Loess Investigations in Mississippi

GEOLOGY OF MISSISSIPPI LOESS

J. O. SNOWDEN, JR.

RICHARD R. PRIDDY

FORESTS OF WEST CENTRAL MISSISSIPPI AS AFFECTED BY LOESS

C. D. CAPLENOR, ET AL

BULLETIN 111

MISSISSIPPI GEOLOGICAL, ECONOMIC AND TOPOGRAPHICAL SURVEY

WILLIAM HALSELL MOORE
DIRECTOR AND STATE GEOLOGIST

JACKSON, MISSISSIPPI

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LETTER OF TRANSMITTAL

Office of the Mississippi Geological, Economic and
Topographical Survey
Jackson, Mississippi

August 15, 1968

Mr. Henry N. Toler, Chairman, and
Members of the Board
Mississippi Geological, Economic and Topographical Survey

Gentlemen:

Herewith is Mississippi Geological Survey Bulletin 111, "Loess Investigations in Mississippi," by J. O. Snowden, Jr., Richard R. Priddy, and others.

This Bulletin is the result of eight years of study. It contains the results of intensive field and laboratory studies. The loess is examined from the standpoint of stratigraphy, mineralogy, chemistry and electrical character. In addition there are supporting articles on ceramic properties and the flora and fauna supported by the loess. Bulletin 111 is the most comprehensive study of the loess that has been made in this area.

Respectfully submitted,

William H. Moore
Director and State Geologist

WHM:js

GEOLOGY OF MISSISSIPPI LOESS

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FOREWORD

This summary of Research Investigations of Loess and Loessal Soils of the Vicksburg, Mississippi, area, 1960-1968, represents the work of several organizations and some 70 individuals, mostly Millsaps College Science faculty and students.

The chief contributors are (1) the National Science Foundation, (2) the Science Division of Millsaps College, (3) the Geology Department of Millsaps College, (4) the Mississippi State Highway Department, (5) the Mississippi Geological, Economic, and Topographical Survey, (6) the Sedimentation Laboratory, U. S. Department of Agriculture, Oxford, Mississippi, and (7) the Geology Department of the University of Missouri.

The details of each contribution are listed in the Appendix. In general, they are as follows:

(1) The National Science Foundation which provided funds for field and laboratory work through three grants to Millsaps College as part of an Undergraduate Research Participation Program from September 1960 through June 1965, for a total of $46,495.00.

(2) The Science Division of Millsaps College which provided the laboratory facilities, student participants, and the faculty to oversee the various projects.

(3) The Department of Geology of Millsaps College whose majors and faculty continued the studies from September 1965 through June 1968, after National Science Foundation support terminated.

(4) The Mississippi State Highway Department which furnished profiles of U. S. Highway 61 northeast of Vicksburg and of Interstate Highway 20 east of Vicksburg, providing horizontal and vertical control for the study of nearly 100 roadcuts.

(5) The Mississippi Geological, Economic and Topographical Survey which, under contract with the National Science Foundation-Millsaps project, dry-cored a series of holes for the physical and chemical study of subsurface samples, logged these holes, provided some of the drafting for this report.

(6) The Sedimentation Laboratory which, through the efforts of Dr. L. L. McDowell, provided six radiocarbon dates by which the successive loess blankets could be defined stratigraphically.

(7) The Geology Department of the University of Missouri which accepted the dissertation of J. O. Snowden, Jr., — Petrology of Mississippi Loess — interpreting and enlarging upon the geological findings of the National Science Foundation—Millsaps project through December 1965.

A person who deserves special recognition for his contribution to this project is Leslie J. Hubricht of 3235 23rd Avenue, Meridian, Mississippi. Mr. Hubricht is an authority on snails (pulmonate gastropods), many species of which are found in the loess. On several occasions he provided reference materials and twice he identified partial suites of snails collected while digging for quantities of snails for radiocarbon dating. Hubricht's contributions are reviewed in the Appendix.

Millsaps Science Division faculty who contributed to these investigations through overseeing teams of students investigating various aspects of the loess were:

In *Biology*
- Dr. C. Donald Caplenor
- Dr. Robert P. Ward
- Prof. Rondal E. Bell

In *Chemistry*
- Dr. J. B. Price
- Dr. C. Eugene Cain
- Dr. R. A. Berry, Jr.
- Dr. Clifton T. Mansfield

In *Geology*
- Dr. J. O. Snowden, Jr.
- Dr. Richard R. Priddy
- Prof. Wendell B. Johnson

In *Mathematics*
- Dr. S. R. Knox

In *Physics*
- Dr. William R. Hendee
- Prof. Charles B. Galloway

Year-by-year records of this teamwork, lists of student participants, and the student-faculty publications resulting from this study are detailed in the Appendix.

GEOLOGY OF MISSISSIPPI LOESS

J. O. SNOWDEN, JR. and RICHARD R. PRIDDY[1]

ABSTRACT

Pleistocene loess deposits in Mississippi are usually symmetrically draped over ridges in the uplands that border the eastern margin of the Mississippi Alluvial Valley. Loess accumulations are normally thickest on ridge crests, being thin or absent in the lower valley areas. Average ridge-top thicknesses decrease in an eastward direction, i.e., away, from the river bluffs.

More than 400 samples of loess and related sediments were collected from 16 hand auger and core holes and by sampling of new highway cuts at 33 selected localities in Mississippi and Louisiana. Mineralogical, chemical, electrical, gamma ray, radiocarbon, and textural analyses of these samples led to the conclusions presented in this report.

Where not modified by post-depositional weathering, Mississippi loess is composed chiefly of detrital, silt-size grains of quartz (mean = 65 per cent by volume), carbonates (mean = 20 per cent), feldspar (mean = 6 per cent), and clay-size layer silicates (mean = 7 per cent). Post-depositional weathering reduces the feldspar content, increases the clay mineral content, and removes or modifies the carbonates. Detrital dolomite and aragonitic gastropod shells are dissolved and reprecipitated lower in the section as concretionary secondary calcite. Calcareous tubules are found throughout, presumably precipitated by the chemical activities of plant roots growing in the loess during and after deposition. Montmorillonite is the dominant clay mineral in the loess, followed in abundance by illite and kaolinite. The non-opaque accessory heavy mineral assemblage is characterized by micas, hornblende, epidote, zircon, and garnet. The mineralogy and texture of unweathered Mississippi loess are very uniform. Where variability occurs, it is usually induced by post-depositional changes, such as weathering, or physical mixing with underlying sediments. The source of loess detritus, indicated by both the clays and accessory heavy minerals, is glacial outwash from the northwest, north, and northeast.

The structural stability of Mississippi loess is produced by a combination of high permeability, resulting in excellent internal drainage, bonding of thin clay husks, which commonly encase larger detrital mineral grains, and an internal "skeleton" of vertically-oriented calcareous root tubules. Weathered loess is less stable because of its higher clay content, which reduces permeability, and the loss of its tubule "skeleton" by leaching.

Leached zones, or paleosols, which are common in Mississippi loess sections, indicate periods of slowing or cessation of deposition. Twelve

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radiocarbon dates of fossil gastropod shells and one of fossil vegetation establish that there are several loess formations in west Mississippi, as likewise in the upper Mississippi Valley region. Most of the loess appears to be stratigraphically equivalent to the Peoria loess in Illinois, but some Farmdale loess is also definitely present below the Peoria. At two localities, at least two carbonate-bearing loess beds, separated by paleosols, occur below dated Farmdale loess, indicating that some of the older (pre-Farmdale) loesses are also present in Mississippi. Unfortunately, these lower loess beds are not exposed and sufficient shell or plant material for radiocarbon dating of them could not be obtained from cores or hand auger samples.

The field relationships, texture, mineralogy, and stratigraphy of Mississippi loess all suggest a glacio-fluvial-eolian origin. The Mississippi loesses are texturally and mineralogically more uniform than those in the upper Mississippi Valley. Otherwise, they are strikingly similar, and are interpreted as representing southern extensions of those deposits.

INTRODUCTION

One of the large loess-blankets of the world occurs in the central United States. Loess, ranging in thickness from a few feet to as much as 200 feet, mantles upland surfaces, mainly along the leeward margins of major Pleistocene glacial outwash-carrying stream valleys. Figure 1 illustrates the generalized distribution of loess in the central United States.

In this report, *loess* is used as a litho-genetic term, following the usual practice in the United States (Frye, Glass, Leonard, and Willman, 1963). Loess comprises deposits in which silt is the chief constituent, but which vary from sandy silts to clayey silts. It is mostly megascopically massive, but may contain micro-structures, and is locally inconspicuously bedded. Where it has not been modified by weathering, loess is usually carbonate-bearing and contains numerous fossil terrestrial gastropods. It is generally buff to tan in color, but locally may be various shades of brown, yellow, red, or gray. The term *loess* is restricted to those deposits that were deposited primarily by wind, (at least interpreted as being an eolian deposit) although they may be locally modified by subsequent (or penecontemporaneous) colluviation. Deposits that have similar texture and mineralogy, but which are known from field characteristics, such as bedding, fauna, or structure, to have been deposited by water, are classified as silts, terrace silts, etc., not as loess.

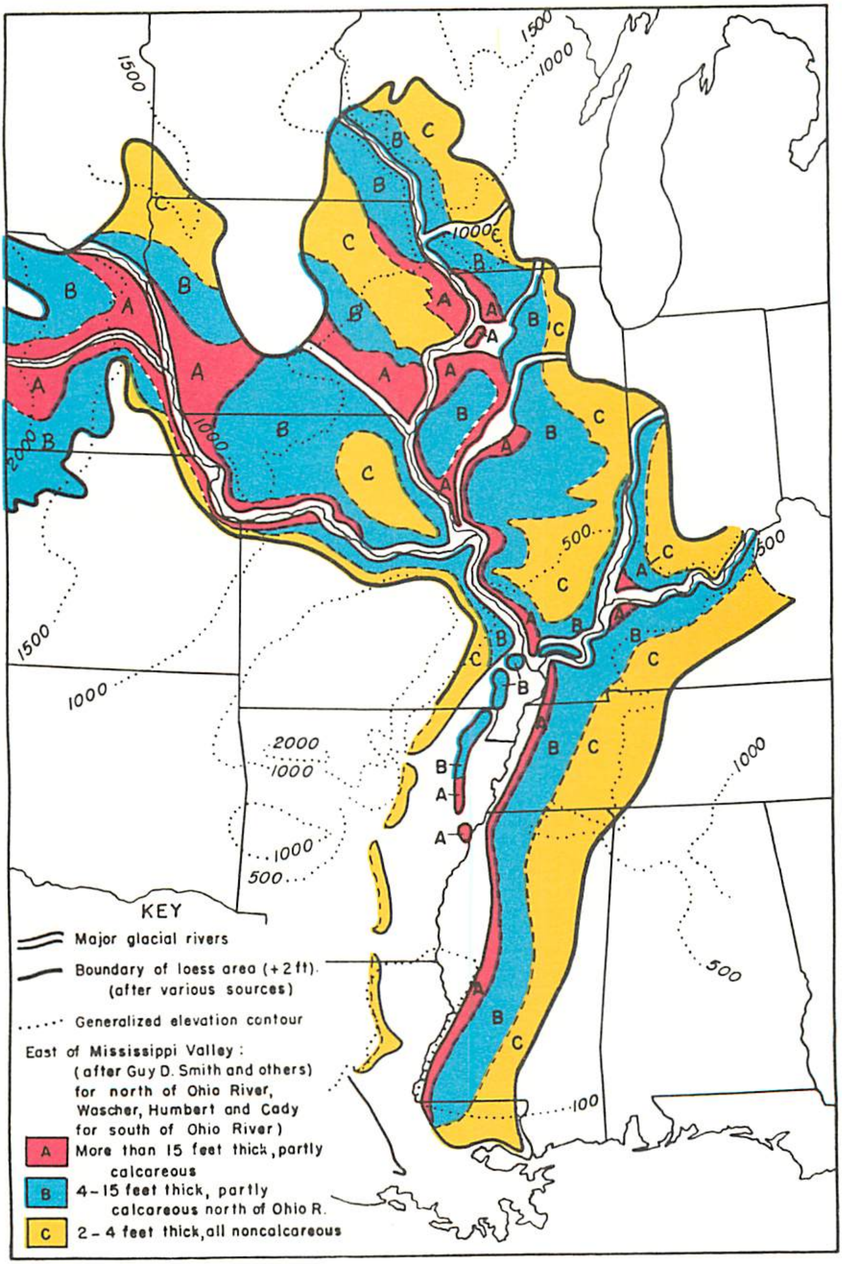


Figure 1.—Generalized distribution of loess in the central United States (from Leighton and Willman, 1950).

This report is concerned with the loess deposits in the lower Mississippi Valley, within the states of Mississippi and Louisiana, which represent the southern extremity of the loess-blanketed region in the central United States (fig. 1). For many years, the origin, stratigraphy, and fauna of loess deposits in the lower Mississippi Valley region have been subjects of interest (Lyell, 1847; Shimek, 1902; Russell, 1944*a*, 1944*b*; Fisk, 1944, 1949, 1951; Wascher, Humbert, and Cady, 1948; Doeglas, 1949; Leighton and Willman, 1950; Krinitzsky and Turnbull, 1967). Relatively little attention has been given to the quantitative mineralogy and texture of these deposits.

The major objectives of this study were to: (1) characterize quantitatively the field relationships, texture, and mineralogy of Mississippi loess, (2) devise a preliminary stratigraphic classification based on radiocarbon ages (3) determine the source of detritus and mode of deposition of the loess, and (4) compare the lower Mississippi Valley loess with that in the upper Mississippi Valley region.

REVIEW OF THE LITERATURE

PRELIMINARY STATEMENT

Geologists and soil scientists of many diverse interests who have worked in loessal regions have been intrigued by the characteristic physical and chemical properties of the loess. From the reports of these investigations, those were selected for review which seem to have the greatest direct relevance to this study of lower Mississippi Valley loess.

Typically, the reports of these studies reflect the individual backgrounds and interests of the authors and often vary considerably in approach and technique. The chief methods of investigation have been (1) stratigraphic, (2) paleontologic, (3) geomorphic, (4) pedologic, and (5) sedimentologic. Most of the studies involve at least two of these methods. An underlying goal common to most of these studies has been to present conclusive evidence of the origin of the loess, i.e., its source and agent or agents of deposition, but as yet there is no unanimity on these points.

SUMMARIES OF SELECTED REPORTS ON LOESS

The first documented scientific observation and recognition of loess in North America was by Lyell (1847), who visited

Natchez, Mississippi, during his first trip to the United States in 1846. Lyell (1834) had studied the Rhine Valley loess and immediately recognized the similar material at Natchez:

> The yellow loam at the top bears a singularly close resemblance to the fluviatile silt, or 'loess', as it is termed, of the valley of the Rhine, between Cologne and Basle, and, like it, contains an abundance of fresh-water and land shells.... the loam, unsolidified as it is, retains its verticality, as is the case of its counterpart, the loess of the Rhine.

A notably comprehensive faunal study of loess in the lower Mississippi Valley was made by Shimek (1902). In this remarkable work, Shimek studies in detail both the loess fauna and the modern land molluscan fauna of the Natchez-Vicksburg, Mississippi area. As was true in the northern loess, he found that there was a close resemblance between the loess fauna and the modern molluscan fauna (Shimek, 1902, p. 292):

> The Natchez fossils bear out the writer's oft-repeated statement that the loess fossils of any given region are practically identical with the modern molluscan fauna of the same region. Indeed, they furnish the most convincing proof of this interesting and important fact which has yet been presented. The most characteristic and widely distributed species of the northern loess, such as *Helicina occulta, Succinea grosvenorii, Pyramidula striatella, Vallonia gracilicosta, Polygyra multilineata* and *Pupa muscorum,* are wholly absent from the southern loess, as, with the exception of *S. grosvenorii,* they are from the modern fauna of that region, while *Succinea avara,* so common in the north, and so frequent there as a fossil, is very rare in both the fossil and modern faunas of Natchez.

It was Shimek's opinion that the physical and biological properties of the loess strongly indicate an eolian origin. He cites the following faunal evidence against the then popular alluvial theory of origin (1902, p. 294):

1. At Natchez several shells of *Helicina orbiculata* were found with the operculum lying within the aperture, a position which it could not occupy if the shell-bearing animal had been deposited in water, for it becomes detached immediately after decay has set in, and would be carried away. Modern upland dead specimens are frequently found with the operculum lying within the shell.

2. The extremely delicate shells of snails' eggs are preserved in the loess. They are so frail that they would scarcely stand transportation by water.

3. The larger perfect fossil snails uniformly have the spire of the shell empty, no clay having been carried into the shell beyond the body-whorl, as would have been the case in drifting and finally submersed shells.

4. The fact that the local fossil and modern faunas are very similar has already been emphasized, and further indicates that transportation of shells from a distance has not taken place.

5. There are no traces of beaches, shore-lines, etc., such as would be left by a large body of water such as this theory postulates, nor does the remarkable homogeneity of the deposit taken together with its distribution suggest the possibility of deposition in flooded streams.

The work of Fisk, Richards, Brown, and Steere (1938) is presented as a series of four papers, dealing with the stratigraphy, paleontology, and paleobotany of Pleistocene sediments in East Baton Rouge, East and West Feliciana Parishes, Louisiana and adjacent Wilkinson County, Mississippi. Included in it is a detailed description of the molluscan fauna from the exposures of loess near Tunica, Louisiana. Fifteen species are identified and illustrated and the original description of each is included. Although several of these genera and species have been renamed (Leonard and Frye, 1960) this work remains as a valuable descriptive reference for the fauna of the loess of the region.

Smith's (1942) pedologic study of Illinois loess is the first regional study in which modern sedimentological techniques were applied to loess. This pioneering work has served as a model for several later studies. Smith collected samples along two straight-line traverses in Central and Southern Illinois. He measured sections of loess at some 40 localities and ran mechanical analyses and carbonate-equivalent analyses on samples collected. From this and other available data, Smith drew a detailed loess-thickness map of Illinois that remains the only one of its kind. His other conclusions were (Smith, 1942, p. 182-183):

1. Differences in the texture of the loess bear, within limits, a linear relation to the logarithm of the distance from the river bluffs.
2. The rate of the thinning of the loess with the distance from its source is a linear function of the logarithm of the distance.
3. The carbonate content of the loess decreases as the loess becomes thinner. The relation between the carbonate content and the loess thickness is expressed by the equation $Y = a - \frac{b}{X}$, when Y equals the percent of carbonates, X equals the thickness of the loess, *a* equals the carbonate content of the loess at the time of deposition, and *b* equals the loss of carbonates by leaching during the period of deposition.
4. The carbonate loss due to leaching during the deposition of the first quarter of the Peorian loess was approximately half as great as the leaching loss in the entire period subsequent to the loess deposition, showing there was a very slow deposition of the loess.
5. The differences in the profiles of the grassland soils found in loess deposits of varying thicknesses are attributed (1) to the differences in the age of that portion of the loess in which the solum is developed,

and (2) to a possible influence of the substratum either thru direct mixing with the loess by animals or thru the return of bases or other nutrient elements to the surface by the grasses.

6. Many of the Prairie soils are not in equilibrium with their environment; the direction of their development is toward the condition of the Planosols.

Vestal (1942), in a study of the mineral resources of Adams County, Mississippi, described the field relationships of the loess in this area. Loess thickness was measured in about 80 test holes drilled throughout the County. Partial chemical analyses were performed on some of these well samples. Although Vestal did not attempt to make any specific stratigraphic conclusions concerning the loess, one of his observations on the nature of the contact between the loess and underlying material may have genetic implications (Vestal, 1942, p. 63):

> It is certain that the loess, accumulating (if it did) through eolian agency on an irregular land surface, would in the early stages of deposition mix with the soil there, which no doubt was a red or brown sandy loam or gravelly loam or clay loam, and impart some of its character to that soil, just as the brown loam farther east has mixed with older soils. Thus, although the contact of the loess with subjacent rock materials would be everywhere one of disconformity, that contact, none the less, would be gradational in many places. The field conditions indicate that such processes were operative and that such a relationship exists today. The fine silt appears to have worked down into the underlying gravel and sand through pressure from above combined with expansion and contraction due to temperature changes and wetting and drying, and also to have been carried downward by seeping water into the highly permeable materials below to such an extent that the formational contact has been obliterated, and gravel may be found in a matrix of ferruginous silty sand or sandy silt. Obviously, under such conditions, the actual contact lies above the uppermost gravel, in the absence of any evidence of stream action or slides. However, at few places does the oxidized contact zone maintain the same level for any considerable distance; it seems rather parallel to the present topography, but with lesser relief, in much the same way that the water-table conforms to the surface topography.

R. J. Russell's (1944*a*) study of lower Mississippi Valley loess has done much to stimulate new interest in the loess of this region. The study is chiefly geomorphic, based on many years of field observations. He gives an excellent general review of the literature, especially that which is concerned with the various theories of loess origin.

Russell recommends that loess be more precisely defined as a lithologic term, without carrying necessary genetic restrictions. He estimates that "over half of the American literature on loess actually refers to loess-like terrace silts." Russell's

(1944*a*, p. 4-5) proposed definition of loess includes the following essential characteristics:

> Loess is unstratified, homogeneous, porous calcareous silt; it is characteristic that it is yellowish or buff, tends to split along vertical joints, maintains steep faces, and ordinarily contains concretions and snail shells. From the quantitative standpoint at least 50%, by weight, must fall within the grain size fraction 0.01 — 0.05 mm., and it must effervesce freely with dilute hydrochloric acid.

The only exception allowed is "leached loess"..... "material immediately overlying unaltered deposits, differing only in absence of calcareous content, which unquestionably was at one time loess." He calls all other similar material "loess-like". Russell is convinced that "the areal extent of loess deposits has been grossly exaggerated by widespread inclusion of loess-like materials." In the lower Mississippi Valley region, much of the loess-like material is considered to be brown loam soils developed on Tertiary formations.

Most of the evidence gathered in that study is used to support Russell's proposed mode of loess origin, called "loessification". The major features of loessification, the origin of loess by downslope mass movement of weathered calcareous backswamp terrace deposits, followed by secondary carbonate enrichment, are developed in the following statements by Russell (1944*a*, p. 10, 24):

> The writer's field work demonstrates that the distribution of lower Mississippi Valley loess depends upon two main factors: (1) slopes, and (2) specific types of Pleistocene terrace deposits, from which it can be derived.
>
> From the stratigraphic standpoint, lower Mississippi Valley loess occurs only as mantles leading upslope to outcrops of finer sediments of Quaternary terraces. No deposit reaches an elevation equal to that of the surface of the highest terrace in its vicinity. On slopes it covers both Tertiary and Quaternary deposits and incorporates materials from these underlying beds.
>
> It is not a geological formation in the technical sense of the term for it has no fixed stratigraphic position. Traced upslope it grades laterally into the upper part of any one of three different Pleistocene formations. [Williana, Bentley, and Montgomery formations, of Fisk (1938; 1949). See Figures 40 and 41 for areal extent.]
>
> In the lower Mississippi Valley loess development correlates mainly with two main factors: (1) the presence of backswamp deposits in terrace formations, and (2) deep dissection. To be acceptable a theory of origin must harmonize with these facts.
>
> The process of loessification starts in parent material that originally was deposited as alluvium on flood plains during the Pleistocene. It affects the finer parts of such deposits, especially those that have ac-

cumulated in backswamps and are present only in minor amounts along Pleistocene meander belts. It is restricted to parts of terrace formations that now stand considerably above flood plains. The deposits must consist mainly of silt and clay. They are somewhat calcareous and contain carbonaceous matter derived from plant remains.

The initial stage of the process is weathering and differentiation of soil profiles. While pedogenic processes are active much of the original calcareous content, including any fossil shells that may be present is lost to ground waters. The resulting product is a brown loam that thickens residually on flats but is relatively mobile on slopes. In deeply dissected territory it creeps into valleys, where it accumulates to considerable thicknesses.

The colluvial phase of the brown loam is derived from the upper parts of the profile of weathering and soil development and hence is characterized by coarser particles than the average present elsewhere. The loss of finer materials goes on at all stages of colluviation and is intensified by churning movements. Surface washing probably contributes to some degree. With increasing distance downslope comes closer approach to the remarkable sorting and uniform texture of loess.

Toward the lower parts of colluvial slopes is a zone of carbonate enrichment, the carbonates having been derived from terrace materials and brown loams on surfaces upslope. Snail shells introduced during colluviation are preserved only where carbonate enrichment takes place and hence characterize materials advanced far in loessification. The introduction of carbonates effects a measure of structural competence, retards creep, makes fracturing possible, and renders faces relatively stable. By the time significant enrichment has occurred loessification is practically complete.

Russell's chief objections to the generally accepted eolian origin of loess are:

1. No hypothetical direction of winds could account for its distribution. It covers slopes leading in all directions and is ordinarily as well developed on one side of a ridge as on the other.

2. The sorting appears too uniform to be the result of deposition by either wind or water.

3. The stratigraphic relationships observed in the field suggest a colluvial origin.

A stratigraphic-pedologic study of loess in the lower Mississippi Valley was made by Wascher, Humbert, and Cady (1948). The purpose of their investigation was:

(a) to determine the field and laboratory characteristics of the loess; (b) to measure loess thickness; (c) to determine possible relationships between the development and distribution of soils and the distribution of loess; and (d) to secure information which might lead to a better understanding of the relationship of the loess in the southern Mississippi Valley to those of the northern Mississippi Valley.

The results of the study "represent more than 1200 field observations and laboratory analyses of 37 samples." Most of the field work was done along the eastern margin of the Mississippi Valley between Owensboro, Kentucky and Baton Rouge, Louisiana. From the numerous measured sections, they constructed a generalized loess thickness and distribution map (*cf.* fig. 13).

The authors (Wascher, Humbert, and Cady, 1948, p. 391-393) recognize three separate loess sheets in this region: (1) the youngest, which they correlate with the Peorian loess of the upper Mississippi Valley; (2) the middle, which is correlated with the Sangamon of the upper valley; and (3) the oldest, which is not named or correlated. The Peorian is the thickest of the units, is usually calcareous and relatively unweathered, and shows little soil profile development. The Sangamon loess is moderately weathered, usually noncalcareous, but was not exposed long enough for a soil profile to develop. The oldest loess has a well developed soil profile and was apparently more severely weathered than either of the other deposits. The alluvial plain of the Pleistocene Mississippi River is the postulated source of all the loess and the prevailing westerly wind the depositing agent.

Doeglas' (1949) publication on lower Mississippi Valley loess is the direct outgrowth of a year spent as visiting professor of geology at Louisiana State University. This is chiefly a mineralogical-textural study of 18 loess, terrace sand, and modern Mississippi River sand samples collected in the Natchez-Vicksburg area of Mississippi. Doeglas reports that the accessory heavy mineral content of the terrace sand is significantly different from that of the loess and modern river sand. The terrace sands contain a staurolite-kyanite-zircon assemblage, whereas, the loess contains a garnet-epidote-hornblende assemblage. The modern Mississippi River sand has an assemblage similar to that of the loess, but contains much more pyroxene. Doeglas also demonstrates a similar relationship between Dutch loess and associated terraces. From the data presented, he concludes that neither the Dutch loess nor that in the lower Mississippi Valley is of colluvial origin as proposed by Russell (1944*a*), but is almost certainly eolian. He suggests a more thorough petrographic study of lower Mississippi Valley loess would be necessary to confirm his findings on a regional scale.

Another work directly concerning the loess geology of the lower Mississippi Valley is that of Leighton and Willman (1950). This publication is the outgrowth of studies that culminated in a two-week field conference, held in June, 1949. The conference was designed to consider the divergent views concerning the loess of the upper and lower Mississippi Valley regions (Russell, 1944*a*, Thwaites, 1944, Holmes, 1944) with the hope of reaching some degree of harmony. The conference was sponsored by state geologists of the states along the field trip route, and was attended by about 40 persons, Pleistocene specialists and others who joined the party for portions of the trip. The conference began at Iowa City, Iowa, and was concluded near Natchez, Mississippi. An itinerary was published by Leighton and Willman (1949). The authors integrated their observations with those of others on the trip, and with those of earlier workers in each region. Among those discussed in detail are Smith (1942), Wascher, Humbert, and Cady (1948). They sharply disagree with Russell and Fisk's theory of colluvial "loessification" in the lower valley, and most of their conclusions for this region are point-by-point refutations of it. Their major arguments are: (1) in all the localities where Russell (1944) states that there is a downslope transition from parent backswamp terrace materials to loess, the "parent material" is underlain by calcareous, fossiliferous loess. They determined this by augering. Therefore, the upslope non-calcareous material is leached loess, not the parent material of it. This argument is further strengthened by the fact that the feldspars in the calcareous loess are fresh, whereas, those in the upslope weathered material are less abundant and are cloudy and corroded. The heavy minerals are cited as exhibiting a similar relationship. They contend that the weathered zone is thicker on the hilltops than on the slopes because of more active erosion of the latter. (2) the carbonates in the loess are chiefly primary, not secondary as stated by Russell (1944) and Fisk (1944) because:

(a) They occur as discrete grains, (b) they are too uniformly distributed to be secondary, (c) they decrease in amount progressively back from the bluffs, and (d) they include grains of dolomite. Available evidence on the deposition of dolomite indicates that dolomite leached from the higher deposits would not be redeposited as secondary dolomite lower in the deposit. The distinctly secondary carbonates, such as concretions and fracture or root coatings, are calcite even where the primary carbonates are highly dolomitic.

(3) the "Lafayette-type" sand and gravel is not the basal portion of terraces that grade upward into the loess because they have different heavy mineral assemblages:

> However, instead of a gradation, there are horizontal zones of weathering separating a succession of loesses above the sand and gravel and also in many places separating the loess from the underlying Lafayette-type gravel. Furthermore, there is a hornblende-garnet-epidote heavy mineral suite in the loess deposits in contrast with a kyanite-staurolite-zircon suite in the underlying sands and gravels. The heavy-mineral suite in the loess deposits is the same as the heavy-mineral suite in the glacial valley trains, and the heavy-mineral suite in the Lafayette-type sands and gravels is the same as that in older Tertiary deposits. This was observed not only by the present authors but independently by Doeglas (1949, p. 114).

(4) meander patterns mapped in some loess covered areas are considered to be "clear instances of reflection through the loess of pre-loess drainage lines."

They conclude, finally, that the loess of the Lower Mississippi Valley is stratigraphically continuous with that in the upper valley and may be correlated to that region. Also, the loess throughout the Mississippi Valley is considered to be eolian.

Fisk's (1951) paper is chiefly a review of recent loess studies in the lower Mississippi Valley, particularly those of Russell (1944), Wascher, Humbert, and Cady (1948), and Leighton and Willman (1950). He also introduces some of his own data and observations collected during several studies of the lower Mississippi alluvial plain and surrounding area (Fisk, 1938, 1939, 1940, 1944, 1947, 1949). Fisk (1951, p. 339-341) reviews his interpretation of the origin and extent of Pleistocene Mississippi River terrace deposits and criticizes Leighton and Willman (1950) for not doing so in their report. Fisk believes that each major interglacial stage was a period of alluviation, and each major glacial period a time of rejuvenation and entrenchment in the lower Mississippi Valley, resulting in four distinct depositional terraces. He reports that the terrace formation process was further enhanced by a post-Aftonian uplift thought to be in excess of 400 feet in the vicinity of Natchez, Mississippi (*cf.* Figure 8). Fisk (1949) mapped these terrace deposits throughout the lower Mississippi Valley (see Figures 46 and

47). He further states (1951, p. 341) that the so-called "Lafayette" and "Citronelle" sands and gravels that so often underlie the loess in this region actually represent the basal facies of each terrace formation. Most of it is thought to be Williana (Aftonian) in age, "when lowered sea level brought about pronounced stream entrenchment, the Tertiary beds were deeply eroded and were the source of great quantities of bed-load materials supplied by local streams to the master river".

Fisk supports Russell's (1944*a*) general concept of loessification, i.e., that the loess in this area is the product of colluvial movement of backswamp terrace deposits. The following data are used as evidence: (1) the grain-size distribution of loess does not differ significantly from that of certain types of fluvial materials, (several mechanical analyses are shown graphically to support this argument), (2) the carbonates appear to be chiefly of secondary origin, as they exhibit clay inclusions, cleavage rhombs, and mass optical extinction, (3) the general lack of a dune-sand facies near the river bluffs, (Fisk feels that winds sufficiently strong to blow silt up to 75 miles from the flood plain should have carried sand-sized materials at least to the base of the bluffs and reworked it into dunes.), (4) lack of fossil trees that should have been buried in the eolian dust and preserved, and (5) the intimate field relationship of the loess with terrace material in some areas. His final conclusion is that:

> It is doubtful that the eolian hypothesis as applied to the lower Mississippi Valley loess has been strengthened by the studies of Leighton and Willman or by those of Wascher, Humbert, and Cady. Its proof there requires far more detailed studies than have been presented and the introduction of a completely new and logical line of reasoning. An acceptable explanation must take into account the geological setting and broad regional relationships and be consistent with the physical and chemical properties of loess. It should benefit from the wealth of data on the Quaternary geology of the region which have been obtained during the last twenty years.

Swineford and Frye's (1951) regional petrographic study of the Peorian loess of Kansas was one of the most thorough of its type. Mineralogical and textural data collected during a ten-year study of the late Pleistocene in Kansas is presented and cross-referenced to two companion papers on the stratigraphy and fauna of the Peorian loess (Frye and Leonard, 1951; Leonard, 1951). In this study, 42 localities were sampled along seven traverses that crisscross central and western Kansas and extend to the eastern border (*cf.* Swineford and Frye, 1951, Figure 2, p. 313). Oriented thin sections, partial chemical analyses, and clay separations were made of, or performed on, some of the samples, and all samples were mechanically analyzed by the pipette method. Electron micrographs and X-ray diffractograms were prepared from the clay (less than one micron) fractions. Heavy and light mineral separations were performed on the 62-30 micron fractions by use of bromoform in a centrifuge.

Mineralogically, the silt fraction was found to be chiefly quartz (about 50 per cent), feldspar (mostly K-feldspar, but containing some sodic plagioclase — about 12 per cent), carbonates (both calcite and dolomite — 10 to 20 per cent), volcanic ash shards (up to 10 per cent), mica (chiefly muscovite — about three per cent), and chert (about one per cent). Minor accessories include black and brown opaques, leucoxene, hornblende, chlorite, biotite, epidote, garnet, various pyroxenes, tremolite-actinolite, zircon, tourmaline, rutile, staurolite, titanite, sillimanite, and zoisite. X-ray diffraction of the less-than-one micron fraction revealed a predominance of montmorillonite, some illite, and a trace of a kaolinite-type mineral.

The texture of the loess reported by Swineford and Frye was similar to that of loess reported elsewhere in North America (Smith, 1942; Kay and Graham, 1943; Russell, 1944). The median grain size decreased geographically away from major stream valleys, believed to be the source of most of the loess. When the median grain size is plotted logarithmically (in phi units) against distance (in miles) from the stream valley, the resulting curve is nearly linear (*cf.* Swineford and Frye, 1951, Figure 4, p. 319).

Their interpretation of the origin of the Kansas Peorian loess is summarized as follows:

> Although some relatively structureless silts on slopes are derived colluvially from higher silt deposits (Elias, 1931) and some loess-like silts at low levels are water-laid, these studies have led to the conclusion that the extensive deposits of massive silts over thousands of square miles of upland and high-terrace surfaces are predominantly the result of eolian action. The facts contributing most importantly to this conclusion are (1) topographic position of loess on extensive divide areas, including highest elements in local topography; (2) textural similarity to that of modern wind-deposited silt; (3) relatively uniform composition over an area of 30,000-40,000 square miles in Kansas alone, where the loess rests

on various stratigraphic units of Pennsylvanian, Permian, Cretaceous, Pliocene, and Pleistocene age; (4) decrease in thickness and median grain diameter in directions away from major outwash-carrying valleys; (5) regional persistence of distinct faunal zones characterized by terrestrial snails; (6) lateral persistence of buried soil profiles which lack evidence of erosion or creep; (7) gradational contact of overlying loess units on buried soils; and (8) lack of any other known agents capable of depositing uniform silts simultaneously on sharply discordant topographic levels. In view of these facts, an eolian origin of the Kansas Peoria loess is accepted without reservation and is implicit in further discussions of local source and distribution patterns.

A very thorough paleontological study of loess is that of Leonard and Frye (1960). This is a study of the Wisconsin molluscan faunas in the Illinois Valley region and includes the rich gastropod faunas of the Wisconsin loesses. Complete molluscan faunal lists are given for the loesses and each species is excellently illustrated. The report is greatly enhanced by the inclusion of several radiocarbon dates obtained from both wood and shell material. There is excellent agreement between dates from wood and those obtained from gastropod shells, indicating that these shells, unlike some non-marine mollusks, are reliable material for radiocarbon age determinations. The faunal ages of the three major loess units are given as follows: (1) Roxana — 40,000 to 32,000 years B.P., (2) Farmdale — 28,000 to 22,000 years B.P., and (3) Peoria — 22,000 to 15,000 years B.P. Measured sections and stratigraphic descriptions of collecting localities are included. Most of these sections are described mineralogically in the later work of Frye, Willman, and Glass (1962).

The other major conclusions are: (1) each loess unit has a distinctive gastropod fauna, recognizable even in the field, and (2) paleoecological conditions are difficult to determine because "small and sedentary animals, such as gastropods, utilize microhabitats that may be considerably at variance with the general environmental pattern of a region." However, they do generalize their paleoecological interpretations as follows:

At least in the region south of the Sangamon River, Illinois was heavily forested in Altonian time; these dense forests, existing in a climate more humid than the present one, continued through Farmdalian time, and perhaps, in southern Illinois, into earliest Woodfordian. After Farmdalian time the vegetative cover was of a much more open type, perhaps essentially a mixed prairie, with trees and shrubs restricted to borders of stream courses and other favorable situations.

There is no evidence of extremely rigid climates during Woodfordian time, even in areas adjacent to ice fronts, although northern Illinois is judged to have had a climate approximating that of the present Canadian Life Zone.

Certainly one of the more comprehensive geologic studies of loess to date is that of Frye, Glass, and Willman (1962). This is a study of the stratigraphy and mineralogy of Wisconsin loess along two winding traverses bordering the Mississippi and Illinois River Valleys in Illinois and the Wabash and Ohio Valleys in Indiana and Kentucky. They collected a total of about 300 samples at 30 stations. A measured section is shown for each locality, complete with radiocarbon dates, lithologies, mineralogical data and references to an earlier publication (Leonard and Frye, 1960) that was a paleontological study of some of these same sections. In addition, the following data are presented in tables: (1) location of each sampling station to nearest quarter-quarter-quarter section, (2) individual sample numbers and stratigraphic unit represented by each, (3) thickness of each stratigraphic unit at each locality, (4) distance below top of unit from which each sample is taken, (5) quantitative heavy mineral analysis of the 0.062-0.250 mm. fraction of each sample, (6) quartz, K-feldspar, plagioclase ratios, (7) percent acid-soluble constituents, (8) averages of light and heavy mineral counts for stratigraphic units and depositional provinces, (9) calcite-dolomite ratios in both bulk samples and the less-than-two micron fraction by X-ray diffraction intensity counts per second, (10) montmorillonite-illite-chlorite+kaolinite percentages in the less-than-two micron fractions, and (11) chemical analyses of typical loess samples from each horizon. From this great wealth of data, the following conclusions are made (Frye, Glass, and Willman, 1962, p. 16):

> The position of Illinois on the North American continent is well suited for demonstration of the concept that the minerals in the loess were derived from the outwash transported through the major valleys. Illinois received sediments both from the regions to the west and northwest where montmorillonite predominates among the clay minerals and from the regions to the east and northeast where illite and chlorite predominate. Furthermore, drainage modifications during the Wisconsinan age resulted in shifting the sediment sources of central Illinois loess between these two regions.
>
> From the data presented in this report, several general conclusions can be drawn.
>
> (1) The source of the outwash from which the loess was in part derived may be hundreds of miles up the major valleys from the point of loess deposition, although the rocks adjacent to these valleys may furnish enough sediment by local erosion to produce a detectable effect on the relative abundance of mineral species in the loess.
>
> (2) An abrupt change in the source of sediments, caused by the blocking of a valley carrying outwash, is sharply reflected in the mineral

composition of the down-valley loess if the source areas involved possessed significantly different mineral assemblages.

(3) The non-carbonate mineral composition of a loess below the B-zone of the surface soil persists as a recognizable assemblage across the region east and southeast of one major source valley to the proximity of the next source valley.

(4) Both the clay and the coarser fractions of the loess were derived locally from the sediment transported through the source valleys.

(5) Differential leaching of calcite and dolomite, and differential leaching of very fine dolomite and silt size dolomite, both in transit and *in situ*, produced marked differences in the carbonate content of loess.

(6) The differences in mineral composition of the several stratigraphic units in the loesses of Illinois can be used for identification of the units.

An excellent general summary of the present state of knowledge of late Pleistocene loess stratigraphy in the mid-western United States is given by Frye, Glass, Leonard, and Willman (1963). They begin by defining loess as a lithogenetic term, referring to deposits in which silt is the predominant constituent, but which range from sandy silts to clayey silts:

It [loess] is generally massive on megascopic inspection, but where coarse may display distinct, although inconspicuous lamination or even micro-cross-bedding. Where it has not been modified by weathering it is commonly more or less calcareous and contains fossil snail shells. It is generally gray, yellow-tan or tan. The term *loess* is restricted to those deposits that were deposited primarily by wind, although at some places they may have been modified by subsequent (or pene-contemporaneous) colluvial movement. Deposits that may have similar textural compositions but that are known from field relations (bedding, fauna, or micro-structure) to have been deposited primarily by water are referred to as silts but are not classed as loess.

Radiocarbon dates from each of the loess units are listed as follows: (1) Roxana loess—37,000$\pm$1500 and 35,000$\pm$1000 years B. P.; (2) Morton loess—20,000 to 22,000 years B. P. (from wood); and (3) Peoria loess—20,300$\pm$400 and 17,000$\pm$300 (from shells). All these dates verify field correlations that had been made between the loesses and other deposits, such as till and water-laid silts.

Mineralogically, the loess is considered by the authors (1963, p. 116) to be a physical mixture, the composition of which depends on the amount of contribution from different sources. An example of this mixing is the clay mineral composition of the loess in Illinois. Loesses from the Illinois River Valley westward show a dominance of montmorillonite, but this mineral decreases in amount eastward from the Illinois Valley. The reverse is true for illite and chlorite. This is because the clay mineral composition of the tills that reached Illinois from the east and northeast show a dominance of illite and chlorite, whereas, compositions of tills from the western center show a dominance of montmorillonite.

The late Pleistocene loesses of the midwest are said to "generally contain abundant and ecologically distinctive fossil molluscan assemblages, although the loesses of Illinoian age are locally barren" (Frye, *et al.*, 1963, p. 116).

The authors (1963, p. 117-118) statements concerning the origin of the midwestern loess are reproduced here:

> The loess deposits of midwestern United States are primarily the product of eolian transport and deposition of silts derived from extensive valley flats that were being alluviated during episodes of glaciation. The eolian origin of these loess deposits is demonstrated by the following relationships.
>
> (1) Loess units are stratigraphically continuous from terraces to gentle slopes to upland divides, and in some places buried soils can be traced from one to the other.
>
> (2) The loess is thickest and coarsest along the bluffs of source valleys and becomes thinner and finer across the uplands away from these sources (Smith, 1942; Swineford and Frye 1951).
>
> (3) Commonly there is a back slope on the surface adjacent to the source valleys; furthermore, the minor soils that occur in the upper part of the thickest loess sequences also slope away from the valley bluffs.
>
> (4) The mineralogy of the loess generally reflects that of the outwash in the source valleys.
>
> (5) Radiocarbon dates (Frye and Willman 1960; Leonard and Frye, 1960) demonstrate that loess in some places is contemporaneous with nearby glacial deposits.
>
> (6) The fossil molluscan faunas require an ecology that can be accommodated by eolian deposition.
>
> (7) The interrelation of the loess with dune sands in the High Plains and the Illinois River valley suggests an eolian origin.
>
> Although the midwestern loesses are derived from valleys by wind action, colluvial movement has occurred on many slopes, and in some tributary valleys water action has eroded and redeposited these silts to produce a deposit whose appearance is similar to that of the valley fills. Although the deposits on slopes may be referred to as colluvial loess, in the Middle West such water-deposited sediment is classed as alluvial silt and not as loess.

Krinitzksy and Turnbull (1967) recently completed a study of loess deposits in Mississippi, which includes observations of numerous geologists and engineers at the U. S. Corps of Engineers, Waterways Experiment Station in Vicksburg, Mississippi. The authors reviewed the problems of loess occurrence, origin, stratigraphy, mineralogy, texture, and cementation. In addition, they presented some fundamental observations on the ground-moisture regime in Mississippi loess that have not been readily available to the geological profession. Finally, the authors' considerable experience with the engineering characteristics of loess was discussed and these characteristics related to the general physical properties of the loess. The following conclusions were advanced (Krinitzsky and Turnbull, 1967, p. 57-58):

> Mississippi loess was developed by eolian transport from braided stream deposits which were present in the Mississippi alluvial valley during late Pleistocene and early Recent time. Its mode of origin facilitated the incorporation of fossil roots, land snails, and vertebrates. It is composed of well-sorted clayey silt, which becomes more clayey with distance from its point of origin and with increased exposure to weathering.
>
> Stratigraphically, Mississippi loess is divisible into the Vicksburg loess, a Basal transition zone and a Pre-Vicksburg loess. Where these layers are weathered, they are designated as Mississippi brown loam.
>
> Calcareous Vicksburg loess contains subtle evidence of stratification which probably indicates periods of quiescence during deposition. It also has an internal skeleton of delicate carbonate tubules and concretions which were formed chiefly by roots that formerly penetrated the loess. The unique strength properties and physical characteristics of the loess are believed to result from its mode of origin and the manner in which the silt grains are bonded by calcareous, ferruginous, and argillaceous cementing materials. The infiltration rates of rainfall into loess are such that the loess ordinarily does not become saturated except where there is a water table. Commonly the loess may remain permanently dry only a few feet below the surface.
>
> Erosion normally takes place by soil creep or colluviation and affects only superficial and peripheral areas in thick loess. However, loess slopes may be oversteepened by undercutting and may fail either by shear or solifluction (liquefaction). Also, deep gullying may take place if running water erodes into the loess.
>
> Shear strength is relatable to density, moisture, clay content, and effectiveness of carbonate and ferruginous cementation. Drying of the loess would increase its strength markedly although there would be greater variation; maximum strength values would be found in the calcareous Vicksburg loess. Consolidation index values decrease, in a general way, with depth.
>
> Mississippi loess is an entirely suitable material for foundations, dams, etc., providing proper design measures are taken. It is stable on properly designed vertical slopes, thus providing economies in excavation effort, but it is highly susceptible to damage by water infiltration unless proper drainage is provided.

GENERAL DESCRIPTION OF THE STUDY AREA

LOCATION

The loess deposits investigated for this report comprise the southern half of a loess-blanketed belt about 50 miles in width that parallels the eastern border of the Mississippi Alluvial Valley from the juncture of the Ohio and Mississippi Rivers to a point 10 miles south of the Mississippi-Louisiana state line. Referring to Figure 1, it will be seen that the southern half of this belt is almost wholly within the State of Mississippi. These deposits will, therefore, be termed "Mississippi loess" or "lower Mississippi Valley loess" in this report. Again referring to Figure 1, the loess-blanketed area also extends northward, paralleling the upper Mississippi, Ohio, Illinois, and Missouri River valleys.

Field observations and sampling for this study were concentrated in the central portion of the Mississippi loess belt, in the region between Jackson and Vicksburg, Mississippi, illustrated in Figure 2. Excellent exposures are provided in this area by numerous road cuts in several new highways, including U. S. Interstate 20, which cross it. Moreover, the loess deposits at Vicksburg are among the thickest in the United States, commonly exceeding 100 feet in thickness near the river bluffs, thereby, being unexcelled for representative investigation. For additional comparative purposes, several samples were collected near Greenwood, Mississippi, north of the principal area, (fig. 3) and at the southernmost extremity of the loess belt near the Louisiana-Mississippi state line (fig. 4).

TOPOGRAPHY

The topography within the Mississippi loess belt, particularly the western portion (zone A in Figure 1) is very rugged, as is well shown by the topographic-location maps (figs. 2, 3, and 4). This region is well known to physiographers as the Loess Hills (*cf.* Fenneman, 1938, p. 80). A fuller discussion concerning the origins of this rugged topography will follow in the chapter on thickness and areal distribution.

At this writing, there is generally excellent topographic map coverage of the Mississippi loess belt. Coverage is complete and up-to-date at the scale of 1:250,000. Topographic maps

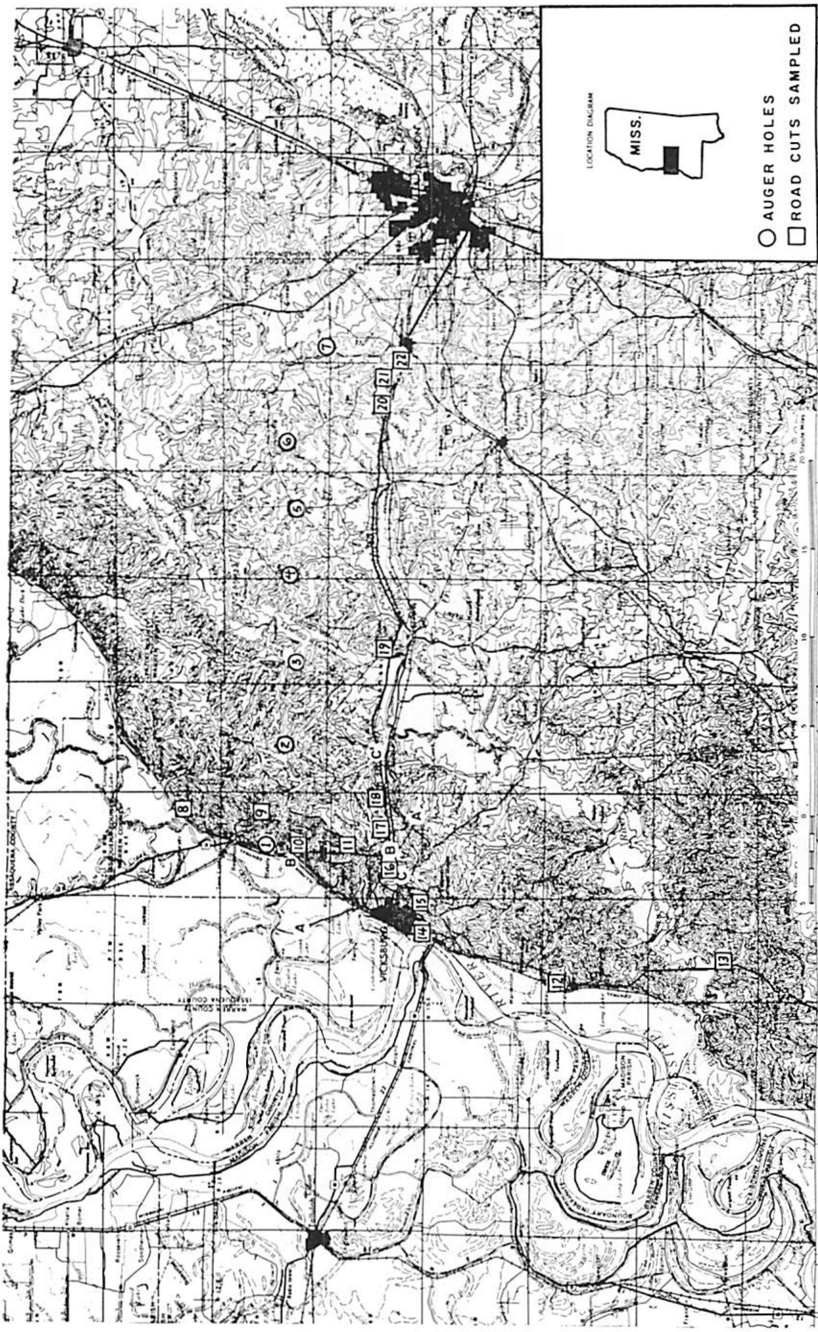


Figure 2.—Sample stations and general topography in the central Mississippi loess belt.

