Technical Bulletin 1348

PHYSIOGRAPHIC HISTORY AND THE SOILS, ENTRENCHED STREAM SYSTEMS, AND GULLIES, HARRISON COUNTY, IOWA

Raymond B. Daniels
and
Robert H. Jordan

U. S. DEPARTMENT OF AGRICULTURE
Soil Conservation Service
in cooperation with
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Issued September 1966

HIGHLIGHTS

Cyclic erosion and sedimentation have helped determine the present landscape in Thompson Creek and Magnolia watersheds in Harrison County, Iowa. The major configuration of the landscape such as position of valleys and drainage divides probably was determined in pre-Wisconsin time. In the 15,000 years since deposition of the Tazewell loess mantle, there have been at least five periods of alluviation on the valley floor. The first two required about 13,000 years for completion. Each of the three periods completed in the last 2,000 years was preceded by erosion of the older fill in some part of the drainage system. Some erosion was channel trenching. Some valley-slope erosion was independent of stream erosion. The resulting geomorphic surfaces of different ages form a complex pattern on the valley slopes and the valley floor.

The soils discussed in this bulletin formed in Tazewell loess but are of different ages because of valley-slope erosion. The soil properties vary with age and slope.

Past and present stream trenching in these watersheds indicates that, if the streams are not controlled, the modern trenching cycle will end in the same fashion as the cycle that preceded it. Filling followed cutting in the earlier cycles. Once the streams are at grade, alluviation again seems likely. Eventually, the streams will flow on a narrow flood plain between banks separating the latest fill from the older fills. Erosion is not likely to destroy the alluvial fill. Watersheds that have a complex cut-and-fill history apparently have a high potential for stream trenching and their use should be planned accordingly.

Gully formation probably is part of the normal cycle of landscape evolution in the thick friable loess of western Iowa. The end result of gullying in this area is an extension of the drainage system. Growth of individual valley-slope gullies can be stopped by directing water elsewhere by practices now common in the area. They should present no serious problem to continued agricultural use.

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ACKNOWLEDGMENTS

This bulletin reports a 1957–1960 study of landscapes, soils, entrenched streams, and gullies in parts of Harrison County, Iowa, supported by Soil Survey Investigations, Soil Conservation Service. The major objectives were to determine the causes and effects of stream entrenchment and gully formation in the thick-loess area of western Iowa and to evaluate the influence of geomorphic processes and physiographic history on the genesis, geography, and classification of soils.

The senior author acknowledges the constructive criticisms of R. V. Ruhe, research geologist, and Guy D. Smith, director, Soil Survey Investigations, Soil Conservation Service, during the field work and the writing of this bulletin. L. E. Tyler, Iowa State soil scientist, Soil Conservation Service, correlated the soils. F. F. Riecken of the Iowa Agriculture and Home Economics Experiment Station spent many hours discussing various parts of the work. Many of the ideas in this report began to take shape during these discussions.

G. H. Simonson, now associate professor of soils, Oregon State University, worked full time on the project during the 1958 and 1959 field seasons. Wilbur Jury, SCS soil scientist, helped start the soil mapping in Thompson Creek watershed. Leland Gile and Robert Turner, SCS soil scientists, and E. H. Runge, K. L. Wells, and R. Arnold, then of the Iowa Agriculture and Home Economics Experiment Station, helped in some phases of the field work.

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STRATIGRAPHY AND GEOMORPHOLOGY

by

Raymond B. Daniels, *soil scientist*

The Pleistocene and Recent deposits, geomorphic surfaces, soils, entrenched stream systems, and valley-slope gullies in Thompson Creek and Magnolia watersheds (fig. 1) were studied in detail. These creeks flow into the Willow River, which is a tributary of the Boyer River. The Boyer River flows into the Missouri River north of Council Bluffs, Iowa. To relate the physiographic history of the watersheds to the glacial history of western Iowa, a reconnaissance study was made of the Pleistocene terraces in the Willow and Boyer River valleys.

In this bulletin the surficial deposits and geomorphology of the area are described first. They constitute the necessary background for the description and discussion of the soils and the report of the investigations on entrenched stream systems. Only the soils formed in Tazewell loess are reported in this bulletin; the soils formed in Kansan till and in alluvium have been reported elsewhere.

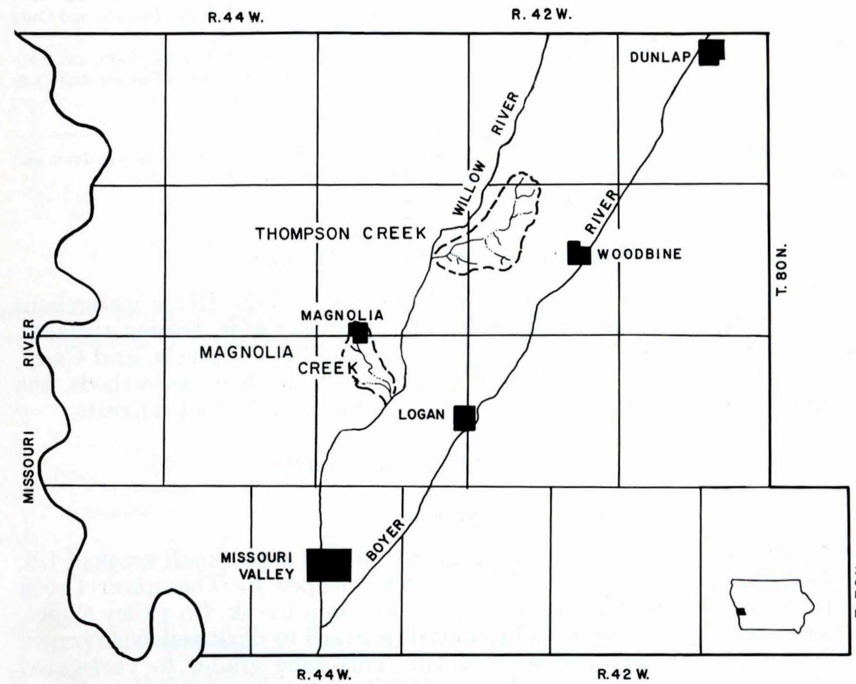


Figure 1.—Location of Thompson Creek and Magnolia watersheds, Harrison County, Iowa.

TABLE 1.—*Generalized Pleistocene section in the Boyer and Willow River watersheds*

Glacial stage	Substage	Interglacial stage	Evidence	Authority
Wisconsin	Cary		Drift	Ruhe [1]
	Tazewell-Cary		Soil	Ruhe et al. (1957).
	Tazewell		Drift, loess	Ruhe;[1] Ruhe, Daniels, and Cady (1966).
	Farmdale		Loess	Michelson (1950), Ruhe (1954a, p. 640).
	Iowan		Drift	Ruhe et al. (1957); Ruhe, Daniels, and Cady (1966).
		Sangamon	Weathered zones, soils, peat, erosion.	Kay and Graham (1943, pp. 63–75); Ruhe, Daniels, and Cady (1966).
Illinoian			Loveland loess	Kay and Graham (1943, pp. 63–75); Leighton and Willman (1950, pp. 601–602); Ruhe, Daniels, and Cady (1966).
		Yarmouth	Soils, erosion, sediment.	Kay and Apfel (1929, pp. 257–281); Ruhe, Daniels, and Cady (1966).
Kansan			Drift	Kay and Apfel (1929, pp. 212–256); Ruhe, Daniels, and Cady (1966).
		Aftonian	Soils, peat, weathered zones.	Kay and Apfel (1929, pp. 183–199); Ruhe, Daniels, and Cady (1966).
Nebraskan			Drift	Kay and Apfel (1929, pp. 141–145); Ruhe, Daniels, and Cady (1966).

[1] Ruhe, Robert V. Reclassification and Correlation of the Glacial Drifts of Northwestern Iowa and Adjacent Areas. Unpublished Ph.D. thesis, Iowa State University. 124 pp. 1950.

Pleistocene and Recent Deposits

The Pleistocene deposits in the Boyer and Willow River watersheds (table 1) are separated stratigraphically by buried soils, erosion surfaces, weathered zones, and interbedded sediments (Ruhe, Daniels, and Cady, 1966). Although pre-Wisconsin deposits occur in these watersheds, the main emphasis of this study is on the Wisconsin to Recent deposits.

PRE-WISCONSIN DEPOSITS

Kansan

Nebraskan till has not been recognized in this area. Small areas of till, probably Kansan, are exposed on valley slopes in Thompson Creek watershed (pl. 1) and in the trench of Thompson Creek. On valley slopes, a soil at the top of Kansan till grades downward to dark yellowish brown (10YR 4/4)[1] oxidized and leached till. This zone grades to variegated yellowish brown and grayish brown (10YR 5/5 and 2.5Y 5/2) oxidized and unleached till. The solum at the top of the till is either a paleosol of Yarmouth or late Sangamon age or a soil of Recent age.

[1] Munsell color notation.

Illinoian

Loveland loess is the only Illinoian deposit recognized in the watersheds (Ruhe, Daniels, and Cady, 1966; Leighton and Willman 1950, pp. 601–602). It is separated from the overlying Wisconsin loess by a paleosol in the Loveland loess and from the underlying Kansan till by a paleosol in the till or, if there is no paleosol, by distinct differences in lithology between the till and the loess. The paleosol in Loveland loess is a dark brown (7.5YR 4/4) silty clay loam that grades to a yellowish brown to brown (10YR 5/4 to 5/3) noncalcareous silt loam. In the few exposures available for study the loess is noncalcareous throughout, but calcareous Loveland has been reported in western Iowa (Kay and Graham 1943, p. 65; Daniels and Handy 1959, p. 116).

Loveland loess is almost completely mantled by Wisconsin loess on the buried divides and valley slopes in Thompson Creek and Magnolia watersheds (figs. 2, 3; pl. 2). Because the loess could not be penetrated,

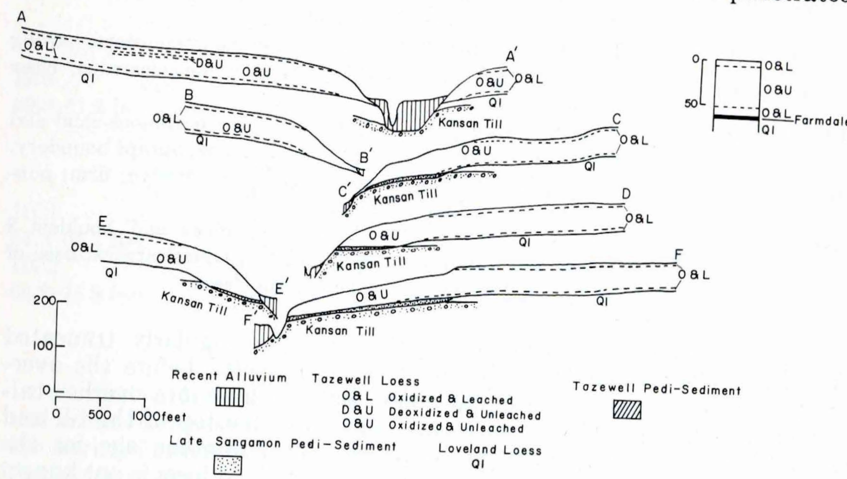


Figure 2.—Distribution of sediments along the long axes of ridge crests in Thompson Creek watershed. The relation of the Farmdale to other sediments is shown in the upper right corner.

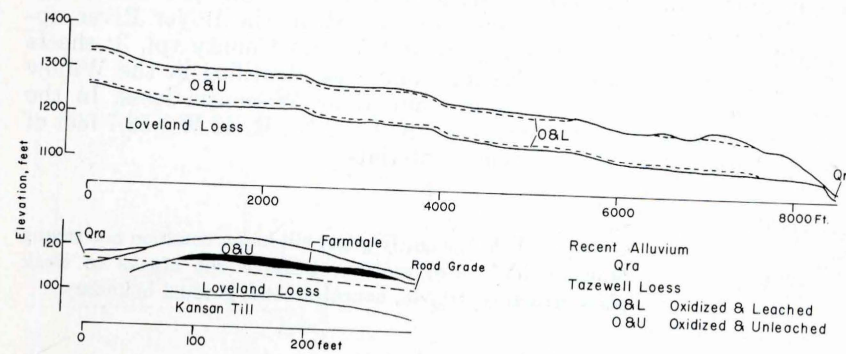


Figure 3.—Distribution of sediments along and across the long axes of ridge crests in Magnolia watershed.

we do not know its thickness in the center of the ridge crests. But in the vicinity of Turton Branch (pl. 1; fig. 2, B–B′) 20 feet of Loveland loess was penetrated without reaching its base.

Sangamon

There is one small area of noncalcareous alluvium overlain by calcareous Tazewell loess in Thompson Creek watershed 200 feet east of the junction of Soetmelk Branch and Thompson Creek (pl. 1). A description of the section follows.

TAZEWELL LOESS	
0–35.0 feet	Brown to yellowish brown (10YR 5/3–5/4)[2] silt loam;[3] few light brownish gray (2.5Y 6/2) mottles; massive; friable; calcareous; abrupt boundary.
ALLUVIUM	
35.0–36.5 feet	Dark grayish brown (10YR 4/2) gritty silty clay loam; massive; noncalcareous; clear boundary.
36.5–41.0 feet	Pale brown (10YR 6/3) silt loam; common coarse strong brown (7.5YR 5/8) mottles; massive; noncalcareous; clear boundary.
41.0–44.5 feet	Grayish brown (2.5Y 5/2) silt loam; discontinuous sand and gravel lenses; massive; firm; noncalcareous; abrupt boundary.
44.5–46.0 feet	Dark gray (10YR 4/1) silty clay loam; massive; firm; noncalcareous; gradual boundary.
46.0–55.3 feet	Grayish brown (2.5Y 5/2) loam; pebbles and boulders 8 inches and less in diameter; massive; noncalcareous; base of section is the flow line of Thompson Creek.

Although there is no paleosol at the top, the angularly truncated bedding indicates that the alluvium had been eroded before the overlying loess was deposited. Borings show that the alluvium overlies calcareous Kansan till. The absence of a paleosol in the top of the till and of Loveland loess in the section suggests a post-Illinoian age for the alluvium. But the relation of the alluvium to Loveland loess is not known and the deposit may range in age from Yarmouth to Tazewell. The alluvium does not crop out in Thompson Creek watershed.

Late Sangamon.—Remnants of pre-Wisconsin alluvium overlying Pennsylvanian and Cretaceous bedrock (Tester 1937) are above the Boyer River valley floor from near the mouth of the Boyer River upstream 20 miles to the northern part of Harrison County (pl. 3: sheets 1, 2). Only one remnant of this alluvium was identified in the Willow River valley (pl. 3: sheet 1). It is mantled by Wisconsin loess. In the limestone quarries at Logan (SE$\frac{1}{4}$ sec. 18, T. 79 N., R. 42 W.) 52.7 feet of Tazewell loess overlie the following materials.

FARMDALE	
A1b 52.7–54.9 feet	Gray (10YR 5/1) slightly gritty silt loam; common fine strong brown (7.5YR 5/6) mottles; massive but breaks to weak platy structure; friable; noncalcareous; gradual boundary.

[2] Munsell color notation of moist soil.

[3] Texture after Soil Survey Staff (1951, p. 209).

LATE SANGAMON PALEOSOL AND ALLUVIUM	
A2b 54.9–56.0 feet	Grayish brown (2.5Y 5/2) gritty silt loam; many fine to coarse strong brown (7.5YR 5/8) mottles; massive; friable; gradual boundary.
B1b 56.0–57.2 feet	Grayish brown (2.5Y 5/2) gritty silty clay loam; many fine to coarse strong brown (7.5YR 5/8) mottles; weak fine subangular blocky structure; firm; gradual boundary.
B21b 57.2–57.8 feet	Olive gray (5Y 5/2) gritty silty clay loam to clay loam; many fine to coarse strong brown (7.5YR 5/8) mottles and streaks; strong fine subangular blocky structure; continuous clay skins; firm; clear boundary.
B22b 57.8–59.2 feet	Olive gray (5Y 4/2) clay loam; many fine to coarse strong brown and reddish brown mottles, streaks, and pipestems; strong fine to medium subangular blocky structure; continuous clay skins; patchy white silt on ped exteriors common; firm; gradual boundary.
B3b 59.2–61.2 feet	Olive gray (5Y 5/2) loam to clay loam; common strong brown (7.5YR 5/6) mottles; weak medium to coarse blocky structure; continuous clay skins in upper part of horizon but mainly vertical in lower part, friable; few sandy lenses; gradual boundary.
IIC1 61.2–65.2 feet	Grayish brown (10YR 5/2) fine to medium sand; massive; noncalcareous; few silt lenses; clear boundary.
IIC2 65.2–75.8 feet	Yellowish brown (10YR 5/6) medium to coarse sands; few pebbles less than ½ inch in diameter; noncalcareous; base of deposit not seen.

In other parts of the quarry, the strongly developed paleosol is absent and massive noncalcareous silty clay loams, clays, or clay loams underlie the buried Farmdale A horizon. Where the Farmdale A horizon is absent, the lower noncalcareous part of Tazewell loess rests directly on massive clay loams, sandy loams, or sands. In several sections the lower sands

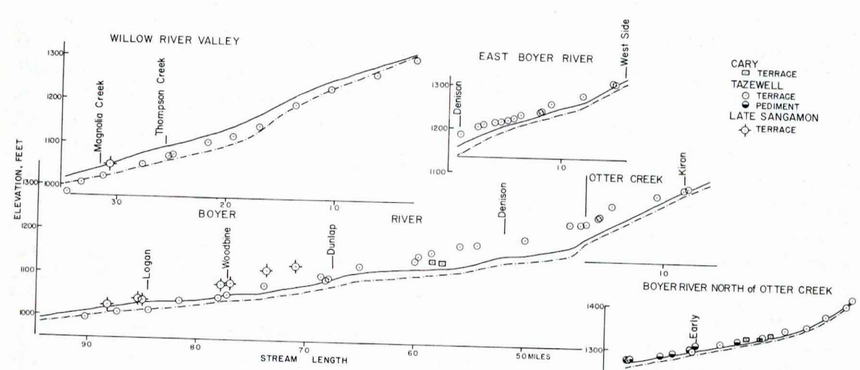


Figure 4.—Profiles of late Sangamon, Tazewell, and Cary terraces in the Boyer and Willow River valleys.

overlie limestone whose surface has a local relief of about 8 feet. The sands are thicker in the bedrock depressions.

The late Sangamon alluvium is noncalcareous and 5 to 15 feet thick. The upper part is a clay loam to silty clay loam that grades downward to sand containing a few fine pebbles. At Logan the top of the alluvium is 7 feet above the modern flood plain, but south of Dunlop it is 50 feet (fig. 4). In the Willow River valley the top of the alluvium is 2 feet below the modern flood plain. This alluvium is mantled by loess and forms distinct topographic terraces[4] in the Boyer River valley.

We made a drilling traverse across the terrace from the uplands on the line between secs. 17–18, and 19–20 (T. 79 N., R. 42 W.). Here noncalcareous sands overlie bedrock; they are thicker toward the center of the valley (fig. 5). A massive noncalcareous silty clay loam overlies the sands. In the center of the terrace the silty clay loam has a very dark gray (10YR 4/1) 3-inch-thick organic horizon at the top. Near the valley slope the silty clay loam is black (10YR 2/1), contains much wood, and is overlain by a massive calcareous dark gray (5Y 4/1) silt that is stratigraphically equivalent to the lower noncalcareous part of Tazewell loess.

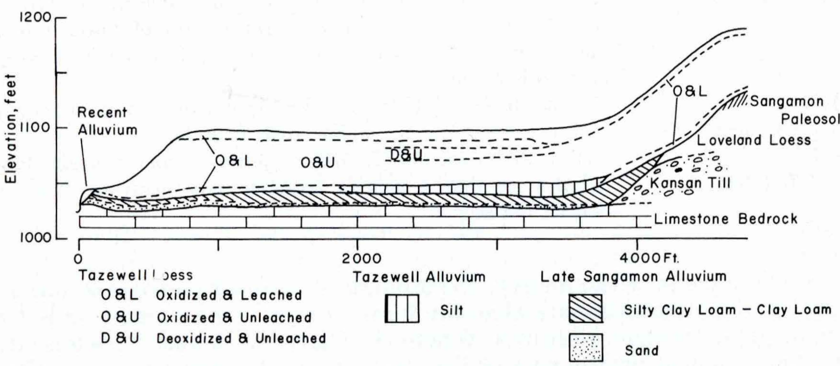


Figure 5.—Relation of late Sangamon terrace deposits to upland deposits at the Logan quarries.

A buried upland surface marked by a weakly developed soil slopes downward to the top of the terrace sediments, truncates the Sangamon paleosol, and merges with the top of this noncalcareous alluvium in a smooth concave profile (fig. 5). The surface of the alluvium is younger than the Sangamon paleosol and older than Tazewell loess. Although we did not see the Farmdale paleosol in this traverse, we saw it in sections less than one-eighth of a mile away. The similarity in lithology and sequence of sediments between these sections indicates that this alluvium is pre-Farmdale. It is late Sangamon as previously defined (Ruhe, Daniels, and Cady, 1966). But streams flowing from the uplands across the terrace may have deposited some material of Farmdale age.

Dating of the material on the high terrace in the Boyer River valley as late Sangamon requires a reclassification of Shimek's Peckenpaugh

[4] Terrace is used to denote a landform in unconsolidated alluvial deposits confined within recognizable valley walls.

sections (SW¼sec. 19, T. 79 N., R. 43 W., Harrison County, on the east bank of the old milldam at Logan). Shimek's (1910, p. 336) classification was:

4. Loess and soil, 20 feet.
3. Loveland, reddish, somewhat sandy, 6 feet.
2. Aftonian
   Sand, cross-bedded, 7 feet.
   Coarse ferruginous gravel, 2 feet.
1. Missouri limestone, exposed 4 feet.

This area was badly overgrown and slumped in 1959, but horizons 4, 3, and 2 were visible. Horizons 2 and 3 must be reclassified as late Sangamon alluvium. The somewhat sandy reddish upper "Loveland" of Shimek is the upper part of the late Sangamon alluvium. Sections similar to the Peckenpaugh can be seen on the north side of an abandoned quarry of the Clark Limestone Company (NW¼NE¼sec. 19, T. 79 N., R. 43 W., Harrison County, Iowa).

WISCONSIN DEPOSITS

Iowan Drift

Iowan drift was recognized by Smith and Riecken (1947, pp. 707–713) and Corliss and Ruhe (1955, pp. 345–347) in the headwaters of the East Boyer River in eastern Crawford County and western Carroll County. Corliss and Ruhe used four lines of evidence to differentiate Iowan drift from Kansan drift.

1. In topographic positions that preclude significant erosion on the Iowan drift surface, calcareous loess overlies calcareous till.
2. In topographic positions that preclude significant erosion on the Kansan drift surface, calcareous loess overlies a leached buried soil in the uppermost part of the Kansan till.
3. An abrupt change in topography occurs at the margin of the Iowan drift.
4. A discontinuity in loess thickness occurs at the margin of the Iowan drift.

In north-central Crawford County, southeastern Ida County, and southwestern Sac County a loess-mantled till having characteristics similar to the Iowan described by Smith and Riecken and Corliss and Ruhe is on interstream divides (fig. 6). The description of a typical section near the SW corner of SE¼sec. 25, T. 85 N., R. 39 W., Crawford County, Iowa, follows.

LOESS	
O & L[5] 0–12.5 feet	Brown (10YR 4.5/3) silt loam; few fine to coarse grayish brown and strong brown mottles; massive; friable; noncalcareous Tazewell loess; abrupt boundary.
O & U 12.5–13.0 feet	Brown to yellowish brown (10YR 5/3 to 5/4) silt loam; few grayer and browner mottles; massive; friable; calcareous; base of Tazewell loess; abrupt boundary.

[5] O & L—ozidized and leached; O & U—oxidized and unleached (Ruhe 1954a, p. 640).

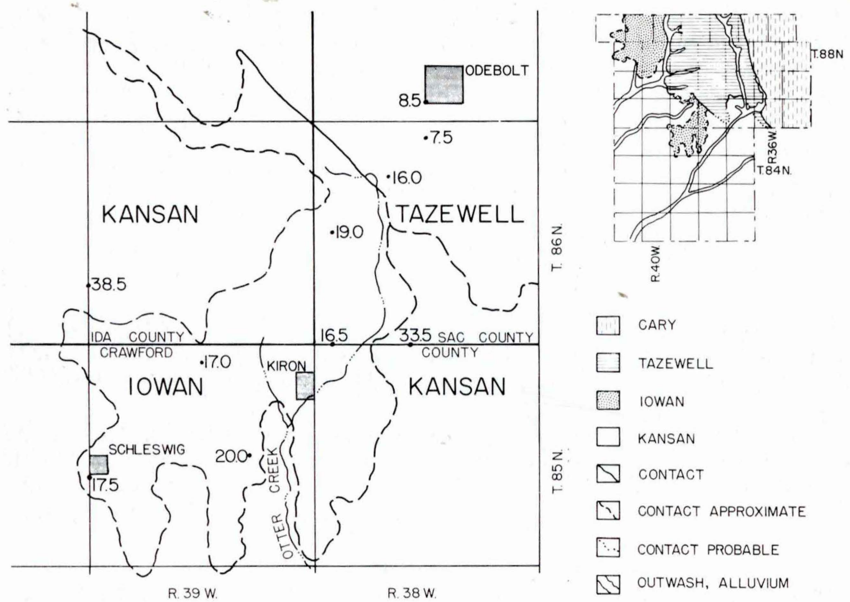


Figure 6.—Left, areal distribution of Iowan drift in north-central Crawford County, southeastern Ida County, and southwestern Sac County, Iowa. (Numbers beside dots give loess thickness in feet.) Right, distribution of Cary, Tazewell, and Iowan drift areas north of T. 87 N., R 40 W. (after Ruhe 1950).

SAND 13.0–15.0 feet	Yellowish brown (10YR 5/4 to 5/6) loamy sand; massive; friable; calcareous; abrupt boundary.
TILL 15.0+ feet	Yellowish brown (10YR 5/4) clay loam; few fine to coarse grayish brown and strong brown mottles; massive; firm; calcareous; base of section at 16.0 feet.

Massive calcareous sands usually separate the calcareous till and the overlying loess in the area mapped as Iowan drift (fig. 6). In contrast, there is a paleosol in the top of Kansan drift. We did not find a pebble band at the top of Iowan drift in road cuts but found one in a few borings. There is no pebble band where calcareous sands separate the loess and till.

The loess that mantles Kansan drift next to the border of Iowan drift has a loam to loamy sand layer 4 to 12 inches thick. This layer is 16 to 20 feet below the surface of the ridge but is 20 feet or more above the Kansan drift surface. The upper and lower boundaries of this sandy material are abrupt, and there is no observable change in the loess above or below the sandy material.

Loess 16½ to 20 feet thick mantles Iowan till; it thickens abruptly to 33 and 38 feet at the Iowan-Kansan border (fig. 6). The loess thickness given for the Kansan area is not a maximum because no measurements could be made on broad level interstream divides. The change across the Iowan-Tazewell border is more gradual than that across the Iowan-Kansan border. In Sac County the loess on Iowan drift is 19 feet thick; 4 miles to the northeast the loess on Tazewell drift is 16 feet thick (fig. 6).

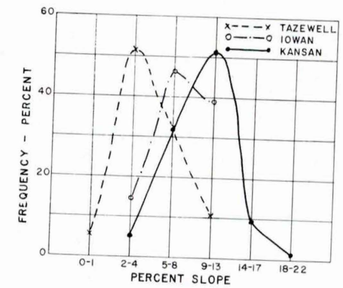


Figure 7.—Frequency curves of slopes on the ground surface exclusive of alluvial areas in the Kansan, Iowan, and Tazewell drift areas in Sac County and Crawford County, Iowa.

The difference across the border is of the same order of magnitude as the range in loess thickness on the Iowan. But the loess on Tazewell drift thins to the northeast from 16 to 7½ and 8½ feet in a distance of about 2½ miles.

Previous work has shown that slope increases progressively from the Tazewell to the Iowan drift and from the Iowan to the Kansan drift in western Iowa (Ruhe 1950, p. 440). Frequency curves compiled from statistically selected 160-acre samples (Arnold et al. 1960) show similar relations (fig. 7).

The absence of a paleosol at the top of the till, the abrupt changes in topography and in loess thickness, and the lobate border suggest that the drift is the Iowan of Smith and Riecken. But the primary evidence that the drift is Iowan is the absence of a paleosol at the top of the till and in the base of the loess and the changes in loess thickness. Nowhere in the area mapped as Iowan drift is there an exposure that shows conclusively a calcareous till overlying Kansan and Nebraskan tills. The area mapped as Iowan drift could be older than Iowan; we need more information to determine the exact stratigraphic placement of the till.

Pre-Tazewell Alluvium

Clay loam to silty clay loam sediments overlie bedrock in the north face of the Logan quarry (sec. 20, T. 79 N., R. 42 W., Harrison County, Iowa). The materials are not markedly different from similar material exposed on the late Sangamon terrace immediately north of the quarry. The description of the section follows.

TAZEWELL LOESS O & U 0–16.0 feet	Brown (10YR 5/3) silt loam; few to many grayish brown and strong brown mottles; massive; friable; calcareous; strong brown (7.5YR 5/6) iron band 6 inches thick at base; abrupt boundary.
TAZEWELL ALLUVIUM (?) 16.0–22.2 feet	Gray (10YR 5/1) silt loam; distinct horizontal bedding (less than ⅛-inch) that is platy when dry; friable; noncalcareous; few wood fragments; radiocarbon sample W879 at 19.4 feet; abrupt boundary with 6 to 12 inches vertical relief.
PRE-TAZEWELL ALLUVIUM Ab 22.2–22.7 feet	Black (5Y 2/1) silty clay loam; massive; firm; noncalcareous; abrupt boundary.

22.7–25.2 feet	Olive gray (5Y 5/2) clay loam; few pebbles at top; massive; firm; noncalcareous; abrupt boundary.
25.2–28.7 feet	Gray (5Y 5/1) clay loam; many strong brown (7.5YR 5/6) horizontal streaks along bedding planes; few limestone pebbles at top; few pebbles throughout bed; distinct horizontal bedding; firm; noncalcareous; clear boundary.
Ab 28.7–29.2 feet	Black (10YR 2/1) clay loam; few wood fragments; massive; firm; noncalcareous; clear boundary.
29.2–30.0 feet	Gray (5Y 5/1) clay loam; interbedded sand lenses; firm; noncalcareous; abrupt boundary.
Ab 30.0–30.5 feet	Black to very dark gray (10YR 2/1 to 3/1) silty clay loam; many wood fragments; radiocarbon sample W880 at 30.2 feet; massive; firm; noncalcareous; clear boundary.
30.5–32.6 feet	Dark gray (5Y 4/1) silty clay loam; few wood pieces in middle of bed; massive; firm; noncalcareous; gradual boundary.
32.6–37.6 feet	Light brownish gray (10YR 6/2) loamy sand and fine to coarse sand interbedded with silty clay loam; distinct horizontal bedding; firm; noncalcareous; base of alluvium, top of Pennsylvanian limestone.

The lower alluvium in the section (22.2 to 37.6 feet) angularly truncates the underlying sand, clay, gravel, and limestone (fig. 8). This alluvium is noncalcareous and has many pebble lenses and dark organic horizons. The organic horizons are massive and have abrupt lower boundaries; the underlying materials show no soil structure or clay movement that indicates beginning soil development. At most, the organic horizons represent A horizons of beginning soils. These horizons indicate a slowdown or cessation of deposition, but the time of their formation may have been relatively short on a moist flood plain. The organic horizons do not necessarily represent interstades in deposition of the basal alluvium.

The laminated dark-colored silt (16.0 to 22.2 feet) in the section disconformably overlies the lower alluvium. The contact is abrupt and is marked by pebble lenses or by an undulating contact having local relief of 6 to 12 inches. The silt is massive when moist but has a distinct horizontally laminated structure when dry. In most areas it is not calcareous, but locally it is weakly to strongly effervescent. The contact between this silt and the overlying loess is conformable although abrupt and is marked by a change in color, structure, and reaction. The conformable relation and the similarity in texture between the silt and the overlying loess

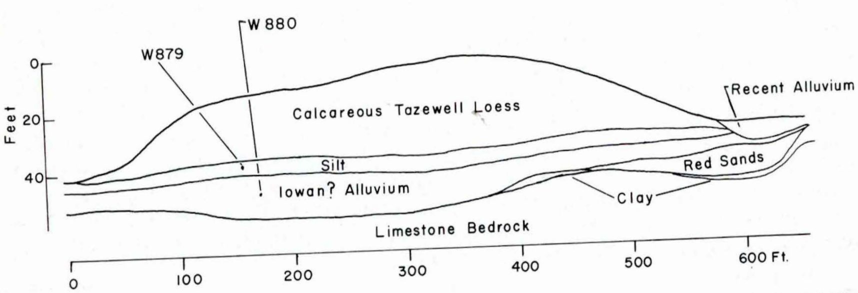


Figure 8.—Sediments exposed in the north face of a quarry at Logan, sec. 20, T. 79 N., R. 42 W., Harrison County, Iowa.

suggest that the silt and loess are closely related in time. Possibly the silt is loess that was deposited in an environment that favored gleying and accumulation of organic matter.

Spruce[6] fragments at 30 to 30.5 feet are 37,600±1,500 years old (fig. 8, W880). Spruce fragments from the middle of the overlying laminated silt 19.4 feet are 19,050±300 years old (fig. 8, W879). The disconformable contact between the laminated silt and the lower alluvium is the major stratigraphic break in the section. This disconformity represents a period of no deposition but does not necessarily indicate that much time elapsed. The radiocarbon dates indicate that the lower 7.5 feet of the lower alluvium is pre-Tazewell and that the upper 7.8 feet is pre-Tazewell to Tazewell. The base of the overlying laminated silt could be 37,600 years old, but this seems unlikely because there is no discontinuity in the silt between the radiocarbon sample and the base. The laminated silt, therefore, probably is Tazewell.

The quarry is at the edge of the upland near the late Sangamon terrace. A small stream flowing from the upland to the Boyer River crosses the terrace just north of the section; the lower alluvium may be related to this tributary rather than to the main stream. The lower alluvium in the quarry cannot be correlated with the late Sangamon alluvium under the adjacent terrace.

Farmdale Loess

Farmdale loess overlies the Sangamon paleosol in Loveland loess and the late Sangamon paleosol in Kansan till on buried ridge crests in Thompson Creek and Magnolia watersheds (figs. 2, 3). Farmdale loess is seldom more than 3 feet thick, and it has a weakly developed AC paleosol in the upper part. The very dark gray (10YR 3/1) silt loam A horizon of the paleosol is 3 to 9 inches thick and grades downward to a dark grayish brown (10YR 4/2 to 2.5Y 4/2) silt loam C horizon. The loess is noncalcareous (table 10). The contact between Farmdale loess and the overlying Tazewell loess is abrupt. Where the A2 horizon of the underlying Sangamon or late Sangamon paleosol is silty, the contact between Farmdale loess and the underlying material is difficult to determine. Wood from the A horizon of the Farmdale paleosol in Pottawattamie County, Iowa, was dated at 24,500±800 years (Ruhe and Scholtes 1956, p. 265).

Tazewell Loess

Tazewell loess continuously mantles the upland in Magnolia watershed and in the upper reaches of the Thompson Creek valley (pls. 1, 2). Downvalley from Mullenix Branch in Thompson Creek watershed, small areas of Loveland loess and Kansan till crop out on the valley slopes. Tazewell loess is 62 to 65 feet thick on the broader divides and high-level ridges in Thompson Creek watershed and at the most is 77 feet thick in Magnolia watershed. Ruhe (1954b, p. 669) demonstrated that the configuration and elevation of a surface influences the thickness of loess deposited on that surface. The thinning of Tazewell loess from the drainage divide to lower ridge crests in these watersheds probably is related to the elevation and configuration of the buried surfaces.

[6] All wood identified by Professor W. D. Bensend, Iowa State University Department of Forestry, Ames, Iowa.

Weathering zones.—Regional weathering zones in Tazewell loess in southwestern Iowa from the surface down are (Ruhe 1954a, p. 640):

O & L zone:	Oxidized and leached yellowish brown silt loam.
D & U zone:	Deoxidized and unleached gray silt loam; iron oxide segregated in tubules and concretions.
O & U zone:	Oxidized and unleached yellowish brown silt loam.
D & L zone:	Deoxidized and leached gray silt loam; iron oxide segregated in tubules and concretions.

The lower deoxidized zone overlies buried A horizons of the Farmdale paleosol.

The weathering zones of Tazewell loess in Thompson Creek and Magnolia watersheds are similar to those of Ruhe. On a gently convex 2-percent ridge crest in the center of a divide in Thompson Creek watershed the section is:

Location: 50 feet southwest of NW corner of SW¼sec. 17, T. 80 N., R. 42 W., Harrison County, Iowa (pl. 1: E.76, 1.46[7]).

Described by: R. B. Daniels and G. H. Simonson.

TAZEWELL LOESS	
O & L 0–5.5 feet	Dark brown (10YR 4/3) silt loam; few grayer and browner mottles; massive; friable; leached loess; abrupt boundary.
O & U 5.5–16.0 feet	Brown (10YR 5/3) silt loam; many to few grayish brown and strong brown (2.5Y 5/2 and 7.5YR 5/6) mottles; massive; friable; calcareous; abrupt boundary.
D & U 16.0–23.5 feet	Grayish brown (2.5Y 5/2) silt loam; many strong brown (7.5YR 5/8) mottles and pipestems; massive; friable; calcareous; clear boundary.
O & U 23.5–51.5 feet	Brown to yellowish brown (10YR 5/3 to 5/4) silt loam; few grayish brown and strong brown (2.5Y 5/2 & 7.5YR 5/6) mottles; massive; friable; calcareous; clear boundary.
O & L 51.5–61.4 feet	Yellowish brown (10YR 5/4) silt loam; many coarse and fine distinct greenish gray (5GY 5/1) mottles in lower part of horizon; massive; friable; noncalcareous; clear boundary.
FARMDALE PALEOSOL	
Ab 61.4–62.0 feet	Very dark gray to dark gray (10YR 3.5/1) silt loam; many fine pieces of charcoal; massive; friable, gradual boundary.
Cb 62.0–66.0 feet	Dark gray (2.5Y 4/0) silt loam; few strong brown (7.5YR 5/6) mottles; massive; friable; leached, abrupt boundary.
SANGAMON PALEOSOL	
Bb 66.0+ feet	Dark brown (7.5YR 4/4) silty clay loam; few grayish brown (2.5Y 5/2) silt grains on exteriors of moderate fine subangular blocky peds; firm; Loveland loess; base of section at 68.5 feet.

Although the weathering zones are similar to those described by Ruhe, there are slight differences. The lower leached loess usually is yellowish brown instead of the gray or grayish brown of deoxidized loess. Furthermore, the deoxidized and unleached zone is missing in many areas and, if present, is not continuous under the long axes of the ridge crests (fig. 3).

[7] On plates E.76 is 76/100 of the distance between grid lines E and F; 1.46 is 46/100 of the distance between grid lines 1 and 2.

The upper leached zone occurs on the major divides and level ridge crests, and in the upper part of Thompson Creek watershed it occupies the largest part of the nonalluvial landscape (pl. 4). This zone is 10 feet thick in the center of upland divides, but it is truncated by topographic saddles and valley slopes (figs. 3, 4). Under ridge crests, the base of the upper leached zone is flat to very gently convex and parallels the ground surface. The leached zone is thinner on ridge shoulders. Calcareous loess is at the surface in some places on valley sides, but in several areas the loess is leached 1 to 3 feet deep. The areal distribution of the upper leached zone was mapped by extrapolating its distribution under ridge crests. Leached loess on valley slopes but below the base of the upper leached zone under ridge crests was grouped with outcrops of calcareous zones. The areal distribution of these weathering zones is an important factor in the distribution of soils in Tazewell loess.

Physical and chemical properties.—Thin sections from oxidized calcareous loess show a fine-grained groundmass without clay concentrations. Many opaque sesquioxide masses 0.05 to 0.34 mm in diameter are present. Vertical pores 0.05 to 0.60 mm in diameter are few to common. Roughly circular concentrations of iron oxide are common around the pores. Maximum diameter of the oxide concentrations is 0.80 mm. There are few horizontal pores and they are no larger than 0.05 mm. Thin sections from the lower leached loess are similar to those from the calcareous loess except that the groundmass is more densely packed and iron oxides line most of the pores. The physical and chemical properties of Tazewell loess are summarized in tables 10 and 12.

Age.—The base of the loess is younger than the underlying Farmdale paleosol and its top is older than Cary because it passes under Cary drift (Ruhe and Scholtes 1955, p. 85; Ruhe et al. 1957, pp. 674–688). The loess is less than 24,500 years old but more than 14,000 and is within the radiocarbon age of Tazewell till in Illinois (Horberg 1955, p. 281; Flint and Rubin 1955, p. 654).

Radiocarbon dates for the lower leached Tazewell loess are not available, but we have dated stratigraphically equivalent horizons. The pre-Tazewell alluvium in the north face of a quarry at Logan, Iowa (sec. 20, T. 70 N., R. 42 W.) is overlain by a noncalcareous laminated silt that is overlain by calcareous Tazewell loess. Wood in the laminated silt, 3.4 feet below its top, is $19{,}050 \pm 300$ years old (fig. 8, W879). The silt is younger than Farmdale but older than samples of wood from calcareous loess in central Iowa. Although it was impossible to trace the silt to the lower leached Tazewell loess, the two sediments must be contemporaneous because they occupy the same stratigraphic position between Farmdale loess and calcareous Tazewell loess. The base of the lower leached Tazewell loess is less than 24,500 years old and its top less than 19,050 years.

Tazewell Alluvium

Loess-mantled terraces of Wisconsin age are distinct physiographic features in the Willow and Boyer River valleys. In much of the Boyer valley the top of the terrace deposits is above the present valley floor. In the Willow valley the terraces are below flood-plain level but their loess mantle rises above the modern flood plain.

Terrace deposits are discontinuous from the mouth of the Willow River valley to within 2 miles of the valley head (pl. 3: sheets 1, 2). The largest remnants are near Thompson Creek and Magnolia watersheds, but their size decreases upstream and near the valley head the areas are almost too small to map.

We found one outcrop of loess-mantled alluvium in the Willow valley on the east bank of Willow drainage ditch (NE¼NE¼sec. 14, T. 80 N., R. 43 W., Harrison County, Iowa) at the northeast end of a steel bridge. The sequence and characteristics of the materials follow.

RECENT ALLUVIUM	
0–7.1 feet	Very dark gray (10YR 3/1) silt grading downward to very dark grayish brown (10YR 3/2); friable; noncalcareous; gradual boundary.
7.1–11.1 feet	Dark grayish brown (10YR 4/2) silt; many grayish brown and strong brown mottles; weak discontinuous organic zone at base; friable; calcareous; abrupt boundary.
TAZEWELL LOESS	
11.1–27.0 feet	Brown to pale brown (10YR 5/3–6/3) silt loam; many fine and coarse grayish brown and reddish yellow (2.5Y 5/2 and 7.5YR 6/6) mottles and black (10YR 2/1) stains; the coarse grayish brown mottles are oriented along modern rootlets; friable, calcareous; abrupt (knife-edge) boundary.
TAZEWELL ALLUVIUM	
27.0–28.7 feet	Light yellowish brown to yellowish brown medium and fine sands grading downward to coarse sands and fine pebbles at 28.0 feet; distinct horizontal bedding; single grained; calcareous; base of section covered by slump; flow line of Willow drainage ditch at 37.0 feet.

The section is located at the edge of a terrace (pl. 3: sheet 1), and although covered by Recent alluvium, the loess crops out about 50 feet east of the section. The Tazewell alluvium is covered by slump but borings show that the surface of the sands and pebbles is almost level. The contact between the loess and the underlying alluvium is sharp. There are no logs, twigs, or organic horizon at the contact.

