GLACIATION AND ORIGIN OF THE GEEST IN THE DRIFTLESS AREA OF NORTHWESTERN ILLINOIS

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Department of Energy and Natural Resources
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View of the loess-mantled erosional surface on the Galena dolomite with the escarpment capped by Silurian dolomite in the background across Smallpox Creek, near Aiken.

ACKNOWLEDGMENTS

This study benefited from discussions in the field with Leon R. Follmer and John P. Kempton of the Illinois State Geological Survey and J. C. Knox of the University of Wisconsin, and from discussions of clay mineralogy with Randall E. Hughes, also of the Illinois State Geological Survey.

ABSTRACT

The presence of glacial deposits within the western margin of the Driftless Area of northwestern Illinois has led to a search for evidence of glaciation elsewhere in the area. Because we were interested in materials not related to the bedrock, we examined the modern stream alluvium and the thick layer of clay underlying the loess. Foreign materials in the stream alluvium indicate that glaciers extended at least 3 to 5 miles east of the Mississippi River, probably before the river occupied its present position. A few coarse grains of igneous and metamorphic rocks found outside the alluvium suggest a very early glaciation because they occur at high levels not likely attained by glacial rivers. They, nevertheless, seem insufficient to outweigh the significant absence of glacial erratics in their vicinity. Well-rounded quartz sand and brown chert pebbles, common in the alluvium but scarce in the geest, are foreign to the bedrock but may be a lag from Cretaceous-Tertiary deposits formerly present.

"Geest" (also called "residuum" or "terra rossa"), the layer of clay that underlies thick loess and overlies dolomite and limestone formations, could contain glacially transported materials. No glacial materials have been found in the geest, however, and perhaps none should be expected. The indication of slow accumulation and the presence of geest on long-existing erosional surfaces suggest that at least a major part of the geest is Tertiary. The abundance of white chert from the underlying Silurian dolomite indicates that the geest on the highest erosional surface is largely residuum from solution of the dolomite.

We determined the clay mineral composition and identified constituents coarser than medium-grained sand. Although the clay in the geest averages 65 percent expandable clay minerals, 25 percent illite, and 10 percent kaolinite, the clay in the dolomite is almost entirely illite. Maquoketa Group shale, almost entirely illite, was altered by weathering to a composition like that of the geest; the illite clay in the bedrock dolomite probably was altered to geest composition when it was released by solution of the dolomite. The clay mineralogy and the presence of phosphatic fossils from the Depauperate Zone of the Maquoketa Group shale (in the gray to light tan geest on the lower erosional surface) suggest that geest near the thinned margin of the shale may be partly altered shale. Foreign materials appear to be largely from Cretaceous-Tertiary sand and gravel. Equally resistant materials in younger glacial deposits, if ever present, would probably be preserved. Evidence from this study suggests that the major part of the Driftless Area in northwestern Illinois was not glaciated.

INTRODUCTION

In the Driftless Area of northwestern Illinois, coarse gravel deposits of glacial origin and scattered boulders composed of igneous and metamorphic materials indicate that glaciers of Nebraskan or Kansan age crossed the Mississippi Valley into northwestern Illinois (Willman and Frye, 1969). These deposits, which occur only on the upland surface near the Mississippi Valley, were deposited before the Mississippi River was entrenched in its present position.

We investigated the possibility that glaciers covered much more and perhaps all of the Driftless Area in Illinois (fig. 1). The study clearly supports the conclusion of many previous investigators that the area is properly described as "driftless"; however, the absence of drift does not necessarily mean that the area was not glaciated.

The area east of the Driftless Area covered by Illinoian drift has a margin that is sharply defined in places, but obscured or deeply eroded in others. The margin is generally masked by a cover of loess; there is little evidence of a terminal moraine. Glacial till commonly occurs just west of the Mississippi Valley, so close that an ice margin has been interpreted as the origin for the Mississippi River. Till has been found on the Illinois side only near Hanover, although high-level gravel and boulders suggest at least temporary ice invasion of Illinois west of Galena. The loesses and soils clearly indicate that the western till is older than the Illinoian; it has been interpreted as Kansan or Nebraskan (Trowbridge and Shaw, 1916; Willman, Glass, and Frye, 1963), or both as pre-Illinoian (Hallberg, 1980).

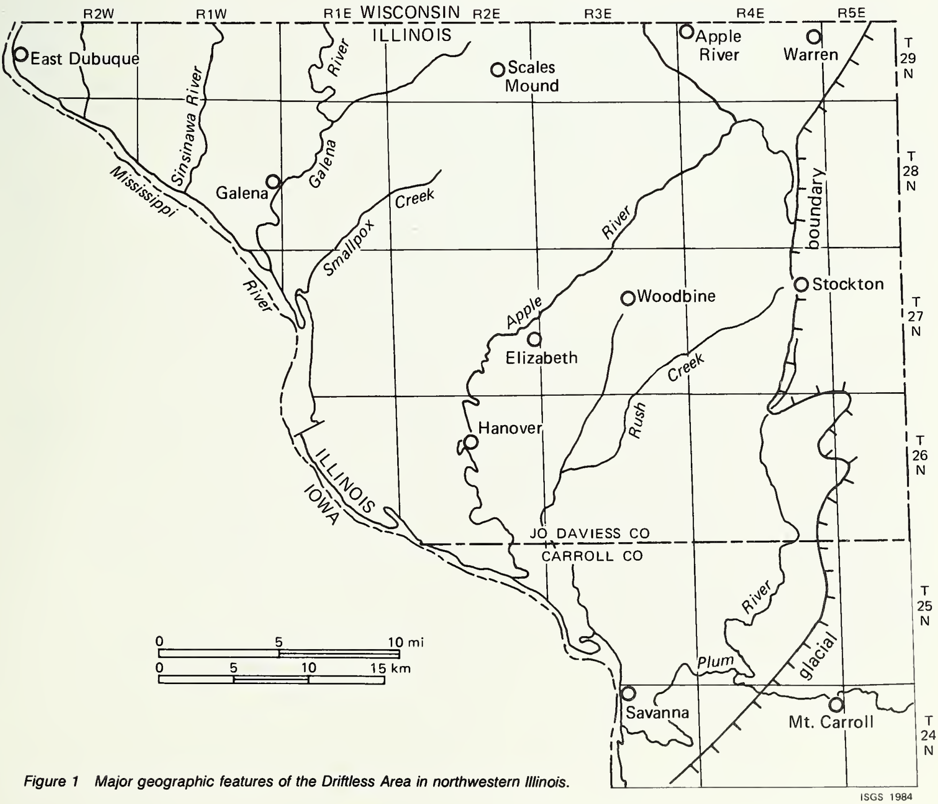


Figure 1 Major geographic features of the Driftless Area in northwestern Illinois.

This study consisted of two parts: (1) an examination of the sand grains, pebbles, and clay minerals in the alluvium along the channels of the present streams, whose headwaters do not extend into areas with glacial drift, to determine whether foreign materials are present, and (2) an investigation of the clay, called "geest," which is generally interpreted as a residual clay resulting from surficial solution of the carbonate formations on which it occurs. The geest might contain rocks and minerals imported by glaciers prior to or after accumulation of the geest.

More than 90 percent of the Driftless Area is covered by loess that ranges from as much as 50 feet thick in the Mississippi River bluffs to 5 to 10 feet thick along the eastern margin of the Driftless Area. A search for remnants of drift in the thousands of small gullies that may locally cut through the loess in such a strongly dissected area is impractical. Some of the gullies, however, may transfer material from buried glacial deposits to the modern alluvium. Willman and Frye (1980) studied the margin of glaciation in an area of thick loess along the Mississippi Valley in southern Illinois. Mineral grains in the sand fraction of material in transit along small streams indicated the presence of glacial deposits not observed in outcrops; such grains were entirely lacking in deposits along streams heading in terrane just outside the projected boundary.

In both parts of the investigation, knowledge of the minerals and various lithologic types of rocks native to the Driftless Area in northwestern Illinois was essential to recognition of foreign materials that could have been brought in by glaciers. The bedrock formations in the Driftless Area are dolomite and shale formations of Ordovician and Silurian age (figs. 2 and 3). The surficial deposits consist of local high-level gravels and occasional boulders in the area close to the Mississippi Valley, alluvial materials along the valleys, and loess deposits that mantle everything except the recent alluvium in the valleys.

Erathem	System	Series	Stage or Group	Formation	Thickness (ft)	Material
CENOZOIC	QUATERNARY	PLEISTOCENE	Holocene Stage	Cahokia Alluvium	0-100	Alluvium
				Peyton Colluvium	0-20	Colluvium
				Parkland Sand	0-30	Dune sand
			Wisconsinan Stage	Peoria Loess Roxana Silt	6-50 0-4	Loess Loess
			Illinoian Stage	Loveland Silt	0-6	Loess
			Kansan-Nebraskan Stages	Enion ?	0-5 0-30	Till ? Gravel
	TERTIARY				0-6	Soil-geest
PALEOZOIC	SILURIAN	NIAGARAN		Racine	75-100	Dolomite, pure, light gray
				Marcus	40-45	Dolomite, pure, tan
		ALEXANDRIAN		Sweeney	50-55	Dolomite; little shale and chert
				Blanding	35-50	Dolomite; much white chert, slightly argillaceous
				Tete des Morts	0-20	Dolomite, pure
				Mosalem	5-100	Dolomite, argillaceous
	ORDOVICIAN	CINCINNATIAN	Maquoketa Group	Brainard Shale	75-100	Shale, green-gray; some dolomite
				Scales Shale	75-100	Shale, gray, lower part gray-brown Depauperate Zone at or near base
		CHAMPLAINIAN	Galena Group	Dubuque	35-40	Dolomite, argillaceous, shaly upper part
				Wise Lake	75	Dolomite, pure, gray to tan
				Dunleith	125	Dolomite, cherty, slightly argillaceous, drab, lower part grades to limestone
				Guttenberg	5-15	Limestone, tan, brown shale partings
				Spechts Ferry	5-10	Shale, green
			Platteville Group	Quimbys Mill	10+	Limestone, pure, very fine grained

Figure 2 Geologic column of the Driftless Area in northwestern Illinois.

STRATIGRAPHY OF THE DRIFTLESS AREA

Ordovician System

In the Driftless Area north of Hanover (fig. 3) the bedrock formations that crop out are largely Ordovician (Trowbridge and Shaw, 1916; Agnew et al., 1956; Templeton and Willman, 1963; Willman and Kolata, 1978). Silurian rocks cap only the prominent knobs and ridges. Because of the southwesterly dip of the strata, the Silurian rocks are more extensive in the southern part of the Driftless Area; the Ordovician rocks are exposed principally in the lower parts of the deeper valleys.

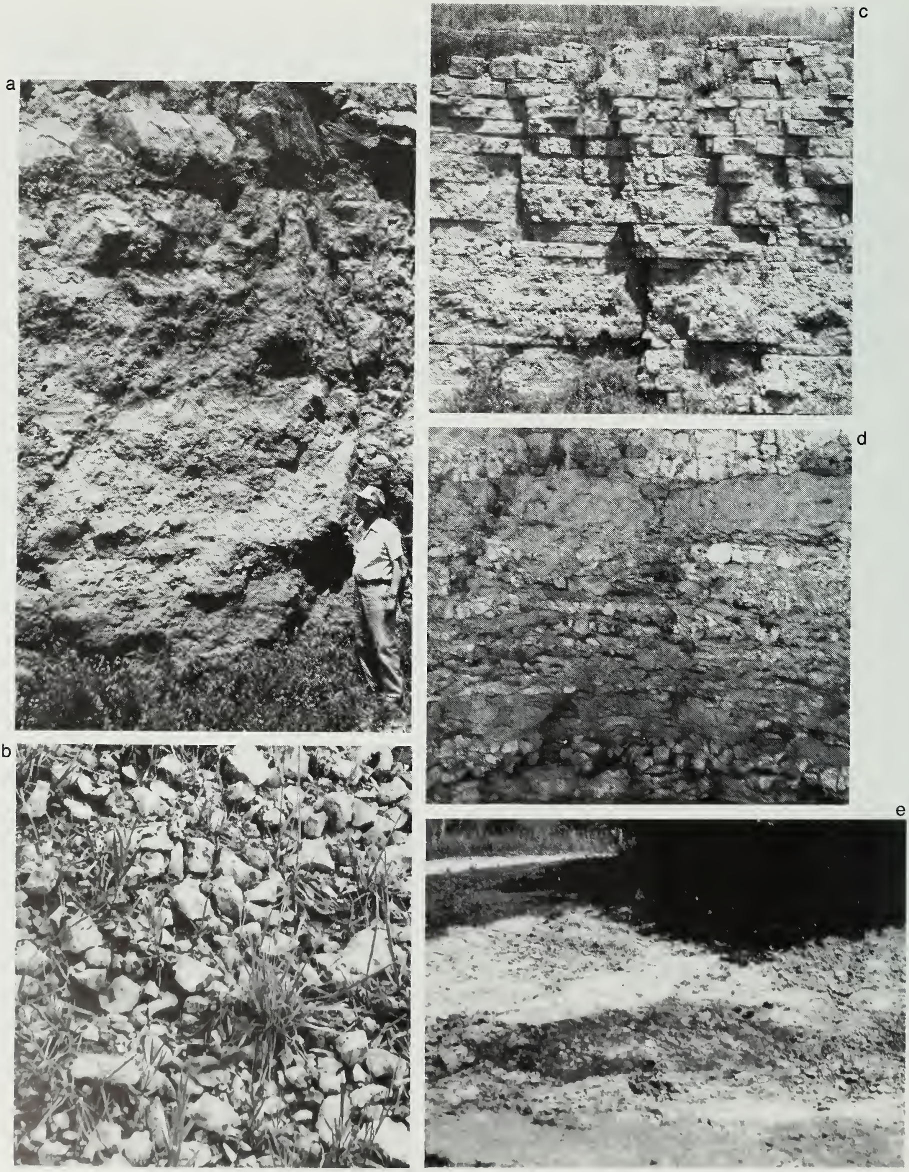
Platteville Group The oldest rocks exposed in the Driftless Area in Illinois belong to the Platteville Group and consist mainly of dense, very fine-grained limestone and medium-grained dolomite. Exposure of the upper 25 feet occurs only in a small area in the bottomland along the Galena River about 3 miles north of Galena.

Galena Group The Galena Group (fig. 2) is about 250 feet thick in the Driftless Area, and it is well exposed along all the major streams and in quarries and road cuts. The Spechts Ferry and Guttenberg Formations at the base of the Galena Group are exposed in the Driftless Area only along the Galena River north of Galena.

The Spechts Ferry Formation at the base consists of 5 to 10 feet of green shale, gray shaly limestone, gray and brown fine-grained limestone, medium- and coarse-grained glauconite, and thin beds of potassium bentonite. The overlying Guttenberg Formation consists of about 15 feet of brown, very fine-grained limestone interbedded with brown-red shale and a thin potassium bentonite. It contains a small amount of chert.

The overlying Dunleith Formation is 120 to 130 feet thick and is widely exposed. It is slightly to moderately argil-

Figure 3 Geologic map of the Driftless Area and occurrence of glacial erratics and possible till, and of high-level outwash gravel.



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laceous cherty dolomite, except in the region northwest of Galena where the lower part grades to a fine-grained limestone facies that progressively thickens to as much as 40 feet near the northwest corner of Illinois. The carbonates and the chert are dull brown or tan gray. The dolomite of the middle part contains strata with 15 to 20 percent insoluble residue, but 5 to 10 percent solid residue is more common. The lower and upper parts of the formation generally have less than 5 percent insoluble residue. Chert nodules are present in nearly all exposures and constitute as much as 10 percent of some members.

The Wise Lake Formation, which overlies the Dunleith, is about 75 feet thick and consists of pure, medium-grained, vesicular to vuggy, thick-bedded dolomite (fig. 4a). The insoluble residue is consistently less than 5 percent, generally less than 2 percent, and in some strata less than 1 percent. This formation contains only a few scattered chert nodules near the base.

The overlying Dubuque Formation, 35 to 40 feet thick, has well-defined, laterally uniform, medium to thin strata (fig. 4c). The base is a persistent layer of dolomite about 0.3 foot thick; prominent shale partings both above and below make it a distinctive marker bed. The lower 15 to 20 feet of Dubuque is a transition zone marked by upward thinning of the strata, increasing content of insoluble residues, and decreasing vesicularity. The upper 15 to 20 feet consists of very argillaceous dolomite that has prominent partings of dolomitic shale. Insoluble residues range from less than 2 percent at the base of the formation to 25 to 35 percent in the upper part and as much as 50 percent in some areas. Because the Dubuque and Wise Lake Formations do not contain chert, neither do the upper 100 feet of the Galena Group.

Maquoketa Group The Maquoketa Group, which overlies the Galena Group, is about 200 feet thick in the Driftless Area. Exposures are scarce, mostly in roadcuts. The Maquoketa consists mainly of shale with locally a few thin beds of dolomite, limestone, and siltstone. Although many beds are silty, the shale is rarely, if ever, sandy. The lower 75 to 100 feet is dark green-brown to medium gray shale, the Scales Shale. At or near its base lies the distinctive "Lower Depauperate Zone," which consists mainly of minute, phosphatic, light gray to dark brown and black fossils commonly imbedded in a matrix of dolomite or in places, pyrite or shale. In some areas an almost inconceivable abundance of disc-shaped pellets, mostly about the size of medium- to coarse-grained sand, dominate the fauna. Snyder and Bretsky (1971) identified them as fecal pellets. Other fossils, mostly mollusks and cephalopods, are 2 to 3 times larger than the pellets. In places the Lower Depauperate Zone consists of one layer as much as 0.9 foot thick, but more commonly it is one or more layers only 0.1 to 0.3 foot thick. It usually occurs in the lower 1 to 2 feet of the Scales Shale, but it may be as much as 9 feet above the base. In a few places it is absent.

Figure 4 (a) Massive, pure, noncherty Wise Lake Formation of the Galena Group exposed in U.S. 20 roadcut, Dixon (Whiskey) Creek North Geologic Section (Circular 440), SW SE SE 35, 29N-2W, Menominee Quadrangle, Jo Daviess County. (b) Concentrate of angular chert fragments on weathered surface of geest on the Silurian Blanding Formation in roadcut 5 miles northwest of Elizabeth, SE NE SW 34, 28N-2E, Scales Mound West Quadrangle, Jo Daviess County. (c) Argillaceous dolomite with thin shale partings of the Dubuque Formation of the Galena Group overlying the more massive Wise Lake Formation at the base of the exposure in U.S. 20 roadcut, Sinsinawa River East Geologic Section, SW SE NW 3, 28N-1W, Galena Quadrangle, Jo Daviess County. (d) Cherty dolomite of the Silurian Blanding Formation exposed in roadcut 5 miles east of Galena, NW NW SW 31, 28N-2E, Scales Mound West Quadrangle, Jo Daviess County. (e) Typical exposure of noncherty geest (the dark material, 1.5 feet thick) underlying Peoria Loess and overlying Dubuque Formation in U.S. 20 roadcut 3 miles southeast of Galena, NE SW SW 26, 28N-1E, Galena Quadrangle, Jo Daviess County.

The Fort Atkinson Limestone separates the Scales Shale from the overlying Brainard Shale elsewhere in Illinois, but it has not been recognized in the Driftless Area in northwestern Illinois.

The Brainard Shale, 75 to 100 feet thick, is commonly greenish gray and lighter in color than the Scales Shale. In some places it contains argillaceous dolomite, in others, numerous 0.1- to 0.2-foot layers of siltstone. The upper part is deeply truncated by the overlying Silurian dolomite in some areas.

Surficial weathering extends to a depth of several feet in most exposures of the Maquoketa Group shales. In places at the top the texture is modified to a nearly structureless, greenish gray clay rarely more than 0.5 foot thick, although on flat surfaces it is as much as 2 feet thick.

Silurian System

Silurian formations constitute the upper part of the bedrock in the Driftless Area (Trowbridge and Shaw, 1916; Willman, Reynolds, and Herbert, 1946; Willman, 1973). Throughout the area where it only caps knobs and ridges, the Silurian dolomite seldom is more than 75 feet thick and generally much thinner. Because of the southward dip, the Silurian strata thicken to as much as 300 feet in the southern part of the Driftless Area, particularly in the synclinal belt along the north side of the Plum River Fault Zone (Kolata and Buschbach, 1976).

The Mosalem Formation at the base is largely argillaceous, partly cherty dolomite that ranges from only a few feet to as much as 100 feet thick where it fills channels in the underlying Maquoketa Group.