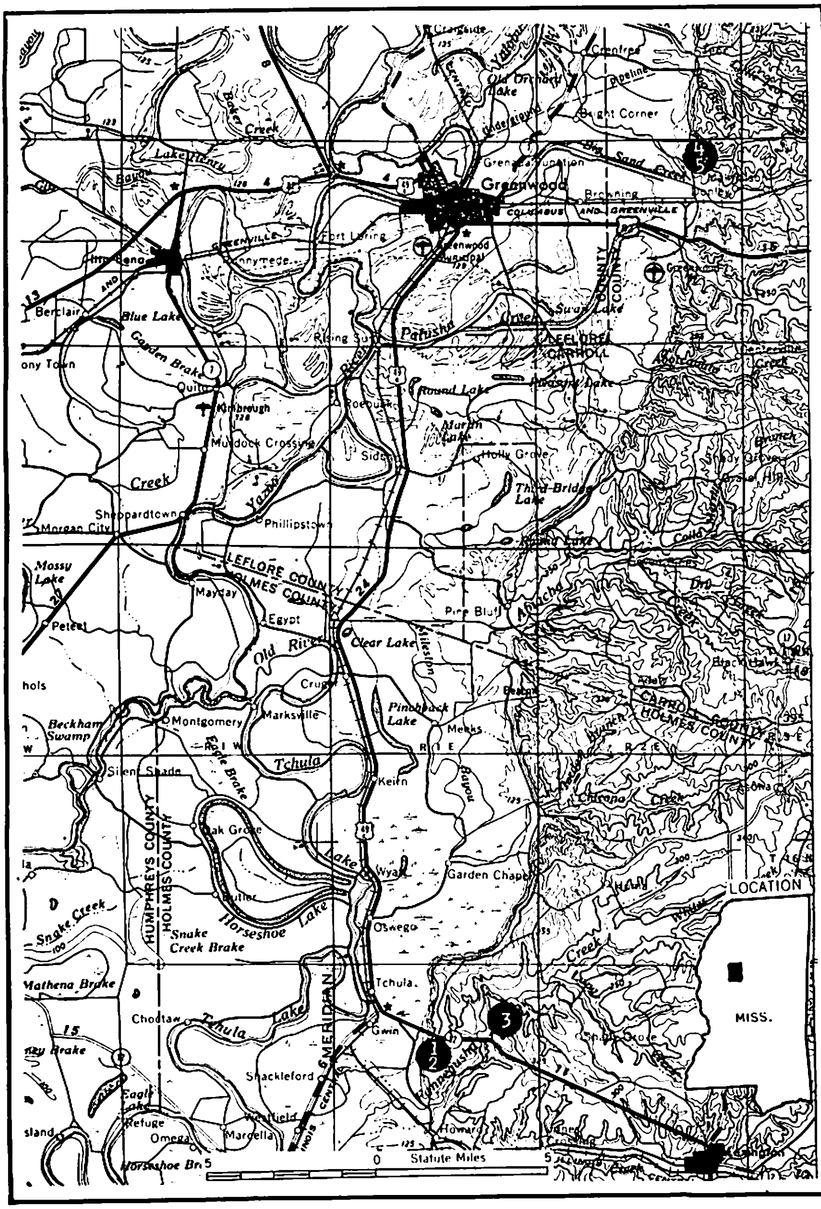


Figure 3.—Sample stations in the Greenwood, Mississippi area.

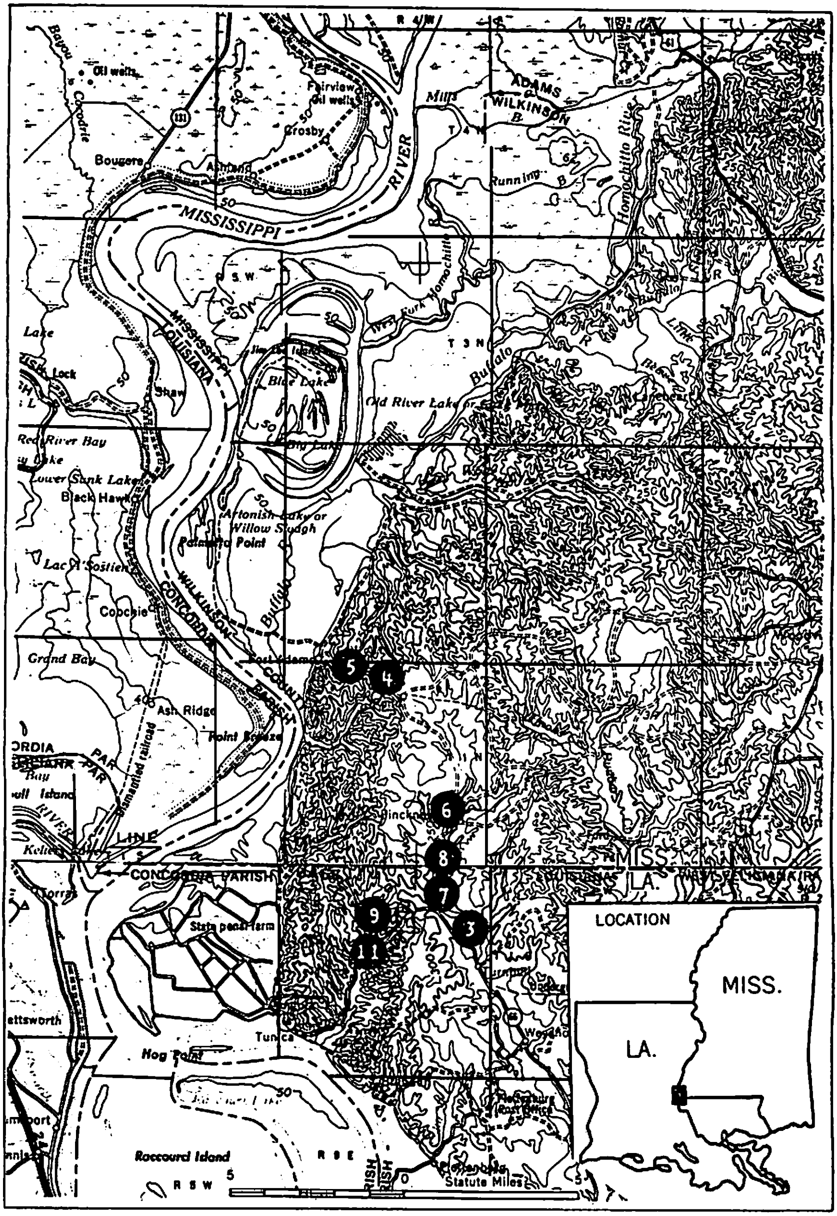


Figure 4.—Sample stations in the Louisiana-Mississippi border area.

are available for most of the area at the scale of 1:62,500 (15 minute quadrangles), and several key areas (the Vicksburg and Natchez regions, for example) have recently been mapped at a scale of 1:24,000 (7½ minute quadrangles). Complete and current information concerning topographic mapping in Mississippi is always available at the Mississippi Geological Survey Office.

FIELD INVESTIGATIONS

PRELIMINARY STATEMENT

Natural exposures of loess are not common in Mississippi. Where they do occur, they are generally poor sampling sites because most natural exposures are in stream valley walls in which the loess is subject to slumping, surface wash, and variable amounts of weathering. To avoid the uncertainties of such localities and to achieve a better geographic distribution, loess sections were studied and samples collected chiefly from artificial exposures, such as fresh road cuts and gravel pits, or from auger or core holes. Locations of sampling and study stations are shown on the location maps, Figures 2, 3, and 4.

METHODS OF FIELD INVESTIGATIONS

Collection of Samples

During the field investigation, samples of loess were collected for chemical, mineralogical and textural analysis, the results of which are presented in subsequent chapters. Samples were collected by the three methods discussed below. All sample locations, elevations, and descriptions are listed in Table 6 in the appendix.

EXPOSED SECTIONS

Road Cuts

Numerous fresh loess sections were exposed along two new highways, (U. S. Interstate 20 and U. S. 61 bypass) through the west-central Mississippi loess belt. Standard engineering practice is to cut the loess vertically and terrace at 15-20 foot intervals, thus providing almost ideal exposures, of which any part may be reached with a small extension ladder (fig. 5).

The position of the road cuts can be determined roughly from the center-line construction profiles of proposed highways furnished by the Mississippi Highway Department. Two profiles are shown here, each greatly reduced, Figure 6. Note the scales at the bottom of each of the two profiles, in miles and in feet.

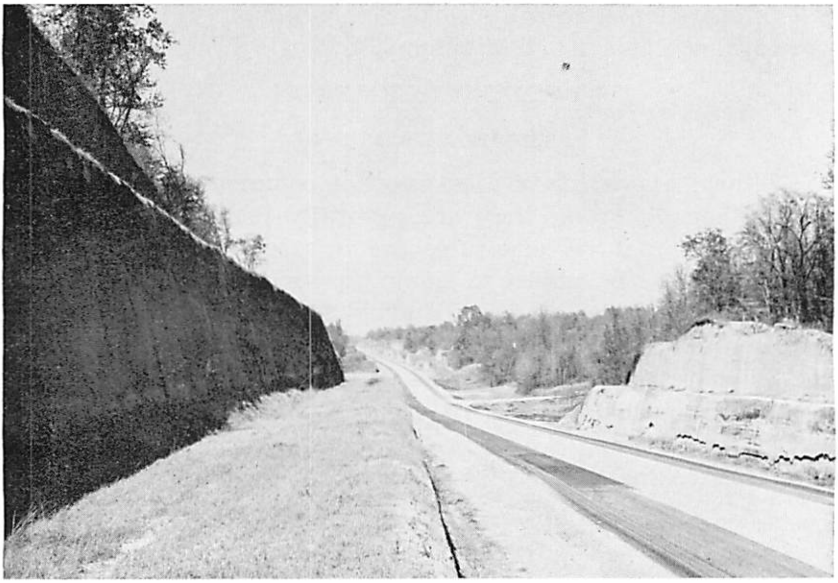


Figure 5.—Vertical, terraced highway cuts on U. S. Highway 61 bypass near Vicksburg, Mississippi.

Profiles can be used advantageously in all new concrete road construction to ascertain horizontal position because figures and arrows were impressed in the wet concrete a few inches from the berm, on the east lane of N-S highways and on the south lane of W-E highways. Each 500 foot distance is indicated by a figure and each 100 foot interval by an arrow. Thus, the figure 125 on U. S. Highway 61 (fig. 6) indicates 12,500 feet from the starting point of construction and the next arrow north indicates 12,600 feet from the starting point.

However, an investigator may discover that a road cut, drawn on a profile at, say 6,425 feet, may not exist. There are several possible reasons for this: (1) the hill may have been bull-dozed off into the adjacent valley, (2) it may have been hauled away, or (3) the cut may be present on one side of the 200 or 300 foot right-of-way but not on the other, by virtue of the profile having been projected on the centerline near the end of a hill,

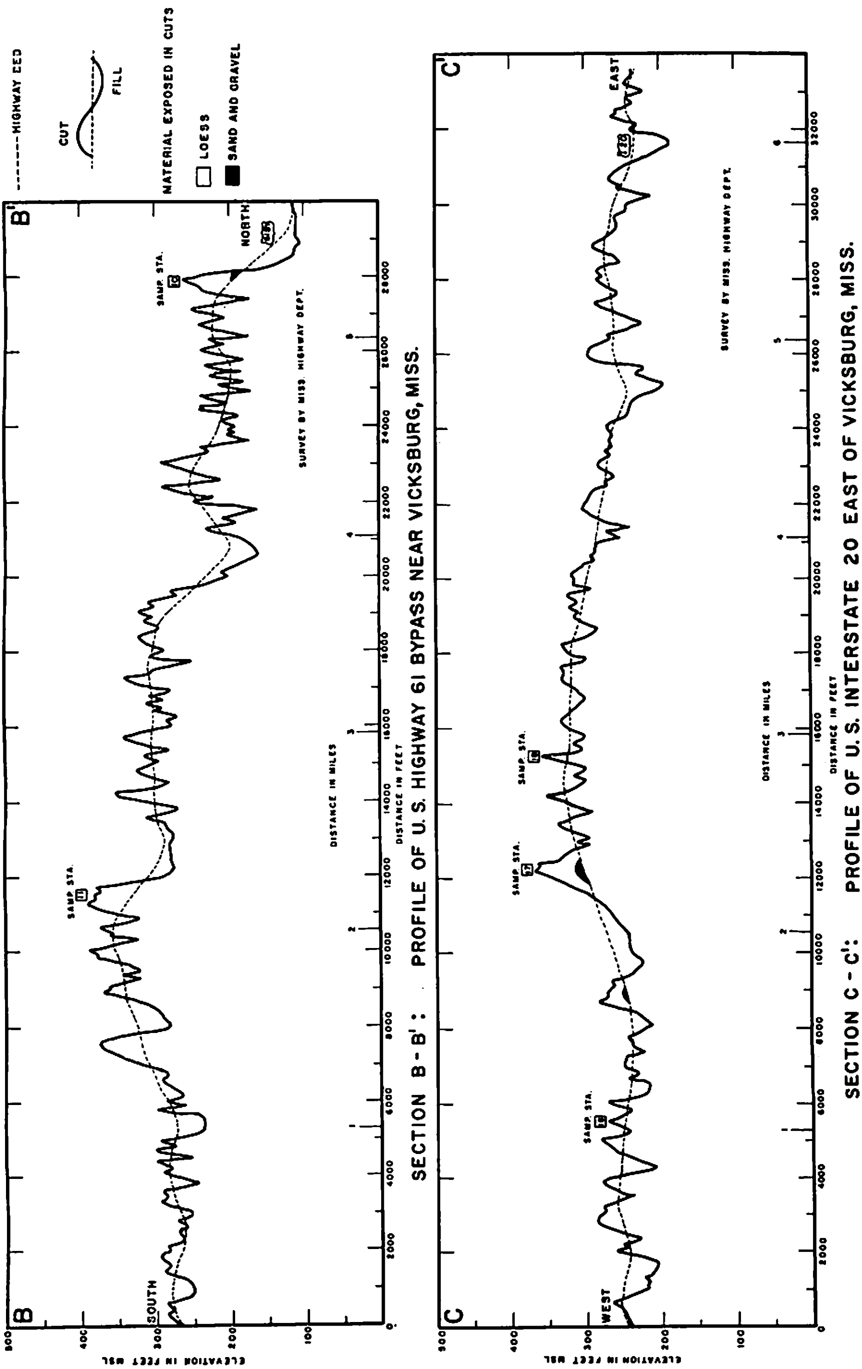


Figure 6.—Highway profiles through the loess hills near Vicksburg, Mississippi.

or (4) the cut may appear to be steepest to the right or left of a hill crest shown by the center-line profile because the hills crossed the proposed highway at an angle.

In this investigation, references to road cuts or test holes are in the footage positions shown by the impressions of figures and arrows in the concrete. Further, they are referenced to one side of the road (north, south, east, or west). The same care has been taken in determining the vertical situation of a test hole or a roadcut. By referring carefully to the footage position, elevations can be determined directly by the elevation of the projected center-line, which has become the elevation of the center of the finished highway. It is obvious that elevation is a controlling factor in rugged terrain such as is crossed by U. S. Highway 61, Figure 6, where deep cuts and thick fills were necessary. Survey profiles of the new highways, shown in Figure 6, may be geographically located on Figure 3.

Discontinuous spot samples at variable spacing were taken at the road cut stations (see figs. 2, 3, and 4 for location). Fossil gastropods and carbonate concretion were also collected at most localities.

Gravel Pits

A few samples were collected from pits where loess is being removed to expose sand and gravel terrace deposits ("Citronelle") below. Localities 8 and 9 (fig. 2) and 1, 2, 4, and 5 (fig. 4) are of this type. The road cut sampling procedure was followed at these localities.

HAND AUGER HOLES

Hand auger holes were drilled through the loess at seven localities along a traverse between the Mississippi Alluvial Valley wall and a point five miles due north of Clinton, Mississippi (fig. 2). Interval samples were collected on the basis of changes in physical appearance of the loess.

CORE HOLES

Three loess sections (fig. 2) were cored from top to bottom using a truck-mounted rotary drilling rig and a dry core barrel. These cores were broken up into six inch sections and are described fully in Table 6.

Measuring Sections

Exposed sections of loess were measured using a steel tape directly on the vertical cuts — a relatively simple process. Auger and core hole sections were measured simply by keeping a record of the depths at which samples are taken. The sample descriptions in Table 6 thus also serve as measured section descriptions.

Due to the draping of loess beds over the pre-loess topography, which will be discussed more fully in the next chapter, it is imperative to measure sections normal to the ground surface — preferably on ridge tops. Vertical sections measured on the flanks of ridges will exaggerate the true thickness of the loess.

Measuring Electrical Properties

Voltage drop (conductivity) and electrical resistance of the loess were measured at most of the collecting stations (see figs. 2, 3, 4, and 6) during the field investigation.

EXPOSED SECTIONS

Exposed loess sections (chiefly road cuts) were measured by driving a fixed electrode into the base of the section, and then attaching two movable electrodes at one foot intervals up the face of the exposure. A 24 volt battery was the power supply. The current that passes through the loess to the upper electrode was measured in milliamps, which can be used to calculate electrical resistance in ohms. Voltage drop between the upper and lower movable electrodes was recorded in millivolts.

AUGER AND CORE HOLES

Measuring the voltage drop and electrical resistances of loess and buried paleosols was much more difficult in the auger and core holes, which are only four to five inches in diameter and up to 109 feet deep. The problem was solved by mounting eight flexible steel rulers on a square timber attached to a cable carrying the necessary wires to the fixed electrode and to the battery. The rulers on the probe were lashed together with twine to permit the cable to reach the bottom of the holes. Then the twine was severed by electrically heating a wire in contact with it, thus allowing the rulers to snap outward to contact the walls of the hole. By raising the cable foot by foot, the conductivity and potential drop were measured, as on the exposed sections.

Gamma Ray Emission Logging

Gamma ray emission of the loess in most of the auger and core holes was measured using a Neltronic 2K continuous gamma ray logger. The holes were logged by personnel of the Mississippi Geological Survey.

THICKNESS AND AREAL DISTRIBUTION

PRELIMINARY STATEMENT

Although no attempt was made to map the loess, *per se,* in detail, the numerous observations and measurements of well-exposed loess sections made in the field by the writers revealed certain major trends in thickness, stratigraphic relationship, and areal distribution of Mississippi loess.

RELATION OF LOESS TO PRE-LOESS TOPOGRAPHY

Most lower Mississippi Valley loess was deposited on highly dissected uplands bordering the Mississippi Alluvial Valley. Pleistocene (?) alluvial sands and gravels ("Citronelle fm.") capped most ridge tops at the time of loess deposition. Today, the loess is symmetrically draped over these ridges. Moreover, the loess cover accentuates the topography, because greater thicknesses are developed on ridge crests than in valleys, causing considerable local variability in thickness. The cross-sections (figs. 7 and 8), highway profiles (fig. 6), and photographs (figs. 9 and 10) illustrate this relationship between thickness and topography. Cross-section A-A′ and the highway profiles, B-B′ and C-C′ may be geographically located on Figure 2. The local variability in thickness is particularly well illustrated on cross-section A-A′ (fig. 7). The general topography of the loess belt in Mississippi is shown by the sample location maps (figs. 2, 3, and 4). The upper portion of the eastern valley wall of the Mississippi Alluvial Plain is made up of a series of truncated loess-covered ridges (figs. 7 and 11).

In a few localities near Natchez and in adjacent Louisiana, the loess thickness appears to have been modified by colluviation, resulting in maximum thickness on ridge flanks rather than on the crests. Such occurrences were important to the

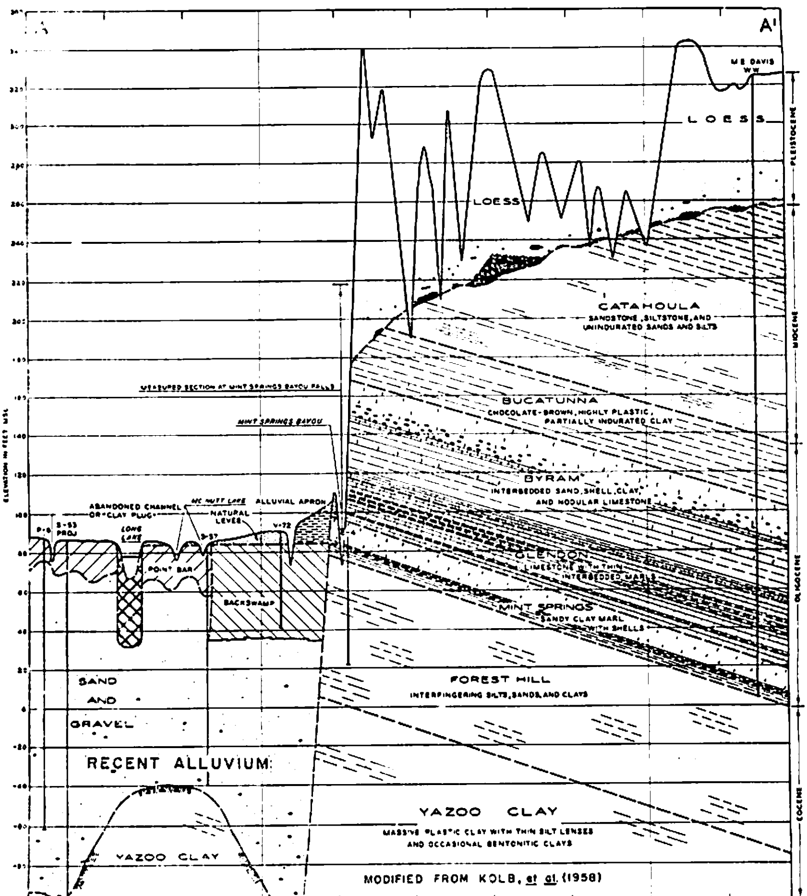


Figure 7.—Section A-A′: Loess distribution and bedrock stratigraphy near Vicksburg, Mississippi.

development of R. J. Russell's (1944*a*) theory of *loessification,* or colluvial formation of loess from backswamp terrace silts. However, in west-central Mississippi, no such flank thickening was recognized by the present authors.

The greater loess thickness on ridge tops indicates that loess deposition did not seriously affect the pre-loess drainage, but rather accentuated the pre-existing topographic relationships. If the loess was uniformly deposited over the area, it has been differentially removed from valley areas during and/or

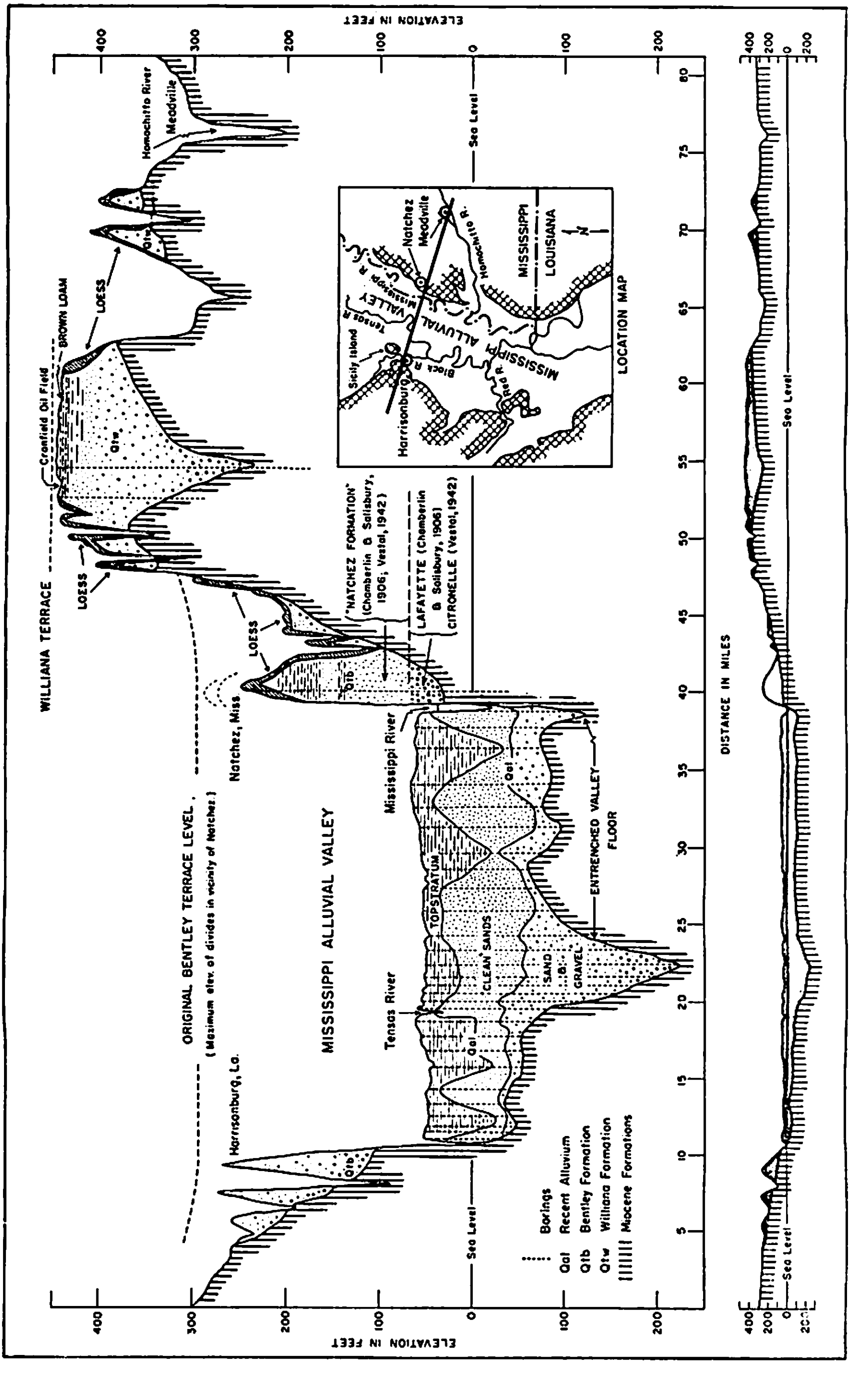


Figure 8.—Cross section of lower Mississippi Valley region near Natchez, Mississippi (from Fisk, 1951).

Figure 9.—Roadcut on U. S. Highway 61 bypass showing loess-pre-loess topographic relationship (photo taken at footage 7000, figure 6).

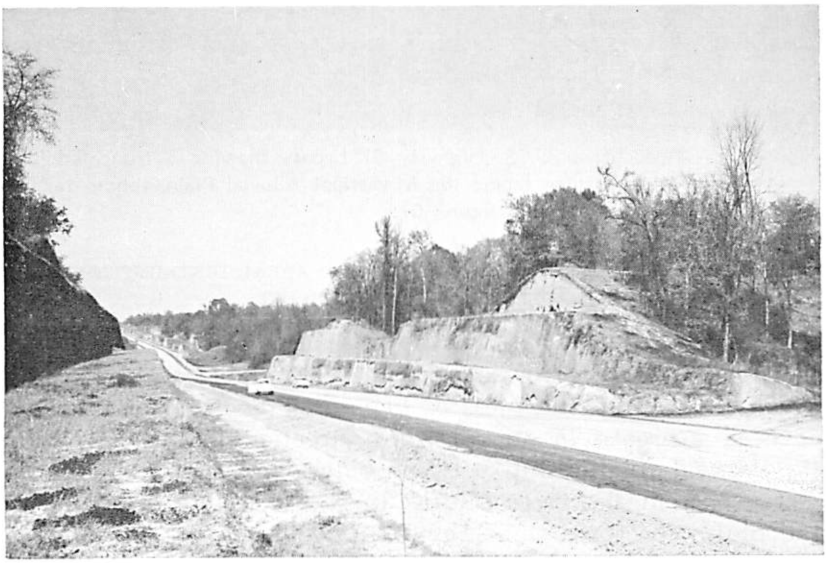


Figure 10.—Roadcut along U. S. Highway 61 bypass showing general topography and highway engineering practice (photo taken at footage 11,500, figure 6).

after deposition. Today loess is readily eroded from deforested slopes and deposited in adjacent valleys. Soil survey maps of the area commonly show a piedmont alluvial plain made of reworked loess along the base of the Mississippi Alluvial Valley walls, indicating at least some fluvial redeposition of eroded loess.

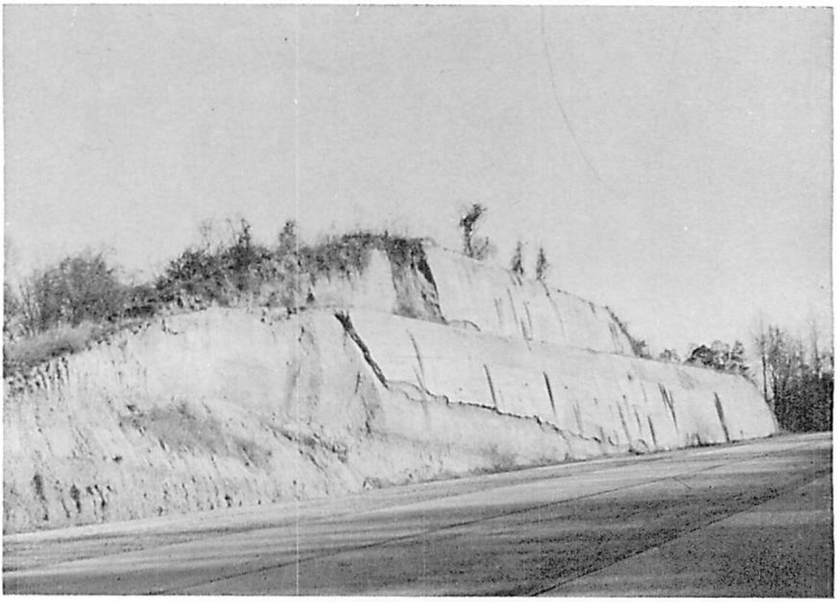


Figure 11.—Roadcut on U. S. Highway 61 bypass showing a truncated loess-covered ridge facing the Mississippi Alluvial Plain (photo taken at footage 28,100, figure 6).

RELATION OF LOESS THICKNESS AND AREAL DISTRIBUTION TO DISTANCE FROM BLUFF

Despite local variations, there is an overall trend in thickness and areal distribution in the Mississippi loess. Both the average ridge-top thickness of loess and the ratio of land area covered decrease in an eastward direction. Figure 12 shows the general relationship between *ridge-top* loess thickness and distance from the river bluffs. In the first few miles east of the bluffs the loess thins rapidly, but the rate-of-thinning decreases after that. Similar logarithmic thickness-distance curves were reported in the Peorian loess of Illinois by Krumbein (1937) and by Smith (1942). However, the thickness data for

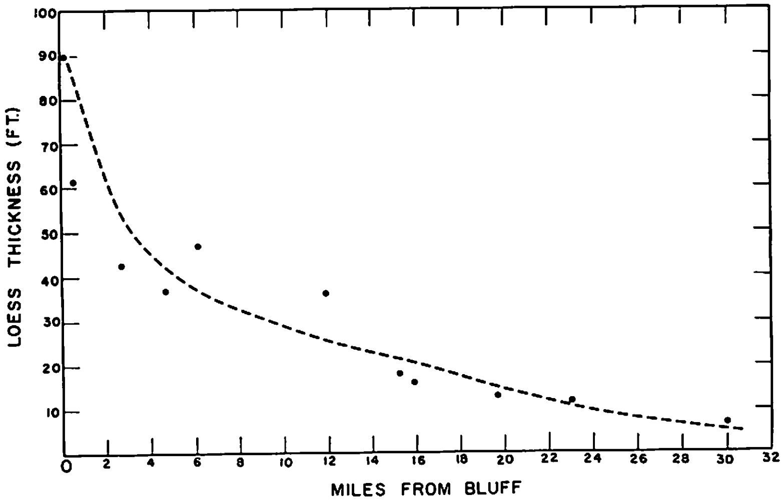


Figure 12.—Relationship between ridge-top loess thickness and distance from Mississippi River bluffs, Vicksburg east to Jackson, Mississippi.

both these reports was randomized along traverses, with no regard for topography, indicating that the Illinois loess is a rather continuous wedge-shaped blanket which thins away from the glacier-draining valleys. If the Mississippi loess thickness had been measured randomly, there would have been a much greater scattering of points on the thickness-distance graph (fig. 12). This is because, as emphasized before, the greatest loess thicknesses are on ridge tops, and the loess is much thinner, or even absent, in valleys.

It seems likely, therefore, that the thickness and areal distribution of Mississippi loess has been considerably affected by the rugged pre-loess topography of the area. In the writers' opinion, had the Mississippi loess been deposited on a smoother surface, it would be a more uniform blanket, perhaps similar to the Illinois loess, which was deposited over a gently undulating till plain. The fact that the Mississippi loess drapes the ridges symmetrically seems to indicate that deposition was uniform. However, erosion was much greater in the already existing valley areas. In other words, loess deposited in the valleys was carried away by streams almost as rapidly as it was deposited. The mechanism of loess deposition will be considered further in the section on loess origin.

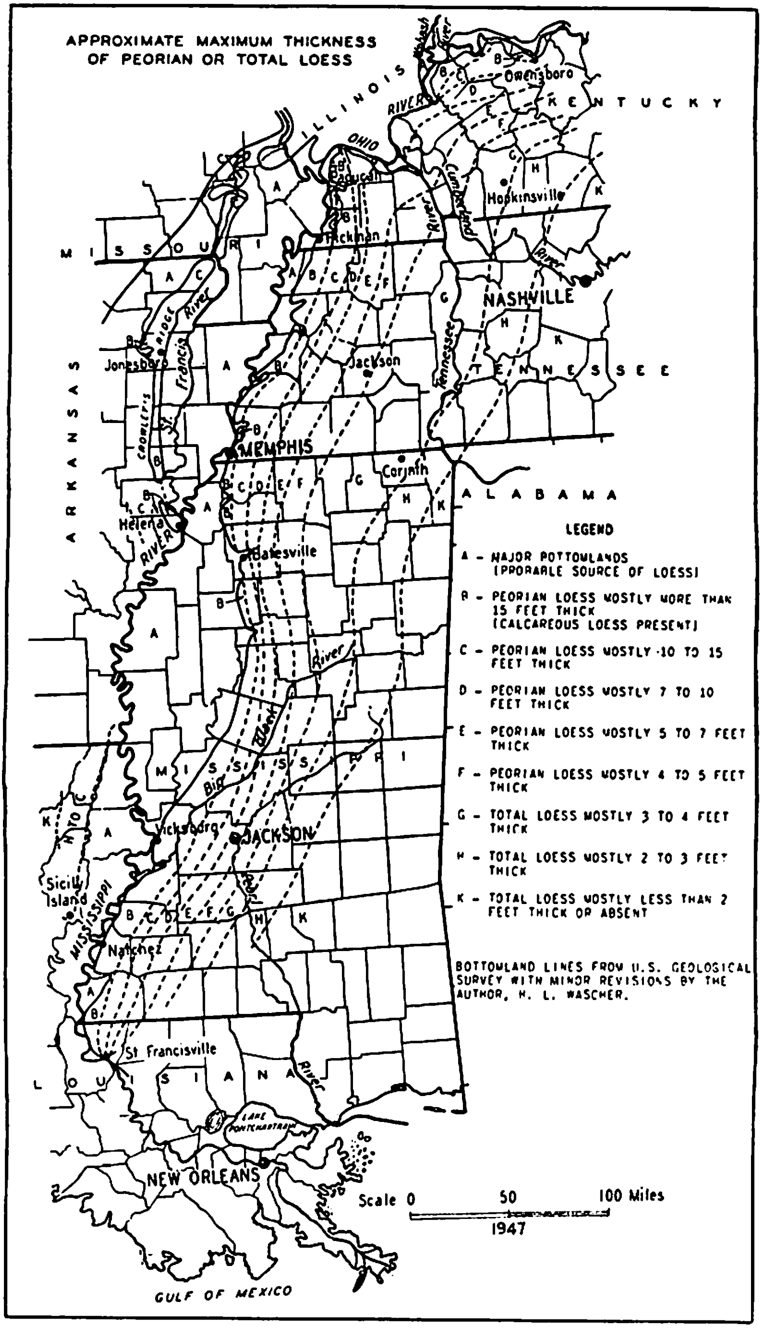


Figure 13.—Thickness of loess in the lower Mississippi Valley (from Wascher, Humbert, and Cady, 1948).

The generalized thickness-distribution map of Mississippi loess by Wascher, Humbert, and Cady (1948), reproduced in this report as Figure 13, is a good guide to maximum ridge-top thickness, but does not indicate that the percentage of area covered also decreases as the loess thins. In zones E-K, for example, where maximum loess thickness is from a few inches to seven feet, only a few per cent of the area is actually loess-covered (fig. 13).

In the eastern portion of the Mississippi loess belt the topography is considerably more subdued than in the western portion (fig. 2). This change in topography is due partly to the thinner and sparser loess in this region but mostly to the more subdued pre-loess topography. Ridges in this area are less frequently capped by Pleistocene alluvial sand and gravel than in the western loess belt, and therefore were more easily eroded. As an example of the scattered distribution of the "Citronelle" in the eastern loess belt, at sample stations 20, 21, and 22 (fig. 2) the loess rests directly on bedrock (Catahoula fm.—Miocene), whereas, at station 7, three miles north of station 22, the loess rests on gravel.

From strictly topographic considerations, one might expect the loess to be more nearly continuous over the eastern part of the Mississippi belt than the western part. However, the rate of deposition was considerably less in the east, which probably more than compensated for the lower rate of valley erosion resulting from less relief there. In addition, post-depositional erosion would be more likely to strip away the thin eastern loess over large areas than the thicker loess in the western part of the belt.

EASTERN LIMIT OF THE MISSISSIPPI LOESS BELT

A line drawn to represent the eastern boundary of the Mississippi loess belt would have to be very irregular due to the spotty distribution of the thin loess in this area. In the eastern loess belt (Zones F-H, fig. 13) the loess is everywhere severely weathered through its entire thickness and is nearly free of carbonates. Where the loess is very thin, it closely resembles some of the residual brown silt-loam soils that are common in Mississippi. This resemblance led R. J. Russell (1944*a*, p. 5-6) to speculate that "the areal extent of loess deposits has been

Figure 14.—Roadcut on U. S. Highway 80 near Clinton, Mississippi showing typical thin leached loess near to east margin. The loess rests on gray silty sand of the Catahoula (Miocene) formation (photo taken at sample station 22, figure 2).

grossly exaggerated by widespread inclusion of loesslike materials," and to advocate applying the term loess only to carbonate-bearing material. However, it has been shown by Nash (1963) that Mississippi residual soils retain an accessory heavy mineral assemblage very similar to their parent material. For example, Nash's study includes soils developed on a silty facies of the Kosciusko formation (Eocene). The non-opaque heavy mineral assemblage of these soils is nearly identical to that of unweathered Kosciusko examined during the present study (sample G-5, table 1). The non-opaque heavy mineral assemblage in the Cretaceous and Tertiary sedimentary rocks of Mississippi is characteristically high in zircon, kyanite, and staurolite (Needham, 1934; Grim, 1936; Sun, 1954; Snowden, 1961; Foxworth, *et al.*, 1962). By contrast, a high percentage of hornblende, epidote, and garnet in the non-opaque heavy mineral fraction characterizes the Mississippi loess. Mixing of basal loess with underlying material is recognizable by a heavy mineral assemblage containing elements from both the loess and Coastal Plain suites. Where weathering is severe, there may be differential removal of such semi-stable minerals as hornblende and epidote, making the loess contribution to a soil difficult to recognize. It is the writers' opinion, however, that non-opaque heavy mineralogy is the best available criterion for establishing the eastward limit of loess deposits in the lower Mississippi Valley. Further details of the heavy mineralogy of the Mississippi loess will be discussed under Mineralogy.

LABORATORY INVESTIGATIONS

PRELIMINARY STATEMENT

Laboratory investigation in this study was directed chiefly toward textural and mineralogical analyses of Mississippi loess. Texture was determined by hydrometer and sieve analyses, whereas, mineralogy was analyzed by a combination of X-ray and optical means. In addition, loess samples were chemically

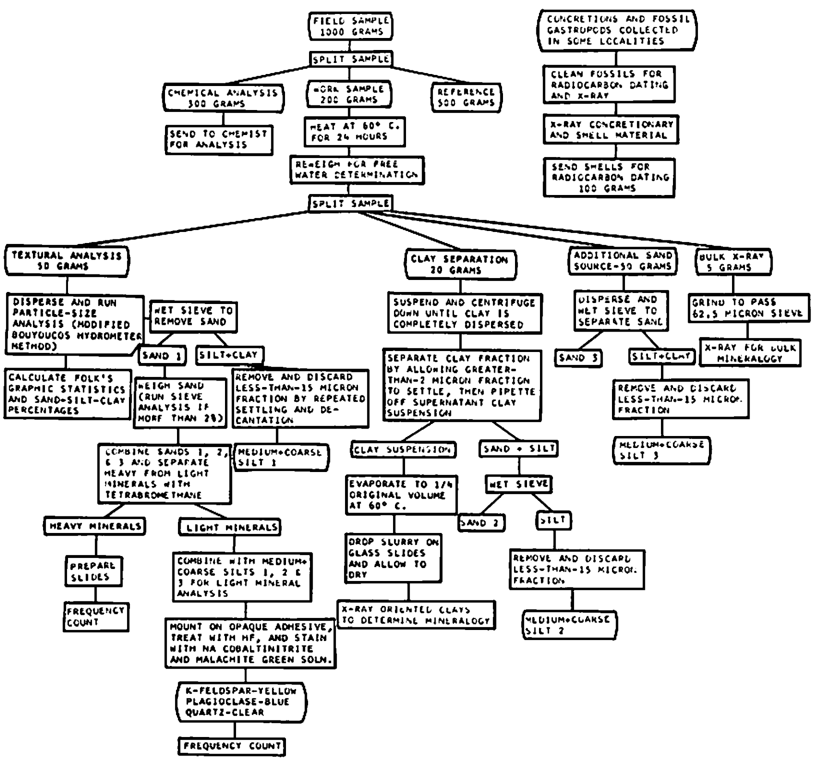


Figure 15.—Flow diagram of preparative procedures and mineralogical-textural analytical techniques.

analyzed for the writers by the chemistry department at Millsaps College, and radiocarbon ages were determined on fossil gastropod shells by a commercial laboratory.

Preparative procedures and analytical methods followed during the laboratory investigations of mineralogy and texture are shown in flow-chart form in Figure 15.

PREPARATIVE PROCEDURES

Bulk loess samples, loess concretions, and fossil gastropod shells were prepared for X-ray mineral analysis by drying at moderate temperature (60°C.) and grinding to pass a 62.5-micron sieve.

Samples for textural analysis were prepared in the following manner:

1. Dry samples at 60°C. for at least 24 hours.
2. Weigh out 50 grams and place in dispersing cup (Bouyoucos type).
3. Add 30 ml. 0.5N "Calgon" solution (sodium hexametaphosphate buffered with sodium bicarbonate) as a clay mineral dispersant.
4. Fill cup to two-thirds mark with distilled water and mix for 10 minutes with the Bouyoucos-type electric mixer.
5. Pour dispersed sample into hydrometer cylinder and fill to liter mark with distilled water. Mix thoroughly by stoppering the cylinder and turning it end over end until there is no sediment clinging to the bottom.

Following the hydrometer analysis, the sand was separated from each sample by wet sieving, and silt and clay were separated by repeated settling and decantation. Both the sand and the silt were retained for mineralogical analysis, but the clay-size fraction was discarded because it was contaminated with sodium during the Calgon treatment.

Clay-size material (less than two microns in diameter) was recovered from a separate dry sample by dispersing the clay in distilled water and allowing the silt and sand to settle, then pipetting off the clay. Frequently, a considerable amount of "washing" of the clay was necessary to deflocculate it. Samples were "washed" by repeated centrifugation until clear and discarding the supernatant liquid. When enough salts are removed by this process, clay minerals will remain suspended long enough for coarser particles to settle. The physical chemistry of clay mineral dispersal and flocculation is discussed in some detail by Baver (1956, p. 24-34). The clay suspension was concentrated by drying, and the resulting slurry dropped on glass slides and allowed to dry, forming an 001-oriented aggregate for X-ray analysis. The slides may further be heated to about 600°C., or the clay may be solvated with ethylene glycol by exposure to vapor overnight in a desiccator at 60°C.

ANALYTICAL METHODS

Minerals were determined by X-ray diffraction and/or by microscopic techniques. Clay minerals were determined qualitatively by X-ray diffraction methods, following the general scheme of Warshaw and Roy (1961), and Brown (1961). Loess concretions, gastropod shells, and bulk loess samples were also analyzed by X-ray powder diffraction.

Accessory heavy minerals and stained light minerals were identified by microscopic examination. Heavy minerals were separated by standard heavy-liquid methods (Krumbein and Pettijohn, 1938, p. 343). Heavy minerals were separated from the sand fraction (larger than 62 microns) of the loess to avoid the difficulties of identification of silt-size heavy minerals, and also to make the analytic results comparable to other major published works (Frye, Glass, and Willman, 1962; Swineford and Frye, 1951). Heavy minerals were mounted in Lakeside cement ($n = 1.54$) and counted using the field counting technique described by Hubert (1960, p. 188).

Non-phyllosilicate light minerals larger than 15 microns in diameter were mounted on an opaque cement as described by Woodruff (1962), etched with hydrofluoric acid fumes, and stained alternately with sodium cobaltinitrite and malachite green solutions (Hayes and Klugman, 1959; Woodruff, 1962). K-feldspar is stained yellow, plagioclase blue, and quartz remains clear and unstained. One thousand grains were field counted on each slide to determine quartz: plagioclase: K-feldspar ratios.

The Bouyoucos (1936) hydrometer method, as modified by Day (1950) and Woodruff (1962, personal communication), was used for textural analyses. Samples containing more than two per cent sand were also sieved to achieve a more nearly complete size analysis. Calculations necessary to convert raw hydro-

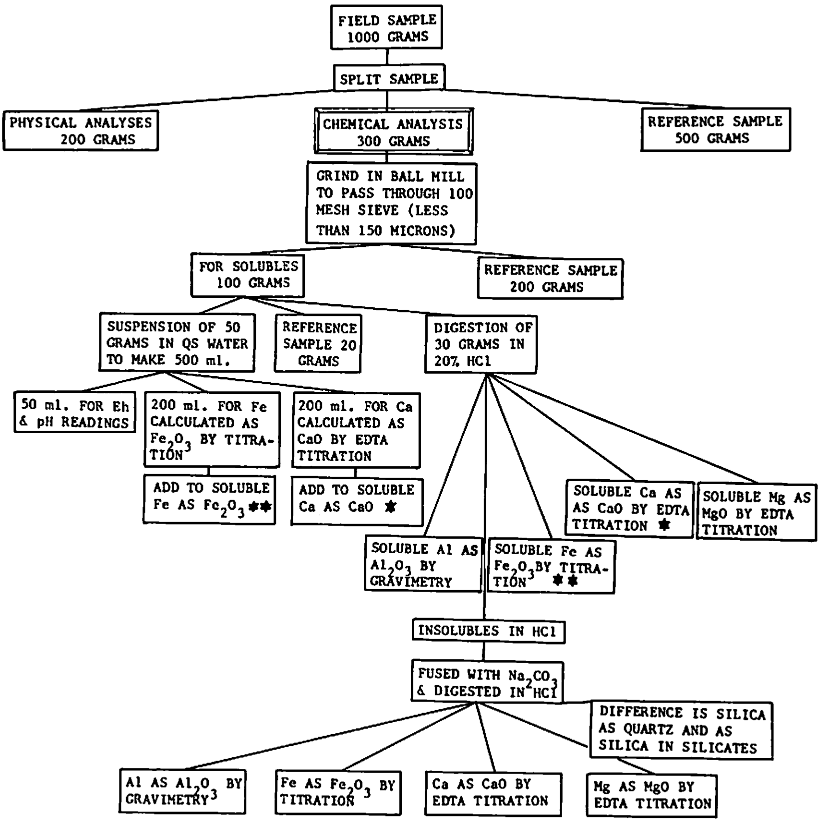


Figure 16.—Flow diagram of preparative procedures and chemical analytical techniques.

meter data (distance settled, settling time, per cent settled) to particle diameters, using the Stokes' Law equation, were programmed for the IBM 1620 computer by the senior author. Cumulative textural curves were drawn and graphic statistical parameters (Folk, 1957) were also computer-calculated, using Kane and Hubert's (1963) program.

Loess samples were analyzed for the writers by the staff of the chemistry department at Millsaps College, using procedures modified from Shapiro and Brannock (1962) (*cf.* fig. 16). Results of these analyses are given in Table 7.

Radiocarbon ages of fossil gastropod shells in the loess from four localities were determined by a commercial laboratory (Isotopes, Inc.) and by Dr. L. L. McDowell of the U.S.D.A. Sedimentation Laboratory in Oxford, Mississippi.

INSTRUMENTATION

X-ray Analysis

A North American Phillips X-ray generator combined with the North American Phillips proportional-type counter, wide angle diffractometer with pulse height analyzer and Brown strip chart recorder were used for X-ray powder-diffraction analyses. Ni-filtered copper K-alpha radiation (wave length 1.5418 Å) with an X-ray generator input of 35 kv and 15 ma was used for all X-ray powder-diffraction work. Various diffractometer scanning rates were used, but most final research runs were made at 1° per minute.

Microscopic Analysis

Heavy and light minerals were identified and counted using the Zeiss GFL and the Leitz Ortholux polarizing microscopes with mechanical stage. Both transmitted and reflected light were used.

Hydrometer Analysis

Texture was analyzed with standard soil-mixing equipment as described by Bouyoucos (1936) and a Bouyoucos Type-A soil hydrometer was calibrated following the theoretical considerations of Day (1950) and Woodruff (1962, personal communication).

Computer

Textural and statistical data were calculated with the IBM 1620-II computer with card input/output, automatic divide feature, floating point hardware, and disk storage.

MINERALOGY

PRELIMINARY STATEMENT

Previous mineralogic studies of lower Mississippi Valley loess have usually been restricted to a single aspect of loess mineralogy, such as heavy minerals (Doeglas, 1949; Fisk, 1951) or soil clay minerals (Glenn, 1960). The most comprehensive previous mineralogic study, which was made by Wascher, Humbert, and Cady (1948), included quantitative heavy mineral analyses, quartz-feldspar ratios, and $CaCO_3$-equivalents of loess from four localities in Mississippi and Tennessee.

Several mineralogic studies have been made of midwestern loess. Those of Swineford and Frye (1951), and Frye, Glass, and Willman (1962), which were comprehensive studies, served as useful guides for the mineralogic portion of this report.

Included in the present study of Mississippi loess are the results of: (1) analyses of non-phyllosilicate light minerals by differential staining and frequency counts, (2) analyses of carbonate mineralogy by X-ray diffraction and chemical techniques, (3) analyses of accessory heavy minerals by optical methods and frequency counts, and (4) analyses of clay mineralogy by X-ray diffraction.

QUARTZ AND FELDSPAR

Detrital grains of quartz and feldspar comprise the largest mineralogical component of Mississippi loess. "Unweathered" samples average (mean) 20 per cent carbonates (chiefly dolomite), 7 per cent clay (used here as the less-than-two micron size fraction, but X-ray analysis shows this fraction to be chiefly phyllosilicates of the "clay mineral" types), 2 per cent accessory heavy minerals, and 71 per cent quartz and feldspar. K-feldspars, represented by orthoclase and microcline, are the chief feldspar components, but small amounts of plagioclase are also present. Quartz: K-feldspar: plagioclase ratio data for the greater-than-15 micron fraction of the loess is presented in Table 1. The average quartz: K-feldspar: plagioclase ratio for all samples is 93.1: 6.6: 0.3. Feldspar content of the loess is reduced by weathering, but feldspars are nowhere completely removed. Clouding of feldspar grains is noticeable in weathered loess, indicating incipient conversion to clay.

Morphological quartz types (*cf.* Krynine, 1950*b*) are largely unrecognizable in the silt-size grains, but most grains appear clear and relatively free of inclusions.

Table 1.—Accessory heavy minerals and non-carbonate light minerals in the loess and related sediments.

	Auger Hole No. 1								Auger Hole No. 2							Auger Hole No. 3			Auger Hole No. 4			Aug. Hole No. 5		Aug. Hole No. 6	Auger Hole No. 7		
SAMPLE NUMBER	1-1	1-5	1-7	1-15	1-20	1-24	1-30	1-35	2-2	2-7	2-14	2-17	2-26	2-31	2-35	3-3	3-7	3-10	4-1	4-10	4-14	5-3	5-7	6-1	7-1	7-7	7-10
DEPTH (FT.)	0.0-0.9	4.2-4.8	6.2-12.1	45.0-45.2	53.0-54.0	67.0-69.0	83.0-87.0	92.0-93.0	3.2-4.2	6.2-9.0	11.3-11.6	14.2-16.1	31.0-35.0	42.5-44.8	51.0-52.0	4.0-10.0	16.0-23.0	36.0-37.0	0.0-1.0	8.8-13.9	18.4-20.0	2.3-3.4	13.0-15.5	0.0-1.9	0.0-0.6	3.8-4.4	6.5-7.8
MICA: BIOTITE-CHLORITE	4	11	25	14	17	11	7	-	4	24	13	12	23	14	3	22	13	x	24	31	x	19	x	11	10	12	x
MICA: MUSCOVITE	33	52	40	42	46	46	51	1	25	47	58	45	49	26	14	49	53	5	60	47	2	55	2	51	32	51	13
NON-OPAQUES	35	17	11	25	17	23	26	30	36	9	11	26	14	26	3	14	21	53	4	12	32	7	57	9	24	8	31
OPAQUES	28	20	24	19	20	20	16	69	35	20	18	17	14	34	80	15	13	42	12	10	66	19	41	29	34	29	56
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
ANATASE	x	-	x	1	x	1	x	-	2	-	-	x	x	x	1	-	-	1	x	x	1	2	x	x	-	-	1
EPIDOTE	36	30	35	29	28	33	26	x	19	28	21	24	23	28	27	25	22	1	29	25	3	21	2	19	17	21	6
GARNET	8	7	6	7	9	8	5	x	10	3	4	6	9	8	2	5	9	2	11	6	x	3	3	3	2	4	2
HORNBLENDE	44	51	51	49	53	43	57	2	37	62	63	63	58	56	29	61	63	6	37	61	2	49	7	39	34	54	10
KYANITE	-	2	x	-	x	-	1	22	x	-	-	-	-	x	9	1	x	22	x	x	9	1	15	2	3	1	34
RUTILE	2	4	1	3	1	2	2	11	2	-	3	1	1	x	3	3	3	7	11	1	5	3	5	1	2	3	3
SILLIMANITE	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	1	-	-	1	-	x	-	-	-	2
STAUROLITE	-	x	-	-	x	-	1	9	x	-	-	-	-	-	x	-	-	17	x	-	14	x	11	x	6	1	11
TOURMALINE	2	3	1	1	3	x	2	8	4	x	2	3	1	x	11	1	1	10	3	2	15	7	9	4	3	3	13
ZIRCON	8	3	6	10	6	13	6	45	26	7	7	3	8	8	19	4	2	33	9	5	50	14	48	32	33	13	18
ZOISITE-CLINOZOISITE	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	x	-	x
TOTAL NON-OPAQUE	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
K-FELDSPAR	6.3	7.0	7.3	7.2	6.9	4.7	2.7	0.9	4.5	4.6	7.5	8.4	6.6	6.5	3.7	6.4	9.8	4.2	2.4	7.0	1.4	5.7	0.3	2.0	3.6	3.8	0.8
PLAGIOCLASE	0.4	0.6	0.5	0.3	0.4	0.1	0.2	0.2	0.2	0.2	0.4	0.3	0.2	0.2	0.0	0.3	0.4	0.2	0.0	0.3	0.1	0.1	0.0	0.1	0.0	0.0	0.0
QUARTZ	93.3	92.4	92.2	92.5	92.7	95.2	97.1	98.9	95.3	95.2	92.1	91.3	93.2	93.3	96.3	93.3	89.8	95.6	97.6	92.7	98.5	94.2	99.7	97.9	96.4	96.2	99.2
TOTAL "LIGHT" MINS.	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

X - LESS THAN 1% HEAVY MINERALS ARE FROM THE >62.5 MICRON FRACTION. LIGHT MINERALS ARE FROM THE >15 MICRON FRACTION.
EACH PERCENTAGE OF A NON-OPAQUE MINERAL IS BASED ON A COUNT OF 300 GRAINS, EXCLUDING MICAS AND OPAQUES.
EACH PERCENTAGE OF A LIGHT MINERAL IS BASED ON A COUNT OF 1000 GRAINS.

