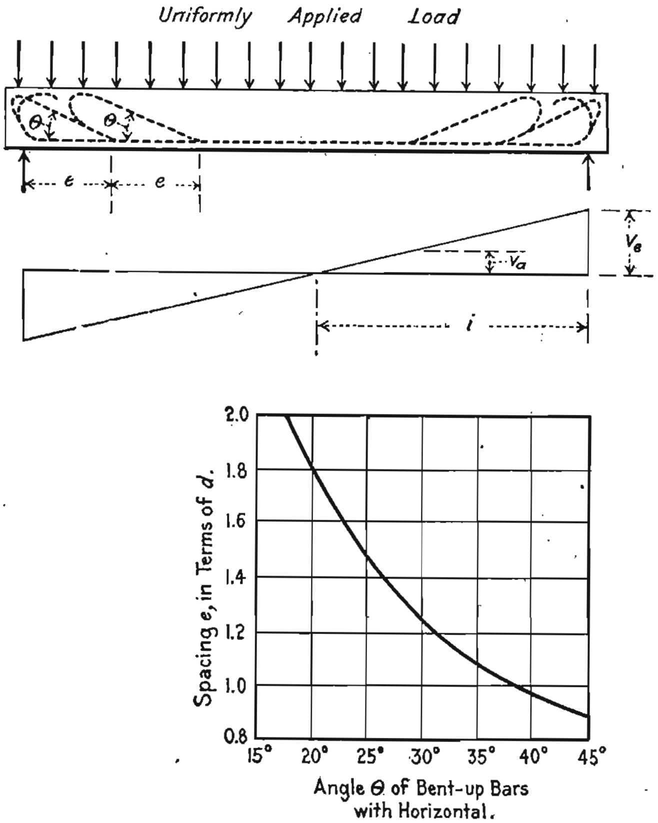

FIG. 110.—Curve showing spacing of bent-up reinforcement for various angles of bend, $e = \frac{0.62\ d}{\sin\ \theta}$ (See footnote to Eq. 12.)

v = shearing unit stress in gypsum;

v_a = allowable maximum shearing unit stress at reaction for beams without web reinforcement, or at first bend for beams with bent-up bars;

v_e = shearing unit stress at reaction of beam having bent-up bars;

u = bond unit stress between gypsum and steel;

q = bearing unit stress between gypsum and anchor;

E_s = modulus of elasticity of steel;
E_g = modulus of elasticity of gypsum.

(*d*) *Ratios.*

k = ratio of depth of neutral axis to depth d of beam;
j = ratio of arm of resisting couple of depth d of beam;
$n = \frac{E_s}{E_g}$, ratio of modulus of elasticity of steel to that of gypsum;
p = steel ratio $= \frac{A_s}{bd}$.

SUMMARY OF EQUATIONS FOR COMPUTATIONS FOR REINFORCED GYPSUM UNIFORMLY LOADED, SIMPLE BEAMS.

Rectangular Beams.

$$f_s = \frac{M}{A_s jd} = \frac{M}{pjbd^2} \tag{1}$$

$$f_g = \frac{2pf_s}{k} = \frac{2M}{kjbd^2} \tag{2}$$

$$v = \frac{V}{bjd} \tag{3}$$

$$k = \sqrt{2pn+(pn)^2}-pn \tag{4}$$

T-Beams.[255]

$$f_s = \frac{M}{A_s\left(d-\frac{t}{2}\right)} \tag{5}$$

$$f_g = \frac{M}{bt\left(d-\frac{t}{2}\right)} \cdot \frac{kd}{kd-\frac{t}{2}} \tag{6}$$

$$v = \frac{V}{b'\left(d-\frac{t}{2}\right)} \tag{7}$$

$$kd = \frac{2ndA_s+bt^2}{2nA_s+2bt} \tag{8}$$

Either Rectangular Beams or T-Beams

$u = \frac{V}{jd\Sigma o}$ (to be used when no anchorage is used) (9)

$u' = \frac{1}{2}\frac{V}{jd\Sigma o}$ (to be used when anchorage conforming with requirements is furnished) (9*a*)

$q = \frac{\pi a^2 f_s}{8B}$ (used when anchorage is furnished by means of plates rigidly attached at their center to the reinforcing bar) (10)

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[255] For all T-beams in which the neutral axis falls within the flange the equations will be the same as for rectangular beams except Eq. 7 for shear, in which for all T-beams the width b' of the stem should be used instead of the width b of the flange. Because of the low position of the neutral axis found with so high a value of n as 30 it will seldom be found that the neutral axis lies within the flange. For cases in which the value of p is less than 0.002 or in which t/d is 0.3 or more, the position of the neutral axis should be determined by means of the formula for rectangular beams. The substitution of $(d-t/2)$ for jd is an approximation giving errors of not more than about 2 per cent for the majority of cases. For more exact formulas for T-beams, reference is made to the Report of the Joint Committee on Concrete and Reinforced Concrete. *Proceedings*, Am. Soc. Test. Mats., Vol. XVII, Part I, p. 260 (1917).

$q = \frac{\pi f_s}{8} \frac{a}{h}$ (used when anchorage is furnished by means of U-hooks on the ends of the reinforcing bars) .... (11)

$$e = \left\{ \frac{2}{3 \tan \theta} + \frac{1}{2} \tan \theta - \frac{1}{6} \right\} d \qquad (12)$$[256]

$$\frac{A_b}{A_s} \substack{= \\ <} \left\{ \frac{x}{i} \right\}^2 \qquad (13)$$

$$\frac{A_b}{A_s} \substack{= \\ >} 0.7 \left\{ \left\{ \frac{x}{i} \right\}^2 - \left\{ \frac{v_a}{v_e} \right\} \right\}^2 \qquad (14)$$

SUMMARY OF PERMISSIBLE WORKING STRESSES AND CONSTANTS.

The working stresses are expressed in terms of the ultimate strength wet and of the ultimate strength dry. In all cases the lower of the two values should be used. Stresses and moduli are given in pounds per square inch.

f_s	16,000
f_g	0.22 f'_g (dry specimen) 0.44 f'_g (wet specimen)
v_a	0.015 f'_g (dry specimen) 0.030 f'_g (wet specimen)
v_e	0.040 f'_g (dry specimen) 0.080 f'_g (wet specimen)
u (for beams without anchorage)	0.01 f'_g (dry specimen) 0.02 f'_g (wet specimen)
u' (for beams with anchorage)	0.05 f'_g (dry specimen) 0.10 f'_g (wet specimen)
q	0.40 f'_g (dry specimen) 0.80 f'_g (wet specimen)
E_s	30,000,000
E_g (for dry hydrated gypsum from mixture of normal consistency)	1,000,000
n (for dry hydrated gypsum)	30

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[256] It has been found, upon further study, that Eq. 12 may be stated more simply as:

$$e = \frac{0.62\ d}{\sin \theta} \text{ (See Fig. 110.)}$$

The values of s as given by the two equations are approximately the same. However, the equation here proposed gives a slightly smaller maximum spacing than the first equation. The main advantage in the change is that of simplicity, and this advantage is considerable. With the second equation the distance between bent-up bars measured at right angles to their direction is held constant at 0.62*d*.

EXPLANATON OF FIGURE 111.

The upper curve of Figure 111 (the graph of Eq. 13) is a parabola with its vertex at the lower left-hand corner of the diagram. Taking the bottom of the beam as drawn, as the zero line, the parabola may be used to represent a moment curve for the beam under uniform load. Therefore, the vertical distance from the bottom of the beam to the curve at any point will be proportional to the area of longitudinal reinforcement required at that point, and the vertical distance to the curve from the horizontal line tangent to it at its vertex will be proportional to the total amount of reinforcement which may be bent up for web reinforcement between the center of

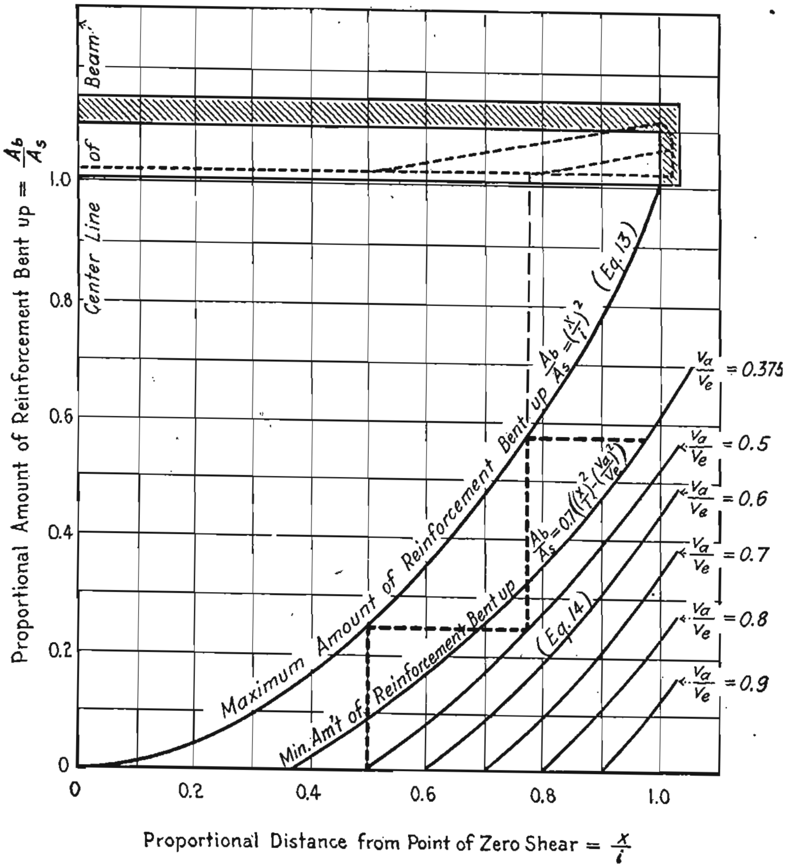

FIG. 111.—Curves showing maximum and minimum amounts of bent-up reinforcement. These curves are graphs of Eqs. 13 and 14, as indicated.

the span (or the point of zero shear) and the point considered. Therefore this parabola represents the maximum amount of reinforcement which may be bent up.

The other curves on the sheet represent the minimum amount of reinforcement which must be bent up for different designs in which the end shear varies from the maximum allowable amount ($0.04f'_g$) to the lowest for which web reinforcement is required ($0.015f'_g$).

In any beam the first point at which web reinforcement will be required is the point at which the shearing unit stress is $0.015f'_g$.

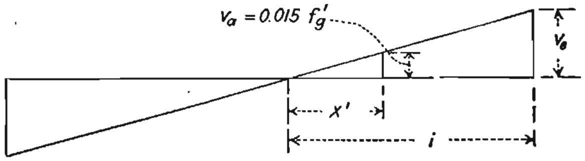

FIG. 112.

Letting x' be the distance from the point of zero shear to the first point of bending, it is apparent from figure 112 that

$$x' = \frac{v_a}{v_e} i = \frac{0.015\ f'_g}{v_e} i.$$

Using various values of the end shear v_e, ranging from $0.04f'_g$ down to $0.015\ f'_g$, corresponding values of x' are found and through these points curves are drawn which represent the minimum amount of bent-up reinforcement required for these cases. These latter curves are graphs of Eq. 14 with different values of $\frac{v_a}{v_e}$ substituted.