The overlying Tete des Morts Formation is a relatively pure, massive, slightly cherty, light gray dolomite that is 15 to 20 feet thick. It forms conspicuous cliffs at or near the top of the Silurian exposures in the ridges and knobs north of Hanover; to the south it thins rapidly and disappears.

The Blanding Formation, above the Tete des Morts, consists of 35 to 50 feet of thin- and medium-bedded, light brownish or pinkish gray, slightly argillaceous dolomite (fig. 4d). It contains some thin green clay partings and light gray to white chert in lenticular beds and rows of nodules. Chert commonly forms 10 to 20 percent of the formation and silicified fossils are common. Except for the chert, the insoluble residue constitutes about 5 to 10 percent of the formation. The Blanding Formation is usually the uppermost bedrock formation in the ridges and knobs in the region north of Hanover.

The Sweeney Formation, about 55 feet thick, is somewhat purer and more vesicular than the underlying Blanding Formation. It contains many green clay partings and a small amount of chert near the middle. In the knob and ridge area north of Hanover, it occurs only in places as the top formation of the bedrock; farther south it is widely exposed.

The Marcus Formation consists of about 40 feet of pure, chert-free, massive, vesicular, light gray-brown dolomite. It is distinguished by the abundance of a large fossil brachiopod, *Pentamerus oblongus*. North of Hanover it is present only in a few of the higher knobs at the top of the Silurian section, but it is widely present south of there.

The Racine Formation at the top of the Silurian section is as much as 75 to 100 feet thick along the north side of the Plum River Fault Zone near the Mississippi River north of Savanna, the only part of the Driftless Area in which it occurs. It consists primarily of pure, vesicular and vuggy, massive to thin-bedded, mottled gray and light brownish gray dolomite that is not cherty.

Tertiary and Early Quaternary Systems

The Geest Between the Paleozoic bedrock formations and the Pleistocene loesses, the only common but patchy unit in the Driftless Area is the dominantly red-brown clay called "geest" (fig. 4e). The geest also underlies the high-level glacial gravels; outside the margin of the Driftless Area, it occurs below glacial tills. It contains a large amount of chert where it overlies cherty formations and little or none over the noncherty formations (fig. 4e). Geest as much as 6 feet thick has been observed on relatively flat surfaces, but commonly the geest is only 1 to 3 feet thick. In places it is truncated by loess or gravel and consists only of fillings of narrow joints in the top of the bedrock. The thicknesses do not necessarily represent an original thickness in any locality because of erosion before deposition of the overlying loess.

Stratigraphically, the geest could have been derived by weathering from the formation on which it rests; geest has not been named or treated as a separate stratigraphic unit. On the basis on this interpretation of its origin, it could be named a soil-stratigraphic unit. However, in some exposures the geest has migrated downslope or collapsed into solution cavities in the bedrock surface. In places it has incorporated shale from the Maquoketa Group and cherty debris not derived from the underlying bedrock; where such lateral movement has occurred, the geest is not an in situ soil. Because the distinctive lithology readily separates it from underlying and overlying sediments, and because its stratigraphic position on a major unconformity seems fixed, the clay perhaps merits classification as a formation, albeit a thin one. If the clay were named as a formation of Tertiary and Quaternary age, the term "geest" would not be needed. Nevertheless, pending further studies, we leave it stratigraphically as part of the formation on which it rests.

Grover Gravel Dark brown, moderately to well-rounded, glossy-surfaced chert pebbles and well-rounded quartz sand grains characterize the gravels variously called Grover, Windrow, and Lafayette-type in the Upper Mississippi Valley (Willman and Frye, 1970). The presence of similar pebbles and grains in the geest and in the alluvium of existing streams suggests the possibility that remnants of these Cretaceous to early Pleistocene gravels may remain in the area, although none have been found. A few partly rounded, cemented blocks of the gravel, called the Grover Gravel in Illinois, have been found on slopes where deposits of the gravel may be present but covered by thick loess.

Quaternary System

Pleistocene Series The Paleozoic bedrock formations in the Driftless Area are generally overlain by unconsolidated deposits of Quaternary age. Mesozoic deposits are not known to be present; the geest that is mainly Tertiary is found in patchy occurrences between the bedrock and the oldest surficial deposits that belong to the Pleistocene Series. These deposits consist of (1) isolated boulders and high-level gravel believed to be associated with Nebraskan or Kansan glaciations (Willman and Frye, 1969); (2) outwash from the Illinoian glaciers along streams crossing the Driftless Area to the Mississippi River; (3) widespread loess deposits of Illinoian and Wisconsinan age; (4) Holocene sediments that are mainly alluvium in the bottomlands of all streams, colluvium on and bordering most slopes, and sand dunes on the bluffs of the Mississippi Valley and the adjacent uplands.

Recent studies in Iowa, Kansas, and Nebraska have indicated that the pre-Illinoian part of the Pleistocene deposits is more complex than indicated by the differentiation into Kansan, Aftonian, and Nebraskan Stages; these deposits have been assigned only to a pre-Illinoian age (Boellstorff, 1978; Hallberg and Boellstorff, 1978; Lineback, 1979; Hallberg, 1980). However, until some suitable replacement is available for consideration, it seems desirable to retain the classification established on the basis of glaciations separated by major intervals of soil formation (Chamberlin, 1895; Leverett, 1899). The classification of four major glacial stages still adequately accounts for the succession found in Illinois.

Nebraskan and Kansan Stages Trowbridge and Shaw (1916) described drift from a locality 1.5 miles west of Hanover (fig. 5) as follows:

> The drift west of Hanover consists of ice-worn pieces of material foreign to this district, ranging in size from cobbles to boulders 2 1/2 feet in diameter. Dolerite, syenite, basalt, schist, porphyry, quartzite, and at least two kinds of granite are represented. The boulders in the banks are surrounded by clay, but this matrix is residual matter from the Maquoketa shale and Niagaran dolomite, rather than a part of the drift. None of the igneous rocks are perfectly fresh, but all show some and many show great evidence of alteration by processes of weathering since their deposition here.

The occurrence of the drift near Hanover at a level 100 feet above the modern floodplain makes ice-rafting unlikely.

We revisited the Hanover locality for this study and found neither boulders nor till. The boulders may have been removed or covered by slumping, or we may not have found the original locality. However, our samples of alluvial material at that locality (P-18: 263-265, table 1 on p. 14) and also about 0.5 mile downstream (P-18: 261) contain granite, other igneous and metamorphic rocks, and a variety of heavy minerals in the sands.

A sandy and pebbly clay exposed in a roadcut south of Duke Creek, less than 1 mile west of Hanover, appears to be a deeply weathered till (fig. 6d) (geologic section 8). (See appendix for a description of geologic sections.) It contains a few igneous rocks, and the variety of heavy minerals that characterize glacial drift are common in the sand fraction.

The high-level gravel deposits found on the upland surfaces near the Mississippi Valley bluffs, 7 miles west of

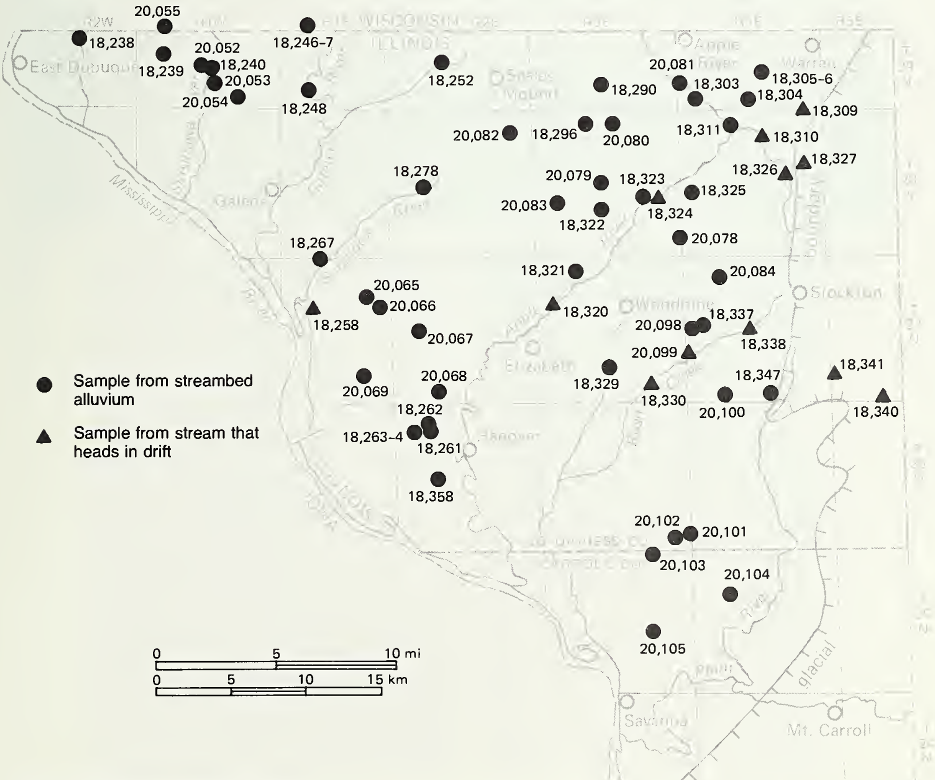

Figure 5 Samples of streambed alluvium.

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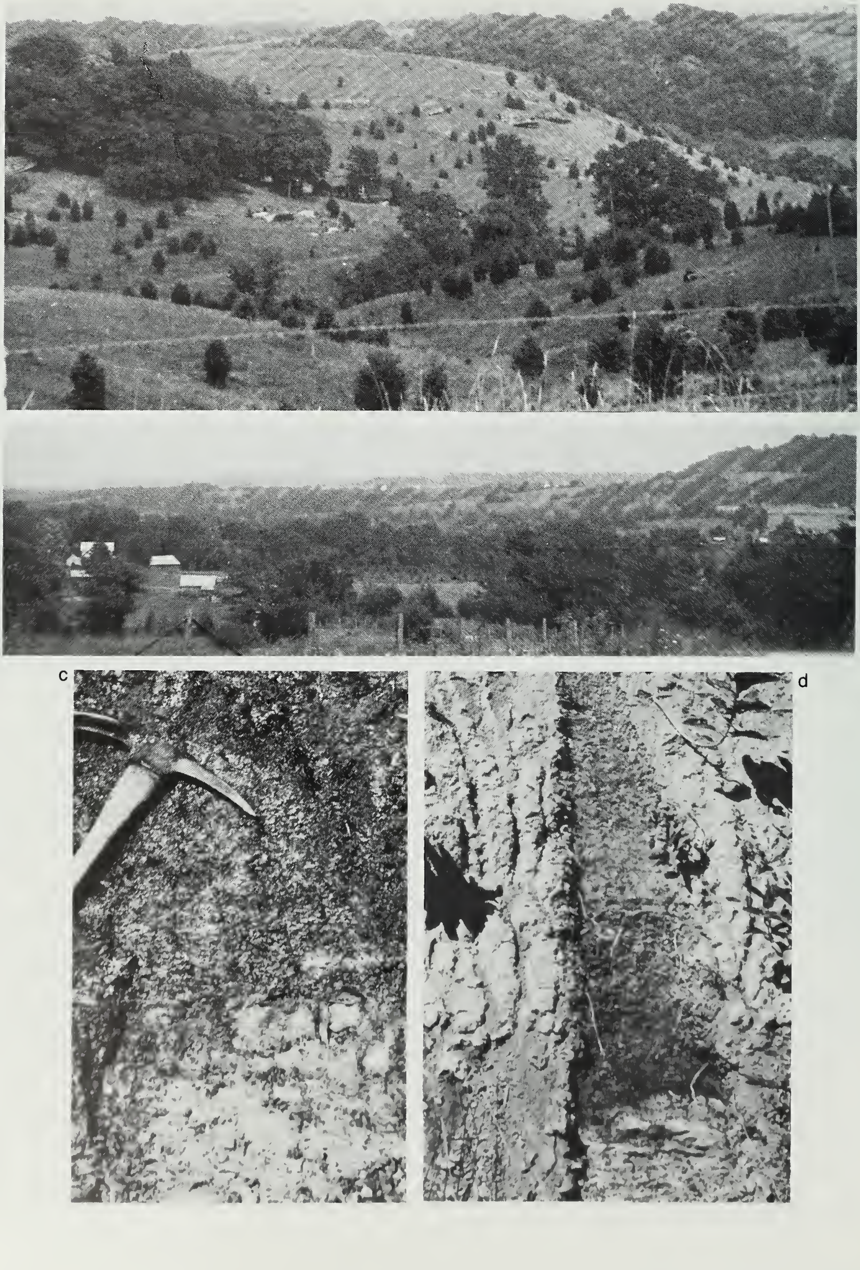
b

c

d



Galena (Willman and Frye, 1969) (fig. 3) contain a few foreign pebbles, but consist mainly of deeply etched pebbles and cobbles of dolomite from the Galena Group. The sands in the gravel contain a typical suite of glacial heavy minerals, including ferromagnesian minerals, garnet, epidote, and others not found in the local bedrock. We studied additional samples (P-18: 236-237) and confirmed the presence of the foreign material. We found no other exposures of high-level gravel, but the presence of deeply etched well-rounded pebbles in the alluvium of several streams suggests that remnants of the high-level gravel occur elsewhere in the region.

The deep etching on the surfaces of the dolomite pebbles and cobbles is far greater than etching on the dolomite pebbles in the outwash of Illinoian age. In most modern stream alluvium, dolomite pebbles are derived from the local bedrock, are angular to subangular, and have relatively smooth surfaces. Etched surfaces are common on the face of the older outcrops, but fragments of the latter are seldom an abundant component of the talus and stream alluvium, and they are not well rounded. Solution over a long interval appears to be necessary to produce the etched pebbles in the gravel; the degree of etching on the pebbles supports an early Pleistocene age.

Illinoian Stage When the Illinoian glaciers stood along the eastern side of the Driftless Area, outwash crossed the Driftless Area along the south fork of Apple River, the east fork of Rush Creek, and eastern tributaries of Plum River (fig. 3). After Illinoian glaciation, Holocene alluvium eroded or buried the original outwash deposits. The sand and gravel transported by modern streams contains foreign rocks and minerals largely eroded from the glacial drift in the headwaters of the valleys.

Wisconsinan meltwater deeply eroded Illinoian outwash along the Mississippi Valley and buried its remnants. However, during its deposition, the Illinoian outwash was the source of the Loveland Silt, which is mostly loess that was blown onto the uplands bordering the Mississippi Valley. The loess probably originally covered the entire Driftless Area, but in many areas it was entirely eroded before Wisconsinan loess blanketed the region.

Figure 6 (a) View of the deeply eroded upland surface showing the rounded surfaces of the loess above cliffs and slumped blocks of the Silurian dolomite and the smooth slopes of the Maquoketa shale to the lower erosional surface on the Galena dolomite, eastward from road at the Winston North Geologic Section, NW NW NE 11, 27N-11E, Hanover Quadrangle, Jo Daviess County. (b) View from an exposure of Silurian dolomite across the dissected Galena dolomite surface to the ridge and knob capped by Silurian dolomite, northwest across Smallpox Creek Valley, 5 miles southeast of Galena, from NW NW SW 31, 28N-2E, Scales Mound West Quadrangle, Jo Daviess County. (c) Geest overlying Dubuque Formation in U.S. 20 roadcut, Sinsinawa River East Geologic Section, SW SE NW3, 28N-1W, Galena Quadrangle, Jo Daviess County. (d) Peoria Loess overlying an intensely weathered clay, probably till, that contains heavy minerals, large chert fragments, and rare igneous pebbles, which are not present in the underlying Maquoketa shale, in a roadcut, Hanover Northwest Geologic Section, NW SW NE 8, 26N-2E, Hanover Quadrangle, Jo Daviess County.

The Loveland Silt is less than a foot thick in many exposures, but its former thickness (perhaps 20 ft at the bluffs) is indicated by an exposure of 6 feet of Loveland Silt in a 1965 roadcut 3 miles north of Mt. Carroll and about 10 miles east of the source area in the Mississippi River bottomland (geologic section 12). However, the thickness in the Mt. Carroll area may have been exceptional because the locality is southeast of a relatively wide southeast-trending segment of the Mississippi River bottomland; this type of relationship normally produced the thickest loess.

The Loveland Silt is entirely leached; in the typical oxidized profiles it is a brown clayey silt with a red or red-brown Sangamon Soil developed in its top. The upper horizons of the soil in the Driftless Area, however, have generally been eroded. The Loveland Silt overlies the geest and in places truncates it to rest directly on the bedrock formations.

Wisconsinan Stage The loess blown from the valley trains of Wisconsinan age along the Mississippi Valley consists of two units: the Roxana Silt and the overlying Peoria Loess.

The Roxana Silt is not as common in the Driftless Area as in areas along the valley farther south, largely because intensive erosion occurred when a lobe of the Wisconsinan glaciers from the northeast crossed Illinois and almost reached the Mississippi Valley south of the Driftless Area. The Roxana is commonly a chocolate-brown, leached silt (geologic section 9) distinguished by its color or texture from the red-brown Loveland Silt or the geest below and the tan, generally calcareous Peoria Loess above. In some less eroded locations, all three silts are gray because of reducing conditions. The Roxana, however, often retains a pinkish hue.

The Roxana varies in thickness, but is rarely more than 1 foot thick; it must have been entirely eroded in much of the Driftless Area before deposition of the Peoria Loess. Its thickness (4 ft) north of Mt. Carroll and its occurrence many miles east of the Driftless Area suggest an original thickness of 12 feet or more in the Mississippi bluffs.

The Peoria Loess was deposited during the latest interval of Wisconsinan glaciation. It forms the surficial material in which the modern soil is developed over almost the entire area. In the Mississippi Valley bluffs, loess is as much as 25 to 50 feet thick; it thins to generally less than 10 feet thick along the eastern margin of the Driftless Area. The upper 4 to 6 feet is generally leached of dolomitic carbonates. Carbonates form 20 to 30 percent of the unweathered loess. In and near the bluffs the loess below the Modern Soil commonly is composed of 80 to 85 percent silt, 10 to 15 percent clay, and less than 5 percent very fine- to fine-grained sand. The loess becomes more clayey and less sandy a few miles away from the bluffs.

In many places the Peoria Loess rests directly on the bedrock or geest, suggesting that less erosion of the area has occurred since deposition of the Peoria Loess than in the interval between it and deposition of the Roxana Silt. Nevertheless, the Peoria is strongly gullied on many slopes and the silt dominates the alluvial fill in all valleys. The loess and the Peyton Colluvium contain an abundance of mineral grains not native to the area but characteristic of the glacial outwash in the Mississippi Valley (P-18: 185), which indicates the presence of glacial drift in the drainage area.

The Parkland Sand (the dune sand found in the Mississippi Valley bluffs or on the uplands close to the bluffs) consists of fine- to medium-grained sand and contains heavy minerals characteristic of the glacial outwash from which it was blown. Only the presence of foreign materials coarser than medium sand indicates glaciation in the area close to the bluffs.

Silt from the loess deposits dominates the Cahokia Alluvium (the alluvium in the valleys), but most samples were a mixture of material from all the formations exposed in the drainage system. Dolomite (rarely chert) dominates the material coarser than silt. The Cahokia Alluvium is mainly Holocene, but the lower part may include late Wisconsinan fluvial deposits.

PHYSIOGRAPHY

Topography

Evidence of glacial diversion of streams is common along the margin of the Illinoian drift; the diversion of Apple River north of Stockton is a typical example. Diversions at the mouths of streams entering the Mississippi Valley are related to varying levels of the Mississippi River and not directly to glaciation. Within the Driftless Area the drainage pattern is consistently dendritic. The few diversions can be explained by bedrock structure more logically than by glaciation. The knobs and ridges do not have asymmetrical shapes that would be expected from overriding by glaciers, but erosion before Illinois glaciation was so great that such shapes would not necessarily be retained by knobs overridden during the early Pleistocene.

The general absence of drift, the unglaciated appearance of the knobs, and the absence of deformed, overthrust bedrock structures produced by ice shove—common in the glaciated area east of the Driftless Area (Doyle, 1965)—are evidence against glaciation. The lack of glacial features appears to eliminate the possibility that the Illinois part of the Driftless Area was glaciated during the Illinoian or Wisconsinan glaciations. If the upland gravels resulted from glaciation, the glaciation must have occurred before the major cycle of erosion that produced the present topography, eliminated glacial erosional features, and swept away all but mere traces of glacial sediments. The contrast is great between the Driftless Area and the area of almost continuous Illinoian glacial deposits east of the Driftless Area and the more isolated but common occurrences of till in the area of Kansan glaciation west of the area. This suggests that if the Driftless Area had been glaciated, the glaciation would have occurred probably more than a million years ago, before the Kansan glaciation. Black (1970) suggested that the Driftless Area in Wisconsin had been glaciated, but Mickelson, Knox, and Clayton (1982) recently concluded that there is no evidence to prove that the Driftless Area in southwestern Wisconsin has been glaciated.