Table 1.—(Continued)

	ROAD CUT 9	ROAD CUT NO. 10				ROAD CUT NO. 11										ROAD CUT NO. 12		ROAD CUT 13	ROAD CUT NO. 14		ROAD CUT NO. 15	
SAMPLE NUMBER	9-15	10-6	10-10	10-16	10-22	11-1	11-2	11-3	11-4	11-5	11-6	11-7	11-8	11-9	11-10	12-1	12-2	13-1	14-1	14-2	15-1	15-4
FEET ABOVE BASE	40.0	13.4-16.4	25.4-28.4	43.4-46.4	60.8-63.8	1.0	3.0	6.0	7.0	9.0	21.0	29.0	37.0	45.0	53.0	0.5	8.0	8.0	1.0	4.0	0.5	12.0
MICA BIOTITE-CHLORITE	13	31	20	25	24	X	2	1	2	11	31	27	27	30	28	X	14	21	19	26	31	24
MICA MUSCOVITE	59	50	53	15	13	1	25	7	8	46	28	46	55	56	53	X	38	37	34	47	32	43
NON-OPAQUES	14	6	9	26	39	25	6	16	17	26	24	12	9	6	7	25	13	19	28	14	14	7
OPAQUES	14	13	18	34	24	74	67	76	73	17	17	15	9	8	12	75	35	23	19	13	23	26
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
ANATASE	1	-	-	-	X	X	1	1	X	-	-	-	-	1	-	X	1	-	1	X	-	-
EPIDOTE	21	17	21	19	18	3	10	19	13	18	14	22	19	25	21	3	25	13	17	21	20	19
GARNET	4	6	11	4	4	X	6	6	1	7	9	6	4	7	5	X	19	16	8	4	19	12
HORNBLENDE	62	70	60	71	69	6	21	21	27	61	73	62	68	56	63	13	43	51	67	68	55	61
KYANITE	-	-	-	-	-	19	7	4	9	X	-	-	-	-	-	16	X	-	1	-	-	-
RUTILE	X	2	X	1	2	7	4	3	3	X	-	3	X	3	3	1	-	-	1	-	1	X
SILLIMANITE	-	-	-	-	-	X	7	X	X	-	-	-	-	-	-	X	-	-	-	-	-	-
STAUROLITE	-	-	-	-	-	21	18	6	4	1	-	-	-	-	-	16	-	-	-	-	-	-
TOURMALINE	3	1	1	X	2	16	3	3	7	1	X	1	X	X	X	5	X	X	X	X	X	X
ZIRCON	9	4	7	5	5	28	23	37	36	12	4	6	9	8	8	46	12	20	5	7	5	8
ZOISITE-CLINOZOISITE	-	-	-	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL NON-OPAQUE	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
K-FELDSPAR	6.9	4.7	6.9	6.3	8.2	0.2	0.7	2.3	3.6	5.4	5.5	6.3	6.4	6.0	6.2	2.1	7.2	9.6	8.9	10.2	6.2	6.7
PLAGIOCLASE	0.2	0.1	0.3	0.1	0.4	0.0	0.1	0.1	0.2	0.2	0.4	0.2	0.3	0.2	0.1	0.0	0.1	0.3	0.2	0.4	0.4	0.2
QUARTZ	92.9	95.2	92.8	93.6	91.4	99.8	99.2	97.6	96.2	94.4	94.1	93.5	93.3	93.8	93.7	97.9	92.7	90.1	90.9	89.4	93.4	93.1
TOTAL "LIGHT" MINS.	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 1.—(Continued)

	ROAD CUT NO. 16			ROAD CUT NO. 17			ROAD CUT NO. 18		ROAD CUT NO. 19			CUT 20	CUT 21	CUT 22	GREENWOOD AREA				LOUISIANA - MISSISSIPPI BORDER AREA							
SAMPLE NUMBER	16-1	16-2	16-3	17-1	17-2	17-3	18-1	18-2	19-1	19-2	19-3	20-1	21-1	22-1	G-1	G-3	G-4	G-5	LM-3	LM-4	LM-5	LM-6	LM-7	LM-8	LM-9	LM-11
FEET ABOVE BASE	0.5	4.0	32.0	19.0	31.0	45.0	4.0	9.0	4.0	6.0	21.0	5.0	7.0	7.0	12.0	4.0	7.0	3.5	3.5	3.0	4.0	5.0	4.0	4.0	4.0	5.0
MICA BIOTITE-CHLORITE	14	15	33	x	3	22	3	19	x	1	18	16	10	3	18	25	21	x	28	15	21	7	15	4	19	5
MICA MUSCOVITE	33	29	47	3	23	49	17	27	3	8	52	54	70	17	36	41	45	29	43	46	31	69	36	37	57	28
NON-OPAQUES	17	16	5	39	27	6	28	32	16	26	8	12	4	25	19	14	15	14	14	16	25	13	28	43	14	34
OPAQUES	36	40	15	58	47	23	52	22	81	65	22	18	16	55	27	20	19	57	15	23	23	11	21	16	10	33
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
ANATASE	x	1	2	-	-	-	1	-	-	-	-	-	-	1	-	-	-	2	-	-	-	1	1	1	x	x
EPIDOTE	12	23	17	x	3	20	8	13	3	10	19	16	11	11	17	17	12	1	10	19	13	11	15	17	15	16
GARNET	8	10	11	x	3	12	x	10	1	5	16	9	25	2	6	11	8	x	x	3	8	9	7	4	8	9
HORNBLENDE	76	63	61	4	30	65	29	70	11	14	58	41	39	23	64	67	76	3	61	73	72	62	68	71	68	30
KYANITE	-	-	-	13	15	-	5	-	8	11	-	-	2	11	-	x	-	13	-	-	-	2	x	-	-	x
RUTILE	x	x	x	9	3	x	5	x	5	6	x	x	x	5	-	-	-	15	1	x	x	x	x	1	x	1
SILLIMANITE	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-
STAUROLITE	-	-	-	17	2	-	7	-	12	14	-	-	3	7	-	-	-	7	-	-	-	x	1	-	-	1
TOURMALINE	x	x	x	5	10	x	10	3	19	7	x	9	3	2	x	x	x	17	x	x	-	x	x	2	x	3
ZIRCON	4	3	9	52	34	3	35	4	41	33	7	25	17	38	13	5	4	42	28	5	7	15	8	4	9	39
ZOISITE-CLINOZOISITE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
TOTAL NON-OPAQUE	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
K-FELDSPAR	0.1	5.4	4.1	3.9	9.8	9.3	8.3	6.9	0.3	3.6	6.2	5.1	2.3	5.2	7.9	6.5	9.6	0.0	6.6	5.1	6.2	8.2	7.5	10.2	5.9	4.6
PLAGIOCLASE	0.3	0.1	0.2	0.0	0.3	0.5	0.2	0.1	0.0	0.0	0.1	0.1	0.0	0.2	0.1	0.2	0.5	0.0	0.2	0.1	0.3	0.4	0.3	0.8	0.2	0.1
QUARTZ	93.6	94.5	95.7	96.1	89.9	90.2	91.5	93.0	99.7	96.4	93.7	94.8	97.7	94.6	92.0	93.3	89.9	100	93.2	94.8	93.5	91.4	92.2	89.0	93.9	95.3
TOTAL "LIGHT" MINS.	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

CARBONATES

The most abundant carbonate mineral in unweathered Mississippi loess is *dolomite,* not calcite, as was assumed by most previous researchers (Russell, 1944; Wascher, Humbert, and Cady, 1948; Fisk, 1951; Krinitzsky and Turnbull, 1967). Leighton

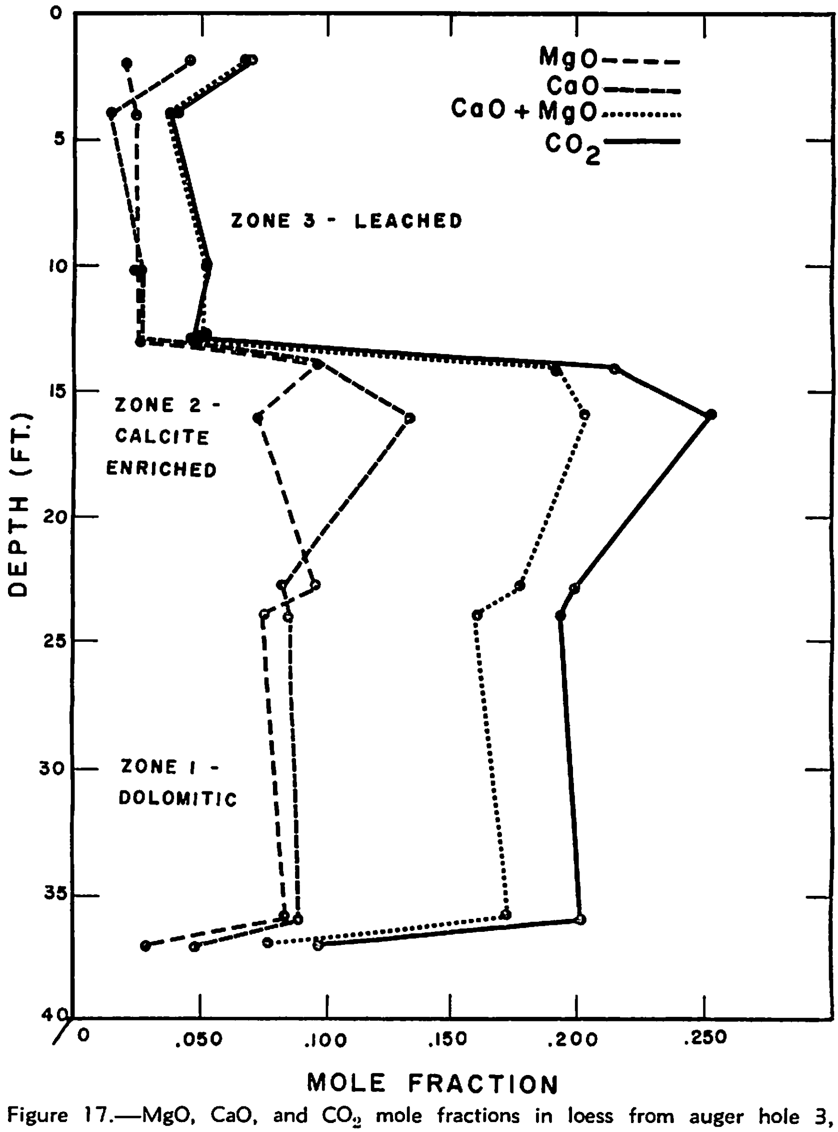


Figure 17.—MgO, CaO, and CO_2 mole fractions in loess from auger hole 3, Warren County, Mississippi, revealing carbonate mineral zones.

and Willman (1950, p. 621), recognizing the presence of some dolomite in the loess, suggested that at least some of the carbonate content was of detrital origin.

Figure 17 is a portrayal of the carbonate compositions of samples from a typical loess section. Points on the graph represent mole fractions of MgO, CaO, and CO_2, based on chemical analyses of bulk loess samples. Ratios of these mole fractions serve as good indicators of carbonate mineralogy. For example, a 1:1 ratio of CaO to CO_2 would indicate calcite, whereas, a 1:1:2 ratio of CaO to MgO to CO_2 would indicate dolomite. In mixtures of calcite and dolomite, the mole fractions of CaO + MgO would approximate that of CO_2 but the CaO mole fraction would be larger than the MgO mole fraction, because of the excess calcium.

Three distinct carbonate mineral zones are recognizable in the loess on the basis of chemical analyses, presented as mole fractions of components:

Zone 1. *Dolomitic zone,* in which the carbonate fraction is nearly all dolomite. In most sections, this is the *lowermost* and thickest zone, least affected by post-depositional weathering. The carbonate composition of Zone 1 is probably similar to that of the entire loess section immediately after deposition.

Zone 2. *Calcite enriched zone,* which is characterized by secondary calcite deposition, chiefly in the form of concretions and root tubule fillings. Dolomite is still the predominant carbonate except in the actual concretionary material.

Zone 3. *Leached zone,* in which carbonate content is sharply reduced by post-depositional solution. Zone 3 usually varies in thickness from 6 to 14 feet. Where erosion is active, the leached zone may be removed, exposing Zone 2 or even Zone 1 at the surface. Loess less than 10 feet thick is often leached throughout. The small amount of carbonate remaining in Zone 3 is dolomitic.

Carbonate mineral occurrences defined by chemical analyses are essentially duplicated by X-ray analyses of bulk loess sam-

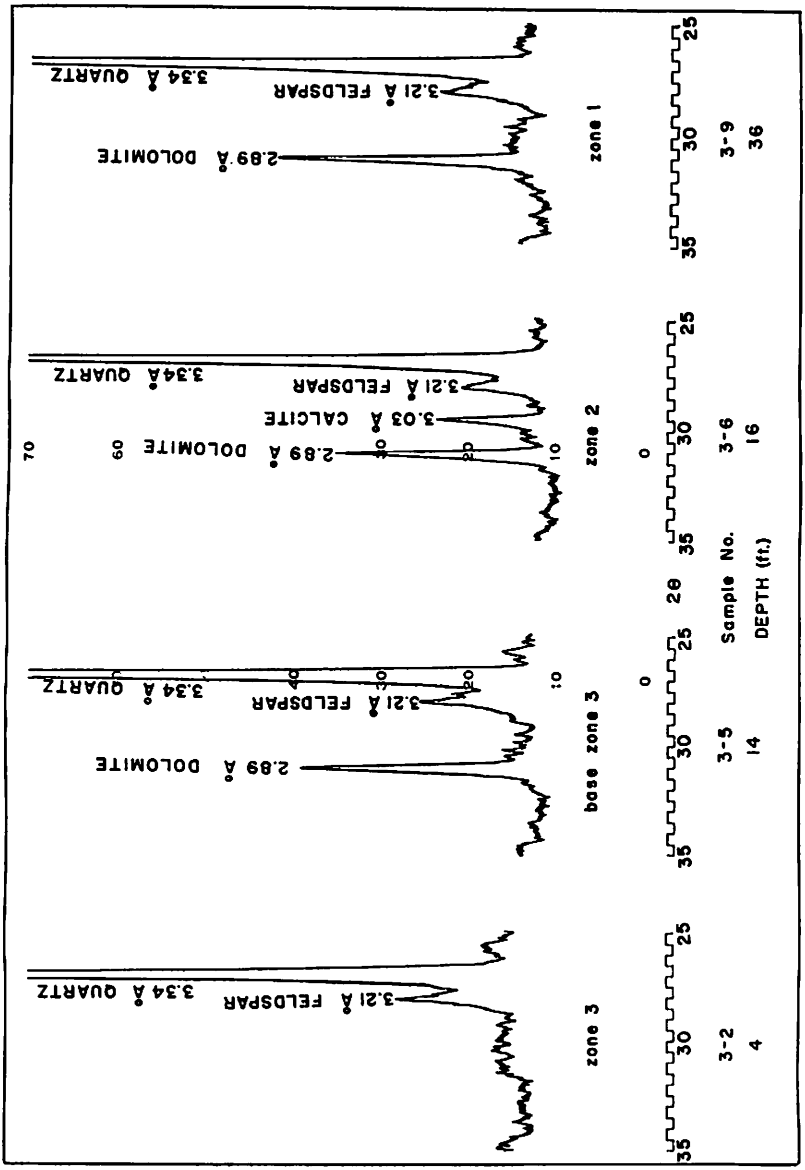


Figure 18.—X-ray diffractograms of bulk loess from auger hole 3, showing mineralogy of the three carbonate zones.

ples. Diffractograms of loess from the leached zone (zone 3) show only a weak dolomite peak; those from the calcite enriched zone (zone 2) have both calcite and dolomite peaks (although dolomite is dominant); and those from the dolomitic zone (zone 1) show strong dolomite peaks, but only a trace of calcite (*cf.* figs. 18 and 19). X-ray analysis of concretionary material shows it to be chiefly calcite (fig. 20).

Fossil gastropod shells are abundant in Zone 1 and common in Zone 2 in most sections, but are exceedingly rare in Zone 3. X-ray diffraction shows the carbonate of shells to be totally aragonitic. Mineralogical comparison of radiocarbon-dated fossil *Allogona profunda* shells with shells of individuals of the same species now living in the loessal soil indicated that all were essentially identical. X-ray diffractograms (fig. 21) show no detectable inversion of aragonite to calcite in any of the shells. X-ray analyses of bulk loess reveal no aragonite, thus indicating little or no contribution of shell fragments. Field observations confirm that the fossil gastropods are indeed usually intact.

Russell (1944*a*, p. 25) and Fisk (1951, p. 352) concluded that the bulk of the carbonate content of Mississippi loess is a ground-water precipitate, introduced after deposition. In Russell's (1944*a*, p. 24) theory of loessification, the introduction of carbonates is the final stage in the transformation of backswamp terrace deposits into loess. However, both Russell and Fisk erroneously concluded that the carbonate in the loess was chiefly calcite, rather than dolomite. Although the presence of dolomite as the more abundant carbonate in the loess does not rule out a ground-water precipitation genesis, it does require a different set of environmental conditions than the precipitation of calcite alone. If the carbonates in the loess are entirely secondary, there has been either direct precipitation of dolomite, or dolomitization of previously precipitated calcite.

The following evidence gathered in this and other recent loess studies indicates, however, that the bulk of the carbonate, probably all the dolomite, in Mississippi loess is detrital: (1) Thin sections of loess from Zone 1 (dolomitic zone) contain numerous discrete, silt-size dolomite grains. Most grains are irregularly shaped, subangular, and comparable in size to the quartz and feldspar grains. A few silt-size rhombs, probably

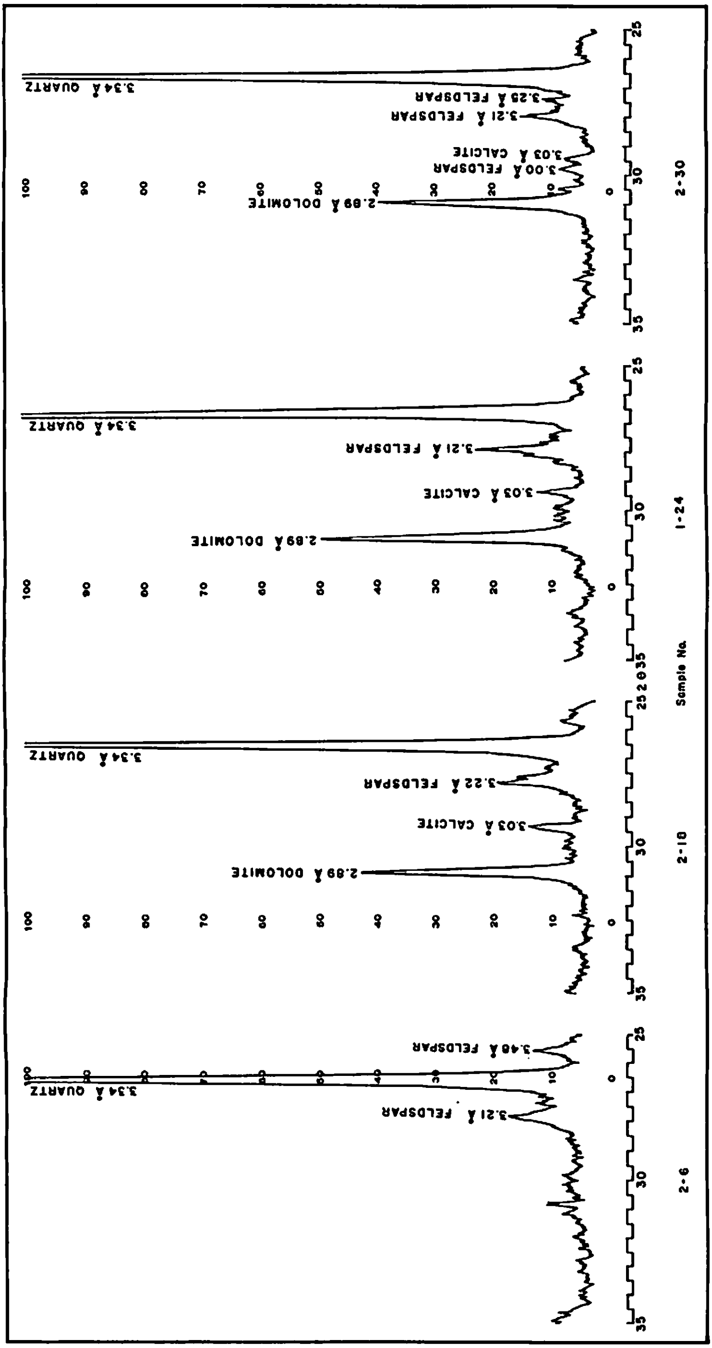


Figure 19.—X-ray diffractograms of bulk loess demonstrating the range of carbonate mineral variation.

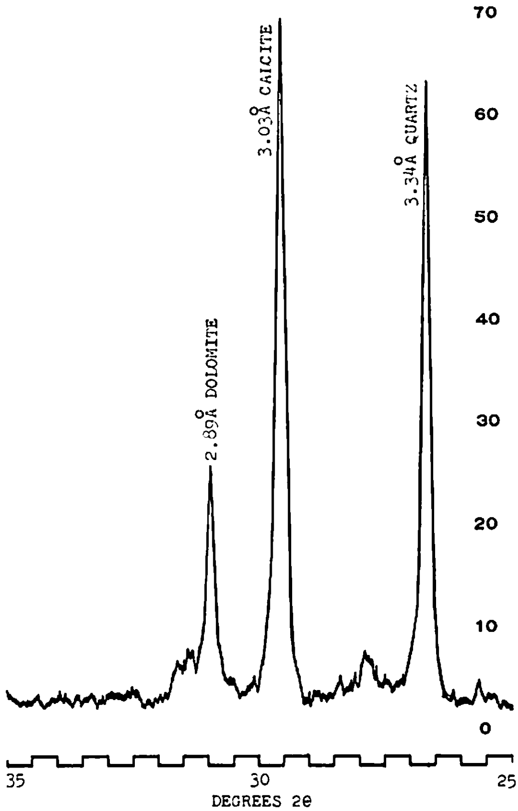


Figure 20.—X-ray diffractogram of loess concretion showing high calcite content due to ground water concentration.

cleavage fragments, are also present. As the rhombs are also size-equivalent to the quartz and feldspar grains, they are not thought to be intrastratal precipitates. (2) Glacial tills in the upper Mississippi Valley, roughly equivalent in age and mineralogy to the Mississippi loess, and presumably having the same ultimate source, contain abundant detrital calcite and dolomite. Moreover, the calcite-dolomite ratios in these tills reflect the carbonate mineralogy of their individual source areas (Willman, Glass, and Frye, 1963, p. 27). (3) The detrital carbonate content of Kansas loesses reflect the carbonate mineralogy of outwash in their source valleys (Swineford and Frye, 1951, p. 321-322). This same relationship is found in Illinois loess, according to Frye, Glass, and Willman (1962, p. 13). Calcite is more common in the Roxana silt south of the Missouri River, as a result of contribution of limestone-rich western outwash. Outwash from the Lake Michigan glacial lobe is richer in dolomite. The detrital nature of carbonates in both the Kansas and Illinois loess is further substantiated by thin-section observations.

There is, on the other hand, considerable evidence that much of the calcite in Mississippi loess is a post-depositional groundwater precipitate. Chemical analyses and X-ray diffraction data reveal that most of the calcite in the loess is concentrated in a zone immediately below the zone of leaching, in the calcite-enriched zone — Zone 2 (*cf.* figs. 17, 18, and 19). Thin-sections from this zone show large, irregular patches of fine-grained

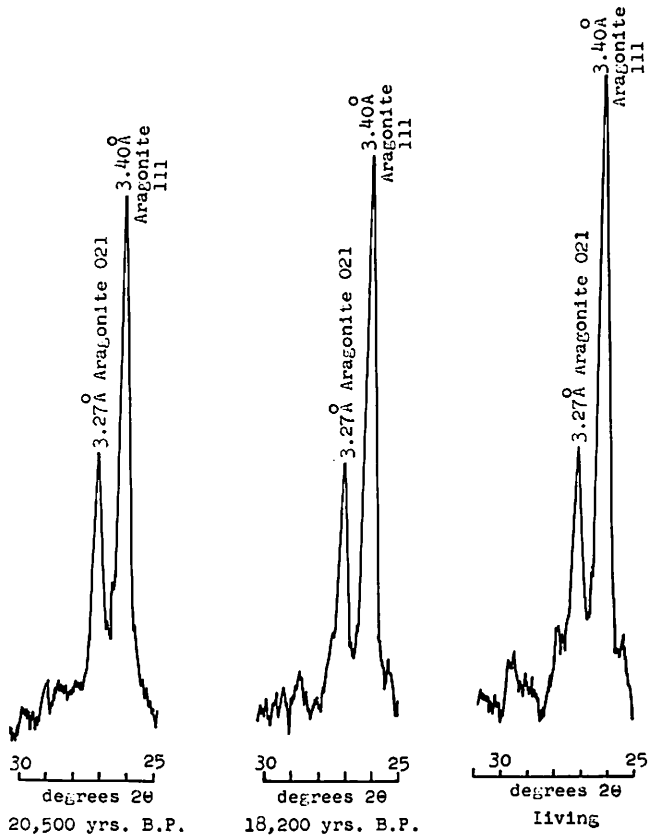


Figure 21.—X-ray diffractograms comparing shell mineralogy of fossil and living **Allogona profunda.**

calcite, which may be incipient concretions. Calcite-encrusted root tubules are very common, as are hard, calcareous concretions.

Concretions tend to be of two general types: (1) smooth surface, colloform structures, usually joined to form roughly cylindrical forms, many resembling human or animal-like figures. (2) more angular, often branched, cylindrical concretions that appear to be a labyrinth of fused root tubules. A number of imaginative names have been applied to the first type, among them Losskindchen, Lossmanchen, Losspuppen, and loess dolls. Krinitzsky (1950) classified the second type as filled tree root tubes. Both types are illustrated in Figure 22.

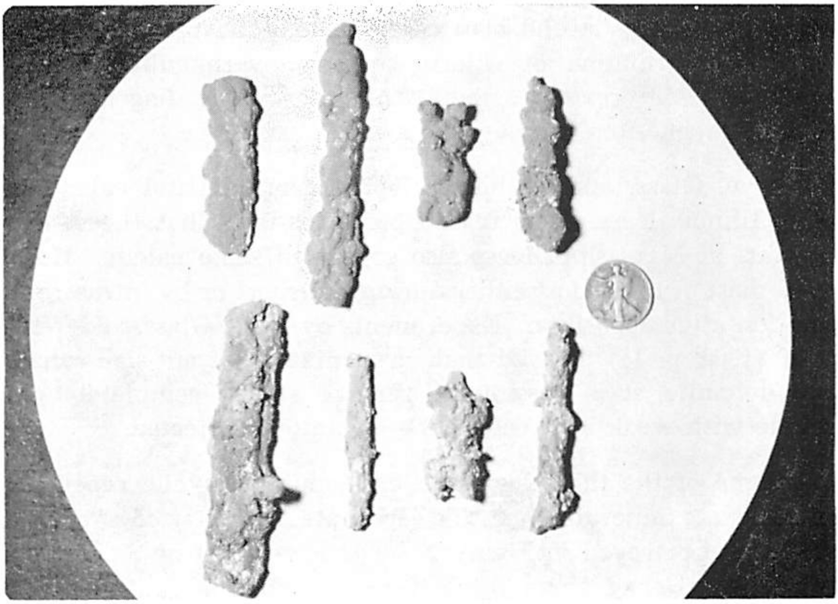


Figure 22.—Loess concretions. Those in top row are smooth "Loesskindchen" type. Branched, rough concretions on the lower row are thought to be calcite-filled tree root tubes.

Small, hollow, calcareous root tubules are locally abundant in the loess, particularly in the calcite enriched zone, presumably formed as encrustations around roots as they removed CO_2 from bicarbonate rich soil water. According to Krinitzsky (1950), both grass and tree roots formed the tubules.

As these secondary carbonate deposits occur chiefly in the calcite-enriched zone (zone 2), and are rare in the dolomitic zone (zone 1), it is concluded that most of the calcite in the Mississippi loess is secondary. Apparently, the carbonate in the upper zone of a loess section is slowly dissolved by bicarbonate-charged water from the soil (zone 3) and then redeposited (most of it) as calcite lower in the section where the pH is higher. Thus, from dissolved dolomite, calcite is reprecipitated, a common phenomenon in dolomite caves. In contrast, magnesium released during leaching is probably sorbed by clay minerals, especially the montmorillonites and vermiculites. Retention of magnesium as a brucite interlayer in the clay may be enhanced within the alkaline environment of the loess. The presence of Mg^{+2} or brucite in the clay complex may be responsible for diagenetic formation of chlorite-corrensite-vermiculite. Keller (1964, p. 47-53) reviews current thinking on the diagenetic effects of magnesium on clay minerals.

Frye, Glass, and Willman (1962) report detrital calcite in some Illinois loess. It is reasonable to assume that the source detritus of Mississippi loess also contained some calcite. However, most of it was lost either during transport or by intrastratal solution after deposition. Experiments by Frye, Glass, and Willman (1962, p. 14) showed that, in a mixture of silt-size calcite and dolomite, it is possible to remove almost completely the calcite with weak acid before the dolomite is affected.

Some of the thick loess sections exhibit a cyclic repetition of carbonate mineral zones. The carbonate chemistry of a "cyclic" section is portrayed in Figure 23. The lower half of the section is calcite enriched (zone 2); the central portion is a thin leached zone (zone 3); and the upper part is dolomitic (zone 1). The upper portion of this section was removed during road construction (fig. 11) which explains the absence of Zones 2 and 3 above Zone 1.

The presence of leached zones (or paleosols) below carbonate-rich zones is interpreted as arising from the cessation of loess deposition, followed by a period of weathering, and then resumption of deposition.

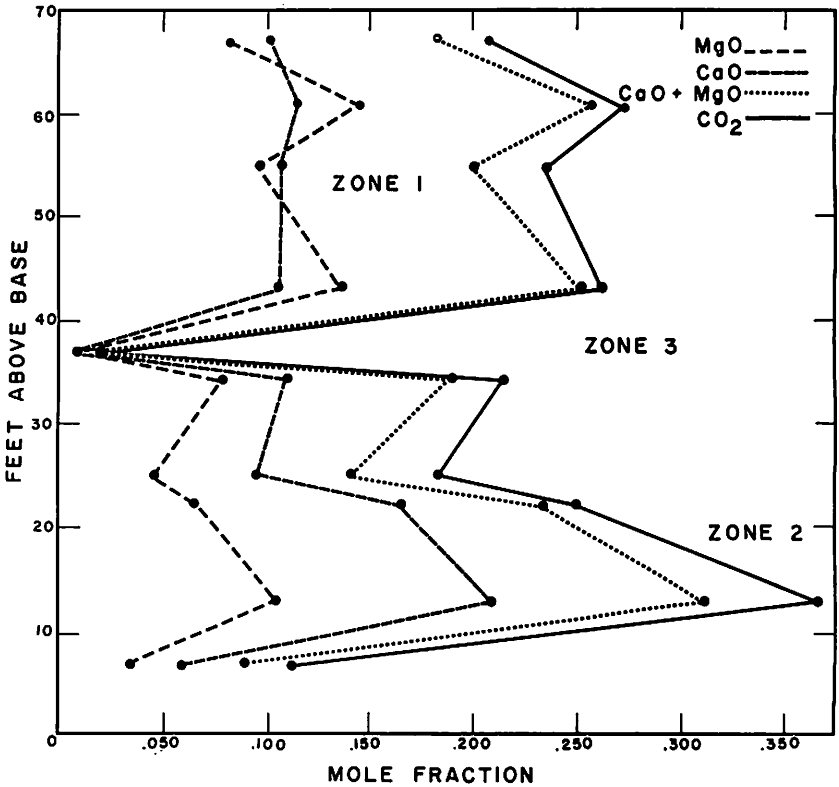


Figure 23.—MgO, CaO, and CO_2 mole fractions in loess at road cut 10 (Figure 6) showing cyclic carbonate mineral zones.

ACCESSORY HEAVY MINERALS

The accessory heavy minerals in the loess and associated sediments were examined in order to: (1) characterize quantitatively the heavy mineral assemblages; (2) help determine the provenance of Mississippi loess, comparing it with loess of other regions, particularly that of the Western Interior and upper Mississippi Valley; and (3) determine mineralogic differences between the loess and underlying sediments that would serve to differentiate loess positively from loess-like residual brown silts and to determine relative amount of mixing between loess and other sediments.

The proportions of the various accessory heavy minerals in the loess and associated sediments are given in Table 1.

Description of Accessory Heavy Minerals

The heavy minerals, which comprise an average of only two percent of the loess are chiefly angular to subangular. Grain diameters larger than fine sand (0.25 mm.) are seldom present, except as obviously secondary irregular flakes of hematite and limonite. By contrast, in the underlying alluvial sands ("Citronelle"), most of the heavy minerals are rounded to well-rounded and are considerably coarser.

Micas and opaques and non-opaque heavy minerals form three groups of relatively homogeneous hydraulic behavior and are reported separately.

MICAS

Biotite-chlorite

The most common type of biotite in the Mississippi loess is a brown pleochroic variety, although a few grains of a green variety are also present. Green biotite is generally scanty in the loess, but is much more common in the Mississippi River terrace silts. Biotite is rare or absent in the "Citronelle" sand.

Although a few grains of chlorite were observed, it is exceedingly rare in the sand fraction of the loess. No chlorite was observed in either the terrace silts or the "Citronelle".

Muscovite

Clear, colorless muscovite is very abundant in both the loess and terrace silts, averaging 63 and 55 per cent of the heavy mineral assemblages. In contrast, muscovite is rare in the "Citronelle", comprising only two per cent of the heavy mineral assemblage. Most of the muscovite flakes exhibit undulose extinction, indicating a metamorphic origin.

NON-OPAQUE HEAVY MINERALS

Epidote

Nearly clear, pale-green to brownish green epidote is common in the loess and terrace silts but absent in the "Citronelle". Most grains are angular, resembling bits of broken bottle glass in ordinary light. The ultimate source of the epidote is probably the metamorphic terrain north of Lake Superior, which, according to Willman, Glass, and Frye (1963, p. 12), contributed most of the epidote to Illinois glacial deposits.

Garnet

Garnet is common in the loess and terrace silts but virtually absent in the "Citronelle" sand. Grains are chiefly anhedral, subrounded to subangular, whose surfaces are commonly pitted. Colorless garnet predominates, but a few grains of a pale pink variety also occur in the loess.

Hornblende

Green, slightly pleochroic hornblende is volumetrically the most important non-opaque heavy mineral in the loess and terrace silts, but is rare in the "Citronelle". Brown hornblende is exceedingly rare. A few grains of actinolite are also listed with the hornblende.

Kyanite

Colorless, non-pleochroic kyanite is common in the "Citronelle" sand but is very rare in the loess and terrace silts. Grains are chiefly cleavage controlled well-rounded tabular rectangles. Some grains contain opaque inclusions and a few have pitted surfaces, presumably the result of alteration.

Rutile

Rounded, red and yellow rutile is common in the "Citronelle" but is rare in the loess and terrace silts. Some grains are very dark with inclusions (?) that may indicate formation *in situ* from the decomposition of ilmenite.

Staurolite

Pale yellow, slightly pleochroic staurolite is a volumetrically important constituent of the "Citronelle" but is rare in the loess and terrace silts. Grains are chiefly angular to subangular with little apparent surface alteration.

Tourmaline

Tourmaline is found in all three sediment types studied, but is most abundant in the "Citronelle". Brown tourmaline is the predominant variety but green and pink varieties are also found in the "Citronelle" sand. All observed grains are dichroic.

Zircon

Rounded and idiomorphic zircon is ubiquitous in the sediment types studied. Some of the rounded grains are almost spherical but most are elongate. Idiomorphic grains are commonly zoned. Most grains are colorless, although zoned crystals appear to have some delicate pastel tints.

OPAQUE HEAVY MINERALS

Hematite and Limonite

Secondary iron oxides are common in the opaque fractions of all sediments studied. The proportion of hematite and limonite in the loess increases sharply in the upper weathered zones, an indication that they are alteration products of other iron bearing minerals. "Citronelle" sands are commonly colored red by iron oxide stains on the grains and clayey detritus.

Ilmenite

Ilmenite is the dominant black opaque mineral in all the sediments studied. Ilmenite grains are well rounded and frequently partially altered to *leucoxene,* which occurs as a dull milky white coating on some grains.

Magnetite

Magnetite is distinguishable from the ilmenite by its much stronger magnetic properties. It is rare (about two percent of the heavy mineral fraction) in the "Citronelle", but somewhat more abundant, relative to ilmenite, in the loess and terrace silts.

Heavy Mineral Assemblages

Three separate, distinct heavy mineral assemblages and one mixed assemblage are recognizable in the sediments studied. Average compositions of these assemblages are illustrated by pie diagrams in Figures 24 and 25.

LOESS

The heavy mineral assemblage of the loess is mica-rich (mean = 63 per cent) with smaller amounts of opaque (mean = 21 per cent) and non-opaque (mean = 16 per cent) minerals. The non-opaque assemblage is strongly characterized by hornblende (mean = 59 per cent), epidote (mean = 21 per cent), garnet (mean = 8 per cent), and zircon (mean = 9 per cent). Variations within the loess are slight, with the exceptions of weathered zones and basal loess that is obviously mixed with underlying sediments. The chief effect of weathering is the re-

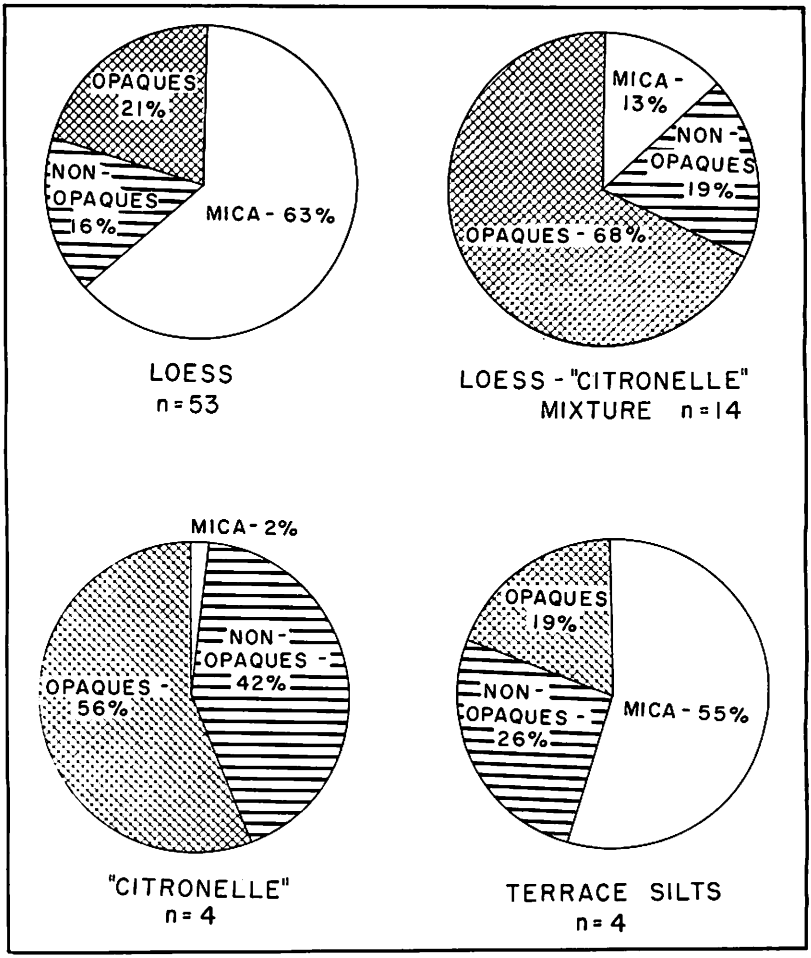


Figure 24.—Mean accessory heavy mineral assemblages of loess and related sediments.

duction of hornblende content, shown by shallow samples in Table 1. Many hornblende grains are bleached and spotted with hematite.

"CITRONELLE"

Sands and gravels of the "Citronelle" formation directly underlie the loess of most localities in Mississippi. However, the "Citronelle" heavy mineral assemblage is strikingly different from that of the loess, as it is characterized by high percentages of opaques (mean = 56) and non-opaques (mean = 42) and contains little mica (mean = 2 per cent). The non-opaque assemblage is largely zircon (mean = 49 per cent), kyanite (mean = 15 per cent), staurolite (mean = 13 per cent), tourmaline (mean = 10 per cent), and rutile (mean = 8 per cent). This is a typical Gulf Coastal Plain assemblage, common in Cretaceous and Tertiary sedimentary rocks in this area. The igneous-metamorphic complex of the Southern Appalachian region is considered the ultimate source of this assemblage (*cf.* Needham,

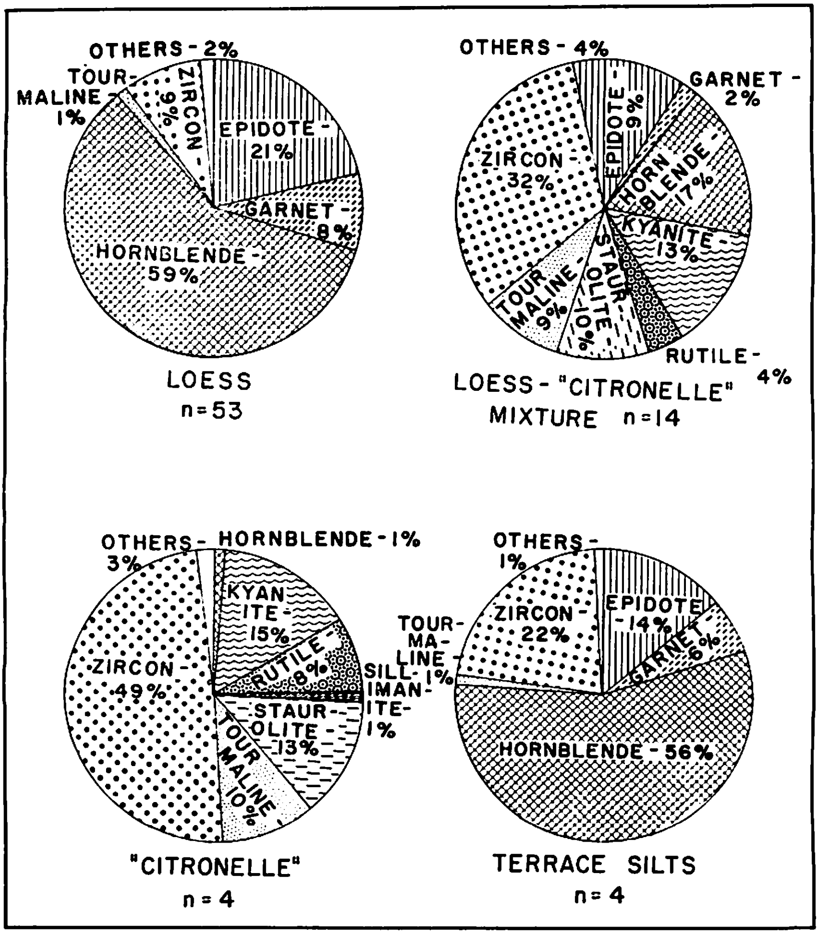


Figure 25.—Mean non-opaque, non-micaceous accessory heavy mineral composition of loess and related sediments.

1934; Grim, 1936; Sun, 1954; Snowden, 1961; Foxworth, *et al.*, 1962).

LOESS — "CITRONELLE" MIXTURE

Physical mixing of basal loess with "Citronelle" sand is commonplace. The "mixed zone" may be several feet thick and is recognizable by its hybrid heavy mineral assemblage. Heavy mineral composition varies widely depending upon the degree of mixing and which element is dominant. The degree of mixing may be expressed numerically by the ratio of hornblende to kyanite (H-K ratio). Hornblende is rare (about 1 per cent) in the "Citronelle" but very abundant in the loess (59 per cent) whereas, kyanite is usually absent in loess but abundant (15 per cent) in the "Citronelle". An H-K ratio higher than 50 indicates unmixed loess; H-K ratios below 0.1 indicate unmixed "Citronelle." Table 2 below shows the range of H-K ratios from mixed loess-"Citronelle" samples.

Table 2. Hornblende-kyanite ratios of mixed loess-Citronelle non-opaque accessory heavy mineral assemblages.

Sample No.	2-35	3-10	5-7	7-10	11-1	11-2	11-3	12-1
H-K ratio	3.2	0.3	0.5	0.3	0.3	3.0	5.2	0.8
Sample No.	17-2	18-1	19-1	19-2	22-1			
H-K ratio	2.0	5.8	1.4	1.3	2.1			

TERRACE SILTS

The four samples of Mississippi River terrace deposits examined have a mean heavy mineral assemblage that is superficially similar to that of the loess. However, three of these contain significant amounts of green biotite that is very rare in the loess. Although evidence is slight, it is the writers' opinion that varietal heavy mineral types, particularly biotite, could be useful criteria for stratigraphic differentiation of Pleistocene Mississippi River terrace deposits.

Provenance of the Loess Based on its Heavy Mineral Assemblage

The immediate pre-eolian source of Mississippi loess is interpreted as the fine, water-transported detritus of the late

Wisconsin Mississippi River Valley. However, most of this sediment was produced as outwash from continental glaciers. To understand fully the ultimate source of the loess, the composition of the glacial tills related to the outwash must be known and, in turn, the source or sources of the glacial till. Evidences for this line of reasoning are (1) the loess heavy mineral assemblage is sufficiently different from that of the adjacent Tertiary coastal plain sediments to preclude any but very minor local contribution, and (2) the non-opaque heavy mineral assemblage in the Mississippi loess is nearly identical to that of the Peoria loess in the upper Mississippi and Illinois Valleys (Table 3). The logical conclusion is that at least their sand-size heavy mineral assemblages had a common origin.

Frye, Glass, and Willman (1962) and Willman, Glass and Frye (1963) clearly show the interdependence of loess mineralogy and the source outwash valleys. The heavy mineral assemblage of the Mississippi loess is, therefore, a "weighted average", reflecting the relative contributions of many upstream outwash valleys (*cf.* fig. 1). The uniformity of the heavy mineral assemblage in the Mississippi loess is probably due to the averaging effect of long distance transport and multiple sources, obscuring slight changes in source or contribution amounts from various sources.

The primary source area for most of the loess heavy mineral assemblage can be traced up glacial outwash streams to the igneous-metamorphic complex of the southern Canadian Shield, although outwash from the Western Interior of the United States and Canada is a probable secondary source. Willman, Glass, and Frye (1963) give a detailed account of till sources and outwash movement in the upper Mississippi Valley region, based on accessory heavy mineral and clay mineral studies.

CLAY MINERALOGY

Identification and Classification of Clay Minerals

Clay minerals in the Mississippi loess were identified mainly from their X-ray powder diffractograms, using the general procedures outlined by Warshaw and Roy (1961), Brown (1961), and Keller (1962). In this study, the clay minerals from 125 samples were identified and assigned to their major groups — kaolin, montmorillonite, illite or hydrous mica, chlorite, vermi-

Table 3. Average non-opaque heavy mineral assemblage of Mississippi loess compared with Upper Mississippi Valley and Illinois Valley loesses.

Depositional Province	Lower Mississippi Valley (chiefly Peoria loess)	Illinois River[1] Valley (Peoria loess)	Mississippi Valley[1] above Alton (Peoria loess)	Mississippi Valley[1] below Alton (Peoria loess)
Number of Samples	53	18	20	11
Minerals:				
Tourmaline	1	1	2	3
Zircon	9	8	5	15
Garnet	8	8	6	11
Epidote	21	22	23	26
Staurolite	—	—	tr.	tr.
Hornblende[2]	59	56	59	37
Enstatite	—	1	tr.	1
Hypersthene	—	tr.	1	tr.
Diopside	—	tr.	tr.	1
Others	2	4	4	6

[1]data from Frye, Glass, and Willman (1962) [2]includes actinolite

culite, and interstratified random mixtures of these groups — for the purpose of applying the data to geologic interpretations, rather than to study for its own sake the detailed mineralogy of individual specimens.

KAOLIN GROUP

Clay minerals of the kaolin group were identified by their characteristic 7Å (001) interplanar spacing, supporting reflections at higher orders, and prism reflections. As it is not usually possible to differentiate among the various members of the kaolin group of minerals unless the clay is nearly monomineralic, which apparently is not true in loess, the term *kaolin* or *kaolinite,* as used in this report, refers to the *kaolin group* of minerals. A relatively high degree of crystallization in the loess kaolin was indicated by the basal spacing between 7.1 and 7.2 Å (Keller, 1962).

Clay minerals in both the kaolin and chlorite groups yield a 7Å interplanar spacing, but they can ordinarily be distinguished by heating to 550°C for 4 hours and again X-raying the specimen. Under this heat treatment, the 7Å reflection of kaolinite is destroyed, whereas, that of chlorite (except for poorly-crystallized "sedimentary" chlorites) remains intact. Heating of chlorites usually also enhances the intensity of its 14Å (001) peak. The identification of all kaolinite in this report was confirmed by heat treatment.

MONTMORILLONITE GROUP

Montmorillonite is used in this report as a group term for clay minerals with (001) interplanar spacings of about 15Å (depending upon the interlayer cations and degree of hydration), which expand to 17Å when solvated with ethylene glycol. It is also considered that the montmorillonite lattice (001 spacing) collapses to approximately 10Å when heated (fig. 26). No attempt has been made to distinguish among individual minerals in the montmorillonite group, as their distinction is nearly impossible in complex mixtures.

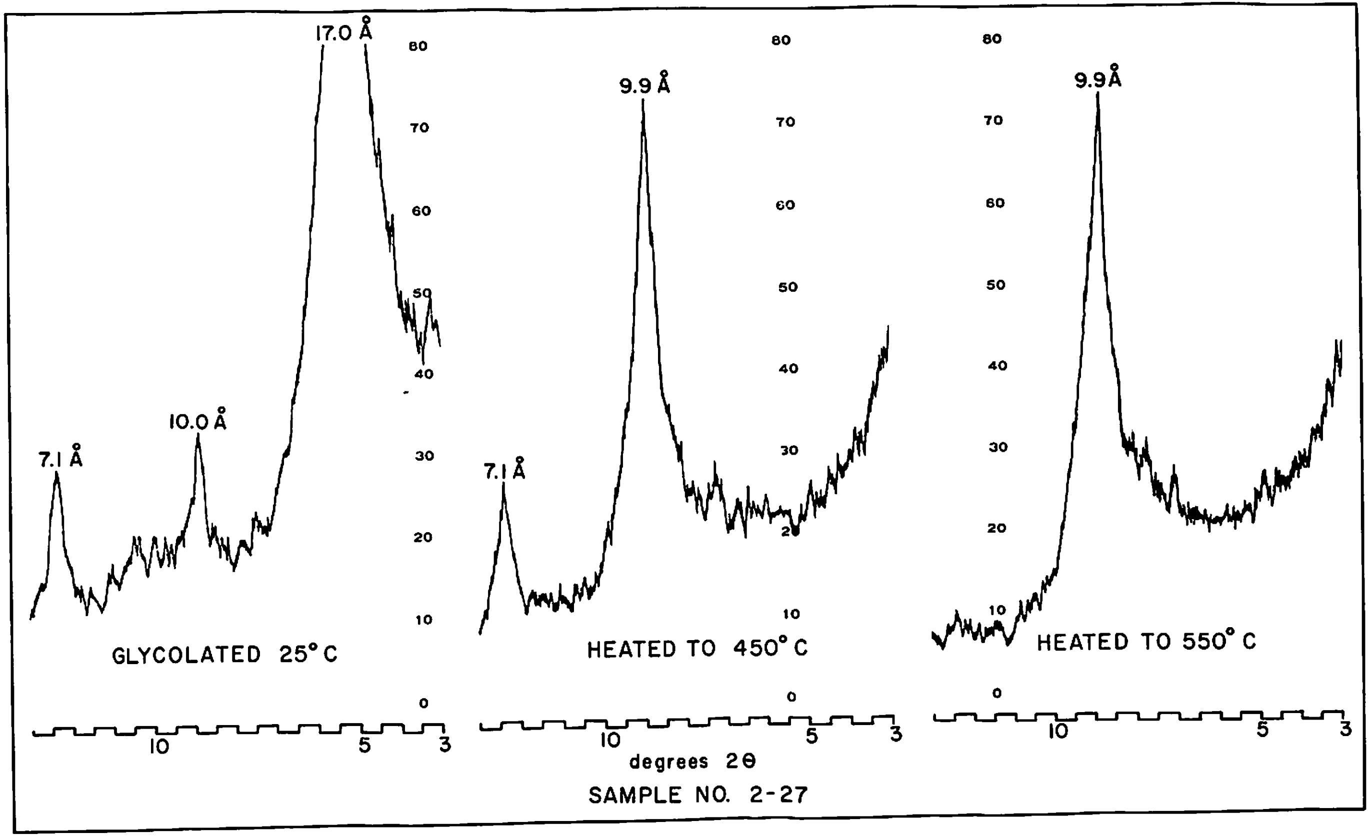


Figure 26.—X-ray powder diffractograms showing typical loess clay mineralogy. The 17 angstrom clay is montmorillonite; 10 angstrom is illite (or hydrous mica); and the 7 angstrom is chiefly kaolinite, as it disappears on heating to 550 degrees C. Sample is the less-than-two micron fraction oriented on a glass slide and solvated with ethylene glycol, heated to 450 degrees C. for 12 hours, and 550 degrees C. for 4 hours.