Solution.—To illustrate the practical use of the diagram let it be required to design the web reinforcement of a beam 8 ft. long to carry a load of 228 lb. per lin. ft. (dead and live load), using gypsum whose ultimate strength is 1600 lb. per sq. in. The allowable end shear is $0.04 \times 1600 = 64$ lb. per sq. in.; but if it be assumed that the minimum section for this span is as shown in figure 113, the end shear will be:

$$v_e = \frac{W/2}{b'(d - t/2)} = \frac{912}{262 \times 7.25} = 48 \text{ lb. per sq. in.}$$

$$v_a = 0.015 \times 1600 = 24 \text{ lb. per sq. in., and}$$

$$x' = \frac{v_a}{v_e} i = \frac{24}{48} i = 0.5\ i.$$

Therefore the first bar will be bent up midway between the center of the span and the support as shown by the stepped line in the diagram, and the intersection of the "riser" of the first step with the parabola shows that one-fourth of the longitudinal reinforcement may be bent up here. The intersection of the "tread" of the first step with the minimum curve shows that the next bend may be at a distance not greater than 0.76 i from the center of the beam. The riser of the second step shows that at this point the total amount of bent up reinforcement must be not greater than about $0.59A_s$. The horizontal line through this point passes above the minimum of the bent-up reinforcement required at the end of the beam and below the maximum allowed at this place, hence the amount of reinforcement bent up is satisfactory. This gives two bends, but if the "treads" of the steps shown were greater than the maximum spacing allowed by Eq. 12 it would be necessary to design the beam with a larger number of bars of smaller area so that bends might be made at closer intervals. Any arrangement of bends which falls between the limiting curves and provides not less than three-eighths of the total area as "through" bars is allowable.

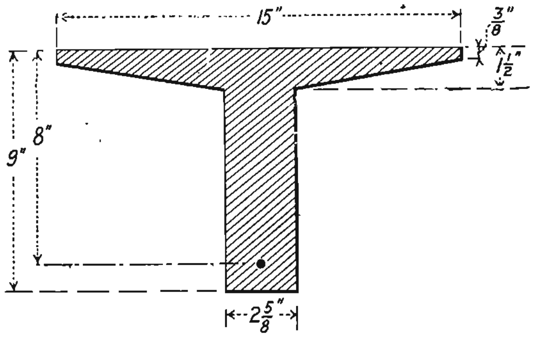

FIG. 113

The combination which employs one 1/4-in. round, one 1/4-in. square and one 5/16-in. round nearly meets the conditions required as shown.

ADDENDUM

Mr. Slater wished to have certain changes made in the report on Design of Reinforced Gypsum Beams which is published above but since this is a committee report (though prepared by Mr. Slater) it has seemed best to print these suggested changes separately rather than to incorporate them in the main body of the report. The changes which are suggested are as follows:

Page 457. Omit portion beginning with "In order that the working stresses" in the fourth paragraph, and ending with "should not be greater than the distance *s*", at the end of the ninth paragraph. For the omitted portion above outlined substitute the following:

"The allowable shearing stress at any section within the distance *s*, however, should not exceed

(1) $v = .015\,f'_g + \frac{A_v}{bs}(\sin\Theta + \cos\Theta)\,f_s$ when Θ is less than 45°

or

(2) $v = .015\,f'_g + \frac{A_v}{bs\,\sin\Theta}\,f_s$ when Θ is 45° or greater.

The distance *s* measured in the direction of the axis of the beam between two successive stirrups or between two successive points of bending up of bars or from the point of bending up of a bar to the edge of the support should not be greater than that given by the equation

(3) $s = \frac{40}{\Theta}d$ where the angle Θ is given in degrees.

Page 457. Omit from the last two lines the words "nor be less than the maximum value given by equation (14)."

Page 459. Add under "(b) Areas":

A_v = right sectional area of bars bent up (or of stirrups) within the distance *s*.

Page 459. Change definition of f_s to the following:
f_s = tensile unit stress in longitudinal or in web reinforcement.

Page 460. Omit symbols v_a and v_c and their definitions.

Page 462. Substitute new equations 12 and 14 for the old ones and add new equation 15, as follows:

(12) $s = \frac{40}{\Theta}d$

$$(14)\quad v = .015\, f'_g + \frac{A_v}{bs}(\sin\Theta + \cos\Theta) f_s \text{ when } \Theta \text{ is less than } 45^\circ.$$

or

$$(15)\quad v = .015\, f'_g + \frac{A_v}{bs \sin\Theta} f_s \text{ when } \Theta \text{ is } 45^\circ \text{ or greater.}$$

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Copies of the following official strength tests are in the files of The Gypsum Industries, and will be loaned upon request:

Willis A. Slater, Illinois University, 1915 to 1917.
James S. Macgregor, Columbia University, 1912, 1913, 1917.
R. H. Danforth, Case School of Applied Science, 1915, 1916, 1917.
M. O. Withey, University of Wisconsin, 1916.
R. W. Hunt & Co., St. Louis, Mo., 1917.

APPENDIX IX

GYPSUM COMPANIES OPERATING IN THE UNITED STATES, CANADA AND MEXICO IN 1921

Acme Cement Plaster Co.
703 Frisco Bldg., St. Louis, Mo., Works—Acme, Tex.; Acme, N. M.; Cement and Acme; Okla.; Laramie, Wyo.; Grand Rapids, Mich.; Gypsum, Ore.; Los Angeles & Palmdale, Cal.; Marlow, Okla.

Albert Manufacturing Co.
Hillsborough, N. B., Can.; Sales Offices—30 Church St., New York City, N. Y.

American Cement Plaster Co.
Lawrence, Kansas; General Sales Office—Chicago, Ill.; Sales Offices—Chicago, Ill.; St. Louis, Mo.; Minneapolis, Minn. Fort Dodge, Iowa; Kansas City, Mo.; Milwaukee, Wis. Works Agatite, Tex.; Blue Rapids, Kans.; Grand Rapids, Mich.; Fort Dodge, Iowa; Gypsum, O.; Milwaukee, Wis.; and Akron, N. Y.

American Gypsum Co.
Livingston Bldg., Rochester, N. Y.; Works—Akron, N. Y.

American Gypsum Co.
Port Clinton, O.; Cleveland, O.; and Detroit, Mich. Works—Port Clinton and Cleveland, O.; and Detroit, Mich.

American Keene Cement Co.
Sigurd, Utah; Sales Offices—Salt Lake City, Philadelphia, Chicago and San Francisco.

Arden Plaster Co.
411 Merchants Nat. Bk. Bldg., Los Angeles, Cal.

Arizona Gypsum Plaster Co.
Douglas, Ariz.

Best Bros. Keene's Cement Co.
Medicine Lodge, Kan.; Sales Offices—New York and Chicago; Works—Medicine Lodge, Kan.

Bestwall Mfg. Co.
McCormick Bldg., Chicago, Ill.; Sales Offices, Chicago; Cleve-

land, O.; New York, N. Y.; St. Louis, Mo.; Works—Grand Rapid, Mich., and Akron, N. Y.

Black Hills Rock Products Co.
(Successor to Rapid City Gypsum, Lime & Portland Cement Co.)
Rapid City, S. D.

Cardiff Gypsum Plaster Co.
Fort Dodge, Iowa; Works—Gypsum, Iowa (no P. O.).

Cayuga Gypsum Co.
Ithaca, N. Y.; Quarries—Union Springs, N. Y.

Centerville Gypsum Co.
Centerville, Iowa.

Chazy Marble Lime Co.
Chazy, N. Y.

Colorado Portland Cement Co. (Gypsum)
Denver, Colo.; Works—Portland, Colo.; (Plaster, Red Buttes, Wyo.)

Conneaut Lake Marl Co.
Meadville, Pa.; Works—Harmonsburg, Pa.

Construction Materials Co.
133 W. Washington St., Chicago, Ill.; Works—20th Ave and Georgia St., Gary, Ind.

Dakota Plaster Co.
Rapid City, S. D., Works—Black Hawk, S. D.

Empire Gypsum Co.
Cutler Bldg., Rochester, N. Y.; Mills—Garbutt, N. Y.

Globe Plaster & Mining Co.
Commerce Bldg., Kansas City, Mo.; Works—Globe (P. O. Carlsbad), N. M.

Grand Rapids Plaster Co.
1204 Grand Rapids Savings Bank Bldg., Grand Rapids, Mich.; Works—Grand Rapids (Eagle Mills) and Grandville, Mich.

Higginson Mfg. Co.
Office and Works—Newburgh, N. Y.

International Gypsum Corp., Ltd.
Annapolis Royal, Nova Scotia; Sales Offices, Montreal, Que., Can.; Works—Eastern Harbour, Nova Scotia.

Iona Gypsum Co.

Iona, Nova Scotia.
*Iowana Plaster Co.
Fort Dodge, Iowa.
Jumbo Plaster & Cement Co.
Sigurd, Utah.
Kelly Plaster Co.
Butler, Pa.; Sales Office—Sandusky, O.; Works—Castalia, O.
J. B. King & Co.
17 State St., New York City; Sales Offices—Boston, Mass.; Buffalo, N. Y.; Philadelphia, Pa.; and Norfolk, Va.; Works—New Brighton, N. Y. and Roslyn, N. Y.
La Tolteca Cia De Cemento Portland, S. A.
Avenida Independencia No. 8, Mexico City, Mexico.
Lycoming Calcining Co.
120 W. Fourth St., Williamsport, Pa.; Works—Garbutt, N. Y.
Manitoba Gypsum Co., Ltd.
504 Loan & Trust Bldg., Winnipeg, Man., Can.; Works—Gypsumville and Winnipeg.
Michigan Gypsum Co.
Grand Rapids, Mich.
Clifford L. Miller Co.
110 E. 23rd St., New York City, N. Y.; Works—Brooklyn, N. Y.
National Wall Plaster Co. of America.
830 New Bank Bldg., Syracuse, N. Y.; Works—Dewitt, N. Y.
Nephi Plaster & Mfg. Co.
322 Ness Bldg., Salt Lake City, Utah; Works—Gypsum, Utah.
Newark Plaster Co.
Newark, N. J.; Sales Office—30 Church St., New York, N. Y.
Niagara Gypsum Co.
Oakfield, N. Y., Sales Offices—597 Michigan Ave., Buffalo, N. Y.; Works—Oakfield, N. Y.
Oklahoma Portland Cement Co.
Denver, Colo.; Sales Offices—Oklahoma City, Okla.; Works—Ada and Homestead, Okla.
Overland Cement Plaster Co.
Laramie, Wyo.
Pacific Coast Gypsum Co.
403 Perkins Bldg., Tacoma, Wash.; Mine—Gypsum, Alaska.
Pacific Portland Cement Co., Consolidated.

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* Taken over by the Universal Gypsum Co. in 1922.

827 Pacific Bldg., San Francisco, Calif.; Works—Mound House, Nev.

Phoenix Gypsum Co., Inc.
Livingston Bldg., Rochester, N. Y.; Mines—Wheatville (no P. O.), N. Y.

*Plymouth Gypsum Co.
Fort Dodge, Iowa; Branch Offices—211 Lumber Exchange, Minneapolis, Minn.; 1313 Chamber of Commerce Bldg., Chicago, Ill.; Builders Exchange, Milwaukee, Wis.

Puget Sound Cement and Lime Co.
424 New York Blk., Seattle, Wash.

Red Buttes Cement & Plaster Co.
606 Ideal Bldg., Denver, Colo.; Works—Red Buttes, Wyo.

Rock Plaster Corporation.
(Successor to Rock Plaster Mfg. Co.)
381 Fourth Ave., New York; Works—150th St. and East River, N. Y.

Southern Gypsum Co., Inc.
North Holston, Va., and Chicago, Ill.; Works—North Holston, Va.

John E. Stewart
Plaster Rock, N. B., Can.

Superior Plaster Co.
925-931 Dime Bank Bldg., Detroit, Mich.; Works—foot of Lycaste Ave., Detroit, Mich.

Texas Cement Plaster Co.
Hamlin, Tex., Sales Offices—Oklahoma City, Okla.; Works—Plasterco, Tex.

Three Forks Portland Cement Co.
Denver, Colo.: Sales Offices—Butte, Mont.; Works—Hanover and Trident, Mont.

Turkey Creek Stone, Clay & Gypsum Co.
304 Central Block, Pueblo, Colo.; Works—Stone City, Col.