The alluvium ranges from silt to gravel in other parts of the Willow valley. In the NW corner of NW¼sec. 29, T. 81 N., R. 42 W., Harrison County, Iowa, the section is:

TAZEWELL LOESS	
0–12.5 feet	Dark brown noncalcareous silt loam; abrupt boundary.
12.5–53.0 feet	Pale brown calcareous silt loam; lower part light brownish gray; abrupt boundary.
TAZEWELL ALLUVIUM	
53.0–65.0 feet	Greenish gray silt loam; many thin (less than 6 inches) intercalated sand layers; abrupt boundary.
65.0–76.0 feet	Greenish gray fine sands becoming coarser with depth; calcareous; gravel in base.

In some sections greenish gray calcareous silty alluvium lies below loess; it has many interbedded layers of fine sand and grades to calcareous sands or gravel, or both. The contact between the silty alluvium and the overlying loess is marked by an abrupt change in color. Silty material at the top of the alluvium is found most frequently in the headwaters of the Willow valley. The top of the Tazewell alluvium is 16 feet lower than the adjacent flood plain at the head of the valley and 35 feet lower than the flood plain at the mouth (fig. 4). We drilled through 23 feet of the alluvium without reaching its base.

Discontinuous loess-mantled terrace deposits are along the valley slopes from the mouth of the Boyer River valley to the vicinity of Westside where they merge with the Iowan drift (Corliss and Ruhe 1955, p. 349; pl. 3: sheets 1–6). The terrace deposits can be traced upstream from Denison to and into the Otter Creek valley where they merge with Iowan drift near Kiron. The terraces are in tributaries that drain Tazewell drift but not in the Boyer River valley in northern Crawford County and southern Sac County. One of the best exposures of the terrace deposits in tributary valleys is in sec. 26, T. 86 N., R. 38 W., Sac County, Iowa, where Kay and Miller (1941, p. 107) described 20 feet of loess overlying 22 feet of sand and gravel. But the deposits are in the Boyer valley from a mile south of Early, Sac County, Iowa, upstream to within 1½ miles of the headwaters of the Boyer River.

A section of the terrace deposit in the Boyer River valley near the junction of the East Boyer and Boyer Rivers (NW¼sec. 14, T. 83 N., R. 39 W., Crawford County, Iowa) is:

TAZEWELL LOESS	
0–4.0 feet	Dark brown (10YR 4/3) silt loam; many grayish brown and strong brown mottles; friable; calcareous; abrupt boundary.
TAZEWELL ALLUVIUM	
4.0–8.5 feet	Very pale brown (10YR 7/4) medium sands; many thin (less than ¼ inch) silt lenses; distinct horizontal bedding; calcareous; abrupt boundary.
8.5–16.5 feet	Light yellowish brown (10YR 6/4) interbedded fine to coarse sands and pebbles; few silt lenses as much as ½ inch thick; distinct horizontal bedding; calcareous; abrupt boundary.
16.5–34.0 feet	Very pale brown (10YR 7/4) interbedded sands and pebbles; distinct horizontal and inclined bedding; individual beds 6 to 24 inches thick; base of section; base of sands and pebbles not exposed.

Downstream from Woodbine, Iowa, the sequence from the top of the terrace deposits downward is a layer of greenish gray silt and interbedded sand, a layer of sand, and then a layer of sand and gravel. Upstream from Woodbine the upper layer is absent. In the Boyer River valley the deposit is mostly sand, and pebbles more than 6 inches in diameter are scarce (Lees 1927, p. 328). In the Otter Creek valley Kay and Miller (1941, pp. 103–109) found that most pebbles are less than 32 mm in diameter and that sedimentary rocks, including limestone and dolomite, make up most of the 16–32 mm fractions.

The contact between the loess and the terrace alluvium is abrupt and smooth, but in some areas these materials are interbedded over a depth

TABLE 2.—*Vertebrate fossils from Tazewell alluvium, Boyer River valley*

Form	Location	Stratigraphic location	Parts identified	Authority
Mammuthus (Parelephas) columbi.	Center NW¼ sec. 26, T. 82 N., R. 41 W., Crawford County, Iowa.	At contact between loess and alluvium.	Mandible, upper third molars, tusks, left foreleg, ribs, and vertebrae.	Frankforter [1]
Mammuthus primigenius Blumenbach.	Center N½NE¼ sec. 16, T. 83 N., R. 39 W., Crawford County, Iowa.	Ferruginous gravel 3 feet below contact of gravel and loess.	Fragmentary tusk, scraps of a skull, upper third molars, cervical vertebrae, one dorsal vertebra, rib, right humerus.	Frankforter [1]
	NW corner sec. 14, T. 83 N., R. 39 W., Crawford County, Iowa.	In sands.	Mastadon teeth and other skeletal remains.	Lees (1927, p. 329).

[1] Written communication, W. D. Frankforter, then (1960) director of Sanford Museum, Cherokee, Iowa.

of 3 to 6 inches. Calcareous loess usually rests directly on calcareous alluvium but in a sand and gravel pit (NW¼sec. 4, T. 82 N., R. 40 W., Crawford County, Iowa; pl. 3: sheet 3), 10 feet of calcareous, fine to very fine, somewhat silty massive sand overlies calcareous sands and fine gravels. Under a hand lens the grains of the overlying sand appear to be frosted, and they may be of eolian origin. The fine-grained sand is capped by Tazewell loess.

Vertebrate fossils in the alluvium are listed in table 2. Invertebrate fossils recovered from alluvium associated with *Mammuthus (Parelephas) columbi* are given in the following list. They were identified by Professor L. A. Thomas, Iowa State University Geology Department, Ames, Iowa. *Lymnea parva* is an aquatic species; the rest of the invertebrates are terrestrial.

	Order of abundance
Cionella lubrica	Rare
Columella alticola	Abundant
Discus cronkheti	Common
Gastrocopta holgingeis	Rare
Hendersonia occulta	Rare
Lymnea parva	Sparse
Pupilla muscorum	Sparse
Retinella electrina	Sparse
Succinea grosvenori	Common
Vallonia gracilicosta	Common
Vertigo modesta	Abundant
Vertigo tridentata	Abundant
Zonitoides arboreus	Rare

Remnants of the loess-mantled terrace deposits can be traced inside the Iowan drift border in the East Boyer River valley and are believed to be related to Iowan deglaciation (Corliss and Ruhe 1955, p. 349). The terrace deposits in the Otter Creek valley occur inside the Iowan border and merge with the Iowan drift. Otter Creek also drains Tazewell drift (pl. 3: sheets 4 and 5) and the terrace deposits could be related to either Iowan or Tazewell glaciations, or to both. Remnants of the deposits in the headwaters of Boyer River valley are found entirely within the Tazewell drift area. In some parts of the Boyer valley the terrace sediments could have been deposited contemporaneously with the recession of both Iowan and Tazewell ice. But the top of the loess-mantled sediments is 30 feet or more lower than the top of Iowan or Tazewell drift on the adjacent uplands. It is possible that the terrace sediments are in valleys cut into Iowan or Tazewell drift and that they considerably postdate deposition of these drifts. Calcareous Tazewell loess directly overlies calcareous alluvium in the terrace deposits in the Boyer and Willow River valleys. The upper part of the alluvium, therefore, postdates Farmdale loess and predates the calcareous zone of Tazewell loess and is less than 24,500 but more than 14,000 years old, recognized Tazewell time (Ruhe and Scholtes 1959, p. 592).

Cary Alluvium

Post-Tazewell terrace deposits occur in the Boyer River valley in northern Sac County and in valleys of streams tributary to the Boyer that drain Cary drift (pl. 3: sheet 6). There is one area of questionable post-Tazewell terrace deposits in the Boyer valley southeast of Arion in Crawford County (pl. 3: sheet 3). The post-Tazewell terrace sediments are not mantled by loess and are indistinct physiographic features in the valley.

In a sand pit (NE¼NW¼sec. 27, T. 89 N., R. 37 W., Sac County, Iowa) the section is:

A1 0–10 inches	Black (10YR 2/1) clay loam to loam; weak medium granular structure; many nearly white sand grains on ped faces; friable; noncalcareous; gradual boundary.
AB 10–14 inches	Very dark gray to very dark grayish brown (10YR 3/1 to 3/2) loam with much mixing of dark brown (10YR 4/3); weak medium subangular blocky structure; friable; gradual boundary.
B 14–36 inches	Brown (7.5YR 4/4) sandy clay loam; common pebbles with intermediate diameter of 1½ inches; very weak medium to coarse blocky structure; common very dark grayish brown to dark brown (10YR 3/2 to 3/3) mottles; medium subangular blocky peds in upper 10 inches; dark brown color extends along vertical cleavage; clear boundary.
C2 36–108 inches	Very pale brown (10YR 7/3) sand; many pebbles with an intermediate diameter of 2 inches; single grained; distinct horizontal bedding; very friable; calcareous; base of section is water level of pit.

The lithology of the alluvium is similar to that of the adjacent Tazewell terrace deposits. Without the loess mantle it is doubtful if the two sediments could be differentiated. The alluvium is clay loam or silty clay loam to sand, but the fine-textured material is at the surface and grades downward to coarser material. Sand is dominant.

The terrace surface is undulating in contrast to the smooth, almost level surface of the adjacent older loess-mantled terraces. Near the Cary drift border in Sac County, depressional or poorly drained areas are surrounded by small areas of highly calcareous material that in some places is fossiliferous. The terrace is 4 to 6 feet higher than the flood plain in the upper Boyer River valley (fig. 4), but in tributaries of Boyer River the scarp is indistinct and merges with the modern flood plain. In areas where terrace and flood plain merge the terrace deposits may continue upstream as intermittent surficial deposits, but we could not make a positive identification. Consequently, we mapped these areas as undifferentiated alluvium and outwash.

The lowest terrace deposits in the Boyer River valley occur only downstream from tributaries draining Cary drift. They can be traced up tributary valleys that drain Cary drift but not to the drift border. These terraces are not loess mantled. A post-Tazewell age is suggested, but either a Cary or a post-Cary age is possible. Because the terraces occur only in stream valleys that drain Cary drift, they apparently are outwash of that drift. A Recent cycle of alluviation and subsequent terracing could produce similar features, but if so, evidence of the Recent cycle should be found in other areas of the Boyer watershed. A Cary age for the lowest terrace deposits in the Boyer valley is more in line with the evidence available than a post-Cary age.

Tazewell-Cary to Recent Alluvium

Tazewell-Cary to Recent deposits in Harrison County are alluvial fills in the present stream valleys. They are exposed by trenching of the Willow drainage ditch and its tributaries (Daniels 1960). We divided the alluvial fill in Thompson Creek watershed and Willow River and Magnolia valleys[8] into five units, collectively named the De Forest formation; the members are Soetmelk, Watkins, Hatcher, Mullenix, and Turton. Type sections for the formation and its members are along Thompson Creek and its tributaries. At the type section for four members, located at the junction of Soetmelk Branch and Thompson Creek (fig. 9; pl. 1), the sequence and characteristics of the alluvium are:

POST-SETTLEMENT ALLUVIUM	
0–3.0 feet	Dark brown (10YR 4/3) silt loam; massive; friable; calcareous; abrupt boundary.
MULLENIX	
3.0–4.5 feet	Very dark gray (10YR 3/1) silt loam; granular; noncalcareous alluvium; clear boundary.
4.5–10.5 feet	Very dark grayish brown (10YR 3/2) silt loam; massive; friable; calcareous; abrupt undulating contact at base.
HATCHER	
10.5–24.3 feet	Yellowish brown (10YR 5/4) silt loam; many grayish brown mottles; massive; friable; calcareous; abrupt boundary.

[8] Soil Conservation Service profiles and plats, scale of 1 inch to 50 feet, of Thompson Creek, Fox Branch, and Turton Branch were available as base maps.

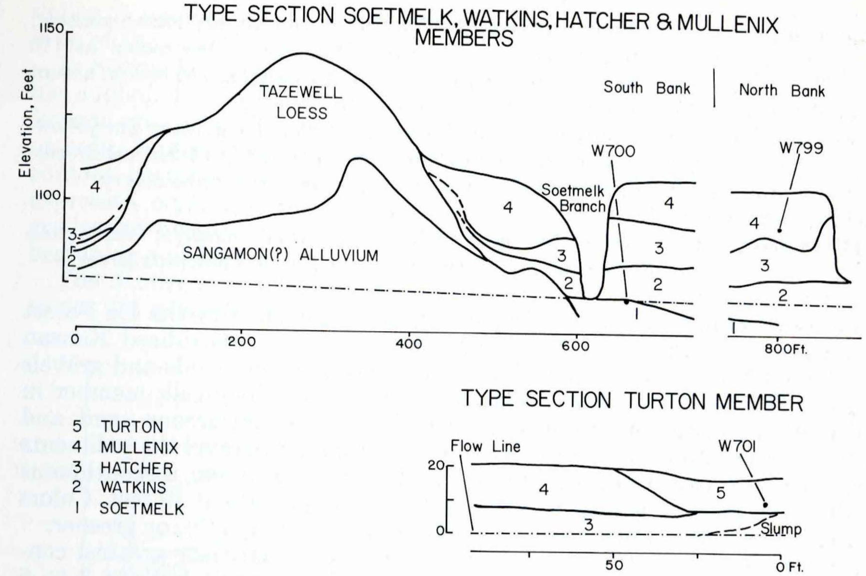


Figure 9.—Sequence of sediments at type sections of the De Forest formation; W700, W701, and W799 are radiocarbon samples.

WATKINS	
Ab	
24.3–24.6 feet	Black (10YR 2/1) silt loam; massive; friable; abrupt boundary.
24.6–32.2 feet	Gray (5Y 5/1) silt loam; massive; friable; calcareous; gradual boundary.
32.2–34.0 feet	Greenish gray (5GY 5/1) silt loam; massive; friable; calcareous; abrupt boundary.
SOETMELK	
34.0–35.0 feet	Dark gray (10YR 4/1) silt loam; many black (10YR 2/1) streaks and stains; massive; friable; calcareous; fossiliferous; many twigs and logs; radiocarbon sample W700 taken from this layer; base of section; flow line of Thompson Creek.

A description of the type section for the Turton member of the formation, located on the east bank of Thompson Creek 200 feet north to northwest of the junction of Watkins Branch and Thompson Creek (pl. 1), follows.

TURTON	
0–7.2 feet	Very dark grayish brown (10YR 3/2) silt loam; numerous gray horizontal bedding planes less than $\frac{1}{16}$-inch thick in lower 66 inches; friable; noncalcareous; abrupt boundary.
7.2–8.2 feet	Very dark grayish brown (2.5Y 3/2) silt loam; many dark reddish brown (5YR 3/4) mottles; massive, friable; noncalcareous; abrupt boundary.

8.2–9.2 feet	Very dark gray (10YR 3/1) loam to silt loam; massive; friable; calcareous; fossiliferous; buried tree rooted at 110 inches; radiocarbon sample W701 taken at 110 inches; abrupt boundary.
9.2–11.2 feet	Very dark grayish brown (10YR 3/2) loam; many fine yellowish red and strong brown mottles; massive; friable; calcareous; fossiliferous; erosion surface in base; abrupt boundary.
HATCHER	
11.2–18.5 feet	Dark olive gray (5Y 3/2) silt loam; massive; friable; calcareous; base of section is flow line of Thompson Creek.

Characteristics.—The Soetmelk is the lowest member of the De Forest formation. It usually overlies calcareous oxidized or unoxidized Kansan till in Thompson Creek and Magnolia watersheds and sands and gravels in the Willow River valley. The lower part of the Soetmelk member in Thompson Creek and Magnolia watersheds is a calcareous sand and gravel layer 6 to 24 inches thick. Above the sand and gravel the sediments are massive calcareous silt loams, and few to common discontinuous calcareous sand lenses occur. Maximum thickness is about 10 feet. Colors are greenish gray, dark greenish gray (5GY 5/1, 5GY 4/1), or greener.

Logs and twigs occur throughout the Soetmelk, but their greatest concentration is at the top in a black (10YR 2/1) organic horizon 3 to 6 inches thick. The organic horizon rests abruptly on calcareous materials. I do not believe that the organic horizon is a buried A horizon; it is more likely a deposit of sediments rich in organic matter.

The Watkins member disconformably overlies the Soetmelk and is a massive calcareous silt loam with little bedding. It is 8 to 13 feet thick in the Thompson Creek valley and 20 feet thick in the Willow River valley. The color of the lowest part is similar to that of the underlying Soetmelk, but the upper part is black (10YR 2/1) to grayish brown (2.5Y 5/2).

The upper part of the Watkins member in the Thompson Creek and Magnolia valleys is a black massive calcareous organic horizon 2 to 8 inches thick. This horizon may be the A horizon of a beginning soil, but there is no related B horizon since the underlying materials are massive and calcareous and have a uniform clay content. In the Willow River valley the top of the Watkins has an organic horizon that could be an incipient A horizon and a sand and gravel layer 1 to 3 inches thick. These layers truncate the underlying sediments. The subjacent materials are calcareous or noncalcareous and have no evidence of soil formation. A discontinuous clayey layer having weak to moderate subangular blocky structure occurs locally. It grades downward to a massive silty clay loam to silt loam. The clayey zone is calcareous or noncalcareous and has the characteristics of a B horizon. A buried soil at the top of the Watkins member in the Willow River valley suggests that the time between deposition of the Watkins and that of the overlying Hatcher was longer in the Willow valley than in the Thompson Creek and Magnolia valleys. It is possible that erosion has removed all trace of a buried B horizon in these valleys.

The Hatcher member overlies the Watkins and is a massive calcareous silt loam. It is 1 to 32 feet thick and is yellowish brown (10YR 5/4 to 4/4) like Tazewell loess, but it also has hues of 2.5Y and 5Y. It rests disconformably on the Watkins. The disconformity in the Willow River valley is marked by sands and pebbles that in places truncate the bedding of the underlying sediments.

In Soetmelk Branch (fig. 10) a disconformity at the top of the Hatcher has a relief of 15 to 25 feet. Most of the pebbles at this contact in Soetmelk Branch are carbonate nodules eroded from the Hatcher or Tazewell loess, or both. In the headwaters and near the mouth of Thompson Creek, the contact between the Hatcher and the overlying Mullenix is a weakly expressed organic horizon. The organic horizon is 3 to 4 inches thick, grades downward into the underlying sediments, and probably represents beginning soil formation.

The Mullenix overlies the Hatcher and is a silt loam to clay. Its color varies but generally is darker than that of the underlying Hatcher. Local

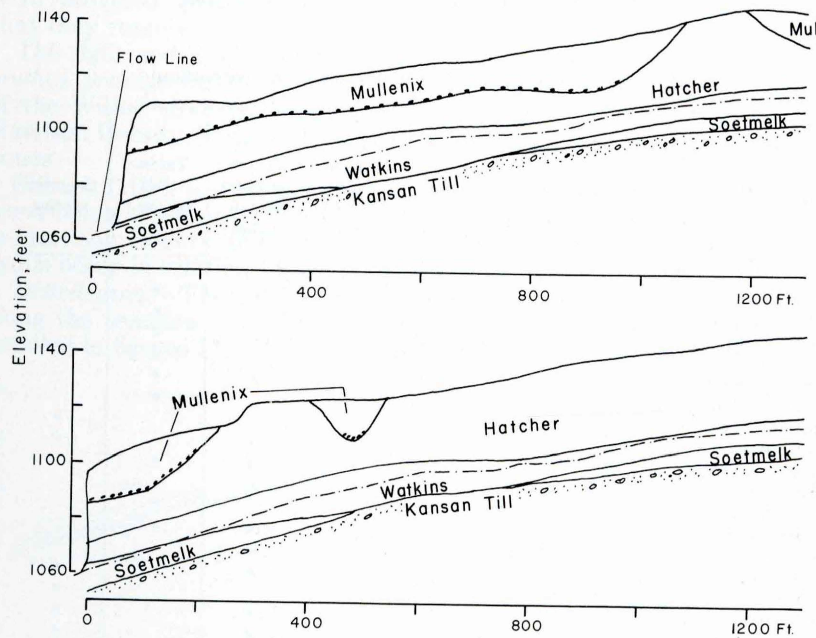


Figure 10.—Relation between the Hatcher and Mullenix fills in the lower part of Soetmelk Branch, Thompson Creek watershed.

cut-and-fill structures are common. The maximum thickness of the Mullenix is about 25 feet near the stream channel in Turton Branch (pl. 1).

The Turton member disconformably overlies the Mullenix and, locally, the Hatcher member. The contact is similar to the contact between the Mullenix and Hatcher. The Turton has a maximum thickness of 12 feet and its colors and textures are similar to those of the Mullenix.

Physical and chemical properties.—The De Forest formation is dominantly silt (table 11). Its sand content, exclusive of sand lenses, is less than 5 percent. Its clay content is reasonably uniform throughout except in buried B horizons (table 11). Dry density of the alluvium is 74 to 88 pounds per cubic foot (table 13) and is of the same order of magnitude as the dry density of Tazewell loess. The saturated shear strength is very low and about the same as that of loess from western Iowa.[9]

Thin sections from the Mullenix and Hatcher show little difference between the members. The groundmass is fine grained and clay is diffused throughout the matrix. Vertical and horizontal pores less than 2 mm in diameter are common in both members. Under the petrographic microscope, iron oxide lines many of the larger vertical pores. In some pores small amounts of oriented clay are associated with the oxide because weak extinction could be followed part way around the pore when the stage was slowly rotated under crossed nicols. There was no evidence of microbedding. In thin sections the morphology of the alluvium is similar to that of Tazewell loess; the major difference is that the alluvium has many horizontal pores and the loess, few horizontal pores.

TABLE 3.—*Invertebrate fossils from the De Forest formation*[1]

Species	From Soetmelk member, organic horizon	From Watkins member, organic horizon	From Mullenix member, 120–140 inches	From Turton member, 98–110 inches	Terrestrial species [2]	Aquatic species
Anguispira sp.	×		×		*	
Anguispira alternata		×			*	
Discus cronkhetei	×			×	*	
Discus shimeki		×			*	
Gastracopta armifers				×	*	
Gastracopta contracta	×	×			*	
Gyraulus labiatus	×					*
Gyraulus similaris				×		*
Helicodiscus parallelus	×	×	×	×	*	
Helisoma antrosa				×		
Hendersonia sp.	×				*	
Hendersonia occulta				×	*	
Lymnaea sp.	×			×		
Lymnaea parva	×			×		*
Pelecypods		×				*
Physa anatina		×		×		*
Physa elliptica				×		*
Pupilla muscorum	×				*	
Retinella electrina	×	×			*	
Sphaerium solidum				×		*
Stenotrema leai aliica		×			*	
Strobilops sparicosta	×	×			*	
Succinea sp.	×				*	
Succinea grosvenori		×	×	×	*	
Tricodopsis sp.	×				*	
Vallonia gracilicosta	×			×	*	
Vertigo modesta	×	×			*	
Zonitoides sp.		×		×	*	
Zonitoides arboreus	×			×	*	

[1] Fossils identified by Professor L. A. Thomas, Iowa State University Department of Geology.
[2] Authority (Leonard 1950, 1952; Pilsbry 1948).

[9] Olsen, G. R. Direct Shear and Consolidation of Undisturbed Loess. Unpublished M.S. thesis, Iowa State University, Ames, Iowa. 1958.

Fossils.—Invertebrate fossils from the alluvium, except those from the Mullenix member, are mixed aquatic and terrestrial species suggestive of flood-plain environment (table 3). Pelecypods are present in the Mullenix member in the Willow River valley. Vertebrate fossils were found in the Hatcher and Mullenix members. At the type section of the Turton member 6 inches above the base of the Hatcher member (fig. 9, sta. 75), elements of a right metatarsus, right scapula (incomplete), left astragalus, two proximal phalanges, a distal phalanx, four partial dorsal vertebrae, five partial lumbar vertebrae, and several rib fragments were recovered.[10] Measurements of the metatarsus indicate a fairly large bison. In the Mullenix member from the same locality (fig. 9, sta. 50) 15 feet above the flow line, the left pelvis, right radius, and two rib fragments of bison were recovered. The bones are not diagnostic, but their small size suggests that they represent the *Bison* (*Bison*) *bison*, a recent form.

The right and upper third molars of a mammoth referred to as *Mammuthus primigenius* Bluenbach have been found on the channel bottom of the Willow drainage ditch in NW¼NW¼sec. 3, T. 81 N., R. 42, W., Harrison County, Iowa, but we could not find the bed that contained the bones.

Shimek (1910, p. 407) reported skulls and bones of bison together with fewer bones of elk and Virginia deer from alluvial deposits of small creeks in Harrison County and Monona County. But I do not know where the skulls occur in relation to the members of the De Forest formation.

Distribution.—The distribution of members of the De Forest formation along the trenches of streams and across the Thompson Creek valley is detailed in figures 11, 12, 13, and 14. Most members have been identified

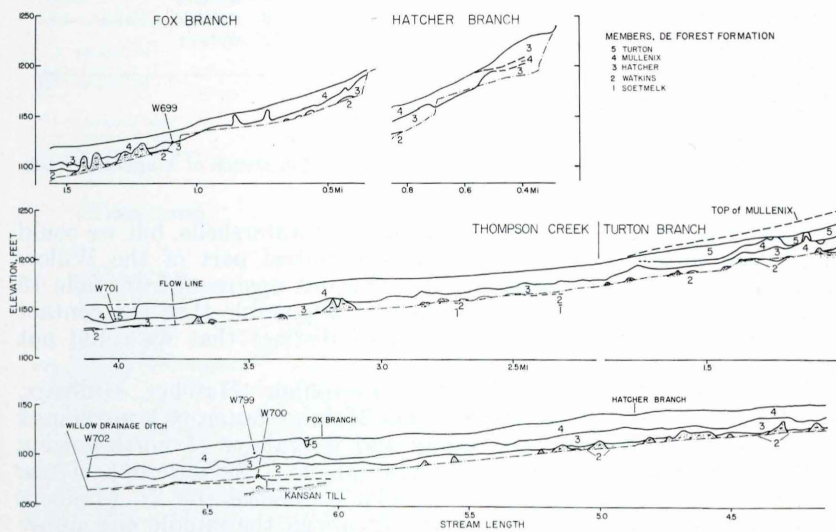


Figure 11.—Members of the De Forest formation exposed in trenches of Thompson Creek and Turton, Fox, and Hatcher Branches.

[10] Written communication 1960, W. D. Frankforter, then director, Sanford Museum, Cherokee, Iowa.

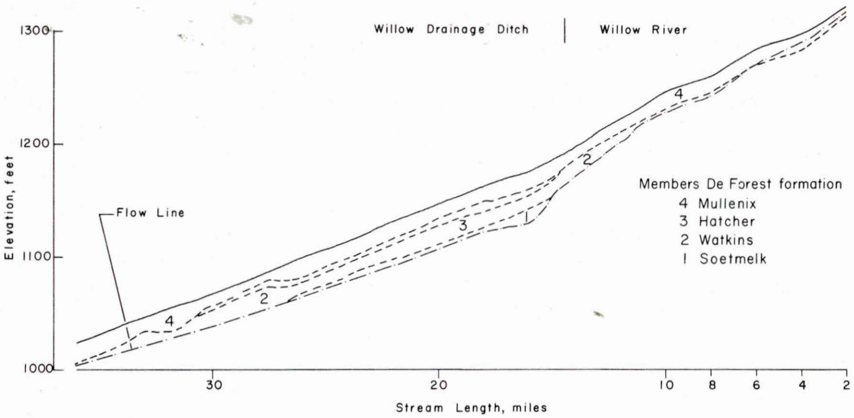


Figure 12.—Members of the De Forest formation exposed in trenches of Willow drainage ditch and Willow River.

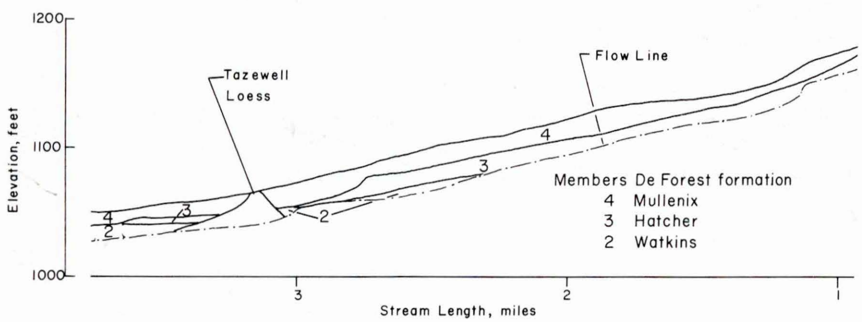


Figure 13.—Members of the De Forest formation exposed in trench of Magnolia Creek.

in stream trenches or bore holes throughout the watersheds, but we could identify the Hatcher member only in the central part of the Willow River valley (fig. 12). It apparently pinches out upstream from mile 15 and downstream from mile 31, although it is possible that the contact between the Hatcher and Mullenix is so indistinct that we could not separate them.

Only three members of the De Forest formation—Hatcher, Mullenix, and Turton—crop out at the surface. The Hatcher outcrops are confined to the south side of the main valley and to valleys of north-flowing streams in Thompson Creek watershed (pl. 1). The outcrops of the Hatcher are of limited extent in Magnolia watershed (pl. 2). Mullenix outcrops are narrow strips next to the stream in the middle and upper reaches of north-facing stream valleys (fig. 15), and a distinct 3- to 10-foot scarp separates the Mullenix and the Hatcher. In other areas of the watersheds, the Mullenix buries the Hatcher and thickens from the valley slope to or nearly to the present stream (figs. 14, 16). Apparently the configuration of valleys of south-flowing streams was not greatly different during deposition of the Mullenix from that of the present valleys.

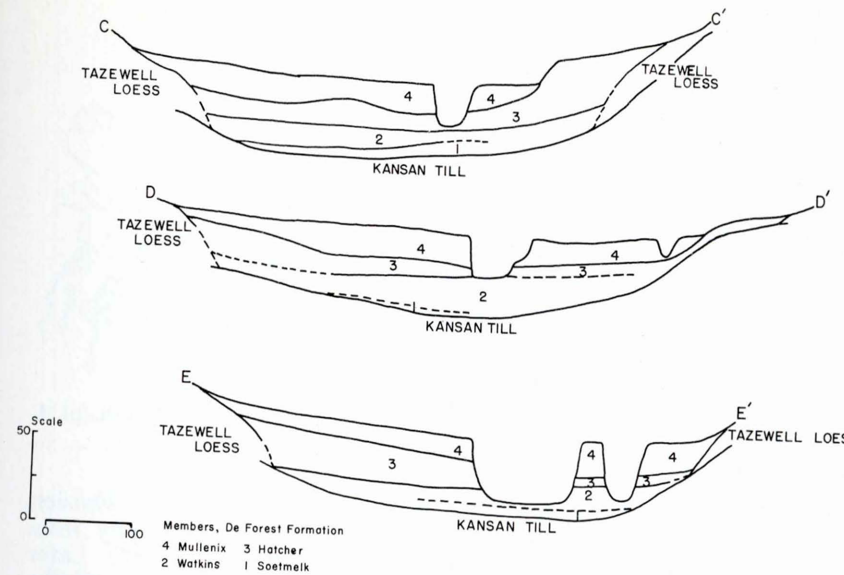


Figure 14.—Distribution of members of the De Forest formation across the long axis of Thompson Creek valley—C–C′, D.43, 2.57–D.48, 2.69; D–D′, C.59, 3.05–C.57, 3.19; E–E′, B.22, 3.59–B.28, 3.74 (pl. 1).

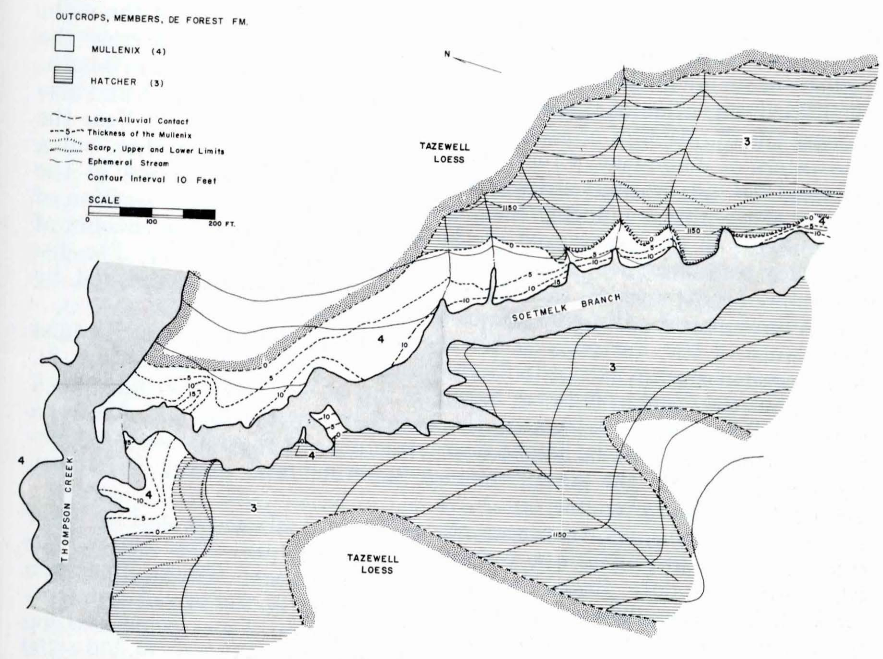


Figure 15.—Areal distribution of the Mullenix and Hatcher fills in the lower part of Soetmelk Branch.

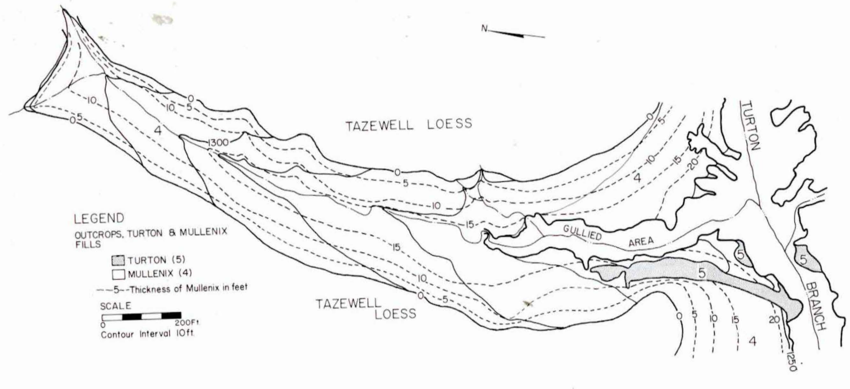


Figure 16.—Thickness of Mullenix fill in a tributary valley of Turton Branch (pl. 1, E.5, 2.0).

Several factors determined the distribution of the Hatcher fill. Erosion of the Hatcher in north-facing tributary valleys was essentially from channel trenching, and large areas were not eroded (figs. 10, 15). Later sedimentation in these valleys did not bury the uneroded parts of the Hatcher, and these areas were left as low terraces. The erosion surface at the base of the Mullenix slopes from north to south across the Thompson Creek valley (fig. 14) and suggests that the stream has migrated laterally in the same direction; possibly south-flowing streams have forced the stream to the south by building small fans on the north side of the main valley. Any southward migration of Thompson Creek would increase the gradient of its north-flowing tributaries by decreasing their stream length. Southward migration of the creek would favor channel trenching and also increase the duration of erosion in the north-flowing tributaries. Near the headwaters of Thompson Creek the Mullenix buried the Hatcher, but a paleosol, not an erosion surface, separates the fills. A paleosol at the contact of the fills is evidence that erosion did not precede deposition of the Mullenix in the upper part of the stream valley and that erosion of the valley sides was not controlled directly by stream activity. The distribution of outcrops of the Hatcher fill probably was controlled by stream erosion and sedimentation of the subwatershed.

Outcrops of the Turton member are narrow discontinuous strips next to the present stream except in Turton and Mullenix Branches (pls. 1, 2). The top of the Turton is lower than the top of the Mullenix (fig. 11). A distinct 10-foot scarp separates the members in Turton and Mullenix Branches; it decreases in height downstream until the tops of the members merge. Where the scarp becomes indistinct and cannot be traced, the Turton member pinches out.

Age.—The Soetmelk truncates Sangamon (?) alluvium and is lower than Tazewell loess but not overlain by it (fig. 10). The base of the Soetmelk may date from Tazewell to basal Cary. The radiocarbon method, however, allows a more accurate dating of the top of the Soetmelk. Detrital spruce logs from an organic horizon 2 feet below the top of the Soetmelk in the Willow River valley (fig. 17) are 14,300±250 years old (table 4, W881). The top of the member in this area is marked

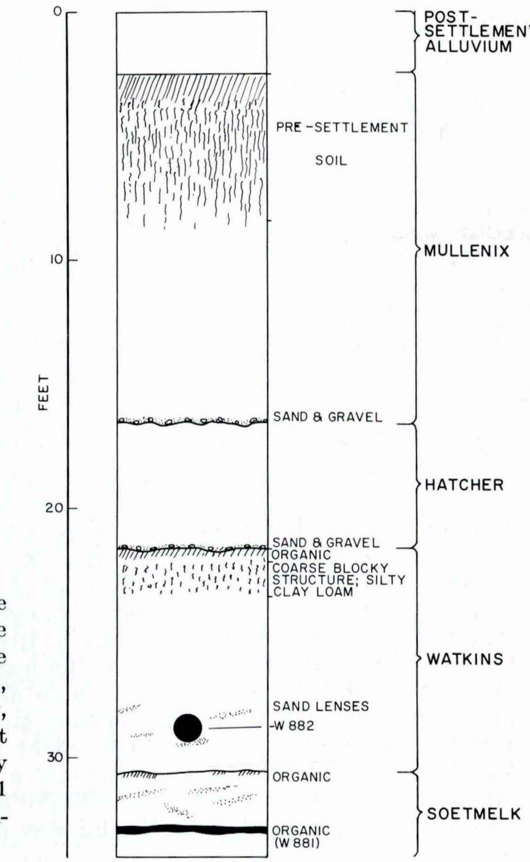


Figure 17.—Members of the De Forest formation exposed in the west bank of Willow drainage ditch in SW¼sec 11, T. 80 N., R. 43 W., Harrison County, Iowa. The section is 100 feet north of an unnamed tributary that enters from the west. W881 and W882 are radiocarbon samples.

by a discontinuous weakly expressed organic horizon that contains wood in places. The wood at the top was not dated. At one of the type sections of the formation (fig. 9), detrital spruce twigs from the upper foot of the Soetmelk are 11,120±440 years old. Deposition of the Soetmelk, therefore, can range from Cary to postglacial time in Iowa (Ruhe and Scholtes 1959, p. 592). Deposition ended about the time the Valders advanced in Wisconsin (Thwaits and Bertrand 1957, p. 859).

A detrital spruce log in the Willow River valley section (fig. 17) 15 inches above the base of the Watkins is 11,600±200 years old (W882, table 4). Sample W882 predates the upper part of the Soetmelk in Thompson Creek (W700, fig. 9 and table 4) but is within the statistical error of the radiocarbon method. Possibly the detrital log was eroded from the Soetmelk and redeposited in the Watkins. A detrital red elm log resting on, but not incorporated within, the organic horizon overlying a buried B horizon at the top of the Watkins is 2,020±200 years old (fig. 12 and W702, table 4). The age of the Watkins member, therefore, ranges from 11,000 to 2,020 years. About 9,000 years is encompassed by the Watkins, but we do not know how much time was required for the development of the paleosol occurring in places in the Willow River valley.

The detrital red elm log resting on the top of the Watkins member

(W702, fig. 11) places a maximum age of about 2,020 years for the base of the Hatcher member. A willow stump rooted in place at the top of the Hatcher (W699, Fox Branch, fig. 11) is 1,800±200 years old (table 4). Thus the Hatcher is 2,020 to 1,800 years old and its upper part, exposed at the surface, must be about 1,800 years old.

At one of the type sections of the De Forest formation, a walnut log 3 feet above the base of the Mullenix member (W799, fig. 9) is 1,100±170 years old (W799, table 4). The major part of the Mullenix, therefore, was deposited less than 1,100 years ago. In places it is overlain by the Turton member (fig. 11) so that deposition must have stopped more than 250 years ago (table 4).

At the type section of the Turton member (W701, fig. 9) a box elder stump rooted 2 feet above the base of the Turton is less than 250 years old (W701, table 4). Since trees growing on the Turton are no older than 76 years (1959), deposition of the Turton must have stopped more than 76 years ago. The major part of this member, therefore, is 76 to 250 years old.

The De Forest formation contains no fauna that can be used as direct evidence for the cause of the cycle of erosion and sedimentation. There is abundant evidence of fluctuations of vegetation in Iowa and other areas during the last 12,000 years (Flint 1953, pp. 173–174; Fries et al. 1961, pp. 688–691; Lane 1931, p. 167; Ruhe et al. 1957, pp. 687–688), but I can make no correlation between these changes in vegetation and erosion or deposition of the De Forest formation. Regardless of the cause of the cyclic cut and fill of the alluvium in the watershed, one feature stands out—the alluvial fill has not been stable during the last 2,000 years. Apparently, the balance between erosion and sedimentation of the alluvial fill has been so delicate that minor changes in the hydrologic properties of the watershed could produce a shift from erosion to sedimentation or the reverse. When we analyze modern gully erosion in the area, we must remember that the fill was not stable even before the watersheds were settled.

TABLE 4.—*Radiocarbon dates from the De Forest formation in Thompson Creek and Willow River valleys, Harrison County, Iowa*

Sample No.[1]	Date[2]	Member	Vegetation[3]
W701	250	Turton	Box elder.
W799	1,100±170	Mullenix	Walnut.
W699	1,800±200	Mullenix	Willow.
W702	2,020±200	Hatcher	Red elm.
W882	11,600±200	Watkins	Spruce.
W700	11,120±440	Soetmelk	Spruce.
W881	14,300±250	Soetmelk	Spruce.

[1] U.S. Geological Survey, Washington, D.C.

[2] Radiocarbon years before present.

[3] All wood was identified by Professor D. W. Bensend, Iowa State University Department of Forestry.

Postsettlement Alluvium

Postsettlement alluvium is a surficial deposit on fans and flood plains of the alluvial valleys. It has been deposited discontinuously since cultivation of the watersheds started about the middle of the last century. The alluvium is distinguished from the dark-colored buried A horizon of the presettlement soil primarily by its lighter color.

Postsettlement alluvium discontinuously overlies the Turton, Mullenix, and Hatcher members of the De Forest formation. It is 1 foot to more than 5 feet thick in the Willow River valley and thickens from the valley slope to the natural levee.[11] Postsettlement alluvium is also thicker on the upstream side of roads, farm lanes, and fences. It is mainly a silt loam, but locally it is interbedded with silty clay to clay. Generally it is calcareous near the valley slope and noncalcareous near the natural stream channel in the Willow River valley. But we cannot predict accurately the occurrence of calcareous or noncalcareous alluvium.

Tin cans of modern design, bottles, and farm implements occur in or are overlain by postsettlement alluvium. Erosion of the uplands or the alluvial fill, or both, is the source of postsettlement alluvium. We do not know how much time elapsed after the area was settled before active erosion of cultivated areas began. But the surface of the Turton member is at least 76 years old and most of the postsettlement alluvium probably has been deposited since then. The absence of flooding since 1925 in the central part of the Willow River valley (Daniels 1960, p. 174) suggests that most of this alluvium was deposited between 1847 and 1925. Alluvium is still being deposited in the lower end of the Willow valley where flooding is frequent, and valley-slope gullies are building fans of alluvium on valley floors in Thompson Creek and Magnolia watersheds.

Geomorphic Surfaces

The sedimentary deposits discussed in the preceding section have helped determine the present landscape in the Boyer and Willow River valleys. In Thompson Creek and Magnolia watersheds the major Pleistocene deposits are Kansas till, Loveland loess, Tazewell loess, and the alluvial De Forest formation. Since late Sangamon, Tazewell, and Cary terrace sediments and Iowan drift were not identified in these watersheds, we do not know how they influenced the present landscape.

Kansan till is deeply buried and the Yarmouth surface could not be studied. The geomorphic surfaces associated with Loveland loess and the late Sangamon pediments were studied but the thick mantle of Tazewell loess prevented detailed investigations. The Tazewell surface is of limited areal extent, and the major geomorphic surfaces in the watersheds are associated with the Hatcher, Mullenix, and Turton members of the De Forest formation.