ILLITE, OR HYDROUS MICA, GROUP

The illite, or hydrous mica, group of clay minerals was identified by the (001) spacing of approximately 10Å, which does not expand upon solvation with ethylene glycol and is little affected by heat treatment. For most samples, it was difficult to decide whether "illite" or "mica" was the more appropriate term for the 10Å clay. Generally, illites are characterized on X-ray diffractograms by more diffuse, or broader, peaks than mica. As both muscovite and biotite are abundant in the silt and sand fractions of the loess, they are probably also present in the clay fraction. However, in this report, the term "illite" is arbitrarily used for all the 10Å material in the clay size fraction.

CHLORITE GROUP

The chlorite group of clay minerals was identified by a (001) interplanar spacing at approximately 14Å, and other spacings, generally well developed, at integral high orders. The well-crystallized chlorite structure is not destroyed by heating to 550°C, but is slightly dehydrated, which usually intensifies the 14Å peak. Chlorite does not expand when solvated with ethylene glycol.

VERMICULITE GROUP

The vermiculite group of clay minerals is difficult to identify in the presence of both chlorite and montmorillonite. Vermiculite regains part of its interlayer water after being heated to 400° or 500°C (Walker, 1961), whereas, montmorillonite and chlorite do not. Therefore, any evidence of rehydration, indicated by movements of the basal peaks after heating, should be attributable to vermiculite. To check this phenomenon, samples were heated to 400°C for one hour, quickly removed to the X-ray diffractometer and scanned rapidly several times while air of 100 per cent relative humidity was introduced into the sample chamber. If basal-peak shifting was noted it was attributed to vermiculite. As the (001) interplaner spacing of vermiculite is dependent on both the type of interlayer cations present and the degree of hydration (Walker, 1961), it is often desirable to introduce cations, such as Mg^{+2}, Na^{+}, or K^{+} and note the changes in (001) spacing, as an additional test for vermiculite.

MIXED-LAYER CLAY MINERALS

Although mixed-layer clay minerals are not common in Mississippi loess, a few of the clays from the upper portions of both modern and ancient soil profiles in the loess showed mixed-layer characteristics. Most of these clays showed a broadening of peaks, suggesting random, non-uniform interstratification, but an occasional peak at about 12Å persisted at 550°C. Glenn (1960) also noted this 12Å peak in loessal soils and suggested that it represented random interstratification of pedogenic dioctahedral (Al) chlorite with illite. Keller (1962) notes that the compositions of mixed-layer clay minerals may be estimated by observing the displacement of (001) peaks in diffractograms of specimens that are room dry, solvated in ethylene glycol, and heated.

Quantitative Estimation of Clay Minerals in Mississippi Loess

A complete mineral analysis of a clay-bearing sediment should ideally include both qualitative identification and quantitative estimation of the clay minerals present. Clay mineral mixtures have been satisfactorily analyzed, under favorable conditions, using X-ray techniques described by Johns, Grim, and Bradley (1954) and Weaver (1958). However, as pointed out by Keller (1962), both these methods employ quantitative estimations based on comparison of appropriate diffraction peaks or lines in patterns of unknown samples with those of standard reference samples. Such comparisons are reliable only if the clay minerals involved are relatively clean and well defined, and are of approximately the same particle-size. The presence of one or more of the following characteristics in natural clay mixtures, according to Keller (1962), may make rigorously quantitative expressions of clay mineral percentages or ratios deceptively misleading: (1) inconsistencies in the chemical compositions of the clay minerals (for example, the iron content of montmorillonites and micaceous clay minerals), (2) variation in the amount of amorphous (to X-ray) material from specimen to specimen, (3) variability in ratios of mixing in clays that show random mixed layering, and (4) differences in the degree of post-depositional weathering of samples.

Early in the present study, it was noted that very strict control of the sample preparation procedure was necessary to obtain reproducible quantitative, and sometimes even qualitative, estimates of the clay mineralogy of loess. Variation in particle-size among the clay minerals is thought to be the chief reason for this sensitivity to sample preparation technique. For example, montmorillonite, which is the most abundant clay in the loess, is finer-grained than the other clay minerals. Figure 27 shows that montmorillonite is confined to the less-than-2-micron parti-

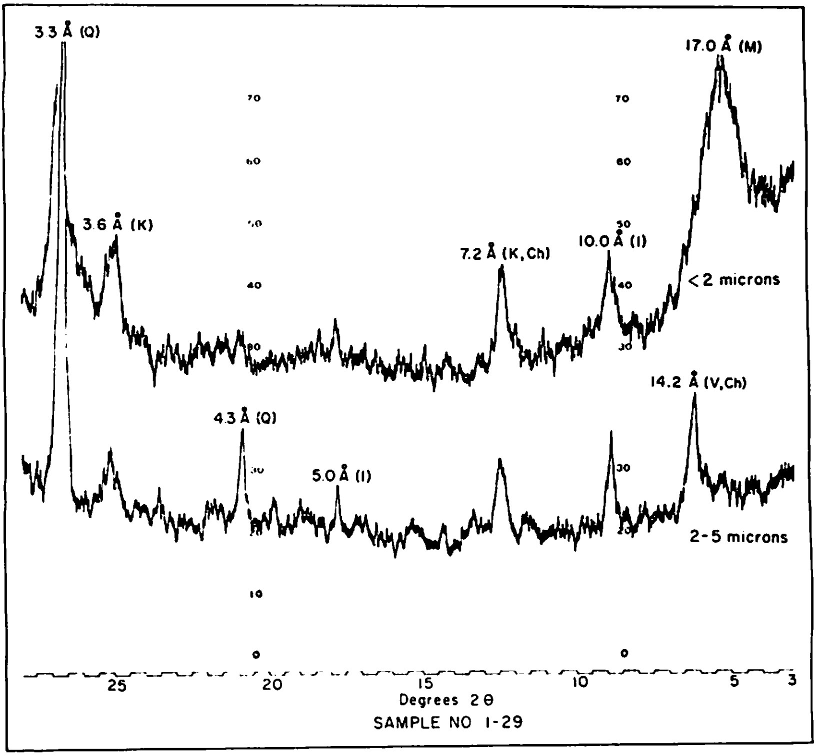


Figure 27.—X-ray powder diffractograms showing mineralogical differences between the less-than-two micron and the 2-5 micron particle diameter fractions of the loess. Both specimens are Mg-saturated solvated with ethylene glycol and vacuum-oriented on a porous tile.

cle-diameter fraction, whereas, the other clay minerals (illite, kaolinite, vermiculite, and chlorite) are all present in the 2-5-micron fraction. Schultz (1955), and more recently Gibbs (1965) have demonstrated that sample preparation is critical in the semi-quantitative X-ray analyses of clay mineral mixtures of variable particle-size. Preparative methods that require slow settling of clays, such as allowing clay suspensions to settle on glass slides, pipetting slurries on glass slides, or centrifuging clay onto glass slides or ceramic tiles, give a quantitative bias for clay mixtures in which the various minerals differ in particle-size. The finest particles settle last and form the surface coating which is evaluated by X-ray analysis. Schultz (1955) suggested X-raying both the top and bottom surface of a sedimented clay sample to determine the extent of particle-size mineral segregation. Gibbs (1965) found that several sample preparation techniques currently in use do not require slow sedimentation and thus, do not introduce a particle-size bias. These methods are: (1) rapid suction of slurries onto ceramic tiles, (2) smearing of thick clay pastes onto glass slides, and (3) powder pressing of dry clay. Gibbs strongly recommends that one of these techniques be used for all quantitative work. Another approach that is used by some clay mineralogists to minimize particle-size bias is to report the quantitative mineralogy of several particle-size subclasses within the clay fraction. This technique is also used to separate "interfering" minerals of different sizes, permitting identification of some minerals that would otherwise be masked on diffractograms.

Although every effort was made to prepare the clay samples uniformly in the present study, most diffractometer specimens were prepared by pipetting a thick slurry of the less-than-2-micron particle diameter fraction onto glass slides. Therefore, in quantitative estimates of these clays, there is a particle-size bias which increases the apparent percentage of fine clay. In the loess, montmorillonite comprises most of the fine (less-than-0.2-micron particle diameter) clay. In view of the variations in particle-size among the clay minerals in the loess and the probable bias introduced in sample preparation, it would be misleading to report quantitative estimations of clay minerals as apparently precise numerical values. Instead, the relative amounts of clay minerals will be described, using Keller's

(1962) terminology, as "dominant", "strong", "moderate", "slight", and "trace". The term "dominant" indicates that a given mineral constitutes essentially all the clay detected in the specimen; "strong" means a mineral comprises approximately three-fourths of the clay in the specimen; "moderate" indicates about half of the clay; "small" and "slight" refer to about one-fourth and one-eighth, respectively, of the clay, and a "trace" means that a mineral is barely detectable on the diffractogram (probably comprising no more than five or six per cent of the specimen).

Distribution of Clay Minerals in Mississippi Loess and Related Sediments

The general distributions of clay minerals in Mississippi loess and related sediments are described below, according to sediment type.

LOESS

As the major emphasis of this study was placed on the loess, most of the clay minerals identified and quantitatively estimated were from the loess. The less-than-two-micron particle diameter fractions of approximately 100 loess samples were studied. Typical X-ray diffractograms of loess clays are shown in Figures 26, 27, and 28. The clay mineral composition of Mississippi loess is surprisingly uniform from sample to sample, and may be generally described as follows:

1. Montmorillonite (+vermiculite) is a moderate to strong component of the clay fraction. The vermiculite contribution to "montmorillonite" peaks is usually slight and is masked by the montmorillonite, but is recognizable by its tendency to rehydrate and expand to about 15Å after heating to 550°C. The 2-5 micron particle diameter fraction of a few loess samples was X-rayed, revealing a vermiculite peak without the presence of montmorillonite (*cf.* fig. 27).

2. Small amounts of illite and slight amounts of kaolinite occur in practically every loess clay sample. In nearly every sample the illite:kaolinite ratio is approximately 2:1. The 7.2Å peaks on loess clay diffractograms are

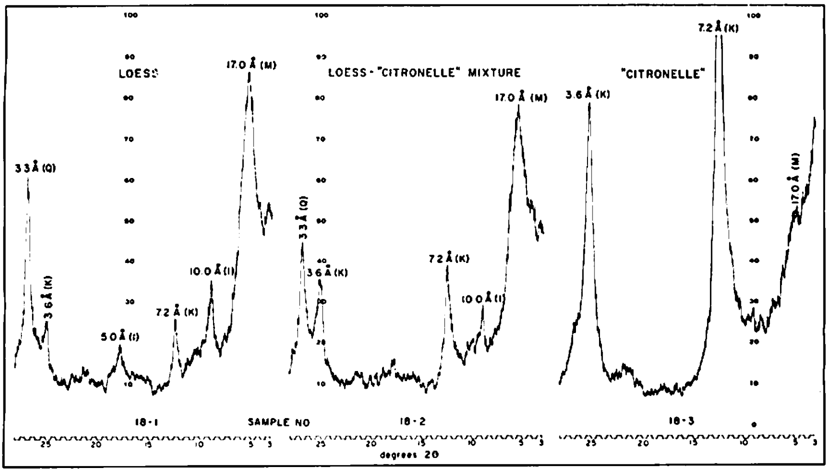


Figure 28.—X-ray powder diffractograms showing clay mineral differences among loess, "Citronelle", and mixtures of the two. The 17 angstrom peaks are montmorillonite, the 10 angstrom peaks are illite (or hydrous mica), and the 7.2 angstrom peaks are kaolinite. Specimens are from the less-than-two micron particle diameter fraction, oriented on glass slides, and solvated with ethylene glycol.

considered to be kaolinite, but heat treatment revealed a trace of chlorite in a few samples.

3. Highly weathered soils developed on the loess (and sometimes as zones within loess sections separating carbonate-bearing loess blankets) exhibited some pedogenic mixed-layering (chlorite and illite) and a general deterioration and broadening of all clay peaks.

Frye, Glass and Willman (1962), quantitatively analyzed numerous Illinois loess clays and devised a "diffraction-intensity" (D. I.) ratio, derived by dividing the X-ray diffraction intensity (counts per second) of the 10Å spacing for illite by that for the 7.2Å spacing for kaolinite and chlorite. These D. I. ratios have proved extremely useful for differentiation and correlation of Illinois loesses, and have even revealed the chronology of diversion of drainage systems, and thus sources of loess detritus, by Wisconsin glacial lobe advances (Glass, Frye, and Willman, 1964). Assuming that sample preparation is reasonably uniform, the D. I. ratio provides a means of differentiating between loess clay assemblages without the necessity of interpreting the data in terms of exact percentages of each mineral. Furthermore, D. I. ratio values do not vary significantly between carbonate-bearing and leached loess, with the exception of highly weathered soil zones.

Diffraction intensity ratios were calculated for about 50 selected Mississippi loess clays, but there was little variation in values. All measured D. I. ratios for Mississippi loess clays, with the exception of highly weathered soil clays, varied between 1.1 and 1.4, the mean D. I. ratio value for all samples being 1.2. This is, incidentally, the same mean D. I. ratio obtained by Frye, Glass and Willman (1962) for Peoria loess clays in the upper Mississippi River Valley, north of Alton, Illinois. Unfortunately, D. I. ratios in Mississippi loess do not have any recognizable stratigraphic significance, probably because of the "averaging" effect caused by mixing of detritus from several sources during long transport. This same "averaging" effect was noted in the heavy mineral assemblages of the Mississippi loess earlier in this report. However, as the more subtle stratigraphic relationships in Mississippi loess are better understood with the aid of future radiocarbon dating, D. I. ratios should certainly be measured, or perhaps an even more sensitive clay mineral ratio devised, which might allow recognition of stratigraphic zones.

"CITRONELLE"

The clay mineral content of the "Citronelle" sands and gravels, which almost everywhere underlie the Mississippi loess, is dominantly kaolinite, with only a trace of montmorillonite, and no detectable illite, chlorite, or vermiculite. Figure 28 shows a typical "Citronelle" clay diffractogram.

LOESS-"CITRONELLE" MIXTURE

Physical mixing of the basal few feet of loess sections with underlying "Citronelle" is commonplace, and may be recognized in clay mineral assemblages by an increase in kaolinite and corresponding decrease in illite and montmorillonite, as shown in Figure 28. As post-depositional weathering may also increase the kaolinite content of loess, this is not a positive indicator of mixing. Accessory heavy mineral content (*cf.* Table 2) is a more sensitive and reliable index to the degree of mixing between loess and "Citronelle".

Source of Clay Minerals in Mississippi Loess

The source of detrital clay minerals in Mississippi loess was outwash from several glacial regions, which was mixed and carried down the Mississippi River drainage system as a valley train. Willman, Glass, and Frye (1963, p. 16) described the sources of midwestern tills and outwash as follows:

> Tills and outwash deposited by glaciers that advanced from the northwest strikingly reflect the exceedingly high montmorillonite content of the upper Cretaceous and younger deposits over which these glaciers advanced. In contrast, the tills and outwash deposited by glaciers that advanced from the northeast contain a high proportion of illite characteristic of the middle to late Paleozoic rocks that occur across Indiana, Michigan, northern Ohio, and southern Ontario, and the tills and outwash from the north strongly reflect the illite and chlorite of the Ordovician, Devonian, and Mississippian shales. In addition to these adjacent sources of clay minerals, the Pennsylvanian bedrock of Illinois has exerted an important influence on the clay-mineral composition of tills in all but the northernmost part of the state.

Griffin (1961) analyzed the clays carried by the Missouri, upper Mississippi, and Ohio Rivers and showed that the detritus carried by modern streams in the area still strongly reflects the clay mineralogy of these Pleistocene glacial deposits.

It is interesting to note that, whereas, the sand-size heavy mineral assemblage of Mississippi loess most strongly reflects a northern and eastern source, the clayey, montmorillonite-rich northwestern outwash was the more important source of the clay-size fraction.

Diagenesis of clay minerals in Mississippi loess is thought to be slight, although an increase in kaolinite and a tendency toward mixed-layering has been noted in loessal soil clays.

MINERALOGICAL CLASSIFICATION

A preferred mineralogical classification of sedimentary rocks is purely objective and descriptive. Some type of mineralogic polar end-member classification system is desirable, and, if the end members are properly chosen, the names of the sedimentary rocks should reflect the genesis and natural groupings of the rocks in the field.

Krynine (1948) applied the principles of igneous rock classification and ternary end-member diagrams to clastic sedimentary rock classification. This classification is based primarily on mineral composition, including the clay fraction, and the rock names are modified by textural adjectives. Krynine (1950*a*) modified the classification to exclude clayey matrix and cements, recomputing the quartz, feldspar, and mica poles of the sand and silt fraction to 100 per cent. Krynine's classification has been further modified by Folk (1954), van Andel (1958), and Hubert (1960). Klein (1963) more fully discusses the evolution and philosophies of these and other modern clastic sedimentary rock classifications.

Hubert (1960), in a study of the Fountain and Lyons formations of the Front Range area, Colorado, recognized the volumetric importance of the transitional rock types between orthoquartzites and arkoses. Because of its sensitivity to these transitional rock types, Hubert's (1960) scheme is preferred for classification of the Mississippi loess. The comparatively fine texture of the loess made two modifications in the classification procedure desirable: (1) quartz and feldspar grains larger than 0.015 mm. in diameter, identified by differential staining, were utilized (rather than only grains larger than 0.030 mm. in diameter as proposed by Hubert, 1960), and (2) mica percentages used for classification came from counts of sand-size (larger than 0.0625 mm. in diameter) heavy mineral concentrate. Comparison of these sand-size mica percentages with those obtained by thin-section point-counts of all grains large enough to identify positively indicated that the sand-size mica percentages are slightly higher than the true values. Because of the low percentages of mica obtained by both methods, it is unlikely that the clan designation of any loess sample was affected by errors in the mica percentage. Material less than 0.015 mm. in diameter was considered matrix.

Figure 29 illustrates the position of Mississippi loess on Hubert's (1960) classification. All samples fall either in the orthoquartzite or feldspathic quartzite field. Compositions were so similar in some samples that they could not be plotted without running the points together. All the orthoquartzite samples came from the upper leached zone of the loess that, in addition to slight lowering of feldspar content is characterized by a lower carbonate content and higher clay content (fig. 30). Therefore, the Mississippi loess is mineralogically a feldspathic quartzite

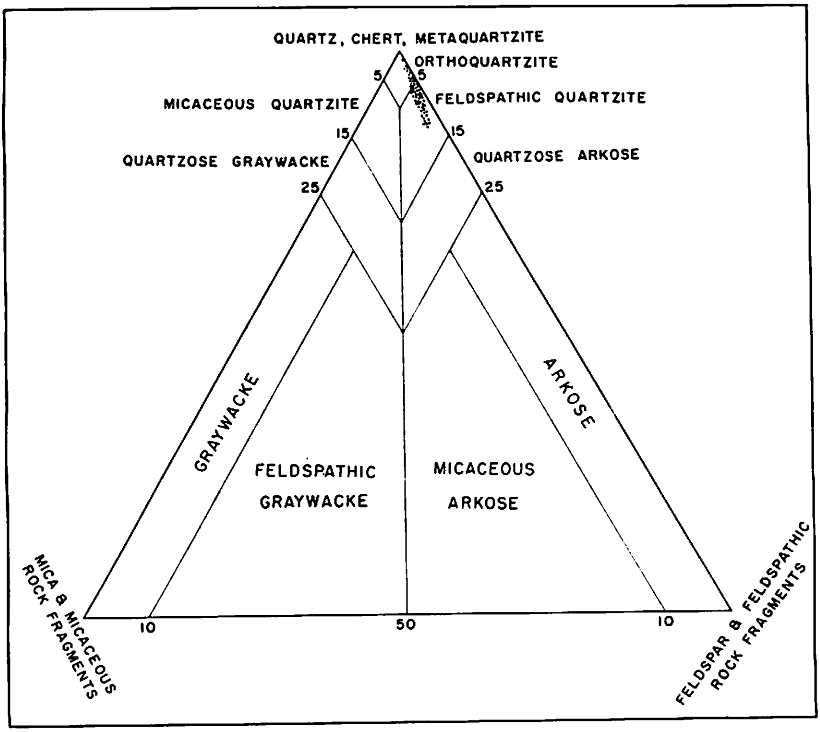


Figure 29.—Petrographic classification of Mississippi loess (classification based on Hubert, 1960).

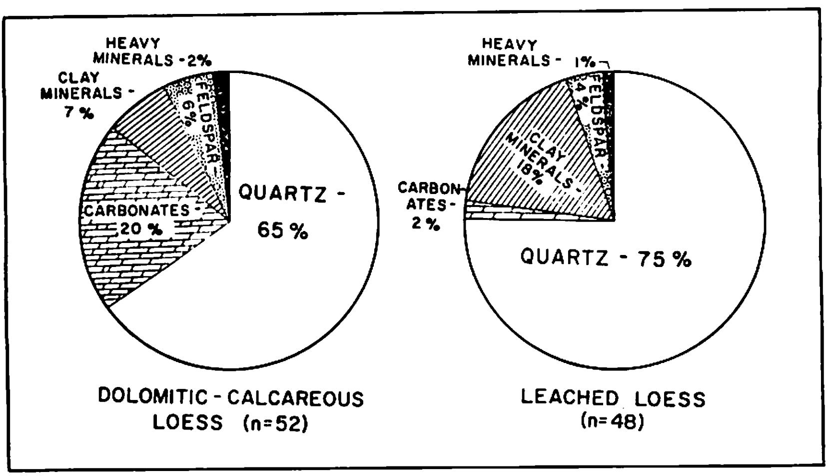


Figure 30.—Mean mineral composition of Mississippi loess.

that is very homogeneous, except where the feldspar content has been lowered by post-depositional chemical weathering.

Other significant mineral constituents of the Mississippi loess, as shown in Figure 30, are non-micaceous accessory heavy minerals, clay minerals, and carbonates. Accessory heavy minerals, while extremely useful in determining provenance of the loess, are not abundant enough for consideration in the mineralogic classification.

Clay minerals, which are ubiquitous in sedimentary rocks, including loess, may possibly be meaningfully incorporated in clastic sedimentary rock classifications in the future. Available X-ray analytic techniques permit at least good estimations, within a few per cent, of components in most clay mineral mixtures. However, pragmatic assignment of clay minerals to the poles of a rock classification, such as chlorite and illite to the mica pole, kaolinite to the feldspar pole, etc., would likely be exceeding the present understanding of clay minerals as source rock indicators. The following statement by Keller (1956, p. 2690) should be considered: "Clay minerals tend to indicate, as do other minerals, the environment under which they were *formed*, but not necessarily the environment of the deposit in which they were *found*". There is no general agreement among clay mineralogists regarding the extent of diagenesis of clay minerals in sedimentary rocks, but until diagenetic processes are better understood, they cannot be ignored. Grim (1958), Weaver (1958, 1959), Keller (1963), and Velde (1965) discuss the problems of interpretation of clay minerals in sedimentary rocks, emphasizing the possible role of diagenesis.

Carbonates comprise a significant fraction of the Mississippi loess except where they have been removed by post-depositional weathering (fig. 30). Detrital dolomite is the most abundant carbonate, but secondary calcite is also present in zones within the loess, representing the reprecipitated $CaCO_3$ fraction of dissolved dolomite. Folk (1961) recommends that detrital carbonates be ignored in determining the clan name of sedimentary rocks if they do not exceed 50 per cent of the total mineral composition. However, such adjectives as "carbonate-bearing" or "dolomitic" are useful in differentiating "fresh" and leached loess (fig. 30).

TEXTURE

PRELIMINARY STATEMENT

Mississippi loess, like the loess of other regions, is characterized by a very uniform texture. In the present study, 82 samples of loess and related sediments were analyzed to determine their textural characteristics and to determine the nature and origin of textural variations.

Although the term *texture* properly comprises the size, shape, and arrangement of grains in a rock, it is used in this report chiefly to denote grain-size of clastic particles. Other textural properties were observed, but not quantitatively determined. The operational definitions and equations used for the calculation of graphic grain-size statistics are those of Folk and Ward (1957, p. 11-15) and Folk (1961, p. 43-51). Table 8 is a compilation of textural data, including (1) vertical position of sample in section, (2) sediment type, (3) distance from river bluffs, (4) Folk's grain-size statistical parameters, and (5) sand-silt-clay ratios. Descriptions and geographic locations of all samples are given in Table 6.

TEXTURAL VARIABILITY

Texture in sedimentary rocks is a response of source materials to the energy of the sedimentary system. Variations in texture, therefore, result from variations in the source materials and/or energy.

Three plausible sources of textural variation in the Mississippi loess are: (1) variation in the texture of source material, (2) variations in the energy of transportation, which would change the competency of the transporting media, and (3) post-depositional textural changes, caused by weathering and other pedogenic effects, cementation, and mixing with other sediments. Evidence gathered in the present study overwhelmingly favors the third alternative, post-depositional changes, as the chief source of textural variation in Mississippi loess. Figure 31 is a triangular plot of the sand:silt:clay ratios of Mississippi loess and related sediments. Sediment types were operationally defined as follows: (1) *carbonate-bearing loess*—carbonate content of 10 per cent or greater (*cf.* fig. 30), (2) *leached loess*—carbonate content less than 10 per cent (*cf.* fig. 30), (3) *loess-"Citronelle" mixture*—contains elements of both loess and "Citronelle" heavy mineral assemblages (*cf.* fig. 25), (4) *"Citronelle"* —nonopaque heavy mineral assemblage is chiefly zircon-kyanite-staurolite (*cf.* fig. 25), and (5) *terrace silts*—gray color and presence of fresh water mollusks. All four terrace silt samples were collected in the Louisiana-Mississippi border area.

The 36 carbonate-bearing loess samples are very uniform in sand:silt:clay composition and, as shown in Figure 31, are clustered near the silt pole. The 25 leached-loess samples are all more clayey than the carbonate-bearing samples. Although part of the clay increase in the leached loess may be due to the weathering products of feldspars and other silicates, or even the insoluble residue of the leached carbonates, the increase is too great to be explained by weathering alone. Figure 30 shows that feldspar, the most likely parent material of clay in the loess, is decreased by an average of only two percent, from six per cent to four per cent, during the leaching process, whereas,

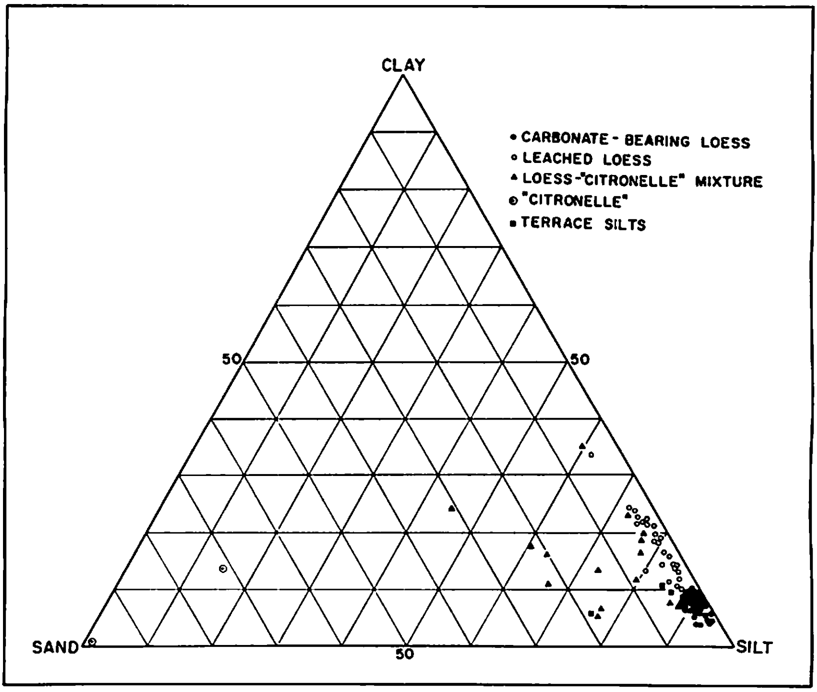


Figure 31.—Grain-size distribution of Mississippi loess and related sediments.

the average clay mineral content increases from seven to eighteen per cent.

Another pedogenic process, the downward washing of clay by infiltrating ground water, is considered by the writers to be the chief mode of clay enrichment of leached loess. Loess, because of its uniform texture and vertically oriented root tubules, has unusually high vertical permeability, which, combined with a relatively low clay content, inhibits the formation of a true clay pan. Thus, water repeatedly percolates to a considerably greater depth than in an ordinary clay-pan soil, as indicated by the leached zone in the loess, which averages about 14 feet in thickness. Water that leaches the carbonates from the loess also carries clay particles, thus slowly enriching the leached zone in clay. Glenn (1960, p. 524) reported the following average clay content of the Loring silt loam profiles, the soil developed on the loess in central Mississippi: A_2-11.0 per cent, B_2-31.6 per cent, B_3-18.9 per cent, and C-15.3 per cent. The average depth of the profile was 65 inches. The top soil is, of course, continually removed by erosion, especially on the steep slopes commonly developed by the Mississippi loess. Comparison of the thin, clay-depleted upper soil zone to the thick clay-enriched leached zone suggests that there has been considerable post-depositional erosion of the loess.

The complex "Citronelle" sediments underlie most of the Mississippi loess and there is usually some mixing of the lower few feet of loess with the "Citronelle". Texture of loess-"Citronelle" mixtures depends on the degree of mixing and the "Citronelle" facies involved. The "Citronelle" varies from almost pure gravel to silty clay, including most intermediate textures. Figure 31 shows the highly variable texture of loess-"Citronelle" mixtures. In fact, all loess samples containing more than seven per cent sand proved to be mixed with "Citronelle" and all were in the lower few feet of the section. Some of the mixing may be due to colluviation of the loess, but most of it seems to be due to sifting downward of loess into the pore space of sandy or gravelly "Citronelle". Contacts between loess and clayey "Citronelle" facies are sharper than between loess and sandy or gravelly "Citronelle". Only one mixed sample was more than 30 per cent clay (fig. 31).

Three of the four Pleistocene Mississippi River terrace silts sampled are texturally similar to the loess. One sample (LM-8) was within the limits of variation of carbonate-bearing loess and two others were similar to leached loess. Russell (1944*a*) and Fisk (1951) reported the textural similarity between certain terrace deposits and loess, and used it as evidence that the terrace silts are the parent materials of loess. Although a much more complete textural study of the terrace silts is needed to evaluate their variability, it must be said that *some* terrace silts cannot be texturally differentiated from loess by their sand: silt: clay ratios, but, as previously stated, their heavy mineral contents appear to be sufficiently different to distinguish them. Figure 32 shows typical cumulative particle-size distribution curves of loess and related sediments.

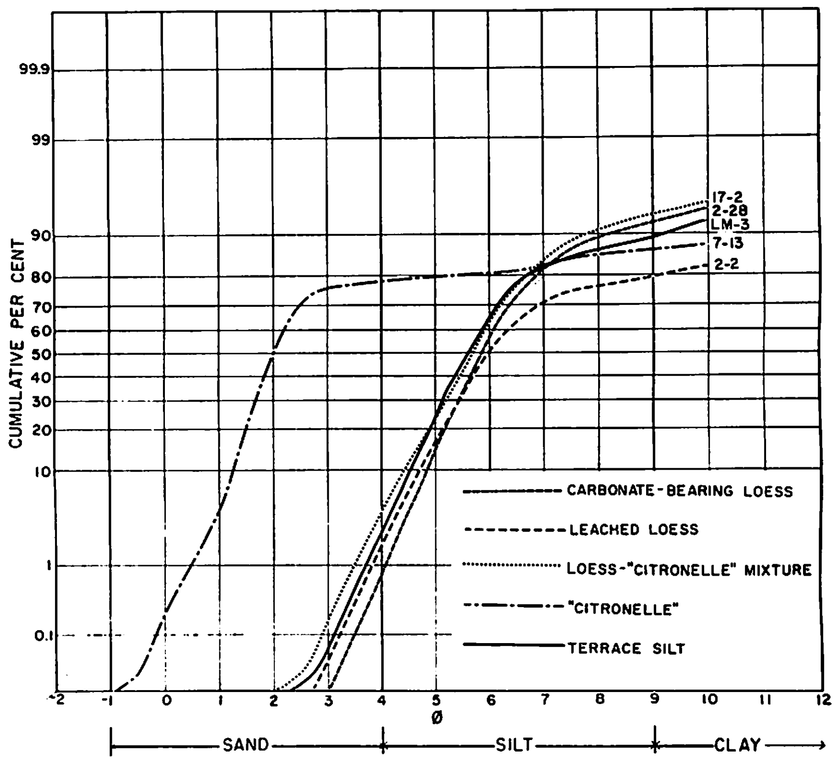


Figure 32.—Typical cumulative curves of Mississippi loess and related sediments.

Geographic Variability

One of the important textural characteristics of midwestern loess, reported by G. D. Smith (1942) and by Swineford and Frye (1951), is the decrease in average particle size with increasing distance from major stream valleys, which are believed to be the sources of the loess. Moreover, when the average particle size is plotted against distance, it is shown to decrease logarithmically with distance from bluffs, as does loess thickness (Smith, 1942; Swineford and Frye, 1951). Smith (1942, p. 177) suggests that this decrease in particle size is not necessarily the result of a decrease in energy of transportation with distance, but may be due to leaching and other pedogenic changes, both during and after loess deposition. Assuming any two Peorian loess sections were deposited within the same span of time, he calculated that a 30-inch loess section was about 1.7 times as old as the top 30 inches of a 300 inch section, and, therefore, had been subjected to significantly more weathering during the course of loess deposition. Swineford and Frye (1951, p. 309) reported that, in addition to being coarser, the loess nearer to the source was better sorted than the more distant loess.

In order to test Smith's hypothesis that the geographic textural change in loess is chiefly of pedogenic origin, mean particle sizes of *only* the carbonate-bearing loess samples from auger holes 1-4 (fig. 2) were averaged and plotted on a scatter diagram. The carbonate-bearing loess is considered to be least affected by post-depositional changes. As shown in Figure 33, there is little difference in the average mean particle size among the four sections. In fact, there is as much or more variability among samples in each section as there is between sections. Thus, it is suggested that most of the apparent geographic relationship to texture of Mississippi loess is in fact due to pedogenic effects. The thinner loess sections have been more completely weathered during and after deposition than the thicker ones. Sections more than 18 miles from the Mississippi River bluffs are usually less than 15 feet thick and are leached throughout. Sampling methods could also greatly affect loess textural data. If samples were collected from the middle of each loess section, each sample would be shallower as the loess thinned, and, hence, more affected by pedogenesis, and therefore,

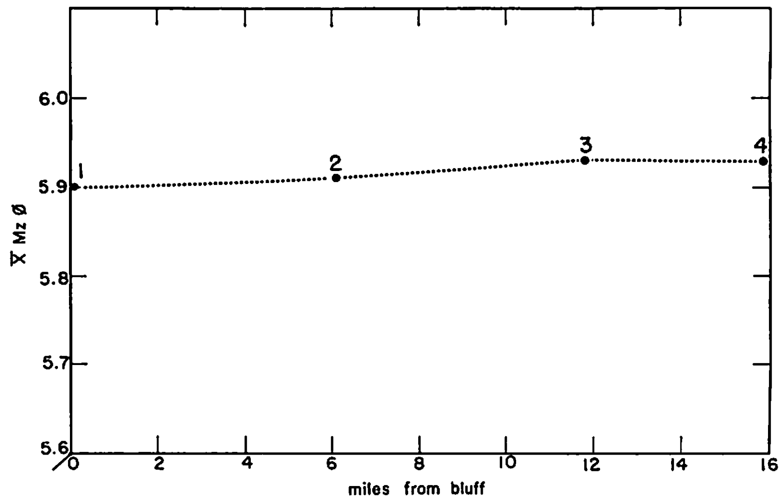


Figure 33.—Average of mean grain sizes of carbonate-bearing loess from auger holes 1-4, showing slight decrease in particle size eastward from Mississippi River bluffs.

would be more clay enriched and finer-grained. Under these conditions, there is no way to get unbiased grain-size data.

Interrelations Among the Textural Parameters

Although statistical textural parameters are algebraically defined so that they are geometrically independent, a significant trend may exist in a given set of samples between any two parameters plotted as a scatter diagram. These trends may provide geologic information that is not evident when the parameters are considered individually. For example, Friedman (1961) was able to differentiate dune, beach, and river sands on the basis of scatter diagram plots of textural parameters, particularly standard deviation and skewness.

Folk (1961, p. 5) has suggested that, in most sedimentary environments, sorting is strongly dependent on grain size. The apparent reason for the relationship between size and sorting is that several particle sizes, or populations of sizes, are supplied abundantly in nature. These are: (1) a pebble population, resulting from mechanical breakage along joint or bedding planes of massive rocks, such as granite, chert, and metaquartzite, (2) a sand-coarse silt population representing the larger insoluble residual products of chemical weathering of such common rocks as granite, schist, metaquartzite, or older sandstones, and, (3) a clay population, representing the fine-grained phyllosilicates that are also produced during the chemical weathering of common rocks. Clays may also be derived from older shales or slates whose particle size was originally determined by weathering processes.

As a physical consequence of these naturally selected size populations, if the mean size of a sediment is within one of the populations, it is likely to be chiefly that size material and, therefore, relatively well sorted. If, on the other hand, the mean size of a sediment falls between populations, it is often a mixture of populations, bimodal, and correspondingly more poorly sorted. When the mean size and standard deviation (sorting) values of a number of samples of a sediment are plotted, the resulting trend is often a sinusoidal curve (Folk, 1961, p. 5a), with the best sorting corresponding to means within natural populations and poorest sorting corresponding to means that fall between populations. Sinusoidal trends between mean size and sorting have been reported in a wide variety of continental and shallow marine sediments (Griffiths, 1951; Folk and Ward, 1957) and also in deep sea sands (Hubert, 1964).

Although loess is a somewhat unusual sediment type, in which at least some of the individual particles were produced by glacial abrasion and later hydraulically sorted by other transporting agents, standard deviation values were plotted against mean size to determine if a recognizable trend exists in the Mississippi loess. Figure 34 shows that there is a strong relationship between mean size and sorting. The modal size population supplied from the loess source is medium silt. The mean size of all carbonate-bearing loess is within the medium silt range (5-6 Ø). Loess with a mean size in the fine silt range is generally more poorly sorted due to mixing with a second mode —clay-size material. Most of the leached loess contains sufficient clay to shift its mean size into the fine silt range (6-7 Ø) with a corresponding decrease in sorting. Thus, the bimodal distribution and resulting poor sorting of the leached loess is not due to a second size population being supplied from the source area, as is true of most sediments, but rather to the pedogenic addition of clay after deposition.

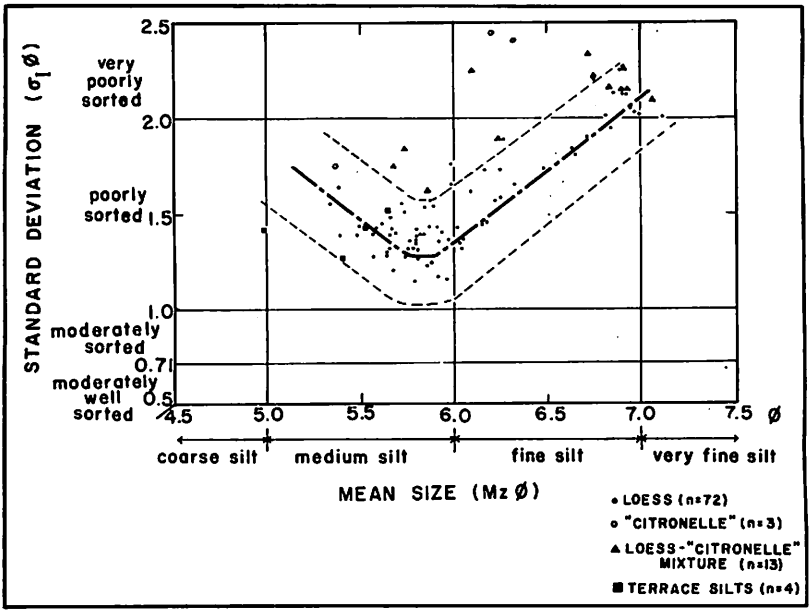


Figure 34.—Mean size versus standard deviation (size sorting). The heavy line represents the trend of loess samples, only. Dashed lines are not statistical confidence limits, which were not calculated because the trend is non-linear.

A weaker trend between size and sorting seems to appear in the loess with coarser mean sizes, between 5 and 5.5Ø (fig. 34), although there are not enough samples to be certain. The decrease in sorting in this range suggests that another coarser size population may be occasionally supplied to the loess. Loess-"Citronelle" mixtures are more poorly sorted in relation to mean size than the loess as they consistently lie above the loess trend line in Figure 34.

Loess is almost always described in the literature as "well sorted" although, as shown in Figure 34, Mississippi loess ranges from poorly sorted to very poorly sorted. The misnomer "well sorted" for loess is probably due to use of Trask's (1932) quartile deviation, which neglects the "tails" of cumulative frequency distributions coarser than the 25th percentile and finer than the 75th percentile, where most poor sorting occurs. Folk's (1957) inclusive graphic standard deviation, which evaluates the cumulative curve between the 5th and 95th percentile, is a much better indicator of sorting than the quartile deviation.

There is also a definite trend between mean size and skewness in the Mississippi loess. Figure 35 shows a definite increase in skewness as mean size decreases, up to about 6.5 Ø. Beyond mean size values of 6.5 Ø the skewness appears to decrease slightly. According to Folk (1957, p. 19), this is the expected relationship in a bimodal distribution. As long as the coarser mode (silt) is more abundant, the grain-size distribution will be fine skewed, the degree of skewness increasing as more of the fine mode (clay) is added. However, as the two modes approach each other in abundance, the skewness reaches a peak, then begins to decrease. When there is a 50-50 mixture of both modes, the curve is essentially non-skewed.

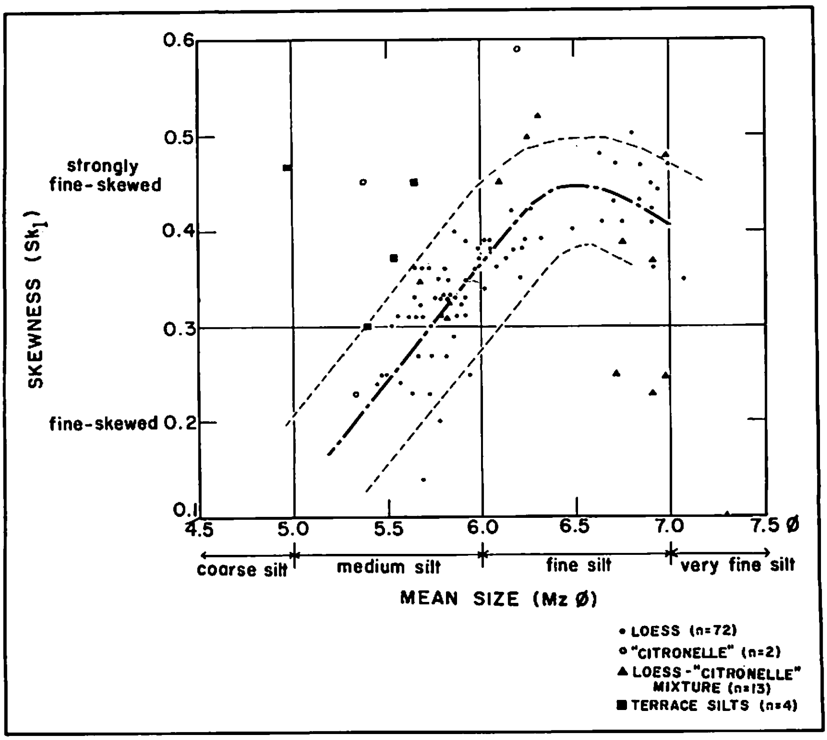


Figure 35.—Mean size versus skewness. Heavy trend line represents loess, only. The significance of the dashed lines paralleling the main trend is the same as in Figure 34.

In the Mississippi loess, the peak skewness occurs at about a 75:25 silt-clay ratio. Loess-"Citronelle" mixtures are scattered on both sides of the loess trend. Interestingly, the four terrace silts were more fine skewed than loess of equivalent mean size, which seems to be the only conspicuous textural difference between them. Analyses of more terrace silt samples are needed to confirm this trend with confidence.

OTHER TEXTURAL AND STRUCTURAL CHARACTERISTICS

Shape and Arrangement of Grains

The shapes of detrital grains in Mississippi loess were qualitatively compared to Powers' (1953, p. 118) and Krumbein and Sloss' (1963, p. 111) visual scales. Most grains are subangular to angular and have medium to high sphericity values. No preferred orientation or special arrangement of detrital grains was detected, even among grains with lower sphericity values.

Cementation and Structural Stability of Mississippi Loess

One of the characteristics that makes loess a unique sediment type is its ability to stand in vertical bluffs, even though it is relatively unindurated. Both leached and carbonate-bearing Mississippi loess will stand in vertical bluffs, yet are so easily disaggregated that extreme caution must be used in transporting bulk samples to prevent them from crumbling to a fine powder.

The following properties of Mississippi loess, observed in this and other studies, should be considered in the discussion of this seemingly anomalous competence: (1) Loess has exceptionally high permeability for a fine-grained sediment. Krinitzsky and Turnbull (1967, p. 42) have established that the permeability of the soils developed on Mississippi loess is lower than the permeability of the loess. Therefore, infiltration rates are slower than the transmission capacity of the loess and it is seldom, if ever, completely saturated with water. (2) Carbonate-bearing loess, especially that in the calcite-enriched zone (zone 2), contains an internal "skeleton" of vertically oriented calcareous root tubules. (3) Shear strength of loess is usually decreased when it is disturbed, even if it is mechanically compacted to its original bulk density (*cf.* Kolb, 1960, p. 138). (4) Although loess will stand in vertical cuts, surfaces cut at an oblique angle and exposed to runoff are readily eroded and deeply gullied in a short time. Oblique cuts must be sodded or matted almost immediately to prevent extensive erosion. Thus, it is standard engineering practice to make near vertical (1 on 1/4 slope) highway cuts in the loess, which incidentally, significantly reduces the amount of material excavated, when compared with the gently sloping cuts usually required in other unconsolidated sediments (*cf.* figs. 5, 9, 10, and 11). (5) Leached loess, although it will stand in vertical cuts, does so less perfectly than carbonate-bearing loess. The upper few feet of the leached zone seem especially prone to wash and slump (*cf.* figs. 9 and 41).

The high permeability of loess is due chiefly to its unusual particle-size distribution. Most other fine-grained sediments have a much higher clay content than does loess, which reduces their effective permeability by filling in the pore space between larger grains. Carbonate-bearing and leached Mississippi loesses have mean clay (less-than-2-micron particle diameter) contents of only 7 and 18 per cent, respectively. Moreover, most of the clay occurs as thin coatings adhering to individual silt grains and does not greatly reduce the size of pores between grains. Holland and King (1949), Swineford and Frye (1951), and Davidson and Handy (1954) all report similar clay-silt particle relationships in loess from various parts of the Midwest. Contact between the thin clay husks of adjacent grains may also help to bind the grains together. Studies by Krinitzsky and Turnbull (1967) of the engineering properties of Mississippi loess, lead them to believe that most of the particle binding is due to bonding of these clay husks to one another. As water saturation greatly increases the tendency of unconsolidated sediments to slump or "flow", the *good drainage properties* of loess resulting from its high permeability greatly increase its structural stability. Clay-binding of the silt grains, particularly in view of the husk-like distribution of the clay, probably also adds structural strength.

According to Smalley (1966, p. 672), particles in typical loess have some cohesiveness because of their small size. Based chiefly on his experimental work with flow of particles through orifices, he concluded that the interparticle forces are very similar to Van der Waals forces and are concentrated at the points of contact. The interparticle forces in an aggregate should ideally stay constant regardless of particle size, thus larger particles are inherently less stable than smaller ones because of their greater potential energy.

A number of workers have shown that the surface tension of thin water films on silt particles can be a powerful bonding agent. Strength tests of undisturbed loess at various water contents are needed to properly evaluate this effect in nature.

Hollow, calcareous root tubules form an internal "skeleton" in the loess, which is thought to increase its structural strength. As most of these tubules are oriented vertically, they also enhance the vertical permeability in the loess. Most shear failures in loess occur as vertical cracks, rather than the spoon-shaped slumps common in other fine-grained sediments, which indicates a greater horizontal than vertical shear strength, probably due to the internal support of the tubules.

Examination of thin-sections of Mississippi loess reveals little true cementation of grains by carbonates. This is in accordance with other observed properties, for if carbonate cementation were widespread, the loess should be much more indurated than it is. However, hard, calcareous concretions, consisting of detrital grains cemented by calcite, are common in Zone 2 (calcite enriched zone) of the loess. Also, several patches of powdery, secondary calcite, which could be interpreted as incipient cementation, were noted partially filling the pore space in Zone 2. The carbonate content of loess may be an indirect aid to stabilization, because lichens, which thrive on the high pH carbonate-bearing loess, seem soon to form a protective cover on vertically cut slopes.

To summarize, the unusual structural stability of Mississippi loess is due to a combination of at least the following properties: (1) high permeability, resulting in good drainage which practically eliminates slump-producing water saturation, (2) binding of silt-size and larger detrital particles by thin clay husks encasing the grains, and (3) an internal "skeleton" of hollow, vertically-oriented, calcareous root tubules. The generally lower stability of leached loess compared to calcareous loess is caused by its lower permeability, due to a higher clay content, and its lack of internal calcareous tubule reinforcement. More experimental work is needed to determine the relative importance of each of the stability-producing properties of loess.

ELECTRICAL MEASUREMENTS AS AN AID IN STRATIGRAPHY

PRELIMINARY STATEMENT

The first three years of National Science Foundation sponsored Millsaps studies showed surprising differences in the chemical and mineral content of the loess. It was soon discovered that there were several blankets of the material in the Vicksburg area, each separated by poorly to well developed paleosols, and each having a distinctive zone of unweathered material overlain by a zone of mineral concentration, and capped by a zone of leached material which grades upward into loessal soil.

This stratigraphic information was determined through conventional chemical and petrographic analyses. However, the procedures were too time consuming for rapid work because it was soon seen that years would pass before all of the outcrop samples could be detailed. In fact, four hours of field work in sampling a 40 foot roadcut usually provided all the materials 10 student chemists and student geologists could process in a month. Newer methods were obviously required.

Three new methods were tried: (1) determining the electrical conductivity of the loess by which outcrops could be zoned in the course of a few hours, (2) measuring the conductivity of loess in holes drilled through the loess which could be recorded in the course of an hour, and (3) measuring the magnetic fields created by the magnetic minerals in the several zones of loess or loessal soils on the outcrop and in holes. The first two methods produced amazing results. The third showed promise but the equipment necessary was too heavy to be used in the field.