United States Gypsum Company
205 Monroe St., Chicago, Ill.; Sales Offices—Boston, Mass.; Buffalo, N. Y.; Chicago, Ill.; Cincinnati and Cleveland, O.; Denver, Colo.; Detroit, Mich.; Kansas City, Mo.; Los Angeles, Calif.; Milwaukee, Wis.; Minneapolis, Minn.; New York, N.

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* Taken over by the Universal Gypsum Co. in 1922.

Y.; Omaha, Neb.; Philadelphia and Pittsburgh, Pa., St. Louis, Mo.; and Washington, D. C. Works—Alabaster, Mich.; Piedmont, S. D.; Blue Rapids, Kan.; Cleveland, O.; Eldorado, Okla.; Fort Dodge, Iowa; Gypsum, Ohio; Southard, Okla; Genoa, O.; Grand Rapids, Mich.; Oakfield, N. Y.; Plasterco, Va.; Detroit, Mich.; Milwaukee, Wis.; Denver and Loveland, Colo.; Amboy, Calif.; Arden, Nev.

Utah Natural Products Co., Inc.
Sigurd, Utah; Sales Offices—Salt Lake City, Utah.

Wassem Plaster Co.
720-721-722 Snell Bldg., Fort Dodge, Iowa; Works—3 miles southeast of Fort Dodge, Iowa.

Windsor Plaster Co., Ltd.
Windsor, Nova Scotia.

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PRELIMINARY STATEMENT

While this bibliography is admittedly not complete, it is thought that not many papers of consequence, published up to 1921, have been overlooked. Many descriptions of antiquated processes in the manufacture of gypsum have been omitted. Many such papers are listed by Von Waldegg (Der Gips, Verlag von T. Thomas, Leipsig, 1906).

Acknowledgment is made of assistance received from manuscript bibliographies of H. J. Brown, and V. G. Marani, as well as published bibliographies shown below. The valuable agricultural bibliography of Olson and St. John and the bibliography of DeKalb on sulphur in agriculture, are reproduced in their entirety. In this same connection a manuscript bibliography of Professor William Crocker has proved helpful.

The following plan has been adopted for this bibliography:

1. General references
2. Bibliographies
3. Descriptions of localities
   - United States (as a whole)
     - by states
   - Foreign
     - Canadian
     - European
     - Australia
     - Asia
     - Africa
4. Geological
5. Chemical and Mineralogical
6. Technical
7. Structural Tests
8. Hydraulic gypsum
9. Gypsum in Portland Cement
10. Miscellaneous
11. Gypsum in Agriculture
    - Older references

Miscellaneous references
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Page 478	*COLORADO.*
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INDEX

A

Abyssinia, salinas in, 115; gypsum in, 115
Accelerators, nature, 371; effect in plaster, 372
Acid phosphates in soils, 266
Acme Cement Plaster Company, 196, 224, 468
Adams, G. I., 474, 475, 487
''Addition,'' amount of, 400
Adhesion of gypsum plaster, 299, 314
Africa, gypsum in, 106
Age and strength of gypsum, 295, 298; of briquettes, 299
Agitation of gypsum, 231; and setting time, 424
Agr. et. Vit., Prog., 533
Agr. Prat., Jour., 533
Agr. Research, Journal, 265, 526
Agricultural gypsum, 248; production, 378
Akad. Handbl. och Tidskr., 535
Alabaster, character, 72; in Spain, 105; in Egypt, 106; from gypsum, 271
Alaska, gypsum in, 79; bibliography, 476
Albert Manufacturing Co., 101, 468
Alfalfa, effect of gypsum on, 262
Algeria, gypsum production in, 382
Algerie et Tunesie, Bul. Agr., 535
Allen, E. T., 73, 496
Alsace, gypsum in, 103
Alum as accelerator, 372; in Keene's cement, 366
Alum cement, 368
Aluminum as hardener, 374; in Keene's cement, 366
America, early use of gypsum in, 187; Geological Society of, 481, 494
American Architect, 467, 500
American Cement Plaster Company, mill, 191, 196, 468; mine, 200; analysis, 208
American Ceramic Society, 286, 383, 407, 419, 496, 501, 510
American Chemical Society, 496
American Geologist, 480, 482
American Gypsum Co., 468
American Institute of Architects, 500
American Institute of Mining Engineers, 129, 477
American Institute of Technology, tests at, 324
American Journal of Science, 485, 502
American Keene's cement, 366
American Keene Cement Co., 468
American Machinist, 502, 511
American Philosophical Society, 489
American Society of Agronomy, 516, 519
American Society for Testing Materials, 246, 281, 284, 383, 420, 454, 501
Ames, J. W., 514, 531
Ammonia tests of gypsum, 507
Analyses of gypsum, 73ff, 207ff, 386
Andre, G., 514
Anhydrite, specific gravity, 63; character, 77; origin, 110, 129; gypsum from, 127; as land plaster, 269; hydraulic gypsum from, 355; determination by thin sections, 396; and high alumina clinker, 247; in cement, 246; in Centerville gypsum, 209; in raw gypsum, 392, 394; estimation, 396, 397
Anhydrite, soluble, 277
Anorganische Chemie, Zeit., 494ff
Anthes, G. P., 506
Arden Plaster Co., 468
Arizona, gypsum in, 81, 108; bibliography, 477
Arizona Gypsum Plaster Company, 81, 468
Arkansas, gypsum in, 82, 108; bibliography, 477
Arkansas Geological Survey, 477
Armour Institute of Technology, 506

Armstrong, E. J., 496
Arsenic, use of gypsum with, 270
Asbestos in gypsum slabs, 428
Asia, gypsum in, 105
Asphalt und Teerind, Zeit., 500
Aubury, L. E., 477
Aurand, H. A., 536
Australia, gypsum in, 106; analyses, 76; bibliography, 493
Austria, gypsum in, 104, 107, 108

B

Backgrounds for gypsum plaster, 315
Bacteria, gypsum and, 262
Baden, gypsum production in, 382
Bag filler, automatic, 243
Bags for plaster, 244
Bailey, E. H. S., 480, 481, 494
Bailey, L. W., and Ells, R. W., 491
Bain, H. F., work of, 183
Baker, P. S., 520
Baker Stucco Co., 224
Bakker, B. A., 502
Balser, L. A., work of, 391
BanBussy, 514
Barger, 514
Bars in gypsum beams, 457
Bartlett, C. O., 499
Basin at Fort Dodge, 175
Basin theory, difficulties of, 115
Bassler and Nickles, 164
Bates, P. H., 246, 508
Bates Valve Bag Co., 243
Batten, E. T., 514
Baumatk, 500
Bavaria, gypsum production in, 382
Baxter, 511
Beams, reinforced, 345; see gypsum beams
Bear, Firman E., 514
Bearing pressure in beams, 456
Beaver Board Company, 191, 200, 328, 337, 339
Beck, L. C., 484
Beckwith, C. S., 525
Bedding of Fort Dodge gypsum, 200
Bell and Cameron, see Cameron and Bell
Bending strength of gypsum, 404
Bernhard, A. D., 514, 533
Berthier, work of, 274
Berry, R. A., 515
Best, John C., patent by, 366
Best Brothers Keene's Cement Co., 468
Bestwall Mfg. Co., 468
Beyer, S. W., analyses by, 210
Bibliography of gypsum, 473
Binns, John A., on agricultural gypsum, 252, 511
Birdsley, C. A., 425
Bischof, 121, 122, 124
Bizzell, J. S., 525
Bjorn, Anderson H., 515
Black Hills, gypsum in, 73, 94
Black Hills Rock Products Co., 469
Black Sea, salt deposits on, 124
Blaine formation, gypsum in, 92
Blair, A. W., 515, 525
Blake, W. P., 82, 477
Blanck, E., 528, 536
Blandon gypsum mill, 188, 195
Blocks, gypsum, 192; see gypsum
Board, gypsum, 193; see gypsum
Boelcker, J. A., 536, see Voelcker, J. A.
Bogdanov, S., 515, 533
Bohme, E., 515
Bohmer, C., 530
Boiret, H., 515
Bolton, O., 511
Boltz, G. E., 514
Bonacino, 513
Bond between cables and slabs, 446; in plaster board, 341; strength tests, 503; stress in beams, 456
Borax as hardener, 374; in Keene's cement, 366
Bossinelli, C., 515
Boullanger, E., 515, 533
Boutwell, J. M., 488
Bowker, 515
Bownocker, J. A., 92, 485
Boyd, C. R., 488
Boyer, J., 492
Boyle, A. C., 477
Bradley, C. E., 515
Bradshaw Clay pit, 148
Brady, F. W., 483
Branson, E. B., 98, 110, 116, 117, 489, 494; Hypothesis of, 116

Breazeale, J. F., 515
Brick and grounds, 315
Briggs, L. J., 515
Bright, H. A., work of, 391
Brioux, Ch., 513
Briquette of gypsum, 294; tests, 296; making, 297; tensile strength, 299
British Columbia, gypsum in, 101
Brodie, O. A., 516
Brooks, W. P., 516
Brown, H. J., 473; Translation of Report on German Methods of Testing Gypsum, 400
Brown, P. E., and Kellogg, E. H., on Sulphur, 260, 516, 536
Browning coat, 309, 316
Buchanan, 510
Building Management, 326, 501
Building Supply News, 499
Burchard, Ernest F., 73, 79, 84, 475ff
Bureau of Standards, tests by, 325, 383, 419, 432, 503; see U. S. Bureau of Standards
Burkhardt, W., 496
Burr mills, grinding by, 216
Burt, B. C., 516
Butler, P. H., 425
Butler and Ryan mill, 196
Buttons, gypsum in, 271
Byer, 517

C

Cables in roofs, 350; in slabs, tests, 436; elongation, 441; bond, 446
Cairo Scientific Journal, 493
Calcined gypsum, specific gravity, 63; early use, 194; in cement, 246; setting, 277; physical properties, 279; uses, 304; definition, 354; hardening, 374; production, 378; tests, 383, 400; microscopic examination, 392; see gypsum
Calciner, Cummer, 237
Calciners, rotary, 235
Calcining methods, early, 190, 192; kettles, 229
Calcining gypsite, 234
Calcining and set, 288
Calcite in raw gypsum, 392, 393
Calcium carbonate in gypsum, 207; hydroxide in gypsum, 395; oxide in hydraulic gypsum, 355
Calhoun, F. H. H., 84, 107
California, gypsum in, 82, 107; bibliography, 478
California Experiment Station, 513; State Mineralogist, 478
Calvino, Mario, on gypsum, 268
Cambrian, gypsum in, 109
Cameron, F. K., and Bell, T. M., 129, 494, 496, 513
Cameron and Kearney on gypsum, 267
Cameron, F. K., and Patten, H. E., 517
Camillus shale, gypsum in, 89
Canada, gypsum in, 98; analyses, 73, 74; quarries in, 101; gypsum roofs in, 350; gypsum production in, 382; gypsum companies in, 468; bibliography, 491
Canada, Department of Mines, 100, 235, 491; Canada Geological Society, 491
Canadian Engineer, 499
Canadian Mining Journal, 68
Canadian Mining Review, 492
Canadian Record of Science, 491
Carbon dioxide, effect of, on deposition, 117
Carboniferous, gypsum in, 88, 109
Cardiff Gypsum Plaster Co., mill of, 189, 195, 224, 469
Cardium edule, 115
Carlier, A., 517
Carpenter, R. C., tests by, 291, 505
Carson blotter test, 450
Carter, E. C., studies on sulphur, 262, 521
Carter, W. J., drill records of, 161
Case School of Applied Science, 507
Cast plaster floors, 365
Casting gypsum floors, 363
Cavazzi, Alfr., 494
Caves in Centerville gypsum, 210
Cawnpore Agricultural Experiment Station, 516
Cayuga Gypsum Company, 90, 469
Cement, production in 1917 and 1918, 41
Cement and Engineering News, 488
Cement Anglais, 368

