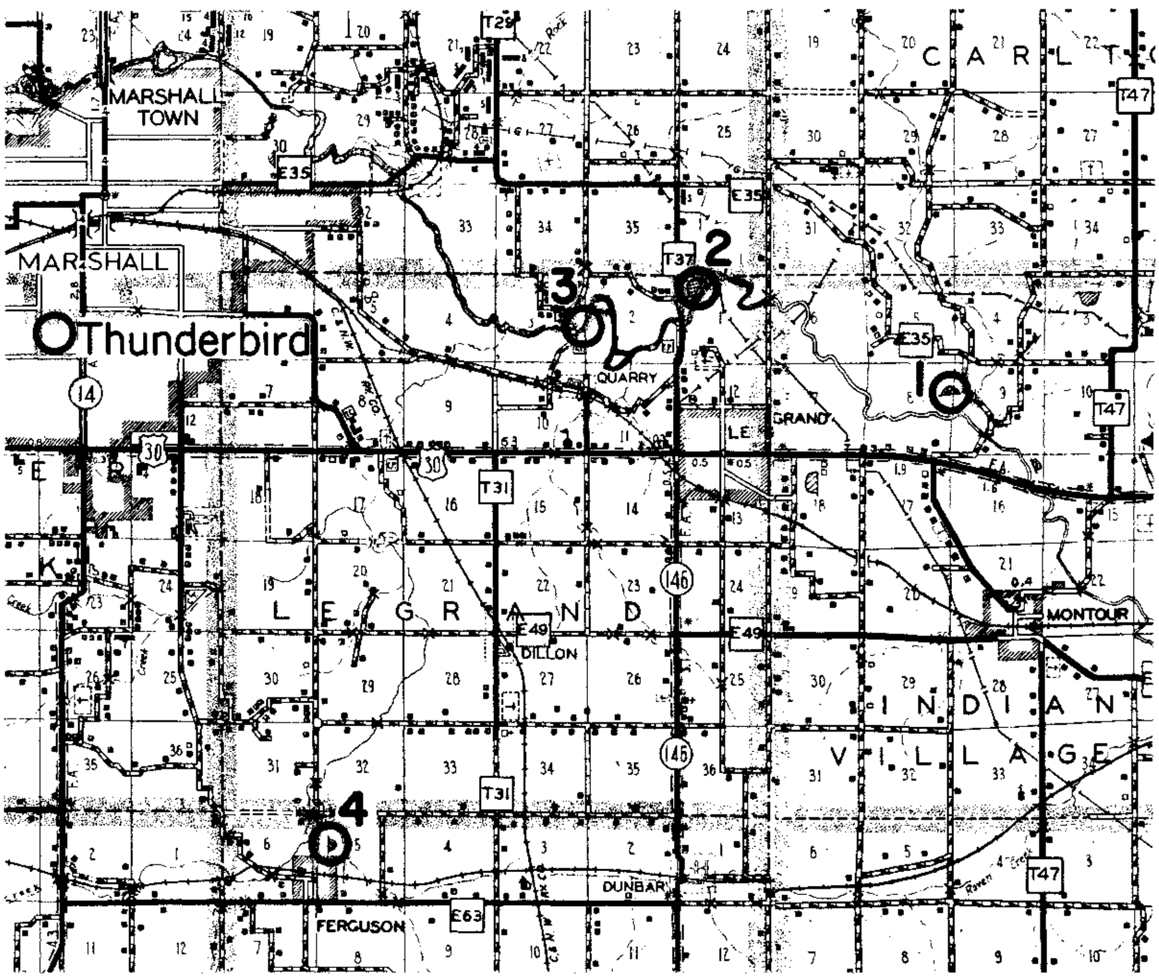
MISSISSIPPIAN CARBONATES of the LE GRAND AREA: ANCIENT ANALOGS of the BAHAMA BANKS

Brian F. Glenister



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Guidebook 47

Mississippian Carbonates of the Le Grand Area: Ancient Analogs of the Bahama Banks

by

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INTRODUCTION

Geological reconnaissance of the carbonates exposed along the Iowa River in the vicinity of Le Grand was initiated by D. D. Owen in 1939 (Owen, 1852). James Hall, "Foundation Professor of Geology, Zoology and Natural History" at The University of Iowa was the first to report crinoids from the area, and subsequent descriptions of these spectacular fossils (Miller & Gurley, 1889; Wachsmuth & Springer, 1890; Miller & Gurley, 1894; Wachsmuth & Springer, 1897; Laudon & Beane, 1937) earned international repute for the site.

Facies change is rapid in the Le Grand area, both vertically and laterally, and the full range of carbonate environments, from oolite shoals to restricted shoreline carbonate muds, occurs within a few miles. These complex facies relationships and their time correlation will provide the focus of the field trip.

F. M. Van Tuyl (1925) was the first to propose subdivision of the carbonates that are now termed the Hampton Formation and referred to the Early Mississippian (Kinderhookian). He recognized, in ascending order, the Chapin, Maynes Creek, Eagle City and Iowa Falls (Fig. 1). Pioneer biostratigrapher L. R. Laudon (1931, 1933; Laudon & Beane, 1937) initiated the modern phase of study by suggesting time equivalence of some of the previously-proposed lithic units.

Detailed lithostratigraphic and biostratigraphic studies of Kinderhookian strata near Le Grand, as well as those at Burlington and Gilmore City, were begun by Alan B. Shaw in 1974, in preparation for the Amoco Production Co. Field Seminar on Stratigraphic Principles. Shaw and Glenister served annually as co-leaders of this Seminar from 1976 to 1981. The Modern Phase of the Seminar involved investigation of Holocene carbonate environments in South Florida. It was followed by a ten-day 1,400-mile Ancient Phase traverse of the Mississippian, from western Illinois to western Montana. Predictability of facies patterns in space and time was stressed throughout. Some of the illustrations from the Amoco Guide are included herein, where they are acknowledged as "Shaw, 1981". Three University of Iowa Master of Science theses dealing with different aspects of the Mississippian of central Iowa (Hager, 1981; Lawler, 1981; Ressmeyer, 1983) received partial support from Amoco, and provided background data for the Seminar. All three were used extensively in preparation of the present guide.

Four stops are planned for the day (# 1-4, front cover). The first three (B. L. Anderson Montour Quarry, Cessford Construction Le Grand Quarry, Three Bridges County Park) lie within a distance of 5 miles along the Iowa River.

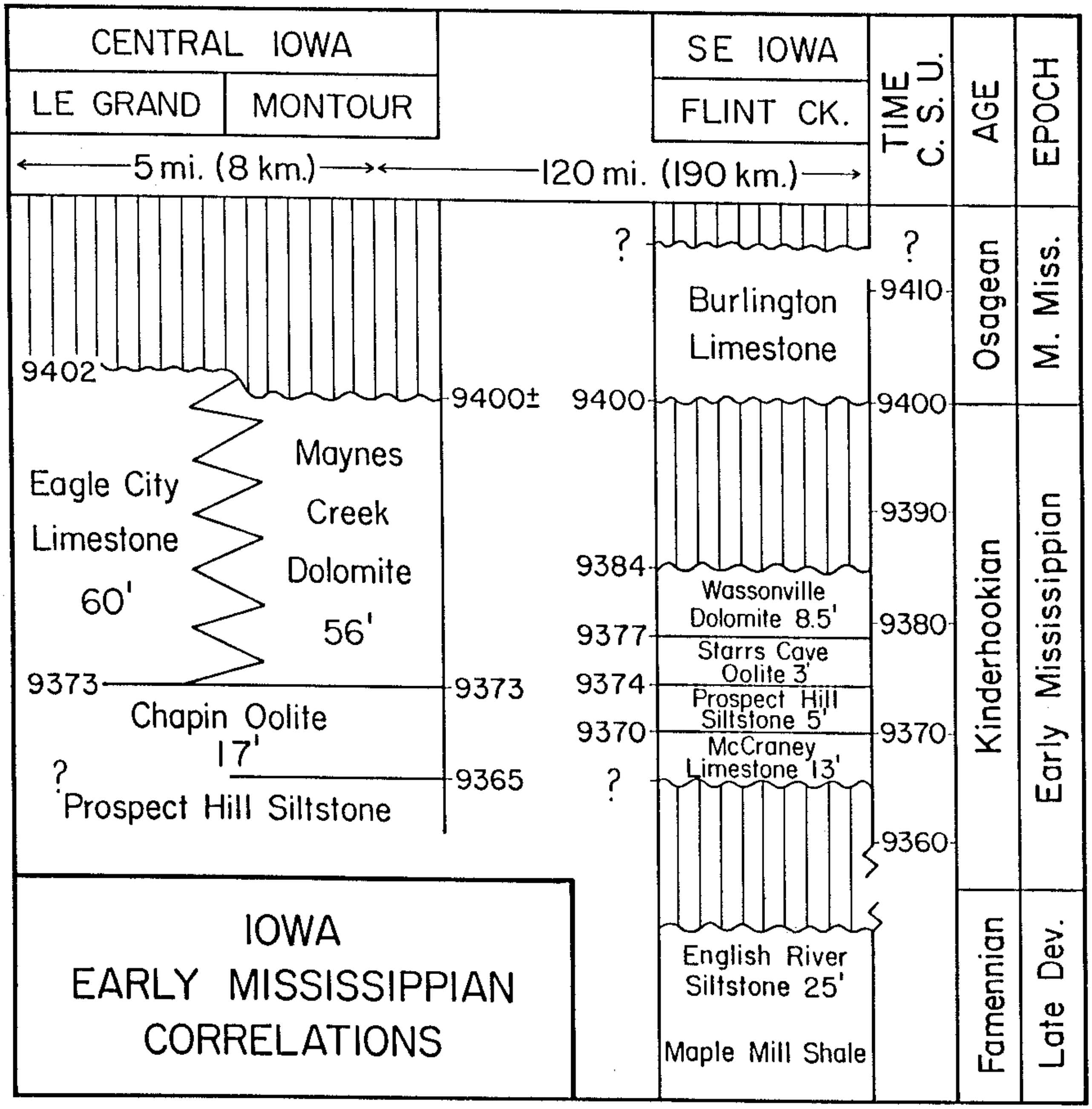

Figure 1. Correlation of Early Mississippian sections, based on graphic methods (Shaw, 1964; Miller, 1977) that utilize all known taxa. Time is expressed as Composite Standard Units (C.S.U.). These C.S.U. result from an equal subdivision of the Mississippian into 1400 parts, accepting the Elsevier (1975) estimate of 35 million years for the Period. The value 9400 was chosen for the base of the Burlington Limestone at Flint Creek and has been projected elsewhere by graphic correlation. Flint Creek is the Starrs Cave Park and Preserve section in the Burlington area of southeastern Iowa. Approximately 120 mi (190 km) distant in central Iowa, Montour is the B. L. Anderson Quarry, Sec. 9, T 83N, R 16W, Tama Co.; and Le Grand is the Cessford Construction Company Quarry, Sec. 1, T 83N, R 17W, Marshall Co. (from Glenister, 1987). See Appendix A herein.

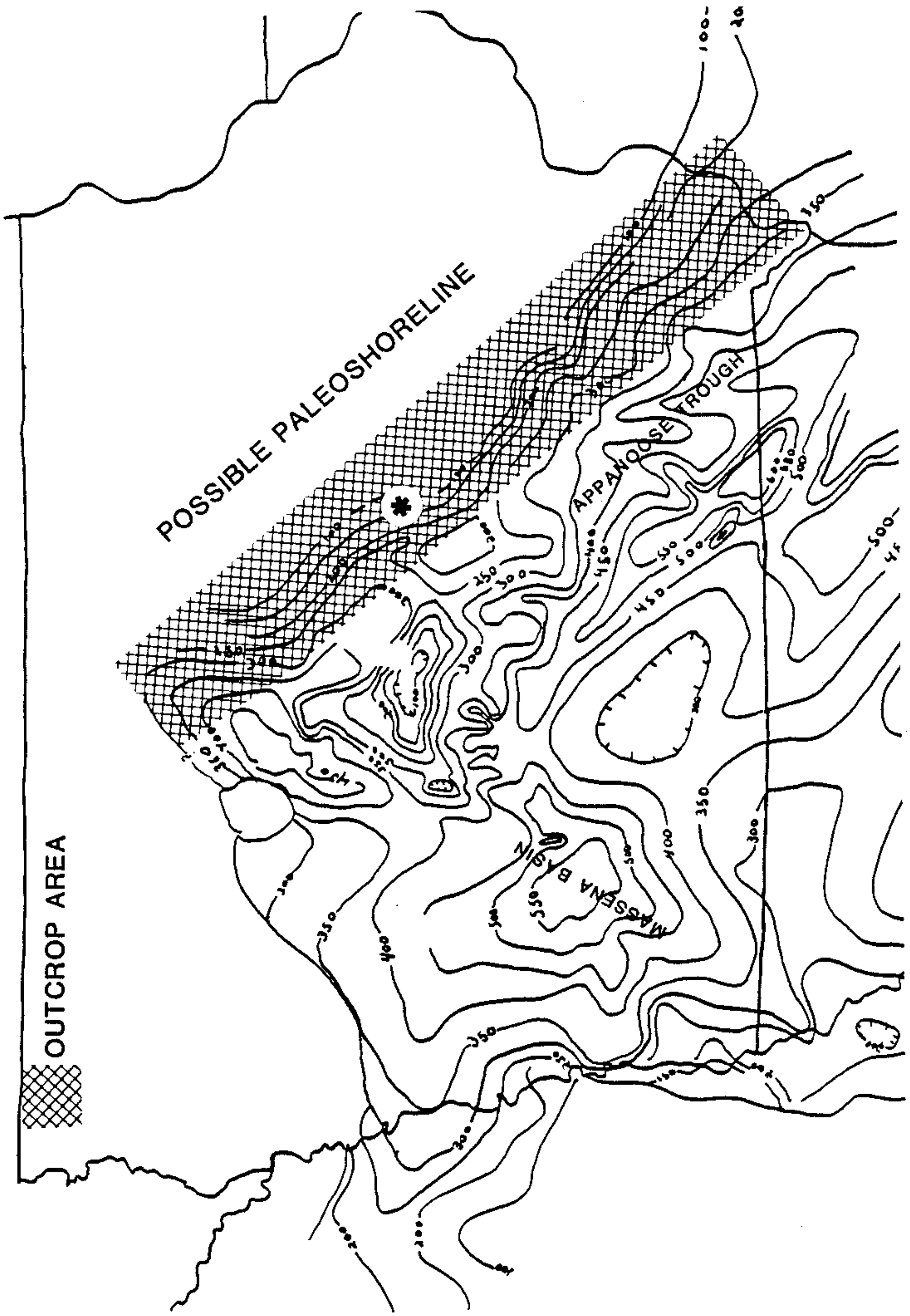

Figure 2. Isopach of Mississippian strata, delineating Appanoose Trough and Massena Basin. The Le Grand area, marked with "*", was situated along the northeastern margin of the Appanoose Trough (after Ressmeyer, 1983, and B. J. Bunker, pers. comm., 1983).