ELECTRICAL CONDUCTIVITY LOGGING OF THE OUTCROPS

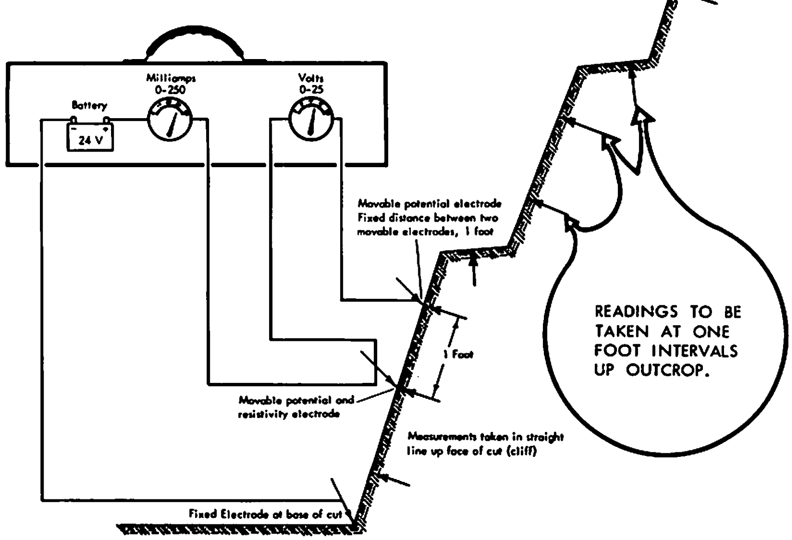
Electrical devices for examining outcrops are not new. About the turn of the century conductivity methods had been perfected for prospecting for coal, the differences in conductivity being a measure of the porosity-permeability of the several coal measure rocks, where mineralized ground water served as an electrolyte.

A similar device was suggested in studying the loess in the Vicksburg area when it was seen that some loess zones were moister than others and that ancient soils (paleosols) separating the loess blankets remained damp long after the zones of loess had dried.

A two year old roadcut of Highway 61 was selected for a test. This is the standard section described in detail in the treatment of stratigraphy (*cf.* fig. 41). Here 57 feet of loess and loessal soils are exposed and here careful chemical and petrographic analyses have been made. A foot-long steel electrode was driven at the base of the cut and a similar electrode was driven at intervals up the face of the cut. Between the electrodes was a 24 volt battery, a voltmeter, and an ammeter. It was noted that voltage and ammeter readings fluctuated with various positions of the movable electrode.

The next step was to measure the electrical behavior within a limited interval. This was accomplished by using two moveable electrodes which were driven into the loess at one foot intervals up the face of the cut. The current passed from the fixed electrode through the loess and loessal soils to the upper

Figure 36.—Diagram of Electrical Circuits used in measuring Self Potential (volts-right) and Resistance (milliamps-left) in outcrops of loess in the Vicksburg area.



electrode and was measured in milliamps (which is inversely proportional to resistance in ohms). Voltage drop between the upper and lower movable electrodes was recorded in millivolts. By this method, five students were able to make three vertical profiles of a 50-foot roadcut in four to five hours. Because of the pseudoanticlinal nature of the loess blankets, one log was always run at the crest of the roadcut and one on each flank. The procedure may detect as many as 5 different over-draping loess blankets, several zones within each blanket, and poorly to well developed paleosols. Figure 36 is a diagram of the procedure. Twelve roadcuts along U. S. Highway 61 were studied by this electrical manner and six were examined along Interstate 20.

ELECTRICAL CONDUCTIVITY LOGGING OF HOLES DRILLED INTO THE LOESS

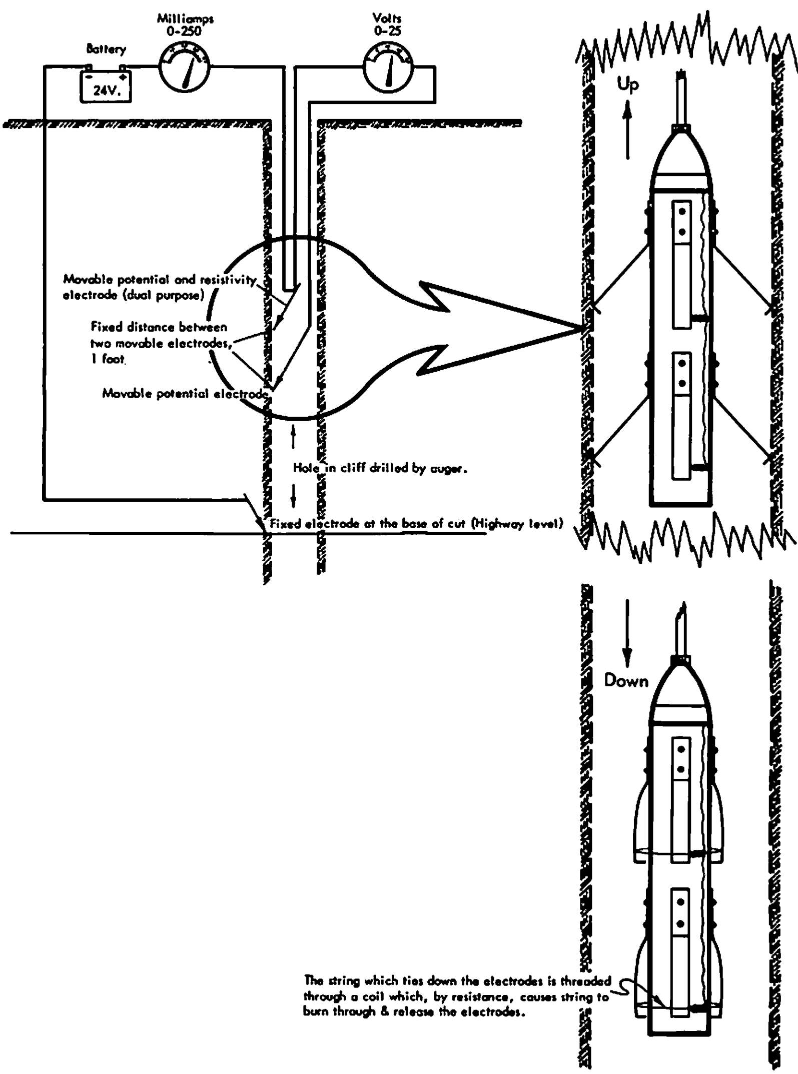
Electrical devices for interpreting the nature of strata penetrated in oil tests and water wells have been used since about 1925. The principle is much the same as in the method reviewed above where there is a source of current, a fixed electrode grounded in the slush pit, and a movable electrode (or compound electrode) which is raised and lowered at will in the hole. Voltage differences and variations in resistance help determine the lithology of the rocks penetrated, once the regional nature of these strata is established. The changes in potential and resistance measured are partly due to the rocks themselves, but the magnitude of their differences is intensified by the drilling mud in the hole which acts as an electrolyte.

Because the zones of loess and even the paleosols are damp or at most moist, the hand auger holes were drilled "dry". Addition of water would have made drilling easier, but would have contaminated the zones. Consequently, any electrical logging of the loess holes would have to be done without the intensification produced by drilling mud or water in the hole, each of which would have served as an electrolyte.

When it was discovered that an outcrop could be detailed electrically without the benefit of an electrolyte, it was determined to measure the electrical behavior of the loess zones, loess blankets, and paleosols in the hand auger holes drilled in 1961, 1962, and 1963. Fortunately, these tests had been capped so re-entrance was easy. One hole was 98 feet deep, another 53 feet, a third was 37 feet, and there were 8 others between 15 and 30 feet in depth.

However, unfortunately, the holes had been dug with a 4-inch diameter post hole auger so that the greatest hole diameter to be expected was 5 inches. The problem of placing electrodes

Figure 37. Diagram of Electrical Circuits Used in measuring Self Potential (volts-right) and Resistance (milliamps-left) of LOESS in Vicksburg area.



down these narrow, dry holes so that they would contact the walls and yet could be moved upward with ease was finally solved by using flexible steel 12 inch rulers. They were mounted on a 2″ x 2″ timber, and were bent to flare out at about 45° as shown in the diagram, (Figure 37). Two sets of rulers were used, 4 at the top of the timber and 4 at the bottom of the timber so that each set would scrape the walls of the hole one foot apart.

After this multiple electrode was attached to an electric cable it was connected with a 24 volt battery, ammeter, and voltmeter as shown in the diagram. Then the flexible rulers were lashed together with light twine inserted through a coil of resistance wire. This probe ensemble, now having a diameter of only 3 inches was lowered to the bottom of one of the 5-inch hand auger holes and electrical logging was ready to begin.

A surge of current burned the light twine and permitted the flexed rulers to spring apart. The first reading was then made of the bottom one foot interval, in milliamps and in volts. Successive readings were made by raising the cable, foot by foot, to the top of the hole.

Twelve hand auger holes were logged in this manner. An example of the reliability of this method is shown in Figure 38, where electrical capacity is plotted in milliamps and is superimposed on the lithologic log of the hole drilled in the east roadcut, footage 12,445, U. S. Highway 61. Details of the lithologic log are shown in Table 4.

Figure 38 shows how the hole was started on the first bench of the roadcut and was drilled 26.5 feet, into the top one foot of the "Citronelle" gravel, the lower 14.5 feet of which was below road level. Figure 38 also shows how, with minor offsets in milliamps where the hole started and at each bench top, the electrical logs of the roadcut and the hand auger hole are continous. Together, the logs provide a complete record of 71.5 feet of loess and loessal soils at this point.

As in the logging of the outcrop the electrical logging of hand auger holes showed a considerable saving of time. The 98 foot hand auger hole, although two years old, was logged electrically in two hours. The 53 foot hole required but one hour, and the 37 foot hole was finished in 45 minutes.

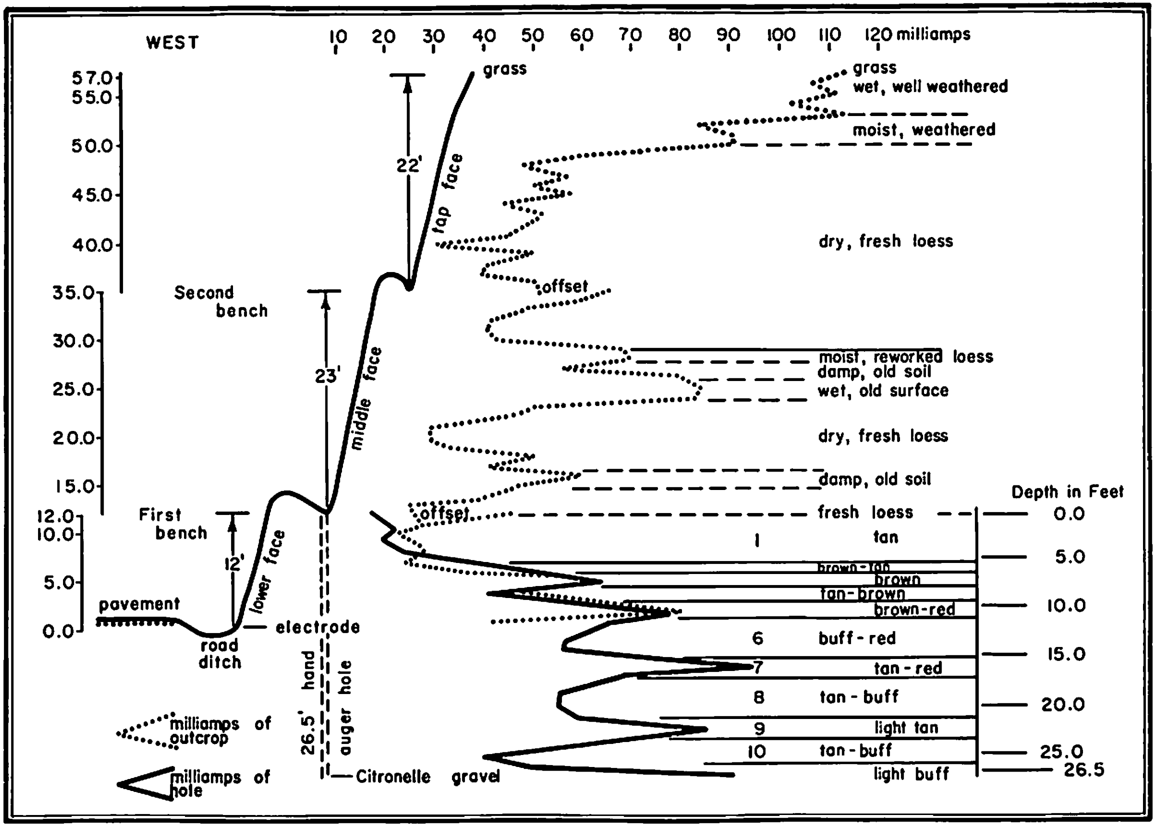


Figure 38.—A comparison of electrical capacity and lithologic differences in a combined exposed and hand-augered section, footage 12,445, U. S. Highway 61 bypass.

Table 4. Record of Hand-Auger Hole Drilled at Footage 12,445, Atop First Bench of Roadcut, East Side of U. S. Highway 61 North, 3 Miles Northeast of Vicksburg, Mississippi

(55 feet of loess in the part of the roadcut, above top of this hole)

		Sample	Interval	Description	Milliamps
hole started atop first bench (elevation 352 ft.)		1	0.0-5.1	loess, silty, tan, dry, mealy, snails	25
		2	5.1-6 2	loess, silty, brown-tan, dry, mealy, snails	23
		3	6.2-7.3	silt, brown, wet (re-worked soil)	60
		4	7.3-8.9	clay, silty, brown-red, damp, lignite fragments	45
		5	8.9-11.2	silt, clayey, buff-red, wet (residual soil)	80
road level at 12 ft. (elevation 340 ft.)	14.5 ft.	6	11.2-14.6	clay, silty, tan-red, moist (residual soil)	55
		7	14.6-16.8	clay, very silty, tan-red (old soil)	90
		8	16.8-20.7	loess, tan-buff, moist, mealy, snails	55
		9	20.7-23.1	clay, silty, with fine sand, light-tan, wet	80
		10	23.1-25.9	loess and clayey silt, tan-buff, dry, mealy, snails	40
bottom hole (11.9 ft. below road level, elevation 325.5 ft.)		11	25 9-26.5	loess, gravel and sand, light-buff, water bottomed in bedrock (Citronelle gravel)	92

Hole drilled and capped February 23, 1964 by Bundy, Brown, McGee, and Priddy.
Hole logged electrically September 30, 1964 by Harvey, Christmas, Crow, and Priddy.

The results of this hole logging program appeared so satisfactory that the holes drilled later by a powered rotary rig were measured in the same manner. The rotary holes were cored dry in September, 1964, through an arrangement with the Mississippi Geological Survey. They were logged by the Survey's Neltronic gamma ray logger, permitting a correlation with the records made by the Millsaps group. The correlation, although in different units, was very satisfactory.

NELTRONIC GAMMA RAY LOGGING OF HOLES

As soon as the 6 holes cored by the Mississippi Geological Survey were completed, gamma ray logs were run with a Neltronic 2K logger. Within a week, Millsaps students had also logged the holes, using the electrode with the flexible rulers described above.

Five of the six holes were drilled along north-south U.S. Highway 61 and a sixth was drilled several miles to the east near Interstate 20. The sites were chosen on hill crests at the road berm, at the base of the steep roadcuts of loess, or atop roadcuts where accessible. Drill sites on the profiles can be located in Figure 6.

The Neltronic gamma ray logger was tested in a 109 foot hole drilled by the Survey atop a 70 foot roadcut on the east side of U. S. Highway 61, footage 23,700, Figure 6. The roadcut had previously been logged by the Millsaps device. A good correlation was obtained after some adjustment was made because the Survey's logger was designed to operate in a water-filled or mud-filled hole. The gamma ray logger records lithologic differences in counts per second.

The principle upon which the gamma ray logger operates is similar to that of a geiger counter which has been used in the preliminary detection of such radioactive materials as uranium ores. It follows that the gamma ray logging will pick up differences in the number of signals per second emitted. In this case the fresh loess, weathered loess, and paleosols encountered in a hole have sufficiently different gamma ray radioactivity to provide a lithological record.

A gamma ray log is shown in Plate 1, which also shows the complete record of all the physical and chemical variables encountered in the 109-foot hole.

UTILIZATION OF PHYSICAL, ELECTRICAL, AND CHEMICAL VARIATIONS IN LOESS STRATIGRAPHY

PRELIMINARY STATEMENT

The first hand-auger hole, a 53 foot test through the loess, showed that there were several blankets of the material. Further, it was seen that poorly to well developed soils separated the blankets. Bases for zoning in this initial test were mostly physical because the cuttings varied in color, moisture content, effervescence with acid, caliche or concretionary material content, snail frequency, and grain size.

Subsequently, all cuttings from other holes and the samples from outcrops were subjected to several chemical tests in the field and to chemical analyses in the laboratory. Later, electrical conductivity measurements of both outcrops and holes were made. Finally, selected outcrop samples were dated by radiocarbon methods. As a consequence, four, and possibly five loess blankets were recognized on some hills in the Vicksburg area, which from oldest (1) to youngest (5) are:

LOESS SEQUENCE	THICKNESS	RADIOCARBON AGE
recent soil		
(5) Peorian	up to 66 feet	22,000 to 12,500 yrs. B.P.
poor paleosol		
(4) Farmdale	0 to 20 feet	28,000 to 22,000 yrs. B.P.
paleosol		
(3) pre-Farmdale	0 to 15 feet	more
paleosol		
(2) pre-Farmdale	0 to 10 feet	than
paleosol		
(1) pre-Farmdale	0 to 8 feet	28,000 yrs. B.P.
Citronelle gravel		

However, field and laboratory observations indicate that the loess itself is well zoned, as pointed out in the discussion of textural variability. The tabulation below shows the effect of weathering to form, ideally, four zones for each loess blanket, much as soils are formed from other bedrock.

Zone

(1) Unaltered bedrock — in this case fresh loess

— — — — — — — — — — — — — — — — — —

(4) A—Horizon (zone of leaching), a well developed soil, with humus — in this case a loessal paleosol

(3) B—Horizon (zone of accumulation) — in this case a zone of carbonate concentration in the loess due to active weathering

(2) C—Horizon (zone of partially decomposed parent material) — in this case a zone of incipient weathering of the loess

(1) Unaltered bedrock — in this case fresh, highly dolomitic loess

— — — — — — — — — — — — — — — — — —

(4) A—Horizon

The physical, chemical, electrical, gamma ray, and radiocarbon criteria for this differentiation are summarized in chart form, Plate 1, the record of a test hole and adjacent outcrop at footage 23,700, east side, U. S. Highway 61, some 6 miles northeast of Vicksburg.

PHYSICAL CRITERIA FOR ZONING

As intimated, the physical criteria for zoning the loess in the Vicksburg area are color, moisture content, degree of effervescence with acid, caliche content, frequency of snails, and grain size. These observations can be made roughly in the field as holes are drilled or as outcrops are sampled. After preserving in glass jars, the loess material was described in more detail in the laboratory.

Color

The weathered loess on most outcrops is buff, gray-buff, or tan-buff. The soils derived from it are tan, brown, and even red.

In contrast, fresh loess is usually light-buff, the slightly oxidized loess of Zone C is yellow-buff, and the more oxidized loess in Zone B is tan-buff. Most of the poorly developed loessal soils are brown-buff, but the well developed soils are tan or even red. In these paleosols mottling is common—tan and buff in poorly developed soils and red and buff, or brown and buff in well developed soils. Presumably, this mottling is due to vegetable and animal life which mixed the silty and sandy clays, of which the ancient soils were composed.

Moisture Content

In general, moisture content reflects the relative freshness of the loess, its extent of weathering, and the degree of development of the paleosols. Unweathered loess is always slightly damp, yet it has the peculiar feel of finely ground cornmeal. However, it is actually moister than it appears, because cuttings sealed in glass jars produce droplets of water which collect on the glass. Yet the material is surprising in that it seems to be porous and pervious to a point. It appears to be eternally moist but it will not permit a hole to fill with water, as was discovered when tests drilled and capped in 1960 were logged electrically with ease 3 years later.

However, the weathered loess in Zone B and C is usually damp, poorly developed paleosols are even moister, and well developed soils may be wet. In fact, paleosols may be so wet as to furnish waxy shavings rather than loose cuttings in deep auger holes. These differences in moisture content which are so evident in the field, are substantiated by laboratory analyses.

As would be expected, the "Citronelle" gravels encountered beneath most of the loess blankets are wet but they are not aquifers. At first this seemed surprising, but then it was reasoned that these gravels were actually the bedrock hills over which the loess blankets were draped. Consequently, the gravels could not act as aquifers because they had no exposures for recharge and discharge.

Effervescence With Acid

As unweathered loess is both fine-grained and dolomitic, fresh samples effervesce well with a 20% solution of hydrochloric acid. And, as would be anticipated, the evolution of carbon dioxide gas is even more profuse in the zone of calcite enrichment, Zone 2, into which $CaCO_3$ has migrated as the tiny dolomite fragments dissolve.

Again, as would be expected, poorly developed soil intervals show little effervescence. Well developed paleosols will not effervesce except where roots have penetrated them. Then there is effervescence where the loess and caliche deposits have filled the voids formed as the roots decay.

Caliche Content

As pointed out, caliche content is dependent on water circulation which is greatest in Zone 2 (Calcite-enriched zone) where caliche nodules may form in a short time on some outcrops. Other nodules may be abundant in test holes where there has been ancient calcite concentration, as each blanket of loess had undergone weathering through exposure.

In digging for snails, caliche nodules have been encountered as much as two feet from a loess face which had been exposed for only two or three years. These "dolls" are always more rounded at the crop, but are progressively more skeletal as one digs farther. In some instances, their origin can be traced to a high snail population where partially dissolved snails are incorporated in a cellular mass of caliche.

Snail Content

In theory, high snail content of loess should indicate its freshness. But like other fossils, these pulmonate gastropods may have been erratic in their habitat. They may not have been present in great numbers in one area when loess was being deposited. And, as they are gregarious creatures today and inhabit areas of fallen timber, one must assume that finding snails laterally and vertically through a zone would be the exception rather than the rule.

Nevertheless, well preserved snails, regardless of their number, should indicate fresh, unweathered loess. In contrast, the absence of snails need not preclude the unweathered state of the loess. Weathering should destroy snails to the extent that only fragments should be found in the caliche-rich zone of carbonate concentration, Zone 2. Of course, no snails should be expected in the paleosols which are created by extensive subaerial weathering.

Grain Size

Grain size of the loess can be roughly estimated at the outcrop or in the cuttings by rolling it between the thumb and forefinger. Unweathered loess is mealy because it is composed of damp silt-sized particles, a few clay particles, and even fewer grains of very fine sand. However, the material from the zone of impoverishment is decidedly clayey as the silt-sized fragments of soluble rocks have been progressively leached. For the same reason, developed soils and paleosols are even more clayey.

CHEMICAL CRITERIA FOR ZONING IN THE FIELD

Soluble Carbonate Determinations

The determination of soluble carbonate in the loess has been mentioned. In the field it was ascertained roughly by the amount of effervescence with acid. In the laboratory samples ground to 100 mesh (150 microns or less) size gave a similar but more reliable measure of the soluble carbonate which was determined as CO_2 fixed in lime water as $CaCO_3$.

Ph and Eh Determinations

Upon the recent development of a portable pH-Eh meter, it became possible to measure other chemical variables in the field. In this work the Photovolt Model 126 was used. The instrument determines the relative acidity-basicity (pH—hydrogen ion concentration) of the loess and its comparative reducing or oxidizing ability (Eh—reducing or oxidizing potential).

In order to measure pH and Eh, water extracts were made of cuttings from holes or of samples dug from roadcuts, in the field, before chemical alterations took place. In each determination a 50 ml volume of loess was placed in a 500 ml flask, shaken with 200 ml of distilled water, and centrifuged on the spot by swinging the flask on a string for 5 minutes. The instrument's electrodes were then immersed in the centrifugate for the pH and Eh readings.

As is customarily recorded, pH 7 is neutral, pH 7 to a theoretical 14 is basic, and pH 7 down to a theoretical O is acid. Similarly, a reading of Eh zero milliohms is neither reducing or oxidizing, but positive milliohm readings indicate an oxidizing environment and negative milliohm readings indicate a reducing environment.

pH READINGS—BASICITY OF LOESS

In general, the pH varies with the degree of weathering, as shown below:

loessal soil (Zone 3), high in humic acids	pH 8.5—9.0 slightly basic
loess of calcite—enriched zone (Zone 2)	pH 9.0—9.9 fairly basic
slightly weathered loess (top Zone 1)	pH 10.0—10.2 very basic
fresh loess (bedrock-Zone 1)	pH 9.7—9.9 fairly basic
uniformly colored paleosols (tan or brown)	pH 9.2—9.5 slightly basic
mottled paleosols (tan and buff, red and buff)	pH 9.5—9.7 fairly basic

All zones are basic. However, there are several apparent anomalies that require explanation.

The top of Zone 1 is more basic than either the bedrock which underlies it or Zone 2 which overlies it because bicarbonate ions are moving through Zone 2 where they are incorporated in the caliche of this carbonate enriched zone. The basicity of the mottled paleosols which is higher than that of the uniformly colored paleosols is attributed to fresh loess having been incorporated in the soil, as explained in the treatment of Color, above.

Eh READINGS—REDUCING-OXIDIZING POTENTIAL OF LOESS

As Plate 1 shows, most of the loess is reducing. In general, the zones show redox potential as follows:

loessal soil (Zone 3), where weathering is active *slightly oxidizing* despite humic acids	Eh +1 to +2
loess of calcite—enriched zone (Zone 2) where oxidation is minimized. *Decidedly reducing.*	Eh —4 to —8

slightly weathered loess (top Zone 1). *Slightly reducing.*	Eh —1 to —4
fresh loess (Zone 1). *Fairly reducing.*	Eh —3 to —5
uniformly colored paleosols (tan or brown). *Fairly reducing.*	Eh +1 to —5
mottled paleosols (tan and buff, red and buff). *Decidedly reducing.*	Eh —4 to —8

In general, Eh is more closely related to the pH plotting than to any of the other variables shown on the chart, Plate 1. However, it will be noted that the Eh record is even more erratic, as if the Eh is influenced by sharp differences in the ion content of the moisture. Observations at other holes where snails and minute flecks of "carbon" (as plant residue) were collected suggest that the organic material acted as, and still acts as, a reducing agent. In a similar manner it has been noted that a single worm or worm boring in freshly sampled Gulf Coast muds will sharply increase nitrogen content and will produce a decidedly reducing situation.

In short, the erratic Eh values seen in this 109 foot hole are very suggestive of discontinuous loess deposition. These fluctuations appear to correlate with the major and minor fluctuations of the thick Wisconsin continental glaciers of the upper Mississippi Valley which are so well documented in Illinois and Iowa.

ELECTRICAL DETERMINATIONS OF LOESS IN THE FIELD

As explained previously in this report, two additional field methods were introduced to determine rapidly the number and nature of the loess blankets and the soils developed between them. The two procedures are variations of electrical logging. One uses a homemade device for measuring differences in voltage and resistance between two movable electrodes driven in a loess roadcut at one-foot intervals or pulled up a test hole. The other uses a multiple electrode pulled up a test hole.

Between Movable Electrodes

When the two movable electrodes were used, it was discovered that the voltage and resistance varied with the electrolytic capacity of the several zones of loess and enabled the ready identification of paleosols.

The chart, Plate 1, shows that voltages vary with lithology, from 15 to 22 volts, as follows:

loessal soil (Zone 3), moist with groundwater and high in ionic content, hence a good electrolyte	17 to 22 volts high voltage
loess of carbonate-enriched zone (Zone 2), where the bicarbonate ion is so quickly tied up in the making of caliche that the zone's electrolytic capacity is reduced	16 to 17 volts lower voltage
slightly weathered loess (top Zone 1), where the bicarbonate ions are moving, thus producing a fair electrolyte	17 to 20 volts higher voltage
fresh loess (Zone 1), where there is little ionic circulation	16 to 18 volts lower voltage
uniformly colored paleosols (tan or brown), where there is a deficiency of bicarbonate ions	1 to 10 volts very low voltage
mottled paleosols (tan and buff, red and buff), where there are a few bicarbonate ions derived from incorporated loess.	8 to 11 volts low voltage

The chart shows that resistance is even more variable than voltage. It is measured in hundreds of ohms, in the range of 250 ohms to 1700 ohms, as follows:

loessal soil (Zone 3)	800 to 1000 ohms fairly high resistance
loess of carbonate-enriched zone (Zone 2, where the bicarbonate ions are being tied up quickly as caliche)	800 to 17 ohms higher resistance
slightly weathered loess (top Zone 1), where the bicarbonate ions are moving freely	600 to 800 ohms low resistance

uniformly colored paleosols (tan or brown), where the ancient soil appears to be high in humic acids	250 to 500 ohms very low resistance
mottled paleosols (tan and buff, red and buff)	500 to 700 ohms low resistance

Gamma Ray Logging

As pointed out in Stratigraphy, a Neltronic 2K gamma ray logger was employed to record lithologic changes in the holes which were dry cored through an arrangement with the Mississippi Geological, Economic and Topographical Survey. These signals are expressed in counts per second.

As the chart, Plate 1, shows, the record of the gamma ray device is very erratic. Most of the variations are in very short intervals, as if, like the Eh record, a great number of interruptions of loess deposition are being detected.

Except for a rough correlation with the pH record, there appears to be little correlation between gamma ray emission and the other parameters. However, these observations can be made which appear to be related to the age of the blankets:

(1) counts per second are high and very erratic in the upper part of the hole, to 47 feet

(2) counts per second are lower in the interval 47 feet to 66 feet

(3) counts per second increase sharply in the interval 66 to 79 feet

(4) counts per second decrease sharply from 79 to 85 feet in an interval of fresh loess

(5) counts per second increase sharply from 85 to 90 feet, where there is a good paleosol and beds of weathered loess

(6) counts per second show the greatest decrease of all, from 90 to 101 feet, an interval of loess and loessal soils

(7) counts per second increase sharply in an interval comprised of thin beds of loess and mottled soils, 101 feet to 108 feet and in the underlying one foot of "Citronelle" gravel.

STRATIGRAPHY

PRELIMINARY STATEMENT

After the several horizons of loess were identified using the techniques described in previous chapters, gastropods were collected from them for radiocarbon dating. The resulting absolute dates, combined with careful field observations, allow at least a preliminary stratigraphic classification of Mississippi loess. In applying this classification, we have also correlated the Mississippi loess with the radiocarbon-dated loess of the upper Mississippi Valley.

PREVIOUS STRATIGRAPHIC REPORTS AND GENERAL OBSERVATIONS

Stratigraphic interpretations of Mississippi loess have been conflicting in previous reports. R. J. Russell (1944*a*, p. 10), who advocated a colluvial origin for the loess, commented on the stratigraphy of lower Mississippi loess as follows: "It (loess) is not a geological formation in the technical sense of the term for it has no fixed stratigraphic position. Traced upslope, it grades laterally into the upper part of any one of three different Pleistocene terrace formations." On the other hand, Wascher, Humbert, and Cady (1947) divided the lower Mississippi Valley loess into three zones, correlating them with previously established stratigraphic zones in Illinois loess. These were, from oldest to youngest: (1) Third loess (Illinoian Glacial Stage), (2) Sangamon loess (Sangamonian Interglacial Stage), and (3) Peorian loess (Wisconsinian Glacial Stage). These zones were correlated with Illinois loess chiefly on the basis of field appearance and degree of weathering, partially determined by the heavy mineral assemblage.

Leighton and Willman (1950) recognized Wascher, Humbert, and Cady's zones, but revised the terminology and correlations to conform to recent revisions in midwestern Pleistocene stratigraphic nomenclature. The term "Peorian" was retained for the youngest loess sheet, but the "Sangamon" loess was renamed "Farmdale" and correlated with the early Wisconsinian loess in Illinois rather than the Sangamonian. The "Third" loess was renamed "Loveland", but still considered to be Illinoian in age. In addition, Leighton and Willman recognized a pre-Loveland loess, which they described as "remnants of a loess-like silt, which is usually chocolate-brown and non-calcareous. . ." Leighton and Willman's zones were also based almost entirely on field appearance, especially their resemblance to their proposed Illinois counterparts.

At the time of the present study, many additional sections of Mississippi loess were exposed along new highways, providing an opportunity to re-examine these field relationships with the benefit of further revisions in Pleistocene stratigraphic correlation techniques and nomenclature. Several two-to-three foot leached zones were discovered in a few of the thick loess sections in the Vicksburg area. These leached zones usually resemble soil profiles, and are physically and chemically similar to the modern soil developed on the loess. The presence of these leached zones, or paleosols, separating beds of carbonate-bearing loess, suggests that there have been several periods of loess deposition in Mississippi, each followed by an interval of leaching, and perhaps non-deposition. However, the number and thicknesses of both the paleosols and carbonate-bearing zones between them vary considerably from section to section, making purely field correlations, in the writers' opinion, rather tenuous. In many sections, paleosols are unrecognizable, or are very subtle, resembling stratification. Paleosols are much more apparent in highway cuts after a few years' exposure due to the difference in structural stability between leached and carbonate-bearing loess. All paleosols follow the contour of the pre-loess topography, which led Russell (1944*a*) and Priddy, Christmas, and Ward (1964) to call them "pseudoanticlinal" structures.

RADIOCARBON DATING OF MISSISSIPPI LOESS

The tremendous value of radiocarbon dates from fossil gastropod shells in the stratigraphic classification of upper Mississippi Valley loess has been demonstrated by Frye and Willman (1960), Frye and Leonard (1960), and Frye, Glass, and Willman (1962). Therefore, in this study, fossil gastropod shells were collected from several horizons in the Mississippi loess for radiocarbon age determination. Insofar as the writers know, these are the only existing radiocarbon dates from lower Mississippi Valley loess. The localities sampled and radiocarbon ages obtained are as follows:

1. Sample station 9 (*cf.* fig. 2 and tab. 6 for precise location), which is a gravel pit exposure near the town of

Redwood, Miss., northeast of Vicksburg. Gastropod shells, which were collected from a two-foot zone, five feet above the basal contact of a 55 foot loess section yielded — 20,500±600 years B. P. Gastropod shells collected from a two-foot zone 15 feet below the top of the same section, near the base of the leached zone (35 feet above the first zone yielded—18,200±500 years B. P.)

2. The other radiocarbon-dated gastropods were collected from road cuts along U. S. Highway 61 bypass, as shown in Figure 39. One sample of "charcoal" (fossil wood and other plant matter) from a paleosol immediately below the lowest loess horizon (at that location) was also dated and is shown in the cross section profile (fig. 39). Sample numbers with the prefix (I) were dated by Isotopes, Inc. of Westwood, New Jersey; those with the prefix (OX) were dated by Dr. L. L. McDowell of the U. S. Department of Agriculture Sedimentation Labotory in Oxford, Mississippi.

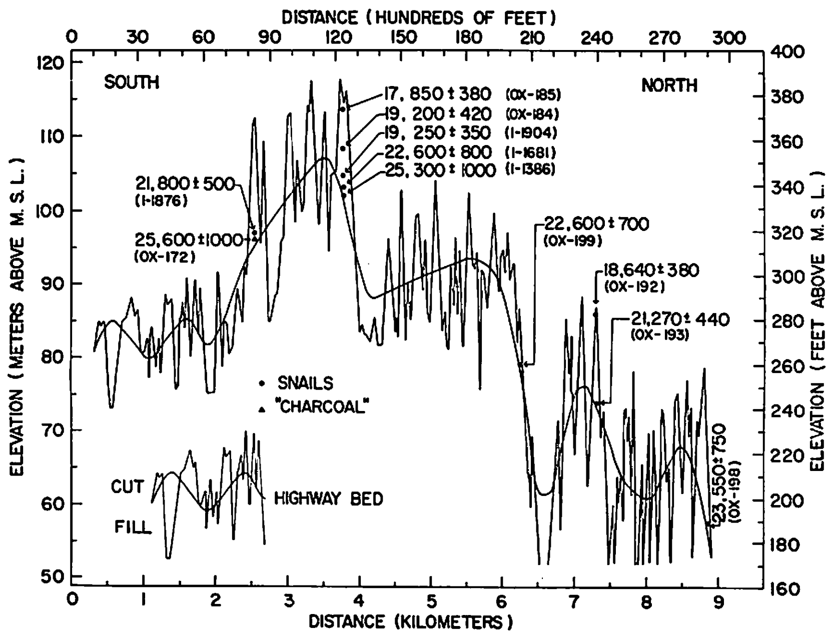


Figure 39.—Location of radiocarbon-dated samples along U. S. Highway 61 bypass.

Table 5 below is a summary of the radiocarbon dating program in this study.

Table 5. Radiocarbon ages of fossil pulmonate gastropod shells and one fossil wood sample from loess deposits near Vicksburg, Mississippi.

Radiocarbon Age (yrs. B. P.)	Stratigraphic Unit
17,850±380	
18,200±500	
18,640±380	PEORIA
19,200±420	
19,250±350	
20,500±600	LOESS
21,270±440	
21,800±500	PEORIA OR FARMDALE LOESS
22,600±700	FARMDALE
22,600±800	
23,550±750	LOESS
25,300±1000	
*25,600±1000	FARMDALE SOIL?

*date from fossil wood in soil immediately underlying the loess; all other dates are from gastropod shells.

These ages are comparable to those obtained from gastropod shells in the upper Mississippi Valley loess by Frye and Willman (1960) and Frye, Glass, and Willman (1962). Figure 40 shows the development of Wisconsin Stage stratigraphic classification in the upper Mississippi Valley, and includes the currently used classifications of Leighton (1960) and Frye, Glass, and Willman (1962), with which the Mississippi dates may be compared. Leighton (1965), who further discusses the stratigraphic succession of loess in the upper Mississippi Valley, strongly disagrees with some of Frye, Glass, and Willman's (1962) revisions that were based chiefly on radiocarbon dates.

Although more radiocarbon dates would be desirable for a truly comprehensive stratigraphic classification, these, together with our field observations and physical and chemical measure-

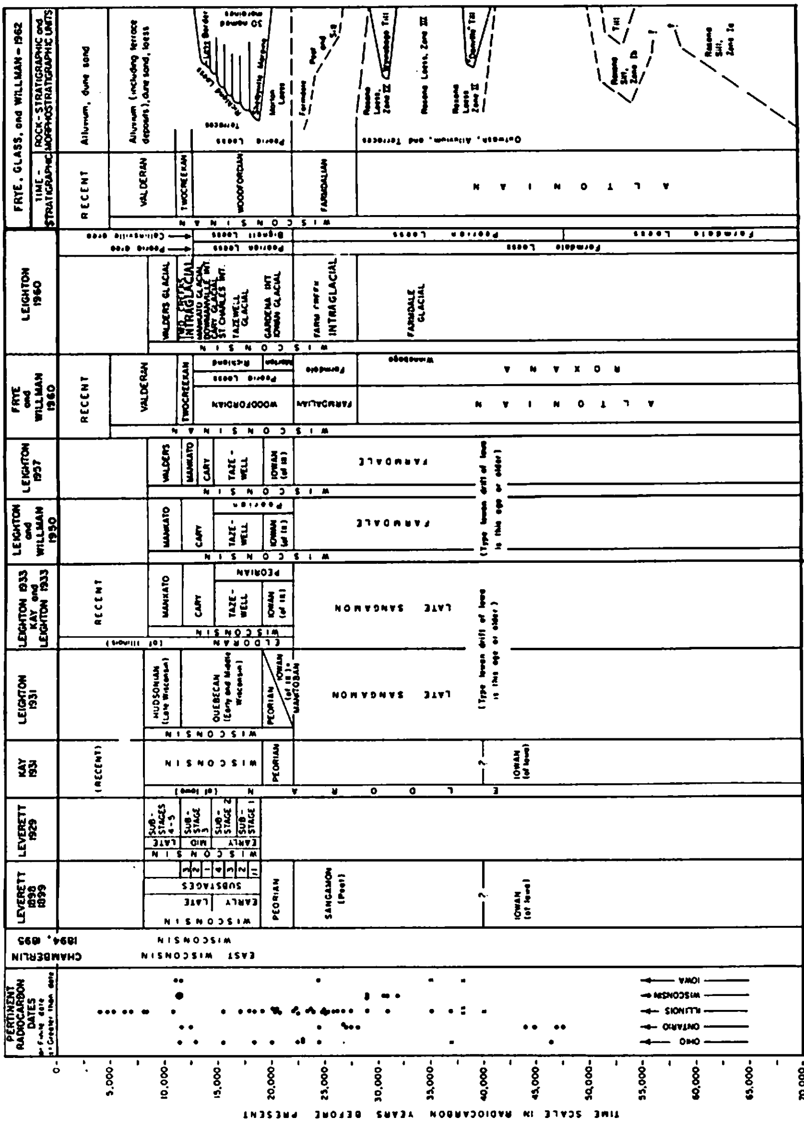


Figure 40.—Development of Wisconsin Stage classification in the upper Mississippi Valley.

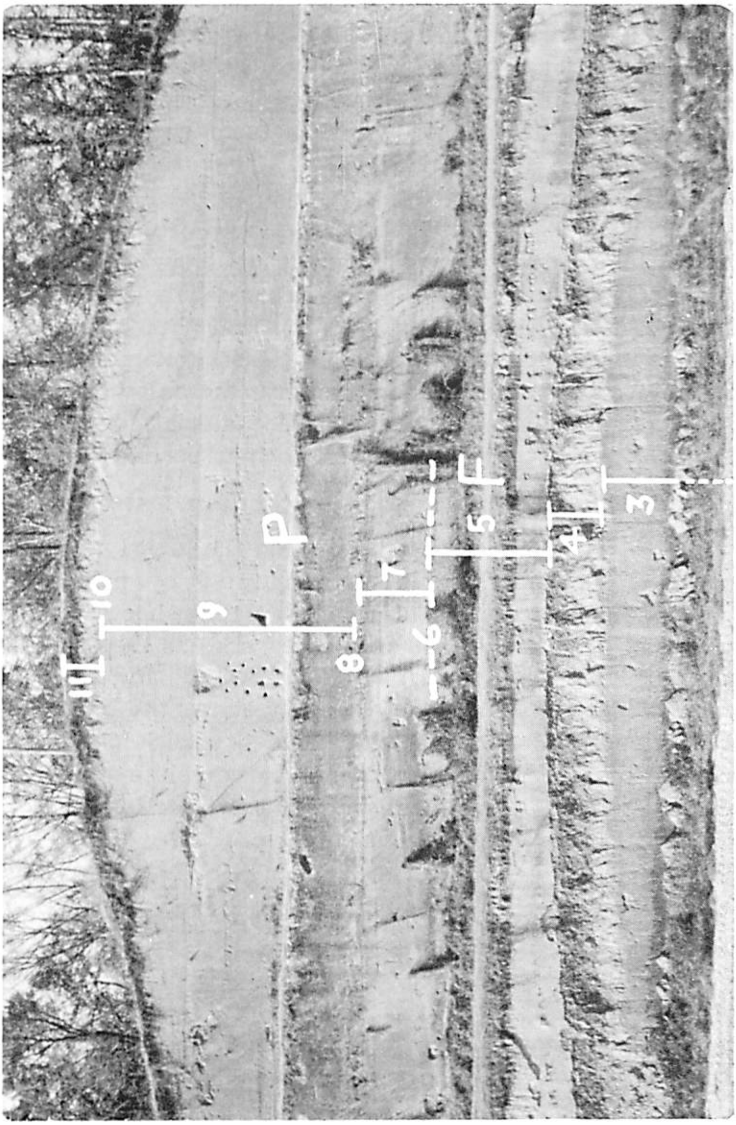


Figure 41.—Standard section of Mississippi loess, exposed in road cut of U. S. Highway 61 bypass near Vicksburg, Mississippi. Numbered zones correspond to those in the measured section: F = Farmdale loess; P = Peorian loess. Zones 1 and 2 are below road level. (Photo taken at footage 12,445, Figure 6).

ments, permit the following conclusions: (1) Mississippi loess is correlative, at least in part, with that of the upper Mississippi Valley; (2) most of the Mississippi loess is equivalent in age to the Peoria loess of Illinois, which, according to Frye, Glass, and Willman (1962) is confined to the Woodfordian Substage of the Wisconsin Glacial Stage (22,000 to 12,500 radiocarbon years B. P.); (3) Some of the Mississippi loess is equivalent to the Farmdale loess in Illinois, which, according to Leighton (1960; 1965) includes all Wisconsin loess older than Peorian (70,000 to 24,000 years B. P.), but is restricted to the Farmdalian Substage (28,000 to 22,000 radiocarbon years B. P.) by Frye, Glass, and Willman (1962); and (4) in at least two localities, there are two carbonate-bearing loesses, separated by paleosols, below dated Farmdale loess, thus indicating that the equivalent of some of the midwestern pre-Farmdale loesses (Roxana?, Loveland?) may also be present. Unfortunately, these lower loess beds are not exposed, and sufficient shell material for radiocarbon dating could not be obtained from their cores.

STANDARD SECTION AND STRATIGRAPHIC CLASSIFICATION

The road cut section at sample station 11 clearly shows several carbonate-bearing loess sheets separated by paleosols. As this was the best example of multiple loess sheets found by the writers in Mississippi, it is designated here as the "standard section" of Mississippi loess. Priddy, Lewand, and McGee (1964) reported multiple loess sheets directly across the highway from the standard section, where they drilled a 26.5 foot hole. However, they did not attempt to name or correlate them at that time. The exposed portion of the standard section is pictured in Figure 41, and measured as follows:

STANDARD SECTION

Measured in the west side of a cut on U. S. Highway 61 bypass, at sample station 11, figs. 2 and 6). The lower 17 feet of the section are not exposed, but were sampled by hand auger. NW¼, NE¼, NE¼, irregular Sec. 9, T. 16N, R. 4E, Warren County, Mississippi 1964.

	Thickness (feet)
Pleistocene Series	
Wisconsinian Stage	
Woodfordian Substage	
Peoria loess	
11. Loess, orange yellowish brown (10 YR 6/4), clayey, leached soil profile	2
10. Loess, orange yellowish brown (10 YR 6/4), partially leached	3
9. Loess, orange yellowish brown (10 YR 6/4), carbonate-bearing, contains fossil gastropods, calcareous concretions abundant near top; radiocarbon age = 17,850±880 years B. P.	23
8. Loess, orange yellowish brown (10 YR 6/4), partially leached clayey (paleosol?)	2
7. Loess, orange yellowish brown (10 YR 6/4), carbonate-bearing, contains fossil gastropods and calcareous concretions; radiocarbon age = 19,250±350 years B. P. near base; 19,200±420 in middle	6
Farmdalian Substage	
Farmdale loess	
6. Loess, moderate yellowish brown (10 YR 5/4), leached clayey (paleosol)	2
5. Loess, orange yellowish brown (10 YR 6/4), carbonate-bearing, contains fossil gastropods; radiocarbon age = 25,300±1000 years B. P. at base; 22,600±800 years B. P. at top	7
Pre-Farmdalian Substage	
Pre-Farmdale loess	
4. Silt, light-brown (5 YR 5/6), strongly leached, very clayey (paleosol)	4
3. Loess, light-brown (5 YR 5/6), partially leached, contains no fossils	8
2. Loess moderate yellowish brown (10 YR 5/4), leached, clayey (paleosol)	2
1. Loess, orange yellowish brown (10 YR 6/4), carbonate-bearing, contains fossil gastropods	8
Total	68

Figure 42 shows a tentative correlation of Mississippi loess with that in the central Great Plains and in Illinois. Correlations are based on the standard section described above, radiocarbon ages, and general field relationships, especially the presence of paleosols separating carbonate-bearing loess. Stratigraphic nomenclature for the Great Plains and Illinois loess is that of Frye, Glass, Leonard, and Willman (1963, p. 112).

It should be emphasized that most of the exposed loess sections in Mississippi are not as nearly completely developed as the standard section. In most sections, paleosols are subdued, and are not believed to represent prolonged periods of leaching. Peoria loess seems to comprise more than 90 per cent of most sections. Most of the pre-Peoria loess is thin and leached throughout. Although the original distribution of the Farmdale and other pre-Peoria loess is not known, it appears that large amounts of it were eroded from the hills prior to deposition of the Peoria loess blanket.

Figure 43 (in the pocket) shows the general loess stratigraphy in the deep road cuts along U. S. Highway 61 bypass, near Vicksburg, Mississippi.

	SUBSTAGE	CENTRAL GREAT PLAINS	ILLINOIS	MISSISSIPPI
WISCONSINAN STAGE	VALDERAN	Bignell loess		
	TWOCREEKAN	Brody soil		
	WOODFORDIAN	Peoria loess	Peoria loess: Richland loess, (till), Morton loess	Peoria loess
	FARMDALIAN	basal transition zone	Farmdale silt and peat	Farmdale loess
			(till)	
	ALTONIAN	sand and gravel	Roxana loess and silt	Roxana loess(?)
SANGAMONIAN		Sangamon soil	Sangamon soil	Sangamon soil(?)
ILLINOIAN STAGE	BUFFALO HART	Loveland loess	Loveland loess	Loveland loess(?)
	JACKSONVILLE	Crete sand and gravel	(till)	
	PAYSON			
			Petersburg loess and silt	
YARMOUTHIAN		Yarmouth soil	Yarmouth soil	

Figure 42.—Stratigraphic correlation of Mississippi loess with that of the Midwest. Central Great Plains and Illinois nomenclature is from Frye, Glass, Leonard, and Williman (1963).

PRE-LOESS STRATIGRAPHY

The loess in central Mississippi almost everywhere unconformably overlies the alluvial sands and gravels of the "Citronelle" formation (figs. 44 and 45). The precise stratigraphic position of the Citronelle is not known, and its status as a geologic formation has been frequently questioned. The Citronelle formation was named for exposures near Citronelle, Alabama, by Matson (1896) and considered to be Pliocene in age on the basis of plant fossils described by Berry (1916). However, Roy (1939) revealed that Berry's plant fossils came from an underlying clay bed which is faulted into a position adjacent to the Citronelle at the type locality. Therefore, most recent reports consider the Citronelle to be Pleistocene in age. Fisk (1949) envisioned the "Citronelle" sands and gravels as the basal facies of four different Pleistocene terrace formations, representing the four interglacial stages. Doering (1958) correlated the Citronelle with Fisk's (1940; 1944; 1952) Williana (Aftonian Interglacial Stage) terrace formation. Doering also recognized a second alluvial sand and gravel formation in Mississippi, the Lissie formation, which he correlates with Fisk's Bentley (Yarmouth Intergalacial Stage) or Montgomery (Sangamon Interglacial Stage) terrace formations. Doering indicates that the sands and gravels underlying the loess at Vicksburg belong to the Lissie formation. The writers do not know which, if any, of these correlations is correct. Evidence from preliminary stratigraphic classification of the loess suggests, however, that the sand and gravel is at least pre-Sangamonian. In this report, all the alluvial sands and gravels underlying the loess are referred to as "Citronelle".

In a few localities in Mississippi, the loess directly overlies one of several Teritary bedrock formations. Near the southern end of the lower Mississippi Valley loess belt, especially in Louisiana, the loess in many places overlies silty, Pleistocene terrace deposits which are commonly mineralogically and texturally similar to the loess. A thorough stratigraphic and petrographic study of these terrace deposits is needed to determine their genetic relationships.

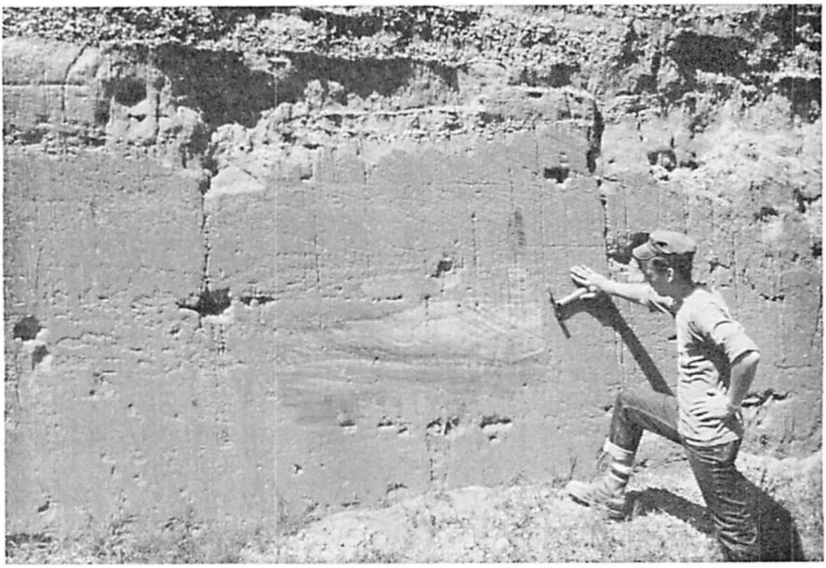


Figure 44.—Cross-bedded "Citronelle" sand and gravel. Surface wash from a 50-foot loess section above obscures the cross-bedding except where it is scraped clean. (Photo taken at sample station 18, Figure 2).

Figure 45.—Sharp contact between the loess and "Citronelle" gravel. (Photo taken at sample station G-5, Figure 3).

ORIGIN

PRELIMINARY STATEMENT

The problem of the origin of Mississippi loess may be conveniently divided into two parts: (1) the source, or provenance, of the detritus which makes up the loess, and (2) the manner in which it was deposited.

SOURCE OF MISSISSIPPI LOESS

It has been shown in this report that Mississippi loess is mineralogically very similar, and at least partly age-equivalent, to loess in the upper Mississippi and Illinois River Valleys (*cf.* tab. 3, fig. 42). Recent detailed stratigraphic and mineralogic studies of loess and glacial tills in Illinois by Frye, Glass, and Willman (1962), Willman, Glass, and Frye (1963), and W. H. Johnson (1964) convincingly demonstrate that the immediate source of the loess was the fine-size fraction of glacial outwash (valley trains), *originally* water-transported and water-deposited by major glacier-draining streams. The carbonate mineralogy, clay mineralogy, and accessory heavy mineralogy of Illinois loess clearly reflect the interdependence between loess mineralogy and source outwash valleys.