Cement factories in Iowa, 42
Cement mill type rotary, 239
Cement retarder, 304
Centerville, deep well at, 183; prospect hole at, 181; selenite from, 68
Centerville gypsum, origin, 129; discovery, 134; properties, 209; caves in, 210
Centerville Gypsum Co., mill of, 199, 209, 216, 469
Centerville gypsum field, location, 134; description, 181; history, 199
Cercelet, M., 517
Cettoline, Sante, 517
Chancrin, E., 517, 533
Chauzit, Jean, 517, 536
Chazy Marble Lime Co., 469
Chem. Applicata, Ann., 494ff
Chemical Abstracts, 494ff
Chemical analyses of gypsum, 73ff, 207ff, 384, 386
Chemical change in calcining, 232
Chemical Industry, 496, 511
Chemical News, 495
Chemical reaction, disseminated gypsum by, 121
Chemical Society of London, 497
Chemiker Zeitung, 495, 498
Chemischen Gesellschaft, 494
Chemistry, Department of, South Australia, 227
Cheops, pyramid of, 185
Chester, soil analyses by, 258
Chicagof Island, gypsum on, 79
Chimie Industrielle, 274
Chim. Ital., Gaz., 495
China, gypsum in, 106
Chip board, 340
Christie, A. W., 517
Chuard, Prof., 248
Chugwater formation, gypsum in, 97
Clark, W. C., 484
Clarke, F. W., 73, 114, 122, 517
Clay as retarder, 370; in raw gypsum, 392, 394
Clay products in 1917 and 1918, 22; kinds, 23
Cleveland Engineering Society, 499
Clionolithes, 146
Coal production in Iowa, 14; distribution, 20; source, 21
Coal for kettles, 231
Coal Measures, selenite in, 67, 121, 128
Coatings of plaster, 309
Cold water paints, gypsum in, 306
Cole, L. H., 67, 68, 100, 126, 474, 491, 499
Collison, Stanley E., 517
Color of calcined gypsum, 279
Colorado, gypsum in, 73, 83, 108; analyses, 75; bibliography, 478, 536
Colorado Portland Cement Co., 469
Coloring gypsum, 375
Columbia University, 127; School of Mines, 496
Composita trinuclea, 146
Composition slabs of gypsum, 426
Compressive strength of gypsum, 290, 314, 384, 388; tests, 65; attainment of, 342
Compressive stress in gypsum beams, 455
Compt. Rend. Acad. Sci. Paris, 274, 494ff, 514, 533
Concrete as insulator, 293
Condit, D. D., 97, 490
Conductivity, heat, 301; sound, 302; structural gypsum, 346
Cone crusher or cracker, 214
Conglomerate, New Basal, 168
Conn, 517
Connate waters, diseminated gypsum from, 121
Conneaut Lake Marl Co., 469
Consistency, normal, field method for, 283; setting time and, 288; see normal consistency
Construction, rapidity of, 347
Construction Magazine, 331, 467, 499
Construction Materials Co., 469
Contract Record (Canada), 501
Contraction and expansion, 299
Cooling the plaster, 235
Copenhagen Station, 517
Cornell Univ. Agr. Exp. Station, 525
Cornices and molding, 317
Corrosion of reinforcement, 345, 503
Cosack, C., 530
Cotton, effect of gypsum on, 266
Coughlin, James, well of, 162
Cox, L. M., 428, 430
Cracker cone crusher, 214

Cracks in slab floors, 444
Craig Coal Company, wells by, 157, 159
Craig's Hollow, 155
Cramer, 497, 508, 513
Crane, W. R., 481, 498
Crania, 146
Crawford, J. J., 477
Crawford mill, 195
Crayons from gypsum, 271
Credner, 107, 108
Creldt, 518
Cretaceous, gypsum in, 67, 102, 108, 172
Crocker, Wm., on agricultural gypsum, 250, 252, 255, 473, 518
Crops, effect of sulphur on, 260
Crushers for breaking gypsum, 213
Crutchman, C. H., records of, 161, 162
Cuba, gypsum in, 102; use of, 268
Culin, F. L., Jr., 477
Cummer process, 237
Cummins, W. F., 487
Curry, B. E., and Smith, J. O., 518; and Morse, 527
Czecho-Slovakia, gypsum in, 104

D

Daikuhara, G., 518
Dakota Plaster Co., 469
Dammer und Tietze, 77, 102, 103, 105, 107
Damron, E. C., 498
Danforth, R. H., tests by, 467, 507
D'Anselme, 497
Danthony, E., and Vermoral, V., 531, 535
Darnell, Smith, 518
Darton, N. H., 88, 89, 483, 486, 489
Davey, Sir Humphrey, 511
Davis, J. A., 425
Davis, W. A., work of, 273, 275, 496
Day, David J., 84, 479
De Coster, 502
De Forcrand, 497
Dead burned gypsum, 354, 366
Dead Sea, 122
Deformation of slab, measurements of, 440
Degrully, L., 518, 533
Deherain, P. P., 518
DeKalb, Courtenay, bibliography, 475, 533
Demolon, A., 518, 534
Dental Cosmos, 502
Dental plaster, gypsum in, 306; production, 379
Deposits by seepage, 125
Des Moines river, exposures along, 142, 147
Des Moines stage at Fort Dodge, 167
Des Moines valley, sections along, 176
Desriot, A., 517, 533
Detroit Building Department, 503; tests by, 333
Deut. Landw. Presse, 514, 533ff
Deutschen Gips vereins, 474
Devonian, gypsum in, 109
Dezani, 518
Dietrich, 518
Dietzall, B. E., 518
Disintegrators, 217
Disseminated gypsum, 120; concentration of, 121
Domes, salt, gypsum in, 95; in Fort Dodge gypsum, 204
Drill records, data from, 156
Drilling of gypsum, 211
Dry spray, gypsum in, 272
Dry-scratch plaster, 315
Drying and ventilating plaster, 320
Drying of gypsum, 215
Dugardin, And., 533
Duley, F. L., 519
Dumas, 501
Dumble, E. T., 67, 94
Dumont, J., 519
Duncombe Stucco Company, 224; mill, 195
Dunes, gypsum, 126
Dupont, C., 518
DuPont DeNemours, E. I., & Co., 506
Durability of structural gypsum, 349
Dusserre, C., 519
Dust collectors, 234
Dyer, Bernard, 519
Dymond, 519

E

Ebermayer, E., 519

Echart, C. F., 519
Eckel, E. C., 96, 366, 474, 488, 501
Economic Geology, 483
Edison roll mills, 213
Efflorescence, effect of, 178
Egypt, gypsum in, 106; bibliography, 493
Egyptian calcining oven, 186
Ehrsam kettles, 230
Ehrsam Mfg. Co., 213, 242
Elasticity of gypsum, 347; modulus of, 455
Elektrochem., Zeit. fur, 496
Ellett, W. B., 519
Ells, R. W., 491
Embar formation, gypsum in, 97
Emery mill, 216
Emley, W. E., test by, 240, 286, 383, 390, 419, 501, 510; Report on Measurement of the Time of Set of Calcined Gypsum, 407
Emley and Faxon, C. F., 375; Report on Result of Testing Gypsum Products, 383
Emley patent for plastic gypsum, 449
Empire Gypsum Co., 469
Encyclopedia Brittanica, 111, 366
Engberding, D., 519
Engineering and Cement World, 467, 499
Engineering and Contracting, 467
Engineering and Mining Journal, 102, 105, 477ff, 486, 499, 510
Engineering Magazine, 492
Engineering News, 467, 499, 501
Engineering News Record, 467, 499
Engineering Record, 467, 499
England, gypsum in, 104, 108, 255; production, 382; bibliography, 492
England, Royal Agricultural Society of, 523, 536
English Keene's cement, 366
Engrais, 533
Eocene, gypsum in, 108
Erfind, 508
Estrich gypsum, 194, 354; see hydraulic gypsum
Ewin, 514
Expansion and contraction, 299
Expansion of calcined gypsum, rate, 412; of Fort Dodge gypsum, 205; of plaster during set, 413
Experiment Station Record, 514ff
Explosives in gypsum mining, 211
Euler, 519
Europe, gypsum in, 103; agricultural gypsum in, 248; gypsum blocks in, 322

F

Factory, 467
Fairbanks, H. W., 477
Faults (?) at Fort Dodge, 174
Faxon, see Emley and Faxon
Feilitzen, H., 519, 535
Fellers, C. R., 520
Felt in gypsum boards, 330
Ferguson formation, gypsum in, 92
Fertility, system of soil, 265
Fertilizer, gypsum as, 248ff, vs. rock fertilizers, 190; cost of, 266
Fibre, 241; nature and purpose, 308
Fiebelkorn, 494
Filtering, gypsum in, 271
Final set, 407, 414, 415; determination, 286
Fineness of gypsum, 219, 280, 384, 387, 402
Finish coat, 309, 317
Fire resistance of gypsum, 346; tests, 503; of hydraulic gypsum, 358; of plaster board, 332
Fire and Water Engineering, 500
First settle calcined gypsum, 232, 276; strength, 343
Fisher, C. A., 97, 490
Flexure tests of gypsum, 505
Flooring gypsum, 354; application, 359
Floors of gypsum slab, 426; reinforcement of, 433; loading for test, 435; see also slabs
Floor tile, gypsum, 353
Florida, gypsum in, 84, 107; bibliography, 479
Florida Agricultural Experiment Station, 517
Floor gypsum, 72, 106
Flux, gypsum as, 270
Foreign material in plaster, effect of, 408

Fort Dodge area, description, 131; location, 132; size and shape, 133
Fort Dodge basin, 174
Fort Dodge beds, character, 168, 200; structure, 173
Fort Dodge Brick and Tile Works, 142
Fort Dodge Clay Works, 146, 147
Fort Dodge Commercial Club, 137
Fort Dodge gypsum, origin, 127, 177; geological age, 171; extent, 179; character of bed, 200; analyses, 208
Fort Dodge Plaster Co., 224
Fothergill, A., on land plaster, 255, 511
Foundry, 510, 511
Fourcray, 520
France, gypsum in, 104, 107; production, 382; bibliography, 492
France, Jour. Soc. Nat. Hort., 526
Franklin, Benjamin, use of gypsum by, 187, 253
Franklin Institute, 490, 501
Fraps, G. S., 520
Fred, E. B., 520
Freemen, O. W., 482
Frey, O., 508
Fritschler, 535
Frost in mixing plaster, 320
Fry, W. J., 528
Fuel requirements, 232; consumption, 244
Fuling's Landw. Ztg., 536
Furring blocks, gypsum, 318, 328
Fusulina secalica, 170

G

Gale, H. S., 64
Galpin, S. L., 170
Galstev, 520
Gang-mold, 295
Garden of the Gods, gypsum in, 83
Gardner, Frank D., 520
Garkell, E. F., 516
Garvin Machine Co., slab floors of, 431
Gary, 492, 498, 500, 508
Gas, natural, production in 1917 and 1918, 45
Gebhardt, G. F., tests by, 291
Geikie, 107, 108, 109
Gen. Sci., Rev., 533
Genie Civil, 501
Geological Society of America, 98, 110, 481, 494
Geological Society of Canada, 491
George, R. D., 83, 478
Gericke, W. F., 520, 524
German calciner, 236
German Estrich, 354
German Gypsum Association, 186, 287, 350, 400
German method of determining normal consistency, 280; of testing gypsum, 400; of measuring initial set, 416
Germany, gypsum in, 103, 107, 108; early use, 187; gypsum blocks, 192; agricultural gypsum, 248; production, 382; bibliography, 493
Gesner, A., 491
Giannetto, F., 520, 521, 533
Gibson, H. G., 485, 499
Gilbert, G. K., 123, 478, 488
Gilbert, J. H., 520, 524
Gill, A. C., 496
Gilmore Portland Cement Company's pit, 153
Girtyella indianensis, 146
Glasenapp, M., 276, 355, 475, 508
Globe Plaster and Mining Co., 469
Godamer, 521
Goessmann, Chas. H., 521
Goldthorpe, H. C., 521
Gould, C. N., 67, 485, 487
Grabau, A. W., 110, 111ff
Grahl, 524
Grand Rapids Plaster Co., 469
Gravel, production in 1917 and 1918, 31
Great Salt Lake, 122; analysis of water from, 123
Greaves, John, well of, 162
Grece, Charles F., on land plaster, 254
Greece, gypsum produced in, 382
Greece, use of gypsum in, 186
Gregory, W. M., 482
Griffith, J. H., 503
Griffiths, A. B., 521
Grignard, Van Rijn, 521
Grimsley, G. P., 63, 85, 248, 254, 277, 312, 474, 477, 481
Grinding mills, 216
Grinding of plaster gypsum, 451