The loess-mantled landscape in the Thompson Creek and Magnolia watersheds has three levels from the drainage divide to the valley floor. In Thompson Creek watershed, the two higher levels are underlain by the Sangamon surface and the lowest by the late Sangamon surface. In Magnolia watershed, all the topographic levels are underlain by the Sangamon surface.

[11] Simonson, Gerald H. Genesis of Alluvium-Derived Soils in the Willow River Valley, Iowa. Unpublished Ph.D. thesis, Iowa State University, Ames, Iowa. 1960.

SANGAMON SURFACES

Sangamon

The Sangamon surface is a depositional surface. It is at the top of Loveland loess below the highest topographic level in Thompson Creek watershed (fig. 2). Well to poorly drained paleosols of this surface are strongly developed. A description of a buried well-drained Sangamon paleosol in Loveland loess on a gently convex ridge crest (roadcut, SE corner of SW¼sec. 11, T. 80 N., R. 43 W., Harrison County, Iowa) follows.

TAZEWELL LOESS	
0–36 inches	Loess with weak soil development; abrupt boundary.
FARMDALE	
A–Cb 36–60 inches	Dark brown (10YR 3/3) silt loam; massive; friable; weakly effervescent; clear boundary.
SANGAMON	
A2b 60–73 inches	Dark brown (10YR 4/3) silt loam; massive to weak platy structure; friable; noncalcareous; clear boundary.
B1b 73–83 inches	Brown (7.5YR 4/2) silty clay loam; moderate fine subangular blocky structure; thin continuous clay skins; many patchy white silt grains on ped exteriors; firm; gradual boundary.
B21b 83–97 inches	Dark reddish brown (5YR 3/4) silty clay loam; moderate fine subangular blocky structure; medium continuous clay skins; many patchy white silt grains on ped exteriors; firm; gradual boundary.
B22b 97–112 inches	Brown (7.5YR 4/4) silty clay loam; weak fine blocky structure; thin continuous clay skins; few patchy white silt grains on ped exteriors; firm; gradual boundary.
B3b 112–139 inches	Brown (7.5YR 4/4) silty clay loam; weak medium blocky structure; clay skins on vertical ped faces; friable to firm; gradual boundary.
Cb 139+ inches	Brown (10YR 4/3) silt loam; massive; friable; noncalcareous; base at 157 inches.

A somewhat poorly drained paleosol and a poorly drained paleosol are described in the appendix. All Sangamon paleosols studied have patchy white-silt concentrations on ped faces in the upper B horizon, but these concentrations are more abundant in the poorly drained paleosol. Clay skins are prominent throughout the B horizons; they are well oriented optically and are as much as 0.54 mm thick. Clay content of the B horizon in the poorly drained paleosol is higher than that in the well-drained paleosol (fig. 18).

The well-drained paleosol is comparable to the modern Gray-Brown Podzolic soils of Iowa, but it has redder hues in the B2 horizon and a more strongly differentiated profile. The somewhat poorly drained paleosol has an A2 horizon and a strongly differentiated textural B horizon. It is classified as a Gray-Brown Podzolic soil. The poorly drained paleosol is classified as a Planosol because the transition zone between the A2 and B2 horizons is 1 inch thick and the increase in clay across the boundary is almost 100 percent.

Where Sangamon paleosols crop out at the surface, they are classified in the Malvern series. Characteristics of the reexposed soil depend on the

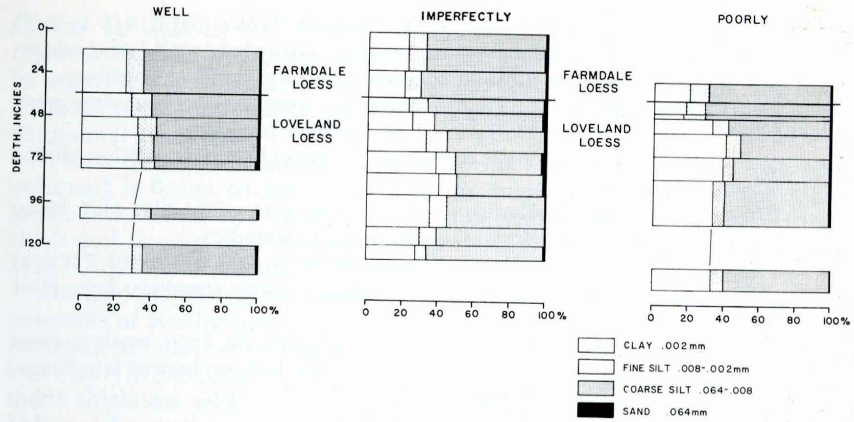


Figure 18.—Particle-size distribution in well, imperfectly, and poorly drained Sangamon paleosols.

drainage of the original paleosol, the paleosolic horizon at the surface, and the degree of modification since exposure. Malvern soils have a wider range of properties than soils of greater extent.

Late Sangamon

Loess-mantled erosion surfaces on low-level ridge crests in Thompson Creek watershed extend from the valley sides to the higher Sangamon surface. This erosion surface truncates Kansan till and Loveland loess and is marked by a stone line at the top of the till (fig. 2). Overlying the stone line is a translocated sediment of coarser texture than the underlying till. This sediment is related genetically to the cutting of the surface on the till (Ruhe, Daniels, and Cady, 1966).

Since Farmdale loess overlies the translocated sediment, the erosion surface is younger than Loveland loess and older than the Farmdale. In Pottawattamie County, Iowa, Ruhe and Cady found that a similar surface truncates the paleosol in Loveland loess. The surface is late Sangamon since it is younger than the Sangamon paleosol and older than Farmdale loess. Weathering of the paleosol extends from late Sangamon to Farmdale. Because Farmdale loess is relatively thin, some weathering may have occurred before Tazewell loess was deposited.

Well-drained soils in the translocated sediment and till are similar to those of the older Sangamon surface. A description of a late Sangamon soil exposed where Thompson Creek cuts the valley slope (pl. 1, C.57, 3.19; fig. 2, E–E′) follows.

TAZEWELL	
0–7.7 feet	Yellowish brown (10YR 5/4) silt loam; massive; calcareous loess; abrupt boundary.
LATE SANGAMON	
A2b 7.7–8.2 feet	Brown (7.5YR 5/2) silt loam; almost massive but breaks to weak fine platy structure; friable; upper 2 inches calcareous but remainder noncalcareous; pedisediment; clear boundary.
B1b 8.2–8.7 feet	Brown (7.5YR 4/4) gritty silty clay loam; weak fine subangular blocky structure; firm; clear boundary.

B2b 8.7–10.7 feet	Reddish brown to light reddish brown (5YR 4/4 to 6/4) gritty silty clay loam grading downward to silt loam; moderate fine subangular blocky structure; gradual boundary.
B3b 10.7–11.5 feet	Brown (7.5YR 4/4) gritty silt loam; few pebbles; very weak medium blocky structure; gradual boundary.
C1b 11.5–14.6 feet	Brown (10YR 5/3) loam; massive; firm; few pebbles; abrupt boundary.
14.6–15.2 feet	Light yellowish brown (10YR 6/4) gritty silty clay loam; massive; friable to firm; gradual boundary.
15.2–17.6 feet	Brown to dark yellowish brown (7.5YR 4/4 to 10 YR 4/4) gritty silt loam; weak medium blocky structure; firm; clear boundary.
17.6–19.5 feet	Yellowish brown (10YR 5/4) gritty silt loam; weak medium blocky structure; firm; stone line in base; base of late Sangamon, abrupt boundary.

KANSAN TILL

19.5–21.2 feet	Brown (7.5YR 4/4) clay loam; weak medium subangular blocky structure; firm; noncalcareous; gradual boundary.
21.2–23.2 feet	Yellowish brown (10YR 5/6) clay loam; many strong brown and grayish brown mottles; massive; firm; abrupt boundary.
23.2+ feet	Variegated yellowish brown and grayish brown (10YR 5/4 and 2.5Y 5/2) clay loam; many redder and browner mottles; massive; firm; calcareous; base of section covered by slump.

This is the only exposure in either watershed where we could study a vertical section through the sequence of materials. The pedisediment in other areas is 6 feet thick instead of the 12 feet in this section. The sediment in this exposure may be a valley phase of late Sangamon alluvium. The paleosol in the upper part of the material has a textural B horizon

TABLE 5.—*Particle-size distribution in a late Sangamon paleosol, Thompson Creek watershed*

Depth below surface (inches)	Horizon	Sand (>62 microns)	Coarse silt (62–8 microns)	Fine silt (8–2 microns)	Clay (<2 microns)
		Percent	*Percent*	*Percent*	*Percent*
92–98	IIA2b	2.7	61.3	10.1	25.9
98–104	IIB1b	3.2	56.4	10.6	29.8
104–116	IIB2b	7.2	62.5	7.9	32.4
116–128	IIB2b	8.9	57.7	7.8	25.6
128–138	IIB3b	14.1	52.4	6.5	27.0
138–175	IIC1b	35.7	38.9	3.5	21.9
175–182	------------	9.6	52.8	8.3	29.3
182–211	------------	15.0	54.2	6.6	24.2
211–234	------------	28.6	41.9	6.7	22.8
234–254	------------	32.3	33.2	6.6	27.9
254–278	------------	32.7	16.6	8.6	32.1
278–290	------------	28.3	28.0	11.6	32.1

similar to that in well-drained Sangamon paleosols in Loveland loess (table 5, fig. 18). Although Sangamon and late Sangamon paleosols cannot be separated on the basis of sequence and color of the horizons, the lower horizons of late Sangamon paleosols contain more sand than those of the Sangamon paleosols.

Where the late Sangamon paleosol crops out at the surface, the pedisediment is 6 feet or less thick and the solum has formed in the translocated material and Kansan till. The modern A1 horizon is about 6 inches thick and is very dark brown to very dark grayish brown (10YR 2/2 to 3/2). Outcrops of the paleosol are classified as Adair soils (pl. 7).

The late Sangamon paleosols in Thompson Creek watershed differ from paleosols of similar age in southwest-central Iowa in two ways. First, the horizons are not so strongly differentiated and the B horizons contain less clay (Ruhe 1956, p. 445). Second, at ridge crests elsewhere pedisediment thickness seldom exceeds 3 feet (Ruhe, Daniels, and Cady, 1966). I do not know the reasons for these differences.

WISCONSIN SURFACES

The Farmdale is a depositional surface at the top of the buried Farmdale paleosol. This surface parallels the underlying Sangamon and late Sangamon surfaces and has a similar areal distribution. Since Farmdale loess is thin and in several areas the paleosol is little more than an A1 horizon over a pre-Wisconsin soil, deposition of Farmdale loess did not change the configuration of the pre-Wisconsin landscape.

Two surfaces younger than Farmdale but older than Cary were identified in the areas studied: (1) Erosion surfaces on valley floors and buried valley slopes that are overlain by calcareous Tazewell loess and (2) a depositional surface at the top of Tazewell loess.

Valley-Floor Surfaces

Calcareous Tazewell loess overlies a translocated sediment at the top of noncalcareous Kansan till in the central part of Thompson Creek watershed (fig. 2, E–E′). The erosion surface at the top of the till is similar to the late Sangamon surface because it truncates Kansan till, Loveland loess, and the Sangamon paleosol. But this surface is 15 feet lower than the late Sangamon surface across the valley, 2 to 3 feet of translocated sediment overlie the till in contrast to 6 feet or more on the late Sangamon, and there is no buried soil in the translocated sediment or in the till.

Loess-mantled surfaces in Sac County, Iowa, are associated with Tazewell terraces on the upper Boyer River valley floor (pl. 3: sheets 5 and 6). The surfaces are at about the same elevation as the adjacent terraces and have the same general morphology, but they are underlain by till rather than by thick terrace sediments. The description of a section of a valley-floor surface (NW corner of NE¼sec. 15, T. 87 N., R. 37 W., Sac County, Iowa) follows.

TAZEWELL LOESS

0–4 feet	Modern soil at top grades downward to brown (10YR 5/3) silt loam; friable, noncalcareous; abrupt boundary.
4–5 feet	Yellowish brown (10YR 5/6) silt loam; massive; friable; calcareous; some mixing of underlying material in lower 3 inches; abrupt boundary.

TAZEWELL SAND AND GRAVELS 5–6 feet	Yellowish brown (10YR 5/4) sand; common pebbles and cobbles with intermediate diameter of 5 inches; single grained; friable; calcareous; abrupt boundary.
TAZEWELL TILL 6+ feet	Dark yellowish brown (10YR 4/4) clay loam; massive; firm; calcareous; base of section at 7 feet.

The top of the till is marked by a bed of pebbles and cobbles 1 to 12 inches thick or by a layer of calcareous sand 12 to 36 inches thick. The gravel or sand is overlain by 6 to 8 feet of Tazewell loess. There is no buried soil in either the sand or the till. The erosion surface cuts into Tazewell till, slopes from the valley sides toward the Boyer River, and merges with the valley sides in a smooth concave profile (fig. 19).

The valley-floor surface in the Thompson Creek valley is younger than late Sangamon because it has cut below the late Sangamon surface. In the Boyer River valley erosion started after Tazewell till was de-

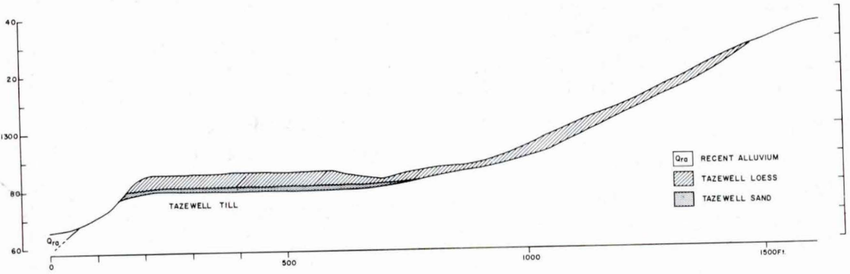


Figure 19.—Profile of a Tazewell valley-floor surface (south section line of SE¼sec. 10, T. 87 N., R. 37 W., Sac County, Iowa).

posited. This erosion cycle ended in Tazewell time because calcareous Tazewell loess overlies the surface. On the basis of radiocarbon dates, erosion was active 19,050 to 14,300 years ago. The surfaces probably are correlative with the early Wisconsin pediments in Adair County, Iowa (Ruhe, Daniels, and Cady, 1966).

Erosion Surfaces on Buried Valley Slopes

An erosion surface overlain by calcareous Tazewell loess starts near the modern alluvial fill and rises toward the interfluve summits. This erosion surface truncates Kansan till, Loveland loess, and the late Sangamon surface (fig. 2, B–B′, C–C′, D–D′). Farmdale loess and the lower leached part of Tazewell loess are absent. The erosion surface on the buried valley slopes may be related to the Tazewell valley-floor surface that was later destroyed by erosion. Since the late Sangamon surface is 45 feet above the lowest part of the erosion surface mantled by calcareous Tazewell loess (figs. 2, F–F′; 14, D–D′), erosion on these valley slopes began after late Sangamon time. Since calcareous Tazewell loess overlies the surface, the erosion cycle ended in Tazewell time.

Depositional Tazewell Surface

Four lines of evidence indicate that there is a depositional Tazewell surface on some of the level to gently convex ridge crests in southwestern Iowa. These lines of evidence are (Ruhe, Daniels, and Cady. 1966):

1. Complete weathering zones, part of the regional sequence, underlie the surface on upland divides and on level to slightly rounded interfluve summits.
2. The upland surface of Tazewell age is parallel to and does not truncate the weathering zones of the loess.
3. The upland surface of Tazewell age is generally parallel to and does not truncate the succession of Pleistocene deposits or geomorphic surfaces.
4. The upland surface of Tazewell age is level (0 percent), so that significant erosion is precluded. There is no evidence of wind erosion.

The top of the loess mantling the flat late Sangamon and Tazewell terraces one-eighth mile or more wide fits the criteria for a depositional Tazewell surface. Flat terraces occur only in the lower reaches of the Willow and Boyer River valleys, however, and the total area of the Tazewell surface in the valleys is small.

The top of the loess in the center of the ridges in the watersheds fits part of the criteria for the constructional Tazewell surface. The ridge crests are only 300 to 400 feet wide and have slopes of 1 to 2 percent across the long axes. Since some runoff and erosion of the ridge crests is possible, they must be mapped as an erosion surface. But the general parallelism between the top of the loess on ridges and weathering zones, Pleistocene deposits, and buried geomorphic surfaces indicates that erosion has been minor. Although the Tazewell surface may have been destroyed, the weathering that started about 15,000 years ago (Ruhe et al. 1957, p. 688) has affected the materials and should be considered in studies of soil genesis.

RECENT SURFACES

The Hatcher, Mullenix, and Turton alluvial fills in Thompson Creek and Magnolia watersheds form a stepped sequence from the valley slopes to the present stream. A smooth sloping surface at the top of each fill roughly parallels the base of the member throughout its outcrop area—these are the depositional Hatcher, Mullenix, and Turton surfaces. The profile of a valley slope traced under the alluvial fill is convex, but the valley slope merges with the top of the fill in a smooth concave profile (fig. 14). The surface at the top of the fill merges with an erosion surface on the valley sides and both must have about the same age. The erosion surface is named for its equivalent depositional surface.

On the south side of the Thompson Creek valley from the mouth upstream to De Forest Branch, the Hatcher surface is almost continuous (pl. 5). It is discontinuous in the De Forest and Turton Branch valleys. On the south side of Thompson Creek from the mouth of the valley upstream to De Forest Branch, the Mullenix surface generally is confined to the valley floor; on the north side of the valley, it is continuous on the valley floor and valley slopes from the mouth to the head of the streams. The Mullenix surface has greater areal extent than all other surfaces in the Magnolia and Willow River valleys (pl. 6). In Thompson Creek and Magnolia watersheds, the Turton surface is discontinuous and is confined to areas next to the present stream system.

As shown earlier, the Hatcher fill has a maximum age of 1,800 years, the Mullenix of less than 1,100 but more than 250 years, and the Turton of less than 250 but more than 76 years. The depositional surface at the top of each fill has the same age. The valley slopes were mapped as the erosional equivalent of the depositional surface on the adjacent fill if the two merged in a smooth concave profile. But it is unlikely that erosion surfaces could remain stable on slopes of 7 to 40 percent. Although the major periods of erosion and sedimentation have been dated accurately, it is possible that there were later cycles that have not been identified. The Hatcher surface is interpreted (pls. 5, 6) as less than 1,800 years old and the Mullenix as less than 1,100 years old.

Amount and Rate of Erosion on Valley Slopes

Valley slopes, shoulders, and ridge crests are the only sources of the alluvial fill on the adjacent valley floor. Where members of the De Forest formation extend from valley slope to valley slope, higher older terrace deposits are either buried or absent. We can estimate the amount and rate of erosion in a watershed if we know the volume of alluvial fill, the area of its source, and its maximum and minimum age. We studied a small subwatershed of Turton Branch in detail to compute the rate of erosion during the Mullenix cycle. The subwatershed has 7.0 acres of Mullenix fill and 23.2 acres of Mullenix erosion surface. The erosion surface is on Tazewell loess. The ridge-crest slopes are 1 to 2 percent and the valley side slopes are 7 to 35 percent. Small drainageways on the valley slopes have 2 to 3 feet of alluvium in their channels, and the adjacent slopes grade to the drainageways in a smooth concave profile.

The volume of Mullenix fill in the subwatershed, computed from 12 cross sections (fig. 16), is 4,029,000 cubic feet or 92.49 acre-feet. If all parts of the 23.2-acre source contributed equally to the fill, 4.0 feet of material was removed from the slopes and deposited in the valley.[12] Since the amount of eroded material transported out of the subwatershed is not known, more than 4 feet of material may have been removed from the slopes. The center of the ridge crests would have been eroded very little compared with the shoulders and valley slopes (Horton 1945, pp. 316–317), so it is doubtful if removal was uniform.

If we assume uniform erosion of the source for the 1,500 years encompassed by the Mullenix fill, the amount eroded is about 0.23 foot every 100 years. At the type section of the De Forest formation, the upper 11.1 feet (79 percent) of Mullenix fill has been deposited in the last 1,100 years (fig. 9, table 4). If 79 percent of the fill throughout the subwatershed was deposited between 1,100 and 250 years ago, 0.36 foot was eroded

[12] The amount of material eroded from the source was computed by assuming that 1 cubic foot of alluvial fill represents 1 cubic foot of material eroded from the uplands. The dry density of Tazewell loess is 83 to 90 pounds per cubic foot, but usually the material near the surface has the lower densities. The dry density of Mullenix fill is 75 to 87 pounds per cubic foot (table 13). Considering the errors inherent in the kind of analysis being made, the assumption that a unit volume of alluvium equals a unit volume of loess is justified.

from the valley slopes every 100 years. Deposition in the subwatershed between 1,800 and 250 years ago averaged 0.85 foot per 100 years and that between 1,100 and 250 years about 1.22 feet per 100 years.

We could not accurately reconstruct the Hatcher fill and compute its volume. But we can make a qualitative comparison of the Hatcher and Mullenix erosion cycles. The Hatcher fill has been mapped or identified throughout the watersheds (figs. 11, 13), and in Soetmelk Branch 32 feet of this fill was deposited in about 600 years (fig. 10, table 4), about 5 feet every 100 years. Thus most of the valley slopes in the watersheds were eroded during the Hatcher cycle. If the amount of uneroded Hatcher fill in Soetmelk Branch is about average for the watershed, the rate and amount of erosion on valley slopes during the Hatcher cycle probably exceeded those computed for the Mullenix.

During the past 2,000 years both valley slopes and alluvial fill have been unstable. The erosion cycle in the alluvium, however, may not have started erosion on the valley slopes since in places a paleosol, not an erosion surface, marks the top of buried Hatcher alluvium. But erosion of the valley slopes and deposition on the valley floor were contemporaneous.

Erosion on the valley sides computed for the Mullenix cycle is comparable to modern rates of erosion measured under different plant covers. At Clarinda, Iowa (Browning et al. 1948, p. 25) the rate of erosion in feet per 100 years under oats is 0.50, under meadow 0.27, and under bluegrass 0.0001; at LaCrosse, Wisconsin (Hays et al. 1949, p. 17) under grain 1.49, under meadow 0.13, and under bluegrass 0.05; at Bethany, Missouri (Smith et al. 1945, p. 34) under oats 0.43, under meadow 0.13, and under bluegrass 0.007. Erosion of 0.23 and 0.36 foot of sediment every 100 years computed for the Mullenix cycle is less than that of modern erosion under rotation oats but greater than that of modern erosion under rotation meadow or permanent bluegrass. Rotation oats or grain give little protection against erosion in early spring when the plant cover is thin (Browning et al. 1948, p. 27). The similarity between the erosion rates under rotation oats and during the Mullenix cycle suggests that the valley slopes had a discontinuous grass cover when they were eroding.

RECENT PHYSIOGRAPHIC HISTORY OF THOMPSON CREEK AND MAGNOLIA WATERSHEDS

The Sangamon and younger surfaces slope toward the present drainage system (figs. 2, 3) in the loess-mantled Thompson Creek and Magnolia watersheds. The major configuration of the landscape, such as placement of valleys and drainage divides, may have been determined in Yarmouth time. Each loess sheet deposited on a rolling landscape increases relief but probably does not change the position of the major landscape elements of the area.

Since deposition of Tazewell loess in the watersheds about 15,000 years ago, there have been five periods of alluviation on the valley floor. The first two periods of alluviation, the Soetmelk and the Watkins, required about 13,000 years for completion. But three periods have been completed in the last 2,000 years. Each period of alluviation during the last 2,000 years was preceded by erosion of the older alluvial fills in some part of the drainage system. Some erosion was channel trenching. Each cycle of alluviation apparently was ended by trenching, although a period of stability may have followed because there are buried soils in places at the top of the older fill.

Each period of alluviation had to be accompanied by contemporaneous erosion of a source area. Truncation of Tazewell loess and its weathering zones and the relation of the valley slopes to the Hatcher and Mullenix fills are proof that the valley slopes were the source of the alluvial fill. But erosion of the valley slopes is not necessarily related to erosion by the stream. In north-flowing tributaries of Thompson Creek, for example, the erosion preceding deposition of the Mullenix fill was channel trenching. In these areas the valley slopes grade to the top of the Hatcher fill, not to the Mullenix fill. Similar relations exist between the valley slopes and the top of the Mullenix or Turton fills. Erosion of the valley slopes during the Hatcher and Mullenix cycles was independent of stream erosion. In fact, valley-slope erosion probably controlled deposition on the valley floor, and erosion of the fill may have been ended by this deposition. A paleosol at the top of the Hatcher fill in the headwaters of the stream system supports this idea.

But the valley slopes may not all have been eroded during one cycle. Many valley slopes grade downward to the top of the Hatcher fill. If these slopes had been eroded during the Mullenix cycle as severely as those that grade to the Mullenix fill, the Hatcher fill would have been buried by the Mullenix. Moving 4 feet or more of material across a terrace without any deposition on or erosion of the older fill, or both, is not likely. The Hatcher slopes may have been eroded during and after the Mullenix cycle, but the amount must have been small because there is so little evidence of erosion.

The alluvial history of these watersheds indicates that landscapes do not develop through continuous slow erosion and alluviation but through periods of erosion and alluviation, probably followed by a period of stability. The resulting landscape is not one in which every part has the same age but consists of many geomorphic surfaces of different ages. In many places the older geomorphic surfaces have been destroyed by erosion but their weathering zones remain; the Tazewell surface is an example. The resulting soil landscape is more complex than indicated by a geomorphic map.

SOILS

RAYMOND B. DANIELS and ROBERT H. JORDAN, *soil scientists*

Introduction

Hutton (1947, 1950) and White et al. (1959) characterized Monona and Ida soils as part of a regional or county-wide study. Our approach was different. We made no attempt to study these soils outside Thompson Creek and Magnolia watersheds (fig. 1). Our primary interest was in studying the relation between the soils and the evolution of the landscape. This approach requires detailed work in small areas. Once the regional work has been done, we believe that such detailed studies give us a firm basis for interpretations of soil genesis.

All soils in the watersheds were studied but in different degrees of detail. Our report is on soils in Tazewell loess—Monona, Ida, and Dow soils. Simonson has reported on the soils in alluvium.[13] Daniels and Cady (Ruhe, Daniels, and Cady, 1966) have reported on soils in Kansan till, which cover a small part of these watersheds.

PARENT MATERIALS AND GEOMORPHOLOGY

The soils discussed in this chapter formed in Tazewell loess. The physical and mineralogical properties of this loess are relatively uniform but the chemical properties, especially the carbonate content, are more variable. The loess has three zones: an upper leached, a middle calcareous, and a lower leached zone. The calcareous zone has two subzones: oxidized loess and deoxidized loess. The upper part of the loess on gently convex divides or ridgetops is leached of carbonate to a depth of 10 feet (figs. 2, 3)—the result of weathering since its deposition about 15,000 years ago (Ruhe et al. 1957, p. 688). Calcareous oxidized and deoxidized loess lies below the upper leached zone. The oxidized and unleached zone is the least weathered part of the loess. There has been some segregation and loss of iron in the deoxidized and unleached loess, which may have been saturated by ground water during late Wisconsin time. But this zone is not water saturated under the modern climate and landscape (Ruhe and Scholtes 1956, p. 272).

The upper leached zone is thickest under the gently convex divides (figs. 2, 3; pl. 4). Its base is almost level under the summits but it becomes convex where the zone is 1 to 3 feet thick on valley slopes, topographic saddles, and low spur ridges. In these positions the thin leached zone is at elevations lower than the base of the thick upper leached zone under the summits. Here it probably represents post-Hatcher or post-Mullenix leaching of the calcareous loess. Soils in this thin leached loess may have started to form 1,800 years ago (or less) in calcareous parent material.

[13] Simonson, G. H. Genesis of Alluvium-Derived Soils in the Willow Valley, Iowa. Unpublished Ph.D. thesis, Iowa State University, Ames, Iowa. 219 pp. 1960.

Geomorphic studies in the watersheds indicate that the soil landscapes are of three ages. The oldest soil landscape may be the gently convex ridgetops. Because they are gently convex across their long axes and have slopes of 1 to 2 percent, it is possible that the interstream divide summits and ridgetops have been eroded in the last 15,000 years. But the amount of material removed from these summits must have been small because their tops parallel the underlying buried geomorphic surfaces and the weathering zones of the loess (figs. 2, 3) and the slopes along the axes are 0 to 1 percent. Soils on the nearly level parts of the ridges may be 15,000 years old. In places the area covered by these soils is little more than a narrow strip down the center of the divide. Pollen studies and radiocarbon dating in central Iowa (Lane 1931, Ruhe et al. 1957) and wood in the Soetmelk member of the alluvial fill suggest that soils on the ridges weathered in a cool moist climate under a boreal coniferous forest. Ruhe suggests that the change from forest to grassland probably occurred 6,000 to 7,000 years ago.

The valley slopes have been unstable at times during the past 2,000 years and they were eroded throughout the watersheds while the Hatcher fill was being deposited. Alluviation on the valley floor and erosion of the valley slopes ended about 1,800 years ago; soils of the Hatcher surface have a maximum age of 1,800 years. The Mullenix erosion and sedimentation cycle followed the Hatcher. This cycle did not affect all parts of the watersheds and large areas of the Hatcher landscape (pls. 5, 6, Hatcher surface) were not eroded or were eroded only slightly. But on the Mullenix erosion surface 4 feet or more of material was removed from parts of the valley slopes and the amount and rate of erosion were large enough to influence soil formation.

To illustrate—soils in Tazewell loess are less than 4 feet thick. In the past 1,800 years, 4 feet or more of material has been removed from valley slopes of the Mullenix surface. Soils on these slopes formed in what was the C horizon of soils that were present 1,800 years ago. Most of the soils of this surface have properties determined by soil-forming factors that have been active for the past 1,800 years. It is possible that soil formation kept pace with erosion so that the sequence of horizons remained the same as the A horizon was being eroded. But this would require the solum to grow downward into the C horizon at a minimum rate of 0.4 foot every 100 years and possibly at two or three times this rate. It seems more likely that erosion removed the old sola on valley slopes and that the present soils formed in the last 1,100 years. Radiocarbon dates from central Iowa indicate that soils of the Hatcher and Mullenix surfaces formed when grass was the dominant vegetation in Iowa (Ruhe et al. 1957).

VEGETATION

Vegetation in the watersheds in 1851 was forest and grass[14] but grass covered the larger area. Forests of oak, elm, hickory, and linden covered some of the ridgetops and flanks that face north or east and less commonly the west-facing slopes.

[14] From 1851 descriptions of subdivisions of T. 81 N., R. 42 W. and T. 80 N., R. 42 W. of 5th Principal Meridian, State of Iowa. State land office records at Des Moines, Iowa, v. 275, pp. 67–190; v. 280, pp. 107–168.

Shimek (1910, pp. 445–467) saw many xerophytes on south- and west-facing slopes and mesophytes on north- and east-facing slopes in Harrison County. He concluded from very few evaporation-pan data that the distribution of plants was controlled by evaporation and exposure. Thirty years later McComb and Loomis (1944, pp. 48–52) found bur oak, *Quercus macrocarpa*, spreading rapidly on less intensively farmed areas and discounted Shimek's theory. They believed that the rapid spread of trees resulted from disturbance and noted that local soil properties favored a grass vegetation, especially on sharply convex ridgetops.

Soils in Tazewell Loess

MORPHOLOGY

Soils of three major series—Monona, Ida, and Dow—formed in Tazewell loess. Monona soils have weakly expressed B horizons. Most Monona soils are noncalcareous throughout the solum although some have free carbonate in the lower B horizon. Ida and Dow soils have AC profiles. The A horizons are calcareous or noncalcareous, but the C horizons are always calcareous. The present vegetation of Monona soils is either forest or grass whereas the Ida and Dow soils are under grass. The morphology of a Monona soil on a forested gently convex ridgetop follows.

Profile M1, Monona silt loam: 1-percent slope; stand of oak and walnut with understory of gooseberry bushes, weeds, vines, and thin grass and a few small openings of bluegrass; Hatcher geomorphic surface.

Described by G. H. Simonson and R. B. Daniels, 7/28/59.

Location: 370 feet north and 555 feet east of south center of sec. 18, T. 80 N., R. 42 W., Harrison County, Iowa.

O2 1 inch–0	Very dark gray (10YR 3/1) and dark brown (7.5YR 3/2) decomposed and decomposing leaves and twigs; abrupt boundary.
A11 0–7 inches	Very dark gray to black (10YR 2.5/1) silt loam; dark gray (10YR 4/1) dry; weak to moderate fine granular structure; many roots; many bleached silt grains apparent when moderately moist to dry; friable; leached Tazewell loess; clear boundary.
A12 7–10 inches	Very dark brown to very dark grayish brown (10YR 2.5/2) silt loam with few spots of very dark gray (10YR 3/1) and brown to dark brown (10YR 4/3); very dark grayish brown (10YR 3/2) crushed; grayish brown (10YR 5/2) dry; weak fine granular structure; friable; many roots; gradual boundary.
B21 10–16 inches	Dark brown (10YR 3/3) silt loam; brown (10YR 5/3) dry; few spots of very dark grayish brown (10YR 3/2); dark brown (10YR 3/3) crushed; many patchy spots of light gray (10YR 6/1) bleached silt grains on peds apparent when dry; moderate fine to medium subangular blocky structure; few very dark gray (10YR 3/1) coatings on exteriors of peds; friable; gradual boundary.

B22 16–24 inches	Brown to dark brown (10YR 4/3) silt loam; dark brown (10YR 3/3) ped coatings; dark yellowish brown (10YR 3/4) crushed; bleached silt grains on peds less prominent than in B21; weak fine and medium subangular blocky structure; friable; gradual boundary.
B3 24–42 inches	Dark yellowish brown (10YR 4/4) silt loam; dark yellowish brown (10YR 4/4) crushed; few dark brown (10YR 3.5/3) coatings on exteriors of prisms; weak medium and coarse prisms breaking to very weak medium blocky structure; friable; gradual boundary.
C1 42–90 inches	Brown or dark brown (10YR 4/3 or 5/3) silt loam; few fine faint grayer and browner mottles; massive; friable; abrupt boundary.
C2 90+ inches	Brown (10YR 5/3) silt loam; few fine faint grayer and browner mottles; few white carbonate concretions; massive; friable; calcareous Tazewell loess.

Virgin Monona soils under forest have darker A horizons than virgin Monona soils under grass (Soils M9, M10, M11 appendix). But there is no consistent difference in the color of the Ap horizons. We saw O2 horizons only in undisturbed forested areas. Patchy spots of bleached silt grains on ped exteriors are in the B2 horizon of some but not all forested soils. The bleached silt grains are apparent only when the soil is dry and cannot be identified in crushed material. We could not accurately separate cultivated soils formed under forest from cultivated soils formed under grass. Consequently, the soils under forest and grass and those under cultivation were grouped in one series.

A horizons of Monona soils have weak to moderate granular structure, but some forested Monona soils have a very weak platy structure in the lower part of the A horizon. In thin sections, aggregates in the A horizons have irregular shapes; ball and kidney shapes are the most common. Exterior surfaces of many aggregates are almost opaque and have a diffuse inner boundary. The opaque areas are 0.04 mm thick.

The B horizons have weak to very weak subangular blocky to irregular-shaped structure. Clay skins are not evident in hand specimens, but the ped exteriors are darker than the interiors and have smooth shiny surfaces. Clay skins are absent in thin sections, but a few vertical pores have discontinuous poorly oriented clay films 0.01 mm thick. Unoriented clay aggregates from the B3 horizon are 0.02 mm wide and 0.06 mm long. Dark brown to very dark grayish brown worm casts are common in the B2 horizons of soils under grass but scarce in soils under forest. Earthworms and grass roots probably are partly responsible for the diffuse to gradual lower boundary of the A horizon (Thorp 1949, p. 181; Weaver et al. 1935, p. 419). The constant mixing of the B horizons by earthworms may have resulted in the relatively weak structure of the soils. Morphological characteristics of Monona soils of the Hatcher and Mullenix erosional surfaces are similar to those of soils on ridgetops, but the sola are thinner.

Ida soils that have not been cultivated have moderately dark colored A horizons. These soils have an AC profile if they are calcareous to the surface, but they have a very weak B horizon if free of carbonate to a depth of 8 inches. If the soil has been cultivated, there is no A horizon. An Ida soil of the Mullenix surface under a grass vegetation (pl. 8: C.18, 2.90) has the following characteristics.

Profile I2, Ida silt loam: 15-percent convex slope, western exposure; field of big and little bluestem, bluegrass, native legumes, and a few weeds; Mullenix geomorphic surface.

Described by G. H. Simonson and R. B. Daniels, 8/6/58.

Location: 450 feet south and 320 feet west of NE corner of SW¼SW¼sec. 7, T. 80 N., R. 42 W., Harrison County, Iowa.

A1 0–8 inches	Very dry grayish brown (10YR 3/2) silt loam; grayish brown (10YR 5/2) dry; mixed moderate fine and very fine subangular blocky structure and moderate fine granular structure; friable; leached Tazewell loess; abrupt boundary.
B (?) 8–14 inches	Brown to dark brown (10YR 4/3) silt loam; light brownish gray (10YR 6/2) dry; common dark brown (10YR 3/3) and brown to dark brown (10YR 4/3) worm casts; weak medium subangular blocky structure breaking to fine granular structure; friable; calcareous; gradual boundary.
C1 14+ inches	Brown to dark brown (10YR 4/3) silt loam; pale brown (10YR 6/3) dry; few grayer and browner mottles; common brown to dark brown (10YR 4/3) worm casts; massive; friable; calcareous.

Dow soils formed in deoxidized Tazewell loess (pls. 1, 4, 8) and their grayish brown colors contrast with the yellowish brown to brown of Ida soils. But these soils do not differ in other morphological properties. The colors of Dow soils are inherited and are not related to present moisture regimes (Ruhe et al. 1955, p. 346). The physical and chemical characteristics of Dow soils have been discussed elsewhere (Ruhe, Daniels, and Cady, 1966).

DISTRIBUTION

The distribution of Monona and Ida soils is controlled partly by the outcrop pattern of the weathering zones of Tazewell loess and partly by the distribution of the geomorphic surfaces. Only Monona soils are in outcrops of the upper leached zone (pls. 4, 8). Both Monona and Ida soils are on the slopes below the major convexity at the base of the upper leached zone (fig. 20). On these lower slopes Monona soils occur either continuously from the crest of the ridge to the valley floor or near the base of the slopes and valley-side drainageways (pls. 7, 8).

The boundary between Ida and Monona soils is gradual in most noncultivated areas. On sharply convex ridgetops under grass, Ida soils are on the west-facing slope and on the ridgetop. Monona soils are on the sharply breaking east-facing slopes under forest. Here, the boundary between Ida and Monona soils is gradational for only 6 to 8 feet. In many places in cultivated areas the boundary between them is a fence line or field boundary. The classification used in mapping these soils in 1957 and 1958 was based on what we believed the soil was like at the time of settlement. The removal of 12 inches or more of the A and B horizons would change the classification of most steeply sloping Monona soils to Ida. A truncated Monona solum on these eroded valley slopes would be difficult to identify. The distribution of Ida soils in cultivated fields may have been controlled partly by the amount of postsettlement erosion.

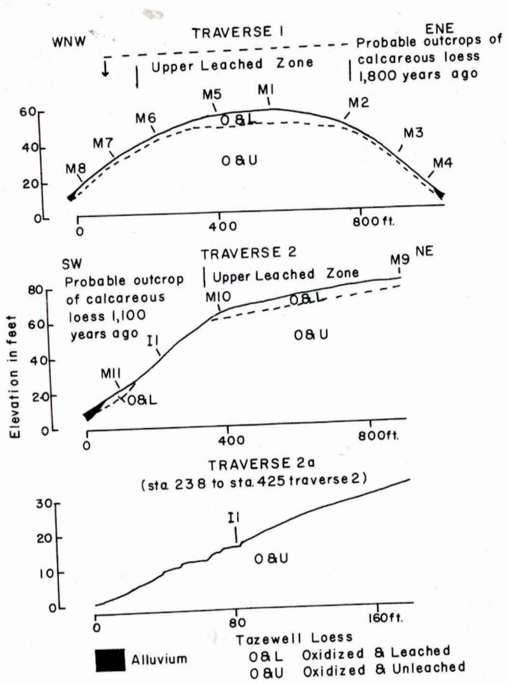


Figure 20.—Relation of Monona and Ida soils to the weathering zones of Tazewell loess.

We measured the distribution of soils below the base of the thick upper leached zone under summits. On north-facing and east-facing slopes of the Hatcher surface, the area of Monona soils is larger than that of Ida soils. They are about equal in area on west-facing slopes, but Ida soils are dominent on south-facing slopes (table 14). Ida soils are dominant on all slopes of the Mullenix erosion surface.

Statistical analysis of data in table 14 shows a highly significant interaction between soil and slope gradient, slope direction and geomorphic surface (F 7,42=186.45; F 3,42=149.56), or soil, slope gradient, and slope direction (F 21,42=30.44). Under a geomorphic surface the distribution of Monona and Ida soils is related to slope direction and slope gradient. Shimek found more xerophytic plants on south-facing than on north-facing slopes. Shimek's and Aikman's (1941, pp. 166–167) observations suggest a moister microclimate on north-facing or east-facing slopes than on south-facing or west-facing slopes. Microclimate may influence the distribution of soils on the landscape, but we do not have detailed analytical data for microclimate.

PHYSICAL AND CHEMICAL PROPERTIES

We sampled 13 virgin Monona soils, 1 cultivated Monona soil, and 2 virgin Ida soils for laboratory study. Twelve of the soils were sampled across continuous landscape units (fig. 20). Three Monona soils, one under forest and two under grass, were from slightly convex ridgetops. These soils are the oldest—15,000 years or less. Nine Monona soils under forest were sampled from the Hatcher erosion surface; two Monona and two

Ida soils under grass were from the Mullenix erosion surface. Slopes are 1 to 25 percent. Soils M8 and M11 are from slightly concave sites on the lower part of slopes. All the other soils are from convex sites where water flow diverges and slope is short. Analytical data, profile descriptions, and laboratory procedures are given in the appendix.

Monona soils have a uniform maximum clay content regardless of geomorphic surface and slope; in 14 Monona soils it is 24.8±1.2 percent and in Ida soils 24.7 and 19.4 percent (table 15). Under forest the clay content is slightly higher in the B horizon than in the A, but under grass the clay maximum usually is in the A1 horizon (tables 6, 15). All Monona and Ida soils have more clay in the solum than in the C horizon, but neither micromorphology nor distribution of clay with depth indicate clay illuviation. Carbonate in the A1 horizon of Ida soil I1 is only in the silt fraction. Concentration of clay by removal of the silt-size carbonate may account for the greater clay content in the solum than in the C horizon. But the leached C1 and B3 horizons in Monona soils have less clay than the B2 horizons (table 15) and an increase in the amount of clay-size material in the solum is indicated.

Tazewell loess and soils in southwestern Iowa contain montmorillonite, lesser amounts of illite and vermiculite, and traces of kaolinite (Ruhe, Daniels, and Cady, 1966; Hanway et al. 1960, pp. 227–228, 230). In soils M1 and M9, the montmorillonite peak is broad in the A1 horizons and sharp in the C horizons, but otherwise there is little change in the X-ray patterns with depth.

The cation-exchange capacity of the clay[15] in the B horizons is 81±6 meq/100 g and in the C horizons is 90±5 meq/100 g. The decrease in exchange capacity of the clay fraction from the C to the B horizon suggests that some of the exchange capacity is in the silt fraction.

About 20 percent of the coarse silt grains in the A, B, and C horizons have some birefringent material on the surface. Similar material on silt grains of a Marshall soil proved to be dominantly montmorillonite (oral communication, D. L. Biggs, associate professor of geology, Iowa State University, Ames, Iowa, 1957). But X-ray data do not identify the birefringent material in the coarse silt fraction of Monona soils. The 2–20-micron silt fraction has birefringent yellowish brown to yellowish red aggregates similar to the material on grains in the coarse silt fraction. Aggregates increase from less than 1 percent in the A1 horizon to 4 or 5 percent in the C horizon of soils M1 and M9. X-ray data show that the 2–20-micron silt has montmorillonite, mica, kaolinite, and some vermiculite as well as quartz and feldspar. The major change with depth is that the montmorillonite peaks are sharper in the C than in the A horizon.