They are close to the erosional edge of the Mississippian exposures, and facies restriction suggests that they are probably no great distance from the paleoshoreline along the northeastern flank of the Appanoose Trough (Fig. 2). The Chapin Oolite maintains its identity between these quarries, and provides an isochronous datum below diverse facies of the immediately superjacent upper Hampton Formation (Fig. 1). This upper Hampton is primarily dolomite at Montour, where it is referred, logically, to the Maynes Creek Dolomite. Within 5 miles, at Cessford and Three Bridges, the facies overlying the Chapin are primarily limestone, and are referred to the Eagle City Member of the Hampton Formation (Fig. 1). Some interfingering of the facies will be observed in the thick quarry sections to be visited. However, such variability, when coupled with less satisfactory exposures, resulted in an unnecessarily complex lithostratigrahic nomenclature (Fig. 3). While expressing admiration for this early work, it now appears that complexities of the sedimentary and diagenetic facies in the Early Mississippian of Iowa are such that lithostratigraphic definition is close to losing all useful function. When time lines are introduced, especially with the precision of graphic correlation (Fig. 1, Appendix A), all lithic units prove to be diachronous, and many of the established lithostratigraphic units can be demonstrated to be mere facies equivalents of each other (Fig. 4). However, distribution of these facies in space and time displays patterns that are both logical and predictable in reference to the Irwin-Shaw Clear Water Model of Autochthonous Sedimentation (Fig. 5).

The final stop will be the Martin Marietta Ferguson Quarry, 6 miles to the southwest of Le Grand. There, a thin sequence of Medial Mississippian Burlington Limestone overlies the Hampton. This represents the northwestern limit of the Burlington facies; further to the northwest, in northcentral Iowa, the time equivalents (Osagean) comprise the shoal carbonate facies of the Humboldt Oolite (Glenister & Sixt, 1982; Baxter & Brenckle, 1982; Brenckle & Groves, 1986). The top of the Chapin Oolite at Ferguson lies 12 feet beneath the quarry sump, but almost 75 feet of interbedded dolomites and limestones (Maynes Creek and Eagle City facies) of the upper Hampton are accessible in the quarry walls (Hughes, 1977). Cross-bedded oolites and hardgrounds characterize this upper part of the Hampton Formation at Ferguson Quarry, and the sequence represents one of the few oolite "factory" areas recognized in Iowa.

STOP #1, B. L. ANDERSON MONTOUR QUARRY

Orientation

Figures 6, 8 and 9 portray the Early Mississippian section at Montour. The main floor of the quarry is the contact between the Prospect Hill Siltstone and the Chapin Oolite, corresponding to the abrupt change from the reddish-brown dolomitic siltstone beneath to the yellowish-gray oolite above. A few feet of the siltstone are exposed periodically, in drainage ditches, along the eastern margin of the quarry. The lower face comprises the Chapin Oolite, all levels being easily accessible from either the quarry floor or the several ramps that lead to the first bench. The high wall is the Mayes Creek Dolomite; basal beds can be sampled from the first bench, and much of the remainder is accessible in relative safety from the track, above the main face, along the west and south sides of the quarry.

Objectives

a) Introduce the Lower Mississipian sequence in the Le Grand area.

b) Interpret and contrast environments of deposition of the Prospect Hill, Chapin and Maynes Creek.

c) Examine abundant fossils, especially those of the Chapin and the "Eagle City tongues" of the upper Maynes Creek, that permit demonstration of diachronism for each of the members (Fig. 1).

Commentary

Prospect Hill Siltstone

The Prospect Hill maintains its identity across the entire Iowa outcrop belt as a yellowish-brown dolomitic quartz siltstone. Spoil heaps from the Montour drainage ditches reveal a diverse fauna, including numerous shark teeth as well as brachiopods and large clams, snails and nautiloids. Invertebrates occur as poorly preserved molds, and have not been studied in detail at this locality. However, the fauna from the type area, near Burlington (summary in Glenister, 1987) has been investigated repeatedly.

Chapin Oolite

In the Le Grand area, the Chapin Oolite comprises a thick bedded, cream to white, medium-grained oolitic grainstone (Lawler, 1981). Bedding planes are commonly characterized by stylolitic surfaces, generally exhibiting concentration of the pyrite that is widely disseminated throughout the unit. Several hardground surfaces, especially the one that appears near the middle of the formation (Fig. 10), can be traced into nearby quarries. As in most Chapin exposures, virtually no cross-bedding is apparent at Montour, suggesting that this is not an ooid "factory" area. Bimodal size distribution of the ooids at many levels (Fig. 11) supports the contention that grains have been transported from some source area. Contact with the overlying Maynes Creek Dolomite is sharp, with truncation of ooid grains.

Regionally, the Chapin/Starrs Cave interval thickens markedly to the southeast, especially in the subsurface of Appanoose and Davis counties (Fig. 12). The unit is pervasively dolomitized in the type area of northcentral Iowa, but consists of oolitic limestone in central Iowa, and crinoidal limestone in southern Iowa (Fig. 13).

All facies of the Chapin/Starrs Cave interval are richly and diversely fossiliferous. At Montour, brachiopods predominate (Figs. 14-22), although euomphalid snails and exquisitely-preserved delicate pectinacean bivalves (*Pernopecten cooperensis*) are abundant at some horizons.

Maynes Creek Dolomite

Facies of the Maynes Creek are highly variable, both vertically and laterally. At Montour, the unit is extensively dolomitized and silicified. It was deposited as shallow marine to supratidal carbonate mud, with

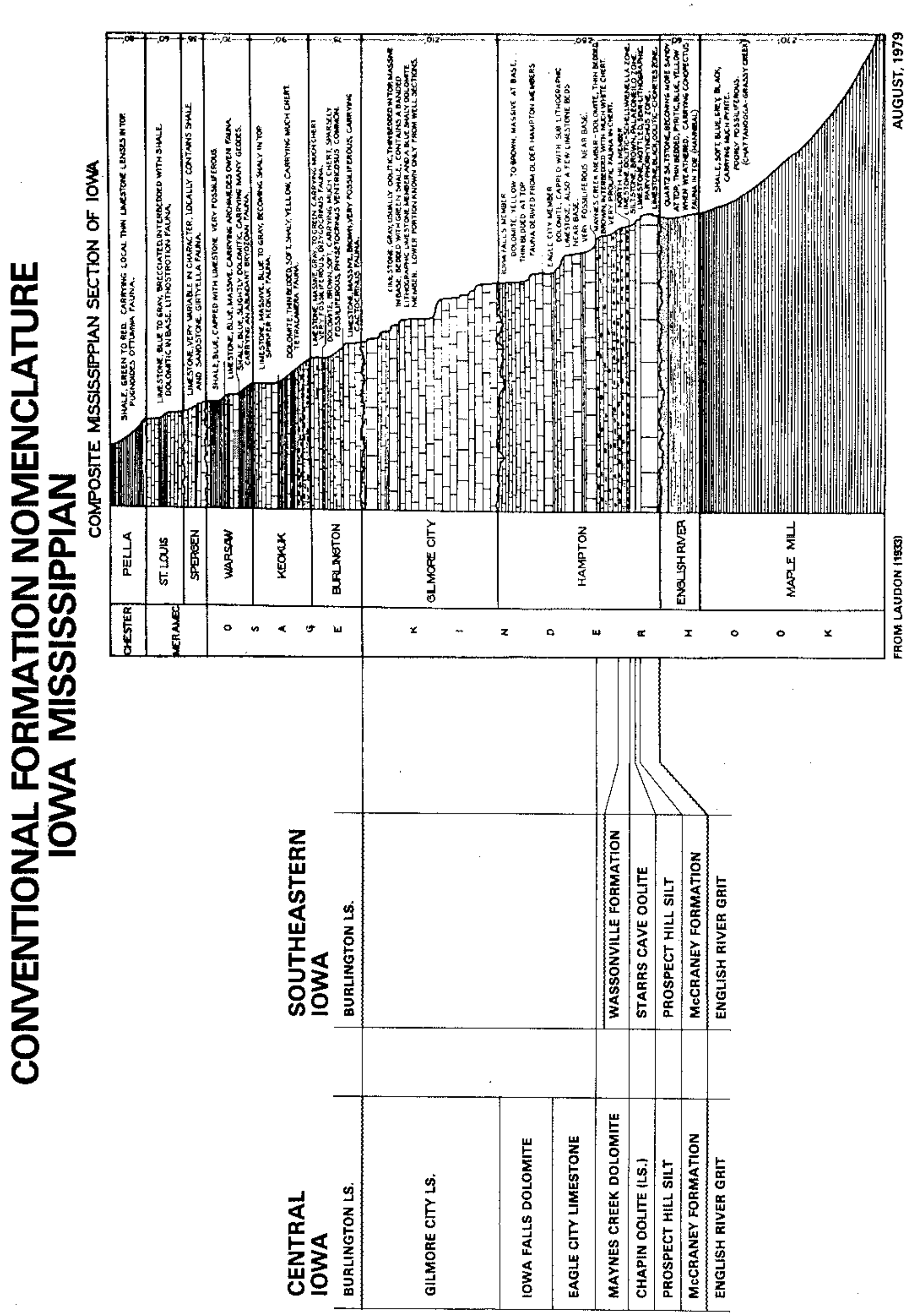

Figure 3. Traditional nomenclature for Iowa Mississippian formations, based primarily on lithostratigraphic succession (composite section from Laudon, 1933).

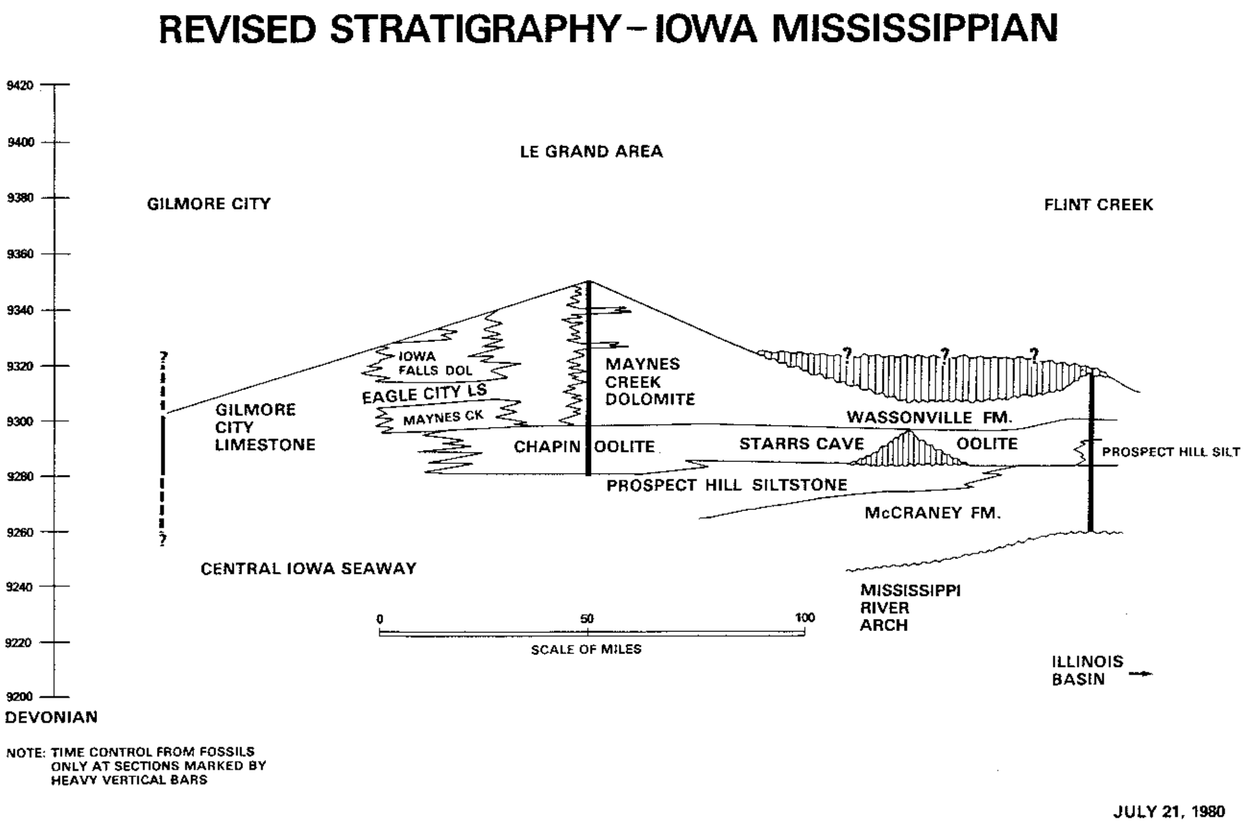

Figure 4. Facies relationships, based on graphic correlation. Figures at left margin are C.S.U. representing time (Fig. 1, Appendix A); 9200 is base of Mississippian, and 9400 is base of the Burlington Limestone at Flint Creek, Burlington (after Shaw, 1981).

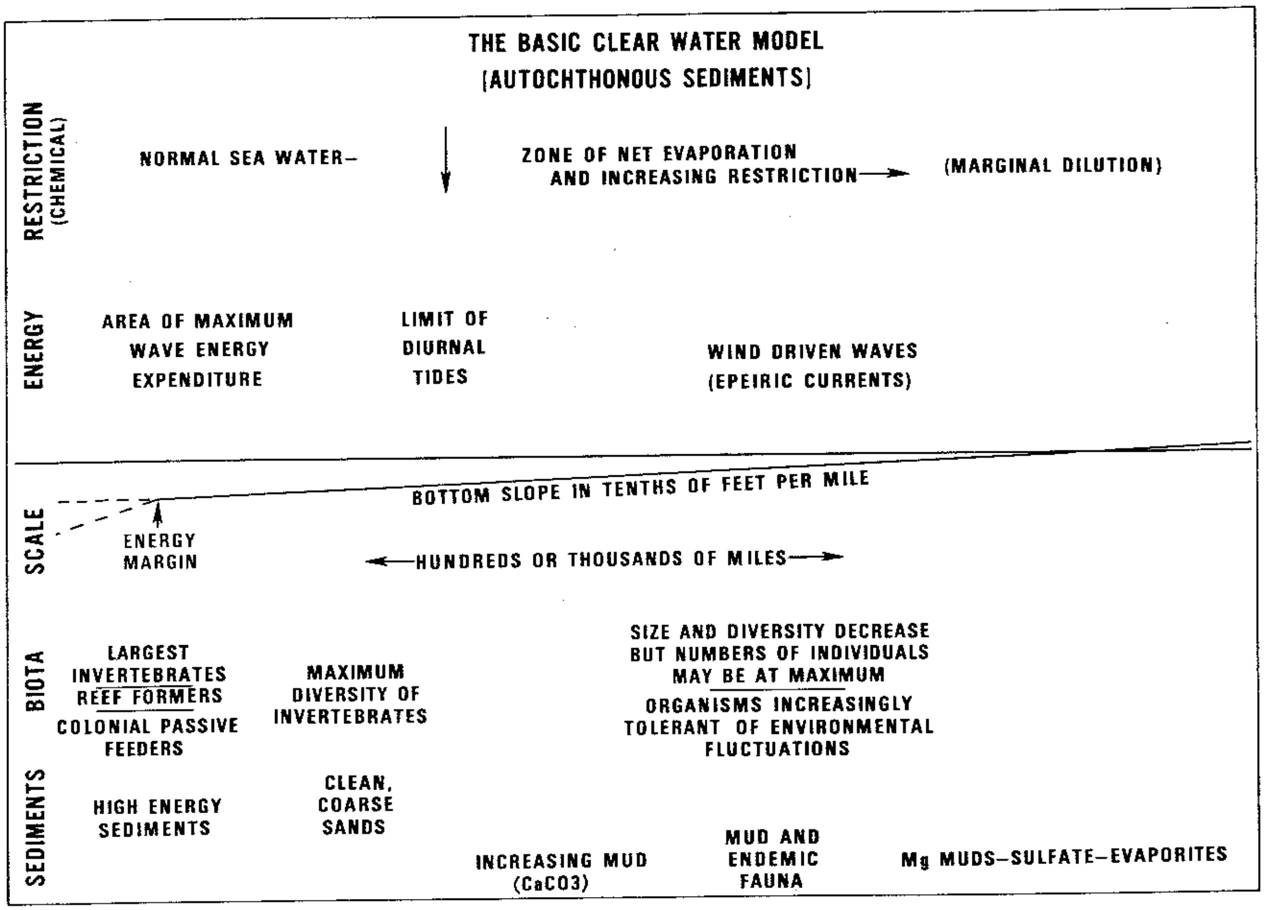

Figure 5. Clear Water (predictive) Model of Autochthonous Sedimentation. Geometry (scale) of sea floor, from shoreline to shelf (energy) margin, determines wave energy and current circulation. These factors in turn largely determine water chemistry, and ultimately the distribution of biota and the sediments they produce (from Shaw, 1981).