Grizzlies, in gypsum mills, 213
Grounds for plasters, 315
Guerbet, M., 516
Guffroy, C., 521, 534
Gwinn, A. R., 516
Gypsite, character, 72; analyses, 74; winning, 211
Gypsum, absorption by, 65; agitation, 231; amount of ''addition'', 400; analyses, 73; and nitrogen secreting bacteria, 262; and root growth, 262; as cotton fertilizer, 266; as fertilizer, 37, 248; indirect fertilizer, 257; as insulator, 291, 292; as manure preservative, 269; bending strength, 404; bibliography, 473; characters, 393; chemical composition, 72; combined with silica, 271; compressive strength, 64, 342; concentration, 178; crushing, 213; decomposition temperatures, 275; deposits of, in United States, 79; domes in, 204; drying, 215; early uses of, 194; effect on land, 251; expansion, 204, 412; factors in time of set, 419; fineness of, 402; German methods of testing, 400; hardening, 373; hardness, 63; heat conductivity, 290; in agriculture, 248; in England, 255; in Iowa, production, 37, 380; in Portland cement, 246, 379; lightness, 293; ''marking time,'' 402, 403; microscopic examination, 392; mined in United States, 376; neutralizes salts, 268; origin, 110; properties, 63; quarrying, 211; rate of drying, 342; reinforcing in, 345; roofs, 349; selenite in, 68; specific gravity, 63; technology, 211; tensile strength, 302, 343, 402; ''time of pouring,'' 401; uses of, 40; time of set, 407, 419; weight of, 63; with sulphur, 86
Gypsum, agricultural, 248; in America, 249
Gypsum, calcined, chemical characteristics, 273; definition, 279; increasing plasticity of, 452; specific gravity, 63; tensile strength, 298; time of set, 407; uses, 304
Gypsum, efflorescent, deposits, 126
Gypsum, fibrous, 71
Gypsum, first and second settle, 233
Gypsum, Fort Dodge, analyses, 208; duration of supply, 180; origin, 177; thickness, 180
Gypsum, hydrated, effect of moisture, 343
Gypsum, hydraulic, see hydraulic gypsum
Gypsum, massive, occurrence, 72
Gypsum, poured, roof and floor, 305, 350
Gypsum, raw, uses for, 270
Gypsum, second settle, 233, 290, 343
Gypsum, structural, 194, 342-353
Gypsum beams, areas, 459; dimensions and angles, 458; properties of, 461; reinforced, 345; design, 454; stresses in, 459
Gypsum blocks, 305; history, 192; manufacture and advantages, 322-328; partitions, 338; production, 379; and grounds, 315
Gypsum board, 193; see also gypsum wall board
Gypsum companies in United States, 468
Gypsum composition slab construction, 426
Gypsum deposits, classes of, 110
Gypsum floor, tests of, 432; tile, 353; types, 353, 358
Gypsum furring blocks, 328
Gypsum Hollow, exposures in, 153; mills in, 194
Gypsum Industries Assn., 294, 329, 338
Gypsum industry, history of, 185; in Webster county, history of, 194
Gypsum mill, primitive, 189
Gypsum partition blocks, 323
Gypsum plaster, adhesion of, 314; backgrounds for, 315; composition and properties, 308; neat, 308; progress in use of, 192, 194; ready mixed, 310; setting, 277; technology, 211
Gypsum plaster blocks, see gypsum blocks
Gypsum plaster board, see plaster board
Gypsum produced by alteration, 126
Gypsum production in 1917 and 1918, 37

Gypsum products, testing, 311-315, 331, 342, 383, 400
Gypsum roof construction, 349; types, 350
Gypsum roofs and floors in Europe, 350
Gypsum slabs, advantages of, 347, 428; coating of, 430
Gypsum wall board, 329, 338; application, 318, 319; use, 193
Gyratory mills, 213

H

Haarmann's Zeit., 500, 508, 511
Haigh, D. L., 315
Hair in plaster, 241; picker, 241
Hall, A. D., 521
Hall, James, 132, 484
Halsted, B. D., 522
Hammer mill, 217
Hammerstein's Theater, reinforcing in, 348, 349; slab floor of, 431
Happen, 522
Hardening gypsum, 373; calcined gypsum, 374
Hardness of plasters, 290
Harris, G. D., 124, 481
Harris, W. G., 519
Hart, E. B., 520, 531; and Peterson, W. H., studies on gypsum, 258, 522, 533
Harter, 522
Hartwell, A. D., 522
Hartwell, B. L., 522, 532
Haskins, H. D., 521
Haviland pit, 142
Hawaii, use of gypsum in, 268
Hawaii Agricultural Experiment Station, 526, 535
Hawaiian Sugar Planters Station, 268, 527
Hawkeye Clay Works section, 140
Haworth, Erasmus,, 481
Headden, Wm. P., 513
Heat conductivity of gypsum, 290, 301; tests, 333, 505
Heat in mixing plaster, 320
Heat of plaster during set, 413
Hebut, A., 510
Heine, F., 510
Heintz, B., 522, 534
Hemihydrate, character, 276; solubility, 277
Henderson, Junius, 536
Henning, C. F., 501
Heraud, A., 533
Herlinger, D., 522
Herrick, C. L., 483
Herst, C. F., 521
Hess, F. L., 110, 124, 478
Hesse, gypsum in, 103
Higgins, W. C., 483
Higginson Mfg. Co., 469
Hilgard, E. W., 513, 523
Hill, B. F., 487
Hill, H. H., 523
Hill, R. T., 477
Hillebrand, W. F., 73, 384
Hillsborough Plaster Co., 101
Hodgson, Fred T., 501
Hoffman, C., 531
Hoffman, H. O., 271, 497
Hogan, J. F., well of, 162
Hogan, J. J., well of, 162
Holiday creek, 155
Holding, W. S., 525
Holmes and Holt, work of, 281, 295, 297, 299, 313
Holt, A. H., tests by, 225; see Holmes
Hopkins, C. G., studies on soils, 265, 523
Horsepower for roller mills, 219
Hoskens, William, patent by, 367
Hot pit, 234
Householder, F. F., tests by, 288, 502; Report on Factors Influencing Time of Set of Calcined Gypsum, 419
Hughes, 519
Hughett, Mark, well of, 162
Hulett, 496
Hull, W. A., work of, 291, 292, 505
Hume, W. F., 493
Hunt, R. W., and Co., tests by, 467, 503
Hunt, T. F., 523
Hunt, T. Sterry, 494
Hunter, Byron, 523
Hutton, C. H., 94
Hutton, J. G., 487
Hydrated lime in gypsum, 344; in Keene's cement, 368

Hydraulic gypsum, 194, 354; early uses of, 186; definition, 279; in Germany, 356; burning, 356; nature, 355; properties, 358
Hydraulic gypsum floor, fire protection, 358; mixing, 360; pouring, 361; tamping, 362; smoothing, 363

I

Idaho, gypsum in, 85, 107; bibliography, 479
Illinois Academy of Science, 467, 502, 506
Illinois Agr. Exp. Station, 523
Illinois State Museum, 67
Imitation marble from gypsum, 271
Impact tests of gypsum, 505
Impregnation of plaster board, 331
Impurities and setting time, 289
India, gypsum in, 105, 109; production, 382
Initial set, 285, 407, 414, 415; determination, 286; and strength, 416
Insecticides of gypsum, 270
Insoluble anhydrite, 395
Institute of Mining Engineers, British, 492
Instruments used in tests of floors, 436
Insulator, gypsum as, 291, 305, 340, 505
Interior plaster, 304
International **Association** for Testing Materials, **503**
International Gypsum Co., 469
International Inst. Agr., 535
Interurban exposures, 149
Iona Gypsum Co., 101, 469
Iowa, gypsum in, 85, 108, early use, 188; production, 380; bibliography, 479
Iowa Academy of Science, 132, 480, 516
Iowa Experiment Station, 260, 516
Iowa Geological Survey, 108, 109, 128, 132, 183, 210, 299, 312, 480, 493
Iowa gypsum, stratigraphy, 136; character, 200
Iowa Hard Plaster Company, 196
Iowa Plaster Association, mill of, 187, 195, 224
Iowa State College, analyses at, 210; tests at, 296, 312, 314
Iowa State University, see State University
Iowana Plaster Co., mill of, 193, 196, 470
Iron Age, 467
Iron ore, production in 1917 and 1918, 46
Iron sulphate for coloring gypsum, 375
Iron Works section, 139
Italy, gypsum in, 105; Soc. Agr., 521

J

Japan Agricultural Experiment Station, 518
Jamison, C. E., 490
Jamison, T., 523
Janicaud, W., 523, 535
Jaw crusher, 213
Jennings and Marquis, analyses by, 208, 210
Jennison, W. F., 491
Joffe, J. S., 525
Johnson, 523
Johnson, Cuthbert Wm., on land plaster, 256, 511
Johnson, H. W., 516
Johnson Brothers clay pit, 154
Jones, J. C., 88, 483
Jones, Linus H., 523
Jones, W. J., 498
Jordan river, analysis of water, 121
Journal of Ceramics, 288
Journal of Geology, 164, 480, 483
Journal of Pharmacy, 514
Journal Landw., 518ff
Jumbo Plaster and Cement Co., 470
Jupe, 519
Jurassic, gypsum in, 89, 108
Just, 495
Jute bags, 244

K

Kalayna, Tomio, 523
Kali, 494
Kalo, Ste. Genevieve near, 165
Kansas, gypsum in, 85, 108; analyses, 74; bibliography, 480

Kansas Academy of Science, 494
Kansas Agricultural Experiment Station, 530
Kansas Geological Survey, 108, 475, 480
Kansas University Quarterly, 481, 494
Kappen, H., 523, 536
Karabugas Gulf, 114
Kay, Geo. F., 479; Letter of Transmittal, 1
Kearney and Cameron on gypsum, 267
Keene, L. A., 273, 496
Keene's cement, 354; definition, 279; properties, 369; production, 379
Keith, Malcolm, 501
Kellogg, E. H., see Brown and Kellogg
Kelly Plaster Co., 470
Kemp, W. J., 492
Kentucky Agricultural Experiment Station, 260, 529
Kettle calcining, 228; coal, 231; discharging, 234
Keyes, Charles R., 132, 137, 138, 143, 168, 174, 179, 480
Keystone Fireproofing Company, 426, 429
Keystone Plaster Company, 400
Kiln for burning hydraulic gypsum, 357
Kime, J. W., well of, 162
King, J. B., & Co., 470
Kirchbergner, N. H., 249
Kirkpatrick, F. A., 425
Kirwin, Richard, 511
Kissivan, 493
Klehe, 510
Knight, W. C., 490
Knode, O. M., 126, 245, 338
Kohl Brewery section, Fort Dodge, 137
Kong, J., 530
Korner and Will, 532
Kosmann, 495
Kossovitch, 524
Koster, 498
Kramer, H. F., 491
Kraus, Arthur, report by, 432
Krocker, 524
Krumbhaar, 510
Krystallogr. u. mineral., Zeit. fur, 496