There is little evidence of feldspar weathering in the coarse silt fraction (table 15: soils M1, M2, M7, and M9) and fresh biotite and hornblende were found in the A horizon in both the coarse and fine silt fractions. It is possible that the clay increase in the solum of Monona and Ida soils is primarily the result of clay concentration by removal of carbonate, dispersion and breakdown of clay aggregates, and dispersion of clay from silt grains. Weathering of primary minerals to clay or formation of clay minerals possibly has added to the total clay fraction, but the evidence

[15] The cation-exchange capacity of the whole soil was determined, but for purposes of discussion the exchange capacity has been assigned to the clay fraction and calculated for 100 grams of clay.

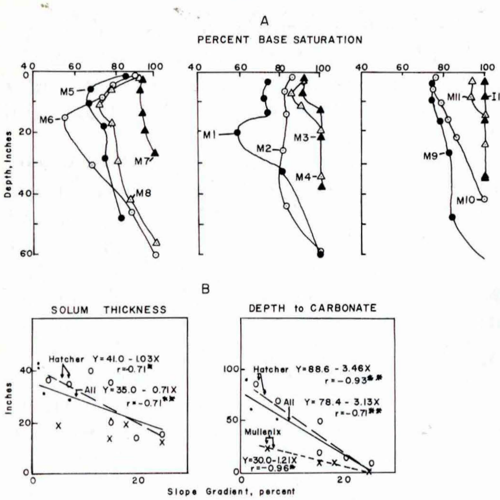


Figure 21.—A, Base-saturation values in Monona and Ida soils. B, Relation between selected soil properties and slope gradient (**significant at the 1-percent level, *significant at the 5-percent level). *All* is the regression equation for the relation between a specific soil property and slope for the 16 soils sampled.

for a clay increase from this source is scarce. Regardless of the cause or causes, this increase occurs rapidly, for the clay maximum is about the same in all Monona soils sampled from one watershed (table 15).

Base saturation is less in the B than in the A horizon of soils under forest, but under grass it increases from the A to the B horizon; an exception is the calcareous Ida soil (fig. 21A). Depth to a base-saturation value of 100 percent is greater under forest than under grass. But depth of organic-matter accumulation of more than 1 percent is less in forested than in grassed soils. There is a greater loss of bases from soils under forest than from soils under grass but less accumulation of organic matter in the lower horizons.

The older soils (less than 15,000 years old) have the thickest sola and the greatest depth to carbonate; soils less than 1,100 years old have the thinnest sola and are shallow to carbonate (tables 6, 15, 17). But depth to carbonate is greater under forest than under grass. Solum thickness and depth to carbonate decrease uniformly as slope increases if all soils and soils of only the Hatcher surface are grouped (fig. 21B). In soils of the Mullenix surface, depth to carbonate is less on the steepest slopes (table 18).

Slope is not an active factor in soil formation because it does not add to, remove from, move, or transform anything within the soil. Slope affects soil properties indirectly through its influence on water infiltration and erosion. The amount of total rainfall lost as runoff from bare soil increases rapidly from 0-percent slopes to 2-percent slopes. Above 2 percent, runoff increases more gradually and is only about 15 percent more on slopes of 20 percent than on slopes of 4 percent (Duley and Hays 1932, p. 352). But erosion is nearly a linear function of slope (Neal 1938, p. 31; Gard and Van Doren 1950, p. 375). More material should be eroded from steep than from gentle slopes if all other conditions are the same. Since stability of the valley slopes of the Hatcher and Mullenix surfaces cannot be proved, the relation between soil properties and slope gradient may be related partly to erosion after the major cycle of erosion on the valley slopes. In Thompson Creek and Magnolia watersheds, slope

Table 6.—*Physical and chemical properties of Monona and Ida soils*

Soil No.	Slope	Age	Vegetation	Solum thickness	Clay ratio B horizon/A horizon	Depth to carbonate	Depth to zone of minimum base saturation	Organic carbon in A horizon	Thickness of horizon with >1 percent organic matter
	Pct.	*Years*		*In.*		*In.*	*In.*	*Pct.*	*In.*
Monona soils:									
M1	1	<15,000	Forest	42	1.02	92	20	2.55	24
M2	7	<1,800	Forest	35	1.04	53	7	------	18
M3	25	<1,800	Forest	15	1.01	10	7	3.20	15
M4	20	<1,800	Forest	14	1.12	14	7	5.15	14
M5	3	<1,800	Forest	36	1.07	86	11	4.88	22
M6	11	<1,800	Forest	40	1.09	52	17	4.63	12
M7	15	<1,800	Forest	21	1.06	21	8	3.09	13
M8	15	<1,800	Forest	36	1.11	48	10	4.25	16
M12	7	<1,800	Forest	26	1.07	71	22	3.43	18
M13	15	<1,800	Forest	25	1.00	36	4	2.86	16
M14	1	<15,000	Grass (cultivated).	43	1.01	------	8	------	43
M9	2	<15,000	Grass	32	0.98	62	10	2.10	32
M10	5	<1,100	Grass	19	0.99	25	6	2.66	25
M11	18	<1,100	Grass	19	0.90	11	9	2.14	29
Ida soils:									
I1	25	<1,100	Grass	12	------	0	0	1.64	12
I2	15	<1,100	Grass	14	------	8	4	2.40	14

gradient places the soils on the landscape in relation to the weathering zones of the loess. The progressive changes in soil properties with slope in some of the traverses (fig. 20) are the result of the welding of two or more cycles of soil formation, and the changes across geomorphic boundaries are gradual, not abrupt.

Slope properties other than gradient may have some indirect influence on soil properties. Monona soils M8 and M11 are on the lower concave slopes where water converges and slopes are longer than for soils farther uphill on convex sites. Soils M8 and M11 have lower base saturation, thicker sola, and thicker clay bulges than soils on similar slopes on convex sites farther uphill. We do not have enough data to quantitatively evaluate slope form. The data do suggest that, through its influence on moisture regimes, slope form has considerable influence on soil properties. Multiple regression equations that include slope form as a variable may be necessary to quantitatively evaluate changes in soil properties. But the most important factor in soil formation is not slope gradient or form but the moisture regime and microclimate that can be correlated with these slope properties.

Cultivated Monona and Ida Soils

The pH increases and the organic-carbon content of cultivated Monona soils decreases with increasing slope (table 16). The pH is higher and the organic-carbon content is lower in cultivated soils than in virgin soils in comparable landscape positions. The pH is similar in cultivated and virgin Ida soils, but the organic-carbon and nitrogen content of the surface horizon is less in cultivated soils. Cultivation lowers the organic-carbon and nitrogen content (Haas and Evans 1957, pp. 11–15, 29), but removal of 6 to 14 inches from the surface horizon of noncultivated soils would do the same thing. Both cultivation and erosion may be responsible for the lower organic-carbon content of cultivated soils.

DISCUSSION AND SUMMARY

Solum thickness of Monona soils appears to be more closely related to vegetation and landscape position—summit, shoulder, side slope, and foot slope—than to the absolute slope gradient. Soils under forest generally are thicker on a given slope than similar soils under grass (table 6). Under a given vegetation, soils are thickest on summits, intermediate in thickness on shoulders (3- to 11-percent slopes), and thinnest on side slopes (15- to 25-percent slopes). Soils on the lower concave slopes have sola of intermediate thickness. These data indicate that in a given landscape position Monona soils thicken very little, or at least slowly, after 250 to 1,100 years of weathering. They may thicken with additional weathering, for soils on ridgetops have somewhat thicker sola, but the largest increase occurs during the early stages of formation. Apparently, the solum forms quickly to about the depth of abundant roots, soil fauna activity, and periodic wetting and drying. Very little chemical weathering is required.

In Monona soils under forest, the increase in clay-size particles to a maximum value of about 25 percent occurs in less than 1,800 years. Under grass a clay content of about 25 percent in the upper leached zone

is reached between 250 and 1,100 years. Tazewell loess apparently has a relatively constant amount of material easily weathered to clay size or dispersed from grain surfaces or aggregates of silt size. After this easily weathered material has been reduced to clay, additional increases in clay are much slower than during the initial weathering.

The pH and base-saturation values are less in the B horizon of forested Monona soils than in morphologically similar soils under grass. This is true in soils on ridgetops as well as in soils of younger erosional surfaces. Leaching of bases is more intense under forest than under grass, but the base-saturation curves are similar in Monona soils under one kind of vegetation, either forest or grass. This similarity in base-saturation curves among soils of widely different maximum age and weathering history indicates that bases are lost rapidly in the first stages of soil formation. These data also indicate that modern vegetation has more influence on the base status of these soils than older cycles of soil formation.

Aspect influences the distribution of soils of a geomorphic surface in calcareous loess. But the effect of slope aspect on soil properties cannot be quantitatively determined from the few soils sampled. Slope form may also influence soil properties, but again data are insufficient to evaluate its effect.

Soil properties are related to slope and to landscape position (fig. 21B). Across a landscape unit (fig. 20) soil properties, such as solum thickness, generally change from summit to shoulder to valley slope (fig. 21B; tables 6, 15). The relation between soil properties and landscape position is not entirely related to differences in slope. Soils on traverse M1 to M8 in figure 20, for example, were eroded during the Hatcher cycle 1,800 years ago. Although the summits may have been eroded, we believe that this erosion was minor because these summits fit all the criteria for a constructional Tazewell surface except width. Soils on the summits may have weathered for 15,000 years with only minor disturbance. The amount of erosion probably increases from the summit to the shoulders—soil M5 (fig. 20) may have been eroded only slightly more than soil M1, but several feet of material may have been removed from soil M6. The difference in the amount of material removed from sites M6, M7, and M8 may have been slight or of little consequence in soil formation if the old soils were removed during the Hatcher erosion cycle.

Soils on the summits, if little disturbed by erosion, have properties determined partly by the climate and vegetation of the past. On the shoulders of the summits, erosion removed a larger part of the previous sola so that less and less of the older soil has been incorporated into the modern soil. Soils on valley slopes probably formed in relatively fresh material since the thickness of the Hatcher fill suggests that the previous sola had been removed from these slopes.

The pH and carbonate content of the parent material also changes from summit to valley slope. Soils on summits and shoulders are within the upper leached zone of Tazewell loess; on valley slopes below the base of the upper leached zone, the soils may have started to form in calcareous loess 1,800 years ago. The history of the soils studied is complex, and it is almost impossible to quantitatively evaluate any one factor of soil formation. But the general similarity among soils of different ages under one kind of vegetation indicates that Monona soils formed rapidly.

Classification

The virgin and moderately eroded phases of Monona soils have mollic epipedons (Soil Survey Staff 1960) 8 to 19 inches thick. The severely eroded phases have ochric epipedons. The B horizon contains more clay than the C horizon, has some structural development, and has a lower degree of base saturation than the C horizon or a redistribution of carbonates. It is a cambic horizon.

The Monona soils mapped in 1957 and 1958 include phases having a thick dark-colored A horizon and severely eroded phases without an A horizon. The assumption made in classifying such a wide range of soils in one series was that the severely eroded phases had an A horizon before cultivation. This assumption is difficult to prove and has the disadvantage of emphasizing properties of the soil that cannot be measured or that may never have existed.

Because a thick dark-colored A horizon is considered one of the properties of a Brunizem, it is doubtful if the severely eroded phases of Monona soils can be classified as Brunizems. Classification of these severely eroded phases as Regosols is also unsatisfactory because these soils have weak B horizons. But under the 1960 classification virgin and moderately eroded Monona soils are separated from severely eroded soils by a difference in epipedons. The virgin soils and the moderately eroded phases are Typic Hapludolls (5.520), and the severely eroded phases are Dystric Eutrochrepts (3.43–3.44). The severely eroded phases of Monona soils having a B horizon are easily recognized and mapped; they do not have the properties diagnostic of Mollisols and should be classified in another series.

Ida soils have been classified as Regosols, but under the 1960 system two classifications are possible. Soil I2 has a mollic epipedon overlying a calcareous cambic horizon; it is an Entic Hapludoll (5.52–1; table 7). Soil I1 cannot be classified because the pedon was not described completely. Soil I1 was sampled on the tread of a catstep about 4 feet downslope from an 18-inch vertical scarp. At the base of the scarp there is no A horizon, but there is an A horizon at the top of the scarp downslope. The horizons are discontinuous, but they were not studied in sufficient detail for classification of the pedon. Eroded Ida soils have weak ochric epipedons. We do not have analytical data so do not know if there is a cambic horizon. Because soil I1 has a weakly expressed cambic horizon, it is doubtful if a cambic horizon is present in eroded Ida soils and they should be classified as Typic Hapludents (1.430). About 90 percent of the Ida soils mapped in the watersheds (pls. 7, 8) have been eroded. The uneroded phases are either Typic Eutrochrepts (soil I1) (3.430) or Entic Hapludolls (5.52–1). Possibly only the eroded phases should be classified in the Ida series and a new series established for the uneroded phases.

STREAM TRENCHING AND VALLEY-SLOPE GULLIES

by RAYMOND B. DANIELS, *soil scientist*

Entrenched Streams

One of our major purposes was to determine the causes and effects of stream trenching and gullying in western Iowa.[16] We wanted to be able to predict the effects of erosion on the landscape if the streams are not controlled. Because Thompson Creek had few control measures, it was ideal for this study. We also studied Willow River watershed to make sure that data from Thompson Creek could be applied to larger areas and Magnolia watershed, in which some erosion-control measures have been installed.

WILLOW RIVER BEFORE 1920

Most of the perennial and intermittent streams in western Harrison County have cut into their alluvial fill in some place.[17] But these streams were not always entrenched. In 1853 Willow River flowed about 6 feet below the flood plain in Monona County.[18] Its channel was 6 to 7 feet wide and $1\frac{1}{2}$ feet deep. The stream meandered on the flood plain; in Harrison County it was 26.3 miles long and its valley 20.2 miles long (Smith 1888, p. 21).

By 1918 Willow River had deepened and widened (table 8). The slope of the river bed decreased downstream, but between successive points on the channel it increased or decreased (fig. 22). These changes in bed slope are not related to entry of tributaries. Structural control is unlikely because glacial till and bedrock are not exposed in the present channel. In 1916 a survey of the Willow River indicated that it was silting its channel, and the changes in bed slope may have been related to local sedimentation as well as to local entrenchment.[19]

[16] An entrenched stream flows in a steep-walled trench cut into alluvium. A valley-slope gully is a small steep-walled, sharply incised, elongate depression on valley sides.

[17] Perennial streams flow continuously; intermittent streams flow only when they receive water from springs or from some surface source (Meinzer 1923, p. 57). Ephemeral streams carry water only during storms and are always above the groundwater table (Leopold and Miller 1956, p. 1).

[18] From 1853 description of subdivision of T. 82 N., R. 42 W. of 5th Principal Meridian, State of Iowa. State land office records at Des Moines, Iowa, v. 275, p. 244.

[19] Dimensions of Willow River and Willow drainage ditch and statements on silting, changes in bed slope, and flooding in different parts of the watersheds and in the Missouri River valley are contained in Harrison County, Iowa, Drainage Record No. 3, pp. 43, 117, and 198; No. 7, pp. 604, 605, 711, 1104, 1106, and 1140; and No. 11, pp. 834 and 856; all on file in office of drainage clerk in the county courthouse at Logan, Iowa.

TABLE 7.—*Classification of soils in Tazewell loess in Harrison County, Iowa*

Modifications of the 1938 classification [1]

Order	Suborder	Great group	Subgroup	Series
Zonal soils	Dark-colored soils of semi-arid, subhumid and humid grasslands.	Prairie soils (Brunizems). [2]	------	Monona.[3]
Azonal soils	------	Regosols [4]	------	Ida.[3]
	1960 Classification [5]			
Entisols (1)	Udents (1.4)	Hapludents (1.43).	Typic Hapludents (1.430).	Ida, eroded phase (I3).
Inceptisols (3)	Ochrepts (3.4)	Eutrochrepts (3.43).	Dystric Eutrochrepts (3.43–3.44).	Monona, severely eroded phases, soils (M16, M17).
Mollisols (5)	Udolls (5.5)	Hapludolls (5.52).	Typic Hapludolls (5.520).	Monona.
			Entic Hapludolls (5.52–1).	Ida (I2).

[1] Baldwin et al. 1938, pp. 993–995.
[2] Smith and Riecken 1950, p. 355.
[3] Simonson et al. 1952, pp. 61, 64.
[4] Thorp and Smith 1949, pp. 119–120.
[5] Soil Survey Staff 1960.

TABLE 8.—*Dimensions of the Willow River and drainage ditch, 1908–1920*

Dimension	Willow River [1]	Willow drainage ditch constructed channel[2]			
		In Missouri River valley		At mouth of Willow valley to Thompson Creek 1918	Thompson Creek upstream to 2½ miles north of Monona-Harrison county line 1920
	1916–1918	1916	1941		
Depth ......feet..	10 to 12	15	About 15	15	11
Top width ......feet..	60 to 100	48	100 to 120	42	42 to 38
Bottom width ...feet..	Unknown	18	40 to 50	12	8 to 12
Bed slope ...feet/mile..	(3)	2.04	Unknown	7.66	8.45 to 12.4

[1] Information obtained from plats and profiles of the Willow drainage ditch at points where it crossed the original channel.
[2] Dimensions of the ditch are on file in the drainage clerk's office, Harrison County courthouse, Logan, Iowa.
[3] See figure 22.

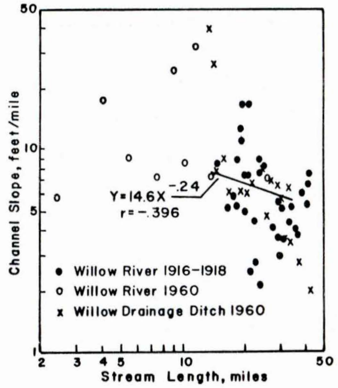


Figure 22.—Bed slope of Willow River before straightening in 1916–18 and of the Willow drainage ditch and river in 1960. Stream length is the distance from a point on the stream to the drainage divide at the head of the stream (Hack 1957, p. 47). Data on Willow River in 1916 are from a point 2½ miles north of the Monona-Harrison county line to the mouth of the Willow River valley. Data on Willow River in 1960 are from a point upstream 2½ miles north of the Monona-Harrison county line.

As early as 1851, Willow River frequently flooded its valley floor to a depth of several feet and the valley floor was considered unfit for cultivation.[20] In the first part of this century flooding of the river and its tributaries (fig. 23) damaged growing crops or delayed planting, but residents disagree on the amount of damage. Flooding of Willow River caused serious damage, however, in the Missouri River valley.

WILLOW DRAINAGE DITCH

To stop flooding of Willow River a drainage ditch was built from Boyer River below Missouri Valley, Iowa, to a point 2½ miles north of the Monona-Harrison county line (fig. 1). The lower reaches of tributaries

Figure 23.—Spring flood of Willow River (April or May) at some time between 1916 and 1918 in sec. 9, T. 81 N., R. 42 W., Harrison County, Iowa. (Photograph by courtesy of H. D. Smith, Woodbine, Iowa.)

[20] From 1851 descriptions of subdivision of T. 81 N., R. 42 W. and T. 80 N., R. 42 W. of 5th Principal Meridian, State of Iowa. State land office records at Des Moines, Iowa, v. 275, p. 190; v. 280, p. 168.

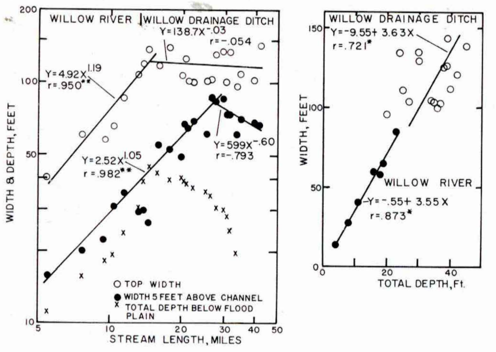


Figure 24.—Relation of top width, width 5 feet above channel bottom, and depth of channel bottom below flood plain to stream length and of top width to depth in Willow River and drainage ditch. Willow River is upstream from the head of the drainage ditch 2½ miles north of the Monona-Harrison county line. (**Significant at 1-percent level, *significant at 5-percent level.)

of Willow River were straightened. Construction in the Missouri River valley was started in 1906 and in the Willow River valley in 1916 (table 8). The upper part of the ditch was finished in 1920.

Changes Since Construction

The drainage ditch in the Missouri River valley was cleaned in 1916 and rebuilt in 1941. In 1954 Smith reported that "... Heavy sedimentation has filled up the bottom of the ditch greatly reducing its capacity. In places the bottom of the channel is only 1 to 2 feet lower than natural ground level."[21] Residents believe that floodwater from the Missouri River had backed up water in the Boyer and Willow ditches in April 1952 and caused considerable silting in the channel.

In 1958 the channel meandered over a bed of silt. The bottom of the ditch was 4 to 10 feet below natural ground level; in 1908 it was 12 feet below. Numerous drainage outlets were partially or completely buried by silt in the channel bottom.

In 1960 the gradient of the ditch in the Missouri River valley decreased from 3.5 feet per mile near the mouth of the Willow River valley to 2.0 feet per mile in its lower reaches (fig. 22, mile 35–42). Accompanying this decrease is a slight decrease in channel width 5 feet above the bed (fig. 24). But 5 feet above the bed the channel was about 55 feet wide in 1941 and 68 and 71 feet wide in 1960. It is narrower in the reaches having the lowest gradient. Apparently the stream is adjusting to low bed slopes by decreasing in width and increasing in depth of flow.

Residents have said that the ditch in the Willow River valley started to deepen and widen soon after construction. The changes since 1924 have been compiled from official county highway bridge records, a survey of part of the ditch in 1942,[22] and measurements made during this field study (fig. 25).

The present channel of the Willow drainage ditch is not like the original channel. The ditch was built with a flat bottom and a straight channel (fig. 26). The banks had slopes of 1:1. The present channel is U-shaped and has numerous silt, sand, and gravel bars at low water; a few small meanders have begun to form. The channel bottom exclusive of bars is a mixture of silt and sand ½ foot to 3 feet thick. Where the ditch banks slope less than 45 degrees, they are almost completely covered by grass, trees,

[21] Harrison County, Iowa, Drainage Record No. 11, p. 834.

[22] Ileff, Earl A. Harrison County, Iowa, Soil Conservation District Engineering Field Book No. 9, pp. 31–41. 1942.

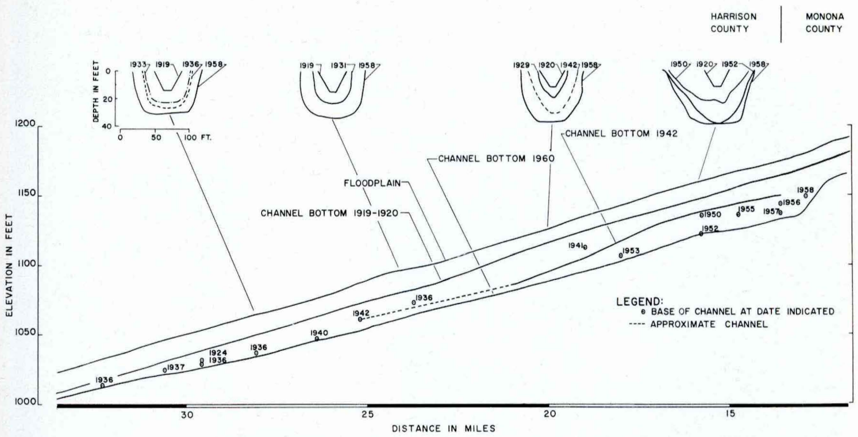


Figure 25.—Profile of Willow drainage ditch in Willow River valley and post-construction changes.

and weeds. The vertical banks are bare. Downstream from mile 20 the banks are nearly vertical, but upstream slump blocks make them irregular.

The channel floor has a maximum depth of 45 feet below the flood plain in the central reaches of the stream (fig. 24). The relation between width 5 feet above the channel floor and stream length probably represents channel adjustments to stream flow. The linear relation between top width and depth is not all cause and effect because in this stream the channel is U-shaped and width of stream flow affects top width.

Residents of the Willow River valley remember a series of falls or nickpoints (vertical or nearly vertical scarps in a stream channel) moving upstream in the drainage ditch.[23] Some of the nickpoints were 10 feet high and many plunge pools were 10 feet deep. These nickpoints were most numerous in the lower part of the Willow valley in the early 1930's, and in the part of the ditch surveyed by Ileff in 1942. Movement of a nickpoint in the Willow drainage ditch since 1953 probably illustrates the behavior of those seen by residents of the Willow valley. This nickpoint moved upstream 1 mile between 1953 and November 1956 and one-half mile between November 1956 and April 1957 (fig. 27). I first saw the nickpoint in July 1957. It moved very little until April 29, 1958. By May 1 it had moved upstream 600 feet. During this 3-day period rainfall in the area was less than 1 inch and there was no heavy flow in the ditch. The nickpoint had disappeared into a series of riffles and pools by August 15, 1958.

During periods of slow headward movement the nickpoints maintain a vertical face. As the face is undercut, vertical shear planes form in the unsupported sediments. The undercut sediments slump and a vertical face is reestablished. These processes are responsible for the slow headward migration of nickpoints.

[23] I have used many observations made by residents in the area to describe changes in the streams and valley-slope gullies studied. These observations were made by Earl Tiby, Earl Thompson, H. D. Smith, Al Schafer, M. Bendict, M. Saring, H. Smith, J. Mullenix, J. Crum, C. Cutler, M. D. Smith, and G. Hare.

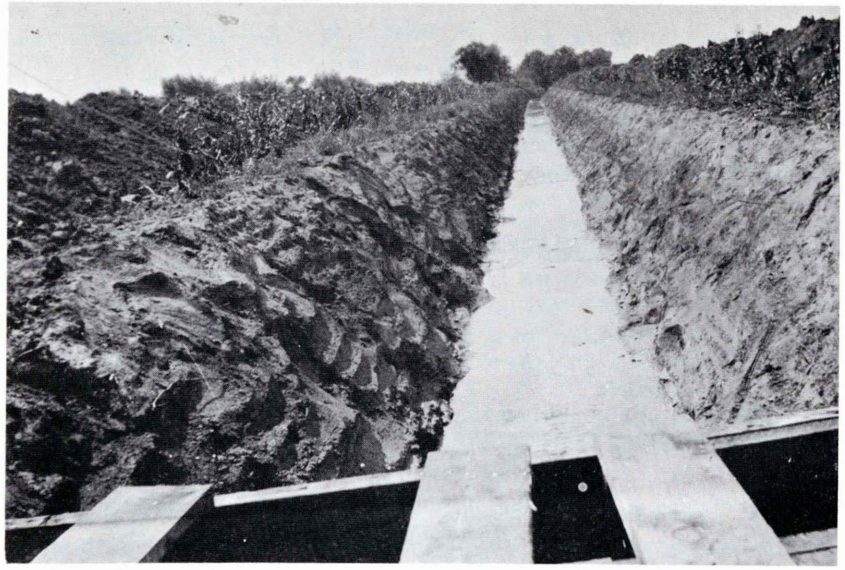
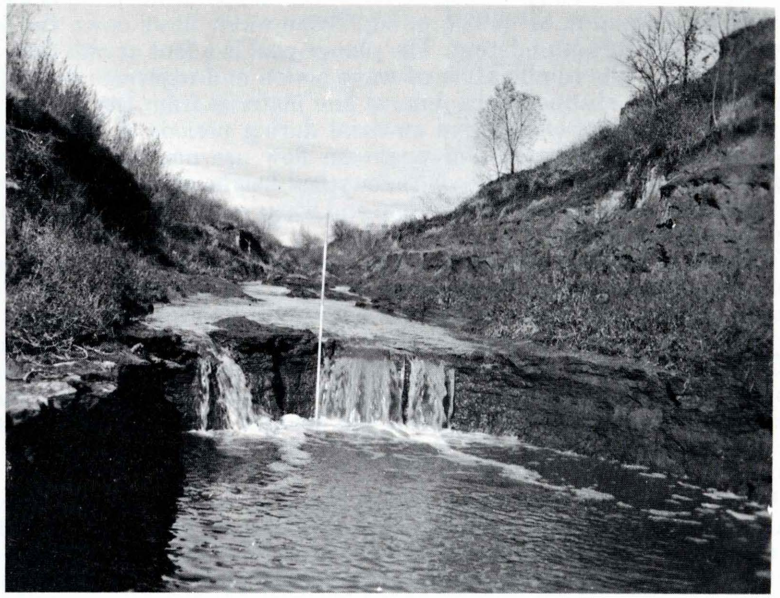


Figure 26.—Top, upstream view of the Willow drainage ditch less than a year after construction (1920–1921) in sec. 3, T. 81 N., R. 42 W., Harrison County, Iowa; depth 11 feet. (Photo by courtesy of H. D. Smith, Woodbine, Iowa.) Bottom, upstream view of the ditch in 1957; depth 42 feet.



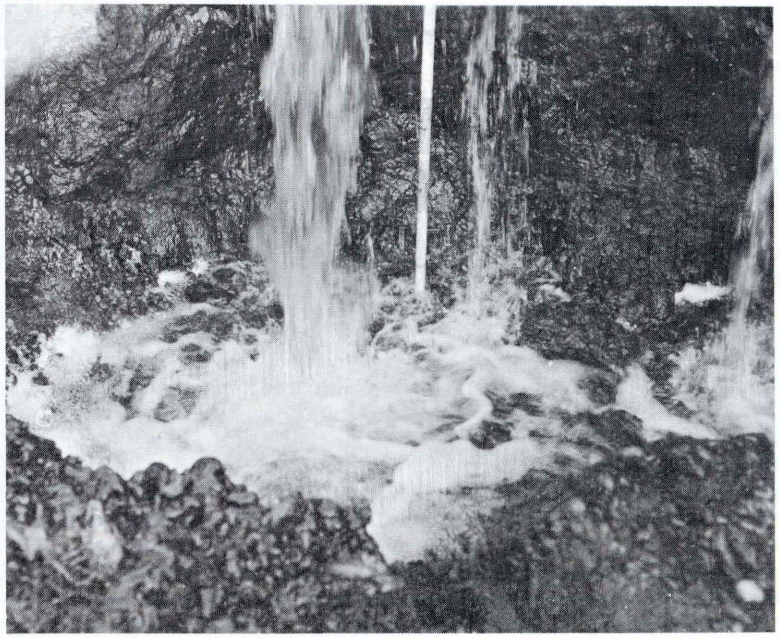


Figure 27.—Top, nickpoint in the Willow drainage ditch, September 1957. Bottom, action of water at the plunge pool of a nickpoint.

Water less than 6 inches deep flows over a nickpoint in the manner described by Ireland et al. (1939, p. 50). Some water flows down the face, even when the face is undercut. The plunge pool is a foot or two from the base (fig. 27). The combination of wave action and upstream flow along the sides of the channel helps remove fine material from the base of the nickpoint. Removal of cohesive material during periods of low water is slow because wave action and upstream flow are not vigorous. If the depth of water equals or exceeds the vertical height of the nickpoint, the plunge pool is 6 to 10 feet downstream and water in the pool has a vigorous boiling swirling action.

There is no bedload and loose silt in the channel immediately upstream from the nickpoint, but downstream rounded silt blocks, 1 to 12 inches across, make up the bedload. These blocks are slump from the face of the nickpoint and from the channel sides. Upstream the channel has small riffles and pools and the bottom is fluted and highly irregular; in cross section, the channel is almost flat and water is about 6 inches deep during low flow. Immediately downstream the channel narrows to about one-half its upstream width; the water is deeper and pools and riffles are common.

After a nickpoint has passed, a seep line is exposed above the channel floor and the saturated material slumps. Slumping increases top width of the ditch and is most active after a nickpoint has moved upstream. But sporadic slumping may occur over several years; in 1960 the banks were slumping at the 1953 site of a nickpoint.

The streambed continues to erode after a nickpoint has passed (fig. 28), and this erosion equals or exceeds that produced by the nickpoint. Accurate records on flow depth of the Willow ditch are not available, and I cannot correlate periods of bed erosion with periods of high discharge. But bed erosion downstream from a nickpoint can be explained partially by channel characteristics. In 1957 the channel was 15 to 20 feet wide above the nickpoint but only 8 to 10 feet wide downstream. Water depth almost doubled downstream although discharge through the reach is constant. Because water depth increased downstream more than bed and water slope decreased (fig. 28), bed shear and erosion should be greatest below the nickpoint (Brush and Wolman 1960, pp. 61, 62). In most streams an increase in the depth-slope product is caused by an increase in depth or by a large increase in slope, both unlikely to last long in natural streams. Nickpoints do not last long in friable cohesive materials.

Cause of Changes

Two major changes have taken place in the Willow drainage ditch since it was built. In the Missouri River valley the ditch filled and between 1908 and 1941 required cleaning and rebuilding. But in the Willow River valley the ditch entrenched.

Where the drainage ditch enters the Missouri River valley, its bottom has widened from 12 feet to 18 feet and its bed slope has decreased from 7.66 feet per mile to 2.0 feet per mile. If discharge is constant, water depth and velocity in a ditch decreases where the ditch widens and the slope decreases (Leopold and Maddock 1953, pp. 8, 14). Silting of the original channel seems to be related to the decrease in bed slope and to the increase in width that reduced velocity of flow in the ditch. But for a given slope and discharge, broad shallow channels carry larger silt loads than narrow deep channels (Griffith 1937, p. 180). The Willow ditch in the Missouri River valley has been relatively stable since 1941. The small changes in the channel suggest that it is adjusting to sediment load and discharge.

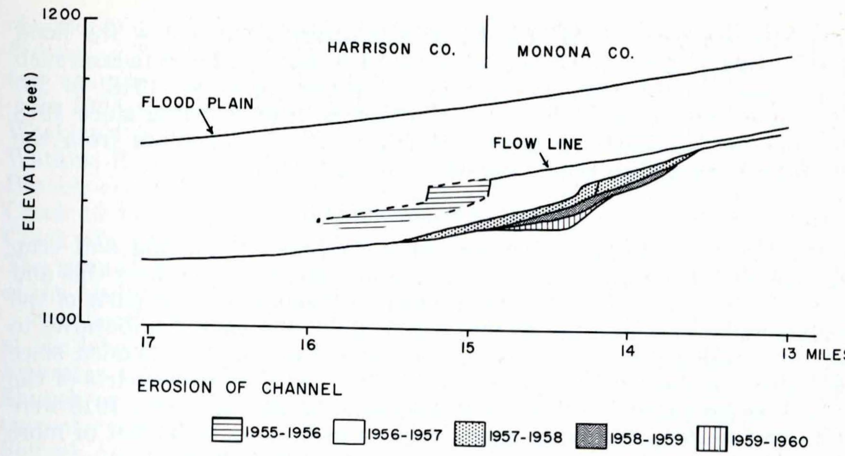


Figure 28.—Changes in the Willow drainage ditch since 1955.

In the Willow River valley, the channel in the drainage ditch was built with a higher gradient and a smoother straighter channel than in the original Willow River. Resistance to flow probably was less in the new ditch (Stillwater Outdoor Hydraulic Laboratory 1947 and fig. 26) and water velocity higher than in the original river channel. This higher velocity plus turbulent flow (fig. 29) along the friable banks and bed would erode the channel.

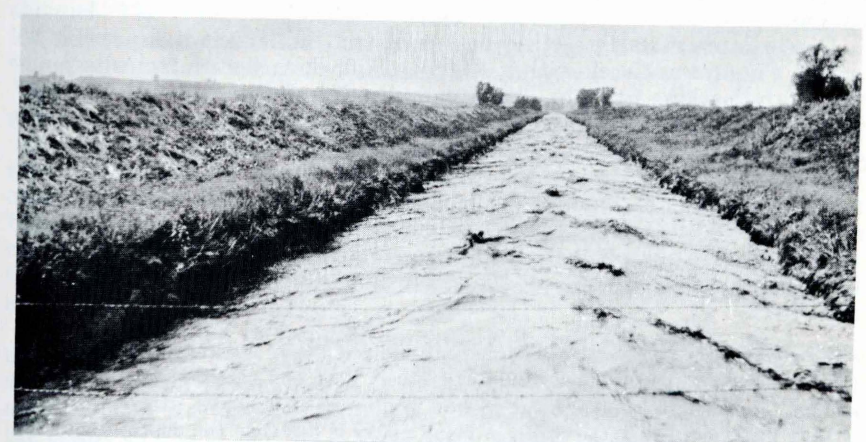


Figure 29.—Willow drainage ditch in sec. 9, T. 81 N., R. 42 W., Harrison County, Iowa, at nearly bank-full stage in 1920, shortly after construction. Note turbulence of the water surface; depth of flow is approximately 10 feet. (Photograph by courtesy of H. D. Smith, Woodbine, Iowa.)

In Monona County, Willow River was about 6 feet below the flood plain in 1850 and about 11 feet below by 1918 (fig. 22). Local factors such as increased runoff through cultivation (Browning et al. 1948, p. 26) may have been responsible for cutting before 1918. Cutting since 1918 probably is the result of headward migration of nickpoints from the drainage ditch and increased runoff from cultivation.

Effects of Entrenchment

The Willow drainage ditch was built to prevent flooding and crop damage and to improve drainage in the low areas. It has done this and more. By trenching the ditch has prevented flooding in most parts of the Willow valley, lowered the ground-water table, and caused tributaries to cut. The valley floor near Thompson Creek has not been flooded since 1925 and not since 1942 in Monona County. Only the lower parts of the Willow River valley are flooded occasionally. Wells dug before 1918 were 20 to 25 feet deep, but since entrenchment wells must be 35 feet or more deep. Tributaries trenched as the drainage ditch trenched.

ENTRENCHED STREAMS IN THOMPSON CREEK AND MAGNOLIA WATERSHEDS

Channels Before 1930

Little is known about the stream channels in Thompson Creek and Magnolia watersheds before or shortly after settlement. But the properties and distribution of the Turton fill indicate that streambeds were 5 to 16 feet below the top of the Hatcher and Mullenix fills (fig. 11). Flood plains of creeks and of several larger tributaries were only narrow strips between scarps separating the Turton and Mullenix fills or the Mullenix and Hatcher fills. Today, nonentrenched streams in forested areas draining less than 40 acres (0.062 sq mi) have indefinite channels on flat to gently concave valley floors. Undoubtedly, presettlement channels were similar.

Descendants of early settlers have said that in 1852 it was possible to bridge Thompson Creek with a 10-foot plank downstream from its junction with Watkins Branch. The stream was 7 to 8 feet below the bordering higher banks. This is about the elevation of the Turton member in the area (fig. 11, mile 4.0). In 1908 a team and wagon could be driven across Turton Branch (NE$\frac{1}{4}$sec. 9, T. 80 N., R. 42 W.; pl. 1: E.50, 2.20), but near the junction of Thompson Creek and Turton Branch the stream was about 10 to 15 feet deep. Residents remember driving down onto a bench (top of the Turton member) before crossing the stream, which was about the level of the bench. About the same time Shimek (1910, pp. 298–299) reported:

"The channels of nearly all the permanent and temporary streamlets in this region (Harrison County and Monona County) are very deep and narrow, sometimes, as in section 7, township 79 north, range 43 west, southwest of Magnolia, reaching a depth of fully forty feet, while the width in many places is less than the depth, suggesting that there has been a recent rapid degradation of the stream bed. This is further shown by the not infrequent hanging valleys of their smaller tributaries. . . ."

In 1916 Thompson Creek was 14 feet deep at its junction with Willow River. A remnant of the channel left when the drainage ditch was built is 30 feet wide at the top. In 1916 Magnolia Creek had a poorly defined channel and usually flooded the Willow flood plain during heavy runoff. Westering Branch in Magnolia watershed (pl. 2) was trenched 15 to 20 feet near its headwaters about 1916—before the Willow ditch was built.

In 1925 a narrow strip of land separated the meandering channel of Watkins Branch from Thompson Creek; a small ditch was dug to force Watkins Branch to abandon a few meanders. Later discharge of Watkins Branch channeled the stream through the cutoff and forced Thompson Creek to flow against its right bank. Some time after 1925 Thompson Creek abandoned part of its channel but the exact date is not known. The abandoned channel has a maximum depth of 11 feet below the top of the Mullenix fill and a top width of 35 feet.

Recollections of residents must be used with caution. A stream flowing at the level of the Turton member is a "gully" to many because a scarp separates the stream from the general level of the older Mullenix fill. Shimek, on the other hand, separated older cycles of trenching from the current cycle. But I am not sure whether the stream trenching noted by Shimek near Magnolia was a continuation of the Turton cycle, was all postsettlement, or a combination of the two.

Present Channels

Almost all streams with a watershed of 40 acres or more have trenched some segments of their alluvial fill. Several small streams have trenched within 500 feet of their heads (pl. 1: C.72, 2.90; B.56, 4.54; C.85, 4.31; D.48, 2.36; D.35, 3.29). Larger streams in Thompson Creek and Magnolia watersheds have cut through the Turton and Mullenix fills and in several areas through the Hatcher and Watkins fills (figs. 11, 12). Locally, Thompson Creek and Turton and Fox Branches have cut into Kansan till (fig. 11).[24] The channels of the streams cut into till are similar to those of streams cut into alluvium.

Bars of silt, sand, and gravel are common in the lower part of Thompson Creek. Trees and other organic debris temporarily restrict flow in the channel. The floor of Thompson Creek upstream from Watkins Branch has few distinct bars, and in most areas the creek flows on alluvium or till. Pools and riffles are common throughout the creek. The floor of Magnolia Creek is similar to that of Thompson Creek, but it has no gravel and only a small amount of sand.

Floors of tributaries of Thompson Creek have few distinct bars and generally only a thin layer of debris (fig. 30, top). Locally, some gravel occurs near outcrops of till, and silt, sand, and gravel collect in pools. Floors upstream from a nickpoint are rough (fig. 30) and have discontinuous patches of gravel; potholes are common. Floors downstream from a nickpoint have pools and riffles and, locally, small bars of silt or sand; there are few potholes.

The cross section of trenched streams is highly irregular to distinctly U-shaped (fig. 30, top). Where the stream impinges on a bank, the cross section is irregular; the opposite bank slumps and vegetation becomes established if the slope is 45 degrees or less. Where the stream flows in the center of the trench, the channel is U-shaped.

[24] The exposures of till in the trenches of Thompson Creek and Turton and Fox Branches represent the minimum amount of till cut into by the streams. In several places the streams have impinged against the upland, and in one bank of the stream several feet of till are exposed whereas in the opposite bank only 1 to 2 feet are exposed.

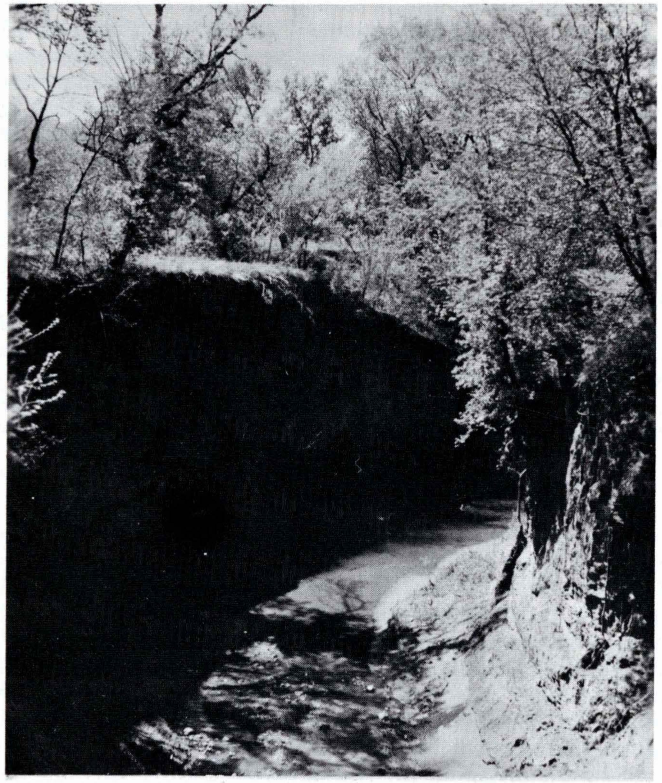


Figure 30.—Top, Thompson Creek in its lower reaches; depth 35 feet, top width 47 feet. Bottom, grooves in channel of Fox Branch less than 100 feet upstream from a nickpoint.