The topography of the Driftless Area in Jo Daviess County consists generally of

- remnants of an erosional surface on the Silurian dolomite, preserved on the tops of isolated mounds and long southwesterly trending ridges that broaden in that direction from narrow ridges near the Wisconsin state line to broad flat-topped surfaces with many branching spurs near the south line of the county;
- cliffs of the Silurian dolomite at the tops of the ridges and mounds;
- steep slopes below the cliffs through the upper part of the Maquoketa Group shale, gradually flattening;
- typical rolling shale topography on the lower part of the Maquoketa;
- dolomite, on the top of the Galena Group, that is largely eroded to a mature topography but contains narrow-bottomed valleys alluviated and graded to the Mississippi Valley bottomland and terraces of Mississippi River backwater silt of late Wisconsinan age in the larger valleys.

To the south, mostly in Carroll County, the Silurian succession thickens notably. The streams have steep but less cliffy valley walls because the cliff-forming Tete des Morts Formation is absent. Also, the Maquoketa Group shale is lower on the valley slopes and is not greatly undercut below the Silurian nor prominently benched on the top of the Galena Group dolomite.

Erosional surfaces

The erosional history of the Driftless Area in Illinois and elsewhere has been studied repeatedly (Trowbridge and Shaw, 1916; Trowbridge, 1921; Martin, 1932; Thwaites, 1935; Bates, 1939; Horberg, 1950). The two erosional surfaces have been interpreted as peneplains—the Dodgeville Peneplain (Trowbridge, 1921) on the Silurian, and the Lancaster Peneplain (Grant and Burchard, 1907) on the Galena. Some have interpreted only the Dodgeville or only the Lancaster as a base-leveled surface, and others contend that both surfaces represent stratigraphically controlled erosional surfaces developed during a single cycle of erosion.

The names "Dodgeville Peneplain" and "Lancaster Peneplain" have been applied to the two surfaces in the Illinois part of the Driftless Area (Trowbridge, 1921; Horberg, 1946). More recently the use of these names in Illinois has been questioned because of uncertainties as to whether the landforms are truly erosional surfaces that correlate with those of southwestern Wisconsin. Their usage is continued in preference to introducing new terms, but we prefer to call them "erosional surfaces" or just "surfaces" rather than "peneplains."

Dodgeville Surface The Dodgeville Surface (fig 6a) slopes south-southwesterly at a fairly consistent rate of 13 to 15 feet per mile from an elevation of 1,240 feet on Charles Mound, north of Scales, the highest point in Illinois, to 850 feet on the axis of the Bob Upton Cave Syncline on the north side of the Plum River Fault Zone at Savanna (Kolata and Buschbach, 1976). The surface truncates the Silurian dolomite, which thins from about 300 feet at Savanna to less than 50 feet at Charles Mound. On the south side of the fault zone the strata are uplifted about 400 feet. The erosional surface extends across the structure and local and only small-scale interruptions show the major lithologic contacts in the stratigraphic section that is truncated.

The Dodgeville Surface within the Driftless Area suggests either a long interval of erosion to a base level or marine planation. Projection of the pre-Cretaceous surface in Iowa, Minnesota, and western Illinois would put the base of the Cretaceous not far above the Dodgeville Surface. Kaolinitic clays, like those in the Cretaceous, occur in local lenses on the top of the Silurian dolomite near Fulton, just south of the Driftless Area.

Lancaster Surface The Galena Group in Jo Daviess County dips southwesterly at an average rate of about 17 feet per mile. The Lancaster Surface (fig. 6b), largely on the Galena Group dolomite, slopes at approximately the same rate. A truly plane surface scarcely exists because the lower part of the Maquoketa Group shale remains on many of the broader surfaces, and the surfaces between the Silurian-capped ridges generally slope toward the master streams, giving the surface a slightly trough-shaped contour. This surface slopes from an elevation of about 975 feet near Scales Mound to about 800 feet near Pilot Knob, and from 1,000 feet near the town of Apple River to 700 feet near North Hanover. Narrow-bottomed valleys having a relief of 100 to 200 feet are sharply incised in the Lancaster Surface.

The formation of the bench on top of the Galena Group results from the retreat of the Silurian Escarpment and stripping of the Maquoketa Group. A single episode of erosion could have caused the dissection of the Dodgeville Surface to the bottomland of the valleys; however, the presence of geest on both surfaces suggests that each surface represents a long interval of relatively stable conditions.

ANALYSES OF STREAM ALLUVIUM SAMPLES

The alluvial material transported by modern streams in the Driftless Area was sampled to determine whether it contains rocks and minerals foreign to the local bedrock (fig. 7). Most samples were collected from small bars in the streams; a few were taken from the floodplain alluvium exposed in banks along the streams. The preferred samples were primarily sand, but their composition varied from rubbly material to clayey and mucky deposits containing only a little sand. The samples averaged about 1,000 grams. At some localities, separate samples of typical pebbles were collected.

In the laboratory a small part of the sample was taken for X-ray analyses of the clays and carbonates, but about half was used for examination of the sand and pebbles. The $<2\mu m$ fraction of the clays was analyzed by X-ray diffraction, using oriented aggregate techniques that are described in more detail in the section on the geest. Many samples contained much fine organic material that was removed by treating with Clorox. The clay minerals are unaffected by this procedure.

The exploratory nature and time limitations of the project required that a simple laboratory treatment be designed for examination of the coarse materials. Subsequently, the sampling procedures, laboratory preparation, and mineral identification could be refined to increase the effectiveness of studying stream sediment.

The treatment consisted of washing out the clay, silt, and fine sand by soaking, agitating, and repeated decanting, followed by wet sieving through No. 5 (4 mm), No. 18 (1 mm), No. 35 (0.5 mm), and No. 60 (0.25 mm) sieves; this resulted in fractions referred to as pebbles, very

Figure 7 Samples of streambed alluvium containing igneous and metamorphic rocks.

Table 1 Sample locations and clay mineral analyses of streambed alluvium.

Sample number	Location (Section, Township-Range)	Clay minerals: Expandables	Illite	Kaolinite and chlorite	Remarks*
P-18					
238	SW SW SE 15 29N-2W	49	39	12	
239	SW NW SW 20 29N-1W	52	36	12	LCV
240	SW SW NW 27 29N-1W	51	37	12	LCV
246	NE NE SW 32 1N-1E	44	34	22	
247	NE NE SW 32 1N-1E	56	32	12	G, L
248	SW SE SE 28 29N-1E	54	30	16	LCV
252	SW SW SW 21 29N-2E	53	32	15	CK
261	SW NW NE 8 26N-2E	68	26	6	
262	NE NE NW 8 26N-2E	54	33	13	
263	NW SE NE 7 26N-2E	15	70	15	C
264	NW SE NE 7 26N-2E	22	65	13	C
267	NW NE NW 3 27N-1E	53	35	12	
278	NE SE NW 20 28N-2E	41	42	17	LCV, CK, G, L
290	SE SE SE 28 29N-3E	50	40	10	CK
296	NW NW SW 4 28N-3E	52	36	12	
303	NE SE NE 31 29N-4E	50	36	14	LCV
304	NW NE SE 33 29N-4E	54	32	14	
305	SW SW NE 27 29N-4E	42	45	13	
306	SE SE NW 27 29N-4E	61	28	11	
308	NE NE NW 30 29N-5E	48	40	12	
309	NE NW NW 1 28N-4E	67	22	11	
310	SE SE SW 3 28N-4E	52	31	17	
311	SW NE SW 4 28N-4E	49	38	13	
320	NE NW NE 18 27N-3E	55	32	13	HCV, G
321	NE NW SE 5 27N-3E	47	40	13	CK, G
322	NW NE NE 28 28N-3E	52	35	13	
323	SW NE SE 23 28N-3E	51	36	13	
324	SW NE SW 24 28N-3E	50	38	12	
325	NW SE NW 19 28N-4E	53	31	16	
326	SW SW SE 14 28N-4E	63	26	11	
327	NW SW NW 13 28N-4E	49	33	18	
329	SE NE SE 28 27N-3E	41	47	12	
330	SW SW NE 35 27N-3E	45	42	13	
337	SW SW SW 17 27N-4E	46	42	12	
338	SW SW SE 16 27N-4E	43	46	11	CK
340	NW SW SW 33 27N-5E	52	40	8	
341	NW SW SW 30 27N-5E	45	45	10	
347	SE NE SW 34 27N-4E	39	52	9	
358	NW NE NE 20 26N-2E	55	31	14	
P-20					
052	NE SE NW 28 29N-1W	54	32	14	LCV, CK, G
053	NE SW SW 27 29N-1W	47	37	16	CK
054	SW NW NW 35 29N-1W	70	21	9	CK, G
055	NW SW SW 32 1N-1W				NC
056	NW SW NW 25 1N-2W				NC
057	NW SW NW 22 1N-2W				NC
065	SE NE SE 11 27N-1E	36	53	11	
066	NW NW NE 13 27N-1E	43	45	12	
067	NE NE NE 19 27N-2E	45	44	11	
068	NW NE SE 32 27N-2E	61	28	11	
069	NE NW NE 35 27N-1E	44	37	19	CK
078	SW NW NW 32 28N-4E	50	32	18	
079	SW SE SE 16 28N-3E				NC
080	SE SW NW 3 28N-3E	62	27	11	
081	SE NE SE 25 29N-3E	52	37	11	
082	SW NW SW 1 28N-2E	36	54	10	
083	SE NE SE 19 28N-3E	39	48	13	
084	SE SE SW 5 27N-4E	41	45	14	
098	NE NW NE 19 27N-4E	46	42	12	
099	NW NW NW 30 27N-4E	64	27	9	
100	SW NW SE 32 27N-4E	42	48	10	
101	NE NE SE 36 26N-3E	43	46	11	
102	NW SE SW 36 26N-3E	46	43	11	
103	SE SW NW 2 25N-3E	43	45	12	
104	NE SE SW 8 25N-4E	47	40	13	
105	SW SW NE 23 25N-3E	53	34	13	

*G, goethite; HCV, high-charge vermiculite; LCV, low-charge vermiculite; L, lepidocrosite; C, chlorite only; CK, chlorite and kaolinite; and NC, not calculated.

coarse-grained sand, coarse-grained sand, or medium-grained sand. The less than 0.25 mm fraction was discarded. After drying, the four fractions were examined with a binocular microscope and the rock and mineral composition was noted. The fractions were not weighed and only general notations of relative abundance of the materials were recorded. In some cases the 0.25 mm fraction consisted mainly of aggregates and was also discarded.

The laboratory treatment was designed to remove all the loess, which contains minerals derived from glacial outwash. The loess was present in all samples and was the prevalent material in many. Nearly all samples of the loess in the Driftless Area contained no material coarser than 0.25 mm, the lower limit of medium-grained sand. A few samples of loess and dune sand within 2 miles of the Mississippi bluffs contained medium- to coarse-grained sand, and in these areas only mineral grains from coarser fractions indicate a source other than loess or dune sand.

The principal rocks and minerals found in the samples (table 1) include igneous and metamorphic rocks, coarse quartz sand and Lafayette-type chert, etched dolomite pebbles and various types of dolomite, Depauperate Zone fossils, and clay minerals.

Igneous and metamorphic rocks

Igneous and metamorphic rocks and the heavy minerals derived from them are the most definite indication of glaciation if they are present in grains coarser than the grains in the loess. These are the only materials that do not occur in the bedrock or in other formations that could have covered the Driftless Area but now are thought to be entirely eroded. However, grains of igneous and metamorphic rocks and minerals are difficult to find even in samples from streams that begin in the area of glacial drift because they are scattered among hundreds of grains of other rocks and minerals. Therefore, the absence or lack of discovery of diagnostic grains does not necessarily indicate the absence of glaciation. Conversely, the presence of these diagnostic grains does not necessarily indicate glaciation. Man-transported material can contaminate the sediment, although other extraneous materials are usually present if contamination has occurred.

Distinctive glacial materials are common in the Illinoian tills in the bordering region (samples P-18: 328, 339, 349, 363, 364) and in the alluvium of streams flowing from the glaciated region across the Driftless Area (samples P-18: 308 to 311, 320, 324, 326, 327, 330, 338, 340, 341) (fig. 7). The distinctive glacial materials are present in the stream deposits in the 25 miles between the glaciated area and the Mississippi Valley. The only sample in which they were not present was taken at the mouth of a large tributary where dilution was likely. The localities where the glacial-type materials were found along streams that do not begin in the glaciated areas are shown in figure 5.

Several samples from localities along the western edge of the Driftless Area, within about 5 miles of the Mississippi River (P-18: 238, 254, 261, 265, 358, and P-20: 068, 069) contained granite or glacial-suite heavy minerals. This suggests that glacial materials are probably much more extensive than indicated by the previously known occurrences near Galena and Hanover. In addition, some samples in that area (P-20: 065 to 067) contained fragments of dolomitic sandstone with the glacial suite of heavy minerals similar to material in the high-level gravels.

Igneous and heavy minerals were present also in a number of streambed samples from the eastern part of the Driftless Area, particularly along tributaries of Apple River (P-18: 290, 303, 321, 322, 325, and P-20: 078). The first two samples were from levels more than 50 feet above the head of the diversion channel of Apple River at the junction with the south fork in Apple River Canyon State Park, 3 and 6 miles northwest of the junction and 6 and 9 miles west of the boundary of Illinoian drift. At the time of the diversion, a backwater lake probably filled the headwaters of Apple River to a level about 150 feet above the present floor of the valley at the point of diversion. Although it seems unlikely that medium- and coarse-grained sand would be carried so far up valley from the diversion, the possibility of ice rafting exists and leaves a question about the significance of these samples.

Apple River samples obtained farther down along Lilly Branch (P-18: 325), Welsh Creek (P-20: 078), Hells Branch (P-18: 322), and Mill Creek (P-18: 321) contained a few igneous and metamorphic grains. These samples were taken as far as 4 miles from the mouths of the tributaries at levels of 15, 45, 50, and 150 feet above the present floor of Apple River. Although not impossible, it seems unlikely that backwater reached such levels, even though much higher river levels occurred during the progressive deepening of the diversion channel. These samples, at distances of 4.5 and 9 miles west of the glacial boundary, seem more indicative of glaciation than those in the upper Apple River drainage area.

Only a few grains of igneous and metamorphic materials were observed in the two northernmost samples (P-18: 290, 303), but they were more common in the other samples. At most they were only a small fraction of one percent. Their source may be as distant as 4 or 5 miles and at much higher levels, perhaps even to the upland. Their widespread distribution in the Apple River drainage area eliminates the possibility of local contamination.

In the southern part of the Driftless Area, grains from a glacial source were found in one sample (P-20: 105) from a tributary of Plum River. The locality, about 50 feet above Plum River, is well above the highest Wisconsinan terrace, which in this region is higher than the highest level of Illinoian outwash. Sand grains as large as those in this sample are not normally found in the loess, but the locality is only 2 miles east of the Mississippi River bluffs, and the possibilities of wind transportation cannot be eliminated.

It is surprising that the grains have survived weathering if they were from a glacial source, especially if the glaciation is as old as suggested by other evidence. We inferred that partly unweathered deposits of drift that are still present were buried by loess relatively recently. Similarly, exposures of Kansan and older drift west of the Mississippi Valley contain partly weathered calcareous till that could not have been exposed to weathering until relatively recently.

Coarse quartz sand and Lafayette-type chert

Other rocks and minerals not found in the bedrock of the region but present in the stream alluvium include medium and coarse, rounded grains of quartz (fig. 8) and rounded pebbles of dark brown chert (fig. 9). These minerals could be evidence of glaciation because they are not found in the bedrock or surficial deposits of the Driftless Area in Illinois or within 50 miles of it but are common in the glacial drift of bordering regions. However, they are abundant in areas to the south in the Tertiary Grover Gravel and the Cretaceous Baylis Formation, and in comparable formations to the west and north; in the past these formations may have been present throughout the Illinois Driftless Area. They may still be present in isolated locations of the Driftless Area, but more likely the quartz and chert are erosional debris (lag) from one of the bedrock formations. Small amounts of quartz and chert are found in the geest on the Galena Group dolomite, but quartz and chert are abundant in the alluvium of the present streams, perhaps hundreds of feet below their original position. Although the Grover Gravel has not been found beneath the drift in the immediately adjacent areas, these distinctive chert pebbles are common in the drift, particularly the basal part. An old drift, if present in the Driftless Area, would probably contain an abundance of these materials.

Figure 8 Samples of streambed alluvium containing rounded and angular quartz.

Some chert-bearing samples of the stream alluvium are from drainage systems entirely within the Maquoketa Group and the upper 100 feet of the Galena Group, although neither contains chert. Chert in these areas could be evidence of glaciation, particularly if the chert is noticeably rounded. Nevertheless, the chert pebbles, particularly the white angular chert, could be a lag material let down from cherty Silurian rocks that had covered the entire region. If so, the chert in some areas would have been released from the Silurian rocks before or during the interval when the region was eroded to the level of the Galena Group dolomite, probably several million years ago. Because chert is variable and weather resistant, it cannot be considered a definite indication of glaciation until more detailed studies establish its derivation. Rounded quartz and brown chert pebbles were probably derived from the Grover Gravel because they constitute more than 90 percent of it, but only 10 percent of most tills.

Etched dolomite pebbles

The presence in some valleys of well-rounded dolomite pebbles that have etched surfaces similar to those found in the high-level gravel (glacial outwash) may also indicate the much wider extent of the outwash (fig. 10). Generally, the angular and rounded pebbles that dominate the coarser materials in most samples have smooth surfaces. Where etched pebbles are present they are mixed with the smooth-surface pebbles. The etched pebbles appear to have attained the rough surfaces while in a long-existing gravel deposit, and since then, they have not been transported far enough for their surfaces to be smoothed.

Some of the samples contained pebbles of dolomite and limestone in a greater variety of colors and textures than is characteristic of the local formations, which suggests the wide variety found in glacial outwash. This character-

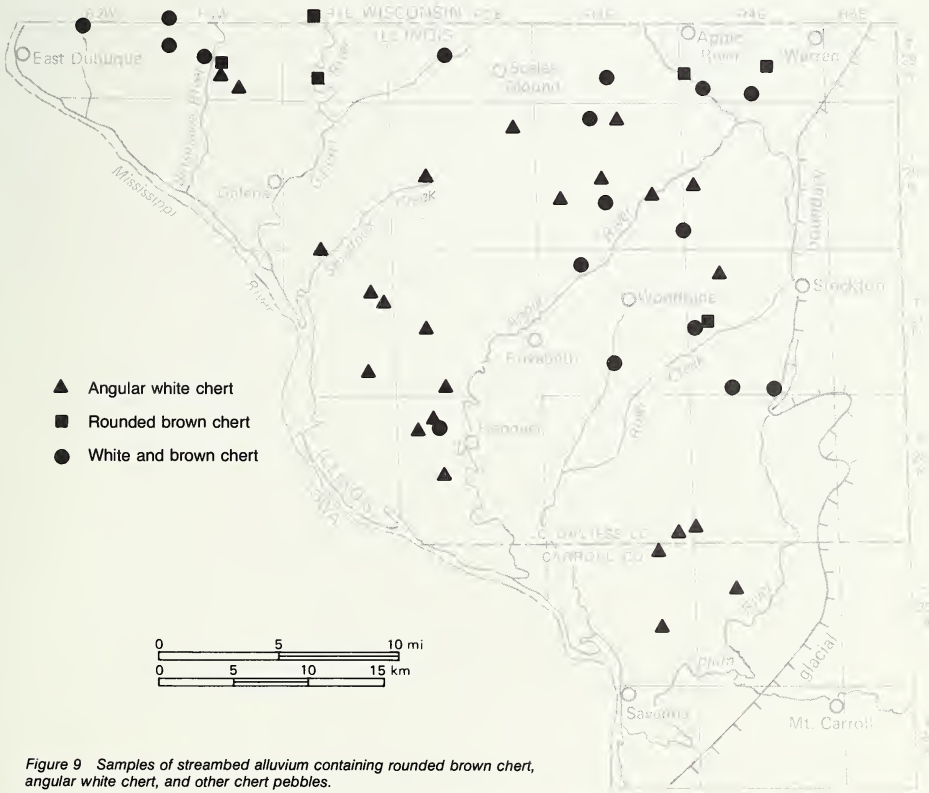


Figure 9 Samples of streambed alluvium containing rounded brown chert, angular white chert, and other chert pebbles.

istic is difficult to evaluate consistently and needs further study. Figure 10 shows the locations of samples that have an unusual variety of textures.