Figure 1 shows that outwash in the lower Mississippi River Valley at the time of loess deposition consisted of a mixture of detritus from several sources, of which the most prominent were: (1) drainage from the northwestern glaciers (Des Moines and Missouri Rivers), (2) drainage from the northern glaciers (upper Mississippi River), and (3) drainage from the northeastern glaciers (Wisconsin, Rock, Illinois, Wabash, and Ohio Rivers). Thus, the mineralogy of lower Mississippi Valley loess is a "weighted mean", reflecting the relative mineralogical contributions of many outwash valleys. Interestingly, both the mean accessory heavy mineral and clay mineral content (based on diffraction intensity ratio) of Mississippi loess are nearly identical to that of upper Mississippi Valley Peorian loess, *north* of Alton, Illinois, as reported by Frye, Glass and Willman (*cf.* Table 3).

MODE OF LOESS DEPOSITION

As noted, the interpretation of the mode of deposition of the loess, and especially that of Mississippi loess, has been controversial. Virtually everyone who has had the opportunity to study the loess of several regions agrees that physical similarities among these deposits are too striking to be explained by any but a common mode of deposition. The genetic implications of these common characteristics have, however, been interpreted in a variety of ways. R. J. Russell (1944*a*, p. 33) appraised the problem as follows: "Fact, opinion, and hypothesis are so interwoven in commonly held concepts of loess origin that they have become indistinguishable". This is probably true of many geologic problems, especially those in which not all the observed data point to a single inescapable conclusion. It is hoped that the new data presented in this report, when considered in the light of previous evidence (and perhaps also opinions), will at least provide a better understanding of the problem of loess deposition. Whether or not the problem is "solved" must, at this stage, be left to the judgment of the reader.

At least 20 different hypotheses, which run almost the gamut of geological possibilities, have been advanced at one time or another to explain the presence and distribution of loess. Most of these theories are reviewed in detail by Scheidig (1934) and Russell (1944*a*). It is shown that sediments known to be deposited by a wide variety of agents may possess one or more of the physical characteristics of loess.

Eolian Deposition of Loess

A survey of recent literature reveals that most geologists consider wind to be the most likely agent of deposition of loess in the Mississippi Valley and elsewhere. Virlet d'Aoust (1857), who prescribed an eolian origin for deposits in Mexico, is given credit for originating the idea, but it was Richthofen's (1877, 1882) classic papers on Chinese loess that did most to popularize it. Chamberlin (1897) and Keys (1898), noting the relationship between outwash valleys and loess in the upper Mississippi Valley region, proposed that the valley flats were the source of the wind-blown silts. Keyes (1898) presented evidence of current eolian deposition of silt along the Missouri River.

Tuck (1938) reported deposition of silt along the Matanuska Valley, Alaska, under conditions which many believe closely resemble those during deposition of loess in the Mississippi

Valley. With the glaciers standing 20 to 45 miles up the valleys, the glacial rock flour is deposited by the braided channels across a broad flood plain. Tuck describes a pall of dust as being visible over Palmer and the surrounding country in dry weather, and even in winter. Section corners staked in 1913 were found to be covered to a depth of several inches in 1935. Péwé (1951, 1955) reported similar occurrences along the Yukon and Tanana Rivers in Alaska.

Referring again to the Mississippi Valley loess, several papers discussed in the "Review of the literature" section of this report, (*e.g.*, Shimek, 1902; Smith, 1942; Vestal, 1942; Wascher, Humbert, and Cady, 1948; Doeglas, 1949; Leighton and Willman, 1949, 1950; and Swineford and Frye, 1951) give considerable evidence for eolian origin. Frye, Glass, and Willman (1962, p. 10) list the following studies as demonstrating, in their judgment, the eolian origin of midwestern loess: Udden, 1894, 1898; Smith, 1942; Leighton and Willman, 1950; Kay and Graham, 1943; Swineford and Frye, 1951, 1955; and Leonard and Frye, 1954. Doeglas (1949, p. 113) considered the findings of van Doormaal (1945) to be adequate proof of the eolian origin of Rhine Valley loess in Holland.

The environmental conditions accompanying the deposition of loess in the Mississippi Valley, as envisioned by proponents of the eolian hypothesis, are well-summarized by Leighton and Willman (1950, p. 622):

> The climate during the time when winds were blowing silt from the glacial valley trains to form loess deposits on the bluffs and uplands varied from periglacial near the ice front to temperate farther south, though slightly cooler than the present. Large, thick snail shells are not present in the loess of the Illinois River Valley for some 70 miles from the Tazewell ice front, but small shells are common.
>
> Wind directions also were variable as at present, but in the main were westerly. The major loess accumulations occurred during the fall when the wind was predominantly from the northwest and relatively low rainfall permitted drying of the silts on the floodplains. Near the mouth of the Mississippi Valley the predominant direction of the wind was from the southwest.
>
> The faunas indicate that rainfall and temperature were adequate to support a forest-type vegetation near the valleys and prairie vegetation on some of the relatively flat uplands, especially in the upper Mississippi Valley.
>
> Repeated flooding of the bottom lands, resulting from progressive aggradation, served both to replenish the supplies of silt and to restrain the growth of vegetation. Fine outwash containing appreciable quantities

of silt was an essential factor. Loess occurs in negligible amounts along valleys having coarse gravel outwash or an excessive amount of clay. In the lower Mississippi the most favorable sources of silt were along the major courses of the river, where the coarser silt and sand accumulated, rather than in those parts of the bottom land where the clay fractions serve to bind the sediments. Variations in these conditions probably account for some of the regional variations in thickness of the loess.

Loessification

The only non-eolian mode of loess origin to be proposed in recent years is that of *loessification,* or the transformation of silty Pleistocene backswamp terrace deposits into loess by a combination of colluviation and introduction of secondary carbonates. R. J. Russell (1944*a*) proposed that the loess in the lower Mississippi Valley, and probably that of most other regions also, was formed by loessification. Russell's proposals met immediate criticism (Holmes, 1944*b*; Thwaites, 1944), and served to stimulate further studies of lower Mississippi Valley loess. Fisk (1944, 1949, 1951) agreed with most of Russell's conclusions, and further elaborated on the loessification theory, especially with regard to the role of alluvial terraces. Both Russell's (1944*a*) and Fisk's (1951) reports were discussed in detail in the section, "Review of the literature", of this report. Fisk's (1949) interpretation of the loess-terrace geology of the lower Mississippi Valley is shown by maps and cross-sections, three of which are reproduced in this report as Figures 46, 47, and 48. Note that the Mississippi loess is interpreted as being derived chiefly from the Bently (Yarmouth) and the Williana (Aftonian) terrace formations (figs. 46 and 47). Fisk interprets the sands and gravels of the "Citronelle" formation as the basal conglomerate facies of each of the terrace formations (fig. 48).

Observations on the Genesis of Mississippi Loess

Some of the paleontological, physical, chemical, and mineralogical properties of Mississippi loess appear to be useful as evidence of loess genesis. Several of these properties and their genetic implications are discussed below.

Terrestrial gastropods comprise almost the entire fossil fauna of Mississippi loess. A few fresh-water mollusks have been reported (Fisk, 1951, p. 354), but they are exceedingly rare. According to the Russell-Fisk concept of loessification, the fossil gastropod shells were introduced during mass movement of the loess, as they could not be present in the proposed alluvial

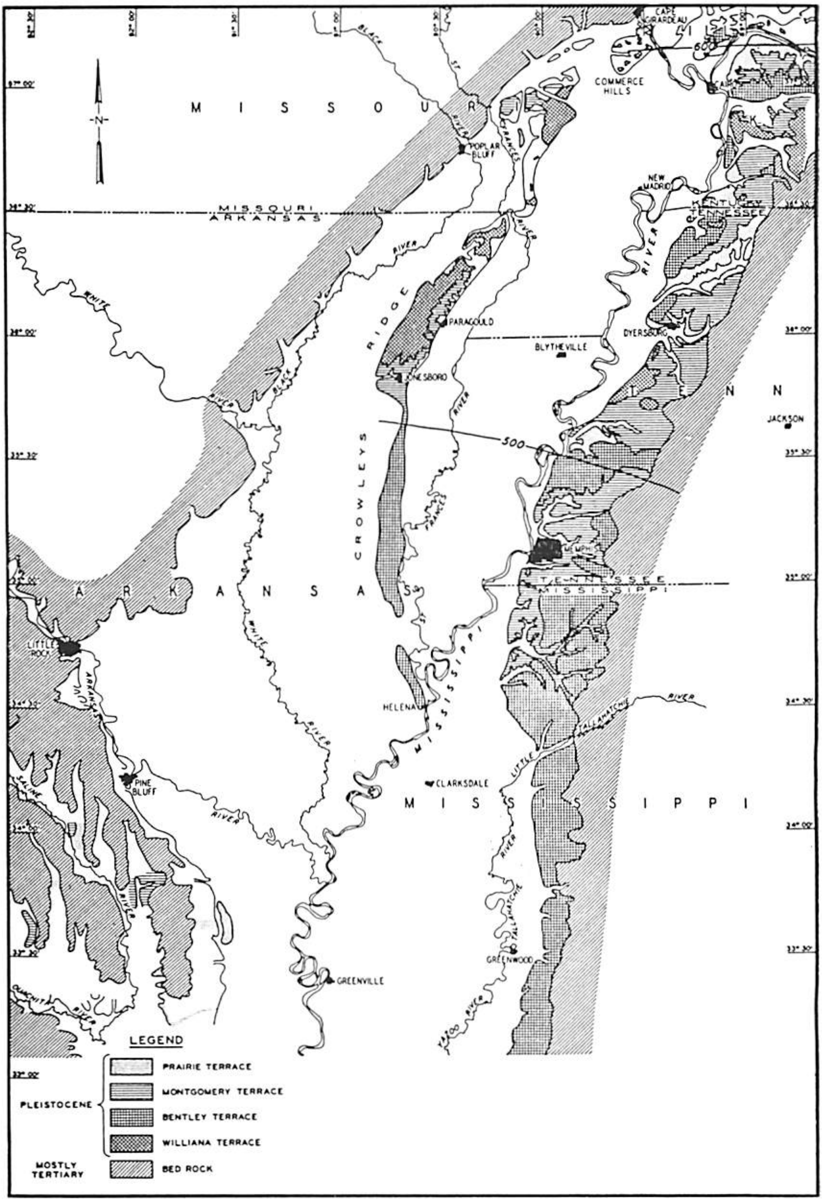


Figure 46.—Areal extent of Pleistocene terraces according to Fisk, et al. (1949) (From latitude 33° 00′ to 37° 15′).

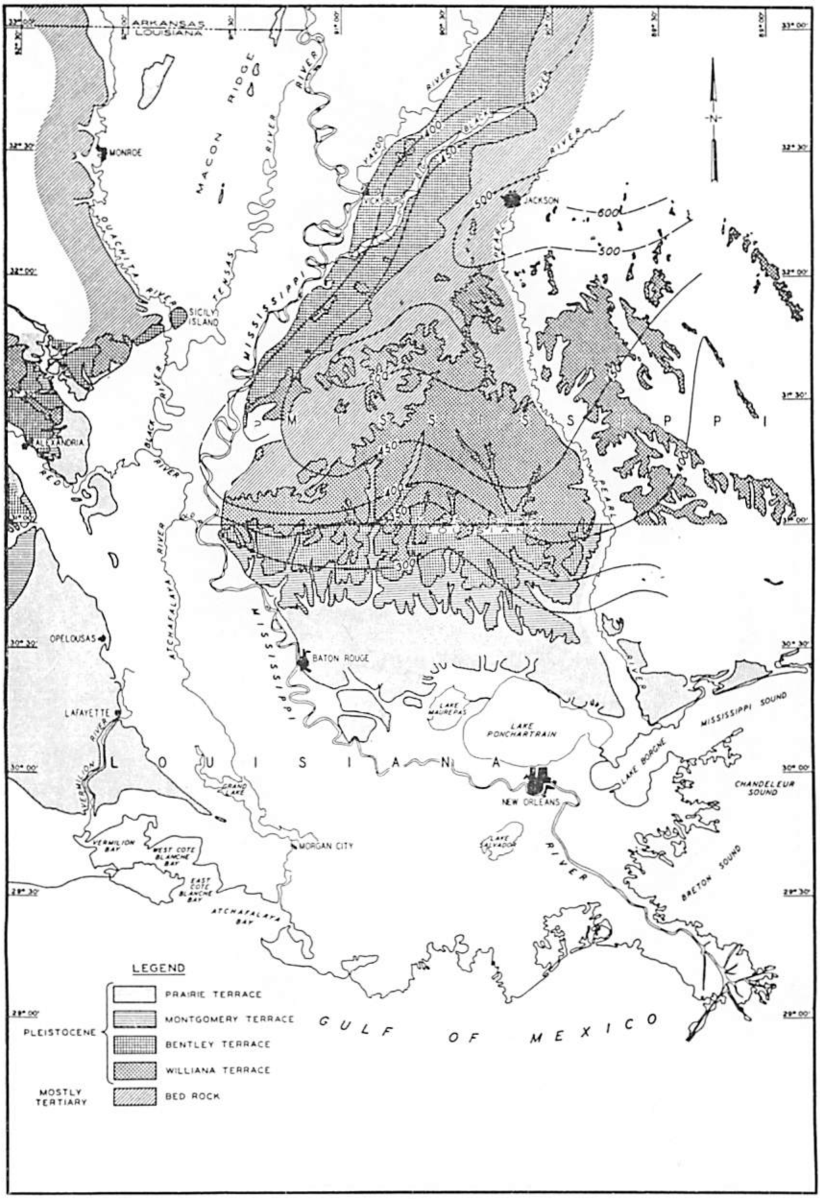


Figure 47.—Areal extent of Pleistocene terraces according to Fisk, et al. (1949) (South of latitude 33° 00′).

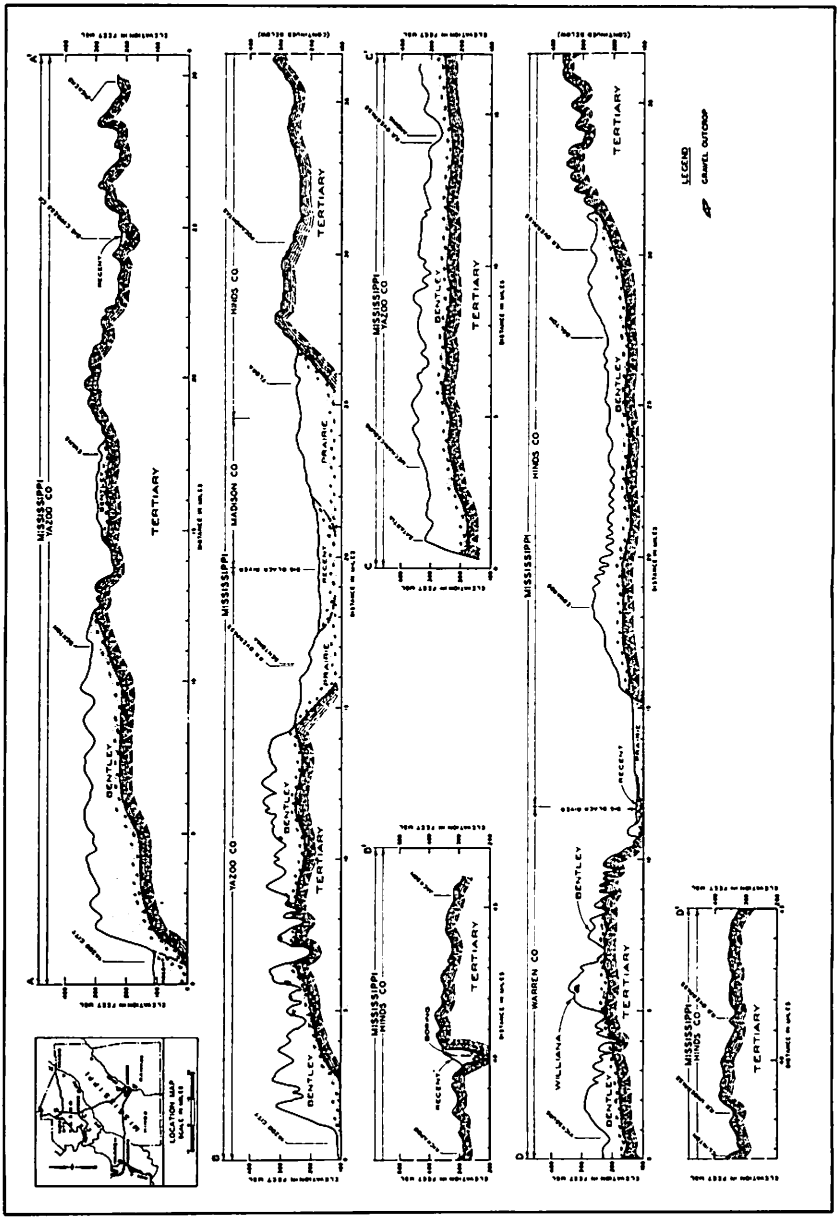


Figure 48.—Cross-sections through the Jackson-Vicksburg area, from Fisk, et al. (1949).

parent material. There is considerable evidence, however, that the gastropods were incorporated as the loess accumulated, i.e., *in situ,* and are fossils in the usual sense of the term: (1) Many of the shells are very fragile and seem incapable of withstanding any type of transport, yet are preserved intact in the loess. Microscopic examination and X-ray diffraction show that fragments of shells, which are aragonitic (fig. 21), are exceedingly rare in the loess. Moreover, Shimek (1902) found several species of *Helicina orbiculata* in Mississippi loess with the operculum lying within the aperture, which strongly indicates no post-death movement. Shimek also found the extremely delicate shells of snails' eggs preserved in the loess, (2) Radiocarbon dating of the gastropod shells in Mississippi loess shows that they occupy definite stratigraphic positions (i.e., shells in the upper part of a loess section are younger than those below them). Radiocarbon ages of gastropod shells in Mississippi loess correspond closely to those obtained by Leonard and Frye (1960) and Frye, Glass, and Willman (1962) from shells in Illinois loess. These dates show that most of the Mississippi loess is Peorian in age (figs. 41 and 42), not Yarmouthian as indicated by Fisk (figs. 46 and 47). Burial by wind-deposited silt is the most rational explanation for the physical and chronological characteristics of the gastropod shells.

Particle-size analyses by Russell (1944*a*), Fisk (1951), and the writers (figs. 31 and 32) show that certain Pleistocene alluvial terrace deposits in the lower Mississippi Valley region closely resemble "typical" loess texturally. Most of the terrace deposits, however, contain more sand and/or clay than carbonate-bearing loess, but still may resemble leached loess or loess-"Citronelle" mixtures (*cf.* figs 31 and 32). Russell (1944*a*, p. 24) found the uniform sorting of the loess difficult to explain as the result of direct deposition from either a wind or water current, and invoked colluviation as the final sorting process. The grain-size data gathered during the present study show that the Mississippi loess, although chiefly silt, is not very well-sorted. It has been established from mineralogical studies that the source of loess throughout the Mississippi Valley region was chiefly glacial outwash. Sediment produced by the mechanical grinding by glaciers would be expected to have a much lower clay mineral and clay-particle-size content than sediment eroded from a normal, chemically weathered terrain. Thus, the source detritus of the loess had a low clay content. Winds blowing over the valley-train outwash could remove the "finer-than-sand" fraction and deposit it on the adjacent bluffs as loess, completing the sorting process. It is well known (*cf.* Bagnold, 1941) that even high winds do not lift the coarser grades of sand more than a few feet off the ground during transport, but silt and very fine sand may be carried high into the atmosphere. Fisk (1951, p. 355) observed if such an eolian separation of sand and silt occurred, there should be lag deposits of sand at the base of the river bluffs. Most of the loess bluffs facing the river have been truncated indicating that there has been at least some valley widening since the loess was deposited, which would have removed any dunes (*cf.* fig. 11). Dune-like structures at the base of loess bluffs in the upper Mississippi Valley region have been reported (Lugn, 1962).

The final phase of Russell's (1944*a*) proposed loessification process is the introduction of secondary carbonates, which "effect a measure of structural competence", retarding further mass movement. However, it was shown in the present study that, discrete, angular, silt-size, detrital dolomite grains comprise most of the carbonate content of Mississippi loess. Secondary carbonates are restricted chiefly to a "calcite-enriched zone" below the leached zone of loess sections (*cf.* figs. 17, 18, 19, and 20), and apparently represent reprecipitation of carbonate dissolved higher in the section. The loessification hypothesis was further weakened when augering revealed the presence of carbonate-bearing "fresh" loess below the supposed backswamp terrace "parent-material" in several of Russell's illustrative areas (Leighton and Willman, 1950, p. 620). In many sections of Mississippi loess, there are distinct leached zones, or paleosols, which indicate interruptions in deposition, followed by periods when leaching was dominant, followed by a resumption of loess deposition. Preliminary radiocarbon dating of gastropod shells from these "zones" indicates that the Mississippi loess is, at least in part, stratigraphically correlative with that in the upper Mississippi Valley, as suggested from field evidence by Wascher, Humbert, and Cady (1948) and Leighton and Willman (1950).

Such zonation could not exist if the loess were colluvially deposited.

Russell (1944*a*, p. 23) felt that the distribution of loess in the lower Mississippi Valley precluded an eolian origin:

> Against eolian origin it may be urged that no actual or hypothetical directions of winds could account for its distribution. It covers slopes leading in all possible directions and is ordinarily as strikingly developed on one side of a ridge as on the other. In pseudoanticlinal exposures, whatever their orientation may be, one limb ordinarily resembles closely the other. It occurs on both sides of the Mississippi and other large rivers.

Actually the distribution maps (figs. 1 and 13) show the great bulk of lower Mississippi Valley loess is on the bluffs bordering the eastern margin of the valley leeward. The even draping of loess over pre-loess ridges, in the writers' opinion, *favors* an eolian origin rather than disproving it. Modern accounts of eolian-outwash silt deposition (*e.g.* Tuck, 1938) indicate that the dust is carried high into the air and "hangs like a pall", settling slowly and rather uniformly over the surrounding countryside. The loose silt would be easily removed from the active drainage areas between ridges, but would tend to accumulate to greater thicknesses on ridge tops, especially if vegetation-covered, as indicated by numerous root tubules in the loess. Thus, the loess topography matches, even exaggerates, the pre-loess topography. Fisk (1944, 1951), in order to explain the occurrence of loess on high divide areas on the bluffs east of the Mississippi River, which he considered derived from once-higher terraces, matching lower ones west of the river, has had to postulate more than 300 feet of post-Aftonian uplift east of the river.

Numerous studies, including the present one, have shown that there is a close relationship between glacial events and loess deposition in the central United States. The bulk of evidence strongly indicates that the loess detritus was: (1) ground to rock flour by continental glaciers, (2) transported down meltwater-carrying valleys as outwash, and (3) swept up and deposited on the leeward bluffs and beyond by prevailing westerly winds. *Therefore, the loess is properly termed a glacio-fluvial-eolian deposit.*

CONCLUSIONS

From the data presented in this report, several conclusions may be drawn:

(1) Most of the Mississippi loess was deposited on maturely dissected uplands bordering the eastern side of the Mississippi Alluvial Valley. Alluvial sands and gravels of the "Citronelle" formation capped most of the ridges at the time of loess deposition. Today, the loess is symmetrically draped over these ridges, with greatest thicknesses usually developed on the ridge tops.

(2) The average ridge-top loess thickness decreases logarithmically with distance from the river bluffs.

(3) Mineralogically, the loess is chiefly silt-size quartz and feldspar.

(4) Three carbonate mineral zones are present in Mississippi loess: (a) a leached zone, which contains little or no carbonates, (b) a calcite-enriched zone, which occurs immediately below the leached zone and is characterized by concretions and other secondary calcite deposits, and (c) a dolomitic zone, in which silt-size detrital dolomite is the chief carbonate. The dolomitic zone is thought to represent the original condition of the loess. The carbonate zones may be cyclic, indicating several periods of loess deposition, each followed by a period of leaching.

(5) Mississippi loess contains a distinctive hornblende-epidote-garnet non-opaque accessory heavy mineral assemblage, which, upstream, is characteristic of glacial outwash, whose primary source was the igneous-metamorphic complex of the southern Canadian Shield. Outwash from the Western Interior region also contributed to the source detritus, as indicated by a relatively high zircon content. The accessory heavy mineral assemblage of the loess is distinctly different from the kyanite-staurolite assemblage of the Tertiary Gulf Coastal Plain formations. Thus, it is possible to distinguish the thin, leached loess in the eastern portion of the Mississippi loess belt from the residual brown silty soils that are common in Mississippi. The eastern boundary of the loess belt could be determined by this means, if enough data were available.

(6) Montmorillonite group minerals dominate the clay mineral assemblage in the loess accompanied by illite and kaolinite in decreasing order of abundance. Vermiculite and chlorite are present but are scanty. Mixed-layer minerals occur commonly in upper soil zones. The clay mineral content of Mississippi loess is very uniform from sample to sample.

(7) The overall mineralogy of the Mississippi loess is uniform, as most samples fall within the feldspathic quartzite field of Hubert's (1960) classification.

(8) Most of the particle-size variation in the loess is caused by post-depositional processes, chiefly weathering and mixing with underlying sediments.

(9) The unusual structural stability of Mississippi loess is due to a combination of: (a) high permeability, which gives the loess good drainage characteristics, (b) binding of silt particles by thin clay husks, which encase most grains, and (c) an internal "skeleton" of hollow, vertically oriented, calcareous root tubules.

(10) Radiocarbon dates from gastropod shells and fossil plant material show that: (a) Mississippi loess is at least partly correlative stratigraphically with that in the upper Mississippi Valley, (b) most of the Mississippi loess is stratigraphically equivalent to the Peoria loess in Illinois, (c) some of the Mississippi loess is stratigraphically equivalent to the Farmdale loess in Illinois, and (d) in at least one locality there are two carbonate-bearing loess sheets, separated by leached zones (paleosols), below dated Farmdale loess.

(11) The Mississippi loess detritus was: (a) derived from outwash carried down the major glacier-draining stream valleys, (b) deposited on the Pleistocene Mississippi-Ohio Valley flats by outwash-choked braided streams, and (c) picked up and carried eastward by the prevailing winds, where it slowly settled on the dissected uplands.

(12) Mississippi loess is mineralogically, texturally, stratigraphically, and genetically similar to that of the upper Mississippi Valley region.

ACKNOWLEDGMENTS

Numerous individuals and organizations have contributed greatly to this study. Most of the financial support for the field and laboratory work and for student assistants came from three National Science Foundation Undergraduate Research Participation grants. The titles and amounts of these grants, along with a complete list of student assistants and their duties is appended to this bulletin.

Many of the concepts and data in this report are based on Snowden's Ph.D. dissertation, "Petrology of Mississippi Loess", done under the direction of Dr. W. D. Keller in the Department of Geology at the University of Missouri at Columbia. Through many conferences and discussions, Dr. Keller contributed valuable ideas to this work.

Dr. L. L. McDowell and the Sedimentation Laboratory, U. S. Department of Agriculture, Oxford, Mississippi, determined the radiocarbon ages of ten gastropod and one bone sample without charge, thus greatly assisting in the development of a radiocarbon stratigraphy of the loess.

Dr. John C. Frye, Illinois State Geological Survey, provided the writers with many reprints of current literature, including his personal copies of some out-of-print material. The staff of the Mississippi Geological Survey cored and logged six holes through the loess in the Vicksburg area, which have proved very useful in our stratigraphic interpretations. The ceramic (pyrophysical) properties of these samples were analyzed by Mr. Thomas E. McCutcheon of Atlanta, Georgia.

Dr. W. T. Kane, Corning Glass Works, Corning, New York assisted with the programming and processing of grain-size data on the IBM 1620 computer. Dr. James B. Rucker, U. S. Naval Oceanographic Office, accompanied Snowden in the field in Louisiana and southwest Mississippi and prepared the X-ray diffractograms of gastropod shells.

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APPENDIX

TABLE 6. LOCATION AND GENERAL DESCRIPTION OF LOESS SAMPLES

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	DEPTH (FT.)	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR[1]
AUGER HOLES								
1-1[2]	NW SE NE 15*	17N	4E	Warren	0.0 - 0.9	319[3]	weathered loess (soil)	Pale yellowish brown 10 YR 6/2
1-2		do.			0.9 - 1.6	318	weathered loess	Moderate yellowish brown 10 YR 5/4
1-3		do.			1.3 - 4.2	316	do.	do.
1-4		do.			3.3 - 4.2	315	do.	do.
1-5		do.			4.2 - 4.8	314	weathered loess w/ a few shell fragments	do.
1-6		do.			4.8 - 6.2	313	do.	do.
1-7		do.			6.2 - 12.1	307	calc. loess	Orange yellowish brown 10 YR 6/4
1-8		do.			12.1 - 18.5	301	do.	do.
1-9		do.			18.5 - 24.1	295	calc. loess w/ concretions	Grayish orange 10 YR 7/4
1-10		do.			24.1 - 30.0	279	do.	do.
1-11		do.			30.0 - 30.6	278	do.	do.

[1]From Rock Color Chart (Goddard, et al., 1963)

[2]First number is locality number, corresponding to numbers on figures 2, 3, and 4.

[3]Elevation values for an interval represent the lowest point in the interval, rounded to nearest foot.

*Irregular Section

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	DEPTH (FT.)	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
1-12	NW SE NE 15*	17N	4E	Warren	30.6 - 36.0	283	calc. loess, shells abundant	Grayish orange 10 YR 7/4
1-13		do.			36.0 - 40.0	279	do.	do.
1-14		do.			40.0 - 45.0	274	do.	do.
1-15		do.			45.0 - 45.2	274	loess, somewhat weathered	do.
1-16		do.			45.2 - 47.8	271	calc. loess w/ concretions	do.
1-17		do.			48.0 - 48.2	271	do.	do.
1-18		do.			48.2 - 51.0	268	calc. loess w/ large concretions	do.
1-19		do.			51.0 - 53.0	267	do.	do.
1-20		do.			53.0 - 54.0	266	loess, somewhat weathered	do.
1-21		do.			54.0 - 61.0	258	calc. loess w/ large concretions, many shells	do.
1-22		do.			61.0 - 65.0	254	do.	do.
1-23		do.			65.0 - 67.0	252	do.	do.
1-24		do.			67.0 - 69.0	250	do.	do.
1-25		do.			69.0 - 70.0	249	calc. loess	do.
1-26		do.			70.0 - 71.0	248	loess, somewhat weathered	Moderate yellowish brown 10 YR 5/4
1-27		do.			71.0 - 76.0	243	weathered loess	Dark yellowish orange 10 YR 6/6
1-28		do.			76.0 - 78.0	241	weathered loess	do.
1-29		do.			78.0 - 83.0	236	calc. loess, somewhat weathered	Grayish orange 10 YR 7/4

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	DEPTH (FT.)	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
1-30	NW SE NE 15*	17N	4E	Warren	83.0 - 87.0	232	weathered loess	Grayish orange 10 YR 7/4
1-31		do.			87.0 - 88.0	231	weathered loess clayey	Moderate yellowish 10 YR 5/4
1-32		do.			88.0 - 90.0	229	do.	Moderate brown 5 YR 4/4
1-33		do.			90.0 - 91.5	227	sandy silt (prob. loess-sand mixture	Moderate yellowish brown 10 YR 5/4
1-34		do.			91.5 - 92.0	227	do.	Moderate brown 5 YR 3/4
1-35		do.			92.0 - 93.0	226	do.	Light brown 5 YR 5/6
1-36		do.			93.0 - 96.0	223	fine sand	Dark yellowish brown 10 YR 4/2
2-0	SW SW SE 21	17N	5E	Warren	0.0 - 2.0	344	weathered loess w/ organic matter (soil)	Moderate yellowish brown 10 YR 5/4
2-1		do.			2.0 - 3.2	341	weathered loess	Moderate brown 5 YR 4/4
2-2		do.			3.2 - 4.2	340	do.	Moderate yellowish brown 10 YR 5/4
2-6		do.			4.2 - 6.2	338	do.	do.
2-7		do.			6.2 - 9.0	335	do.	do.
2-11		do.			9.0 - 10.1	334	do.	Moderate brown 5 YR 4/4
2-12		do.			10.1 - 10.5	334	do.	Moderate yellowish brown 10 YR 5/4

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	DEPTH (FT.)	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
2-13	SW SW SE 21	17N	5E	Warren	10.5 - 11.3	333	weathered loess	Moderate brown 5 YR 4/4
2-14		do.			11.3 - 11.6	332	do.	Moderate yellowish brown 10 YR 5/4
2-15		do.			11.6 - 13.5	330	weathered loess w/ some concretions	do.
2-16		do.			13.5 - 14.2	330	do.	do.
2-17		do.			14.2 - 16.1	328	calc. loess w/ shells and concretions	do.
2-18		do.			16.1 - 19.0	326	do.	Orange yellowish brown 10 YR 6/4
2-19		do.			19.0 - 22.0	323	do.	do.
2-20		do.			22.0	323	do.	do.
2-21		do.			22.0 - 22.6	322	do.	do.
2-22		do.			22.6 - 25.0	320	do.	do.
2-23		do.			25.0 - 27.0	318	do.	do.
2-24		do.			27.0 - 29.0	316	do.	do.
2-25		do.			29.0 - 31.0	314	do.	Moderate yellowish brown 10 YR 5/4
2-26		do.			31.0 - 35.0	309	do.	do.
2-27		do.			35.0 - 37.0	307	calc. loess	Orange yellowish brown 10 YR 6/4
2-28		do.			37.0 - 38.5	306	do.	do.
2-29		do.			38.5 - 40.5	304	do.	do.
2-30		do.			40.5 - 42.5	302	do.	Grayish orange 10 YR 7/4
2-31		do.			42.5 - 44.8	301	do.	do.
2-32		do.			44.8 - 45.0	299	do.	do.

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	DEPTH (FT.)	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
2-33	SW SW SE 21	17N	5E	Warren	45.0 - 47.0	297	loess, somewhat weathered	Grayish orange 10 YR 7/4
2-34		do.			47.0 - 51.0	293	weathered loess	Orange yellowish brown 10 YR 6/4
2-35		do.			51.0 - 52.0	292	clayey loess	Dark yellowish orange 10 YR 6/6
3-1	SE SW SW 20	7N	4W	Warren	0.0 - 2.0	246	weathered loess (soil)	Grayish orange 10 YR 7/4
3-2		do.			2.0 - 4.0	242	weathered loess	do.
3-3		do.			4.0 - 10.0	236	do.	Orange yellowish brown 10 YR 6/4
3-4		do.			10.0 - 13.0	236	do.	Grayish orange 10 YR 7/4
3-5		do.			13.0 - 14.0	232	calc. loess, w/ concretions	do.
3-6		do:			14.0 - 16.0	230	do.	Grayish orange 10 YR 7/4
3-7		do.			16.0 - 23.0	223	do.	do.
3-8		do.			23.0 - 24.0	222	do.	do.
3-9		do.			24.0 - 36.0	210	do.	do.
3-10		do.			36.0 - 37.0	211	sandy, clayey loess, probably mixed	Orange yellowish brown 10 YR 6/4
4-1	SE SW SW 19	7N	3W	Hinds	0.0 - 1.0	261	weathered loess (soil)	Orange yellowish brown 10 YR 6/4
4-2		do.			1.0 - 2.5	259	weathered loess	do.
4-3		do.			2.5 - 4.7	256	do.	Moderate yellowish brown 10 YR 5/4

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	DEPTH (FT.)	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
4-4	SE SW SW 19	7N	3W	Hinds	4.7 - 5.0	256	weathered loess	Moderate yellowish brown 10 YR 5/4
4-5		do.			5.0 - 5.3	256	do.	do.
4-6		do.			5.3 - 5.6	255	do.	Orange yellowish brown 10 YR 6/4
4-7		do.			5.6 - 6.2	255	do.	Dark yellowish orange 10 YR 6/6
4-8		do.			6.2 - 6.9	254	do.	Orange yellowish brown 10 YR 6/4
4-9		do.			6.9 - 8.8	252	loess, slightly calc. w/ a few concretions	do.
4-10		do.			8.8 - 13.9	247	calc. loess w/ concretions	do.
4-11		do.			13.9 - 24.6	246	do.	Grayish orange 10 YR 7/4
4-12		do.			14.4 - 15.8	245	do.	do.
4-13		do.			15.8 - 18.4	242	sandy loess, probably mixed silty, clayey sand	Orange yellowish brown 10 YR 6/4
4-14		do.			18.4 - 20.0	241		do.
5-1	NE SE NE 21	7N	3W	Hinds	0.0 - 0.8	282	weathered loess (soil)	Orange yellowish brown 10 YR 6/4
5-2		do.			0.8 - 2.3	280	weathered loess	do.
5-3		do.			2.3 - 3.4	279	do.	do.
5-4		do.			3.4 - 5.2	277	do.	do.
5-5		do.			5.2 - 12.0	270	do.	Grayish orange 10 YR 7/4
5-6		do.			12.0 - 13.0	269	do.	do.

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	DEPTH (FT.)	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
5-7	NE SE NE 21	7N	3W	Hinds	13.0 - 15.5	267	clayey weathered loess	Grayish orange 10 YR 7/4
5-8		do.			15.5 - 16.0	266	clayey sand	do.
5-9		do.			16.0 - 19.5	262	silty clay	do. (mottled)
5-10		do.			19.5 - 20.5	261	do.	Dark yellowish orange 10 YR 6/6
6-1	SW SW NW 20	7N	2W	Hinds	0.0 - 1.9	316	weathered loess (soil)	Moderate yellowish brown 10 YR 5/4
6-2		do.			1.9 - 5.0	313	weathered loess	do.
6-3		do.			5.0 - 8.2	308	do.	Orange yellowish brown 10 YR 6/4
6-4		do.			8.2 - 11.0	314	do.	do.
6-5		do.			11.0 - 11.8	304	do.	do.
6-6		do.			11.8 - 13.2	303	waxy clayey silt	Dark yellowish orange 10 YR 6/6
6-7		do.			13.2 - 13.8	302	do.	do. (mottled)
6-8		do.			13.8 - 17.5	298	do.	Grayish orange 10 YR 7/4
6-9		do.			17.5 - 18.0	298	do.	do.
6-10		do.			18.0 - 19.3	297	do.	do.
6-11		do.			19.3 - 20.0	296	silty sand	Moderate yellowish brown 10 YR 5/4
7-1	NW SW SE 31	7N	1W	Hinds	0.0 - 0.6	303	weathered loess (soil)	Dark yellowish orange 10 YR 6/6
7-2		do.			0.6 - 1.4	302	weathered loess	do.

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	DEPTH (FT.)	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
7-3	NW SW SE 31	7N	1W	Hinds	1.4 - 2.0	301	weathered loess	Dark yellowish orange 10 YR 6/6 (mottled)
7-4		do.			2.0 - 2.4	301	do.	do.
7-5		do.			2.4 - 2.9	300	do.	Grayish orange 10 YR 7/4
7-6		do.			2.9 - 3.8	299	do.	do.
7-7		do.			3.8 - 4.4	299	do.	do.
7-8		do.			4.4 - 5.9	297	do.	do.
7-9		do.			5.9 - 6.5	296	sandy, clayey silt	Grayish orange 10 YR 7/4
7-10		do.			6.5 - 7.8	295	clayey silt	Dark yellowish orange 10 YR 6/6
7-11		do.			7.8 - 10.4	293	do.	do.
7-12		do.			10.4 - 11.6	291	do.	do.
7-13		do.			11.6 - 12.6	290	silty sand	Light brown 5 YR 5/6

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	FT. ABOVE BASE	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
ROAD CUTS								
8-1	SW SW SE 23	18N	4E	Warren	15	195	calc. loess w/ shells	Very pale orange 10 YR 8/2
9-15	NW SW NE 9	17N	4E	Warren	40.0	305	calc. loess w/ shells	Grayish orange 10 YR 7/4
10-1	NE SW SE 28*	17N	4E	Warren	0.0 - 1.0	197	large pebble gravel	Grayish yellow 5 Y 8/4
10-2		do.			1.0 - 5.0	198	sand	Dark yellowish orange 10 YR 6/6
10-3		do.			5.0 - 7.4	202	pebbly sand	do.
10-4		do.			7.4 - 10.4	205	calc. loess, somewhat weathered	Grayish orange 10 YR 7/4
10-5		do.			10.4 - 13.4	207	calc. loess w/ shells	do.
10-6		do.			13.4 - 16.4	210	do., many concretions	do.
10-7		do.			16.4 - 22.4	213	do., fewer concretions	do.
10-8		do.			22.4 - 24.4	219	do.	do.
10-9		do.			24.4 - 25.4	221	do.	do.
10-10		do.			25.4 - 28.4	222	do.	do.
10-11		do.			28.4 - 34.4	225	do.	do.
10-12		do.			34.4 - 36.4	231	do.	do.
10-13		do.			36.4 - 37.4	233	calc. loess, somewhat weathered	do.

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	FT. ABOVE BASE	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
10-14	NE SW SE 28*	17N	4E	Warren	37.4 - 40.4	234	weathered loess	Orange yellowish brown 10 YR 6/4
10-15		do.			40.4 - 43.4	237	calc. loess w/ shells	Grayish orange 10 YR 7/4
10-16		do.			43.4 - 46.6	240	do.	do.
10-17		do.			46.4 - 49.4	243	do.	do.
10-18		do.			49.4 - 52.4	246	do.	do.
10-19		do.			52.4 - 55.4	249	do.	do.
10-20		do.			55.4 - 58.4	252	do.	do.
10-21		do.			58.4 - 60.8	255	do.	do.
10-22		do.			60.8 - 63.8	258	do.	do.
10-23		do.			63.8 - 66.8	261	do.	do.
10-24		do.			66.8 - 67.8	264	do.	do.
11-1	NW NE NE 9*	16N	4E	Warren	-16.0	315	clayey, sandy silt	Yellowish gray 5 Y 8/1
11-2		do.			-11.0	320	clayey loess	Grayish orange 10 YR 7/4
11-3		do.			1.0	332	do.	Orange yellowish brown 10 YR 6/4
11-4		do.			7.0	339	clayey loess weathered	Light brown 5 YR 5/6
11-5		do.			9.0	341	clayey loess, somewhat weathered	Grayish orange 10 YR 7/4
11-6		do.			21.0	353	calc. loess w/ shells	do.
11-7		do.			29.0	361	calc. loess w/ shells and concretions	do.
11-8		do.			37.0	369	do.	do.

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	FT. ABOVE BASE	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
11-9	NW NE NE 9*	16N	4E	Warren	45.0	377	calc. loess w/ shells and concretions	Grayish orange 10 YR 7/4
11-10		do.			53.0	385	weathered loess (soil)	Orange yellowish brown 10 YR 6/4
12-1	NE SW NE 46*	13N	3E	Claiborne	0.5	237	loess, somewhat weathered, perhaps mixed	Pale yellowish orange 10 YR 8/6
12-2		do.			8.0	245	calc. loess w/ shells	Grayish orange 10 YR 7/4
13-1	SE SW NW 6*	14N	3E	Warren	8.0	108	calc. loess w/ shells	Grayish orange 10 YR 7/4
13-2		do.			4.0	104	do.	do.
14-1	SE SE SE 31*	16N	15E	Warren	1.0	241	calc. loess	Grayish orange 10 YR 7/4
14-2		do.			4.0	245	calc. loess w/ shells	do.
15-1	SE NW SE 28	16N	3E	Warren	0.5	201	calc. loess w/ shells and concretions	Grayish orange 10 YR 7/4
15-2		do.			4.0	205	do.	do.
15-3		do.			8.0	209	do.	do.
15-4		do.			12.0	213	weathered loess (sub soil)	Moderate yellowish 10 YR 5/4

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	FT. ABOVE BASE	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
16-1	SE NW SW 22	16N	4E	Warren	0.5	235	calc. loess w/ shells, unusually gray	Yellowish gray 5 Y 8/1
16-2		do.			4.0	239	calc. loess w/ shells and concretions	Pale yellowish orange 10 YR 8/6
16-3		do.			32.0	272	weathered loess (sub soil)	Orange yellowish brown 10 YR 6/4
17-1a	SW NW NW 24	16N	4E	Warren	16.0	335	loess-sand mixture	Dark yellowish orange 10 YR 6/6
17-1		do.			19.0	338	calc. loess	Grayish orange 10 YR 7/4
17-2		do.			31.0	350	calc. loess w/ shells	do.
17-3		do.			45.0	364	loess, somewhat weathered	Orange yellowish brown 10 YR 6/4
18-1	SE SW SW 13*	16N	4E	Warren	4.0	269	calc. loess w/ shells	Grayish orange 10 YR 7/4
18-2		do.			9.0	274	do.	do.
19-1	SE SE SE 20	6N	4W	Hinds	4.0	227	silty sand (Catahoula fm.-Miocene)	Medium yellowish orange 10 YR 7/6
19-1a		do.			5.0	229	mixed loess and Catahoula	Grayish orange 10 YR 7/4
19-2		do.			6.0	239	calc. loess	do.
19-3		do.			21.0	244	weathered loess	do.

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	FT. ABOVE BASE	ELEV (FT. MSL)	GENERAL DESCRIPTION	COLOR
20-1	NE SW NW 23	6	2W	Hinds	5.0	247	weathered loess	Medium yellowish orange 10 YR 7/6
21-1	SE SW SE 24	6N	2W	Hinds	7.0	324	weathered loess	Grayish orange 10 YR 7/4
21-2		do.			4.0	321	do.	Dark yellowish orange 10 YR 6/6
22-1	NW SE NW 30	6N	2W	Hinds	7.0	342	weathered loess	Pale yellowish orange 10 YR 8/6
G-1	NW NW NW 15	16N	1E	Holmes	12.0	241	calc. loess w/ shells	Grayish orange 10 YR 7/4
G-2		do.			5.5	233	do.	do.
G-3	NE SE SE 11	15N	1E	Holmes	4.0	279	do.	do.
G-4	NW NE NW 14	18N	2E	Carroll	7.0	233	do.	do.
G-5		do.			3.5	176	sandy, clayey silt (Kosciusko fm. - Eocene)	Very pale orange 10 YR 8/2
LM-3	SW NW SW 90*	1S	4W	W. Feliciana, La.	3.5	176	calc. silt w/ fossil wood and mollusks	Light olive gray 5 Y 6/1
LM-4	SE NW SE 7*	1N	4W	Wilkinson	3.0	277	calc. loess w/ shells	Grayish orange 10 YR 7/4
LM-5	SE SE NE 8*	1N	4W	Wilkinson	4.0	258	do.	do.
LM-6	NW SW SW 31*	1N	4W	Wilkinson	5.0	237	silt, somewhat calcareous	Light olive gray 5 Y 6/1
LM-7	SW SW NE 57*	1N	4W	W. Feliciana, La.	4.0	211	calc. loess w/ shells	Grayish orange 10 YR 7/4

TABLE 6. Continued

SAMPLE NUMBER	LOCATION ¼ Sec.	T.	R.	County	FT. ABOVE BASE	ELEV. (FT. MSL)	GENERAL DESCRIPTION	COLOR
LM-8	SE NW NE 57*	1N	4W	W. Feliciana, La.	4.0	227	calc. silt	Light olive gray 5 Y 6/1
LM-9	SW NE NE 77*	1S	4W	W. Feliciana, La.	3.0	N.A.	weathered loess	Grayish orange 10 YR 7/4
LM-11	SW SE NE 79*	1S	4W	W. Feliciana, La.	3.5	N.A.	sandy silt	Yellow olive gray 5 Y 7/1

TABLE 7. CHEMICAL ANALYSES OF LOESS[1]

SAMPLE NUMBER	pH[2]	Al_2O_3			Fe_2O_3			MgO			CaO			H_2O+	H_2O-	CO_2	SiO_2 + other
		sol.[3]	fus.[4]	tot.	sol.	fus.	tot.	sol.	fus.	tot.	sol.	fus.	tot.				
1-1	7.2	2.15	11.51	13.66	2.10	0.92	3.02	0.46	0.40	0.86	0.33	0.72	1.05	12.40	8.37	0.71	59.93
1-2	6.0	3.06	13.36	16.42	3.28	0.67	3.95	0.80	0.44	1.24	0.36	0.81	1.17	11.31	7.78	0.80	57.33
1-3	6.4	2.44	5.18	7.62	3.32	0.99	4.31	0.78	0.30	1.08	0.46	0.67	1.13	11.02	5.88	1.08	67.88
1-4	6.9	2.82	10.13	12.95	2.91	1.28	4.19	0.56	0.36	0.92	0.47	0.83	1.30	10.83	5.17	1.02	63.62
1-5	7.0	2.48	4.80	7.28	2.89	0.81	3.70	1.77	0.41	2.18	0.57	0.57	1.14	10.70	4.26	1.85	68.89
1-6	6.9	1.49	10.94	12.43	3.19	1.02	4.21	0.37	0.66	1.03	0.54	0.89	1.43	10.68	3.96	0.75	65.51
1-7	8.2	0.00	12.10	12.10	2.89	3.44	6.28	4.51	0.10	4.61	4.67	0.18	4.85	10.81	2.24	8.64	50.47
1-8	8.1	0.90	9.98	10.88	2.12	0.80	2.92	4.74	0.98	5.72	6.19	0.85	7.04	10.72	1.66	10.97	50.09
1-9	8.2	1.59	4.42	6.01	2.00	0.38	2.38	1.99	0.17	2.16	9.95	0.76	10.71	10.59	1.26	12.49	54.40
1-10	8.3	1.32	8.14	9.46	2.01	2.01	4.02	4.14	2.96	7.10	7.69	0.71	8.40	10.62	1.10	12.12	47.18
1-11	8.4	1.72	8.20	9.92	2.09	0.58	2.67	3.16	0.42	3.58	6.95	0.61	7.56	10.74	1.17	10.39	53.47
1-12	8.4	4.91	7.26	12.17	1.71	1.30	3.01	3.71	0.28	3.99	7.09	0.88	7.97	10.62	1.11	12.01	49.12
1-13	8.4	2.57	5.91	8.48	1.69	0.50	2.19	3.36	0.33	3.69	6.16	0.65	6.81	10.60	1.34	9.43	57.46
1-14	8.2	1.97	7.25	9.22	1.52	0.91	2.43	3.21	0.24	3.45	5.48	0.77	6.25	10.61	1.23	10.11	56.70
1-15	8.1	1.99	3.61	5.60	2.26	1.48	3.74	3.81	0.49	4.30	2.43	0.10	2.53	10.64	2.65	10.18	60.36
1-16	8.2	2.78	11.82	14.60	1.69	2.10	3.79	3.38	1.54	4.92	6.94	0.72	7.66	10.42	1.57	9.93	47.11
1-17	8.3	2.98	6.94	9.92	2.01	1.97	3.98	3.25	1.67	4.92	8.75	0.88	9.63	10.44	1.28	10.96	48.87

[1]Analyses by Chemistry Dept., Millsaps College

[2]pH values are for H_2O extract

[3]HCl soluble

[4]Na_2CO_3 fusible

TABLE 7. Continued

SAMPLE NUMBER	pH	Al_2O_3 sol.	Al_2O_3 fus.	Al_2O_3 tot.	Fe_2O_3 sol.	Fe_2O_3 fus.	Fe_2O_3 tot.	MgO sol.	MgO fus.	MgO tot.	CaO sol.	CaO fus.	CaO tot.	H_2O^+	H_2O^-	CO_2	SiO_2 + other
1-18	8.3	1.86	7.44	9.30	2.05	0.71	2.76	4.66	1.74	6.40	6.61	0.47	7.08	10.63	1.60	10.63	51.60
1-19	8.3	1.65	5.50	7.15	1.70	1.23	2.93	5.45	0.73	6.18	7.30	0.34	7.64	10.60	1.68	10.62	53.20
1-20	8.4	2.64	3.18	5.82	1.55	0.54	2.09	6.21	0.36	6.57	3.17	0.76	3.93	10.72	1.34	11.17	58.36
1-21	8.4	1.35	7.62	8.97	1.47	1.04	2.51	5.05	0.46	5.51	7.18	0.90	8.08	10.78	1.72	11.16	51.27
1-22	8.5	2.25	8.13	10.38	1.75	0.35	2.10	4.45	0.29	4.74	6.45	0.70	7.15	10.82	1.24	12.76	50.81
1-23	8.4	2.21	10.74	12.95	1.63	0.71	2.34	4.46	0.23	4.69	10.22	0.71	10.93	10.90	1.31	13.95	42.93
1-24	8.4	2.24	9.13	11.37	1.48	1.67	3.15	4.71	0.39	5.10	10.26	0.49	10.75	11.24	2.36	14.15	41.88
1-25	8.4	2.05	7.07	9.12	2.59	2.12	4.71	4.54	1.28	5.82	7.51	1.08	8.65	12.32	2.65	10.88	46.45
1-26	8.2	1.69	5.17	6.86	2.81	4.52	7.33	2.85	0.55	3.40	2.72	0.85	3.57	12.93	6.73	4.53	54.65
1-27	8.1	2.46	8.60	11.06	3.25	3.41	6.66	0.59	2.80	3.39	0.93	1.37	2.30	12.50	3.40	3.07	57.62
1-28	8.2	0.75	10.46	11.21	3.53	1.48	5.01	0.71	0.39	1.10	1.13	0.58	1.71	12.27	4.13	1.92	62.65
1-29	8.4	1.45	6.18	7.63	2.88	1.41	4.29	5.78	0.67	6.45	3.55	0.53	4.08	12.81	8.24	10.29	46.21
1-30	8.2	3.42	8.61	12.03	3.04	2.32	5.36	0.88	0.57	1.45	0.67	0.59	1.26	11.93	3.67	1.43	62.87
1-31	8.3	2.26	8.36	10.62	3.78	2.36	6.14	0.33	0.48	0.81	0.59	0.83	1.42	13.79	13.81	0.80	52.61
1-32	8.0	2.09	4.75	6.84	3.17	1.92	5.09	0.55	0.46	1.01	0.95	0.17	1.12	14.23	11.17	0.98	59.56
1-33	8.3	2.16	4.86	7.02	1.81	1.02	2.83	0.33	0.34	0.67	0.79	0.29	1.08	14.51	6.65	1.31	65.93
1-34	8.1	0.04	5.15	5.19	1.89	1.64	3.53	0.69	0.35	1.04	0.99	0.31	1.30	18.00	5.45	1.20	64.29
1-35	7.9	0.70	8.28	8.98	1.98	1.16	3.14	0.22	0.34	0.56	0.66	0.29	0.95	17.68	4.79	0.65	63.35
1-36	8.1	0.85	2.59	3.44	0.69	2.13	2.82	0.44	0.19	0.63	0.48	0.22	0.70	19.62	0.54	0.53	71.72
2-0	6.6	4.12	8.92	13.04	3.58	1.76	5.34	0.31	0.10	0.41	0.39	0.29	0.68	10.92	4.82	1.30	63.49
2-1	6.5	1.02	10.27	11.29	6.10	1.60	7.70	0.45	0.25	0.70	0.27	0.38	0.65	10.70	4.03	1.31	63.62
2-2	6.3	3.72	9.94	13.66	3.23	0.46	3.69	0.63	0.42	1.05	0.29	0.31	0.60	10.77	3.82	1.21	65.20
2-6	6.1	3.89	11.29	15.18	3.42	0.55	3.97	0.60	0.24	0.84	0.30	0.25	0.55	10.22	2.74	1.59	64.94
2-10	6.5	3.47	11.67	15.14	3.52	0.72	4.24	0.55	0.29	0.84	0.36	0.60	0.96	10.26	2.91	1.10	64.55
2-11	6.5	2.73	11.21	13.94	4.00	3.29	7.29	0.21	0.05	0.26	0.39	0.18	0.57	11.00	2.43	1.46	63.05
2-12	6.5	6.34	9.28	15.62	3.79	3.01	6.80	0.13	0.13	0.26	0.44	0.15	0.59	11.16	3.21	1.30	61.06
2-13	6.8	3.42	5.56	8.98	3.43	3.54	6.97	0.37	0.23	0.60	0.39	0.49	0.88	11.20	3.18	1.32	66.87
2-14	6.8	1.85	8.81	10.69	5.13	2.05	7.18	0.09	0.58	0.67	0.44	0.36	0.80	11.07	3.05	1.28	65.26