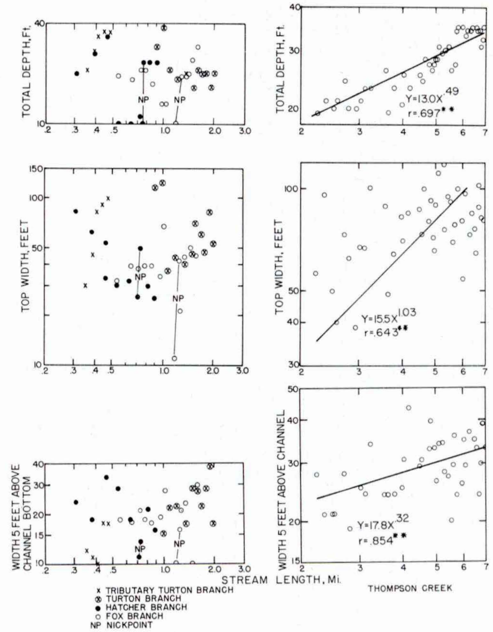


Figure 31.—Properties of entrenched streams in Thompson Creek watershed. (**Significant at 1-percent level, *significant at 5-percent level.)

Total depth, top width, and width 5 feet above the channel floor increase downstream in Thompson Creek (fig. 31). But these measurements have no relation to stream length in tributaries of Thompson Creek. Top width (Wt) is related to total depth in Thompson Creek, $r=0.586^{**}$; in tributaries of the creek, $r=0.667^{**}$.[25] Top width is also related to width 5 feet above the bed (W5) and to total depth (d) in Thompson Creek by the equation $Wt=0.16d+0.63W5+53.78$ (F 2,38+9.25**) and in tributaries of the creek $Wt+2.32d+1.59W5-28.28$ (F 2,35=20.28**). Top width of a V-shaped trench is a function of total depth once the banks are stable. But top width of a U-shaped trench is influenced by bank scour. Because water 5 feet or more deep flowed in Thompson Creek each year between 1957 and 1960, multiple-regression equations relating top width of the trench to width 5 feet above the bed and to total depth probably describe cause and effect relations more closely than equations relating only top width and depth.

Bed slopes in Thompson Creek and its tributaries are extremely irregular (table 19), and there is no statistical relation between bed slope and stream length. In Thompson Creek bed slopes decrease through two or more points and then increase. These changes appear to be systematic and unrelated to outcrops of till in the bed, to entry of tributaries, or to position of nickpoints. On the other hand in Magnolia Creek, bed slope is related to stream length by the regression equation $Y=124.7X^{-1.79}$. This equation is significant beyond the 1-percent level ($r=-.938^{**}$). These variable, possibly cyclic, changes in bed slope and the lack of correlation with stream length in the streams studied contrast sharply with data of others (Hack 1957, p. 54; Leopold and Maddock 1953, p. 48; Leopold and Miller 1956, p. 27). Even streams that are actively trenching sup-

[25] **Significant at 1-percent level.

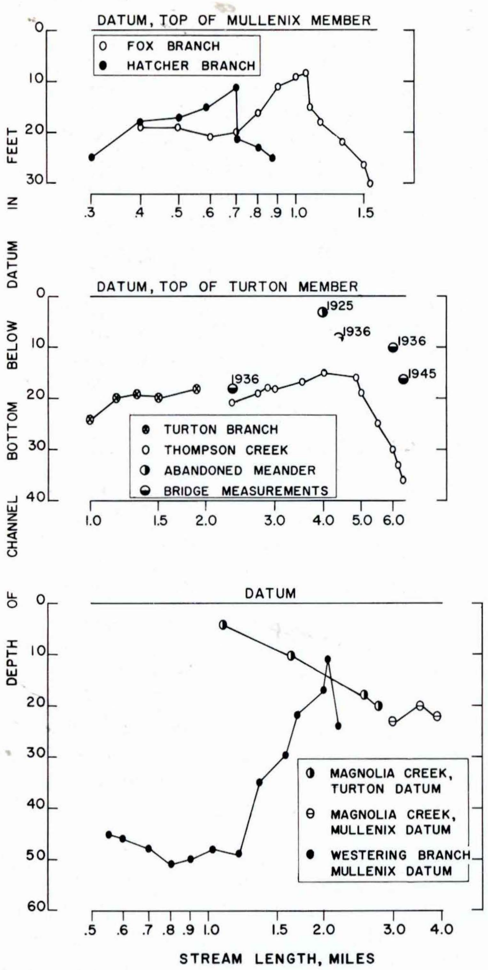


Figure 32.—Depth of modern erosion of selected streams in Thompson and Magnolia watersheds.

posedly maintain a quasi-equilibrium and, in most, bed slope decreases downstream as a power function of stream length (Leopold and Miller 1956, pp. 27, 33). Either Thompson Creek and its tributaries are unique or streams that are trenching are not necessarily in quasi-equilibrium.

Since the end of the Turton cycle, Thompson Creek has lowered its bed 36 feet near its mouth but only 16 feet in its central reaches; upstream the bed is 24 feet lower (fig. 32).[26] Similarly, Fox and Hatcher Branches

[26] Depth of modern stream erosion was measured from the top of the Turton fill if there were enough outcrops to construct a profile. The top of the Mullenix fill was used as a datum in Fox, Hatcher, and Westering Branches because there were not enough outcrops of the Turton fill to construct an accurate profile. No allowance was made for the depth of the Turton or Mullenix channels below the top of the appropriate fill. The top of the Turton fill was used where possible because it was the flood plain of the streams before the current trenching cycle started. Using the lip of the stream trench as a datum would result in erroneous values of trenching because the lip may be 10 to 20 feet above the top of the Turton fill.

have eroded their beds more near the mouth than in the central reaches near the nickpoints, and erosion has been greater above the nickpoints. But in Magnolia Creek streambed erosion is less upstream, and in Westering Branch it is greatest at the main nickpoint.

Erosion during the Mullenix cycle removed 20 to 25 feet of the Hatcher fill (fig. 10, stations 600, 900). In the headwaters of Turton Branch, erosion in the Turton cycle cut a maximum of 25 feet below the Mullenix fill (fig. 11). Only in the lower reaches of Thompson Creek, Hatcher Branch, Fox Branch and in the upper reaches of Westering Branch does the present depth of trenching exceed that of the Mullenix or Turton cycles (figs. 11, 32). The trenching of Westering Branch is extreme. But since we could not accurately reconstruct its presettlement channel, our estimate of trenching probably is too large. Thus, streams have not deepened much more during the present cycle than they did as a result of changes in climate or other conditions before settlement.

Rate of Entrenchment

I could find few records of the rate of trenching of Thompson and Magnolia Creeks. Some time after 1925 Thompson Creek abandoned a segment of its channel near Watkins Branch. The bottom of the channel is about 3 feet below the top of the Turton fill, and this segment of the creek has deepened its channel mainly since 1925. Since 1936 the rate of deepening in Thompson Creek has been greatest in the lower reaches (fig. 32), and most of the trenching probably has occurred since 1945.

At the mouth of Thompson Creek the Willow ditch deepened its channel about 9 feet between 1919 and 1936, about 4 feet between 1936 and 1942, and about 5 feet from 1942 to 1957 (fig. 25, mile 20). Since 1936 the rate of trenching in Thompson Creek below mile 4.0 has been greater than that in the Willow ditch (figs. 25, 32). Trenching of a tributary does not necessarily parallel the time and rate of trenching of its controlling stream.

Movement of nickpoints in Thompson Creek watershed was measured on aerial photographs of different dates (table 9). Tributary A of Thompson Creek and Turton Branch are cutting into the Mullenix and Hatcher fills and other streams are cutting into the Hatcher fill. Movement of the nickpoints between 1938 and 1960 varied considerably between watersheds and within any one watershed. There is no statistical correlation between movement of nickpoints, size of watershed, and proportion of watershed under cultivation.

The nickpoints surveyed by planetable from 1957 to 1960 are cutting into the Mullenix and Hatcher fills. Movement is erratic and not correlated with size of watershed. Nickpoints in cultivated watersheds of 2 acres or less grow more rapidly than those in larger watersheds that are mostly in permanent cover (table 9). The slower growth in noncultivated watersheds may be the result of vegetation reducing the amount of runoff, which reduces the rate of nickpoint advance. In all watersheds more than 90 percent of the yearly nickpoint growth occurs between November and April. Freezing and thawing during the early spring months causes some slumping and spalling. But runoff from snowmelt combined with freezing and thawing probably are the major causes of the increase in nickpoint growth during winter.

Changes in channels upstream and downstream from the nickpoints are small except in Fox Branch. Between July 1957 and April 1958 a nickpoint in Fox Branch moved upstream 31 feet with no major changes in the channel except the formation of three potholes (fig. 33). Between April 1958 and April 1959, the channel deepened 3 feet downstream from the nickpoint and as much as 7 feet upstream. The original nickpoints were obliterated, and the channel developed two new nickpoints and

TABLE 9.—*Rate of headward movement of nickpoints, Thompson Creek watershed*

Measured from aerial photographs

Stream	Year	Growth		Drainage area	Proportion of watershed cultivated[1]
		Total amount	Rate		
		Feet	*Feet/year*	*Acres*	*Percent*
Soetmelk Branch[2]	1938–49	458	41	71	94
	1949–54	(3)			
Fox Branch:					
Tributary A	1938–49	83	8	84	91
	1949–54	166	33		
	1954–60	83	8		
Tributary B	1938–49	104	9	40	66
	1949–54	(3)			
	1954–60	(3)			
Tributary C	1938–49	104	9	54	96
	1949–54	42	8		
	1954–60	(3)			
Tributary D	1938–49	166	15	48	91
	1949–54	63	12		
	1954–60	42	7		
Watkins Branch:					
Tributary A	1938–49	166	15	116	56
	1949–54	126	25		
	1954–60	126	21		
Tributary B	1938–49	126	23	30	53
	1949–54	(3)			
	1954–60	(3)			
Rose Branch	1938–49	(3)		70	97
	1949–54	458	29		
	1954–60				
Turton Branch:					
Tributary A	1938–49	166	15	51	100
	1949–54	42	8		
	1954–60	(3)			
Thompson Creek:					
Tributary A	1938–49	126	11	37	100
	1949–54	(3)			
	1954–60	(3)			

See footnotes at end of table.

TABLE 9.—*Rate of headward movement of nickpoints*—Continued

Measured by planetable

Stream	Year	Growth		Drainage area	Proportion of watershed cultivated[1]
		Total amount	Rate		
		Feet	*Feet/year*	*Acres*	*Percent*
Tributary of Turton Branch	[4] 1957–58	4	4	5.4	100
	1958–59	No change			
	1959–60	No change			
Watkins Branch:					
Tributary A	1957–58	0		44	21
	1958–59	0			
	1959–60	2			
Tributary B	1957–58	0		44	21
	1958–59	0			
	1959–60	2			
Fox Branch	1957–58	31		399	81
	1958–59	8			
Thompson Creek:					
Tributary A	1958–59	1		1.9	100
	1959–60	5			
Tributary B	1958–59	3	0.7		100
	1959–60	5			
Tributary C	1958–59	0	.7		100
	1959–60	7			
Tributary D	1958–59	0	.8		100
	1959–60	2			

[1] Rotation pasture is included in cultivated land.
[2] Destroyed by damming in 1957.
[3] Growth could not be determined.
[4] Initial measurements were between July 1957 and April 1958 but those after 1958 from April to April.

potholes. Changes in the channel of Fox Branch are similar to changes in the channel of the Willow drainage ditch (fig. 28). Apparently a nickpoint does not last long in perennial and intermittent streams but may last for 20 years or more in ephemeral streams (table 9).

Nickpoints in ephemeral tributaries of Thompson Creek are 10 to 20 feet high; one in an ephemeral tributary of Westering Branch (pl. 2: B.96, 2.90) is 55 feet high. We could not find measurable scouring above the nickpoint and there is sapping at the base of some nickpoints. These two factors are primarily responsible for the high and long-lived nickpoints in ephemeral streams. A reduction in height of these nickpoints is brought about mainly through a reduction of downstream scour as the headward movement continues.

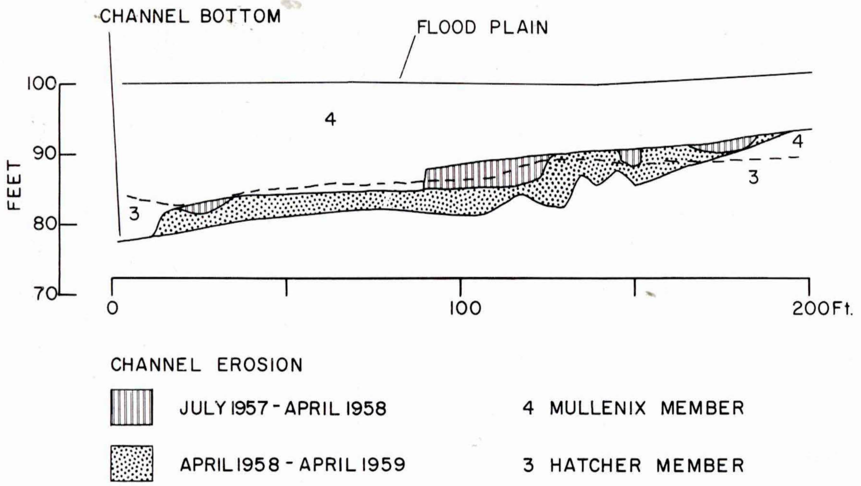


Figure 33.—Changes in the channel of Fox Branch at the site of a nickpoint.

Cause of Entrenchment

Although there is little information on stream characteristics before Harrison County was settled in 1847–48 (Smith 1888, p. 79), it is significant that land surveyors noted no features suggesting that streams were cutting. Smith described the vegetation and landscape of Harrison County in 1870–80 but did not mention any deeply trenched streams.

In 1860, 12,276 acres in Harrison County were classified as improved farmland and in 1870, 54,150 acres.[27] From 1880 to 1910 acreage in row crops, small grains, and hay increased from 138,330 to 262,050. There was little change after 1910. The large increase in cropland acreage about 1880 coincides with the end of the Turton alluviation cycle.

Modern stream trenching probably started some time after 1880 because there is little evidence of stream trenching before 1880 and many streams were trenched by 1910. Several streams in Harrison and Monona Counties were trenched by 1909. Westering Branch and the lower part of Turton Branch were trenched before 1908. But we are dealing with at least two cycles of stream cutting—one that started before 1908 and one that started with construction of the Willow drainage ditch.

Trenching in the headwaters of Westering and Turton Branches before 1916 must have been caused by local factors that affected stream discharge, width, depth, and flow velocity. Two factors that affect discharge are cultivation, road building, and similar activities in the watersheds and regional changes in climate.

The large increase in cropland acreage from 1860 to 1910 must have increased the amount and rate of runoff (Browning et al. 1948, p. 25; Hays et al. 1949, p. 17). Cultivation also increases annual discharge, flow volume during periods of runoff, and peak rates of flow in all but extreme storms (Harrold et al. 1962, pp. 14–16). Any increase in runoff imposes a discharge upon a specific reach of a stream that previously was found only in reaches farther downstream. Initially, greater water depth increases shear on the bed (Brush and Wolman 1960, p. 61). The larger

[27] All land use acreages from U.S. census reports.

sediment load of a stream produced by erosion of cultivated land also increases velocity under the same discharge (Leopold and Maddock 1953, p. 23). Some change in the configuration of stream channels must be expected.

Streams with banks of silt and clay have narrower width-depth ratios than streams with banks and beds of sand (Schumm 1960, p. 180). This suggests that channel depth in silty materials increases at a rate proportional to adjustments in width, an inference substantiated by the width-depth relation in tributaries of Thompson Creek. The exact mechanisms controlling adjustments in depth are not clear, but the effect is to entrench the channel and, initially, to lower the average slope of the bed within a reach (fig. 11, Hatcher and Turton Branches, miles 0.3–0.7, 1.0–2.0). The magnitude of the adjustments apparently decreases downstream.

Stream channels in valleys draining 40 acres or less originally were covered by a dense growth of prairie grasses. These channels are now cultivated. Removing vegetation increases flow velocity by reducing channel roughness (Ree and Palmer 1949, p. 101). Shear forces now operate directly on the bed sediments and not on a mat of grass roots. These conditions are ideally suited to bed scour and to the formation of small nickpoints. Later upstream migration of nickpoints and continued bed scour produced by confining water to a definite channel probably are the major factors in deepening small ephemeral streams.

Cropping the watersheds and some land use practices have undoubtedly caused streams to trench. But regional changes in climate cannot be completely discounted.

The average annual precipitation at Logan, Iowa, has decreased steadily since records have been kept (fig. 34). It was highest in 1880; this seems to have been the end of an upward swing in precipitation. The decrease since 1880 is general throughout the Missouri River watershed (Oltman and Tracy 1951, p. 5). The amount of annual precipitation from storms of 1 inch or more per day has also decreased (fig. 34).

During periods or cycles of increasing precipitation, streams carry more water and runoff increases (Langbein 1949, pp. 8–12; Oltman and Tracy 1951, pp. 21–104; Hershfield 1961, pp. 9–14). But an increase in moisture produces a more dense plant cover and reduces erosion of valley

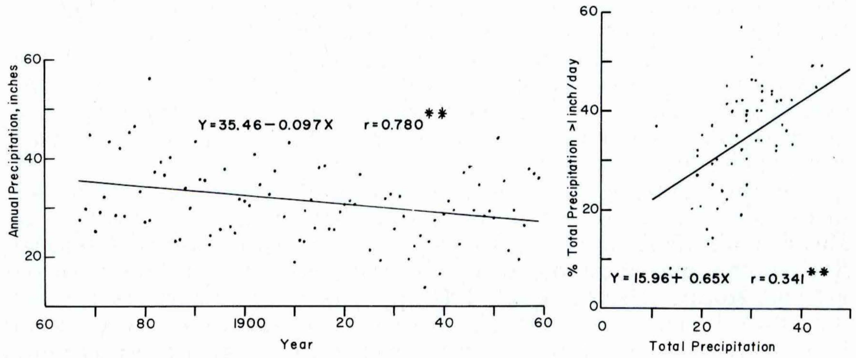
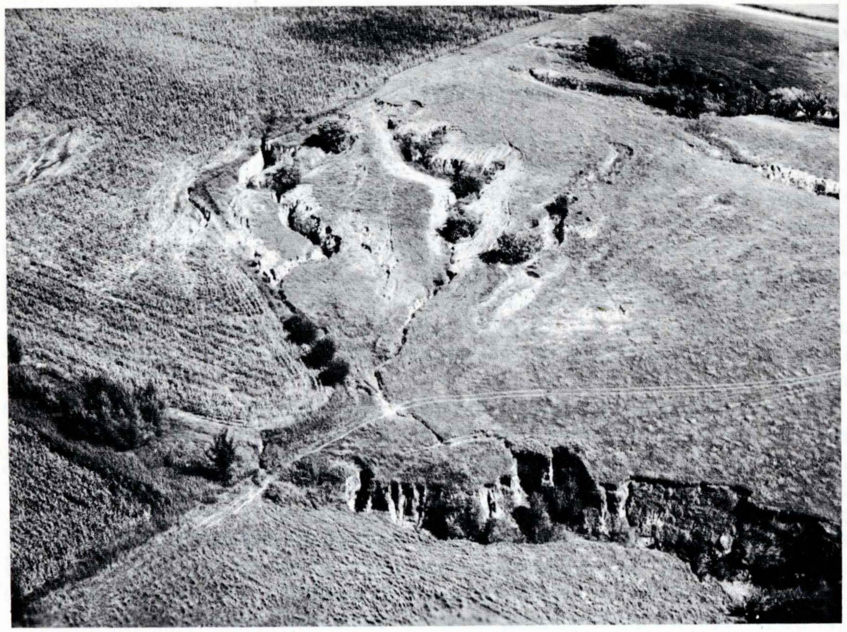


***Figure 34.*—Annual precipitation at Logan, Iowa, from 1867 to 1959 and percentage of annual precipitation from storms of 1 inch or more per day.**



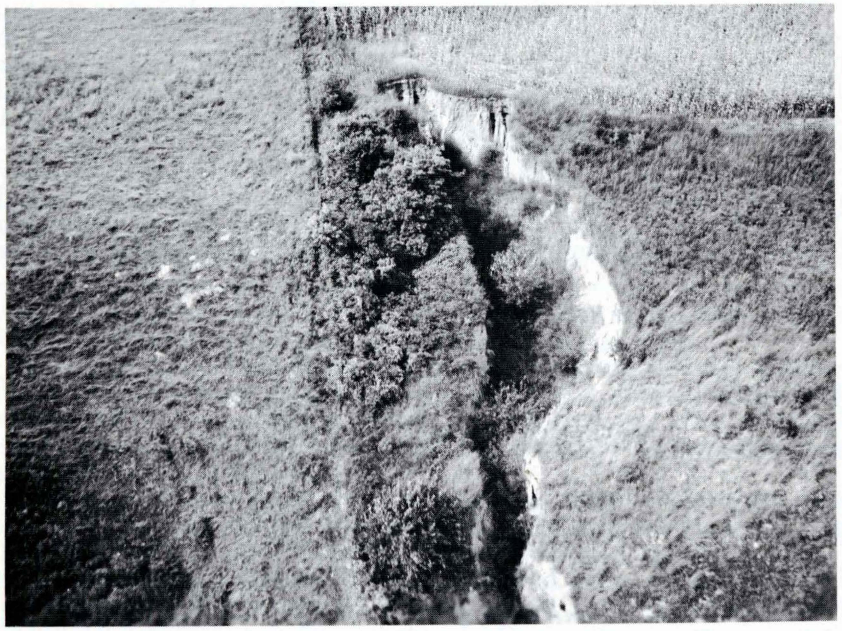
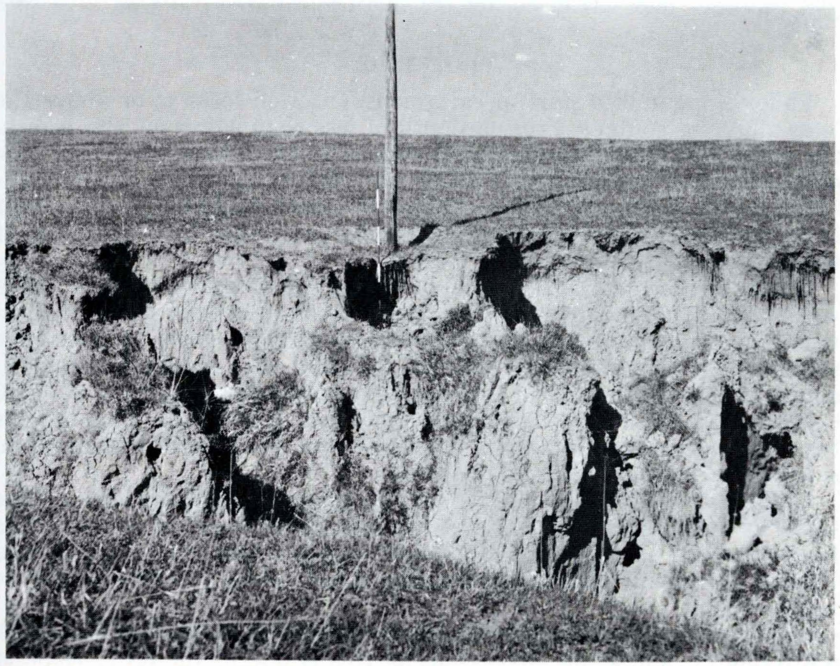


Figure 35.—Valley-slope gullies in NW¼sec. 9 and SE¼sec. 4, T. 80 N., R. 42 W., Harrison County, Iowa.

Figure 36.—Top, walls of a valley-slope gully where water flows over the headwall; maximum depth is 28 feet. Bottom, walls of a valley-slope gully where water flows over the sides downslope from the wall at the head; depth at lip is 4 to 5 feet and channel depth is 17 feet.



slopes (Albertson and Weaver 1942, pp. 35, 44–45; Weaver and Fitzpatrick 1934, p. 290). The increased discharge and reduced sediment load almost require some adjustment in channel width, depth, and slope (Leopold and Maddock 1953). The linear relation between width and depth in tributaries of Thompson Creek indicates that streams adjust during periods of increasing precipitation by trenching.

It is possible that streams in Harrison County might have begun to trench about 1880 even if their watersheds had not been cultivated. Cultivation may have only intensified the trenching started by increased precipitation. But since 1880 annual precipitation at Logan and throughout the Missouri River basin has decreased. Under primeval conditions a shift from a moist to a dry cycle changes the kind and density of prairie grass. Both changes may result in increased erosion of valley slopes and an increased sediment load in streams. Total runoff and mean annual discharge should be less. The streams should aggrade (Mackin 1948, pp. 493–494; Langbein and Schumm 1958, p. 1084). Had the watersheds not been cultivated, the lower precipitation since 1880 probably would have resulted in a period of stream stability or possibly aggradation. Apparently, cultivation has overbalanced climate because stream trenching has continued.

Valley-Slope Gullies

Valley-slope gullies are small, steep-walled, sharply incised, elongate depressions on valley sides (fig. 35). They occur along field boundaries and fence rows and in farm lanes, cattle trails, and channels of drainageways on valley slopes of 6 to 30 percent. Gullies occur on all slope aspects in cultivated or previously cultivated areas but not in areas of virgin timber.

PROPERTIES

Valley-slope gullies start in calcareous Tazewell loess at or above the loess-alluvium contact. From a depth of less than 1 foot at the mouth, the gully floor is cut progressively deeper in an upslope direction. The gully ends in a vertical wall 5 to 28 feet high at the head, but its maximum depth is 5 to 100 feet downslope from the headwall. The cut floor is flat transverse to water flow but usually is covered by 1 to 10 feet of slump from the sidewalls.

Where farming operations have restricted runoff to one or more headwalls in gullies along field boundaries and fence rows or in poorly defined valley-slope drainageways, the gullies grow upslope. Near the head the sidewalls are almost vertical (fig. 36, top), but they slump and spall to angles of 60 to 80 degrees in the central reaches and to angles of 35 to 60 degrees near the mouth. Stabilizing grass and weeds form a continuous cover on sidewalls of less than 40 degrees but a discontinuous cover on sidewalls of between 40 and 60 degrees.

Gullies in channels of well-defined valley-slope drainageways receive water as sheet flow over their sidewalls and as concentrated flow over the headwall. The sidewalls are extremely irregular (fig. 36, bottom), and upslope growth is toward the drainage divide along and parallel to the main channel.

Width at the top of a gully is related to depth but there is considerable scattering of points (fig. 37A). Part of this is due to the lower slope of

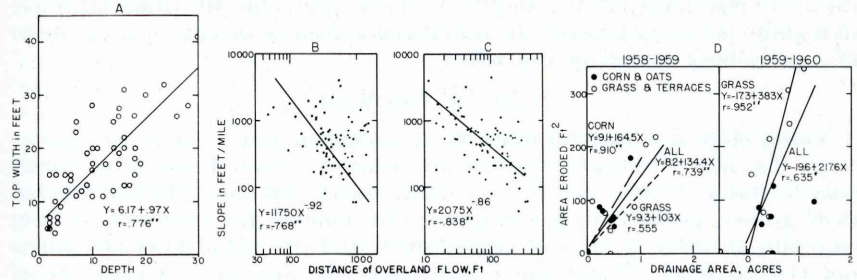


Figure 37.—Properties of valley-slope gullies. Relation between: (A) top width and depth, (B) channel slope and distance from drainage divide, (C) channel slope and distance from the gully headwall, and (D) area eroded and drainage area.

vegetated sidewalls than that of raw sidewalls near the headwall. The floor of a valley-slope gully generally parallels the underlying buried geomorphic surfaces (fig. 38). Since we saw no seepage water in the gullies and did not find ground water and a zone of saturation above the geomorphic surfaces, this parallelism is accidental.

Length of overland flow, the distance from the drainage divide to the wall at the gully head, is related to drainage area, $r = 0.634$. Since bed slope of a stream in uniform materials decreases with stream length (Hack 1957, p. 54), the decrease in slope of a gully floor with increasing distance of overland flow (fig. 37B) may be related to discharge of the gully. Slope of a gully floor also is related to distance from the gully head (fig. 37C) and to factors that influence erosion of the floor material. But

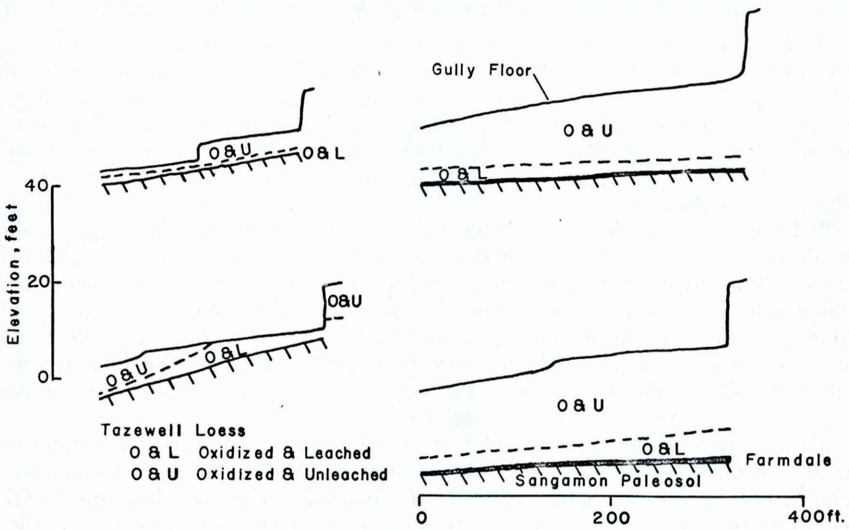


Figure 38.—Relation between buried geomorphic surfaces and floor of valley-slope gullies.

until the discharge, width, depth, velocity, and sediment load of water in a gully can be measured, the mechanisms that determine channel slope of a gully floor cannot be evaluated.

RATE OF GROWTH

Valley-slope gullies grow most at the headwall and immediately downslope (fig. 39). Upslope growth of the head exclusive of slumping occurs only during periods of runoff. Since little water flows over the sidewalls in most gullies, growth at right angles to the channel generally results from slumping in early spring during snowmelt and periods of alternate freezing and thawing. Where water flows over the sidewalls in channels of valley-side drainageways, the gullies widen throughout their length. The size of the area eroded is related to plant cover and to size of drainage area (fig. 38D).

Valley-slope gullies form rapidly during intense runoff. On the afternoon of June 15, 1957, haying equipment easily crossed a small drainageway on the Earl Tiby farm. During the 5- to 7-inch rain that night runoff from a level terrace that drains about 2 acres cut a gully 72 feet long, 8 feet deep, and 8 feet wide at the top in calcareous loess. The headwall was 96 feet downslope from the terrace channel outlet. This gully formed in one rainstorm is typical of all other valley-slope gullies.

MECHANISM

I could see little difference in the way water flows over the headwall of a valley-slope gully and over a nickpoint in an entrenched stream. When runoff is low, water is confined to a small channel upslope from the headwall. Most of the water flows outward and away from the headwall although there is some backdrip (Ireland et al. 1939, p. 50). Under these conditions, the headwall does not erode and little erosion occurs at the point where water strikes the gully floor. But when runoff is high, a sheet of water flows across all parts of the headwall lip. A large part of

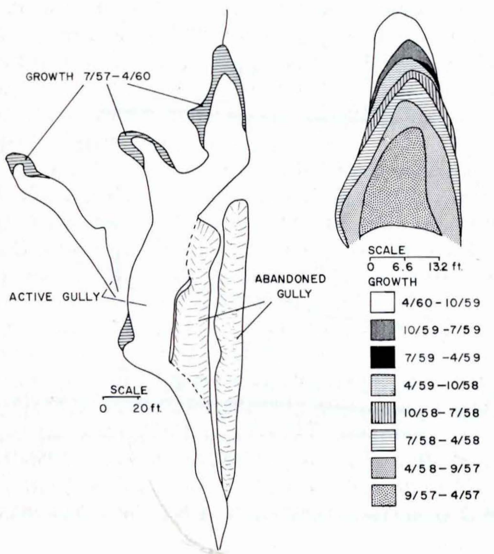


Figure 39.—Growth of a typical valley-slope gully between April 1957 and April 1960.

the water falls out and away, but the backdrip is almost a sheet flow over the entire headwall, which erodes rapidly. Some headwalls have been undercut, but I saw no undercutting during runoff and it is not a normal feature of most headwalls. I did not see any sapping at the base of the headwall by seepage water.

Downslope from the headwall, water moves as a thin sheet where the floor is flat transverse to water flow but generally it is confined to an irregular-shaped channel. False floors are common. The cut floor in many gullies is completely hidden by slump except immediately after very heavy runoff, such as the 5- to 7-inch rains of June 15 and 16, 1957. The large amount of slump on the gully floor increases the sediment concentration of runoff downslope.

Water velocity, discharge, and sediment concentration from valley-slope gullies were not measured. Until this is done, we cannot understand completely what happens when a gully forms.

AGE

The first valley-slope gully that long-time residents of the area recall started about 1880 or 1890 in a cattle trail. Others remember that areas in Thompson Creek watershed were gullied by 1910. The stabilized part of the gully in figure 40 was active about 1917. The oldest trees growing on the floor of a stabilized tributary gully (fig. 35) are 37 years old. But the floor of this gully is 17 feet above the floor of a younger active gully.

In Thompson Creek watershed, 42 valley-slope gullies could be identified on the 1938 aerial photographs and 63 on the 1954 photographs. Sixty-eight gullies were mapped in 1957. Of 21 gullies studied in detail only 2 were present in 1938 and 20 in 1954. Although gullies have been active in the watersheds for 50 years or more, most of the present gullies are less than 20 years old.

FACTORS INFLUENCING GULLY FORMATION

About 50 percent of the valley-slope gullies are along field boundaries, farm lanes, and fence rows and in cattle trails; 50 percent are in channels of valley-slope drainageways. These gullies always start in Ida soils on slopes of 15 percent or more. Drainage basins of gullies along field boundaries or fence rows have been enlarged by cultivation. In most parts of Thompson Creek and Magnolia watersheds, spur ridge crests have a slope of 1 to 2 percent along their axes. Cultivation usually parallels the axes of the ridges, and channels formed during cultivation force runoff along the axes to a field boundary where it is diverted downslope either by end rows or by a ridge produced by cultivation. This combination of increased drainage basin and loss of plant cover makes conditions ideal for erosion. Where gullies have formed in well-defined channels of valley-slope drainageways, the drainage basin and channel of the drainageways are now or have been cultivated. Where gullies occur in noncultivated but pastured areas, the vegetation is sparse.

Valley-slope gullies begin to form when water concentrates in bare channels. Increased runoff or enlargement of the drainage basin through cultivation probably are secondary causes. There are no gullies in undisturbed forested areas. Why gullies start in Ida soils on slopes of 15 percent or more and not in Monona soils is not clear. Possibly the B horizon of Monona soils is more resistant to erosion than the calcareous C horizon of Ida soils.

Effects of Present Cycle

The present stream trenching cycle raises the question of economy in trying to control or reverse the cycle. Control measures in the lower reaches of Thompson Creek, for example, would be expensive because of the large drainage basin, and they might have little effect if the erosion cycle is nearly completed. If trenching continues in the headwaters, erosion control structures may be economically sound if their cost does not exceed the value of the land lost by stream deepening and widening. An economic analysis is beyond the scope of this report, but a prediction of the effects of trenching may be of some value in planning watershed use and erosion control structures.

ENTRENCHED STREAMS

There is little evidence of permanent sedimentation in the Willow drainage ditch in the Willow River valley. There are some sand, gravel, and silt bars but most of them shift with each heavy flow. But in the Missouri River valley, the ditch has partially refilled since 1941 and constant maintenance work is required on the levees. If maintenance were stopped, the stream would soon abandon its present channel. The change in elevation from the mouth of the Willow River valley to the Boyer drainage ditch, the nearest outlet, is greatest along the present ditch. If the stream were to abandon the ditch, its gradient would be reduced and its width would be almost unlimited. These conditions favor aggradation. The kind of channel that eventually would be formed across the Missouri River valley cannot be predicted, but the stream probably would aggrade where it flattens abruptly near the mouth of the Willow River valley.

Raising the base level at the mouth of the Willow River valley would cause deposition up valley. The chances of the stream leaving the ditch in the Willow valley increase more as sediment deposited in the channel reduces the difference in elevation between the bed and the former flood plain. If the stream were allowed to leave the ditch at the mouth of the Willow valley, it would be possible for the ditch to be abandoned upvalley because it is likely that stream length and width would increase and gradient decrease—ideal conditions for sedimentation. Eventually, the effects of entrenchment produced by the ditch would be destroyed. Allowing the stream to leave any segment of the drainage ditch would increase both the hazard and the frequency of flooding, result in swamping of low areas, and increase the area occupied by the stream. I believe that the stream will be confined to its present channel.

Since 1940 the drainage ditch in the Willow River valley has been relatively stable from mile 36 to 26 (fig. 25) and may be at or approaching a stable bed slope. Between miles 13 and 16, however, the bed probably will continue to cut since it slopes 30 to 40 feet per mile, considerably more than during the Mullenix cycle in the same reaches (fig. 22). There is no outcrop of resistant material in these reaches to prevent continued cutting. Deepening of the drainage ditch between miles 13 and 16 probably will produce additional trenching upstream in the Willow River.

Profiles of entrenched streams usually closely parallel their original profiles (Mackin 1948, p. 498; Leopold and Miller 1956, p. 32). Evidence

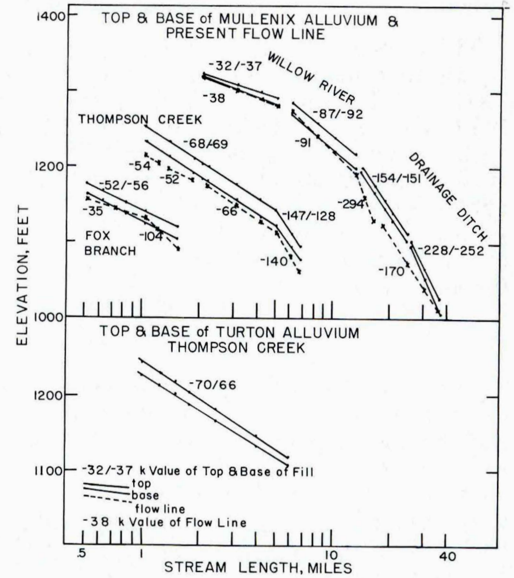


Figure 40.—k values of the base of the Mullenix and Turton fills and of the present stream channels in the Willow River and Thompson Creek valleys. Only a few of the points used in computing the k values are shown.

for this parallelism in these watersheds is the similarity in the k values[28] of the present stream and those of the base of the Mullenix fill in the upper Willow valley (fig. 40). The drainage ditch is an exception, but stream length is less in these reaches. If the Willow drainage ditch is stable below mile 16, its final depth and amount of cutting can be estimated by projecting the k values of the present cycle upstream.

The predicted stable depth of the Willow drainage ditch in its upper reaches is 44 feet if the k value remains the same throughout the drainage ditch (fig. 41). Upstream in Willow River a maximum depth of 59 feet can be predicted at mile 10 and of 44 feet at mile 2 if the k values of the stream parallel the k values at the base of the Mullenix in these reaches. The Willow River may trench its bed 40 feet at mile 8. This estimated trenching probably is a maximum because the alluvium becomes more compact with depth, and till, bedrock, or gravel may crop out before the maximum depth is reached. Any increase in bed resistance to erosion increases the stable k value and reduces the amount of additional upstream trenching. If the Willow River deepens as much as the k values indicate, new cycles of cutting will be initiated in tributary streams and eventually the entire Willow River basin will be trenched as a direct result of trenching in the Willow drainage ditch. Since the predicted maximum depth of Willow River is near its headwaters, it is possible that

[28] Hack (1957, pp. 70–71, 88–89) has shown that the long profile of a stream can be approximated by the equation $B = C - k \log_e L$, where B is the altitude in feet at a point along the stream, L is the river length in miles, and k and C are constants. The stream profile plotted on a semilogarithmic graph is a straight line or a series of straight lines. The constant k describes the change in altitude with changes in stream length. Streams with large k values have steep profiles and those with low k values gentle profiles.

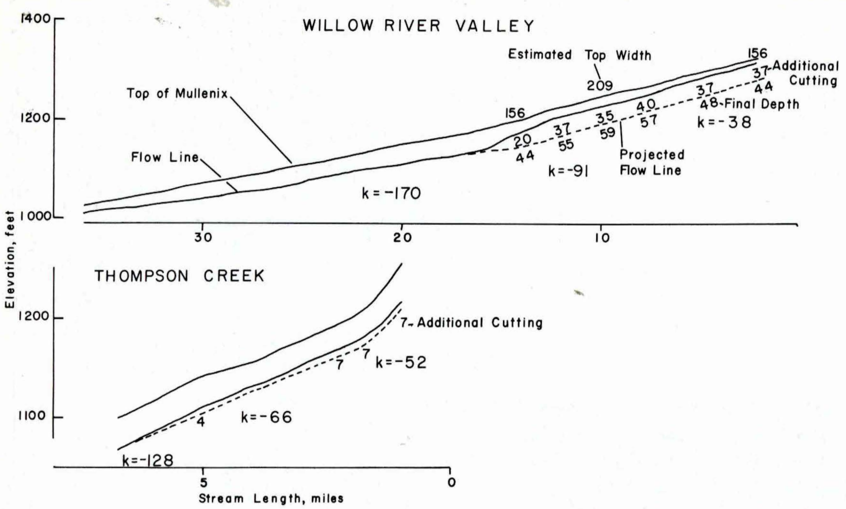


Figure 41.—**Predicted profiles of the Willow River and drainage ditch and Thompson Creek (estimated by projecting k values upstream).**

stream trenching and widening of tributaries will be more severe in the upper reaches of the Willow valley than in Thompson Creek or Magnolia watersheds.

Drop-inlet structures have been built in stream channels and other conservation practices have been installed on valley slopes in the Magnolia watershed. Overall stream stability should result. Active nickpoints not destroyed by sedimentation above the structures will continue to cut, but their upstream progress will be limited to the next upvalley structure.

Thompson Creek, on the other hand, has no major control measures in its watershed. Some reaches in Thompson Creek have either nickpoints 6 to 12 inches high or no bedload. This suggests that these reaches are unstable and may continue to cut. But if the Willow drainage ditch at the mouth of Thompson Creek is stable, the amount of upstream changes in Thompson Creek can be predicted. If in its lower reaches the stream has a stable k value of —128, the k value of the Mullenix in these reaches, the stream should cut about 4 feet at mile 5 before reaching a stable grade. The Mullenix and Turton k values (fig. 40) indicate that the stream will cut an additional 7 feet near its headwaters (fig. 41). Again the depth of cutting estimated should be considered a maximum because till is exposed in the streambed (fig. 11) and the tough compact till is more resistant to erosion than silty alluvium. Apparently the channel of Thompson Creek is nearly at grade and future changes will be small.

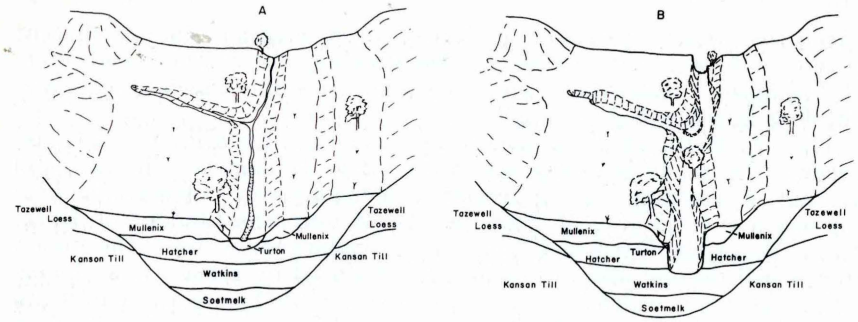
Nickpoints in the central reaches of Hatcher and Fox Branches (fig. 11) should continue to cut, but the present k values downstream from the nickpoints are larger than those upstream. This suggests that the nickpoints will be destroyed and that there will not be much additional trenching. Nickpoints 10 to 18 feet high occur near the head of many streams. They will continue to work headward and, if they start cutting into Tazewell loess, may become progressively deeper. The similarity between the present cycle and the Turton cycle suggests that the present erosion cycle will become gradually less severe in the extreme headwaters of Thompson Creek except where a stream cuts into Tazewell loess and develops into a valley-slope gully.