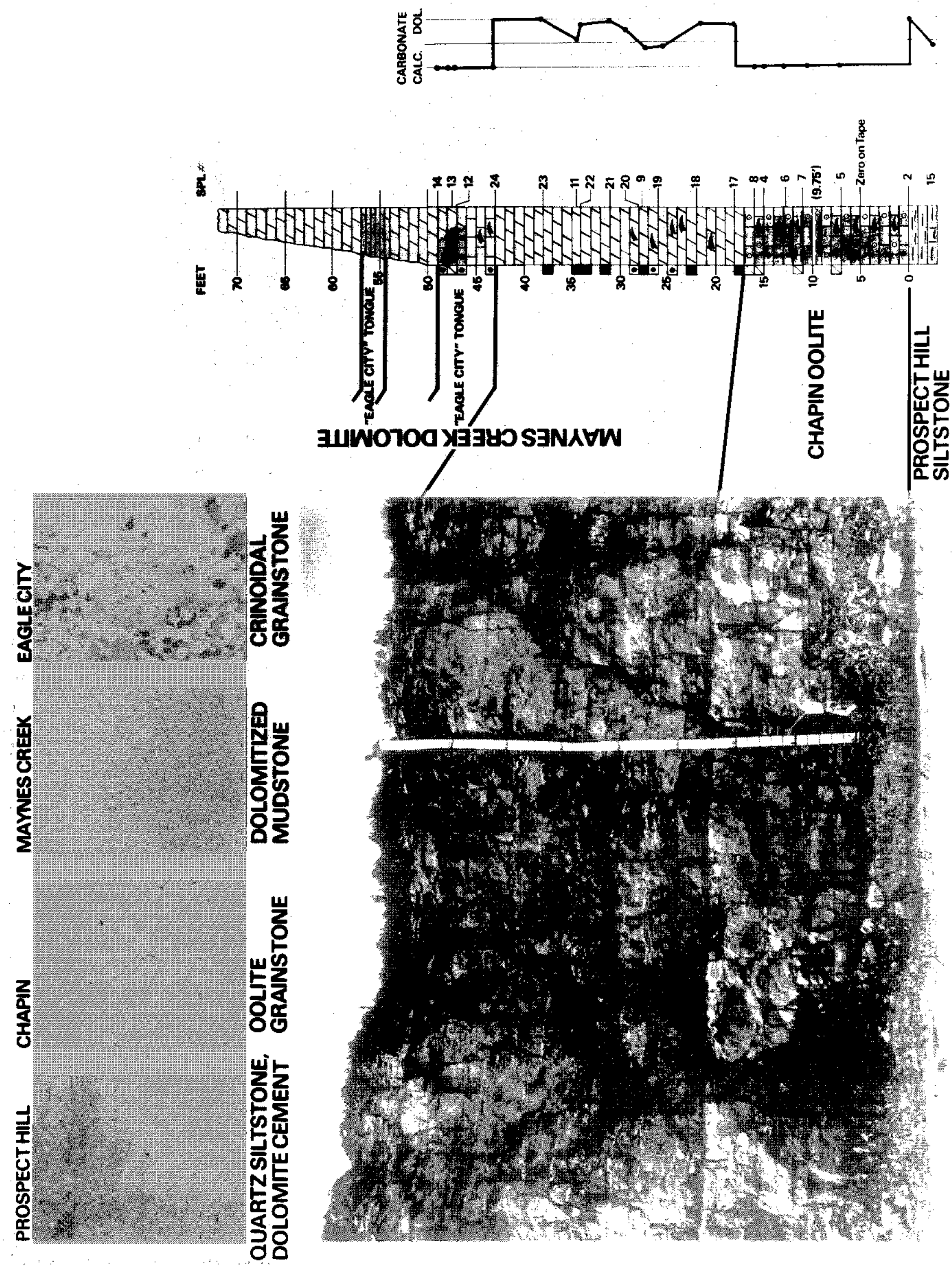

Figure 6. Stratigraphic section, calcite/dolomite content, and representative lithologies, B. L. Anderson Montour Quarry (from Shaw, 1981).

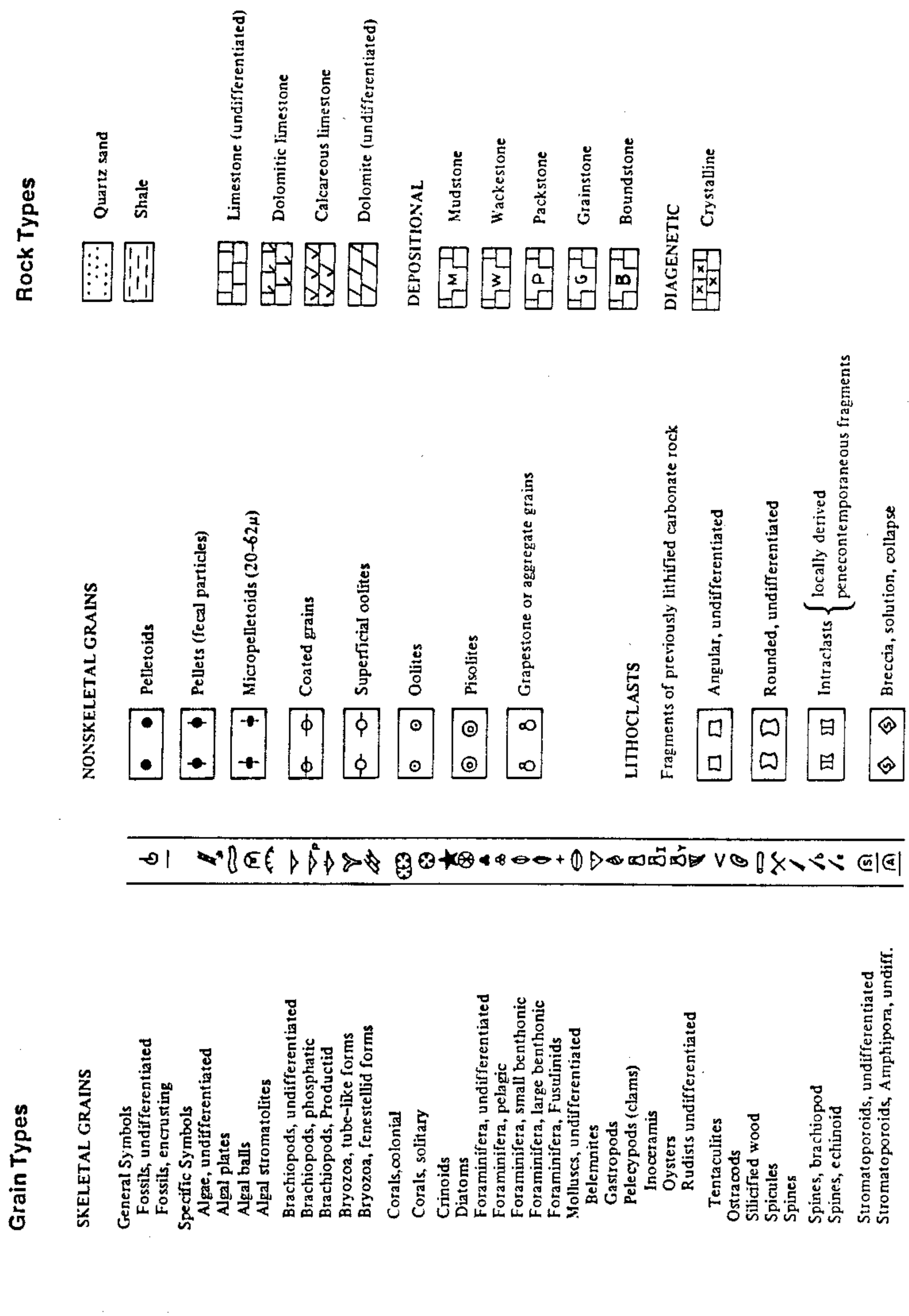

Figure 7. Symbols for grain and rock types used herein in Figures 8, 23, 25 and 27 (Shell Oil Co. standard legend).

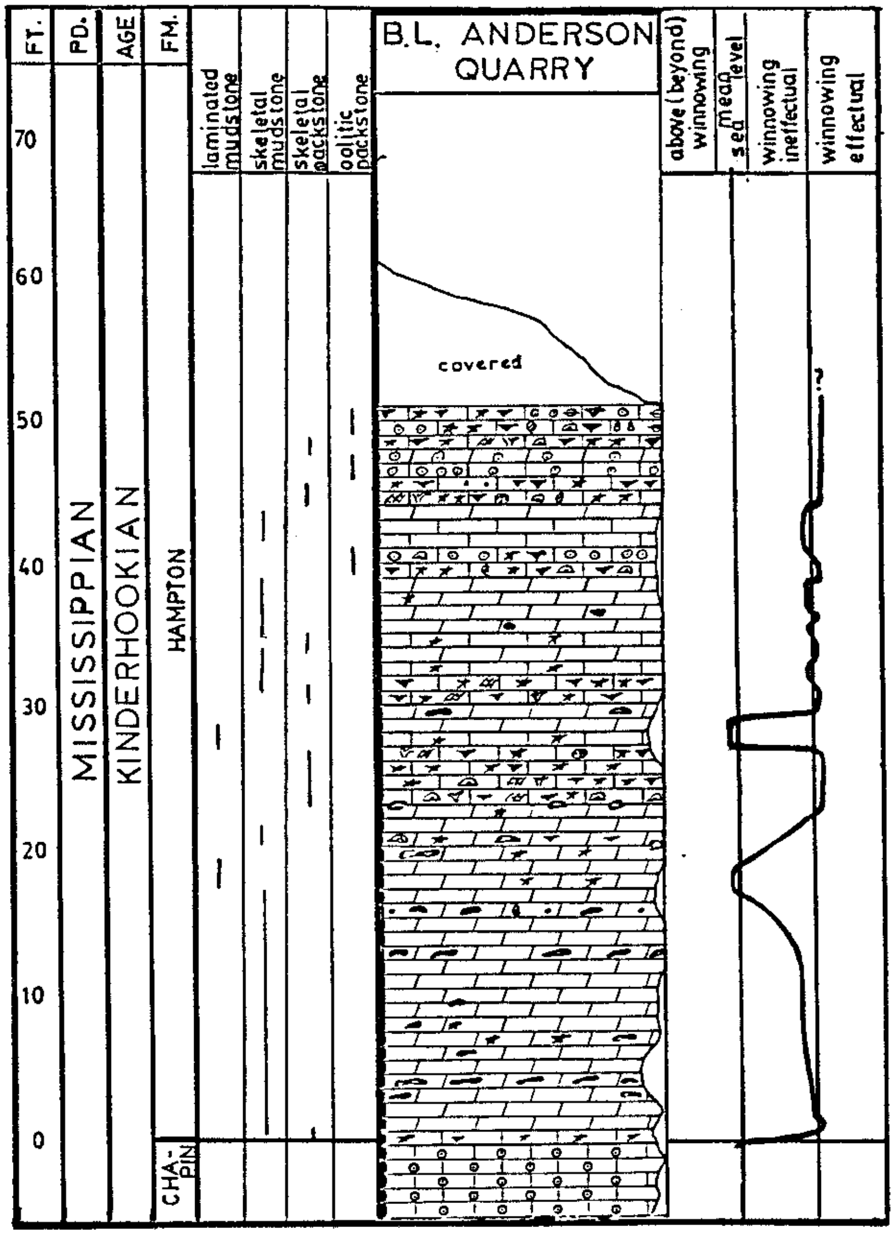

Figure 8. Stratigraphic section, B. L. Anderson Montour Quarry (from Hager, 1981). Symbols, Figure 7 herein.

Sample Number	Footage	% Calcite	% Dolomite	% Quartz	Other	Md Perm.	% Porosity
EAGLE CITY							
14	49	97		3			
13	47.5	94		6			
12	47	97		3			
24	43	100		Tr			
MAYNES CREEK							
23	38	1	98	1			
11	34.1	43	54	2	1% Anhydrite		
22	34	9	89	2			
21	31	2	96	2			
20	28	25	75	Tr			
9	27-28	56	40	3	1% Anhydrite		
19	26	54	46	Tr			
18	23	11	89	Tr			
17	18	15	85	Tr			
CHAPIN OOLITE							
8	16	97		3			
4	15	97		3		0.1	7.6
7	11. 2	97		3			
5	7	97		3		0.2	9.2
PROSPECT HILL							
2	0	1	25	66	4% Feldspar 3% Kaolinite 1% Illite		
15	-2.7	25	20	45	6% Feldspar 4% Kaolinite		

Figure 9. X-Ray diffraction mineral percentages and permeability-porosity data, B. L. Anderson Montour Quarry. Footages are expressed in relation to the top of the Prospect Hill Siltstone, which forms the quarry floor (after Shaw, 1981).

subordinate thicknesses of beds with concentrations of skeletal and oolitic grains. The sequence of major diagenetic events involved penecontemporaneous dolomitization of laminated carbonate muds, silicification of some dolomite and fossil debris to form nodules and irregular tabular bodies, pervasive dolomitization with contemporaneous or subsequent removal of most remaining carbonate mud, cementation by poikilotopic calcite, and selective dissolution of dolomite (Hager, 1981).

Few fossils occur in the basal two-thirds of the Maynes Creek at Montour, presumably a reflection of original impoverishment as well as the effects of dolomitization. Classic stress biotas (small size, low diversity, high abundance) appear higher in the section, especially the essentially monospecific *Chonetes* coquina approximately 40 feet above the base. Comparatively diverse, well-preserved silicified brachiopods are abundant in the packstone near the top of the unit.

STOP #2, CESSFORD CONSTRUCTION LE GRAND QUARRY

Orientation

The original Le Grand Quarry that yielded the spectacular concentrations of fully articulated crinoids and starfish is situated to the south of the Iowa River. Abundant fossils are still available in this quarry, although the most recent discovery of a "nest" of complete crinoids was in 1933 (Laudon and Beane, 1937). The old quarry now serves as headquarters of Cessford Construction Company.

Current Cessford operation is in the western part of the quarry complex, north of the Iowa River and to the east of Marshall County T37. In that western part of the quarry, the Chapin is poorly exposed, and the Maynes Creek face is dangerous and relatively inaccessible. Consequently, the field trip will examine the abandoned east end of the quarry complex. There the floor of the quarry is at the Prospect Hill/Starrs Cave contact. Prospect Hill lithologies and trace fossils may be examined in the spoil from the ditch where the road enters the east quarry. The lower quarry face exposes the full Chapin section, whereas the main face, above the first bench, is the Maynes Creek. The latter can be examined safely via the scree pile in the south part of the quarry.

Objectives

a) Compare the Chapin section, including hardgrounds, with the virtually identical succession at Montour.

b) Contrast lithofacies and biofacies of the superjacent upper Hampton with those at Montour, three miles distant.