TABLE 7. Continued

SAMPLE NUMBER	pH	Al_2O_3 sol.	Al_2O_3 fus.	Al_2O_3 tot.	Fe_2O_3 sol.	Fe_2O_3 fus.	Fe_2O_3 tot.	MgO sol.	MgO fus.	MgO tot.	CaO sol.	CaO fus.	CaO tot.	H_2O^+	H_2O^-	CO_2	SiO_2 + other
2-15	6.7	2.08	12.67	14.75	5.11	0.62	5.73	0.01	0.25	0.26	0.43	0.72	1.15	10.67	2.53	1.40	63.51
2-16	6.8	2.79	10.43	13.22	4.57	1.31	5.88	0.21	0.69	0.90	2.40	0.30	2.70	10.64	2.18	4.18	60.30
2-17	7.2	0.20	6.84	7.04	5.13	1.91	7.04	2.94	0.34	3.28	6.41	0.49	6.90	10.81	2.80	8.48	53.65
2-18	7.7	1.56	8.76	10.34	4.05	1.24	5.29	2.59	0.34	2.93	6.02	0.53	6.55	11.03	2.38	9.39	52.11
2-19	7.6	1.47	7.08	8.55	3.33	0.33	3.66	2.58	0.41	2.99	6.57	0.52	7.09	10.68	2.43	10.79	53.81
2-20	7.6	4.86	6.24	11.10	2.54	0.84	3.38	4.65	0.26	4.91	6.29	0.34	6.63	10.69	3.31	9.30	50.68
2-21	7.6	2.63	10.85	13.48	2.41	1.77	4.18	4.96	0.30	5.26	5.37	0.57	5.94	10.88	2.35	8.99	48.92
2-22	8.0	1.91	10.51	12.42	2.56	0.44	3.00	3.48	1.20	4.68	4.20	3.86	8.06	10.81	4.92	7.57	48.54
2-23	7.8	1.91	11.39	13.30	2.29	0.66	2.95	4.55	0.00	4.55	4.96	0.49	5.45	10.87	2.62	7.81	52.45
2-24	7.7	2.86	7.25	10.11	2.56	0.82	3.38	5.30	0.15	5.45	4.93	0.03	4.96	10.90	2.38	7.82	55.00
2-25	7.4	3.00	5.86	8.86	2.50	1.62	4.12	3.64	0.15	3.79	4.43	0.60	5.03	11.88	2.24	8.98	55.10
2-26	7.7	2.66	7.27	9.93	2.47	0.94	3.41	3.17	0.63	3.80	5.23	0.11	5.34	11.08	2.63	8.17	55.64
2-27	7.9	3.02	7.76	10.78	2.99	1.77	4.76	4.42	0.63	5.05	4.72	0.03	4.75	11.12	2.10	9.18	52.26
2-28	7.8	2.43	8.91	11.34	2.39	0.77	3.16	7.14	0.69	7.83	1.66	0.01	1.67	11.20	1.81	9.01	53.98
2-29	8.2	3.48	7.14	10.62	2.05	0.65	2.70	8.81	0.52	9.33	0.23	0.72	0.95	11.31	2.00	10.19	52.90
2-30	7.8	2.21	13.95	16.16	1.96	1.60	3.56	9.36	0.00	9.36	0.50	0.44	0.94	11.07	1.71	11.58	45.62
2-31	7.7	3.51	8.61	12.12	1.98	0.85	2.83	9.67	0.24	9.91	1.24	0.62	1.86	11.28	2.03	11.30	48.67
2-32	7.8	2.98	15.60	18.58	2.07	0.91	2.98	6.27	0.00	6.27	0.75	0.03	0.78	12.51	1.90	7.28	49.70
2-33	7.5	3.68	12.03	15.71	2.60	1.04	3.64	1.96	1.01	2.97	1.57	0.05	1.62	12.12	2.47	3.41	58.06
2-34	7.7	4.45	8.68	13.13	3.25	0.98	4.23	0.70	0.46	1.16	1.09	0.26	1.35	12.12	4.05	1.85	62.11
2-35	7.8	4.82	8.18	13.00	3.64	0.65	4.29	0.79	0.06	0.85	0.86	0.32	1.18	12.11	3.80	1.81	62.96
2-36	7.2	0.78	4.11	4.89	6.54	1.26	7.80	0.18	0.00	0.18	0.10	0.16	0.26	27.80	1.84	0.42	56.81
3-1	5.9	1.62	9.18	10.80	3.98	1.54	5.52	0.81	0.22	1.03	2.58	0.35	2.93	14.54	2.91	2.90	59.37
3-2	5.7	3.21	10.65	13.86	3.41	1.56	4.97	0.94	0.37	1.31	0.74	0.36	1.10	13.96	4.03	1.61	59.16
3-3	6.3	1.93	11.72	13.65	3.88	1.59	5.47	0.99	0.58	1.57	1.45	0.58	2.03	11.41	2.67	2.24	60.96
3-4	7.3	1.13	6.77	7.90	3.76	2.42	6.18	0.76	0.89	1.65	1.40	0.96	2.36	9.34	2.60	2.01	67.96
3-5	7.8	0.80	6.27	7.07	3.64	2.11	5.75	3.85	0.46	4.31	5.37	0.59	5.96	9.21	1.21	9.42	57.07
3-6	7.6	1.64	7.48	9.12	3.21	1.98	5.19	2.86	0.51	3.37	7.47	0.61	8.08	7.76	1.08	11.07	54.33

TABLE 7. Continued

SAMPLE NUMBER	pH	Al_2O_3 sol.	Al_2O_3 fus.	Al_2O_3 tot.	Fe_2O_3 sol.	Fe_2O_3 fus.	Fe_2O_3 tot.	MgO sol.	MgO fus.	MgO tot.	CaO sol.	CaO fus.	CaO tot.	H_2O^+	H_2O^-	CO_2	SiO_2 + other
3-7	7.3	0.82	8.36	9.18	2.78	1.59	4.37	3.81	0.64	4.45	4.60	0.32	4.92	9.95	1.69	8.76	56.68
3-8	7.9	0.76	6.08	6.84	4.03	2.63	6.66	2.93	0.33	3.26	4.84	0.58	5.42	12.58	1.49	8.48	55.27
3-9	7.8	0.57	8.18	8.75	3.72	0.43	4.15	3.39	0.73	4.12	4.92	0.41	5.33	12.78	1.67	8.90	54.30
3-10	7.6	3.45	6.43	9.88	2.73	2.73	5.46	1.21	0.50	1.71	2.69	0.45	3.14	17.84	9.04	4.12	48.81
4-1	5.9	1.50	10.72	12.22	4.57	1.63	6.20	0.55	0.14	0.69	0.77	0.10	0.87	24.31	16.62	1.31	37.78
4-2	5.7	0.85	10.82	11.67	4.55	1.86	6.41	0.21	0.19	0.40	0.60	0.12	0.72	16.10	13.18	0.70	50.82
4-3	5.5	1.24	10.94	12.18	5.22	2.10	7.32	0.12	0.24	0.36	0.71	0.14	0.85	19.33	4.20	0.73	55.03
4-4	5.3	2.13	7.46	9.59	4.11	1.69	5.80	0.10	0.43	0.53	0.77	0.29	1.06	10.72	10.84	0.75	60.71
4-5	5.5	2.18	3.66	5.84	4.33	2.19	6.52	0.42	0.19	0.61	0.51	0.58	1.09	12.38	12.41	0.85	60.30
4-6	5.4	2.23	4.46	6.69	3.29	2.05	5.34	0.20	0.38	0.58	0.78	0.36	1.14	7.16	3.00	1.09	75.00
4-7	5.6	1.06	8.99	10.05	3.94	2.40	6.34	0.13	0.19	0.32	0.68	0.17	0.85	10.67	3.22	0.71	67.84
4-8	5.9	1.47	7.25	8.72	3.90	2.82	6.72	0.08	0.36	0.44	0.91	0.40	1.31	9.78	7.64	0.91	64.48
4-9	6.0	1.79	9.44	11.23	3.43	2.59	6.02	0.50	0.20	0.70	2.24	0.85	3.09	5.98	3.04	2.52	67.42
4-10	6.9	1.12	8.16	9.28	2.56	3.33	5.89	1.00	0.15	1.15	4.90	0.19	5.09	12.25	2.67	5.63	58.04
4-11	7.2	1.00	6.24	7.24	3.40	3.08	6.48	3.64	0.37	4.01	3.73	2.13	5.86	12.88	7.49	6.73	49.31
4-12	7.2	3.82	7.10	10.92	2.64	2.06	4.70	3.36	0.64	4.00	3.37	0.76	4.13	11.68	16.32	6.12	42.13
4-13	7.1	0.36	8.89	9.25	2.91	3.21	6.12	0.69	0.12	0.81	0.24	0.13	0.37	8.75	5.09	0.91	68.70
4-14	6.9	1.41	11.72	13.13	3.34	2.33	5.67	0.30	0.24	0.54	0.48	0.43	0.91	12.26	18.02	0.67	48.80
5-1	6.9	1.43	8.13	9.56	4.19	3.87	8.06	0.20	0.10	0.30	0.65	0.28	0.93	14.31	4.28	0.74	61.83
5-2	6.8	2.47	5.10	7.57	4.49	5.42	9.91	1.23	0.27	1.50	0.70	0.61	1.31	13.54	3.94	1.87	60.36
5-3	6.5	3.24	12.35	15.59	4.30	3.18	7.48	0.15	0.11	0.26	1.30	0.27	1.57	16.22	5.86	1.25	51.81
5-4	6.3	2.47	10.78	13.25	4.15	4.59	8.74	0.28	0.21	0.49	1.15	0.83	1.98	11.05	5.67	1.25	57.57
5-5	6.7	0.55	9.76	10.31	4.51	2.38	6.89	0.17	0.02	0.19	1.05	0.27	1.32	12.47	2.92	1.03	64.87
5-6	7.1	0.23	1.71	1.94	5.06	4.24	9.30	0.31	0.56	0.87	0.67	0.69	1.36	14.58	8.06	0.89	63.00
5-7	6.4	1.18	1.62	2.80	4.41	4.69	9.16	0.27	0.40	0.67	0.63	0.36	0.99	17.36	9.98	0.82	58.22
5-8	6.3	1.41	2.96	4.37	3.36	4.80	8.16	0.08	0.35	0.43	0.86	0.32	1.18	26.51	6.39	0.91	52.05
5-9	6.2	0.76	5.27	6.03	4.64	4.42	8.86	0.50	0.10	0.60	2.14	0.25	2.39	20.07	10.85	2.52	48.68
5-10	6.1	1.02	2.18	3.20	3.90	0.19	4.09	0.00	0.00	0.00	0.81	0.00	0.81	28.11	9.40	0.48	53.91

TABLE 7. Continued

SAMPLE NUMBER	pH	Al_2O_3 sol.	Al_2O_3 fus.	Al_2O_3 tot.	Fe_2O_3 sol.	Fe_2O_3 fus.	Fe_2O_3 tot.	MgO sol.	MgO fus.	MgO tot.	CaO sol.	CaO fus.	CaO tot.	H_2O^+	H_2O^-	CO_2	SiO_2 + other
6-1	6.2	0.00	8.06	8.06	4.70	3.06	7.76	0.40	0.91	1.31	0.60	0.55	1.15	22.16	3.94	1.27	54.35
6-2	5.7	0.24	9.01	9.25	5.26	2.49	7.75	0.35	0.79	1.14	0.32	0.45	0.77	20.73	11.19	0.92	48.25
6-3	5.9	0.77	11.04	11.81	5.17	2.26	7.43	0.81	0.70	1.51	0.84	0.76	1.60	19.02	9.24	1.33	48.06
6-4	6.0	1.12	9.57	10.69	4.32	2.90	7.22	0.39	0.63	1.02	0.41	0.45	0.86	24.31	16.10	0.98	39.00
6-5	5.9	2.19	13.23	15.42	2.73	2.26	4.99	0.29	0.31	0.60	0.34	0.48	0.82	23.17	12.98	0.86	41.16
6-6	5.9	1.80	9.58	11.38	5.39	2.30	7.69	0.24	0.81	1.05	0.34	0.14	0.48	17.12	10.82	0.78	50.68
6-7	6.0	0.48	10.35	10.83	3.72	2.53	6.25	0.19	0.67	0.86	0.45	0.42	0.87	16.03	9.12	0.83	55.21
6-8	6.1	1.02	11.12	12.14	3.09	2.76	5.85	0.14	0.54	0.68	0.63	0.40	1.03	14.29	10.49	0.76	54.76
6-9	6.1	0.00	9.50	9.50	5.37	1.89	7.26	0.37	0.45	0.82	0.44	0.63	1.07	12.76	4.91	1.07	62.61
6-10	6.0	0.60	5.30	5.90	2.57	2.16	4.73	0.16	0.32	0.48	0.66	0.34	1.00	31.42	5.53	1.07	49.87
7-1	5.3	1.00	13.83	14.83	6.00	3.69	9.69	0.36	0.39	0.75	0.30	1.03	1.33	23.78	7.55	0.87	41.20
7-4	5.6	1.29	12.86	14.15	4.75	2.06	6.91	0.31	0.61	0.92	0.47	0.36	0.83	18.51	4.56	0.83	53.39
7-5	5.5	2.13	14.54	16.67	3.59	1.67	5.26	0.49	0.65	1.14	0.29	0.32	0.61	17.32	4.22	0.83	53.95
7-6	5.5	2.90	10.60	13.50	2.90	2.54	5.44	0.37	0.62	0.99	0.40	0.36	0.76	14.06	3.65	0.90	60.70
7-8	6.0	2.10	10.70	12.80	3.69	1.51	5.20	0.26	0.58	0.84	0.57	0.40	0.97	13.26	2.83	1.07	63.03
7-9	6.5	0.80	3.35	4.15	3.10	2.99	6.09	0.40	0.74	1.14	0.36	0.22	0.58	11.42	1.81	1.15	73.66
7-10	6.4	0.00	8.86	8.86	4.44	1.81	6.25	0.20	0.34	0.54	0.70	0.40	1.10	18.71	2.52	0.87	61.15
7-13	6.4	2.81	8.76	11.57	2.61	1.52	4.13	0.32	0.55	0.87	0.39	0.34	0.73	24.71	7.27	0.86	49.86
10-4	7.1	1.07	10.80	11.87	1.93	1.16	3.09	1.27	0.76	2.03	3.29	0.46	3.75	14.88	5.78	4.91	53.69
10-6	7.6	1.13	5.98	7.11	1.58	0.89	2.47	4.16	0.24	4.40	11.64	0.71	12.17	14.28	4.16	16.24	39.17
10-8	7.3	1.20	6.67	7.87	1.74	1.54	3.28	2.66	0.76	3.42	8.46	0.31	8.77	11.84	12.54	11.01	41.27
10-10	7.5	2.08	7.82	9.90	1.93	1.77	3.70	1.83	0.47	2.30	5.32	0.55	5.87	12.63	1.84	8.07	55.69
10-12	7.6	1.54	8.81	10.35	1.92	1.66	3.58	3.14	1.12	4.26	6.10	0.43	6.53	7.14	9.57	9.37	49.20

TABLE 7. Continued

SAMPLE NUMBER	pH	Al_2O_3 sol.	Al_2O_3 fus.	Al_2O_3 tot.	Fe_2O_3 sol.	Fe_2O_3 fus.	Fe_2O_3 tot.	MgO sol.	MgO fus.	MgO tot.	CaO sol.	CaO fus.	CaO tot.	H_2O^+	H_2O^-	CO_2	SiO_2 + other
10-14	6.1	0.21	10.01	10.22	1.97	1.89	3.86	0.40	1.41	0.81	0.49	0.61	1.10	7.86	11.53	0.92	63.70
10-16	7.4	2.98	7.05	10.03	2.62	1.16	3.78	5.88	0.85	6.73	5.89	1.04	5.80	8.21	11.85	11.53	41.25
10-20	7.7	1.82	4.05	5.87	1.66	1.50	3.16	3.77	0.57	4.34	5.93	0.72	6.65	8.01	7.02	10.28	54.67
10-22	7.4	7.70	7.67	10.37	1.93	1.74	3.67	6.40	0.56	6.96	5.80	0.49	6.29	7.18	4.25	12.03	49.89
10-24	7.6	0.00	7.77	7.77	1.93	1.39	3.32	3.27	0.36	3.63	5.67	0.48	6.15	9.17	1.74	9.22	59.00
11-5	7.5	1.80	10.88	12.68	1.58	2.01	3.59	1.31	0.69	2.00	3.43	0.45	3.88	22.47	2.02	4.61	48.75
11-6	7.7	1.13	10.39	11.52	3.20	1.23	4.43	3.82	1.12	4.94	6.15	0.64	6.79	18.32	1.26	9.00	43.74
11-7	7.7	2.59	8.75	11.34	1.70	1.54	3.24	3.05	1.24	4.29	8.04	0.28	8.32	18.45	1.50	10.86	42.00
11-8	7.6	1.85	9.63	11.48	1.93	1.20	3.13	5.13	0.83	5.96	8.84	0.59	9.43	15.44	1.17	13.54	39.85
11-9	7.5	1.86	10.88	12.74	1.54	1.57	3.11	3.39	1.01	5.40	8.20	0.67	8.87	18.44	1.57	11.01	39.86
11-10	6.6	1.93	12.98	14.91	1.95	1.72	3.67	0.46	0.44	0.90	0.28	0.64	0.92	18.36	3.83	0.63	56.78

TABLE 8. TEXTURE OF LOESS AND RELATED SEDIMENTS

SAMPLE NUMBER	DEPTH (FT.)	ELEVATION (FT. MSL)	MILES FROM BLUFF	Md Ø	Mz Ø	σ_I Ø	Sk_I	K_G	PER CENT Sand	Silt	Clay
AUGER HOLES											
1-1 W	0.0 - 0.9	319[1]	0.1[2]	5.40	6.07	1.96	0.49	1.27	6.3	80.1	13.6
1-5 W	4.2 - 4.8	315	0.1	5.44	5.87	1.57	0.49	1.77	4.0	84.7	11.3
1-7 W	6.2 - 12.1	307	0.1	5.52	6.09	1.60	0.36	1.43	3.0	86.4	10.6
1-15 L	45.0 - 45.2	274	0.1	5.67	5.68	1.20	0.14	1.33	3.9	92.6	3.5
1-24 L	67.0 - 69.0	250	0.1	5.77	5.85	1.23	0.29	1.46	0.9	93.7	5.4
1-29 L	78.0 - 83.0	236	0.1	5.82	5.97	1.36	0.36	1.52	0.9	91.6	7.5
1-30 L	83.0 - 87.0	232	0.1	5.70	6.27	1.89	0.42	1.27	4.2	82.1	13.7
2-0 W	0.0 - 2.0	344	6.1	5.98	6.76	2.20	0.41	0.62	3.5	72.2	24.3
2-2 W	3.2 - 4.2	340	6.1	5.97	6.93	2.03	0.51	0.79	1.8	75.8	22.4
2-7 W	6.2 - 9.0	335	6.1	5.92	6.63	1.83	0.48	1.20	1.6	82.5	15.9
2-14 W	11.3 - 11.6	332	6.1	5.93	6.32	1.64	0.39	1.41	1.3	84.6	14.1
2-17 L	14.2 - 16.1	328	6.1	5.73	5.87	1.24	0.31	1.60	1.7	93.0	5.3
2-24 L	27.0 - 29.0	316	6.1	5.59	5.69	1.39	0.31	1.82	3.2	89.2	7.6
2-25 L	29.0 - 31.0	314	6.1	5.86	5.86	1.42	0.33	1.51	3.5	90.1	6.4
2-26 L	31.0 - 35.0	309	6.1	5.69	5.81	1.39	0.33	1.73	2.0	88.6	9.4
2-27 L	35.0 - 37.0	307	6.1	5.86	6.04	1.31	0.39	1.61	0.3	92.2	7.5
2-28 L	37.0 - 38.5	306	6.1	5.85	6.03	1.33	0.39	1.63	0.8	91.2	8.0

[1]Elevation values for an interval represent the lowest point in the interval, rounded to the nearest foot.

[2]Miles to bluff measured in a due westerly direction.

W = weathered (leached) loess L = "fresh" loess M = loess-"Citronelle" mixture C = "Citronelle"

T = terrace silt

TABLE 8. Continued

SAMPLE NUMBER	DEPTH (FT.)	ELEVATION (FT. MSL)	MILES FROM BLUFF	Md Ø	Mz Ø	σ_I Ø	Sk_I	K_G	PER CENT Sand	Silt	Clay
2-29 L	38.5 - 40.5	304	6.1	5.86	6.05	1.36	0.38	1.62	0.9	90.0	9.1
2-31	42.5 - 44.8	301	6.1	5.27	5.38	1.64	0.31	1.25	16.4	76.9	6.7
3-1	0.0 - 2.0	246	11.8	6.01	6.91	2.08	0.45	0.84	2.0	76.1	21.9
3-3 W	4.0 - 10.0	236	11.8	6.01	6.49	1.72	0.40	1.23	1.8	84.4	13.8
3-4	10.0 - 13.0	233	11.8	5.86	6.02	1.42	0.32	1.67	0.9	89.9	9.2
3-7 L	16.0 - 23.0	223	11.8	5.78	5.78	1.31	0.23	1.98	2.0	90.6	7.4
3-10 M	36.0 - 37.0	211	11.8	5.63	5.84	1.62	0.33	1.36	4.0	81.7	14.3
4-1 W	0.0 - 1.0	261	15.9	6.11	6.96	2.05	0.44	0.93	1.9	78.2	19.9
4-5	5.0 - 5.3	256	15.9	6.10	6.66	1.80	0.41	1.31	1.8	82.9	15.3
4-10 L	8.8 - 13.9	247	15.9	5.91	6.14	1.43	0.37	1.51	1.2	90.0	8.8
4-11 M	13.9 - 14.4	246	15.9	5.92	6.17	1.44	0.38	1.50	1.2	88.8	10.0
4-13 C	15.8 - 18.4	242	15.9	5.34	6.10	2.25	0.45	0.62	22.5	60.5	17.0
4-14	18.4 - 20.0	241	15.9	4.99	6.20	2.45	0.59	0.53	30.9	45.1	24.0
5-1 W	0.0 - 0.8	282	19.7	6.02	6.72	1.90	0.43	1.33	2.1	81.4	16.5
5-3	2.3 - 3.4	279	19.7	6.16	7.00	2.01	0.47	0.82	2.2	76.3	21.5
5-7 M	13.0 - 15.5	267	19.7	6.41	6.91	2.27	0.23	0.53	5.5	59.5	35.0
6-1 W	0.0 - 1.9	316	23.1	5.92	6.86	2.13	0.47	0.81	3.0	73.1	23.9
6-2	1.9 - 5.0	313	23.1	6.06	6.92	2.11	0.42	0.95	3.7	74.6	21.7
7-1	0.0 - 1.9	303	30.0	6.40	6.90	2.26	0.24	0.56	4.8	61.7	33.5
7-5 W	2.9 - 3.8	300	30.0	6.10	6.85	1.96	0.43	1.17	2.2	79.7	18.1
7-7	3.8 - 4.4	299	30.0	5.80	6.22	1.90	0.35	1.40	5.6	78.6	15.8
7-10 M	6.5 - 7.8	295	30.0	5.26	6.31	2.40	0.52	1.01	20.0	63.7	16.3
7-13 C	11.6 - 12.6	290	30.0	2.00	2.50	0.57	0.54	1.42	71.1	15.0	13.9

TABLE 8. Continued

SAMPLE NUMBER	FT. ABOVE BASE	ELEVATION (FT. MSL)	MILES FROM BLUFF	Md ϕ	Mz ϕ	σ_I ϕ	Sk_I	K_G	PER CENT Sand	Silt	Clay
HIGHWAY CUTS											
9-15 L	40.0	305	1.9	5.71	5.79	1.36	0.31	1.86	1.9	89.1	9.0
10-2 C	1.0 - 5.0	198	0.6	1.64	1.60	0.53	0.16	1.60	98.1	1.3	0.6
10-4 M	7.4 - 10.4	205	0.6	5.42	5.73	1.85	0.36	1.08	13.8	72.8	13.4
10-6	13.4 - 16.4	210	0.6	5.33	5.43	1.01	0.24	1.38	3.5	92.7	3.8
10-8	22.4 - 24.4	219	0.6	5.76	5.82	1.39	0.35	1.70	2.3	90.3	7.4
10-10 L	25.4 - 28.4	222	0.6	5.09	5.63	1.28	0.28	2.07	2.7	91.1	6.2
10-12	34.4 - 36.4	231	0.6	5.10	5.66	1.32	0.31	1.83	2.7	91.1	6.2
10-14	37.4 - 40.4	234	0.6	5.12	5.66	1.38	0.27	1.81	2.9	89.7	7.4
10-16	43.4 - 46.4	240	0.6	4.99	5.56	1.38	0.31	1.67	2.8	88.9	8.3
10-20	55.4 - 58.4	252	0.6	5.19	5.98	1.65	0.38	1.38	3.8	82.0	14.2
10-22 W	60.8 - 63.8	258	0.6	5.20	5.89	1.54	0.32	1.45	2.6	87.3	10.1
10-24	66.8 - 67.8	264	0.6	5.52	5.59	1.41	0.30	1.65	3.5	88.9	7.6
11-1	1.0	333	2.7	6.17	6.71	2.37	0.25	0.46	10.2	59.6	30.2
11-2 M	3.0	335	2.7	7.15	7.29	2.17	0.00	0.52	3.8	53.8	42.4
11-3	6.0	338	2.7	6.09	6.91	2.13	0.41	0.56	2.5	71.6	25.9
11-4	7.0	339	2.7	6.40	7.07	2.10	0.35	0.54	2.8	62.4	34.8
11-5 W	9.0	341	2.7	5.64	5.98	1.76	0.37	1.29	5.0	81.1	13.9
11-6	21.0	353	2.7	5.63	5.73	1.27	0.27	1.68	2.8	91.6	5.6
11-7 L	29.0	361	2.7	5.73	5.80	1.37	0.27	1.81	2.6	91.2	6.2
11-8	37.0	369	2.7	5.55	5.57	1.28	0.24	1.85	3.8	90.8	5.4
11-9	45.0	377	2.7	5.48	5.49	1.42	0.25	1.83	5.0	87.8	7.2
11-10 W	53.0	385	2.7	5.71	6.17	1.72	0.42	1.43	3.1	82.7	14.2
12-1 M	0.5	237	0.1	5.99	6.77	2.21	0.39	0.90	4.6	76.6	18.8
12-2 L	8.0	245	0.1	5.70	5.78	1.15	0.20	1.24	1.9	93.7	4.4

TABLE 8. Continued

SAMPLE NUMBER		FT. ABOVE BASE	ELEVATION (FT. MSL)	MILES FROM BLUFF	Md Ø	Mz Ø	σ_I Ø	Sk_I	K_G	PER CENT Sand	Silt	Clay
13-1	L	8.0	108	5.6	5.57	5.69	1.30	0.36	2.04	1.6	91.9	6.5
13-2		4.0	104	5.6	5.54	5.63	1.29	0.33	1.94	2.2	91.7	6.1
14-1	L	1.0	241	0.0	5.68	5.72	1.55	0.23	1.54	5.6	86.7	7.7
14-2		4.0	245	0.0	5.67	5.91	1.42	0.35	1.34	2.6	90.6	6.8
15-1		0.5	201	1.6	5.48	5.48	1.38	0.25	1.87	4.4	89.7	5.9
15-2	L	4.0	205	1.6	5.69	5.93	1.39	0.39	1.34	1.2	91.5	7.3
15-4		12.0	213	1.6	5.56	5.84	1.53	0.40	1.55	3.1	88.0	8.9
16-1	L	0.5	235	3.5	5.64	5.77	1.36	0.35	1.77	1.9	90.4	7.7
16-2		4.0	239	3.5	5.63	5.79	1.34	0.36	2.10	2.0	90.8	7.2
16-3	W	32.0	272	3.5	5.87	6.82	2.01	0.52	1.00	2.1	79.7	18.2
17-1a	M	16.0	335	4.6	5.31	5.32	1.54	0.23	1.23	17.2	76.7	6.1
17-1		19.0	338	4.6	5.13	5.37	1.76	0.43	1.07	22.7	66.4	10.9
17-2	L	31.0	350	4.6	5.68	5.80	1.40	0.31	1.69	2.7	90.5	6.8
17-3	W	45.0	364	4.6	5.69	6.24	1.73	0.50	1.42	1.9	84.0	14.1
18-1	M	4.0	269	7.0	5.46	5.69	1.74	0.35	1.26	8.5	79.5	12.0
18-2	L	9.0	274	7.0	5.57	5.67	1.41	0.32	1.72	2.8	89.2	8.0
19-1	M	4.0	227	15.3	6.19	6.92	2.15	0.35	0.77	4.3	72.6	23.1
19-1a		5.0	229	15.3	5.81	6.73	2.18	0.47	1.04	3.6	76.4	20.0
19-2	L	6.0	239	15.3	5.78	5.92	1.36	0.33	1.69	1.8	90.5	7.7
19-3	W	21.0	244	15.3	5.90	6.22	1.57	0.38	1.40	2.0	86.0	12.0
20-1	W	5.0	247	29.3	6.20	6.92	2.13	0.36	0.95	2.3	76.1	21.6
21-1	W	7.0	324	30.4	6.54	7.18	1.98	0.33	0.99	1.4	77.6	21.0

TABLE 8. Continued

SAMPLE NUMBER	FT. ABOVE BASE	ELEVATION (FT. MSL)	MILES FROM BLUFF	Md ϕ	Mz ϕ	σ_I ϕ	Sk_I	K_G	PER CENT Sand	PER CENT Silt	PER CENT Clay
22-1 M	7.0	342	32.6	6.10	6.98	2.01	0.48	1.12	1.2	79.8	19.0
G-1	12.0	241	0.4	5.78	5.91	1.16	0.31	1.43	1.2	94.3	4.5
G-2	5.5	233	0.4	5.68	5.80	1.27	0.33	1.73	2.0	92.2	5.8
G-3 L	4.0	279	2.1	5.66	5.77	1.31	0.33	1.69	2.2	92.0	5.8
G-4	7.0	236	0.1	5.81	5.95	1.14	0.25	1.27	1.3	94.3	4.4
G-5 T	3.5	233	0.1	5.29	6.35	2.38	0.53	0.63	15.8	62.7	21.5
LM-3 T	3.5	176	5.6	5.61	5.65	1.51	0.45	1.73	5.3	83.9	10.8
LM-4 L	3.0	277	2.3	5.52	5.61	1.44	0.31	1.77	4.4	88.5	7.1
LM-5	4.0	258	1.0	5.46	5.65	1.50	0.36	1.66	4.4	88.6	7.0
LM-6 T	5.0	237	4.6	5.38	5.52	1.41	0.37	2.05	4.9	85.7	9.4
LM-7 L	4.0	211	4.8	5.60	5.73	1.51	0.30	1.52	4.0	88.4	7.6
LM-8 T	4.0	227	5.0	5.37	5.40	1.27	0.30	2.11	3.8	89.8	6.4
LM-9 L	4.0		2.7	5.90	6.24	1.57	0.39	1.51	1.8	85.2	13.0
LM-11 T	5.0		2.5	4.94	4.98	1.41	0.47	1.43	18.5	75.7	5.8

PYROPHYSICAL (CERAMIC) AND PLASTIC PROPERTIES OF MISSISSIPPI LOESS

The Mississippi Geological Survey contracted for ceramic and plastic tests of selected loess samples with Mr. T. E. McCutcheon, Ceramic Engineer, of Atlanta, Georgia. The results of these tests are listed in Tables 9 and 10 below. In addition, Mr. McCutcheon made the following general comments on the samples.

The seven samples of loess from Warren County represent several types of this material. They may be briefly described as being plastic, semi-plastic and non-plastic as to their working properties and red burning and buff burning within a considerable range of firing temperatures. In the testing procedure a blend (50-50) was made (samples 4 and 5) combining two samples having extreme properties as to plasticity and fired color values.

Sample 4, *bar mark MGS* 4—NW.¼, NE.¼, NE.¼, Sec.9, T. 16N., R.4E., Warren County, Mississippi.

This clay does not seem to be typical of the loess inasmuch as it is very plastic, has unusually high dry strength and drying shrinkage and cracks on burning. The clay has characteristics of the brown loam or the alluvium. It has a good firing range between cones 2 and 6 and burns to a bright red color with little alteration in pyrophsical properties. The addition of non-plastic material such as the non-plastic loess and the semi-plastic loess or calcined clay would likely improve the clay making it desirable for use in the manufacture of many heavy clay products.

Sample 5 *bar mark MGS* 5—NW.¼, NE.¼, NE.¼, Sec.9, T. 16N., R.4E., Warren County, Mississippi.

The clay, if it could be considered as such, is more like a silt. It is void of claylike plasticity and extrusion properties except under extreme pressure. In testing, only two test bars could be made which were used for obtaining a limited amount of data. The sample is similar to Nos. 7, 9 and 13. On burning, Sample 5 retains its buff to olive color and its high absorption values except at cone 8 when it becomes vitreous.

In the usual clay products field, Sample 5 has limited uses if considered as the sole constituent of the product. Its non-plastic value, its buff burning color, and its refractory characteristic make it valuable for use as a blend with red and buff burning clays in producing heavy clay products.

The blend of the samples was made to bring into focus the possibility for use of the two clays which otherwise would have very limited possibilities. The proportion, 50% of each, was arbitrarily determined as it was obvious during the testing that each of the two clays could be benefited by the addition of any proportion of the other.

The blend, 50% each of Samples 4 and 5, has normal plastic and drying properties for uses in extruded clay products. On burning, its best development would be between cones 2 and 4. A greater or lesser proportion of each clay to the other would likely result in burned colors from buff to red over a longer temperature range.

Samples 7, 9, 13, *bar marks MGS* 7, *MGS* 9, *MGS* 13—The location of 7 and 9 is NW.¼, NE.¼, NE.¼, Sec.9, T.16N., R.4E., Warren County, Mississippi. The location of Sample 13 is NE.¼, SW.¼, SE.¼, Sec.28, T.17N., R.4E., Warren County, Mississippi.

These clays are in the same category as Sample 5 having poor plastic and extrusion properties and burning to buff colors with high absorption values within the usual heavy clay products temperature range. They should be considered for use as a blending material with more plastic clays as suggested with Sample 4 or other available clays.

Some manufacturers of high grade brick and kindred products who are using white to buff burning plastic clays as their principal raw material and are making them suitable for use in the manufacture of heavy clay products by adding sand and calcined clay could benefit from the use of the natural buff burning loess in proportions relative to the product and need.

Samples 3 *and* 15, *bar marks MGS* 3 *and MGS* 15—The location of Sample 3 is NW.¼, NE.¼, NE.¼, Sec.9, T.16N., R.4E., Warren County, Mississippi. The location of Sample 15 is NE.¼, SW.¼, SE.¼, Sec.28, T.17N., R.4E., Warren County, Mississippi.

The two clays are semi-plastic. It is possible that they can be extruded in commercial practice. The addition of sodium carbonate (¼ of 1%) increases plastic and extrusion properties. Excess water for this purpose is questionable. There are commercial additives which could be used to make these two clays suitable for carefree extrusion. In some recent practices very extreme pressure is used to extrude semi- to non-plastic claylike materials. The drying shrinkage and tendency to warp on drying of the two clays are not appreciable.

On burning in the range of cones 2 and 4, Sample Nos. 3 and 15 have very attractive dark-red to reddish brown colors. Their total shrinkage values and absorption values as well as their strength place these clays as suitable for face and common brick and with the addition of more plastic clays or possible chemical additives they could be used for various hollow ware such as structural tile, fireproofing, conduit and drain tile.

The other loess clays could likewise be adjusted as to the use of plastic clays and non-plastic clays to produce most any usual heavy clay product.

Table 9. Pyrophysical properties of Mississippi loess

Sample No.	Bar No.	Tempt. °F.	Cone No.	Total Lin. Shrinkage in %	Absorption in %	Modulus of Rupture in lb./sq. in.	Color	Remarks
3	MGS 3	2124	2	3.5	14.30	1165	R. Brown	
do.	do.	2167	4	9.0	4.25	2520	do.	
do.	do.	2232	6	11.0	2.15	4380	Brown	Glazed
do.	do.	2305	8	9.5	0.00	2670	Brown	Glazed
4	MGS 4	2124	2	12.3	11.68	2360	Red	Cracked
do.	do.	2167	4	12.5	9.99	3700	do.	do.
do.	do.	2232	6	13.5	7.15	2520	do.	do.
do.	do.	2305	8	15.0	0.00	4220	R. Brown	do.
5	MGS 5	2124	2	N.D.	34.20	N.D.	Buff	
do.	do.	2167	4	do.	30.10	do.	do.	
do.	do.	2232	6	do.	21.20	do.	Lt. Olive	
do.	do.	2305	8	do.	1.10	do.	Olive	
50% 4 & 5	MGS 4-5	2124	2	4.5	20.50	970	Lt. Brown	
do.	do.	2167	4	12.5	11.34	1850	Brown	
do.	do.	2232	6	11.5	0.00	3740	Dk. Olive	Overburned Glazed
do.	do.	2305	8	N.O.	N.O.	N.O.	Dk. Olive	Overburned Glazed

Table 9.—(Continued)

Sample No.	Bar No.	Tempt. °F.	Cone No.	Total Lin. Shrinkage in %	Absorption in %	Modulus of Rupture in lb./sq. in.	Color	Remarks
7	MGS 7	2124	2	1.5	25.70	510	Buff	
do.	do.	2167	4	4.0	16.65	2182	Buff	
do.	do.	2232	6	N.O.	0.00	N.O.	Olive	
do.	do.	2305	8	9.5	0.00	N.O.	Olive Gray	Overburned Glazed
9	MGS 9	2124	2	0.5	31.40	1680	Buff	
do.	do.	2167	4	4.0	19.60	2420	Buff	
do.	do.	2232	6	12.0	0.00	4150	Olive	
do.	do.	2305	8	10.0	0.00	N.O.	Olive Gray	Overburned Glazed
13	MGS 13	2124	2	0.5	31.90	1210	Lt. Buff	
do.	do.	2167	4	0.7	27.40	1670	Lt. Buff	
do.	do.	2232	6	9.0	12.55	1840	Lt. Olive	
do.	do.	2305	8	13.0	0.00	3380	Olive	
15	MGS 15	2124	2	8.5	11.60	1420	Dk. Red	
do.	do.	2167	4	12.0	5.08	2280	Choc. Red	
do.	do.	2232	6	12.5	2.77	3400	R. Brown	
do.	do.	2305	8	12.0	0.00	3040	Brown	Glazed

Table 10. Dry and plastic properties of Mississippi loess

Sample No.	3	4	5	50% 4 & 5	7	9	13	15
Lab. Bar No.	MGS 3	MGS 4	MGS 5	MGS 4 & 5	MGS 7	MGS 9	MGS 13	MGS 15
Water of Plasticity Wet Basis in %	18.10	17.55	17.00	17.10	19.20	17.30	18.25	19.20
Water of Plasticity Dry Basis in %	22.10	21.30	20.40	20.50	23.70	20.95	22.40	23.60
Linear Drying Shrinkage in %	0.5	7.0	0.0	3.0	0.2	0.3	0.0	3.0
Modulus of Rupture in lbs./sq. in.	480	933	221	555	365	255	218	690
Color — dry bar	Dk. Tan	Brown	Lt. Tan	Yellow Brown	Lt. Tan	Lt. Tan	Lt. Tan	Gray Brown
Plasticity	Poor*	Good	Void**	Good	Poor**	Poor*	Poor*	Fair
Extrusion	Poor*	Good	No**	Good	Poor**	Poor*	Poor*	Fair
Warpage	No	Slight	No	No	No	No	No	No

Note* Sodium Carbonate and excess water added

Note** Extrusion impractical with excess water and addition of Sodium Carbonate

PULMONATE GASTROPODS (SNAILS) IN THE LOESS

Mr. Leslie J. Hubricht of Meridian, Mississippi, has contributed to this investigation by identifying 21 pulmonate gastropods which the Millsaps students dug from the loess. As intimated in Acknowledgments, he is an authority on living, air breathing gastropods in the southeastern United States. Some of these snails live today, especially in gardens and in damp places.

The snails Mr. Hubricht identified were extra specimens which had been collected for radiocarbon dating of six of the specific zones along U. S. Highway 61, as shown in Figure 43. Specimens from two other zones were collected from the Redwood area to the north (*cf.* fig. 2).

All of the gastropod shells were large because they could be crushed and cleaned for radiocarbon dating with greater ease than small shells. Consequently, the genera and species listed in the chart below are not representative of the snail population, either numerically or stratigraphically, or from the standpoint of their size.

On the chart (tab. 11) the pulmonate gastropods are listed by (1) genus, (2) species, (3) range today in the United States, (4) nearest living specimens Mr. Hubricht collected, (5) footage and zone where the specimens were dug along U. S. Highway 61, and the zones of loess near Redwood where the last two suites were obtained. Radiocarbon dates of the snails are indicated.

Table 11.—Fossil Gastropods in Mississippi Loess

				U. S. HIGHWAY 61						REDWOOD	
				Footage 12,445		Footage 20,600	Footage 23,700		Footage 29,100	Sample Station 8, Figure 2.	
GENUS	SPECIES	RANGE IN U. S.	NEAREST LIVING SPECIMENS	Zone 7 bottom	Zone 9 top	road level	road level	top of cut	base loess	near base	near top
Allogona	*profunda*	central & northern	N. E. Alabama	X	X		X	X	X		X
Anglospira	*alternata*	central & northern	N. Ala. & Tenn.	X	X	X	X	X	X	X	X
Cionella	*morseana*	Appalachians	N. E. Alabama							X	
Discus	*patulus*	eastern U. S.	hills of Miss.	X	X		X	X			
Haplotrema	*concavum*	eastern U. S.	hills of Miss.	X	X	X	X	X	X		
Helicina	*orbiculata*	southern U. S.	hills of Miss.					X			X
Hendersonia	*occulata*	northern U. S.	Iowa & Smokies		X			X			
Mesodon	*clausus*	central & southern	hills of Miss.		X			X			X
Mesodon	*inflectus*	eastern U. S.	Mississippi	X	X	X	X	X	X	X	X
Mesodon	*thyroidus*	E. U. S. floodplains	Yazoo basin				X				
Mesodon	*zaleus*	central U. S.	N. W. Alabama	X	X		X	X	X		X
Mesomphix	*capnodes*	southern U. S.	hills of Miss.				X				
Stenotrema	*bartatum*	middle to northern	N. E. Alabama	X	X		X	X	X	X	
Stenotrema	*fraterna*	central & northern	Tennessee	X	X		X	X		X	
Stenotrema	*leai alicia*	E. U. S. to Canada	Mississippi			X					
Stenotrema	*stenotrema*	central & southern	hills of Miss.			X	X	X	X	X	X
Succinea	*ovalus*	northern floodplains	Memphis, Tenn.					X			X
Triodopsis	*fostori*	Mississippi Valley	hills of Miss.	X	X			X	X	X	
Triodopsis	*obstricta*	central U. S.	northern Ala.				X	X	X	X	
Triodopsis	*vulgata*	northern Alabama	Lauderdale, Miss.	X	X			X			X
Ventridens	*demissus*	central & southern	hills of Miss.	X	X		X	X	X		X
		Radiocarbon Age		22,600 ± 800 years B.P.	19,200 ± 420 years B.P.	22,600 ± 700 years B.P.	21,270 ± 440 years B.P.	18,640 ± 300 years B.P.	23,550 ± 750 years B.P.	20,500 ± 600 years B.P.	18,200 ± 500 years B.P.

The above study indicates that (1) most of the snails are living species, (2) some of them live in Mississippi, (3) many live in the loess hills, (4) some are relict species in Alabama and in Mississippi (5) some live today in the relative cooler southern Appalachians and (6) many live in the cooler upper Mississippi Valley.

Mr. Hubricht's identifications thus indicate that both southern and northern snail fauna were living on the Vicksburg hills during loess deposition. This mixture was possible if one considers that those snails which preferred cooler weather were dormant during the warm summers and that those which liked warmer weather best were dormant in the cooler winters.

Lastly, Mr. Hubricht's work suggests that there are differences in genera and species sufficient to warrant systematic collecting and identification. Such a biostratigraphic investigation could provide the basis for a good masters problem, or possibly for a doctoral dissertation.

FORESTS OF WEST CENTRAL MISSISSIPPI AS AFFECTED BY LOESS[1]

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ABSTRACT

Six forest communities in west central Mississippi have been sampled for floristic composition. Communities were on thick loess, thin loess, non-loessal upland, and non-loessal creek bottamland. At each community, physical and weather data were taken in an attempt to delimit some environmental factors controlling these forest communities. It was found (1) that the communities on deep loess and creek bottom non-loess were most closely related, (2) that these communities were quite different from the communities of the region as described in the literature, and (3) that the principal environmental factor delimiting the communities is availability of water.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of the late J. B. Price and of C. E. Cain in chemical aspects of the problem, and Richard R. Priddy and J. O. Snowden, Jr., in geological aspects. The U. S. Forest Service cooperated by allowing use of areas in Bluff Experimental Forest and in Bienville National Forest northeast of Vicksburg. Mr. A. W. Johnson, U. S. Forest Service, was particularly helpful in locating suitable areas for study. The Civitan Club and the Jackson Council Boy Scouts of America, kindly allowed use of the Kickapoo Boy Scout Camp Area. The Blake family of Vicksburg, Mississippi, cooperated by allowing study of part of Blakely Plantation.

INTRODUCTION

PRELIMINARY STATEMENT

In most places the bedrock hills overlooking the east edge of the Mississippi Alluvial Plain are blanketed by deposits of intimately mixed silt, some clay, and a very small amount of

[1]This project was supported in part by National Science Foundation Grant EO/3/43-2330.

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fine sand. This windblown material is called loess. Its weathering produces a loessal soil known as Memphis silt loam.

The floristic communities supported by the loessal soil vary with the thickness of the soil and the availability of water. Studies from September 1960 through June 1963 of floristic communities on (1) thick loess, (2) thin loess, (3) non-loessal uplands, and (4) non-loessal creek bottomlands showed, further, that the assemblages on thick loess and creek bottom non-loess were most closely related. The investigation also proved that the communities are somewhat different from those described in the literature before 1900, and that the controlling factor delimiting the flora is availability of water.

GEOLOGICAL SETTING

In order to understand the development of loessal soil it is necessary to comprehend (1) the extent of deposition of the loess, (2) its composition, origin, and deposition, and (3) the weathering processes which have converted loess to loessal soils. These matters are treated in great detail by Snowden and Priddy (1968), in the first part of this Bulletin.

Extent of Loess Deposition

The loess and loessal soils of west central Mississippi are but a part of the vast belt of subdued highlands east of the Mississippi Alluvial Plain, a belt which extends from West Feliciana Parish, Louisiana, north to the Mississippi River bluffs in Wisconsin. Branches of the belt cap the low highlands overlooking some of the tributaries of the upper Mississippi River.

One of the best developments of the loess is in the Vicksburg area where sharp bedrock ridges are capped by four to five blankets of the material separated by poorly developed to well developed ancient soils termed regoliths or paleosols. The several deposits of loess vary in color and in degree of weathering. However, as their ultimate weathering product is loessal soil the loess blankets are treated as a unit in the discussion of the floristic communities developed on the loessal soils.

The loess and loessal soils are thickest on the hilltops in the part of the loess belt adjacent to the Alluvial Plain. The material blew out of the vast Mississippi Alluvial Plain which had been half-filled with glacio-fluvatile material brought in intermittently by the rivers comprising the Mississippi River System during Pleistocene glaciation.

AREAS OF THICKEST LOESS

As a consequence the loess may attain thicknesses of 100 to 125 feet on ridgetops overlooking the plain. These accumulations have thus increased the relief of the area on a miniature scale, producing a rugged topography where ridgecrests were heightened faster than the narrow valleys separating the ridges could be filled. Physiographically, the area has an odd combination of features suggesting early youth, late youth, and early maturity.

At Vicksburg and at Natchez to the south and at Yazoo City to the northeast, the loess may be examined readily in roadcuts and in river bluffs, in a belt up to ten miles in width. Today the loess and the overlying loessal soil can be seen best in cuts along U. S. Highway 61 east and northeast of Vicksburg and along Interstate 20 east of Vicksburg. Nearly vertical roadcuts 70 feet in depth are common and hand augering and power drilling has indicated additional subsurface beds of loess which provide cumulative thicknesses of 100 to 109 feet.

In the Vicksburg area loessal soils have developed to a thickness of 2 to 5 feet on the hilltops and to a thickness of 5 to 10 feet in the narrow valleys which have received contributions of loess and loessal soils through rainwash and gravity slump.

AREAS OF THIN LOESS

Further to the east the loess thins and may be absent on some hilltops. Thus, 20 miles east of Vicksburg the loess blankets can not be differentiated and the weathered windblown deposits have a thickness of only 15 to 30 feet.

On ridgecrests hand auger holes show alternating beds of weathered loess, poorly developed soils, and well developed loessal soils. Hillsides are well clothed with loessal soils, the result of rainwash and slump. Valleys are half-filled with loessal soils, the result of loess contributed through rainwash and some clays, silts, sands, and gravels eroded from pre-loess topography to the east.

The topography is thus one of lesser relief than in the hills overlooking the Alluvial Plain to the west. Hillcrests are broader, the hillslopes are gentler, and the valleys are well developed.

Further east, in the vicinity of Jackson, some 50 miles from Vicksburg, roadcuts and excavations for buildings show loessal soils of 2 to 3 feet in thickness capping a few broad low hills. At this east margin of the loess belt there is no trace of unweathered loess.

Composition, Origin, and Deposition of Loess

As intimated, loess is a mixture of silt, clay, and fine sand which, in the area under consideration, was blown out of the Mississippi Alluvial Plain and deposited on the down-wind hills.

One of the best over-all descriptions of loess is that of Longwell, Knopf, and Flint (1960) in a textbook for students in first year geology:

> What has become of the great quantities of fine material removed from land surfaces by deflation? Part of the answer is given by the peculiar yellowish, fine-grained sediment that covers vast areas in Asia, Europe, and North and South America. Typically it has no horizontal stratification, like that in ordinary sedimentary formations, but occurs in a single massive layer, 20, 50, or even more than 100 feet thick. On the other hand, it is cut by nearly vertical surfaces that divide the deposit into rough columns; for this reason it has the remarkable property of forming high bluffs along valley sides in spite of its soft, earthy character (Fig. 153). This sediment, so similar in widely separated continents, is known by the German name *loess* (lus).
>
> Although loess is exceedingly fine grained, examination with a powerful microscope reveals that a large proportion of the material is not decomposed but consists of fresh, sharp-cornered particles of feldspar, quartz, calcite, mica, and numerous other minerals mingled with clay. It is evident, therefore, that much of the material was ground up mechanically, and that the particles thus formed were not affected by chemical weathering before their deposition. Shells of land snails and bones of land animals are found in the deposits. Moreover, loess forms a blanket of variable thickness, covering older hills and valleys of very irregular surfaces. The wind is the only known agent that could deposit in this way sediments that are uniformly fine grained. General lack of stratification is to be expected in wind-laid silt, since the deposit at any time is irregular, and after deposition it is worked over with the underlying sediments by rain, frost, worms, and growing plants. Slender vertical tubes that are common in loess appear to represent the stems and roots of successive generations of plants that were buried by the accumulating sediment.