The top width of Thompson Creek and its tributaries will increase because the banks generally are steeper than 45 degrees. The rate and amount of widening will be greater in areas actively cutting. The final top width of tributaries of Thompson Creek may be a function of depth, but in Thompson Creek and Willow River valleys top width of the stream trench will depend also on the width influenced by stream flow. In extreme cases top width of the trench may double before the banks are stable, but the alluvial fill will not be completely removed by widening of the stream if downcutting is at or near completion. Proof of this is the relatively narrow area occupied by the Turton member (pl. 1); entrenchment during the Turton cycle was about as severe as in the present cycle. But if alluviation starts in Thompson Creek, the final top width will be reduced in proportion to the amount of filling.

The general similarity between past and present cycles of cutting and filling in the Thompson Creek, Magnolia, and Willow River valleys suggest that sedimentation will occur even though no control measures are started. Although there is little alluviation in the present stream channels, there is much evidence of postsettlement alluviation in the Thompson Creek channel. Downstream from the junction of Watkins Branch and Thompson Creek, 4 to 8 feet of sediment has been deposited over tin cans, bottles, barbed wire, and parts of farm machinery of modern design. There are small remnants of similar sediment throughout Thompson Creek 2 to 15 feet above the present channel bottom. These deposits probably were bars similar to those currently forming. They are discontinuous and cannot be correlated, but their presence is strong evidence that cut-and-fill processes in a stream are contemporaneous.

The few bars now being built by Thompson Creek are partly covered by weeds. Willow trees are stabilizing a bar deposit near the mouth of the valley. Grass is growing on a few of the silty bars in the headwaters of Turton Branch. Vegetation can stabilize the bars if downcutting is completed. Vegetation in a channel decreases water velocity (Ree and Palmer 1949, p. 101) and increases the chance of sedimentation on the bars during periods of heavy flow. Alluviation in the low-water channel does not necessarily follow since it depends on the interaction of width, depth, and velocity of flow.

Past and present trenching indicates that, if the streams are not controlled, the end result of the present trenching will be similar to that of the Turton cycle. The Turton cycle trenched 10 to 25 feet into the Mullenix fill sometime before 1710, and the greatest depth of trenching was about a mile from the headwaters. The Turton and the present trenching of Thompson Creek in its upper reaches are thus very similar (fig. 11). Most of the Turton fill had been deposited by the time Thompson Creek watershed was settled in 1850 (fig. 42A). The top of the Turton fill was the flood plain of Thompson Creek, and the stream flowed in a relatively flat-bottomed narrow trench 5 to 15 feet below the top of the Mullenix fill (fig. 42A). The scarps separating the flood plain from the top of the Mullenix fill apparently were vegetated and had slopes of 45 degrees or less. About 1880 Thompson Creek and its tributaries started to trench; by 1960 they had cut a U-shaped channel 16 to 35 feet below



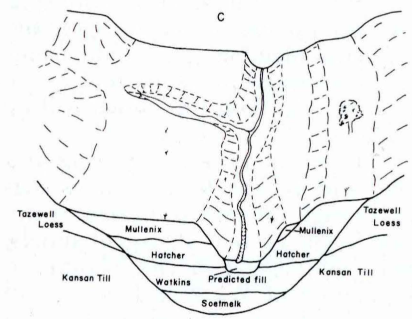


Figure 42.—A, Valley floor of Thompson Creek about 1850. B, Present valley floor. C, Predicted end result of the present trenching cycle.

the top of the Turton fill (fig. 42B), which is comparable to the amount of trenching during the Turton cycle.

Future changes in Thompson Creek cannot be predicted accurately but several lines of evidence suggest the following sequence of changes. The similarity between the k values at the base of the Mullenix and those of the present bed of Thompson Creek suggests that there will be only minor deepening of the channel. Once the bed is at grade, the banks will slump to slopes of about 45 degrees, the maximum slope of scarps separating the Turton and Mullenix fills and the Mullenix and Hatcher fills. In some areas top width of the stream trench may nearly double, but the relation between width and depth suggests that the average maximum top width will be less than 200 feet. The final top width may exceed 300 feet in areas where the stream migrates laterally against one side of the channel, but even this would not remove all the alluvial fill from the valley floor (pl. 1).

Filling followed cutting in the Mullenix and Turton cycles, and alluviation in the Thompson Creek trench appears likely once the stream is at grade. If the Willow drainage ditch is maintained, it is unlikely that alluviation in the Thompson Creek trench could destroy the present trenching cycle. More likely, alluviation will only partially fill the trench (fig. 42C). Widening of the trench will be reduced in proportion to the amount of filling. Eventually the stream will flow on a narrow flood plain between banks separating the latest fill from the older fills, and the landscape will have a configuration similar to the presettlement landscape (fig. 42A, C). I cannot estimate accurately the time required for the cycle to be completed, but the Turton cycle was completed in 250 years

or less and the present cycle may be completed in about the same length of time.

I suggest that control measures designed to reduce the effects of stream trenching in Thompson Creek may be of little long-range value if the stream is at or near grade. But they may be of considerable value in reducing the trenching predicted in the Willow River valley upstream from the Willow drainage ditch (fig. 40). It seems reasonable to concentrate control measures in areas of potential trenching rather than in areas that may be nearly through the trenching cycle.

The complex Recent cut-and-fill cycles in Thompson Creek are similar to cycles in large areas of Nebraska, Wyoming, Colorado, and Texas (Albritton and Bryan 1939, pp. 1430, 1446, 1448; Bailey 1935, pp. 341–345; Leopold and Miller 1954, pp. 15–46; Schultz et al. 1951, pp. 8–26; Scott 1963, pp. 11, 59–60). Although no direct correlation can be made between the sediments in the Thompson Creek valley and those in other areas, the similarity in the Recent history of these areas is evidence that erosion and sedimentation in the Thompson Creek valley are not unique. Many of the alluvial fills in the West and in western Iowa that have a complex cut-and-fill presettlement history are now trenched by modern cycles of erosion. It is possible that the present and past cycles of trenching are related. Although yet unproved, this relation suggests that watersheds with a complex cut-and-fill presettlement history have a high potential for stream trenching. Watershed use should be planned accordingly.

VALLEY-SLOPE GULLIES

Most valley-slope gullies have a vertical headwall, but it cannot be maintained to the drainage divide as indicated by the following lines of evidence. The slope of the gully floor increases as the distance of overland flow decreases (fig. 37B). According to this relation, the average channel gradient 50 feet from the drainage divide would be 60 percent (3,200 feet per mile) and at 10 feet, 260 percent (14,000 feet per mile). Because the shoulders and summits of the drainage divides are convex and the slopes are 2 to 12 percent, the gully floor will intersect the ground surface. Small gullies have a vertical headwall in calcareous loess but not in leached loess. Near the drainage divide, water flows mostly as a sheet. Under these conditions several small headwalls break away from the original headwall and there is an abrupt decrease in height (fig. 36, bottom). The headwall advances largely through the action of runoff water and not through sapping by ground water at the base.

These lines of evidence indicate that as the gully encroaches on the convex shoulders of the summits it will decrease in depth. Where the summits and shoulders and the gully floor are of leached loess, the headwall will be destroyed and the channel will be similar to the upper reaches of ephemeral valley-slope drainageways. Where the summit and shoulders are of calcareous loess, the headwall can maintain its vertical characteristics to within a few feet of the divide. Although the total headward advance varies with the properties of the loess, the end result will be about the same. As the drainage divide is approached, the area eroded by the gully will increase through sheet flow if calcareous loess extends to the divide. But once the cycle is completed and vegetation is reestablished, the eroded area will be similar to the head of many ephemeral drainageways on steep valley slopes today.

Downstream from the gully head, the final gully slope depends on the location of the gully on the valley side. If the gully has been produced by concentration of water along fence rows, field boundaries, or other cultural features on straight to convex valley slopes, little water flows over the sidewalls. Once the gully floor is stable, the slope of the gully sidewalls will decrease by slumping after alternate wetting and drying and freezing and thawing and by rainwash. The sidewalls will continue to erode from rainwash until vegetation becomes established, somewhere near a 45-degree slope. The final gully shape will be a deep trench that has steep side slopes in the central part and a concave-convex head. On the other hand, runoff water flows over the sidewalls of gullies formed in former valley-slope drainageways with well-defined channels. Initially a badlands type of topography may be formed (fig. 36, bottom), but eventually erosion will grade the valley sides to the stream channel. The general gully shape will not be much different from that of the original drainageway.

The end result of gullying is an extension of the drainage system. The final shape of each gully will eventually be that of the present nonentrenched valley-slope drainageways; several of these valley-slope drainageways may have been gullies at one time. In one sense, gully formation is part of the normal cycle of landscape development in the thick friable loess of western Iowa.

I cannot predict the time required for the gully cycle to be completed. Gullies currently active have been active for about 50 years. The gully cycle must be less than 800 years because the last major cycle of erosion of the valley slopes occurred between 1,100 and 250 years ago and there were no gullies when the area was settled.

The growth of valley-slope gullies can be stopped by diverting water elsewhere. A small dike thrown up by a moldboard plow diverts water and prevents additional upslope growth of the gully head. The loess on the banks is easily moved by a bulldozer; before much farmland is eroded, the gully can be filled and shaped into a drainageway—a practice common in the area.

An individual valley-slope gully is a management problem that is usually confined to one farm. With modern techniques, such gullies can be easily controlled; they should present no serious problem to continued agricultural use of the area.

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APPENDIX

Analytical data for Tazewell loess and the soils sampled are given in the following tables. Profile descriptions are included for those interested in the morphology of the soils sampled.

Laboratory Methods

All samples were collected from pits and air-dried. After drying, the samples were prepared by rolling or crushing and sieving to remove individual particles of gravel or rock more than 2 mm in diameter. All laboratory analyses were made on material passing the 2-mm sieve and are reported on an oven-dry basis.

The physical and chemical analyses were made in the SCS soil survey laboratory at Lincoln, Nebr.

Particle-size distribution was determined by the pipette method described by Kilmer and Alexander (1949), Kilmer and Mullins (1954), and Olmstead et al. (1930).

Moisture tension and saturation extracts were determined by methods described in Richards et al. (1954). The pH was determined by a glass electrode; soil to water ratio was 1:1. Organic carbon, cation-exchange capacity, and extractable calcium, magnesium, and hydrogen were determined by the methods described by Peech et al. (1947).

Total nitrogen was determined by the Kjeldahl digestion method (Assoc. Offic. Agr. Chem. 1945). Calcium carbonate equivalents were determined by measuring the volume of carbon dioxide evolved from samples treated with concentrated hydrochloric acid. Extractable sodium and potassium were determined by flame spectrophotometry.

Profile Descriptions

Somewhat poorly drained Sangamon paleosol (pl. 8, D. 83, 2.25):

TAZEWELL LOESS	
0–16 inches	Yellowish brown (10YR 5/4) silt loam; calcareous; abrupt boundary.
FARMDALE	
IIA1b 16–25 inches	Dark grayish brown (10YR 4/2) silt loam; few strong brown to yellowish red (7.5YR 5/6 to 5YR 5/6) mottles and pipestems; almost massive but breaks to very weak fine and medium granular structure; friable; weakly effervescent; gradual boundary.
IIA–Cb 25–37 inches	Dark brown (10YR 3/3) silt loam; few strong brown mottles; very weak medium blocky structure; friable; weakly effervescent; gradual boundary.
IIC1B 37–52 inches	Brown (10YR 4/3) silt loam; massive; friable; weakly effervescent; abrupt boundary.
SANGAMON	
IIIA2b 52–60 inches	Dark grayish brown (10YR 4/2) silty clay loam; weak fine platy to blocky structure; firm; matrix noncalcareous but contains a few carbonate nodules; clear boundary.

IIIB1b 60–70 inches	Dark grayish brown (10YR 4/2) silty clay loam; moderate fine blocky structure; few white silt grains on ped exteriors; firm; matrix noncalcareous; few carbonate nodules; clear boundary.
IIIB2b 70–124 inches	Grayish brown (2.5Y 5/2) silty clay loam to silty clay; moderate fine subangular blocky structure; many patchy white silt grains on ped exteriors; firm; gradual boundary.
IIIB3b 124–134 inches	Grayish brown (2.5Y 5/2) silty clay loam; few strong brown (7.5YR 5/6) mottles; weak to moderate fine to medium subangular blocky structure; firm; gradual boundary.
IIIC1b 134+ inches	Grayish brown (2.5Y 5/2) silt loam; many strong brown (7.5YR 5/6) and few yellowish brown (10YR 5/6) mottles; massive; noncalcareous loess, base at 180 inches.

Poorly drained Sangamon paleosol (SE¼sec. 18, T. 81 N., R. 42 W., Harrison County, Iowa):

TAZEWELL LOESS	
0–17 inches	Brown (10YR 5/3) calcareous loess; abrupt boundary.
FARMDALE	
IIAb 17–27 inches	Dark gray to dark grayish brown (10YR 4/1 to 4/2) silt loam; few brown mottles and black flecks of charcoal; massive; noncalcareous loess; abrupt wavy boundary.
SANGAMON	
IIIA21b 27–34 inches	Dark grayish brown (10YR 4/2) silt loam; massive but breaks to weak platy structure; very friable; noncalcareous loess; clear boundary.
IIIA22b 34–37 inches	Gray (10YR 5/1) silt loam; few dark mottles; weak platy structure; many nodules of underlying B horizon; friable; abrupt boundary.
IIIB21b 37–45 inches	Dark gray (5Y 4/1) silty clay loam; common olive brown (2.5Y 4/4) mottles; strong medium angular to subangular blocky structure; thick continuous clay skins; many patchy white silt grains on ped exteriors; firm; clear boundary.
IIIB22b 45–55 inches	Dark gray (5Y 4/1) silty clay; few olive brown (2.5Y 4/4) mottles; strong fine and medium angular blocky structure; thick continuous clay skins; firm; gradual boundary.
IIIB23b 55–71 inches	Dark gray to olive gray (5Y 4/1 to 4/2) silty clay loam; many olive brown (2.5Y 4/4) and few strong brown (7.5YR 5/6) mottles; moderate medium to fine subangular blocky structure; medium continuous clay skins; gradual boundary.
IIIB3b 71–96 inches	Gray (5Y 5/1) silty clay loam; many fine and medium brown (7.5YR 4/4) mottles; weak medium blocky structure; thin discontinuous clay skins; firm; gradual boundary.
IIIC1b 96+ inches	Dark grayish brown (2.5Y 4/2) silty clay loam; few to many fine grayer and browner mottles; massive; firm to friable; noncalcareous loess; base of section at 132 inches.

The following soils were discussed but not described in the body of this bulletin.

Profile M9, Monona silt loam: 2-percent gently convex slope; bluegrass sod in area containing much buckbrush and a few scattered young ash and mulberry trees; Mullenix geomorphic surface.

Described by G. H. Simonson and R. B. Daniels, 8/6/58.

Location: 475 feet south and 20 feet west of NE corner of SW¼SW¼sec. 7, T. 80 N., R. 42 W., Harrison County, Iowa.

A11 0–8 inches	Very dark brown (10YR 2/2) silt loam; grayish brown (10YR 5/2) dry; fine granular structure; friable; many fine grass roots; leached Tazewell loess; gradual boundary.
A12 8–12 inches	Very dark brown (10YR 2/2) silt loam; grayish brown (10YR 5/2) dry; few dark brown (10YR 3/3) spots; very dark brown to very dark grayish brown (10YR 2.5/2) crushed; moderate fine granular structure; friable; gradual boundary.
B2 12–21 inches	Brown to dark brown (10YR 4/3) silt loam; pale brown (10YR 6/3) dry; few to common very dark grayish brown to dark brown (10YR 3/2 and 10YR 3/3) peds, brown to dark brown (10YR 4/3) crushed; weak fine and medium subangular blocky structure breaking to weak fine granular structure; friable; common worm casts; thin discontinuous coatings on peds; gradual boundary.
B3 21–32 inches	Brown to dark brown (10YR 4/3) silt loam; few dark brown (10YR 3/3) coatings on peds; weak fine to medium subangular blocky structure; friable; common worm casts; gradual boundary.
C1 30–62 inches	Brown to dark brown (10YR 4/3 to 10YR 5/3) silt loam; few grayer and browner mottles; massive; friable; few worm casts; abrupt boundary.
C2 62–80 inches	Brown (10YR 5/3) silt loam; few fine grayish brown (2.5Y 5/2) and strong brown (7.5YR 5/6) mottles; massive; friable; calcareous.

Profile M14, Monona silt loam: 1-percent slightly convex slope; cultivated field; Mullenix geomorphic surface.

Described by G. H. Simonson and P. Ryan, 8/27/58, modified by R. B. Daniels.

Location: 300 feet east and 270 feet north of SW corner of SE¼NE¼sec. 14, T. 80 N., R. 43 W., Harrison County, Iowa.

Ap 0–6 inches	Very dark brown (10YR 2/2) silt loam; dark grayish brown (10YR 4/2) dry; cloddy to massive structure; friable; leached Tazewell loess; clear boundary.
A1 6–12 inches	Very dark brown (10YR 2/2) silt loam; very dark grayish brown (10YR 3/2) dry; very dark grayish brown (10YR 3/2) crushed; weak to moderate fine granular structure; friable; common worm casts; gradual boundary.
B1 12–22 inches	Very dark grayish brown (10YR 3/2) silt loam; dark brown (10YR 4/3) dry; dark brown to very dark brown (10YR 2.5/3) crushed; weak fine to medium subangular blocky structure; friable; common worm casts; gradual boundary.
B2 22–31 inches	Dark brown (10YR 3/3) silt loam; brown to dark brown (10YR 4/3) crushed; weak medium subangular blocky structure; friable; common worm casts; gradual boundary.
B3 31–43 inches	Dark brown (10YR 4/3) silt loam; dark yellowish brown (10YR 4/4) crushed; weak medium subangular blocky structure; friable; common worm casts; gradual boundary.

C1 43–60 inches	Dark brown to dark yellowish brown (10YR 4/3, 4/4) silt loam; yellowish brown (10YR 5/4) crushed; very weak subangular blocky to massive structure; friable; gradual boundary.
C2 60–85 inches	Yellowish brown (10YR 5/4) silt loam; few strong brown (7.5YR 5/6) and grayer mottles; massive; friable.

Profile M15, Monona silt loam, slightly eroded phase: 2-percent convex slope; cultivated field.

Described by G. H. Simonson, 8/11/58.

Location: 212 feet north and 292 feet west of SE corner of SE¼SW¼sec. 18. T. 80 N., R. 42 W., Harrison County, Iowa.

Ap 0–7 inches	Very dark brown (10YR 2/2) silt loam; grayish brown (10YR 5/2) dry; moderate fine granular structure; friable; leached Tazewell loess; clear boundary.
A12 7–11 inches	Very dark brown (10YR 2/2) silt loam; dark grayish brown to grayish brown (10YR 4.5/2) dry; very dark brown to very dark grayish brown (10YR 2.5/2) crushed; very weak medium subangular blocky structure; friable; gradual boundary.
B2 11–18 inches	Dark brown (10YR 3/3) silt loam; brown (10YR 5/3) dry; dark brown (10YR 3.5/3) crushed; weak to moderate fine subangular blocky structure; friable; thin discontinuous coatings on peds; gradual boundary.
B3 18–27 inches	Dark brown (10YR 3.5/3) silt loam; dark brown to brown (10YR 4/3) crushed; weak medium subangular blocky structure; friable; diffuse boundary.
C1 27–40 inches	Very dark brown (10YR 4/3) silt loam; massive; few vertical faces; friable; diffuse boundary.
C2 40–80 inches	Brown (10YR 5/3) silt loam; few browner and grayer mottles; massive; friable; abrupt boundary.
C3 80+ inches	Brown (10YR 5/3) silt loam; common grayer and browner mottles; massive; friable; calcareous loess.

Profile M16, Monona silt loam, slightly eroded phase: 1- to 2-percent convex slope; cultivated field.

Described by G. H. Simonson.

Location: 212 feet south and 159 feet west of NE corner of SW¼SE¼sec. 8, T. 79 N., R. 43 W., Harrison County, Iowa.

Ap 0–7 inches	Very dark brown to very dark grayish brown (10YR 2.5/2) silt loam; grayish brown (10YR 5/2) dry; very dark grayish brown (10YR 3/2) crushed; fragmental breaking to very weak fine granular structure; friable; leached Tazewell loess; clear boundary.
A12 7–11 inches	Dark brown (10YR 3/3) silt loam; brown to grayish brown (10YR 5/3) dry; dark brown (10YR 3/3) crushed; many very dark grayish brown to very dark brown (10YR 2.5/2) worm casts; weak fine subangular blocky structure breaking to fine granular structure; friable; gradual boundary.

B2 11–21 inches	Dark brown (10YR 3/3) silt loam; grayish brown to brown (10YR 4.5/3) dry; dark yellowish brown (10YR 3/4) crushed; thin discontinuous coatings; many very dark brown to dark brown (10YR 2.5/2.5) worm casts; weak fine subangular blocky structure breaking to fine granular structure; friable; gradual boundary.
B3 21–33 inches	Dark yellowish brown (10YR 3/4) silt loam; dark yellowish brown (10YR 3.5/4) crushed; many worm casts; weak fine and medium subangular blocky structure breaking to weak fine granular structure; friable; thin discontinuous coatings on peds; gradual boundary.
C1 52+ inches	Brown (10YR 5/3) silt loam; common fine indistinct grayer and browner mottles; many fine soft iron-manganese concretions; massive; friable; calcareous Tazewell loess.

Profile M2, Monona silt loam: 7-percent convex slope, southeastern exposure; 50-foot-square grassy site in area of about equal amounts of oak and walnut trees and bluegrass; Hatcher geomorphic surface.

Described by G. H. Simonson and R. B. Daniels.

Location: 750 feet east and 310 feet north of south center of sec. 18, T. 80 N., R. 42 W., Harrison County, Iowa.

AO +1 inch to 0	Partially decayed leaves; many fibrous grass roots; mixture of organic and mineral matter in lower part; abrupt boundary.
A11 0–4 inches	Very dark gray (10YR 3/1) silt loam; gray (10YR 5/1) dry; many roots; moderate fine granular structure; friable; leached Tazewell loess; clear boundary.
A12 4–10 inches	Very dark grayish brown (10YR 3/2) silt loam; grayish brown (10YR 5/2) dry; dark grayish brown (10YR 4/2) crushed; moderate fine subangular blocky structure breaking to fine granular structure; friable; thin discontinuous coatings on peds; common concentrations of bleached silt grains on ped exteriors; clear boundary.
B2 10–18 inches	Dark yellowish brown (10YR 3/4) silt loam; yellowish brown (10YR 5/4) dry; brown to dark brown (10YR 4/3) crushed; weak fine and medium subangular blocky structure; friable; thin coatings in larger pores; few bleached silt grains on peds; gradual boundary.
B3 18–35 inches	Brown to dark brown (10YR 4/3) silt loam; brown to dark brown (10YR 4/3) crushed; very weak medium and coarse subangular blocky structure; friable; gradual boundary.
C1 35–53 inches	Brown (10YR 5/3) silt loam; brown (10YR 5/3) dry; few grayer and browner mottles; massive; friable; abrupt boundary.
C2 53+ inches	Brown (10YR 5/3) silt loam; few grayer and browner mottles; massive; friable; calcareous Tazewell loess.

Profile M3, Monona silt loam: Upper part of 25-percent convex slope, eastern exposure; field of mature oak and young elm with ground cover of mixed brush and bluegrass; Hatcher geomorphic surface.

Described by G. H. Simonson, 9/28/59.

Location: 948 feet east and 360 feet north of SW corner of SW¼NE¼sec. 18, T. 80 N., R. 42 W., Harrison County, Iowa.

AO 1 inch to 0	Partially decayed leaves and twigs; abrupt boundary.
A1 0–4 inches	Very dark brown (10YR 2/2) silt loam; dark gray (10YR 3.5/1) dry; few spots of very dark grayish brown (10YR 3/2) evident when crushed; moderate fine granular structure that appears to be predominantly casts of earthworms and other fauna; friable; many fibrous roots; leached Tazewell loess; clear boundary.
B2 4–10 inches	Mixed very dark grayish brown (10YR 3/2) and dark grayish brown (10YR 4/2) silt loam; dark grayish brown (10YR 4.2) and grayish brown (10YR 5/2) dry; weak fine subangular blocky structure; friable; many worm casts; matrix leached but carbonate concretions common; clear wavy boundary.
B3 10–15 inches	Brown (10YR 4.5/3) silt loam; common very dark grayish brown (10YR 3/2) worm casts; weak medium subangular blocky structure; friable; calcareous; clear boundary.
C1 15–28 inches	Brown (10YR 5/3) silt loam; very weak subangular blocky to massive structure; friable; calcareous; common worm casts; diffuse boundary.
C2 28+ inches	Brown (10YR 5/3) silt loam; few fine yellow brown (10YR 5/6) mottles; massive; friable; few worm casts; calcareous.

Profile M4, Monona silt loam: Lower part of 20-percent convex slope, eastern exposure; field of mature white oak, hackberry, and young elm with thin undergrowth of brush; Hatcher geomorphic surface.

Described by G. H. Simonson, 9/29/59.

Location: 1,090 feet east and 360 feet north of SW corner of SW¼SE¼sec. 18, T. 80 N., R. 42 W., Harrison County, Iowa.

AO 1 inch to 0	Partially decayed leaves and twigs; abrupt boundary.
A1 0–5 inches	Black (10YR 2/1) silt loam; dark gray (10YR 4/1) dry; many fibrous roots; moderate fine granular structure that appears to be primarily worm casts; friable; leached Tazewell loess; gradual boundary.
B2 5–9 inches	Mixed very dark gray (10YR 3/1) and very dark grayish brown (10YR 3/2) silt loam; dark gray (10YR 4/1) and dark grayish brown (10YR 4/2) dry; weak to moderate fine subangular blocky structure; friable; common worm casts; common gray silt grains on ped exteriors; matrix leached but contains a few carbonate concretions; clear boundary.
B3 9–14 inches	Dark grayish brown (10YR 4/2) silt loam; few spots of very dark gray (10YR 3/1); weak medium subangular blocky structure; friable; common worm casts; few gray silt grains on ped exteriors; matrix leached but contains a few carbonate concretions; abrupt wavy boundary.
C1 14–24 inches	Brown (10YR 5/3) silt loam; few spots of dark grayish brown (10YR 4/2); very weak medium subangular blocky structure; calcareous; many carbonate concretions; diffuse boundary.
C2 24+ inches	Brown (10YR 5/3) silt loam; few yellowish brown (10YR 5/6) mottles; massive; friable; few worm casts; calcareous Tazewell loess.

Profile M5, Monona silt loam: 3-percent convex slope; field of mature and young elm with sparse ground cover of brush; Hatcher geomorphic surface.

Described by G. H. Simonson, 9/30/59.

Location: 468 feet east and 425 feet north of SW corner of SW¼SE¼sec. 18, T. 80 N., R. 42 W., Harrison County, Iowa.

AO 1 inch to 0	Partially decayed leaves and twigs.
A1 0–4 inches	Black (10YR 2/1) silt loam; very dark gray (10YR 3/1) dry; weak very fine granular structure that appears to be mainly droppings of small fauna; very friable; many light gray silt grains apparent when dry; leached Tazewell loess; clear boundary.
A12 4–8 inches	Very dark gray (10YR 3/1) silt loam; dark gray (10YR 4/1) dry; very dark grayish brown (10YR 3/2) crushed; weak fine subangular blocky structure with a definite tendency to platiness in areas; friable; many droppings of small fauna, including common worm casts; many light gray silt grains apparent when dry; clear boundary. This horizon appears to have some characteristics of an incipient A2.
B1 8–14 inches	Mixed very dark grayish brown (10YR 3/2) and dark brown (10YR 3/3) silt loam; dark grayish brown (10YR 4/2) crushed; moderate fine subangular blocky structure; friable; light gray silt grains in patches and prominent on ped surfaces when dry; common worm casts; gradual boundary.
B2 14–22 inches	Dark brown (10YR 3/3) silt loam; dark brown (10YR 4/3) ped interiors; moderate fine subangular blocky structure; friable; few light gray silt grains on ped surfaces; few worm casts; gradual boundary.
B3 22–36 inches	Dark yellowish brown (10YR 4/4) silt loam; weak medium subangular blocky structure; friable; diffuse boundary.
C1 36–60 inches	Dark brown (10YR 4/3) silt loam; few patches of brown (10YR 5/3); weak medium subangular blocky to massive structure; friable; diffuse boundary.
C2 60–86 inches	Brown (10YR 5/3, 5/4) silt loam; few grayer mottles; massive; friable; clear wavy boundary.
C3 86+ inches	Brown (10YR 5/3) silt loam; few grayer and yellowish brown mottles; massive; friable; calcareous.

Profile M6, Monona silt loam: Upper part of 11-percent convex slope, western exposure; stand of large and small elm trees and some hackberry; Hatcher geomorphic surface.

Described by G. H. Simonson, 9/30/59.

Location: 360 feet east and 425 feet north of SW corner of SW¼SE¼sec. 18, T. 80 N., R. 42 W., Harrison County, Iowa.

AO 1½ inches to 0	Partially decayed leaves and twigs.
A11 0–3½ inches	Very dark gray (10YR 3/1) silt loam; dark gray (10YR 4/1) dry; very fine weak granular structure that appears to be mostly small fauna droppings and earthworm casts; very friable; leached Tazewell loess; clear boundary.

A12 3½–6 inches	Very dark grayish brown (10YR 3/2) silt loam; spots of very dark gray (10YR 3/1) common; dark grayish brown (10YR 4/2) dry; weak fine granular structure with slight tendency to platiness in places; friable; few light gray silt grains apparent when dry; many small fauna droppings and common worm casts; clear boundary.
B21 6–12 inches	Dark brown (10YR 3/3) silt loam; dark yellowish brown (10YR 3/4) ped interiors; moderate fine subangular blocky structure; friable; light gray patchy silt grains on peds prominent when dry; gradual boundary.
B22 12–22 inches	Dark yellowish brown (10YR 3/4) silt loam; dark yellowish brown (10YR 4/4) ped interiors; weak to moderate medium subangular blocky structure; friable; few worm casts; gradual boundary.
B3 22–40 inches	Dark brown (10YR 3/4) silt loam; dark yellowish brown (10YR 4/4) crushed; very weak medium subangular blocky structure; friable; diffuse boundary.
C1 40–52 inches	Brown (10YR 5/3) silt loam; few to common grayer and yellowish brown mottles; massive; friable; abrupt boundary.
C2 52+ inches	Brown (10YR 5/3) silt loam; common grayer and yellowish brown mottles; massive; friable; calcareous.

Profile M7, Monona silt loam: 15-percent convex slope, western exposure; stand of mature oak, walnut, and basswood, completely shaded, and good stand of young trees, ground cover mostly weeds; Hatcher geomorphic surface.

Described by G. H. Simonson and R. B. Daniels, 7/29/58.

Location: 425 feet north and 212 feet east of south center of sec. 18, T. 80 N., R. 42 W., Harrison County, Iowa.

AO 2 inches to 0	Partially decomposed leaves and bark; many fibrous roots; fine granular structure in lower part; clear boundary.
A11 0–5 inches	Very dark grayish brown (10YR 3/2) silt loam; gray (10YR 5/1) dry; weak fine granular structure; many roots; friable; leached Tazewell loess; gradual boundary.
A12 5–10 inches	Very dark gray (10YR 3/1) silt loam; gray (10YR 5/1) dry; few to common spots of very dark grayish brown (10YR 3/2); weak medium subangular blocky structure breaking to fine granular structure; friable; common worm casts; clear lower boundary.
B2 10–16 inches	Brown to dark brown (10YR 4/3) silt loam; light brownish gray (2.5Y 6/2) dry; many very dark grayish brown (10YR 3/2) ped exteriors; weak fine to medium subangular blocky structure; friable; gradual boundary.
B3 16–21 inches	Brown to dark brown (10YR 4/3) silt loam; few very dark grayish brown to dark brown (10YR 3/2 and 10YR 3/3) coatings on ped exteriors; few grayish brown mottles; weak medium subangular blocky structure grading to massive; friable; abrupt boundary.
C1 21+ inches	Brown (10YR 4.5/3) silt loam; few grayer and yellowish red (5YR 4/6) mottles; massive; friable; calcareous; few to common tubular lime concretions less than 1 mm in diameter and few larger lime concretions.

Profile M8, Monona silt loam: Near base of 15-percent slope, western exposure; stand of large elm and hackberry, no understory; Hatcher geomorphic surface.

Described by G. H. Simonson, 9/30/59.

Location: 115 feet east and 430 feet north of SW corner of SW¼SE¼sec. 18, T. 80 N., R. 42 W., Harrison County, Iowa.

AO 1½ inches to 0	Partially decayed leaves and twigs.
A11 0–4 inches	Black (10YR 2/1) silt loam; very dark gray (10YR 3/1) dry; fine granular structure; very friable; many worm casts and small fauna droppings; leached Tazewell loess; clear boundary.
A12 4–8 inches	Very dark gray (10YR 3/1) silt loam; very dark grayish brown (10YR 3/2) crushed; dark gray (10YR 4/1) dry; moderate very fine subangular blocky structure breaking to fine granular structure; friable; common light gray silt particles apparent when dry; many worm and other fauna casts; gradual boundary.
B1 8–13 inches	Very dark grayish brown (10YR 3/2) silt loam; few spots of very dark gray (10YR 3/1); moderate fine subangular blocky structure; friable; common patchy light gray silt grains prominent on ped surfaces when dry; many worm casts; gradual boundary.
B2 13–22 inches	Dark brown (10YR 4/3) silt loam; dark yellowish brown (10YR 4/4) ped interiors; weak to moderate medium subangular blocky structure; friable; few light gray silt grains on peds; many worm casts; gradual boundary.
B3 22–36 inches	Dark yellowish brown (10YR 4/4) silt loam; dark yellowish brown (10YR 4/4) crushed; weak, medium subangular blocky structure; friable; common worm casts; diffuse boundary.
C1 36–48 inches	Brown (10YR 5/3) silt loam; few to common yellowish brown and grayer mottles; massive; friable; few worm casts; abrupt boundary.
C2 48+ inches	Brown (10YR 5/3) silt loam; common yellowish brown and grayer mottles; massive; friable; few worm casts; calcareous.

Profile M10, Monona silt loam: 5-percent slope, west-southwestern exposure; virgin area of bluegrass and buckbrush on a moderately convex interfluve summit near the break in gradient to a steep valley slope; Mullenix geomorphic surface.

Described by G. H. Simonson and R. B. Daniels, 10/19/59.

Location: 465 feet north and 320 feet west of SE corner of SW¼SW¼sec. 7, T. 80 N., R. 42 W., Harrison County, Iowa.

A1 0–4 inches	Very dark brown (10YR 2/2) silt loam; very dark grayish brown (10YR 3/2) crushed; moderate fine granular structure; friable; many fine worm casts, mainly as individual pellets; many fine fibrous roots; noncalcareous Tazewell loess; gradual boundary.
B1 4–8 inches	Mixed very dark grayish brown (10YR 3/2) and dark brown (10YR 3/3) silt loam; dark brown (10YR 3/3) crushed; weak to moderate fine subangular blocky structure; friable; many worm casts, both in strings and as individual pellets; many roots; gradual boundary.
B2 8–13 inches	Dark brown (10YR 3/3) silt loam; few very dark grayish brown (10YR 3/2) spots; weak fine subangular blocky structure; friable; many distinct worm casts; common roots; gradual boundary.
B3 13–19 inches	Dark yellowish brown (10YR 3/4) silt loam; dark brown to brown (10YR 4/3) crushed; few very dark grayish brown and dark brown (10YR 3/2, 3/3) worm casts; very weak medium subangular blocky structure breaking to very fine granular structure that appears to be mostly worm-cast pellets; friable; many worm casts; common roots; clear boundary.
C1 19–25 inches	Dark brown to brown (10YR 4/3) silt loam; dark brown (10YR 4/3) crushed; massive but breaks to very fine individual worm-cast pellets; very friable; many worm casts; abrupt boundary.
C2 25+ inches	Brown (10YR 5/3) silt loam; brown (10YR 5/3) crushed; massive; friable; common worm casts; few fine carbonate aggregates; calcareous Tazewell loess.

Profile M11, Monona silt loam: 18-percent slightly convex slope, western exposure; site is on lower third of valley slope, just below break in gradient to "cat-stepped" steeper upper slope, in area of tall native grasses, mostly big bluestem, on boundary of a downslope stand of young timber; Mullenix geomorphic surface.

Described by G. H. Simonson and R. B. Daniels, 10/20/59.

Location: 460 feet north and 632 feet west of SE corner of SW¼SW¼sec. 7, T. 80 N., R. 42 W., Harrison County, Iowa.

A11 0–6 inches	Very dark grayish brown (10YR 3/2) silt loam; very dark grayish brown (10YR 3/2) crushed; weak fine subangular blocky structure breaking to moderate fine granular structure; friable; common worm casts; noncalcareous Tazewell loess; gradual boundary.
A12 6–11 inches	Very dark grayish brown (10YR 3/2) silt loam; very dark grayish brown (10YR 3/2) crushed; weak fine subangular blocky structure breaking to granular structure; friable; common worm casts; abrupt wavy boundary.
B1 11–19 inches	Very dark grayish brown (10YR 3/2) silt loam; common very dark grayish brown (10YR 3/2) worm casts; weak medium subangular blocky structure; very friable; many worm casts; calcareous; gradual boundary.
C1 19–29 inches	Grayish brown (10YR 5/2) silt loam; weak medium subangular blocky structure breaking to fine granular structure; very friable; many worm casts; calcareous; diffuse boundary.
C2 29+ inches	Brown (10YR 5/3) silt loam; very weak medium subangular blocky structure grading to massive with depth; very friable; crumbles easily because of common worm-cast pellets; calcareous.

Profile M12, Monona silt loam: 7-percent convex slope, northeastern exposure; stand of oak, walnut, elm, and cedar and understory of buckbrush, gooseberry, and sumac with bluegrass in the few small openings; Hatcher geomorphic surface.

Described by G. H. Simonson and R. B. Daniels, 8/7/58.

Location: 475 feet south and 530 feet west of NE corner of SE¼SW¼sec. 5, T. 79 N., R. 43 W., Harrison County, Iowa.

A11 0–5 inches	Black (10YR 2/1) silt loam; gray (10YR 5/1) dry; moderate fine granular structure; friable; many tree and grass roots; leached Tazewell loess; clear boundary.
A12 5–10 inches	Very dark brown (10YR 2/2) silt loam, grayish brown (10YR 5/2) dry; few very dark grayish brown (10YR 3/2) spots; very dark brown (10YR 2/2) crushed; moderate fine subangular blocky structure breaking to fine granular structure; friable; common tree roots; bleached silt-grain coatings on peds prominent when dry; gradual boundary.
B2 10–18 inches	Dark brown (10YR 3/3) silt loam; pale brown (10YR 6/3) dry; few very dark grayish brown (10YR 3/2) spots; dark brown (10YR 3.5/3) crushed; moderate fine subangular blocky structure; friable; common tree roots; few worm casts; gradual boundary.
B3 18–26 inches	Brown to dark brown (10YR 4/3) silt loam; few spots of dark brown to very dark grayish brown (10YR 3/3, 3/2); weak medium to fine subangular blocky structure; friable; few tree roots; gradual boundary.
C1 26–71 inches	Brown to dark brown (10YR 4/3) silt loam; few faint grayer and browner mottles; massive; friable; abrupt boundary.
C2 71+ inches	Brown (10YR 5/3) silt loam; few faint grayer and browner mottles; massive; friable; calcareous.

Profile M13, Monona silt loam: 15-percent slope, northeastern exposure; partly timbered bluegrass pasture (about 25 percent stand of oak, walnut, elm, and ash) with buckbrush, gooseberry bushes, and weeds scattered throughout; Hatcher geomorphic surface.

Described by G. H. Simonson and R. B. Daniels, 10/8/58.

Location: 370 feet east of NW corner of NE¼SE¼sec. 8, T. 79 N., R. 43 W., Harrison County, Iowa.

A1 0–8 inches	Black (10YR 2/1) silt loam; dark gray (10YR 4/1) dry; very dark gray (10YR 3/1) crushed; moderate fine to medium granular structure; friable; leached Tazewell loess; gradual boundary.
B2 8–16 inches	Very dark grayish brown (10YR 3/2) silt loam; dark grayish brown (10YR 4/2) dry; many spots of black (10YR 2/1) and dark brown (10YR 3/3); very dark grayish brown (10YR 3/2) crushed; weak fine subangular blocky structure; friable; many worm casts; gradual boundary.
B3 16–25 inches	Dark brown (10YR 3/3) to dark yellowish brown (10YR 4/4) silt loam; brown (10YR 5/3) to pale brown (10YR 6/3) dry; dark yellowish brown (10YR 4/4) crushed; weak fine to medium subangular blocky structure; friable; many worm casts; gradual boundary.

C1 25–36 inches	Dark brown (10YR 4/3) silt loam; brown (10YR 5/3) crushed; massive to very weak medium subangular blocky structure; friable; common worm casts; leached; abrupt boundary.
C2 36+ inches	Brown (10YR 5/3) silt loam; few indistinct grayer and browner mottles; friable; few to common worm casts; calcareous.

Profile M18, Monona silt loam, moderately eroded phase: 7-percent sharply convex slope across ridge crest; field of sweetclover; Mullenix geomorphic surface.

Described by G. H. Simonson and R. B. Daniels, 9/16/58.

Location: 100 feet south and 240 feet east of NW corner of SW¼SE¼sec. 7, T. 80 N., R. 42 W., Harrison County, Iowa.

Ap 0–6 inches	Very dark grayish brown (10YR 3/2) silt loam; grayish brown (10YR 5/2) dry; few spots of dark brown (10YR 3/3); fragmental structure breaking to weak fine granular structure; friable; leached Tazewell loess; abrupt boundary.
B2 6–12 inches	Dark brown (10YR 3/3) silt loam; brown (10YR 5/3) dry; few spots of very dark grayish brown (10YR 3/2); weak fine subangular blocky structure breaking to weak fine granular structure; friable; many worm casts; gradual boundary.
B3 12–23 inches	Dark brown to brown (10YR 4/3) silt loam; light yellowish brown (10YR 6/4) dry; few spots of dark brown (10YR 3/3), dark brown to brown (10YR 4/3) crushed; weak fine subangular blocky structure; friable; gradual boundary.
C1 23–38 inches	Dark brown to brown (10YR 4/3, 10YR 5/3) silt loam; massive with tendency to weak medium angular blocky structure; friable; common worm casts; abrupt wavy boundary.
C2 38+ inches	Brown (10YR 5/3) silt loam; few grayer and browner mottles; massive; friable; few worm casts; calcareous Tazewell loess.

Profile M17, Monona silt loam, moderately eroded phase: 8-percent slightly convex slope, southwestern exposure; sweetclover seeding in oats stubble; Mullenix geomorphic surface.

Described by G. H. Simonson, 9/11/58.

Location: 554 feet west and 225 feet north of SE corner of SW¼SE¼sec. 8, T. 79 N., R. 43 W., Harrison County, Iowa.

Ap 0–7 inches	Very dark grayish brown (10YR 3/2) silt loam; few spots of dark and very dark brown (10YR 3/3, 2/2); grayish brown (10YR 5/2) dry; fragmental to massive; friable; leached post-Tazewell Farmdale loess; abrupt boundary.
B2 7–17 inches	Dark brown to dark yellowish brown (10YR 3/3, 3/4) silt loam; light yellowish brown (10YR 6/4) dry; brown to dark brown (10YR 4/3) crushed; weak fine subangular blocky structure; friable; many worm casts; diffuse boundary.
B3 17–26 inches	Brown to dark brown (10YR 4/3) silt loam; weak medium subangular blocky structure; friable; common worm casts; gradual boundary.