L

La Croix, A., 492
La Tolteca Cia De Cemento Portland, S. A., 470
Laboratorie d' Essais, 499
Lakes, A., 478
Lamination of Fort Dodge gypsum, 201
Land plaster, early use of, 189; effect, 190; later use, 191; see gypsum
Lappint, wells by, 159
Larsen, Esper S., Report on Microscopic Examination of Raw or Calcined Gypsum, 392
Lath and grounds, 315
Lavoisier, work of, 274
Laws, 524
Le Chatelier, M. H., work of, 274, 497
Lead, production in 1917 and 1918, 44
Leaking of kettles, 231
Leather, J. W., 516
Ledeh, P., well of, 162
Ledges of Fort Dodge gypsum, 201
Leduc et Pellet, 494
Lee, H. A., 478
Lee, W. T., 81, 477
Lees, James H., 136, 140, 143ff, 160, 166, 168, 205, 208, 480; mineral production by, 5
Leighton, H., 91, 484
Lewis, G. A., 492
Lewis Institute, 505
Liechti, P., 524
Lienke, E., 534
Liercke, E., 524
Lightness of gypsum, 347
Lime, production in 1917 and 1918, 28; uses, 29; effect on gypsum, 191; in soils, 266; in Keene's cement, 367; in gypsum, 395
Lime carbonate problem, 117
Lime putty finish, 337, 450
Limestone, below gypsum, 128; in gypsum, 208; specific gravity, 63; gypsum from, 126
Lincoln, D. F., 484
Linder, L. C., 92
Lindgren, W., 486
Linseed oil as hardener, 374
Lint, H. Clay, 524
Liopora, 146

Lipman, C. B., 524
Lipman, J. G., 524
Lizard creek sections, 145, 163
Load on slab floor, 431, 441; tests of gypsum, 504
Loading composition floor, 432; roof, 447
Loew, 525
Long and Miller, 506
Louderback, G. D., 483
Loudon, J. C., 512
Loughlin, G. F., 476
Louisiana, gypsum in, 86; bibliography, 481
Louisiana Geological Survey, 124
Lundteigen, analyses by, 177
Lupton, C. T., 95, 97, 488, 490
Luther, D. D., 484
Lycoming Calcining Co., 470
Lyon, T. L., 525

M

MacIntire, W. H., 525
MacLean's cement, 368
MacGregor, James S., tests by, 467, 505
McCall, A. G., 526
McConnell, Primrose, 526
McCool, M. M., 526
McGee, W J, 132
McGeorge, W., 526
McGowan, R. R., 510
McKay, George A., tests by, 426, 502
McLean, H. C., 525
McMiller, P. R., 526
Mack, 502
Mack's cement, 369
Magnesia in cement, limit, 247
Magnesite as hardener, 375
Magnesium as hardener of gypsum, 374
Magnien, A., 526, 534
Maizeres, 526
Manitoba, gypsum in, 100; bibliography, 491
Manitoba Gypsum Co., Ltd., 101, 470
Manufacturers' Record, 475, 488
Manures, effect of gypsum on, 269
Marani, V. G., 291, 294, 325ff, 473, 499, 500
Marble cement, 368
Mares, H., 526
Marignac, 63
"Marking time" of gypsum, 402, 403
Markwart, A. W., 307
Marmelli, A., 497
Marquis and Jennings, analyses by, 208
Marston, A., tests by, 223, 296, 299
Martin, J. C., 519
Martine, William H., 526
Marvin, W. H., 525
Massachusetts Institute of Technology, 505
Matches, gypsum in, 307
Matteson, W. G., on salt domes, 127
Mayer, J. F., 248
Mechanical World, 510, 511
Medicine Lodge formation, gypsum in, 92
Merrill, F. J. H., 75, 484
Merrill, G. P., 475
Merz, Ph., 513
Meservey, S. T., mill of, 194
Metal lath and grounds, 315
Metcalf, H. T., 492
Metropolitan system slab floors, 430; design, 432
Metz, Phillip, 526
Mexico, gypsum in, 102; gypsum companies in, 468; bibliography, 492
Meyer, F. M., 498
Meyer, J. J., wells by, 159, 161
Meyer, M., 500
Meyerhoff, 64
Michaelis, W., 355
Michigan, gypsum in, 86, 109; analyses, 74, 75; early use of, 188; bibliography, 482
Michigan Geological Survey, 75, 109, 188, 312, 474, 475
Michigan Gypsum Co., 470
Midvale Steel Co., slab roofs of, 427
Miege, E., 536
Millar, Wm., 475
Miller, C. E., 526
Miller, Clifford L., Co., 470
Miller, H. G., 526
Miller, N. H. J., 526
Miller, R. W., 531
Mills, A. P., 475

Mineral City Wall Plaster Co., 195, 224
Mineral Industry, 94, 377, 382, 479, 481
Mineral production in 1917 and 1918, 5
Mineral water, production in 1917 and 1918, 44
Minerals in raw gypsum, 392
Mines and Minerals, 478, 482, 483, 498
Mining and Engineering World, 485
Mining methods with gypsum, 212
Mining Science, 486
Mining World, 478
Minnesota Agricultural Experiment Station, 530
Miocene, gypsum in, 107
Miser, H. D., 477
Mississippian, gypsum in, 87, 96, 109
Mitteilungen Versuch, 492
Mixing boxes and tools, 320
Mixing materials, 240
Mixing methods, 320
Mixing plaster, 242
Modulus of elasticity of dry gypsum, 455
Molded work, 317
Molds, gypsum in, 307
Monroe formation, gypsum in, 91
Montana, gypsum in, 87, 109; analyses, 76; bibliography, 482, 536
Moore, N. C. L., 532
Morocco, gypsum in, 107
Mortar, dried, as accelerator, 371; see plaster
Mortimer, F. S., analyses by, 178
Morse, F. W., 529; and Curry, 527
Moser, 510
Mouldy, R. B., 490
Moye, 398, 474, 495, 496, 500, 509
Müller, Rich., 475, 497

N

National Board of Fire Underwriters, 502
National Wall Plaster Co. of America, 470
Naturwisenschaften, 534
Navy, see U. S. Navy
Neat gypsum plaster, 308
Nedokuchaev, N., 527
Nephi Plaster Mfg. Co., 470
Nevada, gypsum in, 88, 109; bibliography, 483
New Brunswick, gypsum in, 73, 100; analyses, 74; bibliography, 491
New Hampshire Agr. Exp. Station, 518, 527
New Jersey Agricultural Exp. Station, 525
New Mexico, gypsum in, 72, 89, 107, 108; bibliography, 483
New Mexico, Hadley Lab., Univ. of, 483
New York, geology of, 484; gypsum in, 89, 109; analyses, 75; bibliography, 484
New York Geological Survey, 109, 214, 275
New York State Department of Labor, 503
New York State Museum, 484
New Zealand Department of Agriculture, 526
Newark Plaster Co., 101, 470
Newell, F. H., 484
Newland, D. H., 89, 91, 127ff, 484; theory of anhydrite, 130
Newport Plaster Co., 101
Niagara Gypsum Co., 470
Nicholson, John, 512
Nickles and Bassler, 164
Nicolas, G., 527
Niklewski, von Bronislaw, 527
Nile delta salt pans, 115
Nipper for crushing gypsum, 215
Nitrogen, effect of gypsum on, 265
Nells, Charles F., 520
Nolte, O., 527
Normal consistency, 280, 384, 388; determination of, at Iowa City, 281
North Carolina Exp. Station, 520
Northwest Gypsum Plaster Company, 85
Norton, C. L., tests by, 503, 505
Norton, J. H., 527
Nova Scotia, gypsum in, 100, 109; analyses, 74; bibliography, 491
Nova Scotia, selenite in, 67

O

Ochsenius, 110, 126, 493
O'Hara, C. C., 489
Ohio, early use of gypsum in, 188; gypsum in, 91, 109; analyses, 74; bibliography, 485
Ohio Agricultural Experiment Station, 514
Ohio Geological Survey, 91, 93, 109
Oil domes, gypsum in, 86, 124, 125
Oil seepage, gypsum near, 125
Oklahoma, gypsum in, 92, 108; analyses, 74; bibliography, 485; selenite in, 67
Oklahoma Cement Plaster Company, 224
Oklahoma Geological Survey, 74, 474, 485
Oklahoma Portland Cement Co., 470
Oligocene, gypsum in, 107
Olive, E. W., 527; soil analyses by, 258
Olson and St. John, 262, 475
Ontario, gypsum in, 100; bibliography, 491
Ontario Gypsum Co., 101
Opitz, 498
Opstaele, Geo., 493
Oregon, gypsum in, 93; bibliography, 486
Oregon Agricultural Exp. Station, 260, 515, 528
Ornamental work, 317
Orthotetes kaskaskiensis, 146
Orton, Edward, 91, 485
Osborne, 527
Oven, Egyptian calcining, 186
Overland Cement Co., 470
Owen, David Dale, 131

P

Pacific Coast Gypsum Co., 79, 82, 470
Pacific Portland Cement Co., 470
Pacific Rural Press, 536
Packing plaster, 243
Pains, McLennan & Campion, 506
Paraffin as hardener, 374
Parian cement, 366, 369
Paris Basin, gypsum in, 104; analyses, 77
Parsons, A. L., 485
Partition blocks, 323
Paterson, J. W., 527
Patrick, G. E., analyses by, 207
Patten, H. E., 517
Paturel, G., 515
Payen, work of, 274
Peanuts, effect of gypsum on, 192
Pearson, J. C., 503
Peck, S. S., 527
Pedrotti, 185, 474, 501
Pember, F. R., 522, 527
Penetration method of testing plaster, 411
Pennsylvania, gypsum in, 93
Pennsylvania Agricultural Experiment Station, 520, 523
Pennsylvanian series at Fort Dodge, 167
Peppel, S. V., 485
Permian, gypsum in, 83, 85, 92, 94, 103, 108
Permian age of gypsum, 171; at Fort Dodge, 168
Permanent Builder, 500
Persia, gypsum in, 105, 125
Peters, Judge Richard, on gypsum in agriculture, 249, 512
Peterson, W. H., study of gypsum, 262, 527, 536; see Hart and Peterson
Petite Rev. Agr. et Hort., 533
Petroleum, gypsum with, 105
Pfeffer, W., 528
Pfeiffer, T., 528, 536
Philadelphia Building Department, 504
Phoenix Gypsum Co., Inc., 471
Phonograph records, raw gypsum in, 271
Phosphate, effect of gypsum on, 265
Phosphoric acid as hardener, 374
Phosphorus in soils, 260
Physical Chemistry, Jour., 273, 496, 517
Physical properties of calcined gypsum, 279
Physikal Chemie, Zeitschrift, 495, 496
Physikalische Zeitschrift, 494
Piecht, H., 495
Pingel, well of, 162