Depauperate Zone fossils

The distinctive small disc-shaped pellets and molluscan fossils of the Depauperate Zone at the base of the Maquoketa Group were common to very abundant in 43 of the 66 samples from streams (fig. 11). In some samples, only 1 gram of the medium- and coarse-grained sand fractions contained hundreds of the pellets.

Depauperate Zone fossils are present, although rarely abundant, in the Illinoian drift east of the Driftless Area and in the samples from streams that begin in that drift (fig. 7). The Depauperate Zone is also present in Iowa, where it probably was crossed by glaciers from either northeast or northwest.

The phosphatic composition (almost pure apatite) of the pellets accounts for their resistance to weathering; their small size and light weight enable them to resist impact fracturing and abrasion during transportation. In most localities the pellets have been moved 2 to 5 miles from the nearest occurrence of the Maquoketa Shale Group. The abundance of the pellets, considering the scarce natural exposures and the thinness of the zone (generally less than 1 ft), seems incredible. From this observation it seems reasonable to expect resistant minerals in the stream from small remnants of even very old drift.

The presence of the pellets in the stream alluvium of drainage areas entirely above the horizon of the Depauperate Zone noted in 10 localities (samples P-18: 261, 263, 347, and P-20: 066, 068, 100-104) could be evidence of glaciation. However, because neither till nor outwash is found in the area northeast of Hanover, neither appears to be a source for the concentrations found in the alluvium.

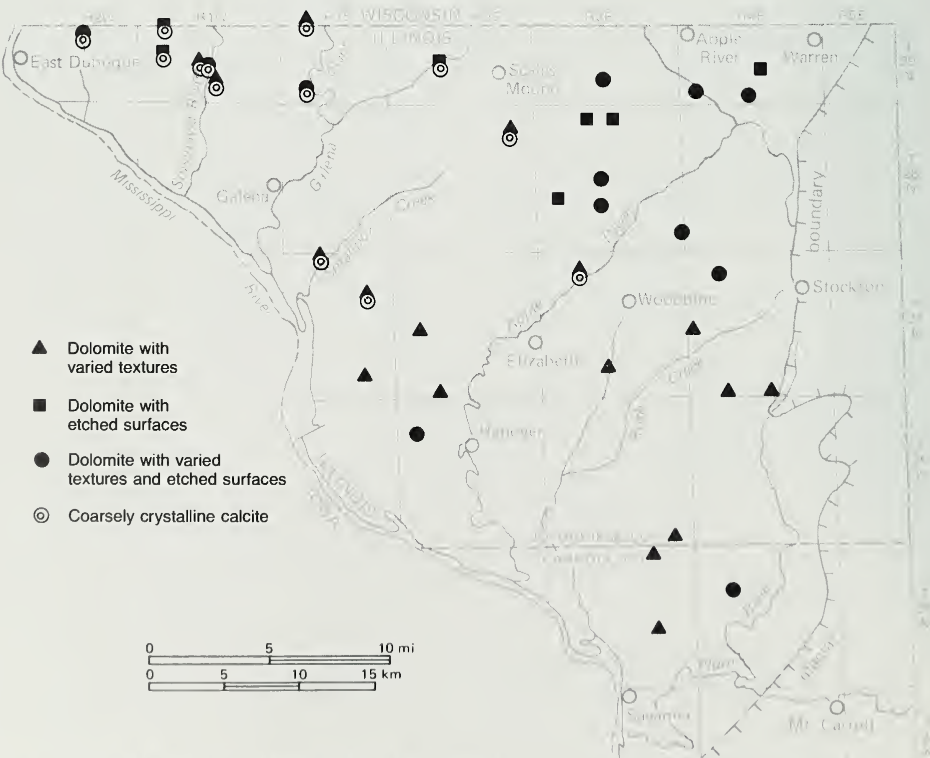


Figure 10 Samples of streambed alluvium containing etched dolomite, a variety of types of dolomite, calcareous sandstone, and calcite.

A similar depauperate fauna occurs at several higher levels in the Maquoketa shale 150 miles to the east in northeastern Illinois (Templeton and Willman, 1963; Kolata and Graese, 1983). It is possible that other depauperate zones, as yet undiscovered, higher in the Maquoketa in the Driftless Area could be a more likely source than the glacial deposits.

Silicified fossils, mostly from the Ordovician and Silurian dolomite formations in the Driftless Area, are present in many samples, but assignment to specific formations is generally difficult. A more comprehensive study is necessary to determine if fossils foreign to the region are present.

Clay minerals

The clay minerals in the streambed alluvium clearly reflect a loess source. The wide distribution of the loess and its relation to the valley sediments are evident. Because the clay mineral compositions of the loess, the Maquoketa shale, and the tills are distinct, it was possible to determine the source from which the alluvium was derived.

The bulk of the loess has a clay mineral composition of approximately 70 percent expandables, 20 percent illite, and 10 percent kaolinite and chlorite, abbreviated 70-20-10. As a result of weathering, the composition of the upper 1 to 3 feet of the loess (the A and B Horizons) was modified to that of sample P-20: 085 (65-22-13), which is typical, and sample P-20: 087 (85-9-6), which shows the local effect of gleying in a poorly drained situation. The clay in unweathered Maquoketa shale contains more than 90 percent illite and no expandables or kaolinite.

The tills are much more variable. The till (possibly Nebraskan) immediately west of the Driftless Area averages 62-14-24 (Willman and Frye, 1969); some samples of western till contained as much as 40 percent kaolinite

Figure 11 Streambed samples containing Depauperate Zone fossils.

and chlorite. The Illinoian till east of the Driftless Area ranges in composition from 20 to 70 percent expandables, 20 to 75 percent illite, and 5 to 20 percent kaolinite plus chlorite (Frye et al., 1969) (fig. 9). Samples P-18: 363 (23-61-16) and P-18: 364 (36-54-10) had compositions typical of the till. Sample P-18: 328 (62-27-11) represented a local situation where loess is mixed with the till; sample P-18: 339 (24-69-7) showed some mixing with the Maquoketa shale, which occurs directly below the till.

To determine the degree of influence of the tills on the abundance of the clay minerals in the present stream-bed deposits, we compared the analyses of 11 samples from streams originating in the area of Illinoian glacial drift with the 49 samples from streams draining areas entirely in the Driftless Area. The samples from streams from the glaciated region average 50-37-13; those entirely from the Driftless Area average 49-39-12. The difference obviously is not significant.

Most of the streambed samples from the Driftless Area contained from 45 to 55 percent expandables. A few apparently were almost entirely derived from the unaltered loess, like sample P-18: 261 (68-28-6) and sample P-20: 054 (70-21-9). At the other extreme, sample P-18: 263 (15-70-15) seemed to be dominated by clay from the Maquoketa shale; samples P-18: 246 (44-34-22), P-20: 069 (44-37-19), and a few others have an unusually high content of kaolinite.

The dominance of the clay derived from the loess apparently accounts for the similar relative abundance of clay minerals in the streams from the glaciated region and those from the Driftless Area. The differences in the sources were readily apparent in the sand fractions, where distinction is based on presence or absence of rocks and minerals not native to the area rather than on relative abundance of materials common to both areas. However, if the extensive area of Illinoian drift east of the Driftless Area did not contribute enough material to modify the clay mineral composition of the stream deposits, it is not likely that small and mostly buried glacial deposits in the Driftless Area, if present, could contribute a noticeable amount of clay minerals to the stream deposits.

The percentage of kaolinite in many stream deposits (15% to 22% in 11 of 60 samples) is nearly twice the amount typically found in the loess. Because only the western glacial drift has this much kaolinite, these analyses might be considered evidence of a glaciation older than the Illinoian. However, a large volume of drift having a high kaolinite content would be required to enrich the large volume of clay contributed by the loess. This would require much larger undiscovered glacial deposits than seems probable. Therefore, another explanation must be considered.

A possible explanation is suggested by two samples from Wisconsin, 0.5 mile north of the Illinois state line, 2 miles southeast of Hazel Green, Wisconsin. Sample P-18: 246, taken from a coarse gravel concentrate in the channel of Scrabble Branch of Galena River, had a clay mineral content of 44-34-22, the highest kaolinite content of the stream samples. The clay minerals in sample P-18: 247, collected almost directly above P-18: 246 from a sand lense in the silty floodplain deposits, were 56-32-12. Scrabble Creek drains an area of about 7 square miles where the bedrock consists of the dolomite and limestone of the Galena and Platteville Groups with a thin remnant of Maquoketa shale on the ridges. The surficial deposits consist of 4 to 6 feet of Peoria Loess and probably patches of geest on the dolomite bedrock. No potential source of kaolinite other than the loess exists, and there is no reason to anticipate differences in the mineral content between the present stream material and the floodplain alluvium.

The indications are that during transportation, the clay minerals were sorted from the loess. Kaolinite is recognized as the coarsest grained clay mineral, illite and chlorite are somewhat finer grained, and expandables are the finest. The varying distances of transportation and the conditions of deposition within the floodplain can produce different degrees of sorting: deposits in the channel show the greatest amount of sorting and deposits in the slackwater areas, the least. The scope of the sorting is indicated by the change from the composition of the loess, which commonly is close to 70-20-10. At the locality cited above, the percentage of kaolinite in the sample from the channel is probably nearly doubled by sorting, whereas the percentage in the floodplain sample is only slightly increased. Sorting of the clay minerals during transportation would reduce the possibility of recognizing clay from old drifts in stream alluvium in the Driftless Area.

Other materials

Some samples contained an abundance of clear, coarsely crystalline calcite, and a few also contained grains of sphalerite and pyrite, minerals typical of the ore deposits mined in the Driftless Area. These minerals are not indicators of glaciation and they are not uncommon throughout the mineralized region, but their abundance in a few valleys suggests that studying the stream alluvium might aid in locating drainage areas that contain ore bodies. Calcite and other minerals found in ore deposits were noted in samples P-18: 238, 239, 240a, 246, 247a, 248, 252, 267, 321, and P-20: 052, 053, 056, 065, 066, 068.

Other materials noted in the samples but not useful in evaluating the possibilities of glaciation include silt aggregates, shale pebbles, brown and black pellets, modern shells, wood, cinders, glass, and other extraneous materials.

ANALYSES OF GEEST SAMPLES

Geest, which rests on the bedrock surface and is overlain by loess, is found where evidence of an early glaciation would be expected. If the geest had been formed after an early glaciation, it might have incorporated minerals derived from the early drift, or might itself be derived from the drift. If present before an early glaciation, it might have glacial materials preserved in its top. Therefore, we conducted a preliminary study of the distribution, stratigraphic relations, and mineral content of the geest (fig. 12).

The geest in the Driftless Area of northwestern Illinois is mainly clay, much of it red and very cherty, but some gray to yellow-tan and not cherty. It is generally less than 4 feet thick. It underlies the loess, rests on relatively flat erosional surfaces on the dolomite bedrock, and most likely was formed before dissection of the surfaces. The wide distribution, fairly uniform character, and lack of stratification of the geest suggest that it is not a normal product of sedimentation.

The geest resembles the soils that characteristically occur on limestone and dolomite formations throughout the Mississippi Valley in the regions that were not eroded by Pleistocene glaciers. These soils have long been thought to be primarily the product of weathering of the carbonate rocks (Chamberlin and Salisbury, 1885; Trowbridge and Shaw, 1916; Akers, 1961; and Black, 1970). However, recent studies in Illinois (Ballagh and Runge, 1970), in Indiana (Olson, 1979; Olson, Ruhe, and Mausbach, 1980), and in Wisconsin (Frolking, 1982) have questioned whether similar clays developed as residual soils from solution of limestone and dolomite because of differences in clay mineral composition and because, in some cases, the amount of clay in the carbonate rocks is inadequate.

The clay mineral composition in both Silurian and Ordovician dolomites is almost entirely illite with minor amounts of chlorite; the clay in the less than 2μm fraction

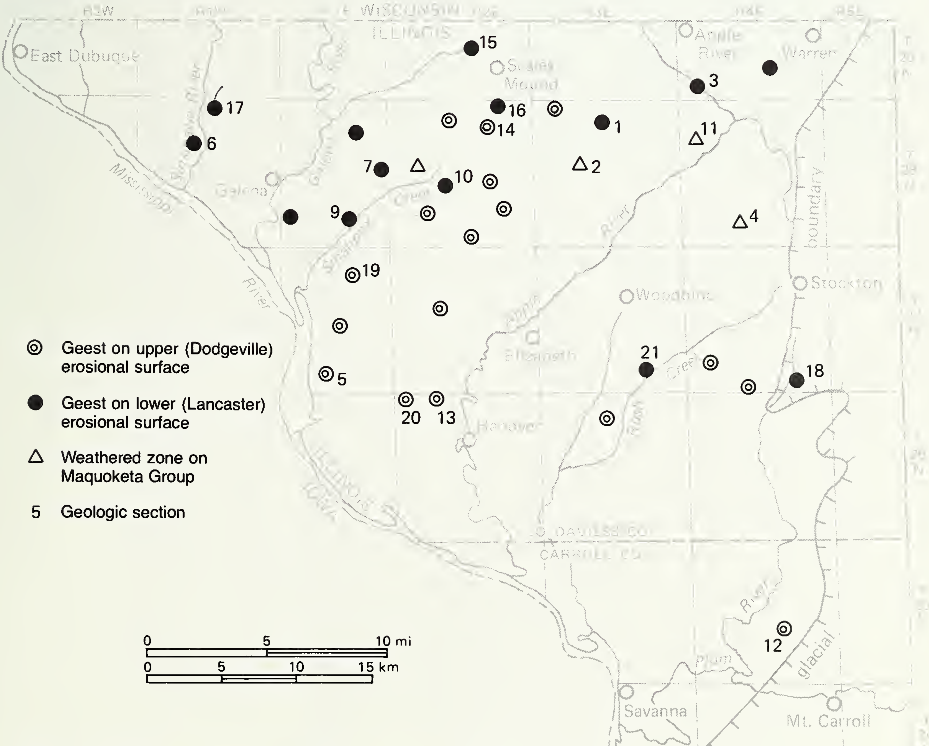


Figure 12 Samples of geest and samples of the weathered zone on the Maquoketa Group.

of the geest averages 60 to 70 percent expandable clay minerals. The question, therefore, is whether the geest is an alteration product of clay derived from solution of the dolomite, or a deposit on the dolomite.

"Geest" is a very old term credited to Baron G. Cuvier (1817), who applied it to all surficial material. In the early 1800s, J. Andre De Luc defined geest as the immediate product of rock decay in situ, differentiating it from the remaining portion of the surficial debris transported and redeposited by streams (McGee, 1891).

The geest has generally been called "residual clay," "residuum," "terra rossa," and "upland red clay." We prefer the term "geest" to "residual clay" or "residuum" because geest is a more general term, broader in materials included and less directly related to origin. "Terra rossa" and "upland red clay" are not appropriate where the clay is not red.

Because this material differs conspicuously in lithology from the underlying rocks, and generally also from overlying rocks, it merits a distinctive name. The term "geest" seems to have been used, although not widely, for material similar to that in the Driftless Area. It is a useful field term, like loess and till, that has genetic implications.

The geest is mainly a clayey residuum from the chemical weathering of carbonate rocks. It contacts sharply with carbonate rocks, and is primarily, but not entirely, their insoluble residue. In a pedogenic sense, it is part of a soil, but it generally lacks soil horizonation. Geest differs from most soils produced on other types of rocks (such as clays, shales, sandstones, and igneous and metamorphic rocks) in which chemical decomposition and physical and organic processes have produced soils whose lower horizons are gradational and clearly related to the parent rock.

None of the 120 samples of geest that were studied contained igneous or metamorphic rocks or other foreign materials that characterize the glacial deposits of the bordering region. Therefore, they did not reveal direct evidence of glaciation. The occurrence in some of the geest of well-rounded medium and coarse grains of quartz and well-rounded brown chert pebbles could be evidence of glaciation because they are not found in the local bedrock or surficial formations. As previously noted, their widespread occurrence in the alluvium of present streams supports the possibility that these materials are a lag from Cretaceous and Tertiary deposits that probably covered the region at one time, and in fact could still be present in places but buried by loess. On the other hand, the study of the clay minerals in the geest raised questions about the origin and age of the clays that could bear on their relation to the glacial deposits.

Clay mineral analyses of clay minerals in the less than 2μm fraction are described in table 2. More detailed information about the geest samples is available on open file at the Illinois State Geological Survey.

Table 2 Clay mineral analyses of geest; bedrock, loess, till, and others.

Sample number	Geologic section	Material	Clay minerals: Expandables	Illite	Kaolinite and chlorite	Remarks*
P-18						
216	17	dolomite	45	50	5	G
217	17	geest	55	29	16	G
218	17	geest	43	51	6	G
219	17	geesl	40	56	4	G
220	17	geest	62	34	4	G
221	17	geest	67	26	7	G
222	17	geest	76	16	8	G
223	17	pebbles				
224	17	geest	73	17	10	G
225	17	pebbles				
226	17	loess	59	19	22	LCV
227	17	loess	62	25	13	LCV
228	17	loess	71	20	9	
229	17	loess	68	20	12	
230	17	loess	72	17	11	
231	17	loess	67	24	9	
232	17	loess	75	18	7	
233	17	loess	72	20	8	
234	17	loess	69	22	9	
235	17	loess	69	20	11	
238		gravel	57	37	6	
237		gravel	51	42	7	
241	6	gravel	56	31	13	
242	6	geesl	70	15	15	

Table 2 *Continued*

Sample number	Geologic section	Material	Clay minerals: Expandables	Illite	Kaolinite and chlorite	Remarks*
P-18						
243	6	loess	68	22	10	
244	6	geest	65	21	14	
249	15	geest	68	23	9	
250	15	geest	72	19	9	
251	15	loess	67	21	12	
253		geest	65	22	13	
254		loess	80	13	7	
255		loess	80	13	7	
256		loess	79	14	7	
257		loess	60	27	13	
258		gravel				
259	5	geest	73	18	9	
260	8	till?	47	45	8	LCV
266		geest	60	28	12	
268	19	dolomite	5	90	5	
269	19	geest	50	32	18	
270	19	geest	71	16	13	LCV
271		geest	66	19	15	LCV
272	7	geest	64	23	13	
273	7	geest	62	18	20	LCV
274	7	geest	55	31	14	
275	7	geest	61	27	12	
276		shale	10	83	7	C
277		loess	69	22	9	
279	10	geest	54	37	9	
280	10	geest	56	34	10	
281	10	geest	54	36	10	
282	10	geest	47	42	11	
283	10	loess	77	15	8	
284	10	geest	50	42	8	LCV
285	10	geest	68	24	8	
286		geest	70	21	9	
287		geest	68	19	13	
288		geest	76	13	11	LCV
289		geest	69	16	15	LCV
291	2	shale	4	93	3	C
292	2	shale	8	87	5	C
293	2	shale	61	28	11	weathered
294	2	loess				NC
295		geest	57	20	23	
297	1	dolomite	0	100	0	G, L
298	1	geest	54	32	14	
299	1	geest	67	24	9	
300	3	geest	73	19	8	
301	3	gravel	42	36	22	HCV
302	3	pebbles				
313	16	geest	49	38	13	
314	14	geest	72	19	9	LCV, G
315	14	geest				NC
316	14	geest				NC
317	14	geest	67	19	14	LCV, G
318		geest	59	24	17	LCV, G
319		geest	79	9	12	LCV
328		till	62	27	11	
331	19	geest	21	70	9	
332	19	geest	43	50	7	G
333	19	loess	70	20	10	
334	19	loess	58	32	10	G
335	19	loess	69	20	11	
336		geest	69	19	12	LCV
339		till	24	69	7	C
342	18	geest	83	13	4	LCV
343	18	geest	48	31	21	
344	18	loess	62	26	12	
345	18	pebbles	29	63	8	G
346	18	fossils	19	73	8	
348		geest	53	29	18	LCV