Commentary

Whereas the Chapin sections at Montour and Cessford are virtually identical in thickness, lithology, hardgrounds and faunal content, facies of the superjacent upper Hampton have changed sufficiently in three miles to

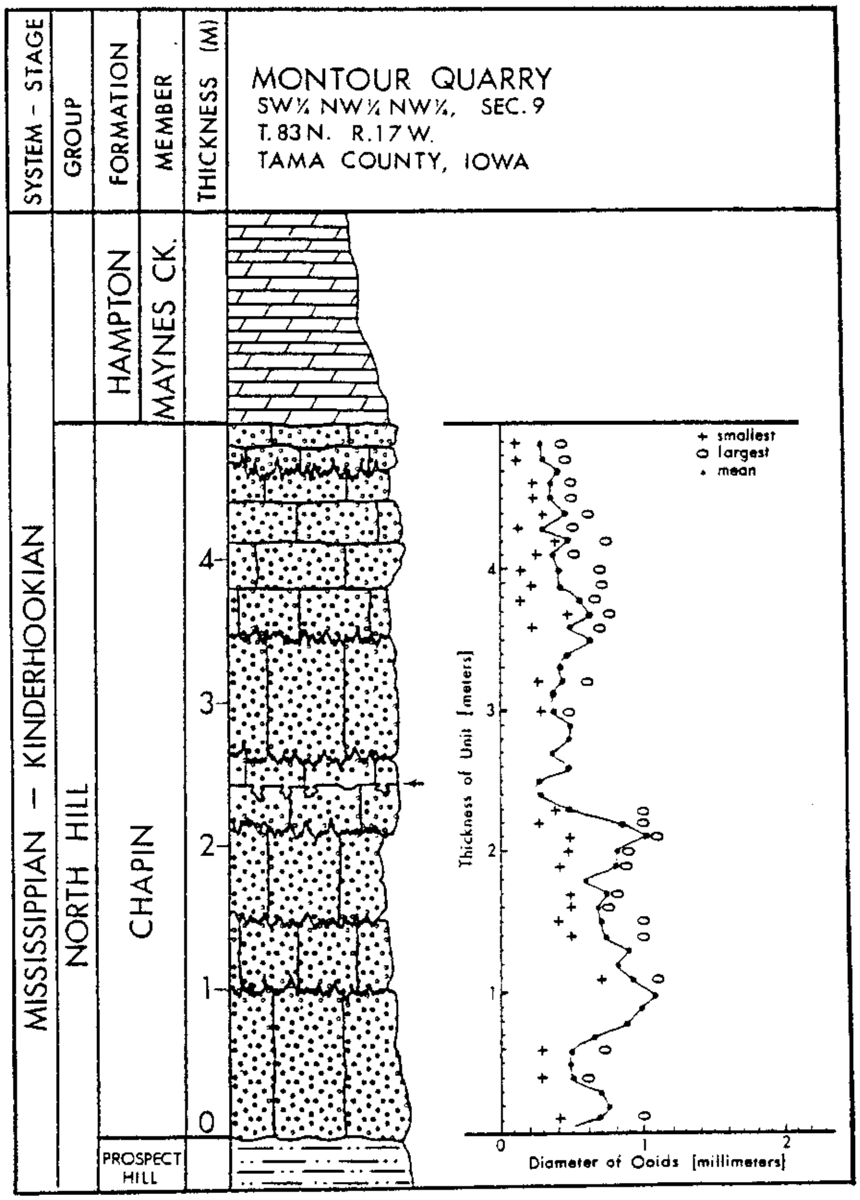

Figure 10. Stratigraphic section of Chapin Oolite in B. L. Anderson Montour Quarry showing variation in mean and modal diameters of ooids. Measurements taken through microscopic examination of thin sections and polished slabs. Samples taken at 10 cm intervals. "+" is mode of smallest ooid diameter, "o" is mode of largest ooid diameter, "." is arithmetic mean ooid diameter. Arrow locates most conspicuous hardground surface (from Lawler, 1981).

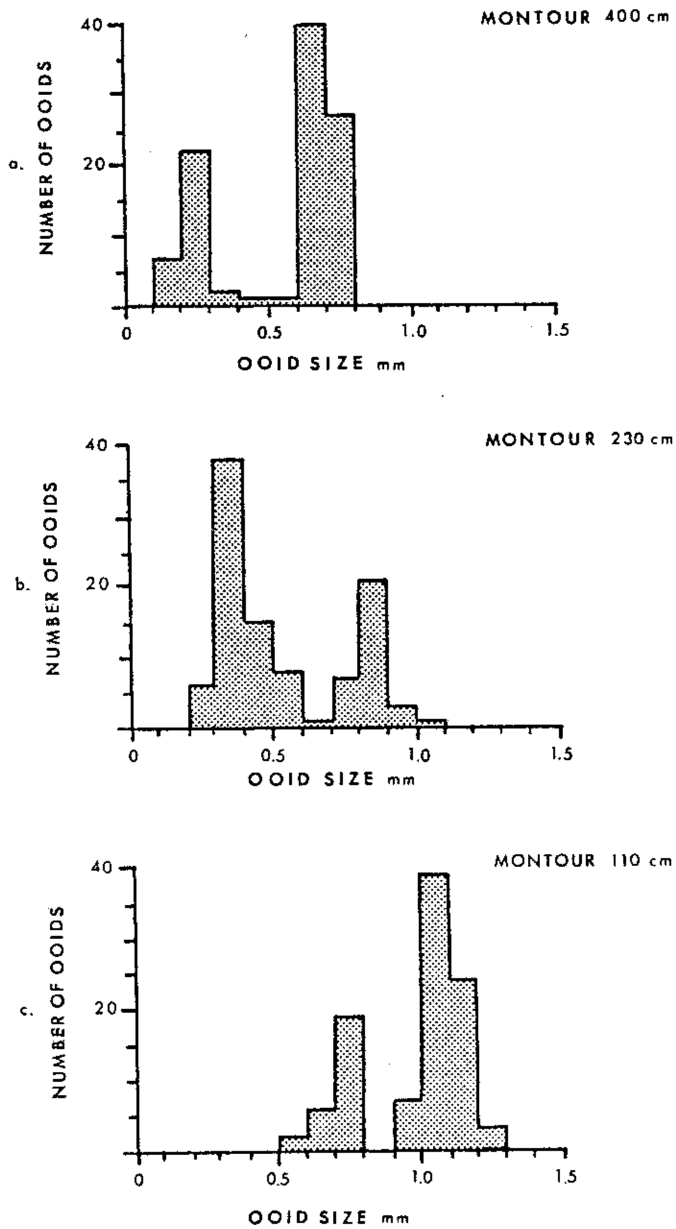

Figure 11. Histograms (n = 100) of samples of Chapin Oolite with bimodal distribution of ooid diameters, B. L. Anderson Montour Quarry. Numbers to right of each histogram are cm elevations of samples above the top of the Prospect Hill Siltstone (from Lawler, 1981).

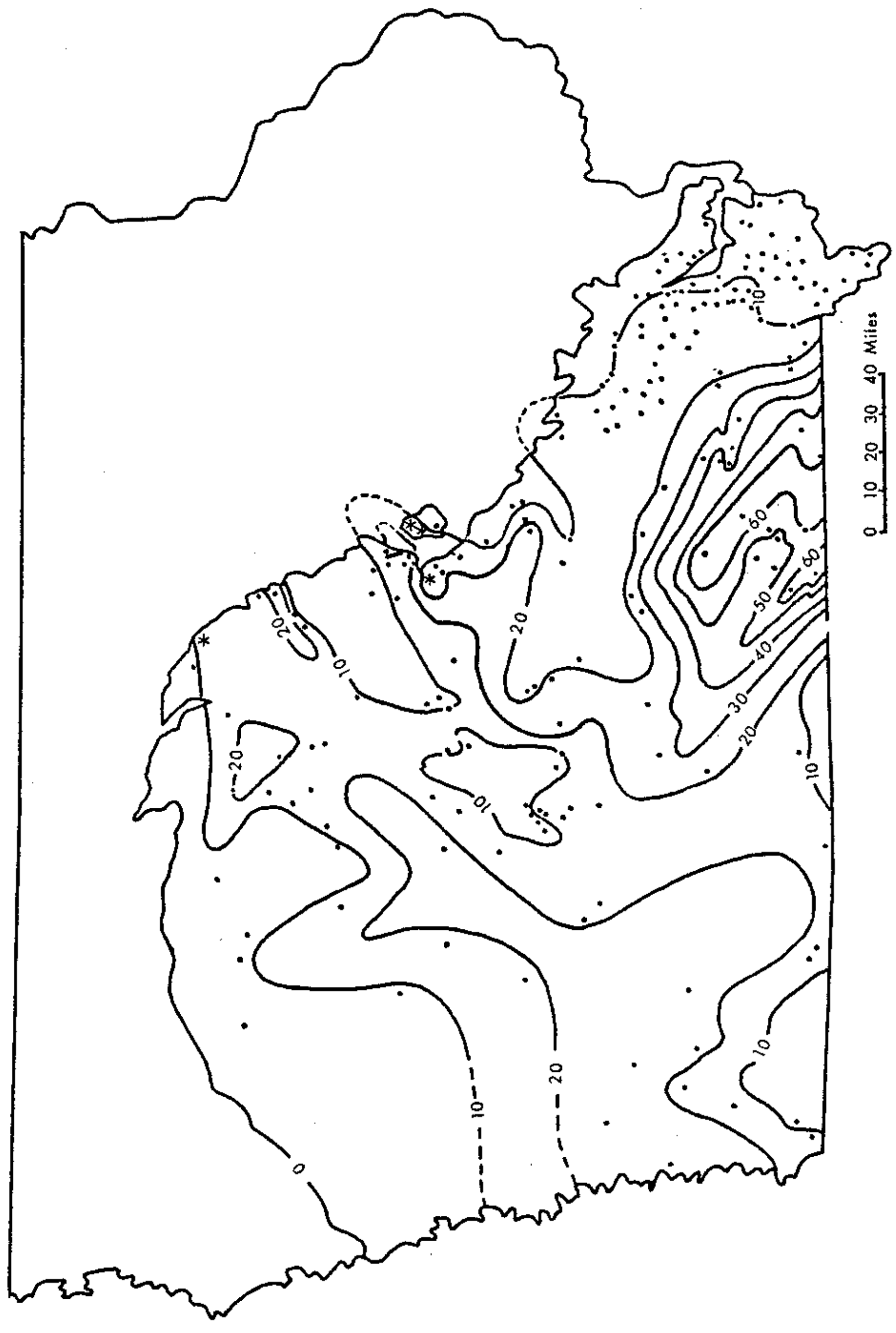

Figure 12. Isopach map of Chapin/Starrs Cave interval, based on Iowa Geological Survey Bureau strip-logs. Dots represent control points, none of which violates contour lines, and "*" indicates studied sections (Chapin, Ferguson, Le Grand, Montour). Contour interval is 10 feet (from Lawler, 1981).

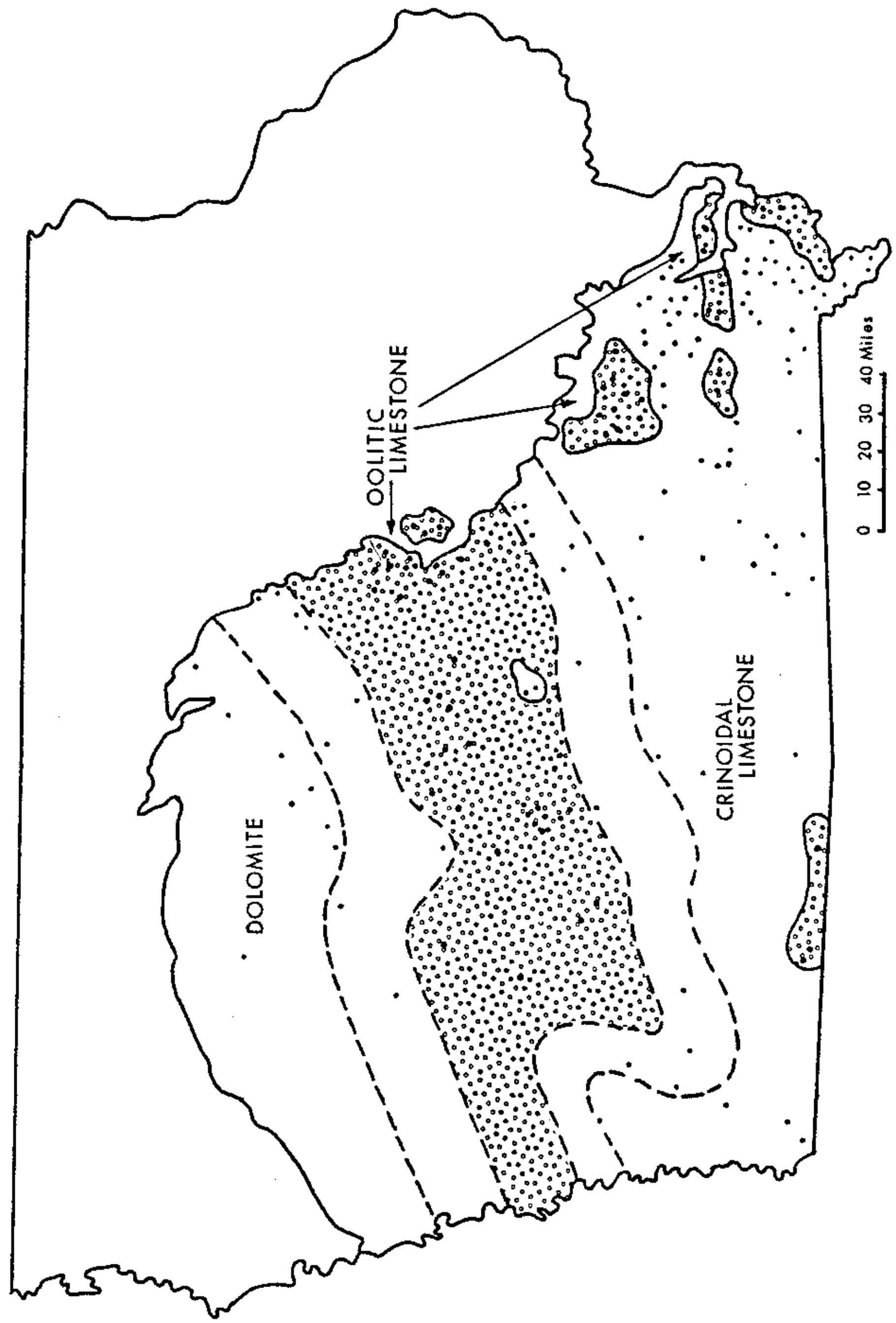

Figure 13. Generalized lithofacies map of Chapin/Starrs Cave interval, based on interpretation of Iowa Geological Survey Bureau strip-logs. Dots represent control points. Three lithofacies dominate: dolomite, oolitic limestone (patterned area), and crinoidal limestone. Dashed lines suggest transitional zones where dominant lithologies intertongue (from Lawler, 1981).