Pitz, W. J., 528
Plaster, cooling, 235; mixing, 240; packing, 244; retarding, 309; coats, 309; tensile strength, 311; application, 315; on plaster board, 336; gypsum, progress in use of, 192, 194; interior, 304; see gypsum
Plaster board, use of, 193; kinds, 305; application, 318, 335; composition, 329; fire tests, 333; impregnation and adhesion, 331; sound tests, 334; manufacture, 340; production, 379; and grounds, 315
Plaster of Paris, weight, 63; water in, 274; character, 304; uses, 306; production, 194, 379; composition, 394
Plastic gypsum, character, 240, 450; Emley patent for, 449
Plasticity, definition, 289; and fineness, 226
Plate glass industry, gypsum in, 305
Pleistocene, gypsum in, 107
Pliocene, gypsum in, 107
Plymouth Clay Products Company, pit of, 154
Plymouth Gypsum Company, mill, 190, 196, 471; mine, 149, 212; analysis of gypsum, 208
Pohlman, J., 485
Polytechn. Jour., 497
Portland, Oregon, Building Department, 504
Portland cement, specific gravity, 63; gypsum in, 246, 379; tensile strength, 302
Potash, production in 1918, 45; in soils, 258; effect of gypsum on, 265
Potash alum in Keene's cement, 368
Pottery and terra cotta molds, gypsum for, 306
Poured roof, 350
"Pouring time," 401
Powder, gypsum, estimation of, 396
Power consumption, 245
Powers, W. L., 528
Precast gypsum roof tile, 347, 352
Prescott, J. A., 528
Price, quoted, 250
Prichard, P., 528
Productus cf. longispinus, 170
Prometheus, 498
Prosser, C. S., 481
Psysical-Chem. Untersuchungen, 474
Puget Sound Cement and Lime Co., 471
Pugnax osagensis, 170
Pugnoides ottumwa, 146, 165
Pyramid of Cheops, 185

Q

Quarries in Canada, 101
Quartz in raw gypsum, 392, 393
Quebec, gypsum in, 100
Quensell, E., 522, 523, 536
Quicklime, specific gravity, 63
Quind. Soc. Agr. Ital., 517, 533

R

Ramming gypsum floors, 363
Rangel, Manuel, 102, 492
Ransome, F. L., 479
Rasmusson & Stone, wells by, 159
Rattigen, F., 186
Raw gypsum as accelerator, 278, 371
Raymond Brothers Impact Pulverizer Co., 221
Ready mixed gypsum plasters, 310
Recent epoch, gypsum in, 107
Red Beds, gypsum in, 92
Red Buttes Cement and Plaster Co., 471
Red Sea, Salinas, 115
Redgrave, G. R., 366, 499, 501
Regasche Industrie Zeitung, 508
Regrinding gypsum, 239
Reimer, C. F., on sulphur, 260, 262, 528, 536
Reinforcement in gypsum beams, 345, 349, 463
Retarded plaster, treatment of, 371
Retarder, effect of, on strength, 311, 343; purpose, kinds, application, 240, 310, 370, 377
Retarding of plaster, 309
Rettger, 528
Revue d. Materiaux, 493
Revue Ind., 502
Rhode Island Experiment Station, 527
Rhombopora lepidodendroides, 170
Richard and Warrington, 532

Richards, E. H., 529
Richardson, G. B., 487, 490
Richmond, T. E., 514
Ries, H., 474
Ringland, Captain George, mill of, 194
Rivers, analyses of water from, 122
Robertson, W., 488
Robinson, W. O., 528
Rock Plaster Corporation, 101, 471
Rock Products, 307, 326, 367, 479, 480, 499
Rogers, A. F., 483, 496
Rogers, A. J., on anhydrite, 127
Rohland, P., 474, 494, 495, 497, 498, 508, 509
Roll mills, 213, 218, 221
Rome, use of gypsum in, 186
Roof block construction, 351
Roof slab, 350, 351
Roofs, reinforcement, 350; of gypsum, 349, 426; advantages, 346
Root growth and gypsum, 262
Rosa, E. B., test by, 446
Rosiwal method, 396
Rotary calciners, 235, 239
Rotary kilns for Keene's cement, 367
Rowe, J. P., 482, 536
Royal Society of England, 496, 519
Rubber goods, gypsum in, 271
Ruffin, Edmund, on land plaster, 254
Ruprecht, R. W., 529
Russ. Jour. Expt. Landw., 534
Russell, E. J., 529
Russell, Israel, 124
Russia, gypsum in, 104, 108, 109

S

St. John and Olson, 262
St. Louis limestone, analyses of, 177; gypsum in, 128; on Lizard creek, 163
St. Nicholas Skating Rink, slab floor of, 304
Ste. Genevieve shales, analyses of, 178; at Fort Dodge, 164; on Lizard creek, 166
Salina stage, gypsum in, 89, 93
Salinas, Red Sea, 115
Salt domes, gypsum in, 95, 124, 125
Salt Lake Mining Review, 483
Salt pans, Nile delta, 115
Salts, neutralized by gypsum, 268; in sea water, 111
Sand, production in 1917 and 1918, 31; proper amounts of, 309; suitable, 309; uses of, 32; and strength of plaster, 312
Sand float finish, 310, 316, 337
Satin spar, 63, 71; character, 68
Satin spar veins, 125
Saxony, gypsum in, 103
Scagliola, gypsum in, 306
Scandinavian Coal Company, 134, 181, 199
Schafer, H., 509
Scharf, H., well of, 162
Schimpf, 498
Schmaker, wells by, 159
Schmidt, R., 494
Schneidewind, W., 529
Schott, J., 497
Schwalm, 509
Science, 529
Sciences, technical, Bulletin des, 494
Scientific American Supplement, 499, 501
Scott, P. R., 527
Scratch coat of plaster, 309, 315
Screening gypsum for tests, 400
Screens, 218, 240
Sea water, analysis of, 111; deposition of gypsum from, 111; deposition of salts from, 113
Sebashnikov, V. V., 529, 534
Second settle gypsum, character and uses, 233, 277; strength, 290, 343
Sections along Des Moines valley, 176
Seed gypsum, 72, 106
Seepage, deposits by, 125
Selenite, 63; characters, 66; in Centerville mine, 210; in shale, 121; in Texas, 95
Set-scratch plaster, 316
Setting of calcined gypsum, 277, 408; heat of, 413; volume changes in, 300
Setting time, determination of, 285; factors governing, 288, 419; German method, 287, 405; measurement, 407; Vicat needle method, 286, 412; and retarder, 240; setting time and sand, 309; and temperature, 390; and water used, 288, 420

Severin, S. A., 529
Shady Oak, strata at, 170
Shaler, M. K., 484
Shales, gypsum in, 121
Sharp, L. T., 524
Shearing strength of beams, 457
Shearing stress in beams, 466
Shedd, studies of soils, 259, 529, 536
Sherbakoff, C. D., 529
Sherwin, 494
Shimer formation, gypsum in, 92
Shive, John W., 523
Shull, Charles A., 529
Siebenthal, C. E., 83, 97, 479, 490
Sieve analyses of plaster, 223, 387
Silurian system, gypsum in, 91, 109
Simmermacker, W., 528, 536
Singh, Thakur Mahedeo, 529
Slab floor, tests of, 432
Slab roofs, installation of, 427
Slabs, condition of, after tests, 445; bond, 446; strength, 429; see also gypsum slabs
Slater, W. A., Report on Design of Reinforced Gypsum Beams, 454; tests by, 342, 466, 467, 502, 503, 506
Slosson, E. E., 490
Smith, A. M., 526
Smith, R. A., 482
Smith, R. H., 521
Smith, T. O., 518
Smithe, on land plaster, 256, 512
Snider, L. C., 474, 486
Snyder, H., 530
Soane, 530
Soavo, Marco, 513
Societe Chimique de Paris, 496, 497
Society Chemical Industry, 273, 497, 510
Society Contractors of Federal Buildings, 498, 501
Society Francais de Min., 492
Soc. Geol. Mexico, 497
Society Nat. Agriculture France, 519
Sodium carbonate, neutralized by gypsum, 268
Sodium sulphate in Keene's cement, 366
Soil Science, 514ff
Soils, effect of gypsum on, 248
Soldier creek, gypsum on, 132; exposures on, 136
Soluble anhydrite, 277, 395, 450
Solution surfaces in Fort Dodge gypsum, 205
Sound conductivity of gypsum, 302, 347; tests, 506
Sound tests of plaster board, 334
South Africa Mining Journal, 107
South America, gypsum in, 102
South Australia, Dept. of Chemistry, 72, 77, 106, 227, 474
South Australia, gypsum in, 72
South Dakota, gypsum in, 73, 94, 108; analyses, 76; bibliography, 486
Southard, George L., 282
Southard viscosimeter, 282, 390
Southern Gypsum Company, Inc., 65, 260, 264, 471, 526
Southern Planter and Farmer, 513
Spain, gypsum in, 105, 501
Spalling in slab floors, 444
Spearfish formation, gypsum in, 94
Speicher, E. M., 105
Spencer, A. C., 479
Spirifer littoni, 165; **pellaensis**, 146, 165
Spirorbis, 146
Sprechsaal, 500, 509
Spring deposits of gypsum, 124
Squamularia perplexa, 170
Stake, E. T., well of, 162
State College, see Iowa State College
State University of Iowa, tests at, 219, 281
Statistics of gypsum, 376
Statuary, gypsum in, 306
Steam tests of gypsum, 506
Stearic acid as hardener, 374
Steiger, George, analyses by, 73, 76
Stein, S., 509
Stein und Mortel, 498, 513
Steinkonig, L. A., 528
Stevenson, J. J., 489
Stewart, G. R., 530
Stewart, John E., 471
Stewart, Robert, 530
Stieglitz, Julius, atmospheric equilibrium, 117
Stirring, effect of, on plaster, 289, 422
Stoklasa, J., 530

Stone, R. W., 81ff, 110, 124, 270, 366, 376, 474ff, 530
Stone, W. H., 488
Stone, production in 1917 and 1918, 28; uses of, 29
Stone bridge section, Fort Dodge, 140
Stone Magazine, 478
Stopr, Fred, 530
Stoner, F. H., on land plaster, 257, 495, 530
Stose, G. W., 96, 125, 488
Stratton, S. W., tests by, 64, 303, 510
Strength, effect of ingredients, 311; see compressive strength, tensile strength
Strength measurements of gypsum, 409
Strength of structural gypsum, 348
Strength tests of gypsum, 506
Strest, J. P., 530
Stretch in cables, tests of, 438
Structural gypsum, 194, 342, 348; weight, 294, 347
Stucco, definition, 304; exterior, gypsum in, 306
Suchting, 530
Sugar cane, effect of gypsum on, 268
Suler, 519
Sulphur, gypsum with, 86, 105; from gypsum, 265; in crops, 258; in soils, loss by drainage, 259; tests of gypsum, 507
Sulphur trioxide in cement, 246
Sulphuric acid from gypsum, 271
Superior Plaster Co., 471
Surface hardening, 374
Surgical uses, gypsum for, 306
Surr, G., 478, 497
Swanson, C. O., 530
Switzerland, gypsum in, 104; bibliography, 493; agricultural gypsum in, 248

T

Takeuchi, 531
Talmage, J. E., 488
Tamping process of making floors, 364.
Tartar, H. V., 528
Taxidermy, gypsum in, 307
Technology of gypsum and gypsum plasters, 211
Temperature, effect of, on time of set, 390, 423, 424; maximum, 414; in calcining, 232, 233; rise of plaster, 414, 415; and time of set, 416.
Temperatures for Keene's cement, 366
Tensile strength of calcined gypsum, 294, 298, 302, 343, 388, 389, 402; of briquettes, 299; of cement, 302; of plaster, 311; minimum, 314; of gypsum beams, 455
Terra alba from gypsum, 270
Test floor, construction of, 432; panel, size of, 435; slab, age and seasoning, 435
Tests of gypsum products, 383; of slab, instruments used, 436
Texas, gypsum in, 94, 108; bibliography, 487; selenite in, 67
Texas Agricultural Exp. Station, 520
Texas Cement Plaster Co., 471
Texas Geological Survey, 108, 487
Texas University Bulletin, 487
Thalau, Walter, 531, 534
Thermal conductivity of gypsum, 506
Thomas, A. O., 146, 169, 480
Thompson, 531
Thompson, Alice R., 535
Thonindustrie Zeitung, 358, 492
Thorne, C. E., 531
Thorpe Brothers, well by, 156
Three-coat plaster, 315
Three Forks Portland Cement Company, 88, 471
Thuringia, gypsum in, 103
Tietze, see Dammer und Tietze
Tile, gypsum, 323
''Time of pouring'' gypsum, 401
Time of set of gypsum, 384, 388, 390, 405, 407; method of determining, 417, factors, 419
Time of working, effect on strength, 410
Tingry, 520
Tonindustrie, see Thonindustrie
Tormin, 475
Tottingham, W. E., 522, 531, 534
Transylvania, gypsum in, 107
Tressler, D. K., 531
Triassic, gypsum in, 94, 103, 105, 108; age of Iowa gypsum, 172
Trilobite, 146
Tripoli, gypsum in, 107
Tritschler, 531