C1 26–38 inches	Dark yellowish brown (10YR 4/4) silt loam; few yellowish brown (10YR 5/4) and brown (7.5YR 4/4) medium mottles; massive; friable; few vertical cleavage faces; few to common worm casts; clear boundary.
C2 38+ inches	Brown to yellowish brown (10YR 5/3, 5/4) silt loam; massive; friable; calcareous loess; few lime concretions.

Profile M20, Monona silt loam, severely eroded phase: 14-percent slightly convex slope, northeastern exposure; cultivated field; Mullenix geomorphic surface.

Described by G. H. Simonson, 9/11/58.

Location: 265 feet north and 132 feet west of SW corner of SE¼SE¼sec. 8, T. 79 N., R. 43 W., Harrison County, Iowa.

Bp 0–8 inches	Brown to dark brown (10YR 4/3) silt loam; common spots of very dark grayish brown (10YR 3/2); light yellowish brown (10YR 6/4) dry; massive; friable; leached Tazewell loess; abrupt boundary.
B3 8–20 inches	Dark yellowish brown (10YR 4/4) silt loam; light yellowish brown (10YR 6/4) dry; common fine grayish brown (2.5Y 5/2) and strong brown (7.5YR 5/6) mottles; common fine black soft manganese concretions; very weak medium blocky structure to massive; friable; gradual boundary.
C1 20–44 inches	Variegated brown (7.5YR 4/4) and grayish brown (2.5Y 5/2) silt loam; common strong brown (7.5YR 5/6) mottles; massive; friable; leached; abrupt boundary.
C2 44+ inches	Variegated brown (7.5YR 4/4) and grayish brown (2.5Y 5/2) silt loam; common strong brown (7.5YR 5/6) mottles; massive; friable; calcareous loess.

Profile M19, Monona silt loam, severely eroded phase: 15-percent convex slope; alfalfa field; Hatcher geomorphic surface.

Described by G. H. Simonson and R. B. Daniels, 9/16/58.

Location: 425 feet west and 430 feet south of NE corner of NE¼SW¼sec. 18, T. 80 N., R. 42 W., Harrison County, Iowa.

Bp 0–4 inches	Mixed very dark grayish brown (10YR 3/2) and brown to dark brown (10YR 4/3) silt loam; brown (10YR 5/3) dry; fragmental to platy structure; friable; leached Tazewell loess; abrupt boundary.
B3 4–13 inches	Brown to dark brown (10YR 4/3) silt loam; light yellowish brown (10YR 6/4) dry; weak medium subangular blocky structure; friable; common worm casts; gradual boundary.
C1 13–36 inches	Brown to dark brown (10YR 4/3) silt loam grading downward to brown (10YR 5/3); light yellowish brown (10YR 6/4) dry; massive; friable; few to common worm casts; leached; abrupt boundary.
C2 36+ inches	Brown (10YR 5/3) silt loam; few grayer and browner mottles; massive; friable; calcareous loess.

Profile I1, Ida silt loam: 25-percent slightly convex slope, western exposure; virgin area of native grasses, mostly big and little bluestem, on a small 10-foot-wide shelf between "catsteps" 6 to 18 inches high; Mullenix geomorphic surface or later.

Described by G. H. Simonson and R. B. Daniels, 10/19/59.

Location: 460 feet north and 495 feet west of SE corner of SW¼SW¼sec. 7, T. 80 N., R. 42 W., Harrison County, Iowa.

A1 0–6 inches	Very dark grayish brown (10YR 3/2) silt loam; dark grayish brown (10YR 4/2) crushed; grayish brown (10YR 5/2) dry; moderate fine granular structure; friable; many worm casts; many roots; calcareous Tazewell loess; clear boundary.
AC 6–12 inches	Dark brown (10YR 4/3) silt loam; common dark grayish brown (10YR 4/2) worm casts; few to common fine grayer and browner mottles; very weak medium subangular blocky structure breaking to granular structure; very friable; many worm casts; gradual boundary.
C1 12–20 inches	Brown (10YR 5/3) silt loam; common dark brown (10YR 4/3) worm casts; common fine grayish brown (2.5Y 5/2) and strong brown (7.5YR 5/6) mottles; massive; very friable; gradual boundary.
C2 20+ inches	Brown (10YR 5/3) silt loam; few fine faint grayer and browner mottles and few fine dark manganese concentrations; massive; friable; few to common worm casts; few small carbonate aggregates; few roots; calcareous.

Profile I3, Ida silt loam: 17-percent slightly convex slope, southwestern exposure; cultivated field; Mullenix geomorphic surface.

Described by G. H. Simonson, 9/11/58.

Location: 740 feet north and 580 feet east of SW corner of SW¼NW¼sec. 8, T. 80 N., R. 42 W., Harrison County, Iowa.

Cp 0–7 inches	Dark yellowish brown (10YR 4/4) silt loam; light yellowish brown (10YR 6/4) dry; few spots of dark brown (10YR 3/3); common yellowish brown (10YR 5/6) and grayish brown (2.5Y 5/2) mottles; massive; friable; calcareous Tazewell loess; few hard lime concretions; abrupt boundary.
C1 7–19 inches	Dark brown to brown (10YR 4/3) and (10YR 5/3) silt loam; common yellowish brown (10YR 5/6) and grayish brown (2.5Y 5/2) mottles; few fine soft manganese concretions; common dark brown to brown (10YR 4/3) worm casts; massive; friable; few carbonate concretions and threadlike concentrations; diffuse boundary.
C2 19+ inches	Variegated brown (10YR 5/3), brown (7.5YR 4/4), and strong brown (7.5YR 5/6) silt loam; common coarse grayish brown (2.5Y 5/2) mottles; common very dark brown to black concentrations and iron-manganese concretions; massive; friable; calcareous.

TABLE 10.—*Physical and chemical properties of Tazewell loess*

Location: 50 feet SW of NW corner of SW¼ sec. 17, T. 80 N., 42 W., Harrison County, Iowa

Formation	Depth (in.)	Horizon	Size class and particle diameter: Sand (2–0.05 mm)	Silt (0.05–0.002 mm)	Clay (<0.002 mm)	0.2–0.02 mm	0.02–0.002 mm	pH (1:1)	Organic carbon	C/N	Free iron (Fe_2O_3)	Carbonate as $CaCO_3$	Water content at 15 atm	Cation-exchange capacity (NH_4OAc)	Extractable cations: Ca	Mg	Exchange acidity	Na	K	Degree of base saturation: (NH_4OAc)	Sum of cations +H	Ca/Mg
			Pct.	Pct.	Pct.	Pct.	Pct.		Pct.		Pct.	Pct.	Pct.	Meq/100 g soil						Pct.	Pct.	
Tazewell loess	54–66	O&L	[1]4.3	75.7	20.0	53.8	26.0	6.9	0.16	5	1.3	<1	10.4	14.1	10.1	4.3	2.4	0.2	0.4	106	86	2.3
	72–96	O&L	[2]4.6	77.1	18.3	54.5	26.9	8.0	.16	6	1.6	4	10.5	14.0	16.1	4.9	.4	.2	.4	154	98	3.3
	204–228	D&U	[2]5.0	76.9	18.1	54.0	27.3	7.9	.16	7	1.4	7	10.3	12.9	19.5	4.4	<.1	.1	.6	191	100	4.4
	360–396	O&L	[2]3.3	79.1	17.6	57.2	25.0	8.0	.12	6	1.1	6	9.4	11.7	16.6	5.3	<.1	.1	.7	194	100	3.1
	720–737	O&L	[1]2.3	80.9	16.7	54.8	28.3	7.9	.24	8	1.0	6	7.9	11.0	14.3	3.7	.4	.2	.6	171	98	3.9
Farmdale	737–744	Ab	[1]2.5	75.8	21.7	48.1	30.2	7.7	.47	9	.7	1	9.8	15.0	13.7	3.1	1.6	.2	.6	117	92	4.4
	744–768	Cb	[1]2.9	75.3	21.8	49.3	28.8	7.8	.39	8	.8	<1	9.9	14.6	13.0	3.1	1.2	.2	.5	115	93	4.2
Sangamon paleosol.	798–822	Bb	[1]4.0	53.1	42.9	38.0	18.7	7.4	.14	4	1.5	<1	18.9	22.6	19.2	5.0	1.2	.3	.6	111	95	3.8

Location: 150 feet N of SW corner of SE¼ NE¼ sec. 4, T. 80 N., R. 42 W., Harrison County, Iowa

Formation	Depth (in.)	Horizon	Sand	Silt	Clay	0.2–0.02 mm	0.02–0.002 mm	pH	Organic carbon	C/N	Free iron	Carbonate as $CaCO_3$	Water content at 15 atm	Cation-exchange capacity	Ca	Mg	Exchange acidity	Na	K	(NH_4OAc)	Sum of cations +H	Ca/Mg
Tazewell loess	63–87	O&L	[1]4.1	74.6	21.3	50.1	28.3	7.0	0.17	6	1.8	<1	10.5	18.3	13.5	5.6	2.4	0.2	0.4	108	89	2.4
	151–175	O&U	[1]5.2	78.1	16.7	55.6	27.4	8.0	.14	4	1.4	6	9.3	16.2	25.9	5.5	.8	.2	.6	199	98	4.7
	288–312	O&U	[2]4.3	77.4	18.3	53.2	28.1	7.9	.14	7	1.0	5	9.4	16.1	23.1	6.1	.4	.1	.8	187	99	3.8
	468–492	O&U	[2]3.1	79.6	17.3	52.7	29.9	8.0	.12	7	1.1	8	9.3	15.3	27.0	5.9	<.1	.1	.8	221	100	4.6
	630–654	O&L	[1]2.3	80.1	17.6	53.3	29.0	7.9	.14	7	.8	1	9.5	16.5	13.5	5.3	<.1	.2	1.1	122	100	2.5
Farmdale	726–744	Ab	[1]2.6	73.7	23.7	47.7	28.3	7.7	.45	8	1.1	<1	10.4	19.5	16.8	4.1	1.2	.2	.8	112	95	4.1
Sangamon paleosol.	744–768	Ab	[1]3.0	74.0	23.0	46.4	30.3	7.7	.34	7	1.4	<1	10.2	18.8	16.1	3.9	1.6	.3	.7	112	93	4.1
	780–792	Bb	[1]3.2	71.8	25.0	45.5	29.5	7.7	.27	6	1.8	<1	10.8	18.3	15.3	3.2	1.6	.3	.6	106	92	4.8
	798–810	Bb	[1]3.0	61.6	35.4	38.1	26.5	7.4	.18	4	1.4	<1	15.7	20.0	16.6	4.0	2.5	.3	.6	108	90	4.2

Location: NW¼ SE¼ sec. 8, T. 79 N., E. 43 W., Harrison County, Iowa

Formation	Depth (in.)	Horizon	Sand	Silt	Clay	0.2–0.02 mm	0.02–0.002 mm	pH	Organic carbon	C/N	Free iron	Carbonate as $CaCO_3$	Water content at 15 atm	Cation-exchange capacity	Ca	Mg	Exchange acidity	Na	K	(NH_4OAc)	Sum of cations +H	Ca/Mg
Tazewell loess	60–84	O&U	[1]6.0	78.6	15.4	59.5	24.7	8.0	0.17	8	1.4	9	8.7	12.0	22.2	4.1	0.4	0.1	0.3	----------	98	5.4
	237–261	O&U	[1]4.6	79.0	16.4	55.3	28.0	8.0	.15	8	1.4	6	9.4	12.8	18.4	5.6	<.1	.1	.6	----------	100	3.3
	480–504	O&U	[1]4.3	79.4	16.3	58.2	25.2	8.0	.14	8	.9	7	8.5	11.8	20.3	4.4	<.1	.1	.6	----------	100	4.6
	720–744	O&L	[1]2.5	81.8	15.7	57.0	27.0	8.0	.14	8	.8	4	7.8	11.2	11.9	4.9	.8	.2	.7	----------	96	2.4

[1] Few to common smooth brown to black concretions (Fe-Mn?).

[2] Few to common smooth brown to black concretions (Fe-Mn?); trace of $CaCO_3$ concretions.

TABLE 11.—*Particle-size distribution and organic-carbon content of the De Forest formation in Thompson Creek watershed*

Section No.[1]	Member	Reaction	Depth below surface (inches)	Horizon and/or sample No.	Class and particle diameter							Organic carbon
					Sand	Silt					Clay	
					62 Microns	62–31 Microns	31–16 Microns	16–8 Microns	8–4 Microns	4–2 Microns	<2 Microns	
					Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	Mullenix	Noncalcareous	0–26	A1–1	0.3	19.6	34.8	12.0	5.9	2.2	25.2	2.84
		do.	26–50	B–2	.2	10.3	34.8	13.9	5.9	3.4	31.5	.68
		do.	50–108	C1–3	.1	15.3	37.7	12.6	5.8	3.4	25.1	.49
		Calcareous	108–166	4	.2	20.1	36.9	11.1	4.7	3.5	23.5	.39
		do.	202–238	5	.1	19.7	37.4	12.2	4.8	3.7	22.1	.32
	Hatcher	do.	292–296	6	.4	15.9	35.8	13.5	5.4	4.2	24.8	.45
		do.	296–351	7	.2	14.5	38.0	13.9	5.6	3.0	25.2	.39
	Watkins	do.	351–363	8	.4	18.9	36.1	12.3	5.1	3.2	24.0	.71
		do.	363–377	9	.1	26.1	39.9	8.2	3.8	2.3	19.6	.17
2	Mullenix	Noncalcareous	0–15	A1–1	1.5	23.2	37.9	8.2	4.1	3.4	21.7	1.76
		do.	15–62	B–2	1.2	33.5	31.8	7.3	3.4	3.1	19.7	1.41
		do.	62–108	C1–3	1.1	27.7	34.4	8.5	4.2	3.1	21.0	.79
		Calcareous	108–134	4	2.6	27.9	32.4	11.3	2.3	3.2	20.3	.86
		do.	153–180	5	2.2	20.9	32.0	11.9	4.8	4.2	24.0	1.28
	Hatcher	do.	180–216	6	.3	9.5	34.9	16.5	7.2	5.1	26.5	.53
		do.	216–256	7	.4	10.1	37.6	16.2	6.5	4.8	24.4	.44
3	Mullenix	Noncalcareous	0–6	A11–1	1.3	28.8	33.2	10.9	3.8	1.5	20.5	1.96
		do.	6–19	A12–2	.7	28.5	34.5	9.8	4.0	1.5	21.0	1.44
		do.	19–34	B–3	.6	21.7	39.9	10.2	4.3	1.5	21.8	.92
		do.	34–50	B–4	.8	20.9	38.7	11.1	4.7	2.4	21.4	.82
		Calcareous	50–80	C2–5	.8	24.1	37.1	9.7	5.0	2.8	20.5	1.28
		do.	80–110	6	.8	20.6	38.9	11.6	5.2	2.9	20.0	.62
		do.	110–148	7	1.2	25.4	37.3	9.7	2.9	2.9	20.6	.56
		do.	148–182	8	3.1	23.9	34.0	10.3	4.8	2.5	21.4	.50
	Hatcher	do.	182–314	9	.7	27.3	37.7	10.0	3.2	2.4	18.7	.12
		do.	314–320	10	.6	6.3	28.3	18.8	9.5	5.7	30.3	.60
	Watkins	do.	326–330	Bb–11	.6	9.8	33.6	16.1	8.6	5.9	25.4	1.68
		do.	330–391	12	4.9	26.2	35.5	8.9	3.0	2.4	19.1	.26
		do.	401–474	13	3.3	43.4	27.0	5.1	2.1	2.7	16.4	.24
4	Mullenix	Noncalcareous	0–20	A1–1	.1	26.5	34.8	10.3	4.5	2.3	21.5	1.61
		do.	20–72	B–2	.0	17.4	31.9	14.4	9.5	1.4	25.4	1.31
		do.	72–126	C1–3	.0	18.4	35.9	12.8	5.8	5.5	21.6	.74
		Calcareous	126–181	4	.1	23.7	38.5	10.7	4.3	2.4	20.3	.44
	Hatcher	do.	199–224	5	1.1	26.8	39.5	5.7	4.0	2.4	20.5	.82
		do.	224–253	6	.2	29.0	35.7	9.2	4.6	2.9	18.4	.68
	Watkins	do.	253–264	7	.0	7.6	28.3	16.1	8.3	5.3	34.4	1.01
		do.	264–303	8	.2	9.2	15.3	13.2	8.6	7.5	46.0	.35
		do.	303–319	9	5.0	32.9	28.6	7.4	3.6	2.0	20.5	.17

[1] Sections are located in Thompson Creek watershed (pl. 1) No. 1—E.56, 2.19; No. 2—D.42, 2.65; No. 3—B.31, 3.82; No. 4—A.52, 3.89.
[2] A buried B horizon.

TABLE 12.—*Dry density and shear strength of Tazewell loess*

Reaction and sample No.	Depth below modern surface	Dry density	Air-dry shear strength	Sand	Silt	Clay	Organic matter
	Ft.	*Lbs./cu. ft.*	*Psi*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Calcareous (O&U):							
1	8	83.1	170.9	1.4	83.6	15.0	0.32
2	19	86.0	168.5	.8	83.8	15.4	.31
3	29.5	89.4	174.8	.9	89.0	12.1	.32
4	24.0	90.0	130.3	1.2	89.3	9.5	.26
Noncalcareous (basal O&L):							
5	15	89.0	202.5	.9	87.0	12.1	.32

TABLE 13.—*Dry density and shear strength of selected samples from the De Forest formation*

[--- indicates not determined]

Sample No. and member	Depth below modern surface	Dry density	Shear strength		Sand	Silt	Clay	Organic matter
			Saturated	Air-dry				
	Ft.	*Lbs./cu. ft.*	*Psi*	*Psi*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1. Mullenix	8	87	1.0	158.0	2.1	83.4	14.5	0.54
2. Hatcher	15	88	1.5	310.0	4.6	79.3	16.1	.89
3. Mullenix	10	75	1.1	---	---	---	---	---
4. Soetmelk	35	74	1.2	---	---	---	---	---

TABLE 14.—*Distribution of Monona and Ida soils by geomorphic surface, slope gradient, and slope direction*

[Measurements from valley slopes below base of the upper leached zone]

Hatcher erosion surface

Slope gradient (percent)	Soil	Slope direction				Total
		North	South	East	West	
		Percent[1]	*Percent*[1]	*Percent*[1]	*Percent*[1]	
7	Monona	0.00	0.00	0.00	0.00	0.00
	Ida[2]	.74	.09	.15	.00	.98
11	Monona	2.82	4.09	1.13	3.81	11.85
	Ida	.27	.51	1.91	.82	3.51
15	Monona	3.21	1.37	2.83	5.87	13.28
	Ida	3.07	4.27	1.93	11.05	20.32
20	Monona	4.10	.39	2.99	6.74	14.22
	Ida	1.81	2.39	2.25	5.55	12.00
25	Monona	3.42	.00	6.30	1.46	11.18
	Ida	.13	1.36	1.24	.98	3.71
30	Monona	1.54	.00	2.85	.51	4.90
	Ida	.49	.00	1.73	.00	2.22
35	Monona	.49	.00	.00	.00	.49
	Ida	.16	.00	.54	.00	.85
40	Monona	.11	.00	.15	.00	.26
	Ida	.00	.00	.23	.00	.23
Total	Monona	15.69	5.85	16.25	18.39	56.18
	Ida	6.67	8.62	9.98	18.55	43.82
	Mullenix erosion surface					
7	Monona	0.00	0.00	0.00	0.00	0.00
	Ida	.74	1.21	.15	.00	2.10
11	Monona	1.18	3.33	2.17	5.14	11.82
	Ida	.19	5.55	.63	3.64	10.01
15	Monona	1.14	.16	2.57	1.42	5.29
	Ida	3.51	5.92	7.44	12.32	29.00
20	Monona	.26	.13	1.42	.33	2.14
	Ida	1.54	18.78	8.40	9.45	32.22
25	Monona	.94	.00	2.44	.00	3.38
	Ida	.00	.23	1.66	.00	1.89
30	Monona	.08	.00	.15	.00	.23
	Ida	.00	.26	1.55	.00	1.81
35	Monona	.00	.00	.00	.00	.00
	Ida	.00	.00	.11	.00	.11
40	Monona	.00	.00	.00	.00	.00
	Ida	.00	.00	.00	.00	.00
Total	Monona	3.60	3.62	8.75	6.89	22.86
	Ida	5.79	26.00	19.94	25.41	77.14

[1] Percent of total of each geomorphic surface.
[2] Includes Dow soils.

TABLE 15.—*Physical and chemical properties of Monona and Ida soils*

Depth (in.)	Horizon	Size class and particle diameter: Sand (2–0.05 mm)	Silt (0.05–0.002 mm)	Clay (<0.002 mm)	0.2–0.02 mm	0.02–0.002 mm	Quartz/ feldspar	pH (1:1)	Organic carbon	C/N	Free iron (Fe_2O_3)	Carbonate as $CaCO_3$	Water content at 15 atm	Cation-exchange capacity (NH_4OAc)	Extractable cations: Ca	Mg	Exchange acidity	Na	K	Degree of base saturation: (NH_4OAc)	Sum of cations +H	Ca/Mg
Profile M1, Monona silt loam																						
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*			*Pct.*		*Pct.*	*Pct.*	*Pct.*		*Meq/100 g soil*					*Pct.*	*Pct.*	
0–7	A11	[1] 3.0	73.1	23.9	49.5	26.3	3.1	6.0	2.55	12.1	1.4	---	11.5	22.9	16.6	4.0	7.4	<0.1	0.5	92	74	4.2
7–10	A12	[1] 2.6	73.9	23.5	49.9	26.6	---	6.1	1.62	11.2	1.4	---	10.5	19.1	12.8	3.9	6.6	<.1	.4	90	72	3.3
10–16	B21	[1] 2.2	73.3	24.5	48.1	27.4	4.2	6.2	.90	9	1.5	---	10.5	17.8	11.3	4.7	5.7	<.1	.4	92	74	2.4
16–24	B22	[1] 2.3	73.8	23.9	47.6	28.5	---	5.1	.69	9	1 6	---	9.8	17.1	8.4	4.3	9.0	.1	.3	77	59	2.0
24–42	B3	[1] 2.4	73.4	24.2	45.8	30.0	---	5.3	.42	---	1.8	---	10.4	17.8	10.7	4.9	7.0	.1	.3	90	70	2.2
54–70	C1	[1] 3.2	76.2	20.6	51.2	28.2	3.8	6.2	.19	---	1.8	---	9.8	17.3	11.8	5.0	4.1	.2	.4	100	81	2.4
92–105	C2	[2] 4.5	80.0	15.5	55.1	29.3	3.2	8.0	.12	---	1.4	6	8.6	15.4	21.0	5.8	<.1	.1	.4	---	100	3.6
Profile M2, Monona silt loam																						
0–4	A11	[1] 3.4	72.2	24.4	48.4	26.9	3.0	6.7	4.09	12.9	1.4	<1	14.6	28.9	24.0	5.2	4.9	<0.1	1.2	105	86	4.6
4–10	A12	[1] 2.6	71.7	25.7	47.8	26.5	---	6.7	1.25	10.7	1.7	<1	11.2	20.1	15.7	4.7	4.5	<.1	.6	104	82	3.3
10–18	B2	[1] 3.0	71.7	25.3	48.4	26.3	3.8	6.6	.68	10	1.8	<1	11.0	19.6	13.0	6.0	4.1	<.1	.5	99	83	2.2
18–35	B3	[1] 3.4	73.8	22.8	51.2	26.0	---	6.2	.31	8	1.8	---	10.6	17.8	10.9	6.2	4.1	<.1	.4	98	81	1.8
35–53	C1	[1] 5.2	74.9	19.9	56.0	23.7	---	6.4	.25	---	1.6	---	9.4	17.5	10.8	6.6	3.7	.1	.4	102	83	1.6
53–63	C2	[2] 5.8	77.1	17.1	57.1	25.1	4.2	7.9	.16	---	1.2	7	8.5	15.8	20.6	6.1	<.1	.1	.4	---	100	3.4
Profile M3, Monona silt loam																						
0–4	A1	3.8	71.9	24.3	52.0	23.3	---	7.5	3.20	12	1.2	<1	13.6	26.3	24.1	6.0	2.6	<0.1	1.6	120	92	4.0
4–10	B2	3.9	71.6	24.5	51.4	23.9	---	7.6	1.11	10	1.4	<1	11.1	21.2	19.3	5.4	2.4	<.1	1.1	122	91	3.6
10–15	B3	[2] 4.4	77.2	18.4	53.1	27.6	---	7.9	.61	10	1.3	8	9.8	17.1	23.6	4.4	<.1	<.1	.6	---	100	5.4
18–28	C1	[2] 4.7	77.5	17.8	55.7	26.0	---	8.0	.28	9	1.3	9	9.0	15.7	22.9	4.2	<.1	<.1	.5	---	100	5.4
34–40	C2	[2] 5.6	78.2	16.2	58.1	24.9	---	8.0	.19	---	1.3	12	8.7	14.5	24.7	4.8	<.1	<.1	.5	---	100	5.1
Profile M4, Monona silt loam																						
0–5	A1	[1] 4.2	72.7	23.1	56.4	20.2	---	7.3	5.15	14	0.8	<1	15.8	30.9	30.2	5.0	3.2	<0.1	1.2	118	92	6.0
5–9	B2	[1] 3.6	71.5	24.9	53.0	21.8	---	6.6	1.15	11	.8	<1	11.1	21.2	15.8	4.9	3.9	<.1	.8	101	85	3.2
9–14	B3	[1] 3.5	71.9	24.6	52.4	22.7	---	7.0	.78	9	.8	<1	11.2	20.3	15.8	5.8	2.6	<.1	.6	109	90	2.7
14–24	C1	[2] 4.3	75.1	20.6	55.3	23.3	---	7.8	.57	9	.8	8	9.7	16.7	26.6	4.7	<.1	<.1	.5	---	100	5.6
38–44	C2	[2] 4.3	79.3	16.4	58.7	24.3	---	7.9	.16	---	.7	10	8.7	14.4	24.2	4.2	<.1	.1	.4	---	100	5.8
Profile M5, Monona silt loam																						
0–4	A1	2.5	74.2	23.3	48.6	27.8	---	6.9	4.88	13	1.2	<1	15.3	29.4	26.7	4.5	6.0	<0.1	0.6	108	84	5.9
4–8	A12	2.5	74.8	22.7	49.6	27.5	---	5.7	2.04	12	1.4	---	10.7	20.9	14.2	3.5	8.4	<.1	.5	87	68	4.0
8–14	B1	2.6	74.6	22.8	46.9	30.2	---	5.4	1.32	11	1.5	---	10.4	18.3	10.9	3.6	7.2	<.1	.4	81	67	3.0
14–22	B2	2.2	72.9	24.9	45.9	29.1	---	5.7	.73	9	1.6	---	10.6	17.7	11.1	4.6	5.8	.1	.4	92	74	2.4
24–34	B3	2.2	74.3	23.5	46.5	29.9	---	5.8	.46	9	1.8	---	10.4	17.6	11.2	5.4	5.8	.1	.4	97	75	2.1
40–50	C1	2.9	73.6	23.5	44.3	32.0	---	6.1	.28	---	1.6	---	11.4	19.3	12.5	6.4	3.9	.1	.4	100	83	2.0
64–74	C2	[1] 3.0	77.2	19.8	52.1	27.9	---	6.4	.24	---	1.8	---	9.9	17.3	11.0	5.6	3.4	.2	.4	99	83	2.0

See footnotes at end of table.

TABLE 15.—*Physical and chemical properties of Monona and Ida soils*—Continued

Depth (in.)	Horizon	Size class and particle diameter: Sand (2–0.05 mm)	Silt (0.05–0.002 mm)	Clay (<0.002 mm)	0.2–0.02 mm	0.02–0.002 mm	Quartz/feldspar	pH (1:1)	Organic carbon	C/N	Free iron (Fe_2O_3)	Carbonate as $CaCO_3$	Water content at 15 atm	Cation-exchange capacity (NH_4OAc)	Extractable cations: Ca	Mg	Exchange acidity	Na	K	Degree of base saturation: (NH_4OAc)	Sum of cations +H	Ca/Mg
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*			*Pct.*		*Pct.*	*Pct.*	*Pct.*		*Meq/100 g soil*					*Pct.*	*Pct.*	
Profile M6, Monona silt loam																						
0–3½	A11	2.9	73.9	23.2	48.1	28.2	--------	7.1	4.63	12	1.3	<1	15.7	32.9	30.1	5.7	4.4	<0.1	1.3	113	89	5.3
3½–6	A12	3.0	73.7	23.3	48.9	27.4	--------	6.4	1.81	11	1.3	--------	11.7	21.8	16.2	4.8	6.2	<.1	.9	100	78	3.4
6–12	B21	2.8	71.8	25.4	47.0	27.5	--------	5.5	.70	10	1.6	--------	10.9	18.3	11.2	4.8	6.0	<.1	.6	91	73	2.3
12–22	B22	2.8	71.9	25.3	46.1	28.5	--------	4.7	.48	10	1.8	--------	10.7	18.5	7.5	4.6	10.3	<.1	.5	68	55	1.6
25–35	B3	3.0	74.3	22.7	50.8	26.2	--------	5.1	.36	9	1.7	--------	10.1	17.8	9.5	5.2	6.7	.1	.4	85	69	1.8
40–50	C1	4.3	72.8	22.9	48.8	27.8	--------	6.7	.24	--------	1.6	<1	11.4	20.4	13.4	7.9	3.1	.2	.4	107	88	1.7
60–70	C2	3.3	80.7	16.0	50.8	32.7	--------	7.9	.19	--------	1.2	8	9.8	16.3	25.3	6.6	<.1	.1	.4	--------	100	3.8
Profile M7, Monona silt loam																						
0–5	A11	[1]3.8	73.1	23.1	52.0	24.6	3.9	7.3	3.09	12.5	0.8	<1	13.3	27.6	24.9	6.0	2.5	<0.1	1.8	118	93	4.2
5–10	A12	[1]3.5	72.2	24.3	52.1	23.5	--------	7.4	1.30	11.6	.8	<1	11.2	22.0	17.4	5.6	2.0	<.1	1.5	111	92	3.1
10–16	B2	[1]3.5	71.7	24.8	50.6	24.5	3.5	7.4	.68	10	.8	<1	11.3	20.2	15.2	5.7	1.6	<.1	1.1	109	93	2.7
16–21	B3	[1]3.8	72.0	24.2	52.4	23.2	--------	7.5	.43	9	.9	<1	11.4	20.2	16.3	6.3	1.6	<.1	.8	116	94	2.6
21–33	C1	[2]4.9	75.3	19.8	55.6	24.3	3.5	7.9	.38	9	.6	7	8.8	16.7	22.3	5.5	.4	<.1	.5	--------	99	4.0
Profile M8, Monona silt loam																						
0–4	A11	[1]3.3	72.7	24.0	51.8	23.9	--------	7.2	4.25	12	1.0	<1	16.7	30.7	29.3	3.5	3.4	<0.1	0.9	110	91	8.4
4–8	A12	[1]4.2	71.0	24.8	51.9	23.0	--------	6.2	1.51	11	1.2	--------	11.0	21.6	15.5	4.0	5.8	<.1	.7	94	78	3.9
8–13	B1	[1]4.0	69.5	26.5	50.6	22.6	--------	5.3	.84	10	1.3	--------	11.0	18.9	12.2	3.8	6.5	<.1	.6	88	72	3.2
13–21	B2	[1]4.1	69.5	26.4	49.6	23.6	--------	5.8	.50	9	1.4	--------	10.8	18.8	12.5	4.8	5.0	<.1	.6	95	78	2.6
24–34	B3	[1]4.2	70.2	25.6	49.9	24.0	--------	5.8	.37	9	1.1	--------	11.5	19.6	12.6	5.6	4.3	<.1	.5	95	81	2.2
34–48	C1	[1]3.9	72.6	23.5	51.1	24.8	--------	6.4	.32	--------	1.0	--------	11.3	19.8	14.3	5.2	2.9	.1	.4	101	87	2.8
52–62	C2	[2]4.5	76.1	19.4	54.1	25.7	--------	7.8	.20	--------	.9	10	10.3	16.9	27.4	4.5	<.1	.1	.4	--------	100	6.1
Profile M9, Monona silt loam																						
0–8	A11	[1]2.5	72.1	25.4	47.8	26.7	3.0	5.8	2.10	10.3	1.6	--------	11.6	21.1	14.0	4.8	6.6	<0.1	0.5			
8–12	A12	[1]2.6	71.8	25.6	47.4	27.0	--------	6.0	1.71	9.6	1.6	--------	11.4	20.4	13.2	4.9	6.6	.1	.3			
12–21	B2	[1]2.4	72.8	24.8	46.3	28.9	3.8	6.0	1.06	10.0	1.7	--------	10.9	19.6	13.1	5.4	5.3	.1	.3			
21–32	B3	[1]2.8	73.4	23.8	46.0	30.2	--------	6.2	.63	9	1.7	--------	10.6	19.4	12.9	5.6	4.1	.1	.4			
30–62	C1	[1]2.9	78.0	19.1	52.3	28.6	--------	6.7	.23	--------	1.7	<1	9.4	16.6	11.4	5.3	3.3	.2	.3			
62–80	C2	[2]4.3	78.5	17.2	60.4	22.3	4.2	8.1	.13	--------	1.5	7	9.1	16.1	20.4	5.8	<.1	.1	.3			
Profile M10, Monona silt loam																						
0–4	A1	3.2	71.2	25.6	46.6	27.4	4.0	6.1	2.66	11	1.6	--------	13.4	23.4	15.2	5.2	6.5	<0.1	0.7	90	76	2.9
4–8	B1	3.0	71.5	25.5	45.2	29.1	--------	6.1	1.88	11	1.6	--------	12.2	22.8	14.1	5.2	6.7	.1	.4	87	75	2.7
8–13	B2	2.8	72.4	24.8	47.2	27.8	4.4	6.2	1.33	10	1.7	--------	11.3	21.0	13.1	5.4	5.0	.1	.4	90	79	2.4
13–19	B3	2.7	74.4	22.9	47.2	29.7	--------	6.4	.96	10	1.7	--------	10.8	19.4	12.8	5.4	4.1	.1	.4	96	82	2.4
19–25	C1	2.6	75.2	22.2	50.1	27.4	4.5	6.6	.72	10	1.6	<1	10.4	18.9	13.2	5.4	3.1	.1	.4	101	86	2.4
36–48	C2	[2]3.7	76.8	19.5	51.0	28.7	--------	7.9	.23	--------	1.5	12	10.3	16.9	26.8	5.7	<.1	.1	.4	--------	100	4.7

See footnotes at end of table.

TABLE 15.—*Physical and chemical properties*

Depth (in.)	Horizon	Size class and particle diameter: Sand (2–0.05 mm)	Silt (0.05–0.002 mm)	Clay (<0.002 mm)	0.2–0.02 mm	0.02–0.002 mm	Quartz/feldspar	pH (1:1)	Organic carbon	C/N
		Pct.	Pct.	Pct.	Pct.	Pct.			Pct.	
Profile M11,										
0–6	A11	4.5	73.0	22.5	57.0	20.3	--------	7.4	2.14	11
6–11	A12	4.2	74.1	21.7	54.6	23.5	--------	7.7	1.75	11
11–19	B1	[2] 4.5	75.2	20.3	54.3	24.9	--------	7.9	1.33	10
19–29	C1	[2] 4.4	76.6	19.0	55.4	25.0	--------	8.0	.78	10
29–40	C2	[2] 4.0	79.5	16.5	56.3	26.7	--------	8.0	.33	--------
Profile M12,										
0–5	A11	[1] 2.5	75.8	21.7	51.4	26.9	--------	6.5	3.43	12.1
5–10	A12	[1] 3.2	74.0	22.8	50.1	27.0	--------	6.5	1.56	10.6
10–18	B2	[1] 2.3	74.4	23.3	49.5	27.2	--------	6.4	.66	9
18–26	B3	[1] 2.6	75.6	21.8	51.3	26.9	--------	6.5	.52	8
34–52	C1	[1] 4.3	76.4	19.3	55.0	25.7	--------	6.2	.28	--------
71–84	C2	[2] 5.5	79.1	15.4	60.9	23.4	--------	8.0	.13	--------
Profile M13,										
0–8	A1	[1] 3.6	73.8	22.6	53.3	24.1	--------	7.1	2.86	11.6
8–16	B2	[1] 4.6	72.7	22.7	53.9	23.3	--------	7.3	.85	10
16–25	B3	[1] 4.8	73.1	22.1	54.0	23.6	--------	7.4	.49	8
25–36	C1	[1] 5.5	75.4	19.1	56.1	24.4	--------	7.6	.41	--------
36–50	C2	[2] 6.0	78.2	15.8	57.8	26.0	--------	7.9	.19	--------
Profile M14,										
0–6	Ap	0.3	75.8	23.9	--------	25.8	--------	6.1	1.91	14.1
6–12	Al	.5	73.5	26.0	--------	27.3	--------	6.3	1.92	13.2
12–22	B1	.4	75.5	24.1	--------	27.0	--------	6.3	1.60	13.3
22–31	B2	.6	77.0	22.4	--------	27.3	--------	6.4	1.10	13.4
31–43	B3	.8	79.1	20.1	--------	27.3	--------	6.5	.66	--------
43–60	C1	.8	77.4	21.8	--------	27.1	--------	6.6	.35	--------
60–85	C2	.6	78.6	20.8	--------	27.4	--------	6.7	.26	--------
Profile I1,										
0–6	A1	[2] 4.6	76.0	19.4	55.5	24.5	--------	7.7	1.64	12
6–12	AC	[2] 5.3	78.0	16.7	58.1	24.7	--------	7.9	.58	10
12–20	C1	[2] 5.7	77.3	17.0	57.4	25.1	--------	8.0	.33	10
30–40	C2	[2] 5.7	80.7	13.6	61.4	24.7	--------	8.0	.14	--------
Profile I2,										
0–8	A1	[1] 3.5	71.8	24.7	50.7	24.4	--------	6.6	2.40	10.6
8–14	AB(?)	[2] 4.2	74.8	21.0	51.6	26.8	--------	7.8	1.12	10.4
14–28	C1	[2] 5.1	76.9	18.0	56.0	25.4	--------	8.0	.49	9

[1] Few to common smooth dark brown to black concretions (Fe-Mn?).

[2] Few to common smooth dark brown to black concretions (Fe-Mn?); few to common $CaCO_3$ concretions.

of Monona and Ida soils—Continued

Free iron (Fe_2O_3)	Carbonate as $CaCO_3$	Water content at 15 atm	Cation-exchange capacity (NH_4OAc)	Extractable cations: Ca	Mg	Exchange acidity	Na	K	Degree of base saturation: (NH_4OAc)	Sum of cations +H	Ca/Mg
Pct.	Pct.	Pct.		Meq/100 g soil					Pct.	Pct.	
Monona silt loam											
1.3	<1	12.1	22.4	18.0	6.2	1.7	<0.1	0.6	111	94	2.9
1.3	<1	11.0	21.3	17.6	6.0	1.7	<.1	.5	113	93	2.9
1.2	5	10.9	17.9	26.0	5.4	<.1	<.1	.5	--------	100	4.8
1.0	11	9.6	15.4	28.4	5.3	<.1	<.1	.4	--------	100	5.4
.7	11	8.5	14.2	24.3	5.6	<.1	.1	.4	--------	100	4.3
Monona silt loam											
1.4	<1	12.4	25.2	21.6	4.5	4.9	<0.1	0.9	107	85	4.8
1.6	<1	10.4	20.6	15.5	4.0	4.9	<.1	.7	98	80	3.9
1.7	--------	9.9	14.2	12.1	6.8	4.1	<.1	.4	--------	82	1.8
1.8	<1	9.5	10.4	11.4	5.4	4.1	<.1	.3	--------	81	2.1
1.6	--------	9.0	12.2	11.4	6.4	3.7	.1	.3	--------	82	2.1
1.5	8	8.0	11.6	20.1	5.9	<.1	.1	.3	--------	100	3.4
Monona silt loam											
1.4	<1	12.3	16.9	24.2	3.5	3.3	<0.1	1.0	--------	90	6.9
1.5	<1	10.2	13.0	17.6	3.5	2.0	<.1	.7	--------	92	5.0
1.6	<1	10.1	11.2	15.6	4.0	1.6	<.1	.7	--------	93	3.9
1.5	<1	9.5	14.1	14.2	5.6	1.2	<.1	.7	--------	94	2.5
1.2	6	8.7	14.1	23.1	5.5	<.1	<.1	.8	--------	100	4.2
Monona silt loam[3]											
1.6	--------	--------	--------	[4] 17.2	--------	3.9	--------	--------	81.3	--------	--------
1.6	--------	--------	--------	[4] 18.7	--------	4.3	--------	--------	81.2	--------	--------
1.7	--------	--------	--------	[4] 16.0	--------	3.6	--------	--------	81.5	--------	--------
1.7	--------	--------	--------	[4] 16.4	--------	2.9	--------	--------	84.8	--------	--------
1.7	--------	--------	--------	[4] 14.4	--------	2.1	--------	--------	87.3	--------	--------
1.6	--------	--------	--------	[4] 16.0	--------	1.6	--------	--------	90.7	--------	--------
1.5	--------	--------	--------	[4] 16.5	--------	1.6	--------	--------	90.1	--------	--------
Ida silt loam											
1.2	6	10.4	18.6	25.1	2.8	<0.1	<0.1	0.6	--------	100	9.0
1.3	8	9.5	16.9	28.3	2.8	<.1	<.1	.4	--------	100	10.1
1.3	9	9.1	16.5	29.8	3.0	<.1	.1	.4	--------	100	9.9
1.3	10	8.3	14.6	26.1	3.2	<.1	.1	.4	--------	100	8.2
Ida silt loam											
1.4	<1	13.0	22.4	16.9	5.3	4.5	<0.1	0.7	102	84	3.2
1.3	6	9.9	18.0	25.5	5.0	<.1	<.1	.4	--------	100	5.1
1.2	9	8.8	16.2	25.8	4.9	<.1	.1	.4	--------	100	5.3

[3] Description from Simonson, G. H. Genesis of Alluvium-Derived Soils in the Willow River Valley, Iowa. Unpublished Ph. D. thesis, Iowa State University, Ames, Iowa. 1960.

[4] Sum of bases.