TAXON NAME	Range* Base	Range* Top	C.S.E. Base	C.S.E. Top
CAMAROTOECHIA 2268 (TUTA)	16	57	9336	9449
CHONETES 2375 (ILLINOISENSIS)**	10	49	9341	9386
2376	4	10	9341	9393
2433 (LOGANENSIS)	5	15	9362	9450
2434 (LOGANI)	1	17	9341	9404
COMPOSITA 2281 (HUMILIS)	5	71	9353	9457
2282 (IMMATURA)	5	—	9341	9444
EUMETRIA 2275 (VERA)	17	57	9366	CHESTER
HOMALOPHYLLITES SP (4280)	72		9360	9456
LEPTAGONIA 2360 (ANALOGA)	17		9360	9426
4348 (CONVEXA)**	7	12	9368	9428
MARTINIOPSIS 2409 (ROSTRATA)	10		9359	9457
NUCLEOSPIRA 3245 (OBESA)		10	9355	9398
OVATIA 3530 (OVATA)		25	DEV	9413
PERNOPECTEN 21319 (COOPERENSIS)	4	17	9368	9378
PLATYCERAS 2005		57	9360	9402
3558 (PARALIUS)		49	9362	9400
PROSPIRA 2317 (PIERSONENSIS)	9	57	9369	9469
2319 (LEGRANDENSIS)	59	71	9359	9438
PUNCTOSPIRIFER 2323 (SOLIDIROSTRIS)	59	71	9360	9445
2327**	15		9360	9412
2328 (UTTINGI)**	49		9389	9446
3504 (SUBTEXTA)		71	9356	9413
RHIPIDOMELLA 21318 (THIEMEI)	7	71	9355	9402
SCHELLWEINELLA 4350 (PLANUMBONA)	11		9360	9452
22111 (INFLATA)	13	49	9359	9425
SEMICOSTELLA 3500 (ARCUATA)	43		9356	9444
SPIRIFER 2316	9	71	9360	9443
2318 (MADISONENSIS)	7	57	9368	9435
4345 (PLATYNOTUS)	16	71	9370	9431
21579	49	71	9363	9460
21580	43		9370	9435
TORYNIFER 2383 (COOPERENSIS)	49	71	9357	9457

*Range in feet above the top of the Prospect Hill Silt.
**C.S.E. range of these taxa not yet well established.

September 22, 1981

Figure 14. Recorded distributions of common megafossils at B. L. Anderson Montour Quarry. Numbers following generic names are specific designations in the Amoco system, and are followed by the equivalent Linnaean name, where known. Ranges are given, both in feet above the top of the Prospect Hill Siltstone at Montour and in Composite Standard Units (Appendix A). Most species are illustrated and their total ranges portrayed, herein, in Figures 15 - 22 (from Shaw, 1981).

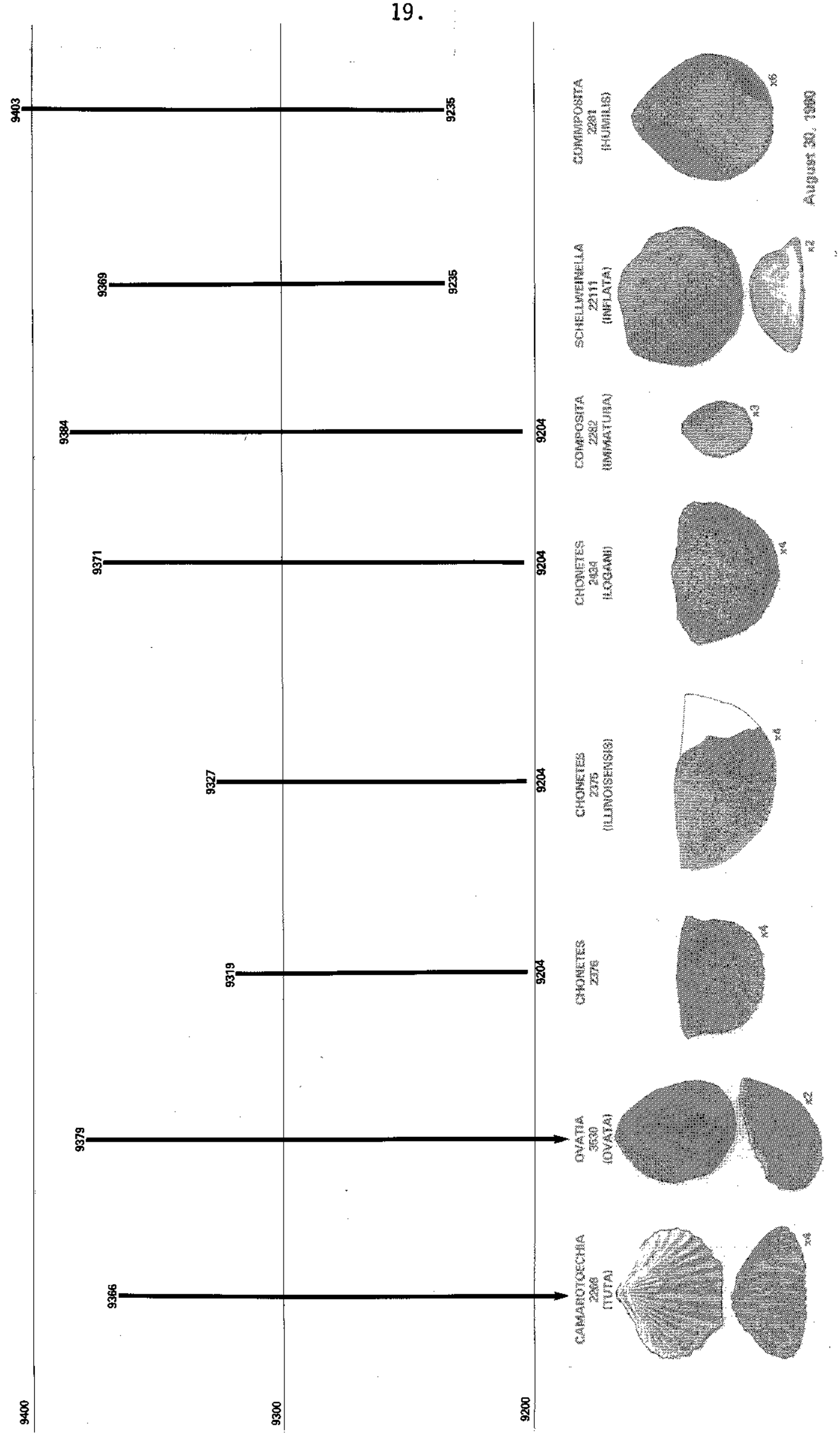

Figure 15. Montour fossils 1, see explanation of Figure 14 (from Shaw, 1981).

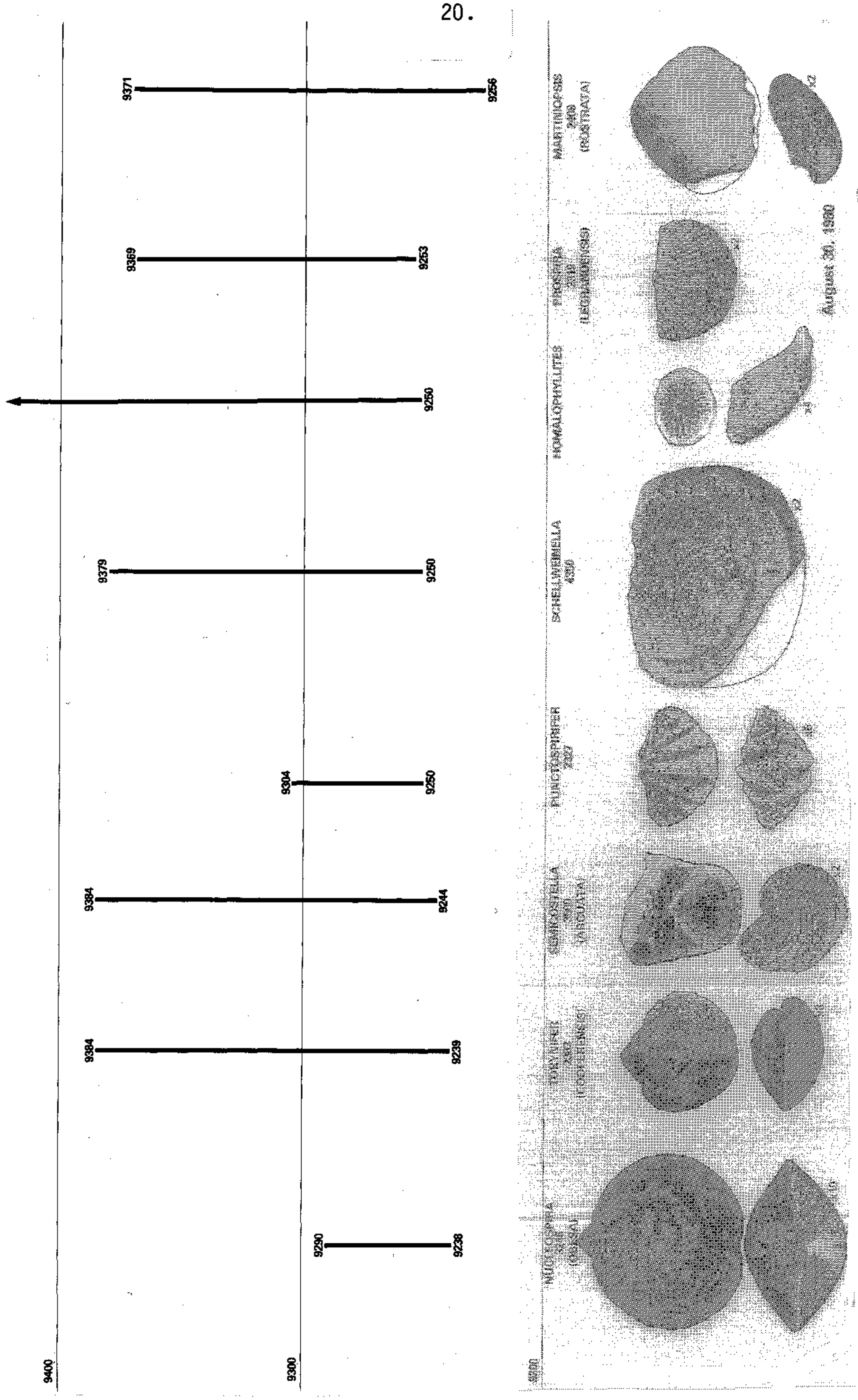

Figure 16. Montour fossils 2, see explanation of Figure 14 (from Shaw, 1981).

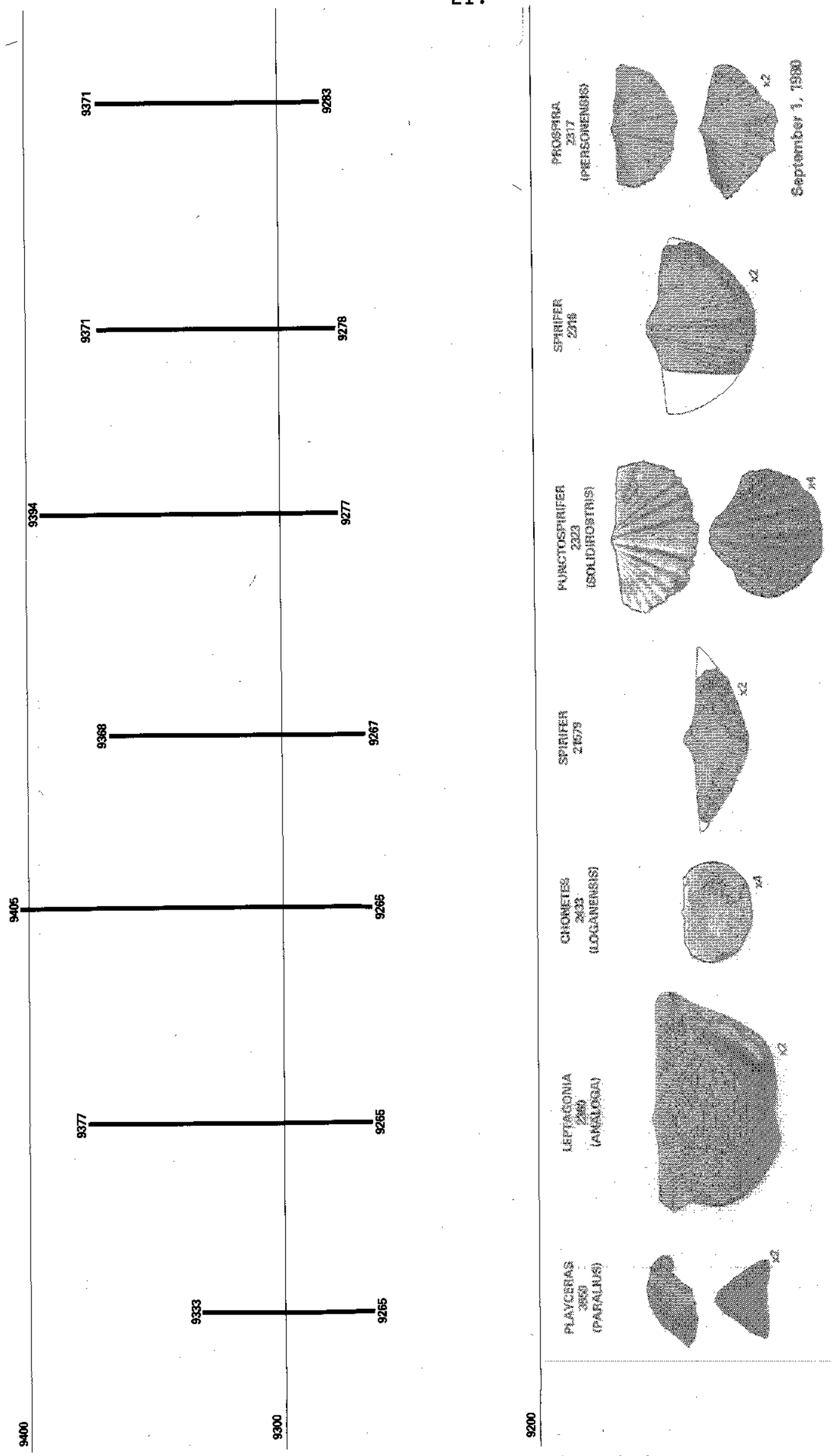

Figure 17. Montour fossils 3, see explanation of Figure 14 (from Shaw, 1981).

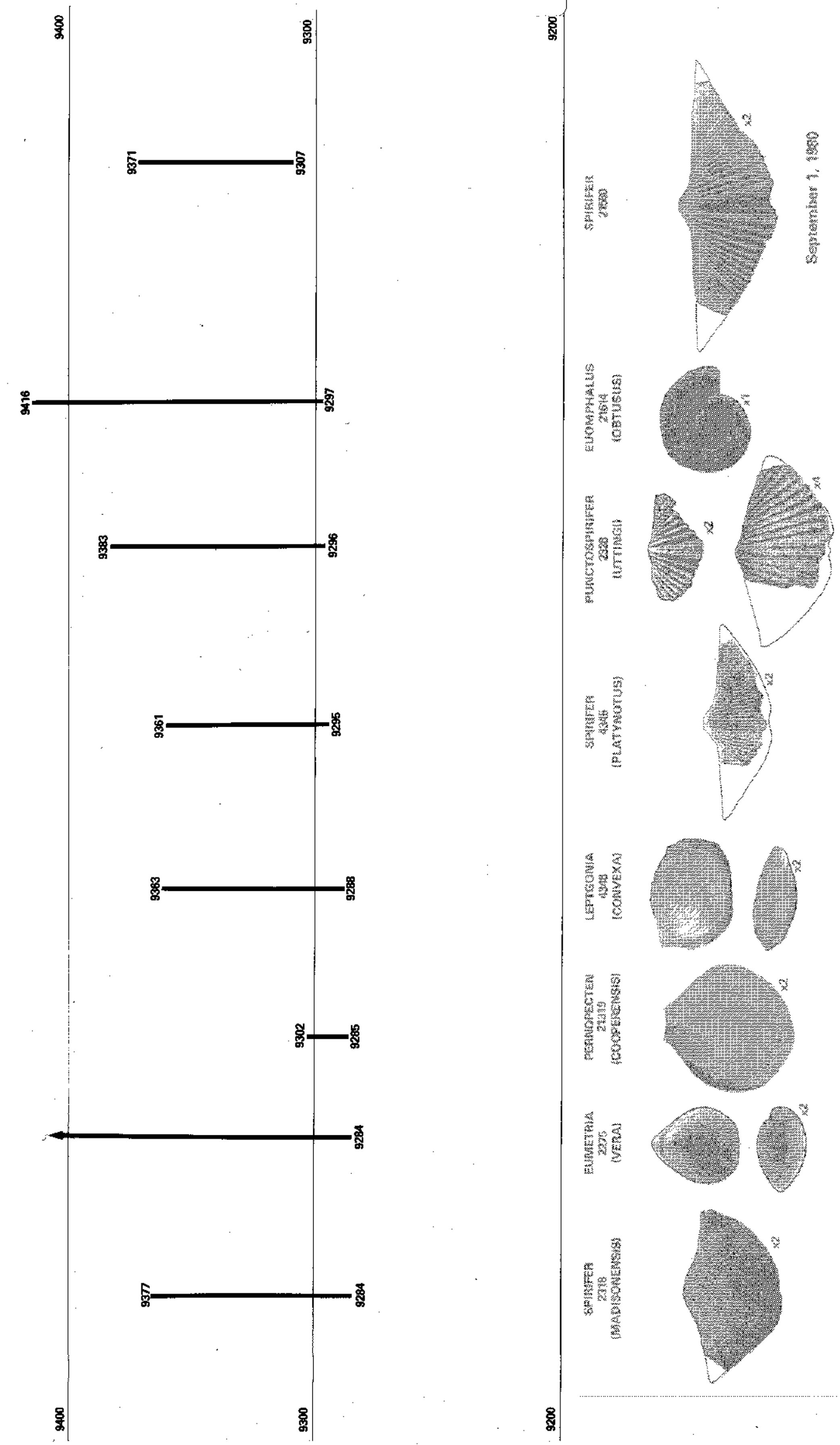

Figure 18. Montour fossils 4, see explanation of Figure 14 (from Shaw, 1981).