Troug, E., 531
Trowel finish, 310, 316
Troxell, E. R., 502
Trumbull, L. W., 491
Truss action in beams, 466
Tschiffeli, M., 249
Tunis, gypsum in, 107, 108
Turkestan, gypsum in, 105
Turkey, gypsum in, 105
Turkey Creek Stone, Clay and Gypsum Co., 471
Tutton, 496
Two-coat plaster, 316
Two Mile creek, gypsum on, 153
Tyrrell, J. B., 491
Tyssowski, J., 491

U

Udden, J. A., 487; theory of anhydrite, 130
Unconformities at Fort Dodge, 173
Underwriters Laboratories, specifications, 327; tests, 504-507
United Kingdom, gypsum produced in, 382; see England
United States, gypsum deposits of, 79; bibliography, 475; gypsum companies in, 468; gypsum produced in, 376, 382
United States Bureau of Mines, 82ff, 270, 467, 474
United States Bureau of Standards, 64, 65, 375, 383
United States Department of Agriculture, 129, 266, 270, 494, 513
United States Geological Survey, 5, 63ff, 181, 210, 376, 392, 474ff
United States Gypsum Company, 195, 196, 245, 425, 471, 505
United States Navy, tests by, 426, 467, 502
Universal Gypsum Company, 196, 199, 470
University of Illinois, 506
University of Iowa, analyses by, 208; tests at, 295
University of Texas, 130
University of Wisconsin, 507
Urban, J., 531, 535
Usiglio, work of, 119
Utah, gypsum in, 95, 107, 108; bibliography, 488
Utah Natural Products Co., Inc., 472

V

Valve-packer, 243
Van Bemmelen, 531
Vanino, 509
Van't Hoff, J. H., 64, 474, 496, 508; and Meyerhofer, 129
Van Tuyl and Weller, 164, 165
Vercier, J., 531
Vermoral, V., 535; and Danthony, E., 531
Viaduct section, Fort Dodge, 138
Vicat needle for measuring set, 281, 390, 411, 416
Victoria Department of Agriculture, 527
Vie Agr. et Rurale, 534
Vincent, Webb, mill of, 194
Vincent Clay pit, 150, 170
Virginia, gypsum in, 96, 109; analyses, 74; bibliography, 488
Virginia Agricultural Experiment Station, 514
Virginia Jamestown Exposition, 489
Virginias, The, 488
Viscosimeter, see Southard
Viscosity measurements of plaster, 422
Voelcker, Augustus, 532
Voelcker, J. A., 532
Volume, changes in, 299
Von Seelhorst, 518
Von Waldegg, H., 228, 357, 364, 365, 368, 374, 473, 474

W

Wagner, P., 532
Walkenried, medieval cloister of, 364
Wall board, character, 305, 338; application, 319; manufacture, 340; production, 379; coloring, 375; see plaster
Walter, Seth S., 517
Ward, Mr., mill of, 196
Warner, H. W., 516
Warrington and Richard, 532
Wasem Plaster Co., mill of, 192, 196, 472

Washburn College, tests at, 312
Washington, George, use of land plaster by, 254, 512
Washington, State College of, 475
Washington Agricultural Experiment Station, 262, 514
Water in gypsum mines, 213; tests of gypsum, 504; used and consistency, 282; and setting time, 288, 420; and tensile strength, 295, 298, 313; and viscosity, 424
Watertown Arsenal, tests by, 64
Watson, F. R., tests by, 334, 506
Watson, T. L., 489
Way, J. T., 532
Webb, S. G., 501
Webster County Poor Farm, wells on, 156
Weed, W. H., 87, 483
Weems, J. B., analyses by, 207
Weidner, 500, 501
Weigert, 495
Weight of calcined gypsum, 280
Weigmann, H., 530
Weller, Stuart, 164; and Van Tuyl, 164, 165
Wentworth Gypsum Co., 101
West, Mr., quoted, 250
Western Society of Engineers, 342, 344, 467, 503
Wheeler, H. J., 532
Whitacre, J. J., tests by, 342
White, C. A., 132
Whittier, 494
Whiting, Albert L., 523
Wiegner, George, 532
Wilder, Frank A., 132, 136, 140, 143, 147, 158, 171, 192, 236, 303, 474, 479, 480, 493, 494, 510; Report on Gypsum, 47
Wilhoit, 492
Wilkins, 525
Wilkinson, P., 499
Will and Korner, 532
Williams, C. G., 531
Williams, S. G., 485
Willis, L. G., 525
Wilms, 518
Wilson, J. K., 532
Windsor Plaster Co., Ltd., 101, 472
Winterbottom, D. C., tests by, 72, 227, 288, 474, 493
Wire, lath and grounds, 315, 318
Wisconsin Agricultural Exp. Station, 258, 520
Withey, M. O., tests by, 467, 507
Wittich, E., 497
Wolf-Osterberg, 533
Wolff's Ash Analysis, 257, 532
Wood chips in gypsum slabs, 428; fibre, 241; fibre machines, 241; fibre plaster, 308, 309; lath and grounds, 315
Woodworth, Phillip B., tests by, 506
Woolworth, P. D., tests by, 334
Working of plaster, effect on strength, 410
Working stresses in gypsum beams, 457, 462
Workman, Albert C., 514
Workmanship of plaster, 320
Worthen, A. H., 132
Wright, C. W., 476
Wurtemberg, agricultural gypsum in, 248; gypsum in, 104
Wyoming, gypsum in, 97, 108; analyses, 75; bibliography, 489
Wyoming Agricultural College, 490
Wyoming University, 490

Y

Yakushkin, 520
Yield of gypsum, 389

Z

Zahnheilk, Corresp., 510
Zaphrentis, 170
Zechner, 498
Zeckstein formation, gypsum in, 103
Zhur. Russ. Fiz. Chim. Obsch., 533
Zinc, production in 1917 and 1918, 44; as hardener, 374, 375; as accelerator, 372
Zolla, D., 533
Zuckerindus. Bohmen., Ztschr., 535
Zulkowski, 511

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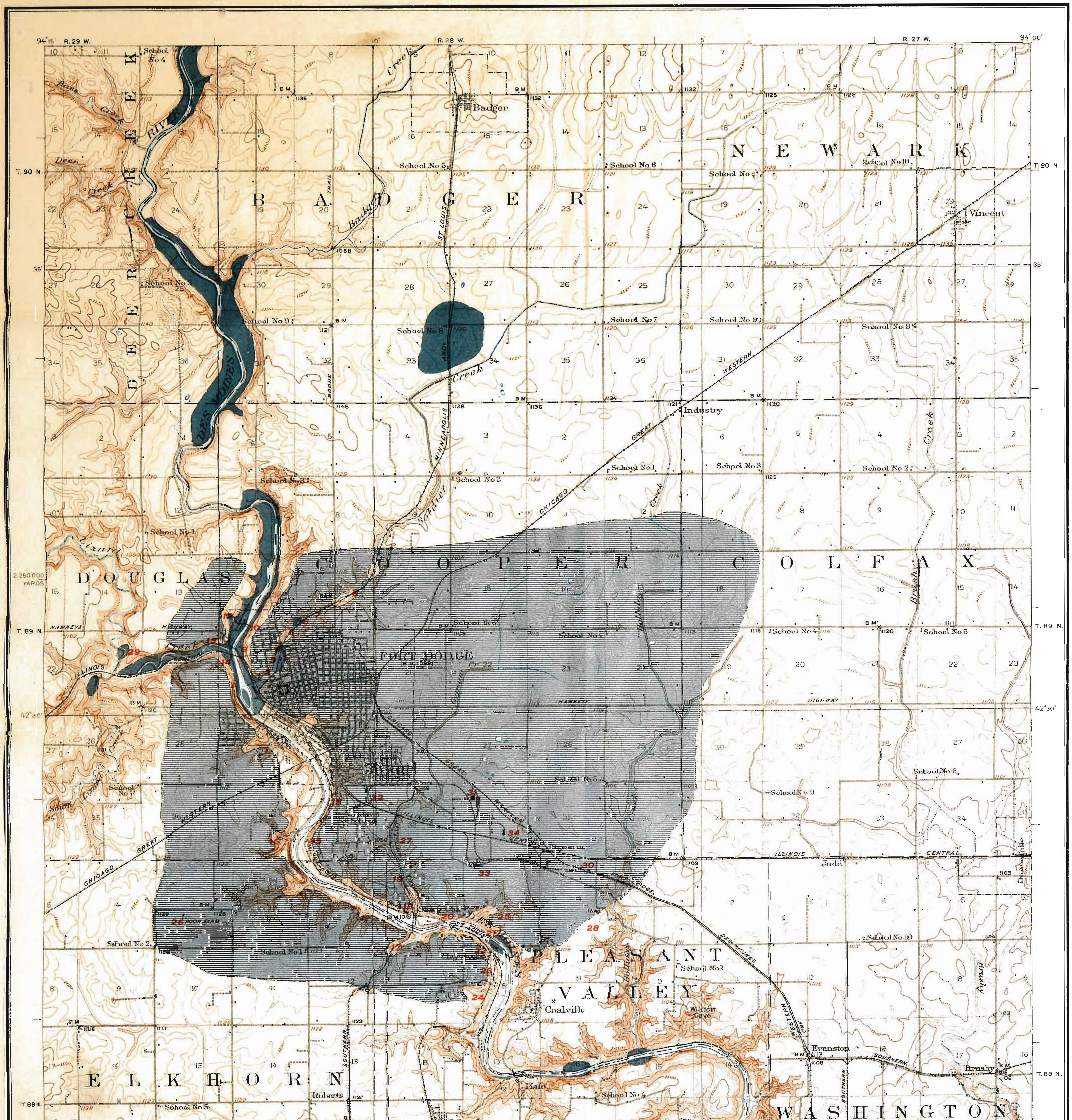
IOWA
FORT DODGE SPECIAL QUADRANGLE



WILLIAMS-WEBB CO. INC., WASH. D. C.

LEGEND

▤

PERMIAN

Fort Dodge beds

Gypsum is generally present in this area though in some places it has been removed by erosion. The line on the north and east is only approximate.

☐

PENNSYLVANIAN

Des Moines

Includes all the area which is not colored

■

MISSISSIPPIAN

Includes Ste. Genevieve and St. Louis

CONVENTIONAL SIGNS

CULTURE *(printed in black)*	RELIEF *(printed in brown)*
Towns and cities	2766 Figures *(showing exact heights above mean sea level)*
Railroads	Contours *(showing height above sea, horizontal form, and steepness of slope of the surface)*
Electric railroads	
Roads	Depression contours
	DRAINAGE *(printed in blue)*
Private roads	
Bridges	Rivers
Fords	Creeks
County lines	Ponds
Township lines	Springs
Triangulation stations	Swamps

C. H. Birdseye, Chief Topographic Engineer.
W. H. Herron, Division Topographic Engineer.
Topography by W. L. Miller and J. M. Rawls
Control by F. J. McMaugh, J. M. Rawls, and F. L. Whaley.
Surveyed in 1919 and 1921.
SURVEYED IN COOPERATION WITH THE STATE OF IOWA
Geology by Frank A. Wilder and James H. Lees.
of the Iowa Geological Survey

Miller
Rawls

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1000 500 0 1000 2000 3000 4000 5000 6000 7000 Yards

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 10 feet.

Datum is mean sea level.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1921