Table 2 *Continued*

Sample number	Geologic section	Material	Clay minerals: Expandables	Illite	Kaolinite and chlorite	Remarks *
P-18						
349		gravel	38	47	15	
351		geest	66	25	9	
352		geest	58	25	17	
353	13	geest	65	25	10	LCV
354	13	geest				NC
355	13	loess	71	18	11	
356	13	loess	70	21	9	
357	19	loess	59	24	17	LCV, C
359		dolomite	10	84	6	G
361		loess	66	19	15	
362		loess	70	21	9	
363		till	23	61	16	
364		till	36	54	10	LCV
365		geest	78	13	9	G
366		gravel				NC
367	17	dolomite	2	97	1	G
368	17	dolomite	12	85	3	G
P-20						
059	19	geest	79	11	10	
060	19	geest	66	20	14	
061	19	geest	70	17	13	
062	19	geest	69	17	14	
063	19	geest	58	26	16	CK, HCV, LCV
064	19	loess	64	24	12	CK, HCV, LCV
070	4	shale	1	94	5	C
071	4	shale	1	93	6	C
072	4	shale	1	93	6	C
073	4	shale	1	93	6	C
074	4	shale	2	92	6	C
075	4	shale	4	89	7	C
076	4	shale	63	28	9	weathered
077	4	shale	58	33	9	weathered
085		loess	65	22	13	
086		loess	75	15	10	
087		loess	85	9	6	
088		loess	80	13	7	
089		loess	82	12	6	
090		loess	72	18	10	
091		loess	75	16	9	
092		loess	72	17	11	
093		loess	74	16	10	
094		loess	79	13	8	
095		loess	64	26	10	
096		loess	63	27	10	
097		loess	70	20	10	
107	5	geest	72	19	9	
108	5	geest	77	13	10	
109	5	geest	79	13	8	
110	6	dolomite	17	75	8	C
111	6	dol. sand	33	59	8	C
112	6	gravel	85	11	4	C
113	6	geest?	84	12	4	
114	6	geest?	84	11	5	
115	6	geest?	82	14	4	
116	6	geest?	86	10	4	
117	6	geest?	85	11	4	
118	6	geest?	81	14	5	
119	6	geest?	74	18	8	
121	8	geest?	80	15	5	
122	6	geest	82	13	5	
123	8	geest	81	13	6	
124	6	geest	81	12	7	
125	8	geest	83	11	6	
128	8	loess	71	19	10	
127	8	loess	73	18	9	
128	8	loess	68	21	11	
129	8	loess	68	21	11	

Table 2 *Continued*

Sample number	Geologic section	Material	Clay minerals			Remarks*
			Expandables	Illite	Kaolinite and chlorite	
P-20						
130	6	pebbles				
131	6	geest	63	23	14	
132	6	geest	63	27	10	
133	6	geest	64	21	15	G, L
134	17	dolomite	2	97	1	G
135	17	geest	72	17	11	
136	17	geest	59	22	19	
137	17	geest	70	18	12	
138	17	geest	70	21	9	
139	17	geest	75	14	11	
140	17	geest	70	18	2	
141	17	geest	75	14	11	
142		gravel	67	23	10	
149		shale	8	88	4	C
150		loess	72	20	8	
151	10	pebbles	52	42	6	
152	10	geest	53	37	10	
153	10	dol. sand	0	100	0	
154	10	geest	55	36	9	
155	10	geest	63	26	11	
156	10	geest	62	24	14	
157	10	geest	69	19	12	
158	10	geest	70	17	13	
159	10	loess	70	21	9	
160	16	dol. sand	9	85	6	
161	16	geest	56	34	10	LCV
162	16	geest	57	33	10	LCV
163	16	geest				NC
P-21						
313	17	geest	63	30	7	
314	6	geest?	69	23	8	
315	19	dolomite	4	96	0	
316	20	geest	75	16	9	CK
317	20	rubble	84	11	5	
318	20	loess	81	14	5	
319	8	till	15	78	7	C
320	8	till	20	73	7	C
321	8	till	76	19	5	G
322	9	dolomite	4	94	2	C, G
323	9	dol. sand	19	77	4	C, IR
324	9	geest	71	21	8	
325	9	geest	74	17	9	
326	9	geest	72	19	9	
327	9	loess	72	19	9	
328	9	loess	75	15	10	
329	9	loess	72	18	10	
339		shale	1	95	4	C
340		shale	1	95	4	C
341		shale	1	96	3	C
342		shale	9	86	5	C
345	9	silt	72	14	14	
346	4	shale	1	94	5	C
347	4	shale	1	93	6	C
348	4	shale	1	93	6	C
349	4	shale	1	92	7	C
350	4	shale	1	92	7	C
351	4	shale	1	92	7	C
352	4	shale	1	91	8	C
353	4	shale	2	89	9	C
354	4	shale	2	86	12	C
355	4	shale	7	84	9	C
356	4	shale	3	90	7	C
357	4	loess	74	19	7	weathered
358	8	till	47	49	4	
359	8	till	15	80	5	C
360	8	till	51	43	6	
361		shale	3	94	3	C, DZ

Table 2 *Continued*

Sample number	Geologic section	Material	Clay minerals: Expandables	Illite	Kaolinite and chlorite	Remarks*
P-21						
362		shale	3	94	3	C, DZ
363		shale	2	93	5	C
364	20	geest	81	13	6	
365	20	clay	2	98	0	
366	20		0	0	0	G
367	11	shale	2	96	2	C, G
368	11	shale	3	95	2	C, G
369	11	shale	6	92	2	C, G
370	11	shale	63	33	4	LCV, G
371	11	shale	76	20	4	LCV, G, L
372	11	shale	86	10	4	LCV, G, L
373	11	loess	76	16	8	
374	11	loess	76	16	8	
375	11	loess	75	17	8	
376	11	loess	77	15	8	
377	11	loess	74	17	9	
378	11	loess	76	15	9	
379	11	loess	71	20	9	
381	11	loess	75	17	8	
382	11	loess	83	10	7	
383	11	loess	83	11	6	
384	11	loess	86	7	7	
385	11	loess	84	10	6	
386	11	loess	87	7	6	
387	11	loess	82	10	8	
388	11	loess	86	8	6	
389	16	dolomite	2	95	3	C
390	16	dol. sand	18	81	1	C, IR
391	16	dol. sand	60	36	4	C, IR
392	16	dol. sand	49	47	4	C, IR
393	16	dol. sand	35	61	4	C, G
394	16	geest	55	39	6	LCV, G
395	16	geest	61	32	7	LCV, G
396	16	geest	63	30	7	LCV, G
397	16	geest	58	35	7	LCV, G
398	16	geest	54	38	8	LCV, G
399	16	geest	61	33	6	LCV, G
400	16	geest	61	30	9	LCV, L
401	16	geest	65	27	8	LCV, L
402	16	geest	65	28	7	LV
403	16	geest	63	29	8	LCV
404	16	geest	66	26	8	LCV
405	16	geest	70	23	7	LCV
406	16	geest	71	20	9	LCV
407	16	geest	71	22	7	LCV
408	16	loess	67	26	7	
409	16	loess	68	23	9	
410	16	loess	76	16	8	
411	16	loess	48	45	7	G
412	16	loess	63	30	7	G
413	16	loess	64	28	8	
414	16	loess	64	28	8	
415	16	loess	69	22	9	
416	14	dolomite	11	78	11	G
417	14	geest	80	14	6	LCV, G
418	14	geest	78	15	7	LCV, G
419	14	geest	74	17	9	LCV, G
420	14	geest	76	14	10	LCV, G
421	14	geest	77	13	10	LCV
422	14	geest	75	13	12	LCV, G
423	10	clay	23	75	2	C
424	10	dol. sand	29	66	5	G, IR
425	10	geest	66	28	6	LCV
426	10	geest	67	27	6	LCV

*C, chlorite only; CK, chlorite and kaolinite; DZ, Depauperate Zone fossils; G, goethite; HCV, high-charge vermiculite; IR, insoluble residue; L, lepidocrocite; LCV, low-charge vermiculite; NC, not calculated, sample highly weathered.

Distribution and thickness

Despite the thick cover of loess, exposures in roadcuts suggest that the geest is widespread on relatively flat areas of the Dodgeville and Lancaster Surfaces. The geest is rarely more than 4 feet thick on flat surfaces. A more common thickness is 1 to 2 feet; however, it can fill joints that have been widened by solution to as much as 10 to 15 feet. Such occurrences are more common on the Galena dolomite that underlies the Lancaster Surface than on the Silurian dolomite that underlies the Dodgeville Surface. These features are probably more abundant than is apparent from the limited outcrops, although karst features are scarce in the Driftless Area.

Weathered shale from a few inches to several feet in thickness has been found on the Maquoketa Group in outcrops and auger borings on relatively flat surfaces. No typical geest, however, has been discovered; this may be related to the relatively steep slopes of much of the Maquoketa terrane, the low permeability of the shale, and the lack of the distinctive appearance of the soils developed on the carbonate rocks. Because of the absence of geest in the broad expanse of the Maquoketa Group, the geest on the dolomites is probably not a sediment.

Geest is widespread in the Driftless Area north of Illinois in Wisconsin (Frolking, 1982). Patches of geest, generally only 1 foot or less thick, and overlying Galena dolomite, occur beneath the Illinoian glacial drift in the region east of the Driftless Area, particularly in eastern Jo Daviess County and in Stephenson County. Glaciers eroded geest from these areas. Geest is rarely, if ever, found in the large area of Silurian dolomite in northeastern Illinois where younger Wisconsinan glaciers eroded much of the bedrock, the geest, the older drifts, and even the oldest Wisconsinan drifts. The geest is usually thinner on the relatively pure dolomite (such as the dolomite of the Wise Lake Formation) and thicker on the shaly dolomite of the Dubuque Formation and the very cherty dolomite of the Blanding Formation.

Stratigraphic relations

A major unconformity separates the geest on the two erosional surfaces from the underlying Paleozoic formations. Thousands of feet of middle and late Paleozoic formations and probably some late Cretaceous and Tertiary strata were deposited and then stripped from the region during several intervals of uplift and erosion.

The geest has essentially the same strongly unconformable relations to the bedrock on both the Dodgeville and Lancaster Surfaces. On the Lancaster Surface, however, the geest rests on much older formations; accumulation of the geest began much later than on the Dodgeville Surface.

In most exposures the dolomite bedrock is fresh, except for varying degrees of oxidation and fracturing occurring at the contact with the geest. In others, solution has removed the bonds between the crystals in the upper few inches of the dolomite, leaving a friable material described as "sugary dolomite" or "dolomite sand." However, the top of the bedrock is well defined. Like the clay mineral content of the solid dolomite, clay mineral content of the dolomite sand is typically almost entirely illite. In some samples, clay washed from the sand is also nearly all illite. In others, the clay has the components of the geest; it probably is clay from the geest that has filtered downward into the sand.

The geest is overlain by Peoria Loess in more than 90 percent of the outcrops we examined. In places, colluvial material dominated by loess overlies the geest. The contact of the loess and the geest is distinct, and generally distinguished by a change from the red or gray geest to the gray-brown, leached basal part of the Peoria Loess. The chocolate brown Roxana Silt and the red-brown Loveland Silt are present in some places below the Peoria Loess. They are distinguished by their siltiness, color, and clay mineral composition. In a few localities other Pleistocene materials occur between the loess and the geest. The high-level gravels underlie the loess and truncate the geest. In the Galena West Section (geologic section 6) pebbly, greenish gray, gleyed clay, part of which is probably of glacial origin, underlies the loess and truncates red geest.

Age of geest formation

According to the stratigraphic relationships, there is a large gap between the Silurian and mid-Pleistocene during which the geest could have formed. No indigenous fossils or material suitable for isotopic dating have been found in the geest. Nevertheless, the interval in which most of the geest accumulated can be reduced greatly by considering the age of the erosional surfaces on which it occurs. The Dodgeville Surface on the Silurian rocks is probably not far below the major erosional surface on which the late Cretaceous sediments were deposited. They probably covered much, if not all, of the Driftless Area. Because the Cretaceous sediments have been eroded and the surface level might have been reduced, the surface probably is early Tertiary.

Accumulation of the geest may well have started at this time, approximately 50 million years ago, or whenever tectonic and climatic conditions caused a significant reduction in the erosion of broad areas. However, this condition may not have been reached until much later in the Tertiary. The process of geest formation then may have continued until interrupted or at least retarded by a renewed cycle of erosion, and later by the cover of loess.

Character

In different exposures, the geest ranges from more than 90 percent material of clay size to about 50 percent chert, where it might be called breccia. It is almost entirely red or red-brown on the Dodgeville Surface on the Silurian dolomite, but on the Lancaster Surface on the Ordovician (Galena Group) dolomite, it is red, yellow, or gray.

Table 3 Summary of clay mineral analyses of geest by the formation on which it occurs.

Surface Formation	Number of samples	Clay minerals Expandables	Illite	Kaolinite
Dodgeville				
Blanding				
average	25	73	16	11
range		65-80	11-25	6-16
Lancaster				
Dubuque				
average	65	62	29	9
range		40-83	13-56	4-21
Wise Lake				
average	10	67	21	12
range		63-73	15-27	8-15
Overall average		65	25	10

The overall clay mineral composition averages 65 percent expandables, 25 percent illite, and 10 percent kaolinite (table 3), although the red geest on the Lancaster Surface has a much greater range of composition than that of the geest on the Dodgeville Surface. The percentages are not entirely comparable because of unequal sampling, but it appears that the geest on the Dodgeville Surface contains less illite than that on the Lancaster Surface.

Clay mineralogy

In this paper we use the terms illite, kaolinite, and chlorite in the conventional sense. Illite includes all 10Å clay minerals that do not expand when solvated with ethylene glycol or collapse after heating to 375°C for one hour. Kaolinite is a 7Å clay mineral; chlorite, a 14Å mineral. Neither expands when treated with ethylene glycol or collapses when heated.

We use the terms "expandable clay minerals," and "expandables" to include all clay minerals that expand to about 17Å when treated with ethylene glycol and collapse to 10Å with heating. Montmorillonite (smectite) and any montmorillonite-like vermiculitic material that has altered from illite or chlorite are expandables. When treated with ethylene glycol, the diffraction peaks for montmorillonite are characterized by a symmetrical peak at 17.1Å. The diffraction peaks of the vermiculitic material are asymmetrical and pointed, and lie between 14Å ("high-charge vermiculite") and 17Å; the most common is 16.5Å ("low-charge vermiculite").

Both types of vermiculitic materials can originate from either chlorite or illite parents, and each collapses to 10Å upon heating. However, the high-charge vermiculite is not considered an expandable because it does not expand to 17Å when treated with ethylene glycol. If tests to identify expandables are based on heating, low- and high-charge vermiculite as well as montmorillonite will collapse, resulting in an inflated amount of expandables. More precision is possible if the more sophisticated methods of soil mineralogists (involving cation saturation, heating, and glycol solvation) are used; however, these methods are too time-consuming for stratigraphic correlations, which require large numbers of samples.

The calculations of clay mineral percentages are derived from the peak heights of the glycolated diffraction trace. Ideally, all calculations should be comparable, but this is not always possible. Laboratory error is in the range of 1 to 3 percent, under favorable conditions. Weathering is the principal cause of most variance in the calculated clay mineral composition of similar materials.

Alteration of clay minerals by weathering is affected by two major processes. Under reducing conditions, for example, clay minerals generally "open up" and form expanding types with large intensity peaks (Jackson, 1955). On the other hand, well-drained conditions favor the formation of "degraded" types of clay minerals and a decrease in intensity of expandable peaks. The result, therefore, is a decrease in amount of calculated expandable clay minerals and a proportional increase in amount of illite, kaolinite, and chlorite. For example, in the Peoria Loess, the following variations in clay mineral percentages may occur:

Conditions	*Expandables*	*Illite*	*Kaolinite & chlorite*
Poor drainage	80	13	7
Reducing	75	17	8
"Normal" loess	70	20	10
Oxidizing	60	27	13
Well drained	50	33	17

The average composition of "normal," essentially unweathered, dolomitic Peoria Loess, which has been traced in the bluffs along Mississippi River for about 1,000 miles is 70-20-10. Under reducing conditions, the height of the expandable peak is increased, but the ratio of the illite to kaolinite and chlorite remains 2:1. Under oxidizing conditions the intensity of the expandable peak is reduced, but the ratio of illite to kaolinite and chlorite remains 2:1. Therefore, a significant difference in composition would be indicated by a change in the ratio.

A calculated value such as 70-20-10 does not give a true picture of the clay mineral composition unless some notation about the nature of the expandables is indicated. For example, some samples of clay from the Peoria Loess and from the geest showed identical compositions of 70-20-10. However, the peak for expandables in loess is symmetrical and occurs at 17.1Å. The third-order reflection at 5.7Å indicated that all or almost all the layers are fully hydrated. The peak for expandables in geest may be asymmetrical and pointed, expanding to about 16.5Å. Because of the position of the third order reflection, this low-charge vermiculite may be considered a random type of mixed-layer clay mineral that has only 55 to 80 percent of the layers hydrated. This type of diffraction pattern can only form from the degradation of high-charge illite or chlorite, the dominant clay minerals in the Silurian and Ordovician dolomites and the Maquoketa shale. An inverse relationship exists between illite and low-charge vermiculite.

Therefore, given certain geochemical conditions, illite will "open up" to form the low-charge vermiculite found in geest. Its formation from loess is improbable, although mixing at the contact with the loess is possible. High-charge vermiculite may be an intermediate phase or may result from the alteration of chlorite. The large differences in types of clay minerals present in loess and geest seem to preclude the possibility that the geest could be formed by illuviation of clay from the Peoria Loess.

The clay in the dolomite is essentially illite with no kaolinite. However, the geest invariably contains a small amount of kaolinite accompanying the low-charge vermiculite. The kaolinite evidently was formed during the alteration of the illite. However, the alteration of any feldspar in the dolomite would also contribute kaolinite to the geest.

Because of the acid-reducing conditions associated with the opening up of the illite, the clays have distinctive colors (such as green, yellow-green, and gray) that are produced by iron in the ferrous state. Subsequently, when this material is oxidized, the iron is converted to the ferric state and the colors are red, tan, and brown. Accompanying the oxidation is the formation of the two iron hydroxides—geothite and lepidochrosite. The presence of geothite indicates only oxidizing conditions, but the presence of lepidochrosite indicates oxidation of material previously in a reduced state.

Geest on the Dodgeville Surface

Geest occurs on four formations on the Dodgeville Surface. A cherty geest on the cherty dolomite of the Blanding Formation is present on the knobs and ridges of the northern part of the area. Slightly cherty geest occurs on the slightly cherty Sweeney and Tete des Morts Formations, and noncherty geest occurs on the noncherty Marcus Formation, but these formations do not occur widely on the erosional surface.

Geest on the Blanding Formation In the geest on the Blanding Formation, the presence of abundant white chert, like that in the dolomite beneath it, leaves little doubt that the geest comes largely from solution of the dolomite. No higher formations that could have supplied the chert exist. The next younger formation (Sweeney) contains only a small amount of chert and the 200 feet of Silurian formations above that contains no chert at all, so the geest could not be a lag from the erosion of these formations. It seems unlikely that clay from solution of the dolomite would be washed from the chert rubble and that later another clay would be substituted for it. Therefore, clay from solution of the dolomite must be present in the geest.

The geest in many exposures on the Blanding Formation has a very uniform appearance. It is described in geologic sections 5, 13, 14, and 19 (appendix), and it was sampled in eight other localities.

The chert in the geest is highly fragmented and angular because of weathering, and shows no evidence of abrasion or sorting that would indicate transportation. Many 0.2 to 0.3 foot pieces, a few as much as 0.5 foot, come from beds of chert of that thickness in the dolomite. Smaller fragments that can be as small as thin flakes vary in abundance, depending on the degree of exposure to weathering and the resistance of each type of chert to fracturing caused by weathering. In the geest the major chert pieces appear to be in contact with each other, thus forming the framework of the deposit, but smaller chert fragments are also abundant in the clay matrix that fills the remainder of the space. As a result of the compaction and bonding by the clay, the geest becomes a fairly rigid material.

The relative amounts of clay and chert in the geest are difficult to estimate. The chert content seems to vary from 30 to 40 percent in the most clayey examples to 60 to 70 percent in the most cherty material. The dolomite itself rarely contains less than 10 percent chert or more than 50 percent chert. On the basis of many observations in the Driftless Area, Willman (1973) estimated that the chert constituted about 20 percent of the geest. The rest of the insoluble residue consists mainly of clay, but is slightly silty (5% to 10%) in some exposures.