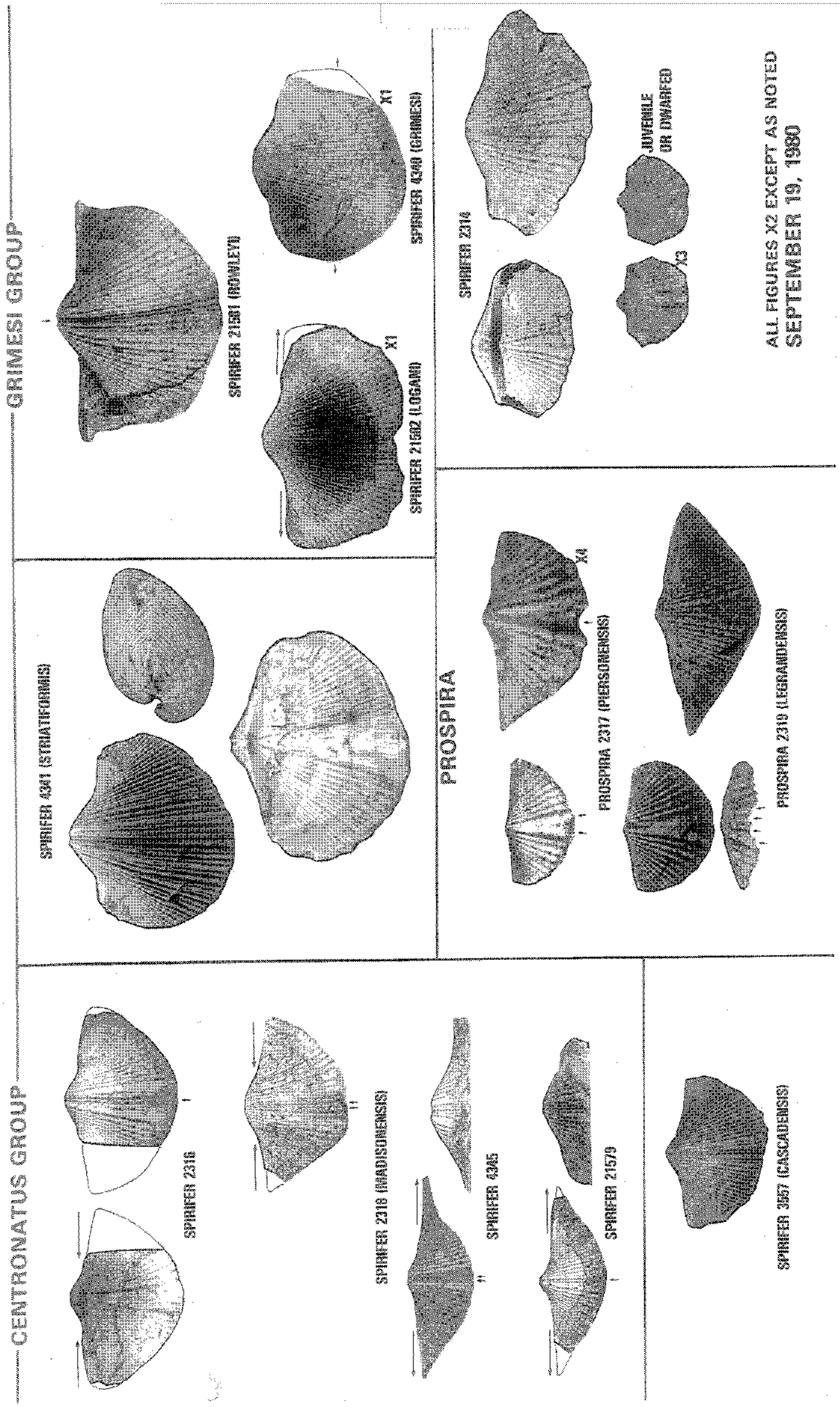

Figure 19. Spiriferaceans. Arrows point to specifically diagnostic features. See explanation of Figure 14 (from Shaw, 1981).

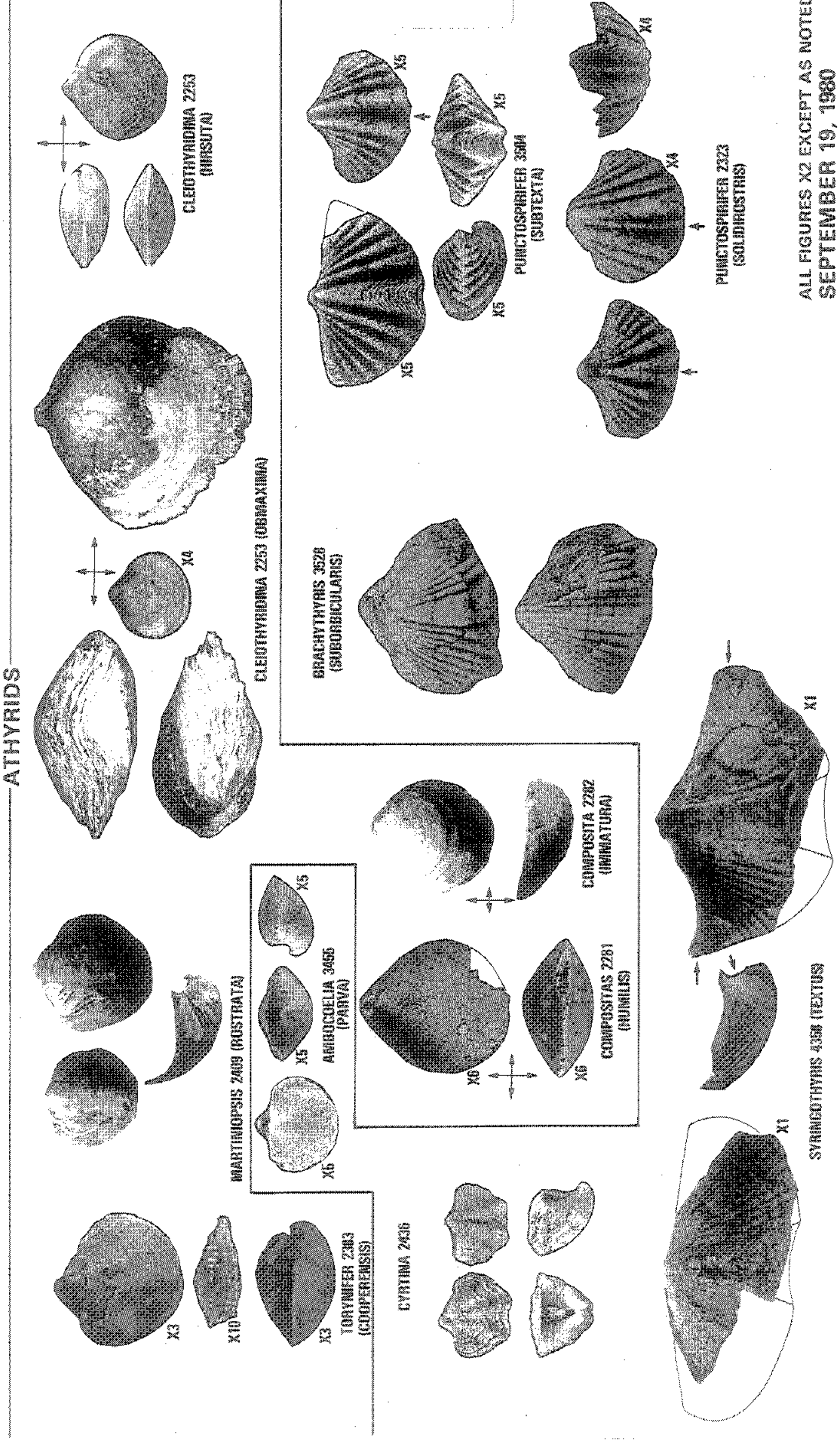

Figure 20. Miscellaneous spiriferids. Arrows point to specifically diagnostic features. See explanation of Figure 14 (from Shaw, 1981).

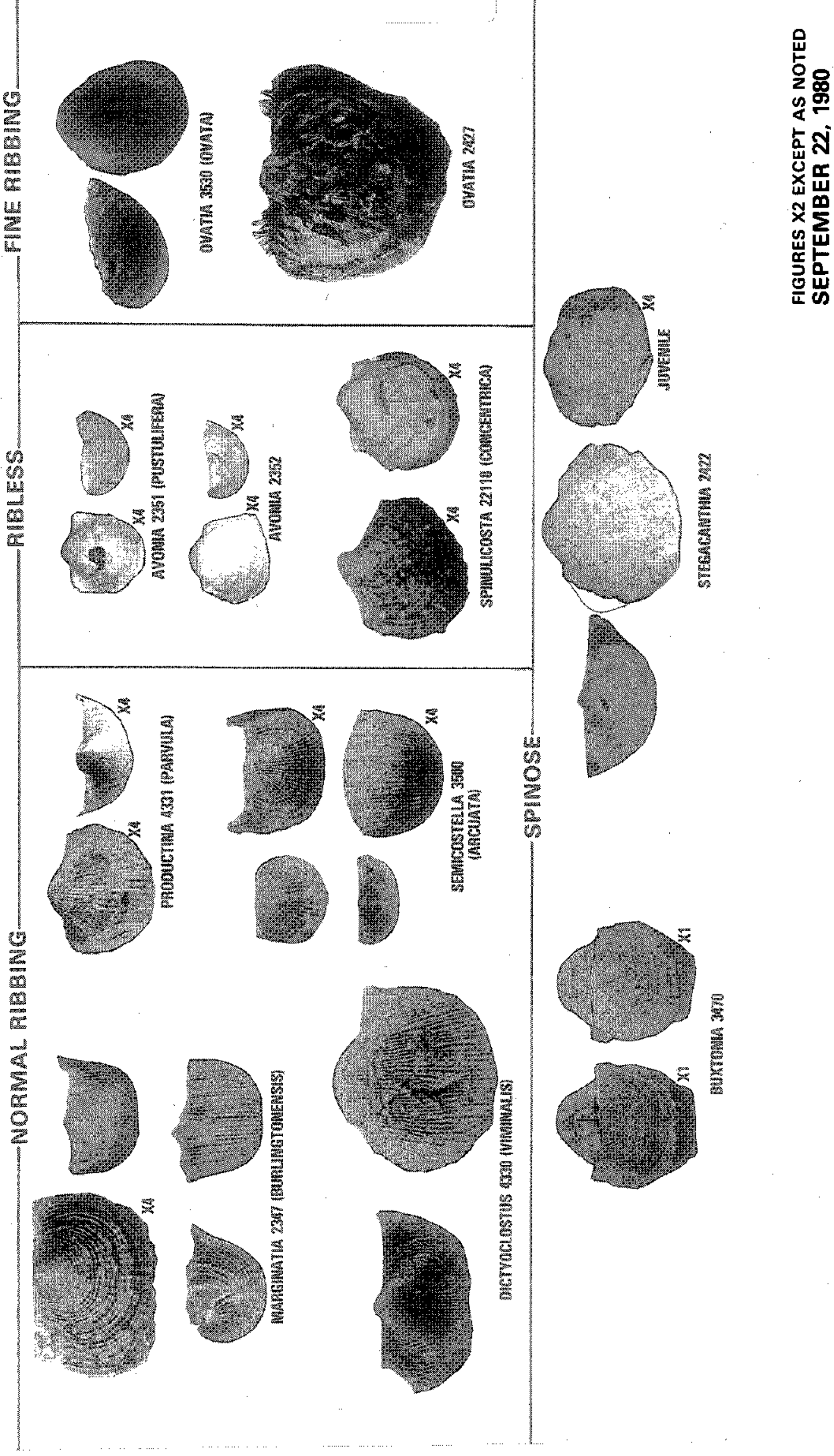

Figure 21. Miscellaneous common megafossils. See explanation of Figure 14 (from Shaw, 1981).

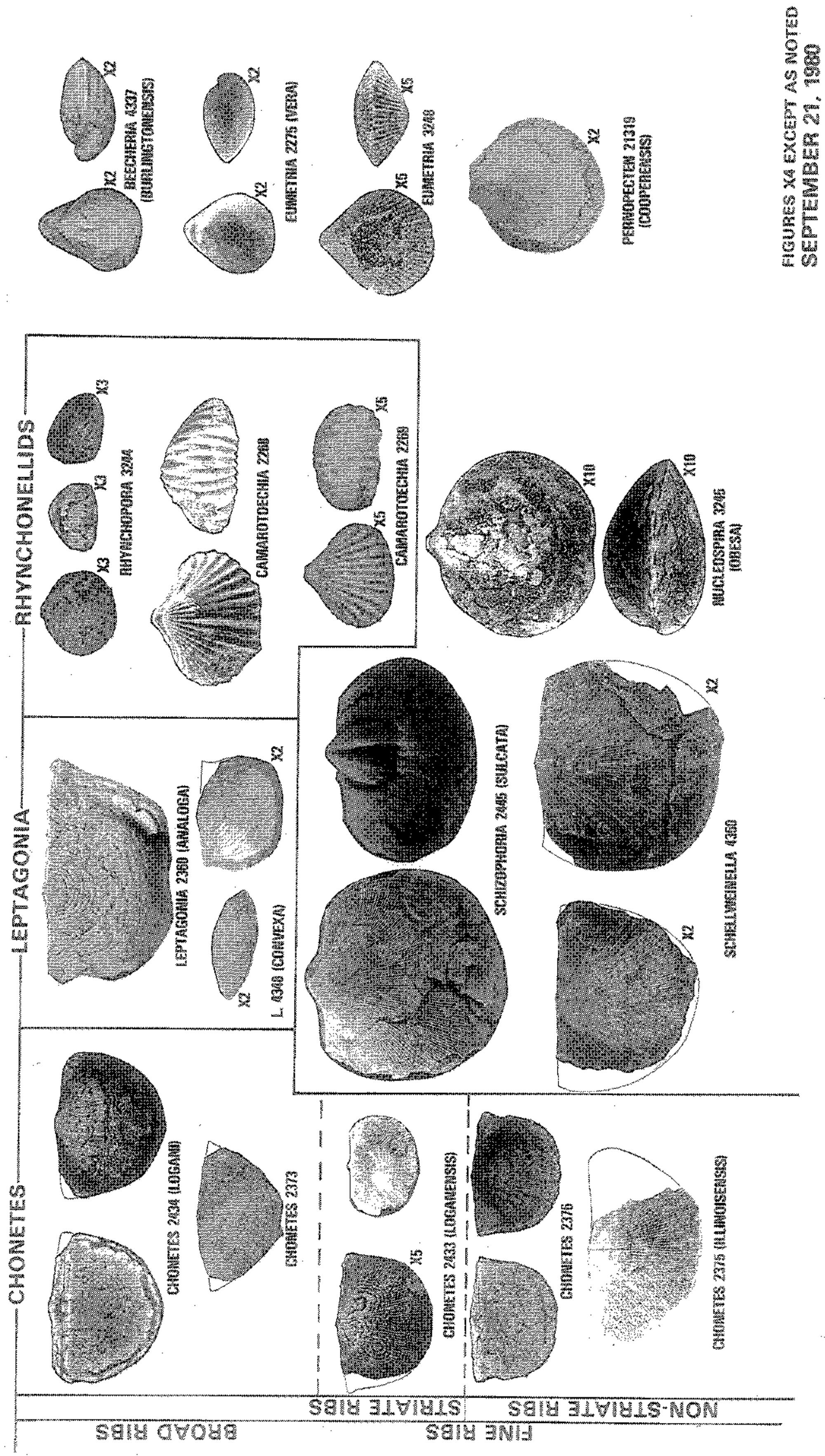

Figure 22. Productid brachiopods. See explanation of Figure 14 (from Shaw, 1981).

justify reference of this Cessford interval to the Eagle City Limestone (Figs. 1, 23, 24). Such abrupt changes in facies are sufficiently common in the Kinderhookian of Iowa that lithostratigraphic designation has lost most of its traditional function (Figs. 3, 4).