TABLE 16.—*Chemical properties of cultivated Monona and Ida soils*

Soil and slope	Depth (inches)	Horizon	pH	Organic carbon	Nitrogen	C/N
				Percent	*Percent*	
Monona:						
M15 (2 percent)	0–7	Ap	5.8	2.14	0.204	10.5
	7–11	A1	5.9	2.02	.193	10.5
	11–18	B1	5.8	1.17	.118	9.9
M16 (2 percent)	0–7	Ap	5.8	1.41	.143	9.9
	7–11	A12	6.5	1.31	.128	10.2
	11–21	B1	6.7	.98	.100	10
M17 (8 percent)	0–7	Ap	6.4	1.18	.121	9.8
	7–17	B2	7.0	.50	.058	9
	17–26	B3	7.2	.27	.036	8
M18 (7 percent)	0–6	Ap	6.2	1.70	.170	10.0
	6–12	B1	6.6	.98	.103	10
	12–23	B2	6.9	.54	.057	9
M19 (15 percent)	0–4	Bp	6.4	1.62	.168	9.6
	4–13	B3	7.0	.38	.046	8
	13–21	C1	7.1	.25	.034	7
M20 (14 percent)	0–8	Bp	6.7	.68	.076	9
	8–20	C1	7.2	.22	.032	7
	20–44	C2	6.9	.16	.025	6
Ida:						
I3 (17 percent)	0–7	Cp	7.9	.42	.048	9
	7–19	C1	7.9	.21	.029	7
	22–34	C2	8.0	.14	.019	7

TABLE 17.—*F values from analysis of variance of physical and chemical properties of Monona and Ida soils by geomorphic surface, vegetation, and soil*

Soil property	Source of variation					
	Geomorphic surface		Vegetation		Soil (Monona and Ida)	
	F value	Level of significance	F value	Level of significance	F value	Level of significance
		Pct.		*Pct.*		*Pct.*
Solum thickness	2,13=5.05	2.5	1,14=1	—	1,14=7.49	2.5
Depth to carbonate	2,12=6.05	2.5	1,13=13.48	0.5	1,13=4.00	10.0
Depth to zone of minimum base saturation	2,13=4.50	5.0	1,14=4.25	10.0	1,14=5.74	5.0
Thickness of horizon with >1 percent organic matter	2,14=9.15	.5	1,14=6.25	5.0	1,14=1.66	25.0
Organic carbon A1 horizon	2,13=<1	—	1,13=17.29	.5	1,13=<1	—

TABLE 18.—*Relation between soil properties and slope gradient*

Sample	Regression equation	F value	Level of significance	Correlation coefficient
Solum thickness				
			Percent	
All profiles	Y=35.01−0.710X	1,14=14.95	0.5	−0.709
Hatcher surface	Y=41.01−1.027X	1,7 = 7.96	2.5	−0.708
Mullenix surface		1,2 = 1.80	(1)	(1)
M1–M4	Y=35.80−1.24X	1,2 =42.29	2.5	−0.977
M1–M8		1,3 = 1.47	(1)	(1)
M9–M11	Y=25.50−0.634X	1,2 = 4.25	25.0	−0.825
Depth to carbonate				
All profiles	Y=78.40−3.13X	1,13=32.25	0.5	−0.712
Hatcher surface	Y=88.58−3.46X	1,7 =45.66	0.5	−0.932
Mullenix surface	Y=30.04−1.21X	1,2 =25.51	5.0	−0.963
M1–M4	Y=85.21−3.28X	1,2 =30.43	5.0	−0.946
M1–M8		1,3 = 1.10	(1)	(1)
M9–M11	Y=39.50−1.20X	1,2 = 7.23	25.0	−0.885
Thickness of horizon with >1 percent organic matter				
All samples	Y=28.00−0.676X	1,14= 9.65	1.0	−0.639
Forest	Y=21.06−0.357X	1,8 = 7.91	2.5	−0.705
Grass	Y=35.97−0.922X	1,4 = 6.08	10.0	−0.776
M1–M4		1,2 1	(1)	(1)
M1–M8	Y=23.83−0.714X	1,3 =10.83	5.0	−0.884
M9–M11		1,2 = 2.51	(1)	(1)
Organic-carbon content, A1 horizon				
All samples	(1) (1)	1,13 1	(1)	(1)
Forest	(1) (1)	1,8 1	(1)	(1)
Grass	(1) (1)	1,2 = 1.18	(1)	(1)

[1] Less than 25-percent level.

TABLE 19.—*Channel slopes of Thompson Creek and selected tributaries*

Stream or tributary	Stream length[1]	Channel slope	Stream or tributary	Stream length[1]	Channel slope
	Miles	*Feet/mile*		*Miles*	*Feet/mile*
Thompson Creek	2.26	34.4	Thompson Creek—Con.		
	2.36	17.3		6.16	17.2
	2.48	22.0		6.31	35.0
	2.57	42.0		6.39	14.9
	2.66	11.1		6.49	22.5
	2.79	46.1		6.53	18.8
	2.91	16.8		6.69	36.4
	3.06	20.0		6.77	13.5
	3.15	26.4		6.84	27.2
	3.29	24.6		6.95	43.4
	3.52	19.7	Turton Branch	.90	142.8
	3.66	21.1		.98	27.3
	3.81	15.4		1.09	67.9
	3.98	24.2		1.18	42.5
	4.08	28.2		1.33	13.1
	4.15	18.7		1.48	93.1
	4.45	30.7		1.57	26.9
	4.51	19.0		1.67	27.8
	4.64	11.7		1.78	34.7
	4.73	29.8		1.90	47.8
	4.83	33.0		1.98	82.6
	4.90	20.2	Fox Branch	.55	95.9
	4.95	21.7		.64	87.0
	5.06	15.9		.72	67.1
	5.14	26.6		.78	48.6
	5.24	31.7		.86	21.3
	5.33	31.0		.95	24.8
	5.41	25.2		1.07	36.2
	5.52	24.8		1.18	(2)
	5.65	37.5		1.23	37.7
	5.78	17.6		1.27	72.7
	5.86	13.5		1.38	76.8
	5.97	17.6		1.47	75.4
	6.12	19.0		1.57	33.8

1 Distance from drainage divide.
2 Nickpoint.

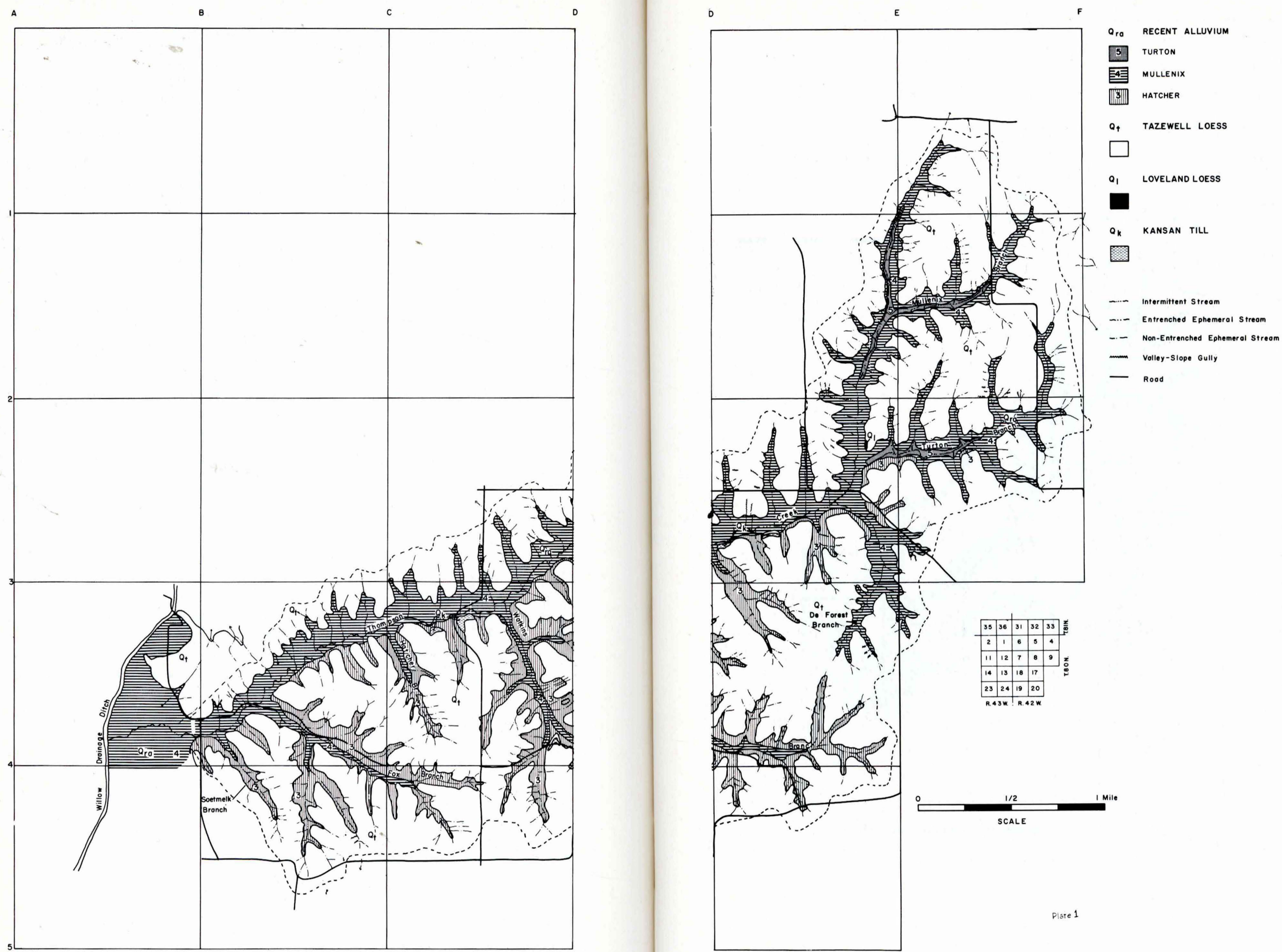


Plate 1.—Surficial deposits of Thompson Creek watershed.

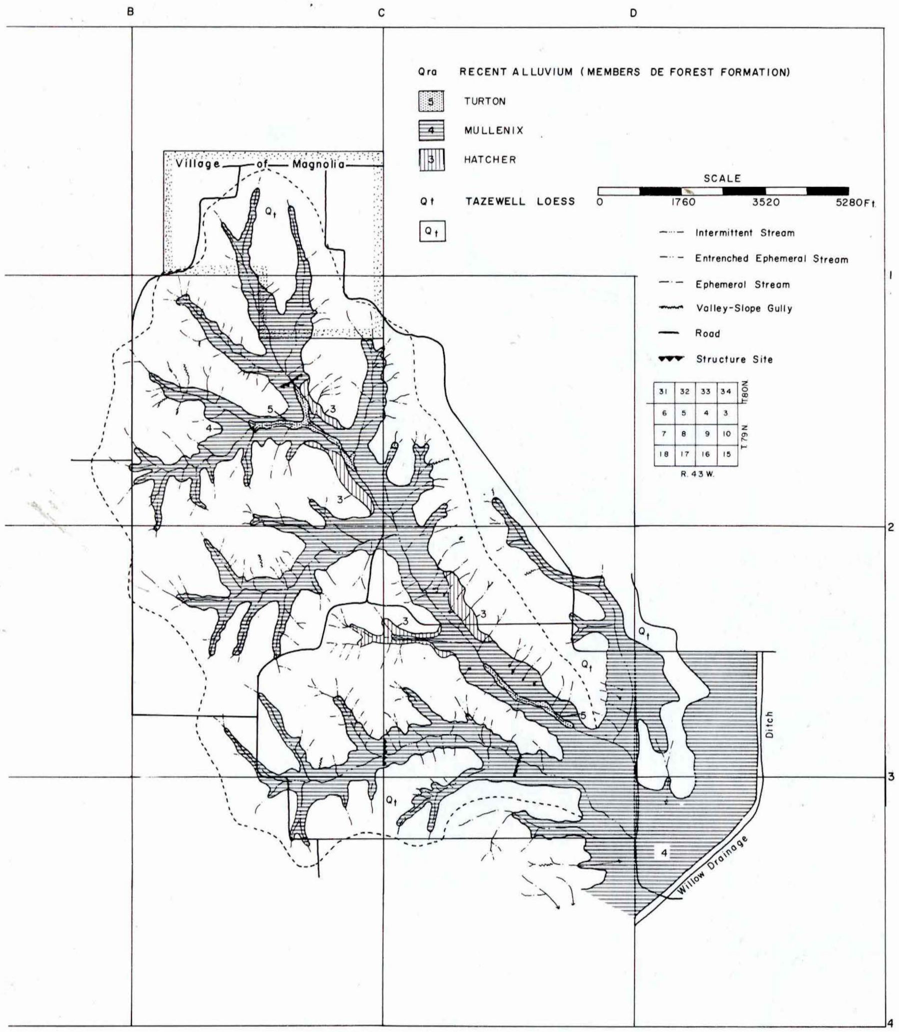


Plate 2.—Surficial deposits of Magnolia watershed.

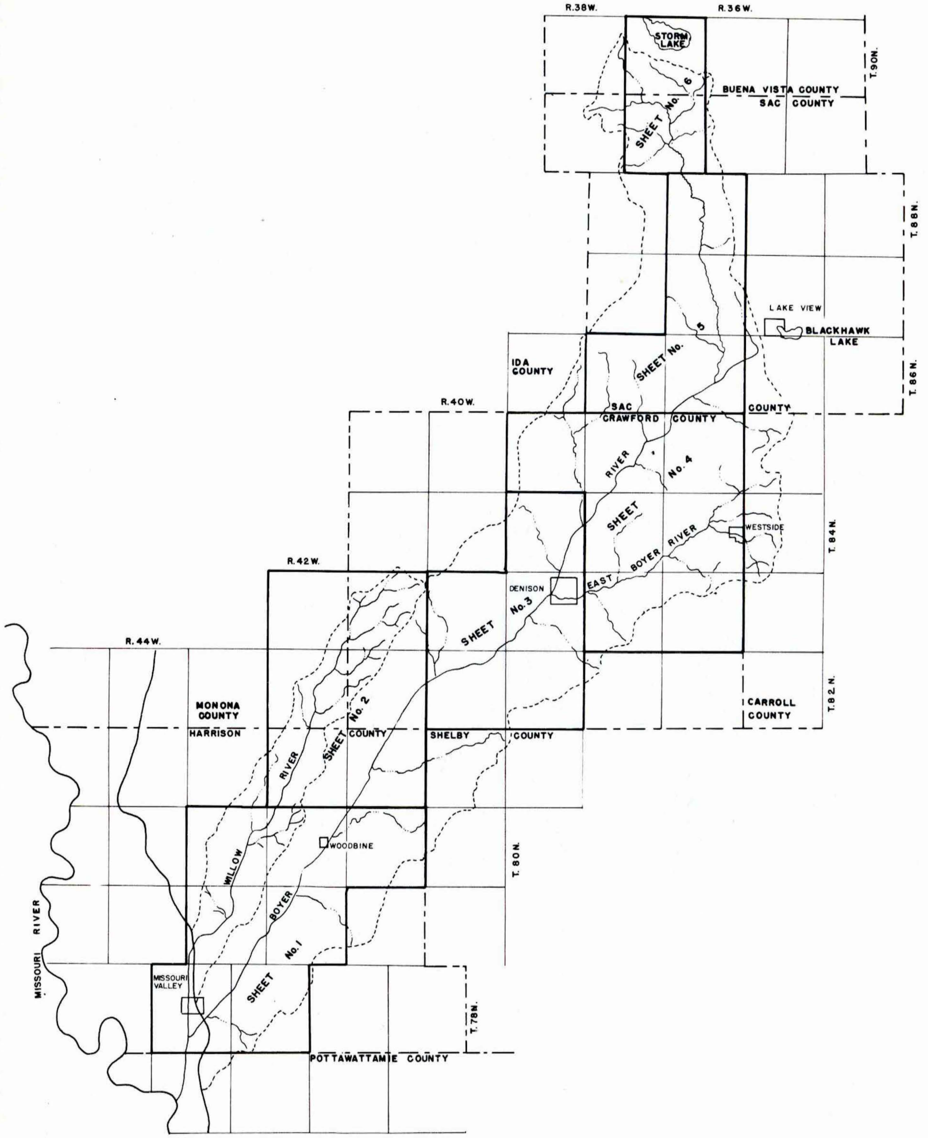


Plate 3.—Distribution of late Sangamon, Tazewell, and Cary terraces in the Boyer and Willow valleys (index).

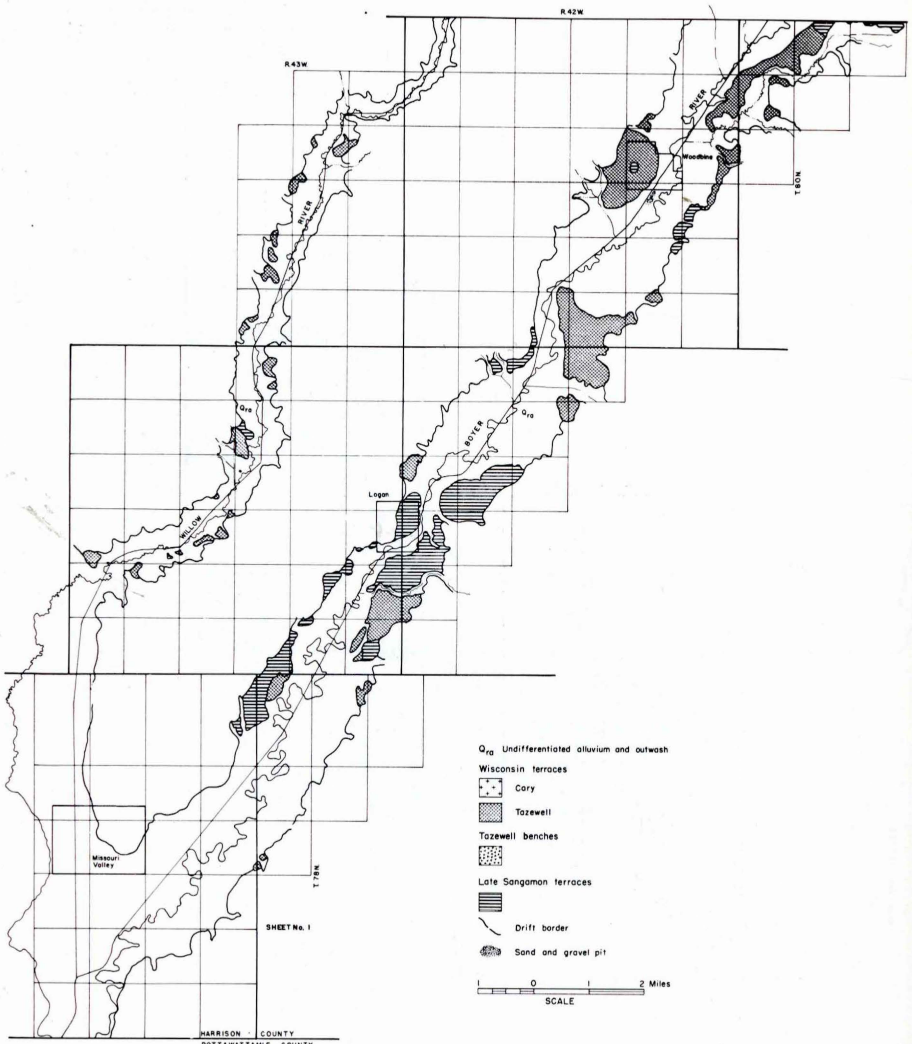


Plate 3, sheet No. 1.

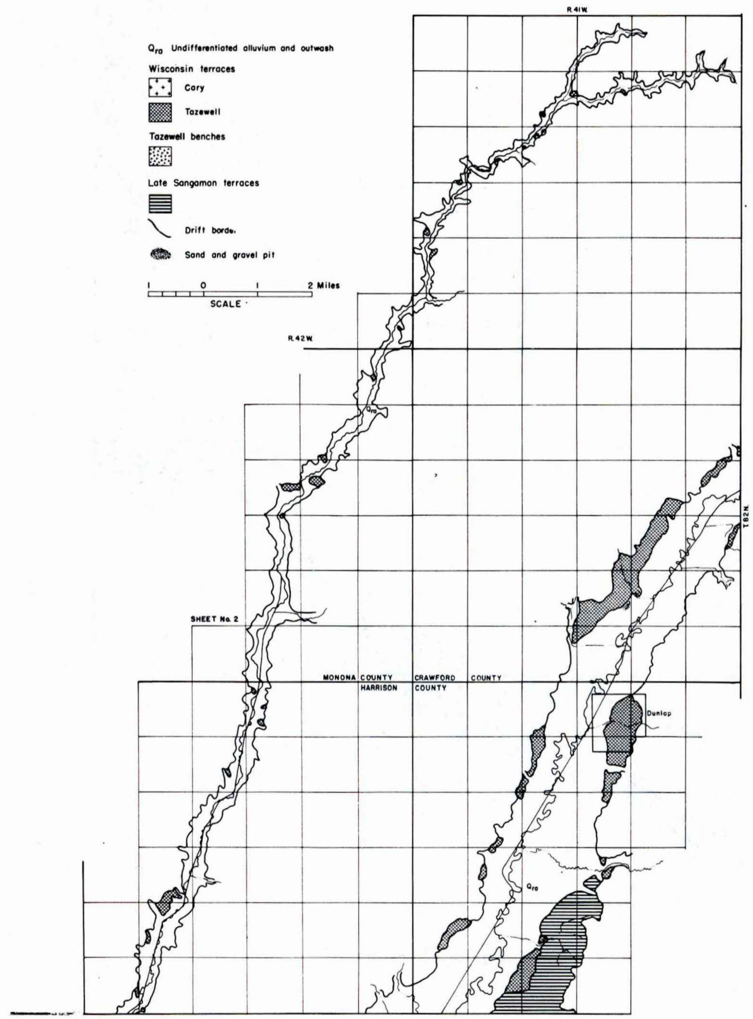


Plate 3, sheet No. 2.

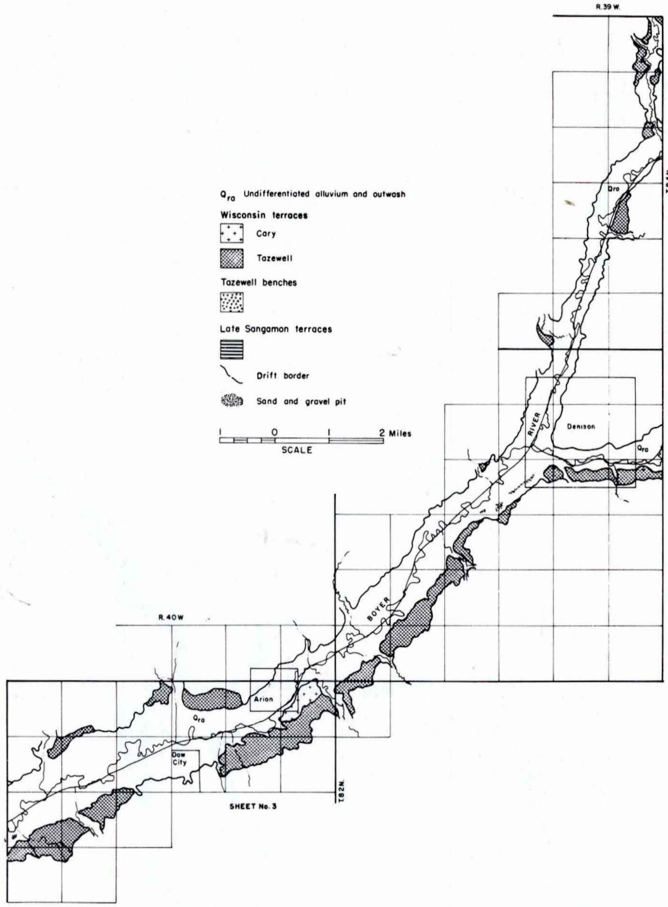


Plate 3, sheet No. 3.

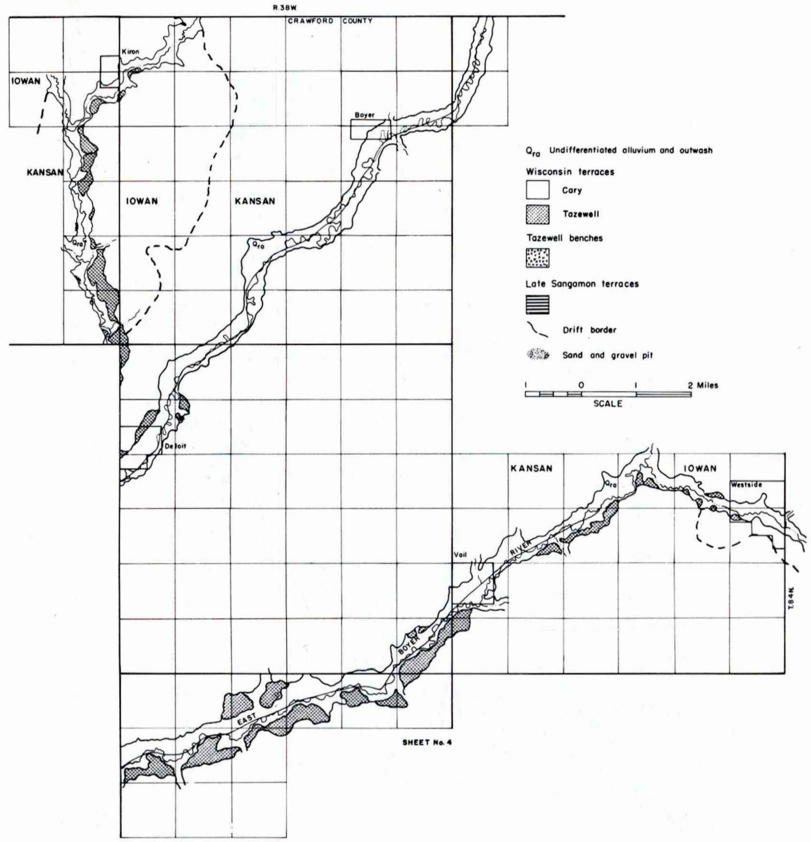
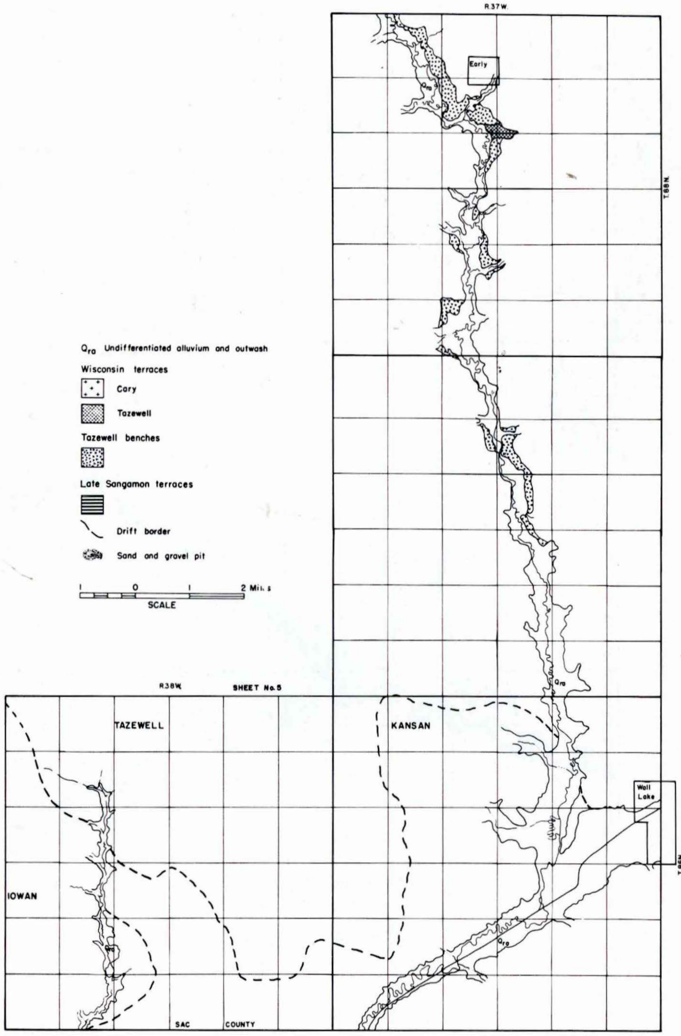


Plate 3, sheet No. 4.



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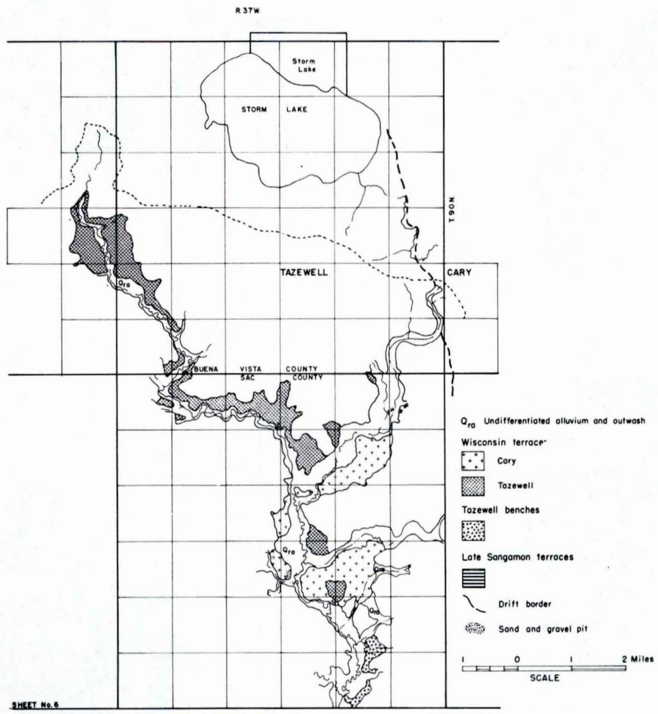

Plate 3, sheet No. 6.

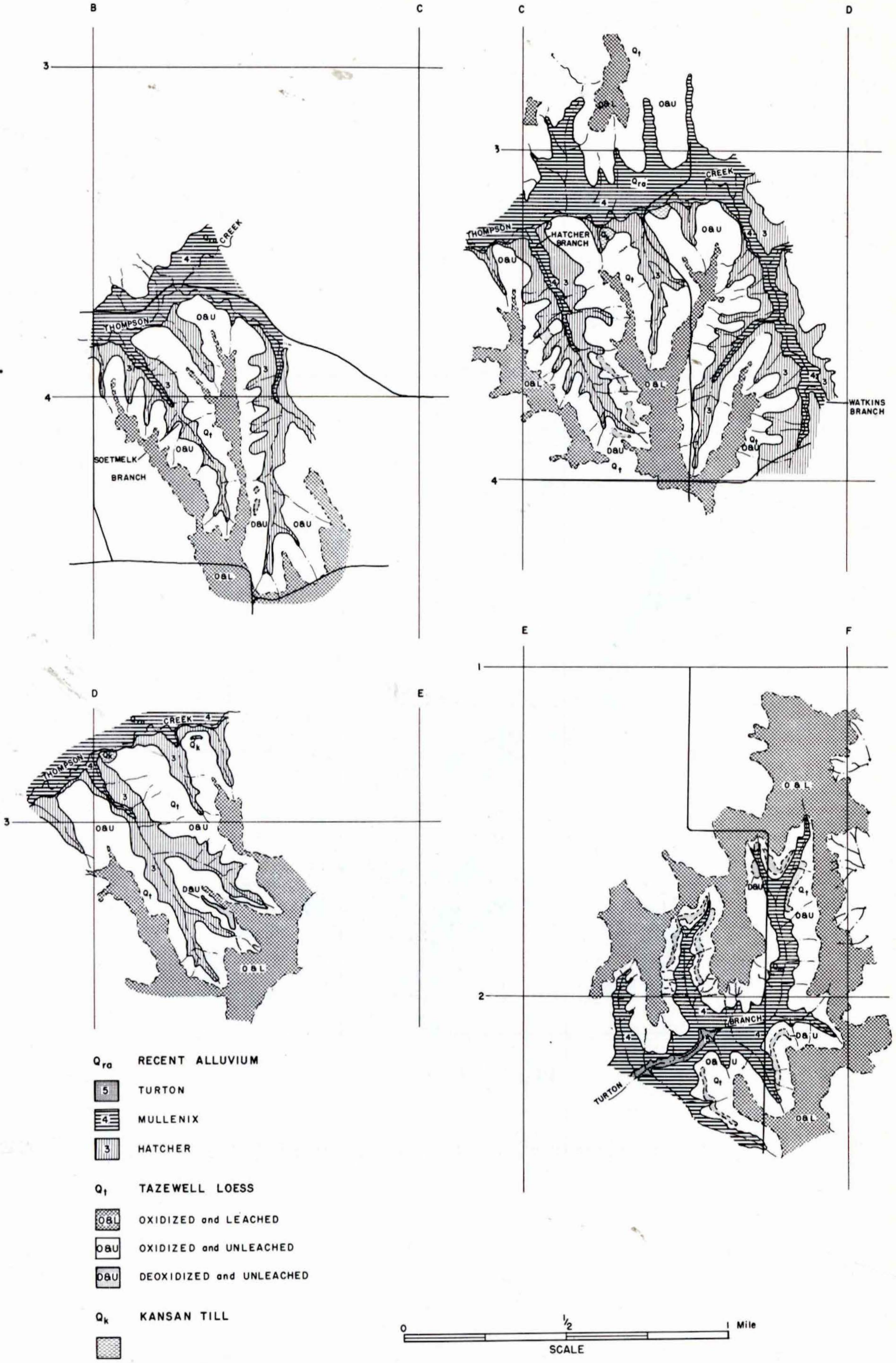

Plate 4.—Surficial deposits and areal distribution of weathering zones of Tazewell loess in selected areas of Thompson Creek watershed.

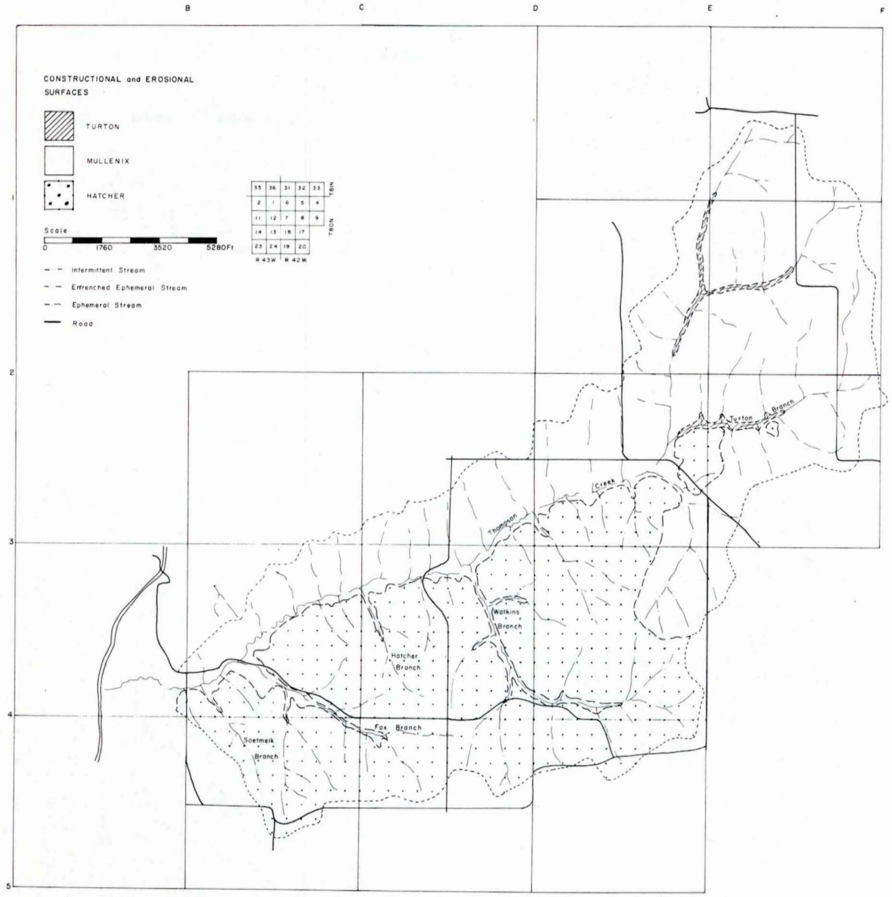

Plate 5.—Geomorphic surfaces in Thompson Creek watershed.

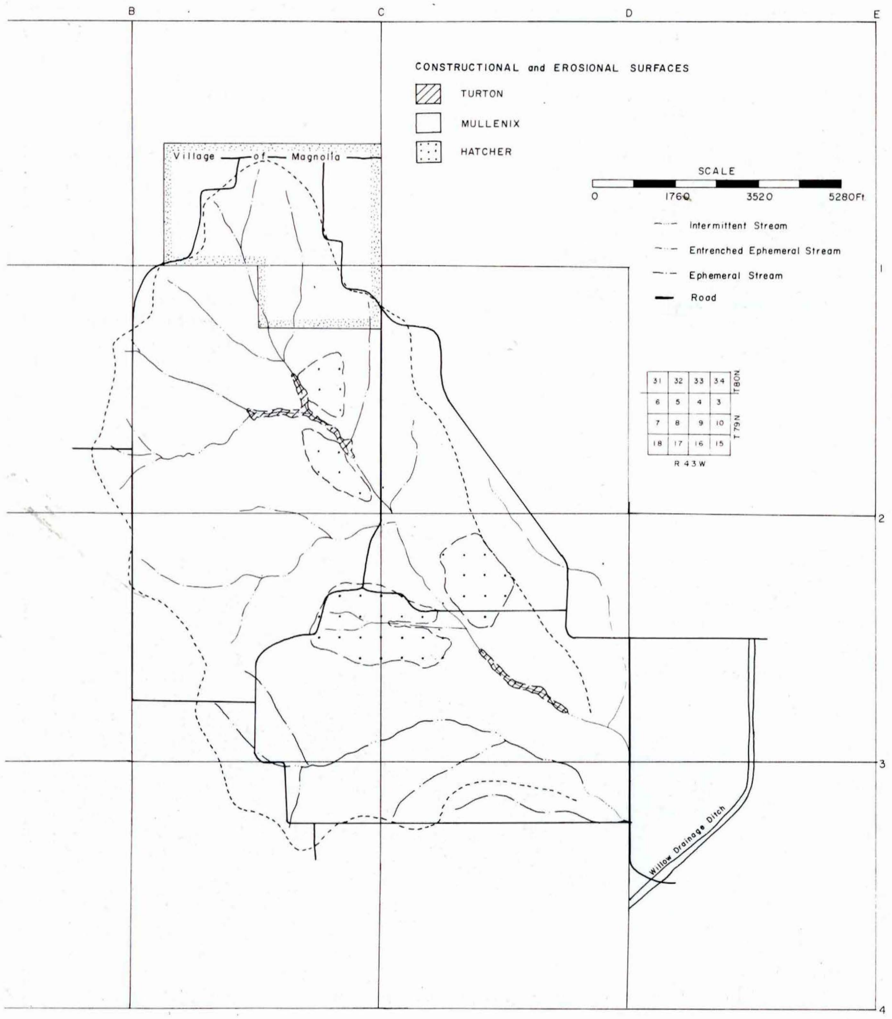

Plate 6.—Geomorphic surfaces in Magnolia watershed.

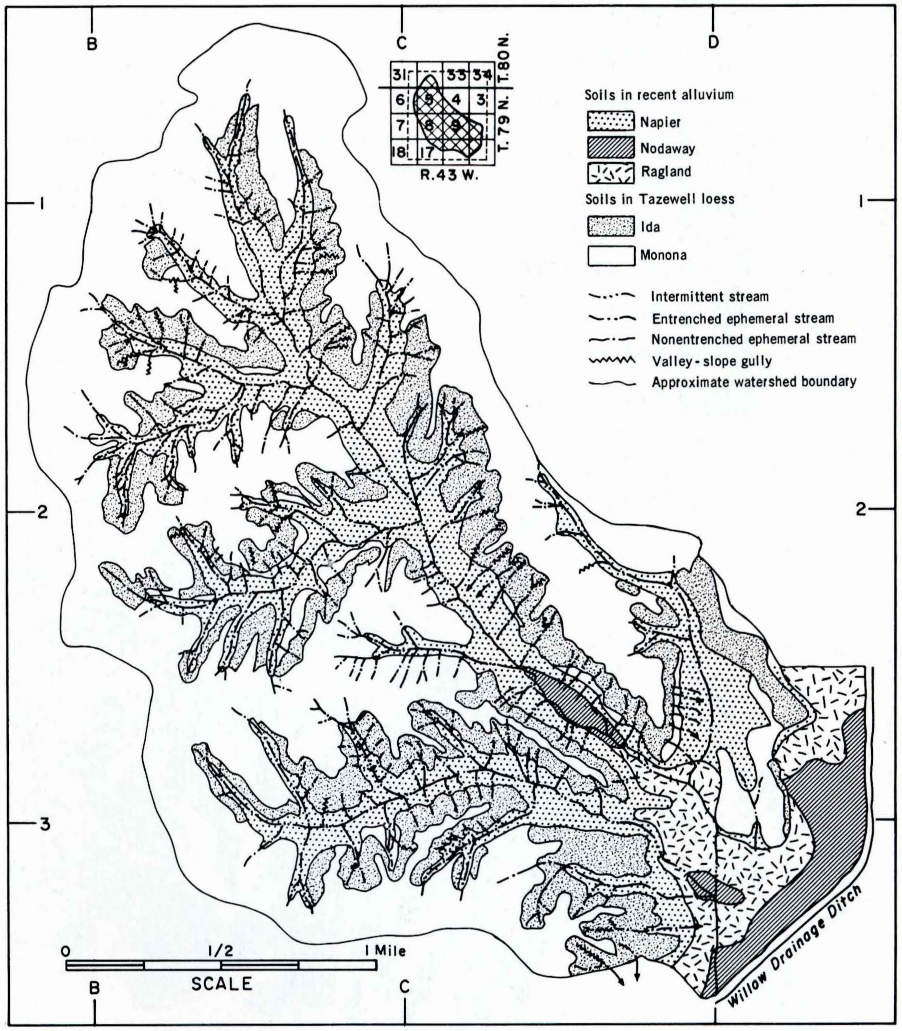

Plate 7.—Soils in Magnolia watershed (G. H. Simonson).

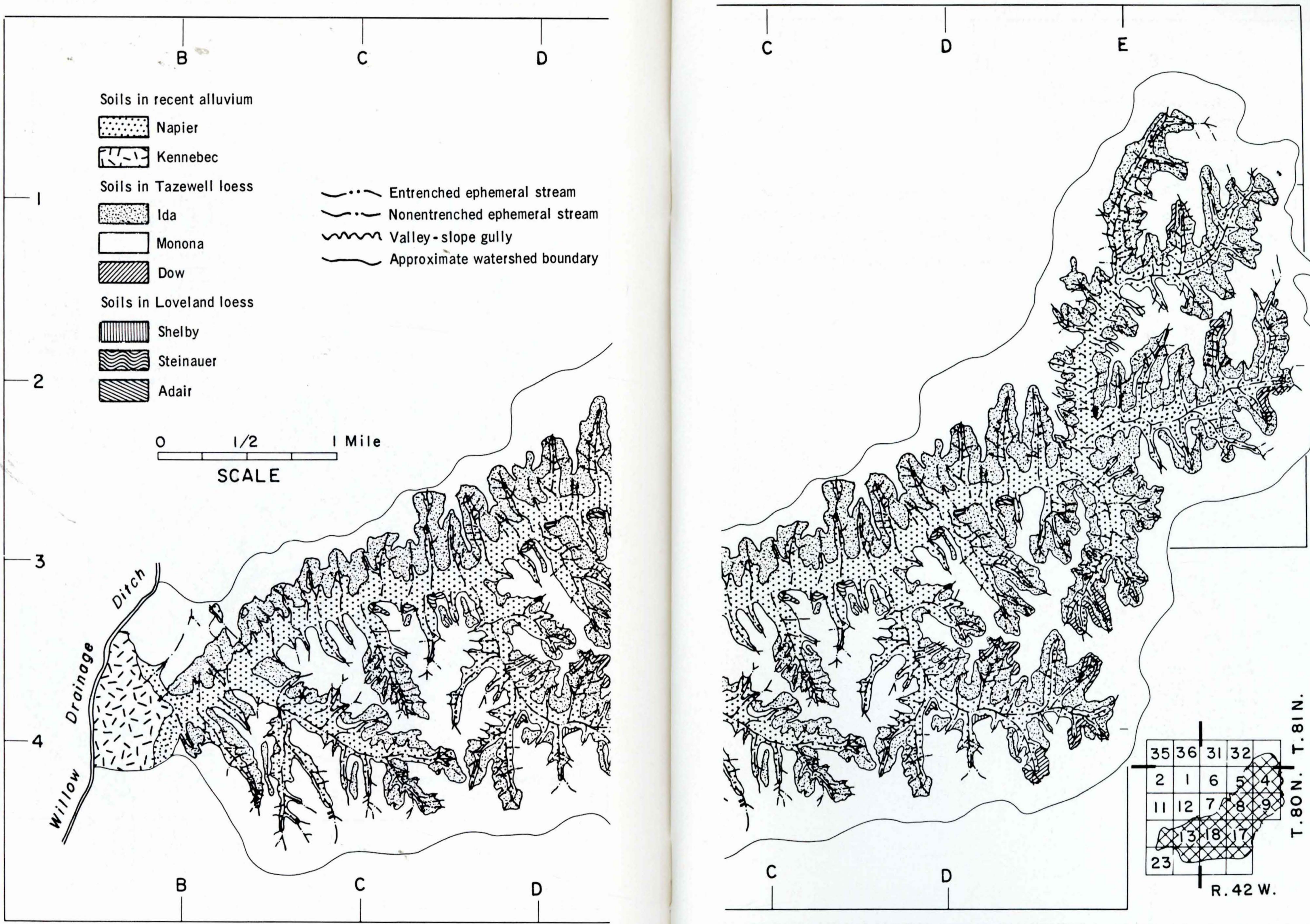

Plate 8.—Soils in Thompson Creek watershed.

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