The dolomite may have been much thicker, but assuming an average of about 4 feet of geest, a solution of perhaps 20 to 25 feet of dolomite would be required to provide the chert; this would release perhaps a foot or two of clay. Lateral variations in both chert and clay content make such estimates broad generalizations at best. The dolomite probably generally contains two to three times as much chert as clay, and where this is the case, an additional source of clay may be needed to fill the space between the chert fragments.

In addition to the chert, the geest commonly contains less than 1 percent of materials that may have been on the surface when the geest began to accumulate. These materials are angular and well-rounded, medium and coarse grains of quartz sand and a few well-rounded brown chert pebbles. Quartz silt is also present, but in most places its presence is scarcely apparent. The quartz sand and brown chert pebbles do not occur in the bedrock formations of the area, and, like the same materials in the modern stream alluvium, may be a lag deposit derived from Cretaceous or Tertiary formations. Quartz sand was found in 8 of 12 localities; well-rounded grains, in 5 localities. A few rounded brown chert pebbles were found in one locality; only one in another.

The clay minerals in 25 samples of the geest on the Blanding Formation average 73 percent expandables, 16 percent illite, and 11 percent kaolinite (table 2). Normally, no chlorite is found in the geest. The presence of even a small amount in a few samples suggests some mixture with loess. Three samples, containing only 65 and 66 percent expandables, were anomalies produced by weathering. If these samples were eliminated, the illite content would be reduced to only 10 percent. Four samples (P-18: 266, 269, 352, and P-20: 063) that contained only

50 to 60 percent expandables were not included in the averages because the low numbers are the result of poor diffraction traces. In 8 of 11 localities the geest contains low-charge vermiculite.

In the three localities sampled in some detail (geologic sections 5, 9, 14), there is no apparent systematic variation in composition that would suggest either a profile of weathering or a stratigraphic sequence. Basal samples include the highest expandables (80%), the lowest illite (11%), and the lowest kaolinite (6%).

In all three localities the basal sample rested directly on the dolomite. Clay in the insoluble residue of the dolomite, obtained by solution in 5 percent acetic acid, is almost entirely illite (P-21: 315, 416) and contained no kaolinite. This composition is characteristic of the clays in Paleozoic shales, limestone, and dolomites older than late Mississippian (Kinkaid Limestone). We found no compositions intermediate between the clay in the dolomite and the geest; at their contact, the illite content ranged between 11 percent and 25 percent.

However, one exposure at a fresh roadcut near St. Johns Church (geologic section 14), 2 miles south of Scales Mound, records three stages of filling of a solution-widened joint. The oldest filling, nearly vertical against the dolomite walls, is typical of coarsely cherty, red geest. Its clay mineral composition shows that it is continuous with the geest of the flat upland surface. The central part of the filling is sharply defined, tan-brown clayey silt without chert. The steepness of the contact suggests that these two materials were on the overlying surface before they settled or collapsed into the opening. The third filling is reddish brown, silty clay deposited horizontally across the central filling. It is also cherty, but the chert is in the form of small, roughly sorted pebbles, many of which are partly rounded. This unit appears to be preserved because further settling or compaction forced the filling below the bedrock surface. Peoria Loess overlies and dips slightly into the filling, perhaps a result of depositional or continued sinking of the filling.

Expandable clay minerals from the central and top fillings were very low in intensity, but the ratio of illite to kaolinite remained the same as in the other geest samples. This indicates there was no change in the extent of alteration of the illite, and the composition corrected for low intensity would be close to that of the other geest samples. A sample collected from the top unit (P-21: 332) also was not entirely typical. It has a high content of kaolinite (66-18-16), which suggests that the colluvial material was derived from a different source than the geest or represents a more advanced stage of alteration than the normal geest.

No equivalents of the middle and top fillings were observed elsewhere. The noncherty silt could be a deeply weathered, old loess, part of an extensive deposit that is now preserved only in such solution/collapse features. The third filling, across the top, is a colluvium. It also may represent a widespread sheet because it contains materials, particularly brown chert pebbles, that are rarely present in the geest. They, as well as many white chert pebbles, are rounded, indicating a significant amount of transportation not shown by chert fragments in the typical geest. Because this exposure is on the highest surface in that locality, the sources of the foreign pebbles and other remnants of the colluvium most likely were eroded before deposition of the loess. We can infer that these events took place before dissection of the region. The strong red color and clay mineral composition also suggest that the material was deposited long before the overlying Peoria Loess.

Geest on the Sweeney Formation We sampled geest on the Sweeney Formation in three locations, including the Winston South Section (geologic section 20) northwest of Hanover. Two samples of the geest from this section (P-21: 316 and P-21: 364) have compositions (75-16-9 and 81-13-6) similar to the geest on the Blanding. The latter composition is almost identical to the composition (80-14-6) of the basal sample of the geest on the Blanding in the St. Johns Church Section (geologic section 14). However, the geest on the Sweeney Formation, like the dolomite, contains little chert. Sample P-23: 316 was unusual because it contained a small amount of chlorite.

In the Winston South Section a dark brown, colluvial, cherty rubble (P-21: 317) is overlain by a clayey silt (P-21: 318); both overlie the geest. Their clay minerals are similar in composition (84-11-5 and 81-14-5) to those of the geest. The clay in the rubble may be partly derived from the geest; the upper, silty clay may be mainly weathered loess. The high content of expandables suggests that the silt accumulated under gleying conditions. Because the section is on a narrow ridge top near the Mississippi River bluffs and because the river was entrenched in the early glacial period, conditions were probably not favorable for the accumulation of colluvium and for gleying. This suggests that the silt and colluvium are older than the Peoria Loess, which has been eroded from this exposure.

Ten feet below the top of the dolomite, a narrow joint in the Sweeney Formation at this exposure contains white clay (P-21: 365) that is almost pure illite (2-98-0). The upper part of the joint is filled with red geest and dolomite rubble. The white clay contains a small amount of white chert. The only available source for the white clay is the dolomite. It appears that clay, freed by solution of the dolomite, has been carried into the joint. It perhaps originated partly from solution of the walls of the joint, which would require the solution of many feet of dolomite above the present top of the bedrock. The composition is unusual because the clay found in nearly all solution-widened joints has the geest composition.

Geest on the Sweeney Formation was sampled at two other localities. At one locality, 3 miles northwest of Schapville, the expandables in one sample (P-18: 318) were low in intensity and the composition (59-24-17) was anomalous. At another locality, 2 miles west of Schapville, the composition of sample P-18: 351 (66-25-9) was just within the general range of the composition of geest on the Dodgeville Surface, but the broad diffraction pattern of the expandables indicates that it also has been considerably modified by weathering.

Geest on the Tete Des Morts Formation Geest on the dolomite of the Tete des Morts Formation was sampled (P-18: 295) 2 miles southeast of Scales Mound. The dolomite and geest contain very little chert, unlike the geest on the cherty Blanding Formation exposed nearby. The clay mineral composition (57-20-23), like that of sample P-18: 319 on the Blanding, is unusual in the greater content of kaolinite than illite.

Geest on the Marcus Formation The thin geest (0.1 ft thick) on the dolomite of the Marcus Formation in an exposure northeast of Mt. Carroll (geologic section 12) was described as residuum in 1965. This occurrence reflects the exceptional purity of the Marcus, which commonly has less than 2 percent insoluble residue. However, the geest may have been thicker and partly eroded before deposition of the Loveland Silt. Neither the geest nor the dolomite contains chert. Lafayette-type gravel is present in nearly all sections. White chert that has some partly rounded fragments is more common and more abundant than the brown chert. The source of the white chert most likely is the Blanding Formation, which is 250 feet higher stratigraphically and at some sections no nearer than 4 or 5 miles. Because there is no evidence of sorting, it is unlikely that colluvial or stream action transported the chert from present exposures of the Blanding; the chert is more likely a lag from the retreating Silurian Escarpment.

Some quartz sand is present in the geest on the Lancaster Surface, as on the Dodgeville Surface. None was found in geologic section 16, and it is scarce in geologic sections 1, 3, 18, and 21. A few well-rounded grains were present in most sections, but they were common only in geologic section 17. Again, there is no source for such sand in the bedrock; it is most likely a lag from the Cretaceous or Tertiary gravel.

The possibility that these sand grains were wind-blown from the Mississippi Valley seems unlikely. They are coarser than any we observed in the Peoria Loess, and they show no relation in abundance or size to those in the valley. Because geest was probably formed long before the Mississippi Valley, wind-blown origin from that source is most unlikely. Also, a wind-blown origin would not account for rounded brown chert pebbles and other coarse constituents of the geest.

Geest on the Lancaster Surface

Geest is found on two formations on the Lancaster Surface: the Dubuque and the Wise Lake.

Geest on the Dubuque Formation Most of the exposures of geest on the Lancaster Surface examined in this study are on the Dubuque Formation at the top of the Galena Group (geologic sections 7, 9, 16, 17, 18, 21). The geest rests on surfaces cut into the dolomite from a few feet to as much as 20 feet. Large areas of the erosional surface still have a thin cover shale of the Maquoketa Group, but the contact with the shale was not exposed at any of the geologic sections.

The most striking constituents of the coarse fractions washed from the geest on the Dubuque and never found in the geest on the Dodgeville Surface are minute fossils from the Depauperate Zone of the Maquoketa Group. Studies of the stream deposits indicated that such fossils probably occur at several horizons in the Maquoketa shale, but most likely those observed in the geest come from the basal zone that is the most continuous. Its stratigraphic position is not far above the erosional surface on the Galena Group dolomite.

In the Maquoketa Group the fossils commonly occur in one or more well-consolidated beds that are generally dolomitic. Some contain considerable argillaceous material, which is almost 100 percent illite, like the clay in the shale (P-21: 361-363). However, in the geest the fossils are surrounded by clay that has a high-expandable composition similar to that of the geest. Therefore, the fossils are either a residual constituent, like the sand and chert, incorporated in the clay residue from solution of the dolomite, or they are embedded in clay that is an alteration product of the Maquoketa shale, unrelated to the solution of the underlying dolomite. Where the clay also contains quartz sand or chert pebbles, it is unlikely that the clay is derived mainly, if at all, from the Maquoketa shale.

The variable distribution of the chert in the geest on the Dubuque Formation is well exposed in the Sinsinawa River East Section (geologic section 17). The exposure to the east is in a slight depression and probably is a filled solution cavity. It contains chert in the lower 1.5 feet, neither chert, sand, nor fossils in the next foot, and more chert in the upper 1.6 feet. Because the units are well defined, differ slightly in shades of gray, and the upper units are slightly silty, the deposit appears to be essentially a sequence of sediments, marked by a strong red-brown weathered zone at the top and sharply separated from thin but typical Roxana Silt above. Depauperate Zone fossils were observed only in the basal sample, but that position is 15 to 20 feet below the top of the Dubuque Formation. They are at least that much lower than the base of the Maquoketa Group, which may be present in a slightly higher area only a few hundred yards southeast of the exposure.

In an exposure on a relatively flat surface about 100 yards west of the filled depression just described, a little white chert occurs in the top of the red-brown geest. In this position the chert could have been a lag deposit on the dolomite; it now is separated from the dolomite by clay from solution of the dolomite. This is one of the sections where the nearest possible source for the white chert is several miles away. Chert occurs similarly at the top of geologic section 16, south of Scales Mound; this strongly suggests that the geest is an in situ accumulation.

Depauperate Zone fossils were found in all the sections containing geest (but not in all samples) on the Dubuque Formation that were studied in some detail (geologic sections 7, 9, 10, 16, 17, 18, 21). None was found in the samples from four geologic sections and two other localities sampled on the Wise Lake Formation. The abundance of the Depauperate Zone fossils varies considerably from section to section. This may be related to the depth of truncation of the top of the Dubuque Formation.

In the Scales Mound South Section (geologic section 16), where the Depauperate Zone fossils are abundant, the base of the geest appears to be on a surface near the top of the Dubuque Formation. Even there, the basal 4 inches have silicified crinoid stems from the dolomite and no Depauperate Zone fossils. A few Depauperate Zone fossils are mixed with crinoid stems in the next 4 inches and then become more abundant in the upper 12 inches. We inferred that at least the lower 4 inches of the geest (48-45-7) and possibly the next higher 4 inches (63-30-7) are products of solution of the dolomite. Although the clay in the upper part of the geest may also come from solution of the dolomite, the abundance of the fossils suggests that the clay may be mainly from the Maquoketa Group. In either case, the original clay material was illite, and it has now been altered to the geest composition.

A series of samples (P-21: 393-407) taken at 1-inch intervals at this section showed variations in content of expandables ranging from as low as 59 percent to as high as 71 percent (table 2). The alterations in composition suggest that there is no soil profile and that illuviation is not a major process in accumulation of the geest.

The presence of chert pebbles in the base of the loess above and the absence of a strong red color at the top of the geest suggests that the geest may have been thicker and the red zone eroded before it was covered by the Peoria Loess.

Although there is no evidence of soil horizonation development, the clay minerals in the geest on the Dubuque show a general, but not uniform, upward decrease in the percentage of illite that falls roughly into three zones. For convenience we call these zones X, Y, and Z, with X at the base. These zones may be gradational and to some extent overlapping. All three occur only in the Sinsinawa River East Section (geologic section 17), but zones present are never out of proper sequence.

Zone X occurs in geologic sections 10, 16, 17, and 21. It is characterized by relatively high illite; 14 samples averaged 52-40-8, with expandables ranging from 40 to 57, illite from 33 to 56, and kaolinite from 4 to 13. It is light tan or gray in the field, but the less than 2µm fraction on slides commonly is yellow or tan. It is never orange or red.

Zone Y occurs in geologic sections 10, 16, and 17 and is characterized by lower illite. The average composition of 20 samples was 62-30-8; the expandables ranged from 61 to 71, illite from 20 to 35, and kaolinite from 4 to 9 percent. This zone contains materials that are more tan than those in zone X.

Zone Z occurs in geologic sections 7, 9, and 17 and is characterized by the lowest content of illite, a strong red color, and close similarity in appearance and composition to the geest on the Dodgeville Surface. In some exposures zone Z is the only zone present. The average of 11 samples was 72-18-10; the expandables ranged from 70 to 75, illite 14 to 21, and kaolinite 8 to 12 percent. On the diffraction slides the color of the less than 2µm fraction is orange-red.

In the Lake Galena Section (geologic section 10) samples (P-18: 279-282) are typical of the X zone; samples from a higher exposure at the south end of the roadcut (P-21: 425-426) have the composition of the Y zone. In part of this exposure a very silty clay (P-20: 155-158) overlying geest (P-20: 154) may be an old loess because the clay contains higher kaolinite and lacks low-charge vermiculite. It is brownish tan rather than red, and it does not contain Depauperate Zone fossils, which are abundant in the other samples.

In this exposure the upper 4 to 6 inches of the dolomite is weathered to a sand, and below it a thin lens of clay (P-21: 423) has a composition of 23-75-2. It is mainly an unaltered insoluble residue of the dolomite mixed with a moderate amount of geest.

A few anomalous analyses (P-18: 217, 273, 343) of geest on the Dubuque Formation are characterized by exceptionally high kaolinite (15 to 21%). Two samples—one stongly weathered sample that was probably from zone Z (P-18: 272), and another that was extreme in all respects (P-18: 342)—were not included in the averages, but they have a bearing on the origin of the geest, as discussed later.

Geest on the Wise Lake Formation Geest on the Wise Lake Formation is described in geologic sections 1, 3, 6, and 15. The clay minerals in the geest in 10 samples averaged 67-21-12; expandables ranged from 63 to 78 percent, illite from 16 to 17 percent, and kaolinite from 7 to 15 percent. It appears that the amount of illite is significantly lower and the kaolinite higher in the geest on the Wise Lake than on the Dubuque, although the samples were scarcely adequate to demonstrate the relationship. Most of the geest on the Wise Lake has a strong red color and matches the low illite zone Z on the Dubuque dolomite.

In the Apple Canyon Lake Quarry Section (geologic section 1), the geest on the top surface of the dolomite (P-18: 299) has a typical zone Y composition (67-24-9); geest in a joint (P-18: 298) has a significantly lower content of expandables but a nearly identical illite-kaolinite ratio (54-32-13). This indicates that the clay from the joint may have been washed in from a weathered zone formerly present but now eroded from the geest at this location.

Geestlike material

Material that is mostly clay and resembles geest is poorly exposed in a roadcut northwest of Hanover (geologic section 8). It contains an abundance of chert, which could not come from the underlying Maquoketa shale, and rare igneous and metamorphic pebbles. Heavy minerals characteristic of the glacial drift are common in the sand fraction. The material is probably weathered glacial till similar to that described from a nearby locality (Trowbridge and Shaw, 1912). Five samples (P-18: 260, P-21: 320, 321, 358, 360) were all close to the average of 49-42-9. The other two samples showed extreme variation (15-80-5 and 79-9-12), which suggests inclusion in the till of high-illite Maquoketa shale and an extreme alteration product in which illite and kaolinite are reversed in abundance.

An exposure 3 miles west of Galena (geologic section 6; samples P-20: 112-125) contains many angular fragments of white chert, well-rounded pebbles of brown chert, and rounded grains of quartz sand. The presence of heavy mineral grains, like those in the glacial drift in the upper two samples, suggests possible glacial origin. Like the geest on the Dubuque Formation, the samples all contained Depauperate Zone fossils, were light gray to greenish gray, and had a central black band. This band suggests stratification or possibly zone staining; the green color and unusually high content of expandables suggests alteration in a reducing environment.

Because this material overlies and appears to truncate Z zone-type red to red-brown geest on the top of the dolomite (P-18: 242, P-20: 131-133), it is younger than the geest. It probably is related to the early Pleistocene high-level gravel and lacustrine clay in the Dixon North Section (Willman and Frye, 1969), which is 4 miles northwest.

Weathered zone on the Maquoketa Group

We examined the weathered zone on the shale of the Maquoketa Group in roadcuts and auger holes and compared it with the geest on the dolomite formations. In all the exposures the thin weathered zone on the shale still physically resembles the shale and not the geest. However, the clay minerals in the most weathered part are present in essentially the same proportions as in the geest.

In an auger hole on a relatively flat area 2 miles southwest of Millville (geologic section 11), the basal one foot (P-21: 367-369) was typical high-illite shale with no kaolinite. The shaly structure of the next higher 6 inches (P-21: 370) was mostly destroyed. The clay mineral composition (63-33-4) shows major alteration of the illite to expandable minerals (low-charge vermiculite), the introduction of kaolinite, and the presence of both lepidocrosite and goethite. The presence of lepidocrocite indicates reducing conditions followed by oxidation. This interval and the next 6 inches (P-21: 371) are the B horizon of the soil profile. The upper 6 inches contains secondary calcite probably derived from the Peoria Loess above. The next higher sample (P-21: 372) contained white chert and appeared to be a colluvial silty material, essentially the A horizon on the shale.

Because the nearest exposure of chert is in a small knob more than 1 mile northeast, and a third of that distance has a slope toward the knob, the presence of chert can be explained only as a lag from a retreating escarpment.

In a roadcut at the west end of Benton Mound (geologic section 4), the lower 12 feet of the shale is essentially composed of illite (P-20: 070-075). The uppermost sample (P-20: 076) was strongly altered greenish gray shale that has almost the same composition (63-28-9), as the weathered shale in the Millville Southwest Section (geologic section 11). Probe samples somewhat higher on the slope (P-21: 346-356) also indicated low expandables at the top, but the more strongly altered zone apparently was truncated before deposition of the overlying Peoria Loess (P-21: 357).

A thin weathered zone on the shale is exposed on a gentle slope, 1 mile west of Guilford (P-18: 176, 177, and P-20: 149, 150). At the top of the shale, a 1-inch zone, dominantly greenish gray, contains a few white chert pebbles and retains only slight shaly structure. Its clay mineral composition (10-83-7) is only slightly modified from that of the Maquoketa shale 6 inches below (8-88-4). The basal 2 inches of the overlying loess has a few chert pebbles and is colluvial. Its clay mineral composition (69-22-9) is similar to that of a sample of the loess, typical of the Peoria Loess, 1 foot higher (72-20-8). Samples from a similar section 2 miles north of Elizabeth (P-21: 339-342) indicated that the content of illite was high up to the contact with the loess. The shaly structure was mostly destroyed in the upper foot, leaving a greenish gray silty clay.

In a roadcut through a ridge of Maquoketa shale, the Apple Canyon Lake Section (geologic section 2), typical high-illite shale (P-18: 291-292) is overlain by 1 foot of weathered shale (P-18: 293). The composition of this shale (61-28-11) shows alteration of the shale comparable to that in the Millville auger boring (geologic section 11).