STOP #3, THREE BRIDGES MARSHALL COUNTY PARK

Orientation

Three Bridges Park is located, in an abandoned quarry complex, south of the Iowa River and to the north of the town of Quarry. The face exposes approximately 20 feet of the upper Hampton Formation (Figs. 25, 26). Precise relationship to the Chapin Oolite is unknown. However, oolitic limestone exposed at low river levels downstream from the iron bridge, 10 feet below the base of the quarry section, probably lies close to the top of the Chapin.

Objectives

a) Interpret environments of deposition.

b) Attempt correlation with Stops #1 and #2.

Commentary

Both lithofacies and biofacies at Three Bridges suggest that this is the most open environment of the lower Maynes Creek/Eagle City succession encountered in the first three stops. Absence of consequential thichnesses of dolomite necessitate assignment to the Eagle City Limestone. Correlation with other studied sections would be facilitated by availability of a core drilled into the top of the Chapin from the quarry floor. However, consideration of faunal, compositional and sedimentologic data suggests the correlation presented in Figure 27.

Facies of the upper Hampton in the five mile traverse from Montour Quarry to Three Bridges can be compared in relation to an easily identifiable subjacent datum, presumably an isochronous surface, the top of the Chapin Oolite. The facies change rapidly from dolomite dominance at Montour, referable to the Maynes Creek Dolomite, to limestone dominance of the Eagle City Limestone at Three Bridges. Consideration of both lithofacies and biofacies suggests depth control, from shoaling conditions at Montour to progressively more open circulation and deeper water at Cessford and Three Bridges. Facies relationships across this transect generally conform to the lithologic and biotic predictions of the Basic Clear Water Model (Fig. 5).

STOP #4, MARTIN MARIETTA FERGUSON QUARRY

Orientation

Time will not afford the opportunity for detailed examination of the Ferguson Quarry section. However, virtually the entire face is referable to the upper Hampton Formation. Contact with the Chapin lies 12 feet below the

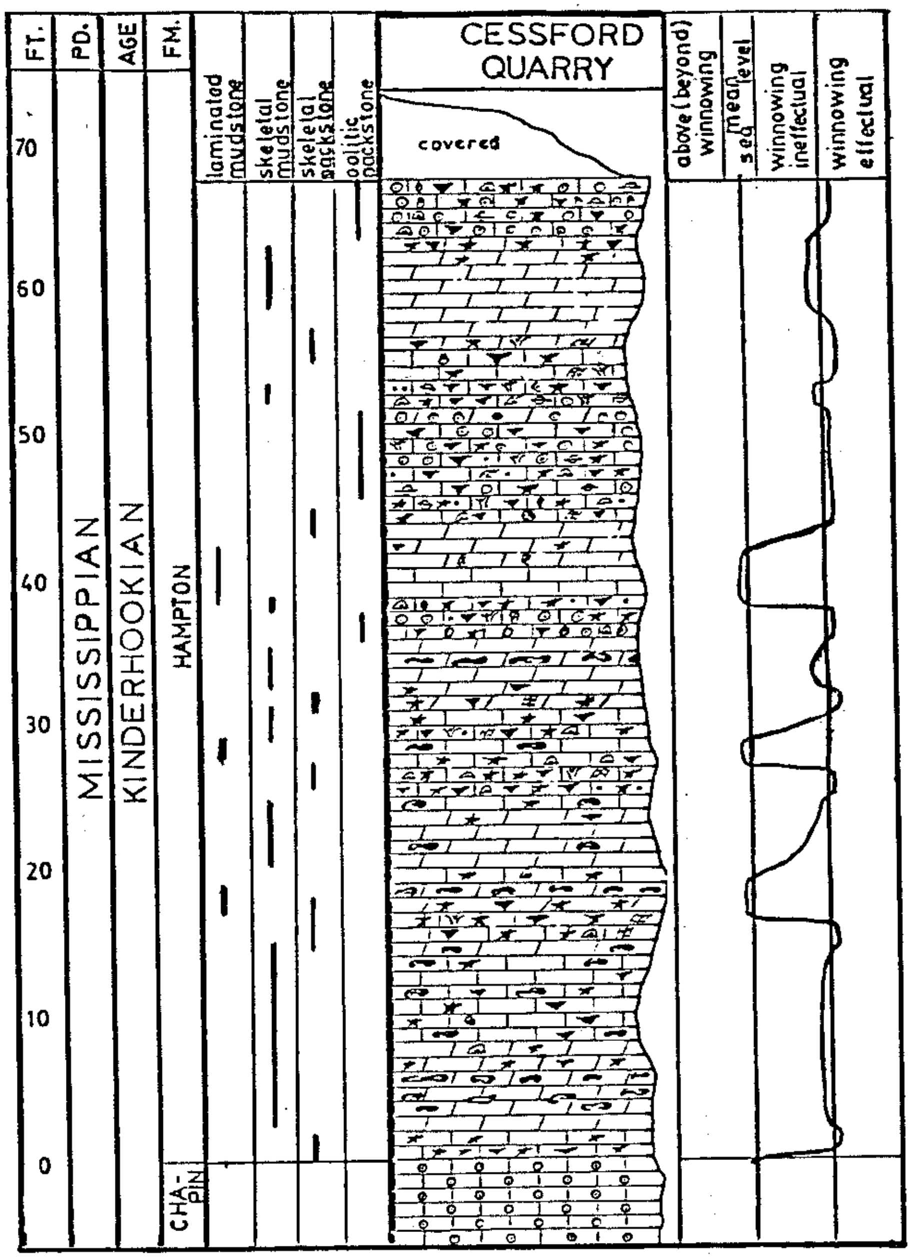

Figure 23. Stratigraphic section, Cessford Construction Le Grand Quarry (from Hager, 1981). Symbols, Figure 7 herein.

Footages*	% Calcite	% Dolomite	% Quartz	% Pyrite
EAGLE CITY — MAYNES CREEK				
68	100		Tr	
67	98		2	
66	99		1	
65	96	1	3	
64	97		3	
63	88	10	2	
62	3	95	2	
61	14	83	3	
60	43	55	2	
59	8	82	10	
58	21	77	2	
57	13	85	2	
56	9	87	4	
55	2	94	4	
54	99		1	
53	97		3	
52	98		2	
51	36	62	2	
50	14	82	4	
49	62	36	2	
48	97	2	1	
47	74	10	16	
46	93	5	2	
45	78	17	5	
44	92	4	4	
43	97	2	1	
42	38	60	2	
41	40	59	1	
40	91	9	Tr	
39	53	46	1	
38	97	2	1	
37	100		Tr	
33	45	53	2	
32	2	98	Tr	
31	34	66	Tr	
30	90	9	1	
29	61	36	3	
28	94	6	Tr	
27	92	7	1	
26	100		Tr	
25	58	42	Tr	
24	51	49	Tr	
23	64	35	1	
22	29	71	Tr	
21	7	91	2	
20	7	91	2	
19	66	34	Tr	
18		98	2	
17	84	14	2	
16	91	7	2	
15	13	86	1	
14	24	75	1	
13	12	86	2	
12	62	38	Tr	
11	58	42	Tr	
10	46	54	Tr	
9	59	41	Tr	
8	53	45	2	
7	39	58	3	
6	9	88	3	
5	27	72	1	
4	21	76	3	
3	13	84	3	
2	2	95	3	
1	59	39	2	
0	95		1	4
Chapin Oolite*				
17	98		2	
16	97		3	
15	98		2	
14	98		2	
13	98		2	
12	95		2	3
11	98		2	
10	98		2	
9	98		2	
8	98		2	
7	98		2	
6	98		2	
5	98		2	
4	96		2	2
3	96		2	2
2	98		2	
1	98		2	

*Footages are above bases of respective formations.

Figure 24. X-Ray diffraction mineral percentages, Cessford Construction Le Grand Quarry (from Shaw, 1981).

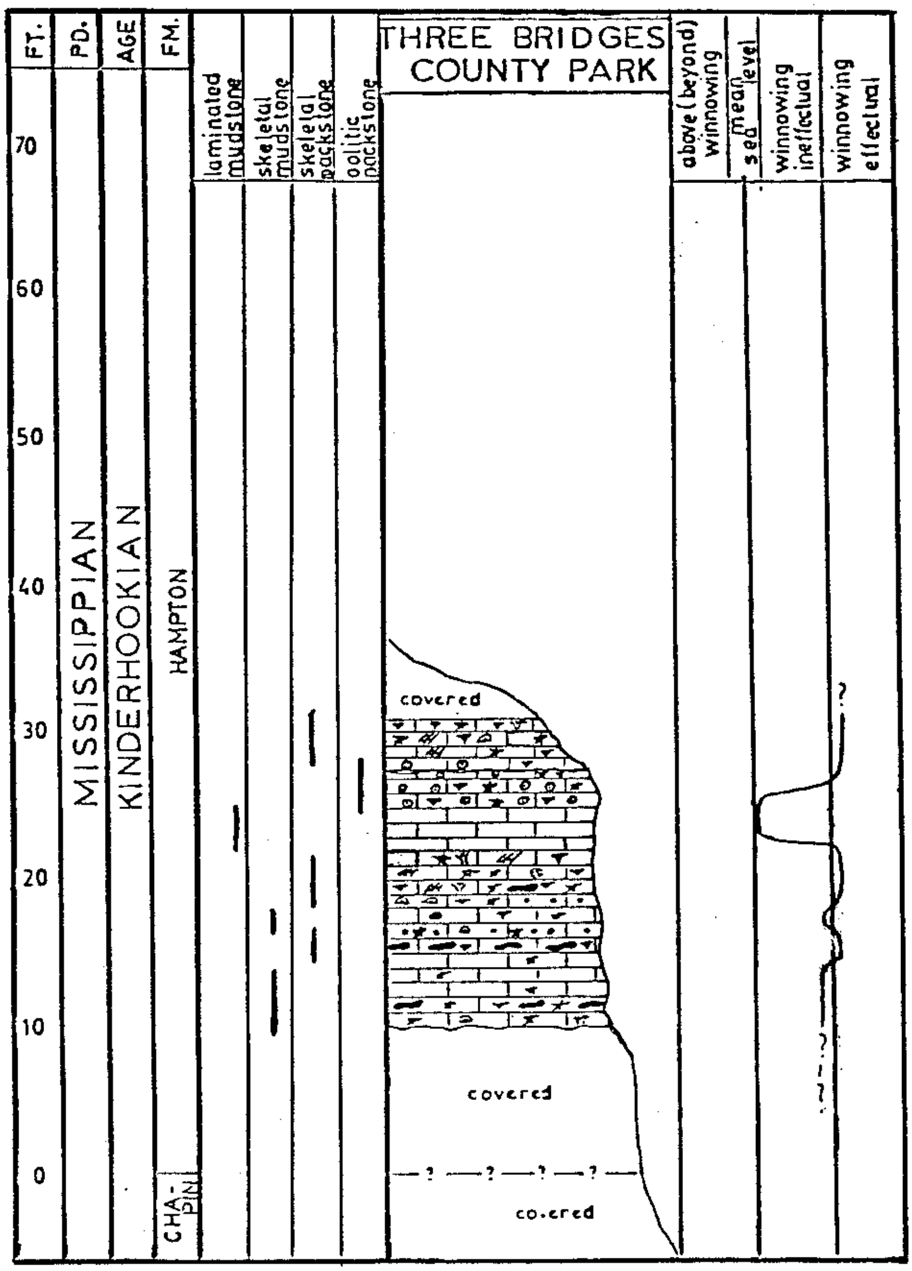

Figure 25. Stratigraphic section, Three Bridges County Park (from Hager, 1981). Symbols, Figure 7 herein.

Eagle City Formation

Footage	**% Calcite**	**% Dolomite**	**% Quartz**
19	100		Tr
18	100		Tr
17	100		
16	100		
15	100		
14.1	100		Tr
13	49	51	
12.3-12.6	65	35	
12	100		
11.1	100		
10	100		
9	100		
8.3-8.4	97		3
8	100		
7	100		
6	100		
5	100		
3.8	91	9	
2.5	60	40	
2	73	27	
1	83	17	
0	70	30	

September 22, 1981

Figure 26. X-Ray diffraction mineral percentages, Three Bridges County Park (from Shaw, 1981). Footages are above the base of the section; precise relationship to top of the Chapin Oolite is unknown, but probable alignment is suggested in Figure 25 (from Shaw, 1981).