Because the Peoria Loess rests directly on most of the surfaces of the Maquoketa, they probably were eroded during the Wisconsinan. The thin profiles of weathering on the Maquoketa shale were developed after erosion of the Loveland and Roxana Silts and before deposition of the Peoria Loess; therefore, they do not represent a long interval of time. There was no trace of the strong red color that characterizes much of the geest or might be expected of even a Sangamon Soil. More deeply weathered soils may occur on flat upland surfaces, but none was among the few exposures of the Maquoketa observed in the present study. However, the profiles show that the illite of the Maquoketa shale typically alters to a material that has a clay mineral composition like that of the geest. This material is the first alteration product and has a sharp boundary at its base.

Figure 13 Looking north from U.S. Route 20 on Terrapin Ridge, one mile east of Elizabeth, Jo Daviess County, Illinois. Slope is developed on shale of the Maquoketa Group.

ORIGIN OF THE GEEST

To discover the origin of the geest, we must determine the source of the clay. The clay might have originated (1) as a deposit on the dolomite, (2) as a Beta soil horizon, (3) from airborne dust, (4) by colluviation from the Maquoketa shale, or (5) from solution of the dolomite formations.

Deposit on the dolomite

The sharp contact of the geest with the underlying dolomite, the difference between the clay minerals in the geest and the dolomite, the isotopic evidence of different sources (Frolking, 1982), and the apparent lack of an adequate quantity of clay in some formations to account for the thickness of the geest suggest that the geest could be unrelated to the underlying dolomite.

Colluvial movement of the geest into solution-widened joints and solution-collapse features on the surface of the dolomite have given a weak layering to the geest in a few exposures. These are deposits on the dolomite, but there is no indication of sorting of the mixed clay and chert fragments that would require any appreciable transportation by running water.

The presence of the geest on the dolomite formations but not on the intervening Maquoketa Group eliminates the possibility of any continuity between the geest on the two erosional surfaces, whether wind-blown or water-laid. It would be particularly difficult to have a sediment deposited on the Galena Group that did not overlap the Maquoketa Group. The geest appears to be much older than any known glacial deposits that could be a source. Because it lacks the gradations in character and the high content of quartz silt typical of loess, its primary origin as loess is unlikely. The geest has the regional continuity of a soil, and the development of different soils on the dolomites and on the intervening shales explains the relations better than deposition as a sediment.

Beta soil horizon

Ballagh and Runge (1970) suggested that material probably equivalent to the geest in the Ashdale soil in Stephenson County, Illinois is a Beta horizon produced by illuvial concentration of very fine-grained clay on the surface of the dolomite. Ballagh and Runge (1970) dated carbon from the middle and base of the clay-rich horizon that overlies dolomite in the Ashland soil profile. The middle portion was dated as 9,330 ± 190 years B.P.; the base, 4,270 ± 95 years B.P. Ballagh and Runge concluded that these results indicate that clay-rich organic matter complexes can move through the Beta horizon of the soil to the contact with the dolomite. These dates, however, do not support interpretation that the entire layer of geest has been moved by this process. If the geest is a Beta clay it probably came from a source eroded long before the Peoria Loess was deposited in the Driftless Area, before about 23,000 years B.P.

Illuviation and other soil processes causing mixing may account for the uniformity of some of the geest, particularly that on the Blanding Formation. It does not seem to be an essential process in the gray geest on the Galena dolomite, which has a zonation more related to differences in degree of clay mineral alteration, either in place or by derivation from nearby sources. It seems unlikely that the illuviation and replacement that formed the Beta horizon can operate regionally under differing drainage situations to produce a continuous and fairly uniform material like the geest.

Airborne dust

The thin geest on the Wise Lake dolomite may include a significant amount of airborne clay. There are not many exposures of geest on the Wise Lake, and the geest appears to be less than half as thick as that on the Dubuque dolomite. The Wise Lake is so pure that only 1 foot of geest would require the solution of 50 to 100 feet of dolomite, which is more than is available at most localities. Two to 4 inches of clay is more likely the maximum to be expected from solution of the section of the dolomite above the geest at most exposures. An additional source, therefore, seems necessary.

There are two possible sources for additional clay on the Wise Lake. It could have been airborne or let down from either the shaly Dubuque Formation or the Maquoketa shale. Where the Wise Lake is the top formation on the Lancaster Surface, the margin of the Maquoketa is generally several miles distant. The Dubuque is much closer and geest on the surfaces near the top of the Wise Lake could have received some colluvial clay from the solution of the Dubuque dolomite. The general absence of Depauperate Zone fossils, so common in the geest on the Dubuque, also suggests that the Maquoketa had been widely eroded from the vicinity of the Wise Lake exposures before the formation of the geest.

If much of the clay on the Wise Lake is mainly airborne, we should find more evidence of it on the Maquoketa shale. Considering the unknown amount of erosion of the geest preceeding the deposition of the overlying loess, any estimate of thickness is certainly speculative. The clay mineral composition of the geest on the Wise Lake is so close to that of the geest on other formations that addition of the airborne clay may not be recognizable because of similarities in amount and composition.

There is an adequate source of illite in the Dubuque Formation to account for the thickness of the geest on that formation; the additional wind-deposited clay would add to the volume but not significantly change the clay mineral composition. On the Silurian surface, where there may be a deficiency in volume of clay needed to fill the spaces between the chert fragments, the slowly accumulating airborne materials may be mixed by normal soil processes with the clay from solution of the dolomite.

The clay minerals in the Pleistocene loesses occur in essentially the same proportions as those in the geest, although they differ in age. This would be expected because most of the outwash in the glacial valley trains, which is the source of the clay in the loess, came mainly from surficial material eroded by the glaciers. The outwash is probably comparable in composition to the surficial materials available to the winds in preglacial times.

The composition of much of the glacial drift in the areas bordering the Driftless Area (like sample P-18: 328) and particularly in tills of the older drifts, is also very close to that of the clay in the geest (Frye et al., 1969). Because the tills are calcareous and slightly, if at all, modified from their composition when picked up by the glaciers, they also indicate the general composition of the surficial materials of that time after homogenization by glacial transportation.

The surficial materials in Tertiary time were probably similar to geest. The landscape of late Tertiary time would have had a soil and vegetation cover and this would certainly have caught dust from local and distant sources. The dust may have been the principal component of the A horizon of the soil and would have contributed clay to the underlying materials. We have no way to estimate the amount of such material in the geest, but there can be little doubt that it is present (Seyers et al., 1969).

Colluviation from the Maquoketa shale

Colluviation from the Maquoketa shale could have contributed clay to the geest only on the Lancaster Surface. The lower part of the soil on the Maquoketa below the Peoria Loess certainly does not have characteristics of age that would be expected on a Tertiary or early Pleistocene surface. The general absence of the Roxana and Loveland Silts, which no doubt were deposited in the area, indicates the vigorous erosion that took place before disposition of the Peoria Loess. Presumably erosion would have been more effective on the shale surfaces than on the dolomite. Any contribution of weathered Maquoketa to the geest, therefore, probably did not come from the exposures we examined, but from a soil long since eroded.

The presence of Depauperate Zone fossils in the geest on the Dubuque dolomite indicates that the Maquoketa shale was nearby. The question is whether the fossils were left as a lag on the surface of the dolomite and then incorporated in the geest and mixed through it by soil processes, were in weathered Maquoketa shale that colluviated onto the dolomite surface, or were in an in situ soil at the shale-dolomite contact. All situations appear to exist. In some sections on the Galena dolomite, particularly where the geest is red, there is no indication of a contribution from the Maquoketa shale.

Solution of the dolomite formations

Origin of the geest by solution of the underlying dolomite is strongly favored by the facts that the geest is cherty on the cherty formations, less cherty on the slightly cherty formations, and not at all cherty on the noncherty formations, and that the geest tends to be thicker on the argillaceous or cherty formations than on the pure dolomite.

The source of the chert in the geest on the Dodgeville Surface is without question the underlying Blanding Formation. Consequently, most of the clay in the geest, if not all, must come from that formation. The most likely source for the remainder is airborne clay, the quantity of which is difficult to estimate.

On the Lancaster Surface much of the geest is on the Dubuque Formation, which is argillaceous dolomite and is an adequate source for the clay in the geest. However, the abundance of fossils from the Depauperate Zone of the Maquoketa shale suggests that in places near the thinned margin, the shale may have been a major source of the clay.

Interpretation of the geest as derived from solution of the dolomite requires alteration of much of the illite from the dolomite to expandable clay minerals and kaolinite. Poor drainage and an organic-rich soil, fostered by low permeability of the dolomite, could supply the acid-reducing conditions favoring expansion of the illite. Under these conditions the original color of the geest was probably gray or greenish gray. The frequent presence of lepidocrocite, which has been shown to result from oxidation of previously reduced material, suggests that the red color formed later under better drainage that would have resulted from dissection of the erosional surface.

The sharp contact of the geest with the dolomite suggests that the alteration takes place when the clay leaves the alkaline environment of the dolomite and enters the acid-reducing conditions immediately above. Because no transition zone is apparent, the alteration goes to an advanced degree promptly.

The rate of accumulation of the geests is uncertain, but it would not be uniform. Black (1970) stated that at an average rate of solution of dolomite of 0.5 to 0.75 inch per thousand years, it would require at least 960,000 years to form the residuum exposed at one site in the Driftless Area in Wisconsin. Because the deposit is truncated and the solution rate diminishes with cover, Black suggested that the deposit is much older. Using the same rate of solution of the dolomite, and an estimate of 20 feet of Blanding dolomite dissolved to provide the chert in the geest on the Dodgeville Surface in Illinois, it would require at least 480,000 years to form the geest, but in this case, the geest may have been much thicker, and the elapsed time could be much longer, perhaps millions of years.

CONCLUSIONS

The origin of the geest as primarily a residuum from solution of the dolomite formation is indicated by (1) its presence on the dolomite formations and not on the intervening areas of the Maquoketa Group; (2) the presence in the geest of angular fragments of chert where the underlying dolomite is cherty and the absence of chert where the dolomite is not cherty; (3) the generally thicker geest on the impure formations; (4) its lack of bedding and its uniform physical characteristics over an extensive region; and (5) evidence that under acid-reducing conditions the clay minerals of the geest are a normal product of alteration of the illite and chlorite in the dolomite formations.

The geest probably contains some clay from other sources. Because the geest accumulated over a long period of time, it should contain some airborne clay. The clay mineral composition of the airborne clay probably was similar to that of the geest and its addition would not greatly modify the composition of the geest.

Geest on the Lancaster Surface at a position close to the top of the Galena dolomite contains an abundance of Depauperate Zone fossils. It may have been formed, at least partly, by alteration of the Maquoketa shale, which is dominantly illite, like the clay in the dolomite. A shale source for the clay seems unlikely where the erosional surface is well below the top of the dolomite; it is not necessary because the upper part of the dolomite is argillaceous and shaly.

In addition to clay minerals, the geest contains angular chert fragments and siliceous fossils from solution of the underlying dolomite and materials (primarily quartz sand, rounded chert pebbles, and phosphatic fossils) that were on the bedrock when the weathering cycle was initiated. Although the geest appears to be largely Tertiary in age, no indigenous fossils or material suitable for isotopic dating have been found. Evidence indicating that much of the geest is an old material includes the following:

- Geest is overlain by drift that is at least as old as Kansan and possibly much older. However, the basal part of the geest probably contains clay from continuing solution of the dolomite.
- Regional solution of 30 feet or more of dolomite, a very slow process, is required to supply the clay and chert in the geest. The rate of solution of the dolomite probably decreased as the clay thickened and became less permeable. The rate may also have declined when renewed erosion ended the interval of conditions most favorable for formation of the geest. Alteration of the illite and chlorite from the dolomite to the assemblage of expandables, illite, and kaolinite in the geest was more rapid than the solution of the dolomite. The absence of a transition zone at the geest-dolomite contact suggests that the alteration took place promptly when the clay was released by solution of the dolomite.
- In places the geest contains rounded quartz sand grains and rounded brown chert pebbles apparently derived from Cretaceous and Tertiary sand and gravel that formerly covered the area. The widespread occurrence of such material suggests that the geest began to form when remnants of the Cretaceous or Tertiary sediments were still present.
- Local concentration of chert in colluvial lenses on and in the geest were derived from nearby higher features which, on the Dodgeville Surface, no longer exist, and which, on the Lancaster Surface, were probably derived from the Silurian Escarpment that since has retreated several miles.

If the geest is a slow-forming product of solution of the dolomite, two interpretations could account for its occurrence on both erosional surfaces. Either the geest did not start to form until after exposure of the lower (Lancaster) surface, or the geest on the upper (Dodgeville) surface is much older and was well-developed before erosion exposed the lower surface. The character of the geest suggests that the latter interpretation is more probable and favors the following sequence of events in the physiographic history of the region. Geest apparently began to form on the Dodgeville Surface soon after erosion had removed most of the Cretaceous and early Tertiary sediments from the Driftless Area. The formation of the geest may represent millions of years, perhaps extending through the middle Tertiary, indicating an interval of stability with low relief and slight erosion.

Renewed uplift initiated another interval of erosion during which the streams cut through the Silurian dolomite and the Maquoketa shale to the Galena dolomite. Lateral retreat of the Silurian Escarpment exposed broad areas of the Galena and formed the Lancaster Surface. The time required for this process can scarcely be estimated, but the erosion of 300 feet or more of sediment over a large area must have taken several million years. The complete oxidation of the geest on the Dodgeville Surface to a strong red color suggests that it is older than the less oxidized geest on the Lancaster Surface.

Accumulation of the geest on the Lancaster Surface obviously did not begin until after the Silurian Escarpment retreated and the Maquoketa shale was stripped from the Galena dolomite. The geest apparently indicates another interval of relatively stable conditions on the poorly drained erosional surface. The Lancaster geest generally is not as thick as that on the Dodgeville Surface, but it could have been eroded. Geest formation on the Lancaster may represent several millions of years of the late Tertiary and early Pleistocene.

The first glaciers of the early Pleistocene blocked the northward flowing rivers that headed in the Silurian Escarpment. The presence of waterlaid silt and clay beneath the oldest glacial deposits in the area suggests that a lake formed between the ice front and the escarpment and that its overflow initiated erosion of the Mississippi River channel.

By Kansan time the Mississippi River probably had eroded a deep channel, 500 to 600 feet deep in the narrow gorge through the crest of the escarpment south of Galena. The incision of the Mississippi River permitted the entrenchment of streams in the Lancaster Surface as well as oxidiation and erosion of the geest.

The evidence strongly favors interpretation of the geest as primarily Tertiary; therefore, it is most unlikely that the geest has any relationship to glaciation. Geestlike clay materials are not known to occur on older glacial deposits in the Midwest. The weathered zones on the oldest glacial deposits have well-developed soil profiles and they contain materials that demonstrate their glacial origin.

The geest occurs at a stratigraphic position where, if Pleistocene, it could contain residuum from an earlier glacier. It could also be a deeply weathered glacial deposit, or could represent a trap for glacial material overridden by a glacier. The absence of Canadian Shield material, if ever present, might be explained by weathering or by the growth of a local center of ice accumulation. There is no evidence to suggest the latter.

It is difficult to believe that such resistant material as the Precambrian quartzite could have been entirely eliminated by weathering. Well-rounded grains of quartz sand from the St. Peter or older sandstones that occur in the geest are not etched, but retain their original frosting. The rounded chert pebbles also lack evidence of solution, and they are less resistant to chemical weathering than the quartzite. Solution of the variety of stable heavy minerals that occur in glacial deposits also seems improbable. It is necessary to account for the rounded grains of coarse sand and brown chert pebbles in the geest as a lag from much older Tertiary and Cretaceous gravels. We could scarcely have a lag from these materials and none from a much younger drift sheet.

The most significant evidence, therefore, is not what the geest contains, but what it does not contain--the distinctive heavy minerals and the pebbles, cobbles, and boulders of igneous and metamorphic rocks from the Canadian Shield. Nevertheless, the discovery of till or even a few igneous boulders in the central part of the Driftless Area in northern Illinois could still confirm the very thin evidence of glaciation suggested by this study of the stream alluvium.

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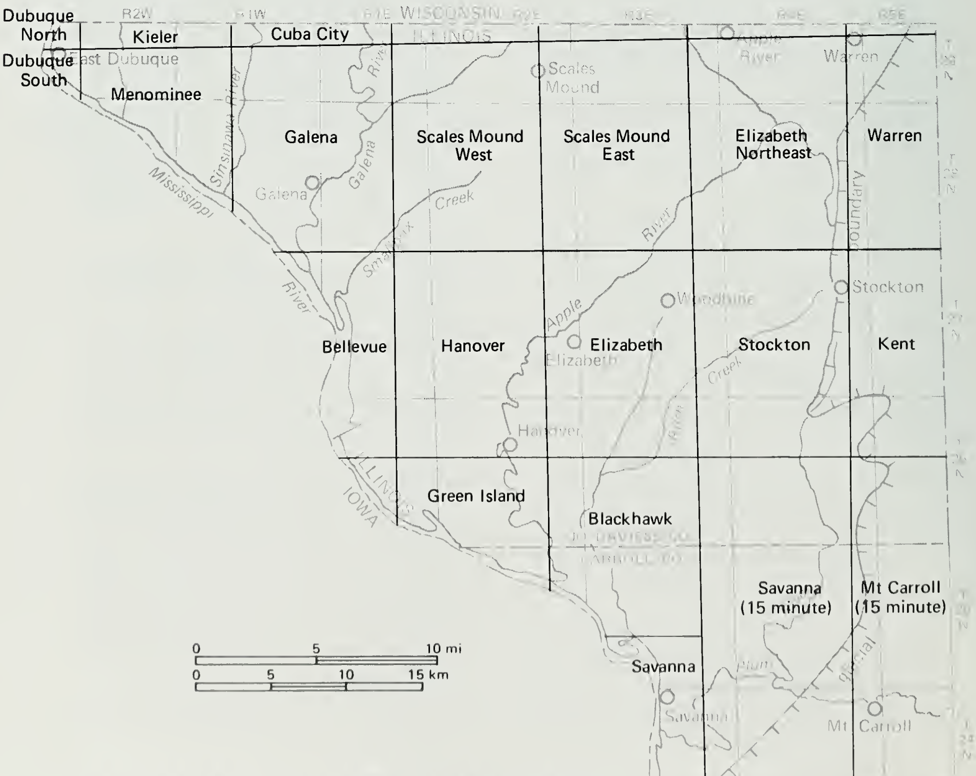

Figure 14 Quadrangles (7½ minute) of the Driftless Area referred to in appendix.

APPENDIX. GEOLOGIC SECTIONS

1 Apple Canyon Lake Quarry Section Quarry between the north branches of Apple Canyon Lake, SE NE SE Sec. 4, T. 28 N., R. 3 E., Jo Daviess Co., Scales Mound East Quadrangle.

A solution-widened joint in the Wise Lake Dolomite is filled with a rusty red geest, sample P-18: 298, which is overlain by brown, slightly reddish geest, P-18: 299, less than 1 ft thick, that extends over the relatively flat top of the dolomite on both sides of the joint. P-18: 297 is from the weathered dolomite immediately below the geest.

2 Apple Canyon Lake West Section Roadcut in top of ridge 1 mile west of Apple Canyon Lake dam, SW NE SE Sec. 17, T. 28 N., R. 3 E., Jo Daviess Co., Scales Mounds East Quadrangle.

Leached Peoria Loess, P-18: 294, 1 ft above base, overlies weathered Maquoketa Group shale; clay, smooth, brown, mottled black, P-18: 293, at top; clay, gray with brown streaks, P-18: 291, 1 ft down near bottom of ditch.

3 Apple River Southeast Section Roadcut 2.5 miles south-southeast of Apple River (town), on north side of Apple River, SE NW NE Sec. 31, T. 29 N., R. 4 E., Jo Daviess Co., Elizabeth Northeast Quadrangle.

Exposure at top of bench cut in Wise Lake Dolomite, about 35 ft above river level, shows colluvial Peoria Loess overlying 0.5 ft of brown chert gravel with a silty clay matrix, P-18: 301, overlying 0.25 ft of brown geest, P-18: 300, on weathered dolomite. Typical pebbles from the gravel, P-18: 302, are mostly brown, subangular pebbles as large as 0.15 ft in diameter, and a few smaller dark red chert pebbles.

4 Benton Mound Section Roadcut through west spur of Benton Mound, 4 miles northwest of Stockton, NW NE NW Sec. 33, T. 28 N., R. 4 E., Jo Daviess Co., Elizabeth Northeast Quadrangle.

Weathered zone of the Maquoketa Group shale on a moderate slope near the base of Benton Mound; clay, black to very dark gray, granular, A-horizon of surface solum, P-20: 077, 2 ft below surface; gray-tan shale with black spots, sharp contrast at top, gradational base, P-20: 276, 1 ft down; greenish gray shale, mottled yellow-tan, somewhat more weathered upward, more black material in joints, more yellow-tan, P-20: 075-071, downward at 1-ft intervals; greenish gray shale, slightly oxidized on fracture faces, P-20: 070, 10 ft down at base of exposure. Detailed probe samples: P-21: 357 at base of A-horizon; P-21: 356 0.5 ft down in B-horizon; P-21: 355-346 downward at 0.25-ft intervals to 3.25 ft below surface.

5 Blanding North Section Exposure along lane leading to top of Mississippi River bluff, 2 miles north of Blanding, NE SW SE Sec. 28, T. 27 N., R. 1 E., Jo Daviess Co., Bellevue Quadrangle.

Thick Peoria Loess overlies about 3 feet of geest on a slight slope along the easternmost curve of the lane. The geest consists of white angular chert (about 50% chert) in pieces up to 0.3 ft, in a matrix of red-brown clay, P-18: 259. Additional samples of 1-ft intervals consist of P-20: 109 at top, P-20: 108 in middle, and P-20: 107 at base. The geest overlies cherty dolomite of the Blanding Formation, P-20: 106.

6 Galena West Section Shallow roadcuts and auger holes in new subdivision, west of Sinsinawa River, NE SE SW Sec. 9, T. 28 N., R. 1 W., Jo Daviess Co., Galena Quadrangle.

An auger hole 80 feet east of main N-S road and 100 ft north of lane leading eastward to circle encountered 2 ft of weathered Peoria Loess, P-20: 129, 0.5 ft below top; P-20: 128, 0.5 ft down; P-20: 127, 0.5 ft down; P-20: 126 at base, 0.5 ft down.

An auger hole 40 ft east of main road and 40 ft north of lane, sampled at about 0.25-ft intervals, encountered below the weathered Peoria Loess (1) gray-brown clay with little mottling, little sand, and small brown chert pebbles, P-20: 121-125, upward; (2) clay, predominantly black with gray-brown and rusty brown areas and chert pebbles, P-20: 119-120, upward; (3) clay, brown and rusty brown with black spots and brown chert pebbles, P-20: 117-118, upward; (4) clay, greenish gray with some small chert pebbles and Mn-Fe spots, P-20: 113-116, upward; (5) chert gravel, pebbles to 0.1-ft diameter in matrix of tan-gray clay, P-20: 112, at base of auger hole; (6) at this level in nearby road ditch, weathered dolomite sand, P-20: 111, overlies Wise Lake Dolomite, P-20: 110. P-21: 314 is a sample of the greenish gray clay (5) in the ditch west of the auger hole.

Pebbles, P-20: 130, on the surface in this area include abundant rounded brown chert, a few angular to rounded white and red chert pebbles, common to abundant rounded very coarse grains of quartz, a few pink quartz grains, and a few etched dolomite pebbles.

In the ditch on the west side of the road, west of the end of the lane to the circle, red-brown geest overlies the weathered dolomite; P-18: 242 is from the geest about 1 ft above the dolomite; P-18: 243 is from the base of the colluviated Peoria Loess 0.5-ft above the geest sample. About 25 ft north the geest contains abundant chert pebbles, mostly small, and appears to be colluvial, P-18: 244. Additional samples of the geest at this locality are P-20: 133 at top; P-20: 132, 0.3 ft down; P-20: 131, at base 0.3 ft down.

Pebbles, P-18: 241, on the surface of a hill about 200 yards north of the above section, are mostly brown rounded chert and include rounded cemented blocks of the brown chert gravel and coarse quartz sand, possibly slumped from near the top of the hill. No crystalline rocks noted.

7 Guilford West Section Excavation for pipeline in Galena Territories on crest of ridge, 2.25 miles west of Guilford, NW SE SE Sec. 13, T. 28 N., R. 1 E., Jo Daviess Co., Scales Mound West Quadrangle.

Leached Peoria Loess, 2-4 ft thick, P-18: 275, 0.5 ft above base, overlies 1.5 ft of geest with a few rounded dark brown chert pebbles, P-18: 273, light brownish red clay in upper part, P-18: 272, red-brown clay in lower part, rests directly on Dubuque Dolomite: P-18: 274 is collection of typical pebbles from the geest.

8 Hanover Northwest Section Roadcut about 0.15 mile south of Duke Creek, 1 mile northwest Hanover, NW SW NE Sec. 8, T. 26 N., R. 2 E., Jo Daviess Co., Hanover Quadrangle.

Dark brown clay, P-18: 260, 2 ft thick, containing cobbles of weathered dolomite and angular white chert fragments, overlies Maquoketa Group shale about 80 ft below the base of the Silurian dolomite. It contains a few pebbles of igneous rocks and probably is a deeply weathered old till. It is in the vicinity of exposures reported by Trowbridge and Shaw (1916). A streambed sample, P-18: 261, from nearby Duke Creek contains pebbles of foreign rocks and minerals. Dugout nearby, P-21: 319 at base, has weathered dolomite and shale pebbles. P-21: 320, 3 ft up, has few small, deeply etched dolomite pebbles, and P-21: 321, 3 ft up, near top, has no dolomite or recognized shale, is red-brown, and has B-horizon characteristics. Resampled, P-21: 358, at base, P-21: 359, 1 ft up, and P-21: 360, 1 ft up at top in red-brown B-horizon.

9 Horseshoe Mound Southeast Section Roadcut of U.S. 20, 1 mile southeast of Horseshoe Mound at upland level on west side of Smallpox Creek, NE SW SW Sec. 26, T. 28 N., R. 1 E., Jo Daviess Co., Galena Quadrangle.

Peoria Loess, on southside of road, 5 ft leached on 5 ft calcareous, overlies 2 + ft leached Roxana Silt, P-21: 345; on north side of road, leached Peoria Loess, 5.5 ft thick, P-21: 329 1.5 ft above base, P-21: 328 0.5 ft above base, P-21: 327 0.1 ft above base; geest, 1.7 ft thick, P-21: 324 0.1 ft below top, P-21: 325 0.7 ft above base, P-21: 324 0.1 ft above base; Dubuque Dolomite, weathered to sand, P-21: 323 0.1 ft below geest; weathered dolomite, P-21: 322 1.3 ft below geest.

10 Lake Galena Section Roadcut, south side Smallpox Creek, 0.5 mile east of Lake Galena, 5.5 miles east of Galena, SE SE NW Sec. 20, T. 28 N., R. 2 E., Jo Daviess Co., Scales Mound West Quadrangle.

Leached Peoria Loess, 4 ft thick, P-18: 283 at base, overlies 1-1.5 ft geest consisting of two 0.3-0.5 ft lenses of red-brown clay separated by tan-brown silty clay; the lenses converge downslope to make a single red-brown unit, the base of which fills irregularities in the underlying Dubuque Dolomite; P-18: 282 top of upper lens, P-18: 281 between the lenses, P-18: 280 middle of lower lens, P-18: 279 base of the geest where 1.5 ft thick downslope from the split in the geest, P-18: 284 from red-brown clay filling a solution-widened joint. P-18: 285, pebbles from on top of the geest, consists mostly of rough-surfaced, etched, silicified dolomite pebbles, a few angular, etched, white chert pebbles, silicified fossils, a few dark brown chert pebbles, and Depauperate Zone fossils.

Additional sampling about 25 yards downslope (north) from the previous sampling: geest with abundant pebbles, P-20: 151, above very dark brown clay with some pebbles and Depauperate Zone fossils, P-20: 152, on the Dubuque Dolomite, P-20: 153. The geest also shows an interlayering of clay and loess, suggesting episodic downslope movement (creep) as recently as during or after loess accumulation; samples evenly spaced in 1.5-ft zone from the top down; tan loess, P-20: 159; brown clay and silt, P-20, 158; tan silt and clay, P-20: 157; brown clay and silt, P-20: 156; tan silt and clay, P-20: 155; and red-brown clay, P-20: 154, on the weathered dolomite.

11 Millville Southwest Section Auger hole in ditch west side road, 2 miles southwest of Millville, NE SE SW Sec. 7, T. 28 N., R. 4 E., Jo Daviess Co., Elizabeth NE Quadrangle.

Depths below top: Peoria Loess, leached, P-21: 388 (B-horizon), 1 ft; P-21: 387, 1.5 ft; P-21: 385, 2 ft; P-21: 385, 2.5 ft; Peoria Loess, calcareous, P-21: 384, 3 ft; P-21: 383, 3.5 ft; P-21: 382, 4 ft; P-21: 381, 5 ft; P-21: 380 (no sample), P-21: 379, 6 ft; P-21: 378, 6.5 ft; P-21: 377, 7 ft; P-21: 376, 7.5 ft; P-21: 375, 8 ft; P-21: 374, 8.5 ft; P-21: 373, small chert fragments, 9 ft; cherty colluvial soil on Maquoketa shale, P-21: 372, 9.5 ft; P-21: 371 contains caliche nodules, 10 ft; P-21: 370, B-2-horizon, 10.5 ft; Maquoketa shale, P-21: 360, 11 ft; P-21: 368, 11.3 ft; P-21: 367, 11.6 ft, base of hole.

12 Mt. Carroll North Section Roadcut near SE corner Sec. 23, T. 25 N., R. 4 E., Carroll Co., Mt. Carroll (15-min) Quadrangle.

Peoria Loess, silt, tan, leached, weakly developed surface soil on a soil with an organic A-horizon and a color B-horizon at base that merges laterally with the surface soil (2-3 ft); silt, leached, light yellow, tan-brown, or buff, massive, P-2467 7 ft below top, P-2052 at base, 12 ft thick; silt, transition zone, leached, darker than above, contains Mn-Fe pellets; P-2051 middle, 1 ft thick; Roxana Silt, brown, clayey, leached, massive, P-2050 middle, 4 ft thick; Loveland Silt, red with heavy clay B-horizon at top, clay skins and Mn-Fe coatings on micropeds, P-2049 middle, 6 ft thick; Yarmouth Soil, residuum, heavy clay, dark red, clay skins, Mn-Fe coatings and pellets, no silt or sand, P-2048, 0.1 ft thick; on Silurian dolomite (Marcus Formation). Described by J. C. Frye, John P. Kempton, James E. Hackett, and H. B. Willman, May 5, 1965.

13 North Hanover Section Roadcut at Y intersection 1.5 miles southwest of Hanover, SE NW NE Sec. 5, T. 26 N., R. 2 E., Jo Daviess Co., Hanover Quadrangle.

Peoria Loess, 9 ft thick, tan-brown leached silt, P-18: 356, 5 ft below top, P-18: 355, 3 ft lower and 1 ft above a distinct contact with geest; brown, slightly reddish, clayey silt with small white chert fragments, P-18: 354, overlying 0.5 ft red clay with white chert fragments, both etched and fresh chert, P-18: 353. The underlying Blanding Dolomite is not exposed. The upper silty part of the geest may be a mixture of a pre-Peoria Loess with the geest.

14 St. Johns Church Section Roadcut at top of hill, 0.8 mile north St. Johns Church, 2.4 miles south of Scales Mound, SE NW NW Sec. 11, T. 28 N., R. 2 E., Jo Daviess Co., Scales Mound Quadrangle.

Beneath weathered Peoria Loess, red-brown geest with abundant angular chert fragments overlies the very cherty Blanding Dolomite and fills solution-widened joints as much as 8 ft wide. In the largest joint, P-18: 314 is from the red-brown clay along the walls of the joint; P-18: 315 is from tan-brown clayey silt without chert in the central part of the filling; P-18: 316 and P-21: 322 are from reddish brown silty clay with subrounded brown chert pebbles unlike the local chert. It occurs in a horizontal band across the top of the noncherty clay in the central part of the filling and is the youngest of the three materials. The geest represented by P-18: 314 extends across the top of the dolomite, fills smaller joints and, in a sag on the surface of the dolomite, is as much as 5 ft thick. P-18: 317 is from the central part of the geest in the area where thickest. Samples where the geest is 2.6 ft thick consist of P-21: 416, the dolomite 4 inches below the geest; P-21: 417, the basal 0.2 ft of the geest; P-21: 417-422, upward at 0.5 ft intervals to the top of the geest.

15 Scales Mound Northwest Section Quarry on east road 1.5 miles northwest of Scales Mound, SW SW NE Sec. 22, T. 29 N., R. 2 E., Jo Daviess Co., Scales Mound West Quadrangle.

Leached Peoria Loess, 3 ft thick, P-18: 251, 0.5 ft above base, overlies with sharp contact pebble-free red-brown geest 1 ft thick; P-18: 250 at top of geest is slightly lighter brown and silty and may include some deeply weathered loess; P-18: 249 at the base of the geest rests directly on chert-free Wise Lake Dolomite.

16 Scales Mound South Section Roadcut on lane on west side of road 1.25 miles south of Scales Mound, NE NE NW Sec. 2, T. 28 N., R. 2 E., Jo Daviess Co., Scales Mound West Quadrangle.

Leached Peoria Loess overlies gradationally 1-2 ft of geest, which overlies Dubuque Dolomite. P-18: 313, from the geest about 0.8 ft above the dolomite, contains abundant Depauperate Zone fossils and a few brown chert pebbles. On additional sampling, the mixed clay and loess with chert pebbles at the top is represented by P-20: 163, the geest by P-20: 162, 0.5 ft down, and P-20: 161, 0.5 ft farther down and 0.3 ft above the base. P-20: 160 is from the top of weathered dolomite. To evaluate uniformity, samples were collected at 1-inch intervals from the weathered dolomite at the base, P-21: 389 through P-21: 410, immediately below the loess. Large samples for study of the coarse constituents were collected at 4-inch intervals with P-21: 411 at the base and P-21: 415 at the top.

17 Sinsinawa River East Section Exposure in solution-widened joint in roadcut on south side of east-bound land of U.S. Highway 20, 100 yards west of road connecting the lanes, and nearby exposures, SW SE NW Sec. 3, T. 28 N., R. 1 W., Jo Daviess Co., Galena Quadrangle. The upland surface is generally flat.

Leached Peoria Loess, P-18: 235, 1 ft below ground surface, B2-horizon of the surface solum; P-18: 234, 5 ft lower, tan-brown, indistinctly blocky B3-horizon; P-18: 233, 4 ft lower, light brown, indistinct platy structure, possibly B3-horizon; P-18: 232, 3 ft lower, light brown, mealy; P-18: 231, 2 ft lower; P-18: 230, 7 ft lower at base of leached loess; P-18: 229, top of calcareous loess; P-18: 228, 1 ft lower, weakly calcareous, base of calcareous loess. Roxana Silt, silt and very fine sand, 0.4 ft thick, pinkish tan, compact, leached, no chert, P-18: 226. Geest and loess mixed, silt and clay, 0.6 ft thick, chert pebbles in middle, P-18: 224; P-18: 225 pebbles. Geest and loess mixed, clay and silt, 1 ft thick, dark brown with black mottles, abundant chert fragments as much as 0.2 ft in diameter, sharp contacts top and bottom, P-18: 222 upper part, P-18: 221 lower part, P-18: 223 pebbles. Geest, light gray, dark brown to black mottles with red-brown halos, mottling increases in density upward, no chert pebbles, 1 ft thick; P-18: 218 upper part; P-18: 217 lower. Dubuque Dolomite, silty, medium to thin bedded, 0.3 ft marker bed at base, 15 ft thick, P-18: 216 at top. Brown clay, P-21: 313, fills a joint 10 ft below the top of the dolomite. Wise Lake Dolomite, pure, vuggy, medium to thick beds, 10 ft thick, base concealed.

In an exposure immediately adjacent west of the above, P-18: 368 is from the weathered sugary dolomite sand immediately below the geest and 0.7 ft above P-18: 367, which is from the solid dolomite.

In an outcrop at the road connecting the two lanes, P-20: 134 represents a very silty bed in the Dubuque Dolomite about 10 ft above the base.

In an outcrop of clay-filled crevice about 50 yards west of the first exposure described, P-20: 135 is from red-brown geest on the side of the fill, P-20: 136 is from gray-brown slightly cherty clay with some black mottling in the middle of the fill. It resembles the gray cherty clay previously sampled, P-18: 219-222.

About 50 yards farther west, the top of the dolomite is relatively flat and weathered "sugary," and is overlain by 2 ft of red-brown, massive clay with indistinct microblocky fracture, some slickensides, and cherty only at the top, P-20: 137-141 upward at 0.5 ft intervals to a sharp contact with the loess.

18 Stockton South Section Quarry on east side Plum River, 4 miles south of Stockton, NW SW NE Sec. 35, T. 27 N., R. 4 E., Jo Daviess Co., Stockton Quadrangle.

Peoria Loess, 4 ft thick, the basal part, gray and tan leached silt, grades upward to brown silt with the surface solum on top, P-18: 344 from lower 0.5 ft. The loess overlies 3 ft of geest of which the upper 1 ft is red-brown clay, P-18: 343, which has a microblocky structure and a few brown chert pebbles in the lower part. The lower 2 ft is yellow-tan clay, P-18: 342, that contains Depauperate Zone fossils, P-18: 346, and brown chert pebbles up to 0.3 ft across, P-18: 345. The geest rests on noncherty Dubuque Dolomite.

19 Winston North Section. Roadcut at T intersection 1.5 miles north of Winston tunnel, NW NW NE Sec. 11, T. 27

N., R. 1 E., Jo Daviess Co., Hanover Quadrangle.

Leached Peoria Loess, 3 ft thick, overlies 5 ft of very cherty geest consisting of angular white chert in a matrix of red-brown clay, P-18: 270, 4 ft above base; P-18: 269, 0.5 ft above the base on Blanding Dolomite, which contains nodules and lenses of white chert; P-18: 268 at top, 2 ft exposed.

Resampled below the Peoria Loess: geest mixed with loess, tan-brown silt with small chert fragments, P-20: 064 at base; overlies geest, reddish brown clay with chert fragments up to 0.2 ft in diameter, P-20: 063, 0.5 ft below top; P-20: 062, 0.5 ft down; P-20: 061, 0.5 ft down; P-20: 060 with smaller chert fragments 0.5 ft down; P-20: 059 tan-brown clay with large chert fragments to 0.3 ft in diameter, 0.5 ft down; overlies weathered cherty Blanding Dolomite, P-20: 058 and P-21: 315.

20 Winston South Section Quarry on westside road, 4 miles south southeast of Winston, SE NE NW Sec. 6, T. 26 N., R. 2 E., Jo Daviess Co., Hanover Quadrangle.

Silt, clayey, largely Peoria Loess, 3 ft thick; P-21: 2187 0.5 ft above base, underlies quarry stripping debris and overlies 0.7 ft silty colluvial cherty rubble, P-21: 317; on 0.7 ft reddish brown, slightly cherty, silty geest, P-21: 316; on Silurian (Sweeney) dolomite with little cherty; light greenish gray to white clay; P-21: 365; fills a solution-widened joint, 10 ft below top of quarry; black-brown geothite, P-21: 366, completely fills a narrow joint.

21 Woodbine South Section Quarry 3.7 miles south southeast of Woodbrine, NW NE SE Sec. 35, T. 27 N., R. 3 E., Jo Daviess Co., Stockton Quadrangle.

At the top of the quarry an unusually thick section (10 ft) of Peoria Loess occurs in a depression on top of a slumped block, possibly a sink hole; P-18: 335, 4 ft below the top, is yellow-tan and gray mottled, leached silt; P-18: 334, 3 ft lower, is rusty tan, compact, leached silt and clay; P-18: 333, 3 ft lower, at the base, is weakly calcareous gray silt; a 0.1 ft rusty brown layer is at the contact with the underlying Dubuque Dolomite. Outside the slumped area the dolomite is overlain by a foot or less of geest, P-18: 332, which consists of brown clay with some silt and contains Depauperate Zone fossils. It is overlain by about a foot of leached Peoria Loess.

Yellow-tan clay, P-18: 331, filling a widened joint in the face opposite the section described above, is overlain by the geest, P-18: 332, which is generally present on top of the dolomite.

Looking eastward near the Winston North Geologic Section in Jo Daviess County, Illinois. Deeply eroded uplands showing the rounded surfaces of the loess above cliffs of Silurian dolomite overlying Maquoketa shale.