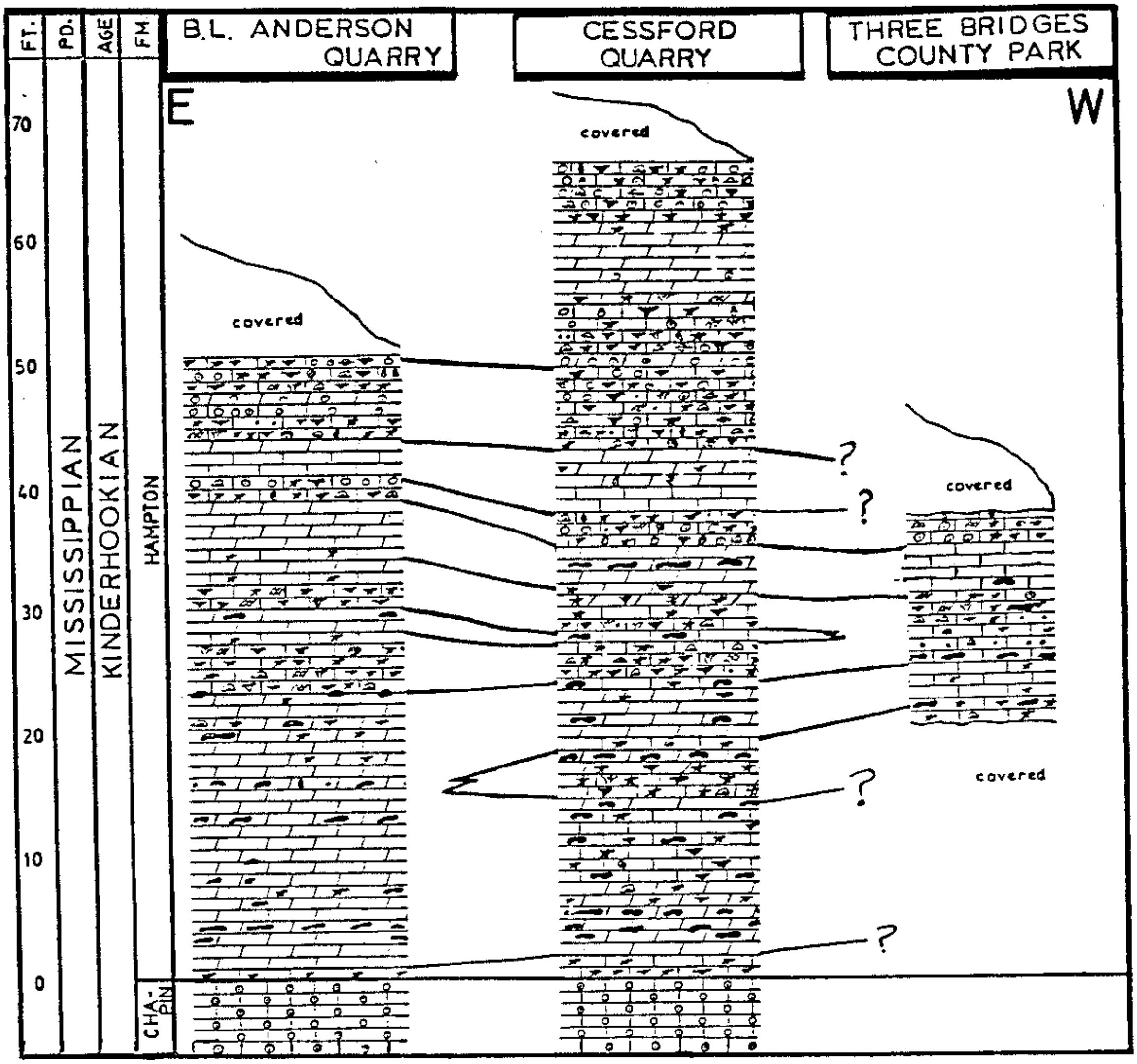

Figure 27. Stratigraphic columns for three studied sections. Possible correlation is based on faunal, compositional and sedimentologic data (from Hager, 1981). Symbols, Figure 7 herein.

quarry sump (Hughes, 1977), and the upper few feet of a small outlier above the eastern quarry wall represent the northwesternmost extent of the Burlington Limestone.

Thick cross-bedded oolites constitute a significant proportion of the 75 foot upper Hampton section at Ferguson. They are interpreted as large active shoals that persisted for long periods (Ressmeyer, 1983), part of the "factory" that provided ooid grains for the shelf areas along the northeastern margin of the Appanoose Trough (Fig. 2). Montour, Cessford and Three Bridges are interpreted as backshore shelf environments that accumulated ooids during storms. Collectively these localities provide close analogs to the Holocene bank/shoal systems of the Bahamas (e.g., Harris, 1979).

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APPENDIX A
(from Shaw, 1981)

A Primer on Graphic Correlation and Composite Standards

Graphic correlation, like many interpretive tools in geology, is based on some fairly simple assumptions that are easily understood. In actual application, skill and experience are important because the real world is different from the ideal. The technique thus differs in no way from log interpretation, or seismic, or other geologic evaluation procedures. The purpose of this summary is to put before you the basic ideas behind graphic correlation and Composite Standards so that you can understand their use in the Seminar. No attempt can be made to make you an expert in graph interpretation.

The Data

Graphic correlations are based on two types of factual data: the fossils and their stratigraphic positions. Both are subject to error, but we hope, of course, that these are minimal.

The Assumptions

Correlation (graphic or otherwise) is based on the assumption that each extinct organism had a finite range in time and that, as the ranges of more and more fossils become established, shorter and shorter segments of geologic time will be characterized by specific combinations of fossils. In the oil business a widely used modification of this concept is that as ranges become better-known the succession of range limits, usually extinctions or "tops", will become firmly established as relative points in time (Fig. 1). Graphic correlation uses the upper and lower limits of range ("tops" and "bases") as its primary data and is therefore using fundamentally the same data as traditional Gulf Coast methods.

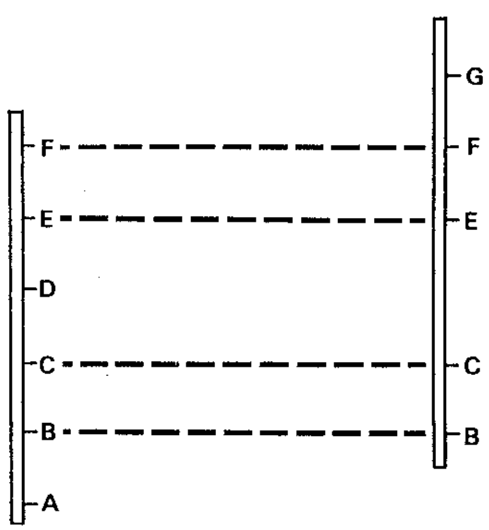

Figure 1. Traditional Correlation
The common occurrence of paleantologic markers ("top" zones, assemblages, "bases"), represented here by letters, are regarded as time-equivalent (or nearly so) and lines connecting these points are called "time lines/planes." Markers must occur in each section for correlations to be made.

A second assumption behind all use of fossils for correlation is that, statistically, information from stratigraphically located fossils is more likely to inform us about the true correlations than to mislead us. Thus, it is assumed that correlation of two "tops" is more likely to indicate approximate time equivalents than the correlation of a "top" with the "base" of the fossil in another section. In this, paleontologic interpretation is like the interpretation of a core or a log. The core or log **may** have chanced upon some wholly atypical characteristics somewhere through its length, but we assume that on the whole (statistically) most of the log or core is a representative sample. The same assumption governs fossil correlation.

In short, we assume that occurrences of the same fossils in successive sections do give us information about time and that that information can be expected in general to be biased toward true contemporaneity rather than against it.

The Graph (Mechanics)

Graphing itself is very simple. The X-axis is, at first, the stratigraphic interval represented by one section, while the stratigraphic interval of the other section is laid off along the Y-axis (Fig. 2). Initially, the stratigraphic position of the "base" of a fossil that is found in both sections is plotted on the graph, using the stratigraphic level of each "base".

Then the "top" of the range of the fossil is plotted in the same way. Successively, all other fossils common to both sections are plotted. (In Gulf Coast paleontology, where "bases" are traditionally not recorded, only "tops" are used.)

It should be obvious that data from long, well-sampled sections will give us much better information than spot sampling. Likewise, common fossils are going to show us their full range sooner than do rare ones. So, too, easily recognizable fossils are of more help because we are less likely to make mistakes in identification that will make our basic data unreliable. You will learn on the Seminar that all of these factors affect interpretation at some time or other.

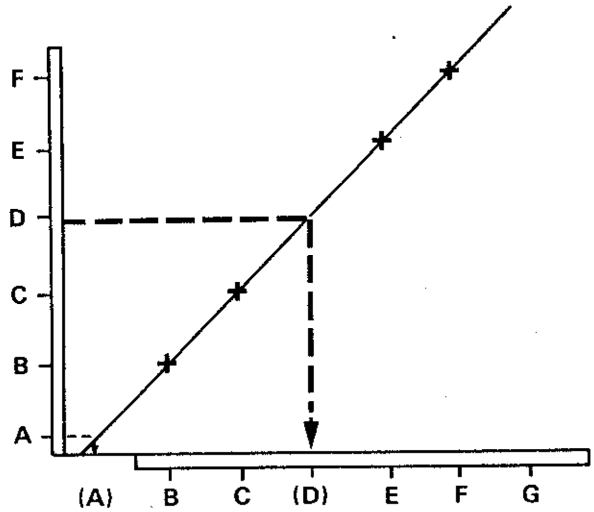

Figure 2. Graphic Correlation
Sections with common markers become the axes of a graph. If ranges are complete, the points of correlation fall on a "Line of Correlation." Missing data from one section (Markers A and D) can be "projected" into the X-axis. Data can be accumulated from many sections this way and a "Composite Standard" results.

The Graph (Interpretation)

If there are many points (stratigraphic levels) in the two sections we are comparing that are time equivalents, and if we could know that equivalence exactly, we could express each pair of points as an X, Y point on our graph. When all equivalent pairs had been plotted they would form a line of some shape or other across our graph. This would be the "Line of Correlation" (L.O.C.), and that is what the graphic method of correlation trys to locate as accurately as possible. The L.O.C. can be expressed by an "Equation of Correlation" in the form CSU = a+bY. The "b-value" is an expression of the relative rate of rock accumulation (after compaction and diagenesis) compared to that reflected by the X-axis.

Actually, the "b-value" itself is a factor by which the stratigraphic interval at Y is multiplied to obtain Composite Standard Time Units; more familiar is the reciprocal of b, which expresses the stratigraphic thickness at Y relative to that at X per unit time.

One of the underlying characteristics behind the graphic method is that we are looking for something on the graph that is there. When we correlate one "Kinderhookian" section with another, as we will do often during the Seminar, we are trying to relate sections that we have reason to believe contain points of equal age. The problem is to locate these equivalent points as accurately as possible, not to create them.

The Composite Standard

Once we have located the L.O.C. as best we can with the data at hand (and bad or inadequate data will not permit a credible L.O.C.) we are justified in combining the ranges of the two sections. This combination, which can be done graphically or mathematically, is called "compounding", and the resulting combined range information is called a "Composite Standard". In future correlations, beyond the first pair of sections, this Composite Standard is invariably used as the X-axis scale, so that we plot out graphs against the combined information from all previously correlated sections. This makes the correlations much more reliable than correlations made against single sections, one at a time.

Basic Graph Patterns

Not all correlation graphs look alike, but there are some basic patterns that repeat themselves and are easily recognized. These are shown in simple, scaleless diagrams in Figure 3. Bear in mind that the Composite Standard is represented by the horizontal (X) axis in all of these diagrams, so that the explanations refer to characteristics of the section plotted on the vertical (Y) axis.

3A. When rock accumulated at rates greater than that in the X-section the slope of the L.O.C. will be steep because much rock is accumulated in a short time. In this case 1/b >1.

3B. This is the opposite of 3A. The accumulation rate is slower than at X so the L.O.C. has a low slope and 1/b <1.

3C. Whenever beds are missing from the Y section younger fossils will come to rest directly on older

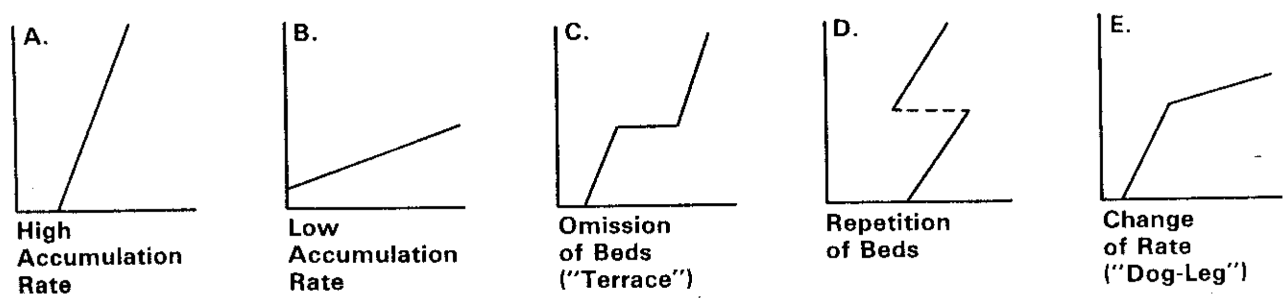

Figure 3. Basic Graph Patterns

ones so that the time represented by the omitted beds becomes condensed into the plane of omission. This causes the L.O.C. to be offset, and a line called a "terrace" may be drawn opposite the break in the section. The presence of a terrace in a graph simply expresses the omission; it does not discriminate faulting from erosion or non-deposition.

3D. Repetition of beds will offset the L.O.C. toward older correlations, and the graph "starts over" again. This pattern is only fault-induced.

3E. This is the graph of an "expanded section" sometimes seen in Gulf Coast wells. This has not been seen to occur on the craton or in epeiric seas in which there is not room for growth faulting on such a scale.

During the Seminar you will see all of these basic patterns, except 3E.

The Composite Standard Time Scale

When a Composite Standard has been created it would be possible to express correlations in terms of footage in the original section on the X-axis. But this is rarely satisfactory both because the scale is parochial and because the addition of section older than that in the original (surface) section gives us negative numbers. Negative numbers do not feel comfortable in a scale used for time. So the original scale of the X-axis is converted to something that permits all numbers to be positive and to increase with increasing time.

For this purpose any scale will do if it fits the problem, but Amoco has reached the stage at which it must consider the development of a single scale for all of Phanerozoic time so that no numbers will be repeated at multiple points in geologic time. At present we are using an experimental scale based on the estimate of the Phanerozoic being 575 MM years long, according to the widely-used Elsevier chart. If this time is divided into 25,000-year increments, there are 23,000 such units. Each such unit is at this time being used as equivalent to one Composite Standard Unit. According to the same Elsevier chart, the Mississipian began 230 MM years ago, which places the base at 230 MM/25 M = 9200 CSU.

The "Kinderhookian" is cited at lasting 5 MM years, so its top would be 9400 CSU. These two points have been more or less arbitrarily located and the scale converted accordingly.

Composite Standard Bookkeeping

Keeping track of the ranges of hundreds or even thousands of fossils in scores or hundreds of sections is obviously a major bookkeeping job that can only be done by computer. You will see this printout on the Seminar and may study it if you wish. In it are listed all the X-axis values for all the fossils so far studied from the Mississippian sections you will be seeing. It may see formidable, but it is nothing more than an elaborate memory that keeps track of all correlations made to date.

From time to time it is essential to review the correlations in each Composite Standard to see whether they would be adjusted in light of data subsequently accumulated. In the Mississippian Composite this is necessary about twice a year, but at each review the adjustments get smaller. Since many interpretations of range could become reciprocal it is essential to have some data at the core of the Standard that do not change. This is the Standard Reference Section (S.R.S.) in which all ranges are converted directly from footage to CSU. Ranges at this S.R.S. cannot be altered except by new information on that section. Thus, the S.R.S. provides a pivotal set of data that cannot be altered by changes of opinion about subsequent correlations. Without this, the Composite would degenerate into the most efficient mathematical accommodation of the data and would have no geochronological meaning. The S.R.S. now in use is the lower Lodgepole section at Browns Gulch, Little Rocky Mountains, which you will visit.

The Composite Standard, because it summarizes all previous knowledge about the ranges of each fossil, is the most likely basis for locating the Line of Correlation that we know lies somewhere on our graph. That basis stems from the likelihood that fossils are the only **commonly available** data that have inherent time significance.

Throughout the Seminar you will be presented with examples of graphs and their interpretations. Some correlations are strong, some weak, and you should be able to see and evaluate the differences. Graphs are no more infallible than seismic or logs, but at the same time the information they supply must weigh as heavily as more familiar tools, when available.

We expect that you will come away from the Seminar with an appreciation of why a consideration of time is crucial to Exploration. Whether documented by good graphic correlations or merely inserted as a conceptual frame of reference, your attitude toward time in making stratigraphic interpretations is all-important.