Except for a very few items the above description applies very well to the Vicksburg area loess. Differences are as follows:

(a) The loess does show some stratification but it must be admitted that stratification is more a matter of blanket deposition, reflecting the several intervals of outwash in the Plain.

(b) The blankets show minor layering as wind deposition had been interrupted, a layering which is indicated by the etching of beds as roadcuts progressively weather.

(c) Only a little calcite is present in the unweathered Mississippi loess. The angular carbonate fragments are chiefly dolomite from the dolomitic terrain of the upper Mississippi Valley.

Chemical and textural examinations by Snowden and Priddy (1968) show other evidence that the loess is derived from the outwash of glacial debris from the upper Mississippi Valley where continental glaciers dumped masses of sedimentary, igneous, and metamorphic rocks. These appear in the unweathered sample as mineral fragments, which, in the order of their abundance, are: quartz, feldspars, dolomite, calcite, clay minerals, and about 2 per cent heavy minerals.

Weathering Processes Which Produce Loessal Soils

Mostly through chemical weathering and a little physical weathering many of these constituent minerals alter readily. Being of silt, clay, or fine sand size some are immediately soluble, others are attacked by hydration and hydrolysis, and others are subjected to carbonation which quickly readies them for solution. In the present humid climate of Mississippi these processes are accelerated and it is reasonable to believe that they were equally active during mild glacial summers and during the prolonged mild interglacial intervals.

Analyses show that the stages in conversion of loess to loessal soil were as simple as today because some of the paleosols appear to have developed the same C, B, and A horizons noted in the most recent loessal soil. The ultimate product is Memphis silt loam on the thick loess, Loring silt loam on thinner loess, and Grenada silt loam on very thin loess. The little altered quartz fragments produce the texture, feldspars supply potash and soda, dolomite and some ferromagnesian "heavies" are responsible for the lime and magnesia, and iron from the ferromagnesians has produced the tan to brown colors.

STATEMENT OF THE PROBLEM

The loessal uplands typically support dense hardwood forests. This growth differs from the upland forests to the east by the near absence of the pines so characteristic of the latter. Less superficial examination quickly indicates an almost total floristic difference between the forest of the loessal uplands and the forests of non-loessal uplands to the east.

One purpose of the present study has been to determine the composition of some relatively undisturbed plant communities on (1) thick loess, (2) thin loess (or soil derived from the mixing of weathered loess with the substrate), and (3) clay soils which had received no loess and which are designated non-loess in this study.

Another purpose has been to attempt to characterize those factors responsible for the gross differences in community composition. The factors which have been considered in this study are those which appear most likely to be effective — climate, mineral nutrients of the soils, pH of the soils, and moisture coefficients of the soils.

Selection of Sample Areas

In order to pursue the investigation, stations were selected for intensive study: (1) in an area of thick loess, (2) in an area of thin loess, (3) in an area of upland non-loess, and (4) in an area of bottomland non-loess. They are located on the map, Figure 1, and described as follows:

AREA OF THICK LOESS (as at Vicksburg)

The stations sampled in this region were (1) a part of Blakely Plantation, about 10 miles north of Vicksburg in the northeast corner of Irregular Section 15, Township 17 N., Range 4 E., Warren County, Mississippi, and (2) a portion of the Bluff Experimental Forest Station, U. S. Forest Service, near Oak Ridge, Section 28, Township 7 N., Range 5 W., Warren County, Mississippi, about 20 miles northeast of Vicksburg.

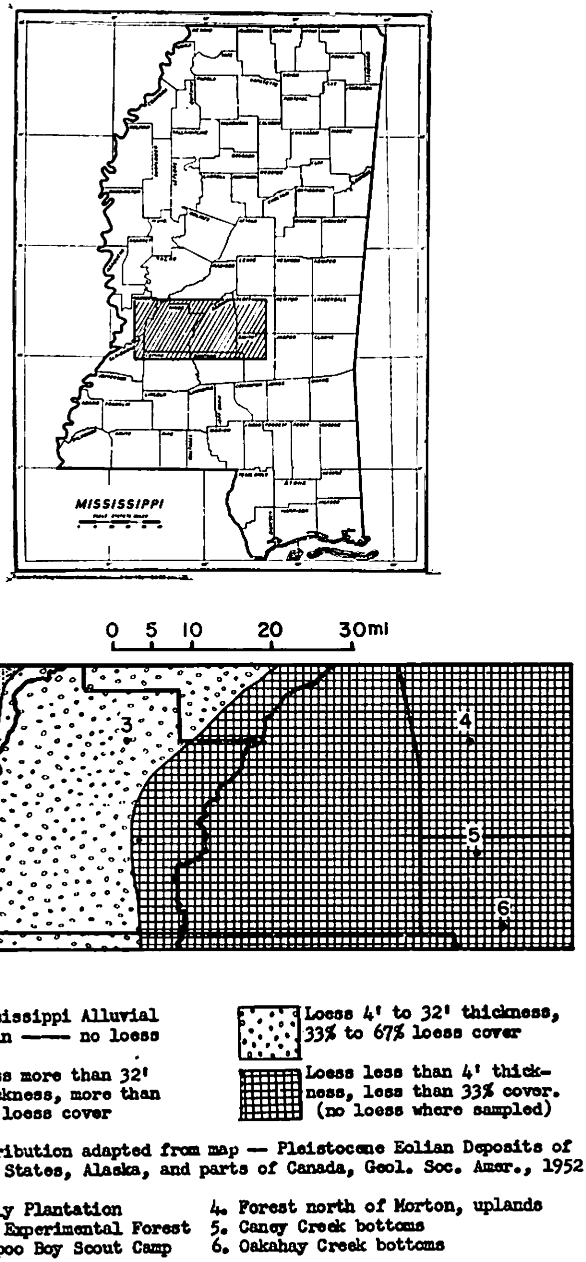

Figure 1.—Map showing distribution of loess and six sampled areas, west central Mississippi.

AREA OF THIN LOESS (as at Camp Kickapoo)

In the present study, the forest community taken as a sample of the shallow loess type was located within the Kickapoo Boy Scout Camp in north central Hinds County about four miles north of Clinton, Mississippi, Township 17 North, Range 1 West, Section 31. It lies in a transition zone of the Jackson Prairie Region and the South Central Plateau. The surface soil is brown loam of loess origin modified by the underlying Jackson clays (Lowe, 1921). The soil of the ravine which was sampled was a sandy brown loam.

AREA OF UPLAND NON-LOESS (as in Scott County)

The particular area discussed in this section lies on a fairly level, poorly drained upland. The soil is entirely non-loessal in origin and is composed of mixed clay, silt, and gravel. It lies near the southern margin of the vegetational area termed alternatively the Central Prairie Region (Hilgard, 1860), the South Central Region (Dunston, 1910), and the North Central Plateau (Lowe, 1921). The sampled area is located approximately five miles northeast of Morton, Mississippi, in Bienville National Forest, Section 31, Township 7 N, Range 7 E, Scott County, Mississippi.

AREA OF BOTTOMLAND NON-LOESS (as in Smith County)

Two forests located in creek bottomlands outside the region of direct influence of loess were sampled. One was on the east side of Oakahay Creek approximately three miles northwest of Raleigh, Smith County, Mississippi, Township 3 North, Range 7 East, Section 33. The other was on the north side of Caney Creek approximately four and one-half miles south of Pulaski, Smith County, Mississippi, Township 4 North, Range 7 East, Section 8. These bottoms were similar in that both were well drained and evidently rarely flooded. Neither showed evidence of standing pools of water characteristic of southern swamps.

PREVIOUS INVESTIGATIONS

The region of loess and loessal soils was recognized early in the development of Mississippi as an agricultural belt of considerable fertility. The most reliable descriptions of its floristic communities are found in the accounts of Wailes (1854), Harper (1857), Hilgard (1860), Dunston (1910), and Lowe (1913, 1915, 1921, and 1923). These men had been commissioned at various times to report on the geology and agriculture of the State. They were well-schooled, were keen observers, and were meticulous in recording their observations but there are sometimes wide divergences in their accounts.

The differences can be attributed to changing flora as a result of nearly 200 years of human occupation which caused (1) the virtual disappearance of some forest species due to overcutting, (2) natural but selective reforestation of farmlands which had been abandoned, and (3) purposeful propagation of some species where specialized forests were desired. Therefore this investigation had to take into account surprising changes in flora. These changes also made the selection of sites for study difficult because truly virgin woodlands no longer exist and apparent long established forests often proved to be former farmlands.

In the following historical discussion of the forests of the four areas selected for study care has been taken, where possible, to compare the forests prior to 1900 with those of the post 1900 interval.

FOREST COMMUNITIES ON THE THICK LOESS (as at Vicksburg)

The region of loess and loessal soils was recognized early in the development of Mississippi as an agricultural belt of great fertility. Hilgard (1860) rated this loam as the best in the State despite what he thought was its tendency to erode rapidly. Not having many roadcuts or excavations in which to observe the several loess blankets which accentuate the hills he had concluded, falsely, that the area was well dissected by stream action. But he was correct when he stated that it was well drained and had a peculiar topography of great relief on a minute scale. Some of the apparent dissection is historical, for unimproved roads, through travel and yearly grading, have been reduced to levels 20 to 30 feet below the original land surfaces, only a little deeper than in the days when Hilgard travelled them.

Early accounts of the vegetation of Mississippi refer to the loess hills generally, or if they are more specific, they refer to the area extending from just north of Vicksburg to Natchez.

Hilgard (1860) spoke of these hills as comprising the southern river counties (Wilkinson, Adams, Franklin, Jefferson, Claiborne, and Warren), where there were two types of forest on two kinds of soil.

The one soil Hilgard described as a light calcareous loam silt covering the main body of the hills and being bared by erosion on the sharper, narrow ridges. This soil is to be identified with slightly weathered loess in the area of thick loess. The other, to the east, was a brown clayey loam covering the surface of level or gently undulating uplands where the loess is deeply weathered. This belt is identified as the area of thin loess.

It was soon evident that plant communities supported by the thick mantle of loess were sufficiently different from those of adjacent areas to attract attention from the early settlers and early scientists.

Wailes (1854) observed that the umbrella tree (*Magnolia tripetala*) and *Castanaea pumila* were confined to the belt of thicker loess and that sassafras trees, 3 to 4 feet in diameter, were being cut to provide shingles. Similarly, huge white oak were used in wagon making and in fashioning baskets for cotton picking, and that the larger basswood (*Tilia* spp.) were felled to obtain the inner bark for shredding to make tobacco ties.

A few years later, Harper (1857) noted that the area of thick loess supported extraordinarily large trees. He used their size to support his contention that the loess soils were unusually fertile.

Hilgard (1860) then observed that the soil on thick loess supported, in addition to the species already listed, poplar, (tuliptree), sweet gum, mulberry, and honey locust. In some places basswood and gum occupied whole areas. But Hilgard regarded cane as the plant most indicative of this soil type, and considered the tuliptree to be the principal indicator of the highly calcareous soil.

Many years later Dunston (1910) reported that the original forests of the loess hills contained only hardwoods. He listed the principal commercial species as white oak, yellow poplar (tuliptree), ash, hickory, sweet gum, magnolia, beech, tupelo gum, and walnut. By the time Dunston wrote (1910), at least half the area contained a mixture of loblolly and shortleaf pines with hardwoods; while old fields were usually occupied by pine to the exclusion of merchantable hardwoods. He stated that the reproduction of better species was excellent, with ash, sweet gum, water oak, and hickory especially abundant.

Then in 1913, Lowe listed the following trees as prominent in the loess forest: *Quercus alba, Q. velutine, Q. prinus* (probably *Muehlenbergii*), *Q. rubra L.*(?), *Q. aquatica* (*nigra*), *Q. Michauxii, Magnolia grandiflora, M. cordata, M. macrophylla, Liriodendron tulipifera, Juglans nigra, Ulmus americana, U. fulva* (*rubra*), *Fagus ferruginea* (*grandifolia*), *Tilia pubescens* Ait., *Morus rubra, Carpinus caroliniana, Ostrya virginica* (*virginiana*), *Carya tomentosa, C. amara* (*cordiformis*), *Gleditsia triacanthos, Cercis canadensis, Pyrus angustifolia, Acer rubrum, Cornus florida, Castanea pumila, Celtis mississippiensis* (*laevigata*), *Prunus americana, Robinia pseudacacia* (*Pseudo-Acacia*).

In a later report Lowe (1921) remarked upon the dominance of hardwoods, stating that pine was present almost solely as second growth in old fields or other openings; and that red cedar, though not uncommon on slopes, was probably not a part of the original flora. He observed that several lime-loving trees, such as Durand's oak, butternut, and hackberry, that were common in lime soils of northeast Mississippi skipped the intervening regions and reappeared in the loess hills.

FOREST COMMUNITIES ON THE THIN LOESS
(as at Camp Kickapoo)

In the area of thin loess the soil is a brown clayey loam covering the surfaces of gently undulating uplands. It has been produced from the thinner deposits of loess downwind, to the east, of the thicker loess belt overlooking the Mississippi Alluvial Plain. As the area has been long cultivated few mature stands of forest can be found although early accounts of the region indicate a heavy cover of very large trees.

Unfortunately, details of the pre-1900 vegetation in the area are not easily extracted from the early papers because the thin loess was not recognized and because there was confusion as to the vegetational area and/or physiographic belt in which northern Hinds County belongs. Thus Harper (1857) would have placed the (Kickapoo) site where Eocene strata and the younger Tertiary strata meet — the juncture of the Jackson Prairie and the belt of Vicksburg Hills. Hilgard (1860) would have placed it in his Central Prairie Region — the Jackson Prairie. Dunston (1910) would have placed it in the South Central Region (which included the Vicksburg Hills). Finally, Lowe (1913) would have placed it in the Jackson Prairie belt. Actually, the Kickapoo site is at the very south edge of the Prairie belt and within distant view of the Vicksburg Hills belt at the north edge of Lowe's Long Leaf Pine Hills belt.

Hilgard (1860) discussed the forests of northern Hinds County as being predominantly composed of large post, Spanish, and scarlet oak, accompanied by large blackjack oaks and hickory, and an undergrowth of dogwood and persimmon. In this report Hilgard (1860) noted a transition from the oak-hickory forests of northern Hinds County (our Jackson Prairie) to oak-hickory-pine forests of the southern part of the county (Lowe's Long Leaf Pine belt).

Lowe (1921) listed the following species as typical of the Brown Loam region of northern Hinds County: post oak, blackjack oak, tanbark oak (?) and Texas oak (probably *Quercus Shumardii* var. *Shumardii* Buckl.). These were said to be accompanied by hickory, persimmon, and cedar (*Juniperus virginiana*).

Thus the region of Camp Kickapoo (characterized edaphically by thin loess) has been considered dominated by oak forest as distinguished from the area of deep loess, to the west, which was dominated by mixed hardwoods. It might be expected that the ravine forests of the thin loess would be post-climax to the rolling uplands, and would therefore be composed of mixed hardwoods.

FOREST COMMUNITIES ON UPLAND NON-LOESS
(as in Scott County)

According to Lowe (1923), the original forest of the North Central Plateau was a mixed growth of pine, Spanish oak, blackjack oak, white oak, chestnut, and hickory. Hilgard (1860) listed post oak, rather than white oak, as one of the three dominant upland oaks, although he listed white oak as a common bottomland tree. He mentioned dogwood and persimmon as understory trees in speaking specifically of Scott County, in which the present sample area is located. Wailes (1854) noted that chestnut had lately become diseased, and seemed to be rapidly dying out. Harper (1857) briefly mentioned that shortleaf pine (*Pinus echinata*) occurred, but gave an extensive list of hardwood trees. He included eight oaks — red, black, white, overcup, post, blackjack (which was especially common), chestnut, and Spanish, and listed three hickories (*Carya tomentosa, C. cordiformis,* and *C. ovata*) sweet gum, poplar (tuliptree), persimmon, sumac, sassafras, and walnut.

The prevailing upland forest of the Southern Region of the North Central Plateau (Lowe, 1913) consisted largely of loblolly (*Pinus taeda*) and shortleaf pine (*Pinus echinata*), but included post, blackjack, and Spanish oaks, plus other hardwood species. Lowe (1913) also noted that most of the virgin loblolly-shortleaf pine timber had been cut over, but that large tracts of original forest still remained just north of the Jackson Prairie, because of inaccessibility to a railroad.

To the two pines and three oaks listed above, Lowe (1915) added two more oaks (red and black), two hickories (*Carya tomentosa* and *ovata*), and nine other hardwood species: winged elm, sweet gum, black gum, sassafras, sumac (*Rhus copallina, glabra,* and *typhina*), chestnut, and persimmon.

According to Harper (1857) the undergrowth of the North Central Plateau was composed of buckeye, wax myrtle, "honeysuckle" (*Rhododendron* spp.), huckleberry (*Vaccinium corymbosum* and *vacillans*), *Hydrangea arborescens, Rhus* spp., and French mulberry. (*Callicarpa americana*). The vines and climbers he mentioned were *Bignonia radicans* and *B. capreolata, Gelsemium sempervirens, Lonicera sempervirens* and *L. flava,* and sarsaparilla (*Schisandra coccinea* Michx.).

Lowe (1913) provided a list of shrubs found in the Southern Region of the North Central Plateau, as well as an extensive list of herbs of this area. Also, according to Lowe (1915), six herbaceous species commonly found in the upland woods of the North Central Plateau were *Viola palmata, Spigelia marilandica,* (pink root), *Sanicula canadensis,* and *S. marilandica, Podophyllum peltatum,* and *Tradescantia virginica.*

FOREST COMMUNITIES ON BOTTOMLAND NON-LOESS
(as in Smith County)

The two forests which were studied in the bottomland non-loess area are only 11 miles apart. Yet they lie in two different vegetational provinces of the State. The Oakahay Creek area on the south is at the extreme north edge of the Longleaf Pine region and the Caney Creek area is at the south edge of the Jackson Prairie belt. Both areas are delimited by characteristic vegetation of the uplands. But, what is most important here, the bottomland forests of the two regions are identical.

The soils of these creek bottoms are sandy, brownish-gray, with occasional outcrops of white clay. The richness of the vegetation indicates fertile soil. Lowe (1921) stated that, in creek bottoms such as that of the Oakahay Creek, the alluvial soil resulting from stream deposits coupled with its water-logged condition induces an acidity simulating conditions of a northern bog. He suggested that the characteristic vegetation of the creek bottoms of the area is suggestive of bog flora.

Wailes (1854) noted only slight cutting of valuable oak in the area but Hilgard (1860), speaking specifically of the Oakahay Creek bottoms, listed heavy growth of white and chestnut oak (certainly *Quercus Michauxii*), beech, hickory, sweetgum, water oak and magnolia (*Magnolia grandiflora*). Harper (1857) had recorded, in addition to those above, sweet bay, tupelo gum, sycamore, cottonwood, pawpaw, prickly ash, red maple, linn (*Tilia* spp.), Hercules club, *Xanthoxylum Clava-Herculis,* holly (*Ilex opaca*), elm, dogwood, cypress, chinquepin, birch, and ash. He stated that old field pine (*Pinus taeda*) and shortleaf pine (*Pinus echinata*) appeared on cut-over bottoms.

METHODS USED IN THIS INVESTIGATION

GENERAL STATEMENT

It is obvious that the observations of floristic communities recounted above were made by men who were dedicated and fairly thorough. However, they had little formal training in botany, they did not have time for detailed work in small areas, and they did not have available the tools or the methods for thorough measurements of the ecological differences which are commonplace today.

Therefore, the remainder of this report is devoted to (1) methods of vegetation analysis, (2) the observations made when these methods were applied, and (3) a discussion of the ecological relationships which includes a summary of the flora in the four areas sampled and the conclusion that the vegetation on thick loess is more like that of non-loess bottomlands than the vegetation in adjacent areas of thin loess or non-loess uplands.

VEGETATION ANALYSIS

As previously mentioned, six areas were chosen for detailed study. In each an attempt was made to locate relatively slightly disturbed forests developed on (1) thick loess, (2) thin loess, (3) upland non-loessal soil, and (4) creek-bottom non-loessal soil in an east-west line approximating the latitude 32° 25′ (fig. 1). Forests of the latter category were sampled only after preliminary observations indicated that many of the species originally considered indicative of thick loess were also present in well-drained creek bottoms in non-loessal areas.

Vegetation was sampled by a modified point-centered quarter method developed for ecological use by Cottam and Curtis (1956). Modifications included addition of a 4 by 4 meter and a 1 by 1 meter quadrat at each point to sample shrub and herb layers, respectively. Woody-stemmed plants exceeding 3.9 inches DBH were considered part of the tree layer; those less than 3.9 inches DBH, but over 1 foot tall were sampled in the shrub layer; and those less than 1 foot tall were sampled in the herb layer. Diameters of stems of plants of the shrub layer were measured with vernier calipers to the nearest millimeter 4 inches above the ground. Cover was estimated in the herb layer quadrats. By this modification an importance value (I.V. = sum of relative frequency, relative dominance, and relative density) (Phillips, 1959) could be assigned each species in every layer of each community.

Adequacy of sampling was determined with species-area curves by the method of Cain (1938). Nomenclature of plants in sections of results and discussion follow Fernald (1950) unless the authority is given. In the introduction names follow the sources or have the presently accepted name (Fernald, 1950) in parentheses.

CLIMATIC STUDIES

Two permanent weather stations were established, one in the deep loess area at Bluff Experimental Forest near Oak Ridge, Warren County, and one at Kickapoo Boy Scout Camp near Jackson, Hinds County. At each station a U. S. Weather Bureau shelter was mounted on a stationary base 4-1/2 feet from the ground. Enclosed in each of these shelters were a Bendix-Friez weekly recording Hygrothermograph, a Dickson dual-lead weekly recording thermometer (Minicorder), and a Taylor Sixes Type maximum-minimum thermometer. Sensing leads from the recording thermometer were buried in the soil at depths of 3 and 18 inches. A Tru-Check rain gauge was affixed 6 feet from the ground to a stake in open areas adjacent to each weather station. Loss by evaporation between weekly readings was prevented by pouring a small volume of mineral oil into the gauges. Soil samples were taken at weekly intervals at 3, 12, and 18 inches. These samples were kept in standard metal soil cans and weighed before and after drying at 105° C. to a constant weight.

MINERAL NUTRIENTS IN THE SOIL

Soils studied in this investigation have been analyzed for soluble constituents by modifications of standard procedures. A weighed sample was digested in hydrochloric acid. Aliquot parts of the filtrate were used for both volumetric and gravimetric analyses.

One aliquot was analyzed for lime (CaO) and magnesia (MgO) in 30 minutes by successive titrations employing ethylene diamine tetraacetate (EDTA), a modification of the Price-Priddy (1961) method for determining sulfate, calcium, and magnesium in coastal waters. A second aliquot was used to determine iron as Fe_2O_3 by ceric sulfate titration. A third aliquot was used to obtain an ignited residue of combined Fe_2O_3-Al_2O_3, from which the Al_2O_3 content was found by difference. These minerals were selected for assay because preliminary observations indicated them as possible critical materials. No attempt was made to determine amounts of nitrate, phosphorous, and potassium, as Quarterman and Keever (1962) were unable to correlate soil content of these minerals with southern forest types.

pH — RELATIVE ACIDITY AND BASICISITY

Soil pH was determined with a Beckman pH meter, Model G. Determinations were made both in the field and from samples brought into the laboratory in soil cans. In all communities multiple determinations were made of humus and soil down to 18 inches in depth.

SOIL MOISTURE CONTENT

As previously stated, weekly soil samples were taken at the deep loess and shallow loess areas at 3, 12, and 18 inch depths, and were dried to determine field water content. In addition, mixed soil samples from each area were analyzed for field capacity by both the cake pan evaporation method, and by the Gooch crucible method (Carlton, 1961). In the latter determination suction was applied to saturated soil samples for 1 hour. The single suction line was branched so that two replicates could be run at one time, thus allowing more adequate checking of samples. The wilting coefficient of each type of soil was determined by standard methods using tomato and sunflower plants as test organisms.

RESULTS OF MEASUREMENTS

GENERAL STATEMENT

In the interval September 1960 through May 1963 great volumes of data were collected and by July 1963 sufficient conclusions had been drawn to warrant this report on present conditions. Conclusions are summarized as to (1) vegetation analyses in each of the four areas sampled, (2) differences in climate, (3) differences in mineral nutrients, (4) differences in moisture content, and (5) differences in the pH of the soils.

VEGETATION ANALYSIS

Vegetation in the Area of Thick Loess

The report of the present vegetation of the loess hills deals only with forests approximating the thirty-second parallel and does not, therefore, incorporate plants whose range is chiefly north or south of this particular area. Tables 1, 2, and 3 list the various species occurring in the areas sampled, arranged in order of their importance values.

The forest of the deep loess was dominated by sweetgum, basswood, water oak, tuliptree, cherrybark oak (*quercus falcata* var. pagodaefolia), and bitternut. The understory was particularly noted for the abundance of hop hornbeam and blue beech. The important shrub-layer transgressives were dogwood, blue beech, bitternut, ash, and American and slippery elm. Most important shrub species were oak-leaved hydrangea, pawpaw, common hydrangea, and spice bush. The most important members of the herb layer were poison ivy, species of *Carex* and *Viola,* and crossvine (*Bigonia capreolata*). Christmas fern (*Polystichum acrostichoides) and fragile fern* (*Cystopteris fragilis*) were common.

Plants of note which were present on the loess (though not necessarily appearing in the samples) were red cedar (*Juniperus virginiana*), *Pachysandra procumbens,* maidenhair fern (*Adiantum pedatum*) white baneberry (*Actaea alba*), ginseng (*Panax quinquefolius*), and the wall-fern (*Pteris serrulata* Poir.). The latter was found growing rather abundantly on the soil of the rapidly eroding loess ravine banks at the western edge of the loess area.

The conspicuous characteristics of the plant communities of the loess hills were (1) dominance of mesophytic hardwoods, (2) importance of calciphiles, (3) importance of cane in upland sites (as opposed to its usual position in lowlands), and (4) the presence of *Magnolia acuminata.*

Vegetation in the Area of Thin Loess

The species of the samples taken in the thin loess area are listed in Tables 4, 5, and 6.

The tree layer was dominated by mixed hardwoods, including beech, black gum, black oak (*Quercus velutina*), mockernut hickory, white oak, sourwood, and sweet gum. The shrub layer contained, as most important species, transgressives of the above, plus witch hazel (*Hamamelis virginiana*), wild black cherry, highbush huckleberry (*Vaccinium arboreum*), winged elm, and flowering dogwood. The most important herbs were *Hordeum pusillum, Arundinaria gigantea, Panicum* spp., *Carex* spp., and *Polystichum acrostichoides.* The ravine vegetation of the area may thus be characterized as mixed hardwood forest with species of oaks and certain acidophiles (*Oxydendrum arboreum, Nyssa sylvatica,* and *Vaccinium arboreum*) as important constituents.

Although the rolling lands and crests were not sampled due to their severely disturbed character, it was evident that they are still dominated (in a vestigial way) by post oak, Spanish oak, and blackjack oak.

Vegetation in the Area of Upland Non-Loess

Tables 7, 8, and 9 provide a list of species found in the upland non-loess sample area.

Only thirteen species were in the tree layer at this site. *Pinus taeda, Pinus echinata,* Spanish oak (*Quercus falcata*), and white oak were dominant. Other species with an importance value greater than 10 were mockernut hickory, post oak, willow oak (*Quercus phellos*), and white ash (*Fraxinum americana*). It is interesting to note that blackjack oak, which has consistently been listed in the literature as a dominant hardwood in the upland forest communities, was not represented in the community by even a single individual. Also, neither willow oak nor white ash have been mentioned as important trees of this area in available literature.

In the shrub layer, *Rhus radicans* and *Vitis rotundifolia* were most abundant. Loblolly pine (*Pinus taeda*) and post oak were two other important species of this layer. Other species with an importance value greater than 10 were *Fraxinus americana, Ulmus alata, Crataegus* spp., and *Diospyros virginiana*. Species of importance in the herb layer of upland non-loess forest were *Uniola sessiliflora, Rhus radican, Pinus taeda* and or *echinata, Carex* spp., *Aster* spp., *Desmodium* spp., *Solidago* spp., *Panicum* spp., and *Scutellaria* spp.

Vegetation in Area of Bottomland Non-Loess

Lists of the most important species of plants of the non-loessal creek bottoms are found in Tables 10, 11, and 12. Table 10 combines data from both the Oakahay and Caney Creek areas. Data from Tables 11 and 12 are from the Oakahay Creek area, only.

The forests were dominated by sweet gum, beech and spruce pine. Most important associates are mockernut, shortleaf pine, laurel oak, white oak, loblolly pine, and slippery and American elm. The outstanding understory species was blue beech (*Carpinus caroliniana*), which, in the size class above 3.9 inches diameter breast high, occurred with sweet gum in greatest density (Table 10).

In the shrub layer the most important species were blue beech, with an importance value twice that of any of the next most common species, greenbriar (*Smilax* spp.), water oak, winged elm, pignut, American ash, French mulberry (*Callicarpa americana*), and silverbell (*Halesia* spp.) (Table 11).

The common plants of the herb layer were *Carex* spp., *Uniola sessiliflora, Panicum* spp., *Mitchella repens, Rhus radicans,* and *Elephantopus carolinianus* (Table 12).

Important species restricted to this area of the present study were spruce pine (*Pinus glabra*), laurel oak (*Quercus laurifolia*), overcup oak (*Quercus lyrata*), horsesugar (*Symplocos tinctoria*), and ginger (*Asarum Ruthii*). The first three are normally restricted to bottomland situations.

PHYSICAL FACTORS AFFECTING VEGETATION

Effects of Climate

Weather data taken at the stations in the thick and thin loess regions are summarized in Table 13.

Noticeable differences may be seen in average air and soil temperature, those in the thin loess region being slightly higher in all categories. Total precipitation for the duration of study was greater in the area of thin loess. The latter datum is of considerable importance, for it can be correlated with actual moisture of the soil samples taken weekly at the stations.

Effect of Mineral Nutrients

The chemicals determined were acid extractable CaO, MgO, and Fe_2O_3. Results are summarized in Table 14.

It is evident that both calcium and magnesium are in considerably higher concentrations in thick loess than in the other soils.

In the thick loess concentrations of CaO and MgO vary greatly with topographic position. The crests of hills have low concentrations, due to leaching, while valley floors and eroding slopes have high concentrations. Perhaps of more importance than the mean CaO content of loess (2.00%) are the extremes (O.33% and 9.95%). Such variation in base content correlates pH, and with the distribution of such calciphiles as *Pteris serrulata* Poir., *Adiantum pedatum*, and *Rhamnus caroliniana*, found only on rapidly eroding slopes in the loess area.

Effect of Moisture

At each level at which actual soil moisture was determined on a weekly basis, the thick loess was found to have a higher percentage of moisture than the thin loess (Table 16).

The difference in each case was statistically highly significant. Thus, the thick (unmixed with substrate) loess had the uniform capacity to retain a greater percentage of water than did the thin loess (weathered loess mixed with substrate sand and clay). This was true even though the thin loess area received considerably more rainfall on a weekly basis during the same period (see Table 13).

Field capacities, as determined by the Gooch crucible method, were as follows: thick loess, 30.8 ± 0.69% (standard error of the mean); thin loess, 18.7 ± 1.68%; upland non-loess, 19.4 ± 1.58%; creek bottom non-loess, 21.7 ± 1.00% (Table 17). The differences between the latter three were not significant, but the latter three were significantly lower than the first. Field capacity was also determined by the cake pan evaporation method for thick loess, thin loess, and upland non-loess. In this procedure lower values were obtained for all soils, but they were in the same sequence and of the same order of magnitude.

Table 17 summarizes field capacity, permanent wilting point, and, by difference, available water for composite soil samples from the four communities. It is obvious that thick loess and creek bottom non-loess have the greatest amount of available water.

Effect of pH

Mean values of the pH of the soils of the various communities are given in Table 15.

There is no statistically significant difference between the non-loessal soils, but soils with more loess are significantly and progressively more alkaline. Of significance, also, is the wide range of pH values obtained in the thick loess. Range of values in non-loessal soil was from 4.30 to 5.30, whereas, in thick loess it was from 5.36 to 7.94.

When samples were taken from soil just below the humus (or at surface when no humus was present), soil pH varied rather consistently with topography in the thick loess. Highest pH values were found on rapidly eroding slopes (mean = 7.23) and valley floors (mean = 7.36), and lowest values on the crests of the hills (mean = 6.67). In the thick loess on hill crests, the pH of material from two auger holes increased sharply from 6.7 to 7.8 between the 10 and 15 foot depth.

DISCUSSION OF RELATIONSHIPS

PLANT COMMUNITY RELATIONSHIPS

The sampling of vegetation of west central Mississippi has resulted in the recognition of two distinct forest types: (1) Mixed Hardwood forest of the thick loess, thin loess, and non-loessal creek bottoms, and (2) Pine-Oak-Hickory forest of upland non-loess. Coefficients of similarity may be used to express floristic and structural relationships among these communities (fig. 2). In this case the coefficient of similarity was derived by the formula $C = \frac{2W}{A + B} \times 100$; where C = coefficient of similarity, A = number of species of one community, B = number of species of the other community, and W = the number of species common to both communities (Phillips, 1959). This coefficient is given for the tree layer only. Due to seasonal variation encountered in the herb layer and difficulty in establishing the species of certain important genera in this layer, emphasis in interpretation has been placed upon the woody constituents of the various communities studied.

For comparison, the following groupings may be made (1) species common to all forests, (2) species confined to the Mixed Hardwood forest, and (3) species confined to the Pine-Oak-Hickory forest. For this purpose only those species whose importance value equaled or exceed 10 are considered.

Species Common to All Communities

The species common to all communities were sweet gum (*Liquidambar styraciflua*), mockernut (*Carya tomentosa*), white oak (*Quercus alba*), black oak (*Quercus velutina*), white ash (*Fraxinus americana*), pignut (*Carya glabra*), winged elm (*Ulmus alata*), red haw (*Crataegus* spp.), red maple (*Acer rubrum*), sedges (*Carex* spp.), panic grass (*Panicum* spp.), *Aster* spp., and beggar's tick (*Desmodium* spp.).

Species Restricted to the Mixed Hardwood Forest

Those restricted to the Mixed Hardwood forest were cherrybark oak (*Quercus falcata* var. *pagodaefolia*), basswood (*Tilia* spp.), water oak (*Quercus nigra*), elm, slippery and American (*Ulmas rubra* and/or *americana*), tuliptree (*Liriodendron tulipifera*), hop hornbeam (*Ostrya virginiana*), blue beech (*Carpinus caroliniana*), box elder (*Acer negundo*), spruce pine (*Pinus glabra Walt.*), American beech (*Fagus grandifolia*), laurel oak (*Quercus laurifolia*), oak-leafed hydrangea (*Hydrangea quercifolia*), common hydrangea (*Hydrangea arborescens*), pawpaw (*Asimina triloba*), French mulberry (*Callicarpa americana*), silverbell (*Halesia* spp.), wild black cherry (*Prunus serotina*), Christmas fern (*Polystichum acrostichoides*), giant cane (*Arundinaria gigantea*), and crossvine (*Bigonia capreolata*).

Species Confined to Upland Non-loess

Those confined to upland non-loess were post oak (*Quercus stellata*) and persimmon (*Diospyros virginiana*). (Actually these trees are common in the thin loess area on dry ridges and in severely disturbed areas).

Species Found Only in Thick Loess and/or Creek Bottoms Non-loess

Some species are more restricted in that they were found only in thick loess and/or creek bottom non-loess. These were *Tilia* spp., *Hydrangea aborescens, Nemophila microcalyx, Cystopteris fragilis, Pachysandra procumbens, Adiantum pedatum, Actaea alba, Panax quinquefolius,* and *Pteris serrulata,* (thick loess only); *Quercus nigra, Quercus falcata* var. *pagodaefalia, Carpinus caroliniana, Acer negundo,* (creek bottom non-loess and thick loess only); *Quercus laurifolia* and *Pinus glabra,* (creek bottom only).

EXPLANATION OF MIXED RELATIONSHIPS

It thus appears that, in the general study area, some factor (or factors) common to thick loess uplands and creek bottom non-loess supports the growth of many species which disappear in the uplands as the loess progressively thins eastward. Eastwardly many species are progressively more restricted to the bottomlands where they become associated with a few distinctive bottomland species.

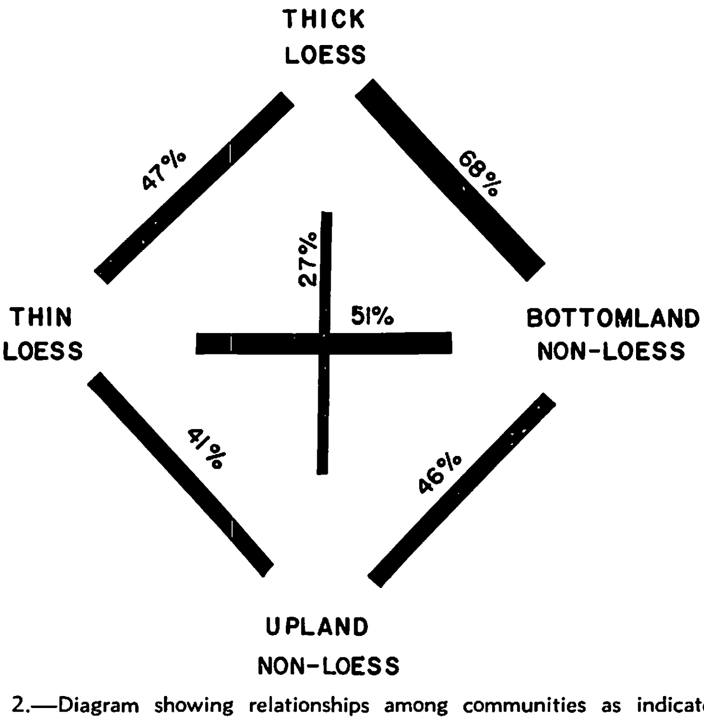

Figure 2.—Diagram showing relationships among communities as indicated by coefficient of similarity (number with percent sign). Thickness of each connecting bar indicates relative degree of correlation between communities.

Possible Pleistocene Mixing of Forests

In view of the Pleistocene origin of the loess deposits and the fact that Pleistocene forests of the lower Mississippi Valley were composed of a mixture of genera of northern and southern origin (Brown, 1938; Dukes, 1959), the area under consideration would have been subjected to invasion by genera of diverse ecological capacities at the time when part of the land surface was being slowly elevated by loess accumulation. Such mixture of species would have resulted from marked migration during several climatic fluctuations in Tertiary and Quaternary times. It appears that genera now occupying these areas were able to persist largely because of their ability to withstand the warmer and more arid intervals which followed the Pleistocene. The genera which have persisted in sites with best water conditions have been those which have also persisted in more northern areas where reduced evaporation would reduce transpiration. Plants able to withstand summer drought have successfully maintained themselves on uplands where water relations were less favorable.

This mixing may explain why it is difficult to relate the communities of this study to those described in the literature. Braun (1950) considered the southern loess hills to be occupied by forests belonging to the Western Mesophytic Forest Region and that near the southern extremity of the loess hills they contained elements of the Southeastern Evergreen Forest Region. As the former region is a mosaic of very different forest types, designation of a forest to it serves no real purpose.

The forest of the loess hills of west central Mississippi is quite different from that described by Braun (1950) from loess bluffs near Reelfoot Lake, Tennessee, some 300 miles to the north, the coefficient of similarity being only 34%. Correlation is not as good between these two communities as between the abstract Mixed Mesophytic Forest climax (Braun, 1950) and the loess hills forest of west central Mississippi (41%).

Of the ten most important tree species on deep loess, five (or closely related species) have been listed by Braun (1950) as characteristic of the Mixed Mesophytic Forest Region (*Tilia* spp., *Liriodendron tulipifera, Carya cordiformis, Ostrya virginiana,* and *Carpinus caroliniana*).

Neither does the loess hills forest correlate well with the abstract Southern Mixed Hardwood Forest (38%) (Quarterman and Keever, 1962).

Loess Hill Forest is a Composite Forest

The forest of the loess hills is actually a composite of elements from the mixed mesophytic forest to the north (Mixed

Mesophytic and Western Mesophytic Forests of Braun, 1950), the bottomland forests to the west in the Mississippi Alluvial Plain, and the mixed hardwood forest (Quarterman and Keever, 1962) to the south and east. Loess forest are characterized by (1) the great importance of cherrybark oak (*Quercus falcata* var. *pagodaefolia*) and (2) the great number of species of trees, illustrating its composite nature.

The community most similar to the Southern Mixed Hardwood Forest, considered by Quarterman and Keever (1962) to be the climax of the region of our study, is the one on thin loess. (fig. 3) The non-loessal upland community of this study did not correspond as closely to their abstract community as might be expected. The former was composed of more xerophytic

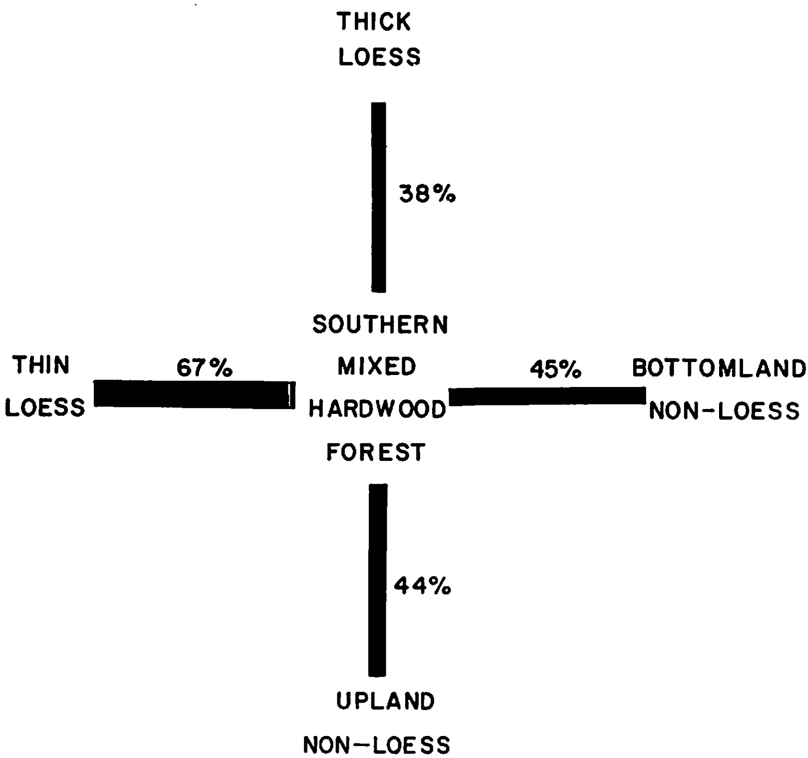

Figure 3.—Diagram showing coefficient of similarity of each community sampled in this study with the abstract Southern Mixed Hardwood Forest (Quarterman and Keever 1962).

species, though differences between the two may have been related partly to degrees of disturbance rather than wholly to water relations.

In the present study those species which were important in thick loess, only, or in thick loess and creek bottom non-loess communities, absent or relatively unimportant in thin loess communities, and absent in upland non-loess communities, were *Quercus falcata* var. *pagodaefolia, Tilia* spp., *Quercus nigra, Ulmus rubra, U. americana, Liriodendron tulipifera, Carya cordiformis, Carpinus caroliniana,* and *Acer negundo.* On the basis of available water in loess and water of percolation in creek bottoms, these species may be considered the most highly mesophytic of the important trees of the communities samples. Only one of these, *Quercus nigra,* was included in the list of structurally important species of the Southern Mixed Hardwood Forest (Quarterman and Keever, 1962).

These data indicate that communities of thick loess and creek bottoms are post-climax to Southern Mixed Hardwood Forest. The status of the former community is controlled edaphically, the latter topographically.

Quercus laurifolia and *Pinus glabra,* both important in creek bottom communities, and absent from thick loess, are near their northern limit of distribution in the state of Mississippi in the creek bottom sampled (Little, 1949), and their absence from thick loess may result from temperature sensitivity or distribution pattern rather than soil type or topography.

The position of *Tilia* spp. is unique in that its distribution in the west central part of the state is intimately related to the presence of loess. Its center of distribution is in the thickest loess, where it is an important forest tree. In the area of thin loess it is common along streams, but does not appear in ravine forests as at Camp Kickapoo. East of the area of marked loessal influence, it is not present even along creeks. That the pattern of distribution observed here is not consistent throughout the lower Gulf Coastal Plain is evident from the report of Quarterman and Keever (1962) where *Tilia* is a component of Southern Mixed Hardwood Forest.

Only Moisture Appears to Control Relationships

The climatic data of most value presented in Table 13 is that concerned with rainfall. This datum is important because it validates the data showing significant differences in soil moisture of the areas. Without concomitant rainfall records for the sample areas, per cent moisture of soil samples taken directly from the field would be worthless. Slightly higher values for air and soil temperatures in the area of thin loess may merely reflect greater exposure, and probably have no validity. This conclusion is substantiated by 30-year records of air temperature from Vicksburg and Jackson (nearest stations to thick and thin loess sample areas, respectively), which indicate no significant difference between the two areas (U.S.D.A. Yrbk. of Agric. 1941). No other climatic data indicate differences worthy of consideration.

Other data indicate certain distinct differences among the environments of the various communities. These differences are all related to the substrate, and in all of them thick loess is distinctly different from the soils of the other communities. Thick loess has (1) higher pH, (2) greater concentrations of extractable CaO and MgO, (3) greater actual field water (data compared only with thin loess), (4) greater field capacity, and (5) a greater amount of available water. Thus, it appears that there would be two community types; one loessal, one non-loessal. This is not the case. Of the two most clearly related communities, one is supported by deep loess, the other by a non-loessal bottomland soil. Upland soils with a definite loessal influence support communities related to both the above communities, but not as closely related to either as they are to each other (fig. 2).

Therefore, it appears that loess does not supply a specific controlling agent, such as a micronutrient. If there were such an agent, it would be expected that thin (mixed) loess would support the same general community type as thick (unmixed) loess, but in a form reflecting both loess and the soil with which it is mixed. Also, it would be expected that communities outside the influence of loess would be totally different from communities on loess. Some broader mechanism of control must be sought. The apparent controlling factor in the development of similar communities on deep loess and non-loessal creek bottomlands is availability of water, in spite of differences in mineral concentrations, pH, and water coefficients. In loess, water is available because of the peculiar characteristics of the substrate which retains much water between field capacity and permanent wilting point. In the creek bottomlands, the availability of water is related to topography, the bottomland soils receiving both run-off water and water of percolation from adjacent uplands. Thus, it appears, the general determinant of community types is availability of water.

The concept which ascribes almost total control of the nature of the plant community to water relations alone is certainly a generalization for which very numerous exceptions may be found. The presence of *Pteris serrulata* Poir. only on rapidly eroding loess in this area of study is a prime example. Yet, in this study, it appears that water is the only broadly-based controlling factor which causes the segregation of mature forests, as distinguished on the basis of dominating trees. Apparently in the southern United States, at least, water is a limiting factor of such magnitude in the physiology of trees that, except under extreme variation of other factors, it may be considered the source of community differentiation.

SUMMARY

The forests of the loess hills have long been recognized as distinct from the forests of the hills to the east of them because of the luxuriance of the former and because they were composed almost entirely of hardwood trees. The present study has attempted (1) to describe more adequately these forests of west central Mississippi, on thick loess, thin loess, and on non-loessal soils, and (2) to discover the chief environmental factors delimiting the communities. To accomplish the first objective six forest communities were sampled by a modification of the method of Cottam and Curtis (1956). In each community data were taken concerning climate, certain soil minerals, actual soil moisture under field conditions, pH, and moisture coefficients of the soils.

It was found that the communities most closely related floristically were those supported by thick loess and creek-bottom non-loess. Most unrelated communities were those on thick loess and upland non-loess. It was concluded that the close

relationship of the former communities was derived from the relatively high level of water availability in the two communities. In the thick loess water relations were good because of the nature of the substrate which proved to have the highest per cent of available water of all the soils tested. Water conditions were favorable in the creek bottomlands because of an adequate available water percentage, and because the topography of the creek bottoms allowed them to receive both run-off and water of percolation from surrounding uplands.

When compared to descriptions of plant communities of the region in the literature, those sampled generally appeared to be rather distinct communities. Closest similarity was between the forest on thin (mixed) loess and the Southern Mixed Hardwood Forest of Quarterman and Keever (1962). In view of those water relationships already mentioned, it has been concluded that forests on thick loess represent an edaphically controlled post-climax to the Southern Mixed Hardwood Forest.

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Table 1. Tree layer of thick loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Liquidambar styraciflua	15.2	19.7	13.6	48.5
Tilia spp.	6.4	8.4	6.0	20.8
Quercus nigra	5.6	7.5	6.1	19.2
Liriodendron tulipifera	4.3	10.7	4.0	19.0
Quercus falcata var. *pagodaefolia*	3.8	8.7	3.9	16.4
Carya cordiformis	5.7	2.7	5.7	14.1
Ostrya virginiana	5.1	1.7	4.8	11.6
Quercus shumardii	1.9	6.2	2.1	10.2
Acer negundo	3.6	2.4	3.6	9.6
Ulmus rubra	4.1	1.8	3.5	9.4
Carpinus caroliniana	4.2	0.5	4.3	9.0
Carya glabra	3.4	1.7	3.5	8.6
Fagus grandifolia	2.8	2.8	2.6	8.2
Cornus florida	3.2	0.9	3.6	7.7
Sassafras albidum	2.7	1.4	2.9	7.0
Quercus michauxii	2.5	1.1	3.1	6.7
Fraxinus americana	2.2	1.2	2.5	5.9
Pinus taeda	2.2	2.6	1.7	6.5
Quercus alba	1.9	2.3	2.1	6.3
Ulmus americana	2.1	1.1	2.4	5.6
Platanus occidentalis	1.2	2.9	1.3	5.4
Carya tomentosa	1.4	2.1	1.5	5.0
Prunus serotina	1.8	1.1	2.1	5.0
Morus rubra	1.2	1.1	1.5	3.8
Quercus muehlenbergii	1.2	1.5	1.1	3.8
Ulmus alata	1.4	0.6	1.7	3.7
Quercus velutina	1.4	0.6	1.5	3.5
Celtis laevigata	1.0	0.3	1.3	2.6
Cercis canadensis	0.8	0.2	1.0	2.0
Acer barbatum	0.8	0.2	0.8	1.8
Juglans nigra	0.5	0.8	0.5	1.8
Juniperus virginiana	0.6	0.4	0.6	1.6
Oxydendrum arboreum	0.5	0.4	0.7	1.6
Robinia pseudo-acacia	0.7	0.2	0.6	1.5
Quercus phellos	0.3	0.8	0.3	1.4
Melia azedarach	0.5	0.2	0.6	1.3
Quercus spp.	0.3	0.2	0.3	0.8
Aralia spinosa	0.3	0.1	0.3	0.7
Ilex opaca	0.3	0.1	0.3	0.7
Magnolia acuminata	0.3	0.1	0.3	0.7

Table 2. Shrub layer of thick loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Carpinus caroliniana	10.2	20.8	5.7	36.7
Cornus florida	9.5	9.4	7.8	26.7
Ostrya virginiana	5.0	11.1	5.0	21.1
Fraxinus americana	6.1	5.2	6.2	17.5
Hydrangea quercifolia	6.3	6.9	3.7	16.9
Tilia spp.	5.4	6.8	4.7	16.9
Carya cordiformis	6.6	3.8	5.2	15.6
Carya glabra	3.8	5.0	4.0	12.8
Hydrangea aborescens	6.5	2.9	3.3	12.7
Asimina triloba	3.4	.5	7.8	11.7
Ulmus rubra	5.2	1.7	4.8	11.7
Quercus nigra	3.3	.8	4.2	8.3
Quercus michauxii	1.9	3.2	2.7	7.8
Hamamelis virginiana	2.0	3.2	2.3	7.5
Ulmus alata	1.6	2.4	2.7	6.7
Liquidambar styraciflua	1.5	1.7	2.5	5.7
Acer negundo	4.2	.3	1.0	5.5
Lindera benzoin	2.6	.8	2.0	5.4
Prunus serotina	1.4	1.3	2.5	5.2
Morus rubra	1.2	1.5	1.8	4.5
Quercus falcata var. *pagodaefolia*	1.1	1.4	1.8	4.3
Fagus grandifolia	1.3	1.1	1.5	3.9
Sassafras albidum	1.4	.3	1.3	3.0
Ulmus americana	.6	1.2	1.0	2.8
Rhamnus caroliniana	.9	1.0	.7	2.6
Quercus alba	.6	.7	1.2	2.5
Callicarpa americana	.5	.6	1.0	2.1
Quercus velutina	.4	.2	1.3	1.9
Acer barbatum	.4	.6	.8	1.8
Acer rubrum	.4	.6	.8	1.8
Cercis canadensis	.5	.3	1.0	1.8
Ilex opaca	.4	.8	.5	1.7
Celtis laevigata	.5	.1	1.0	1.6
Magnolia acuminata	.4	.3	.7	1.4
Quercus shumardii	.3	.2	.7	1.2
Halesia spp.	.4	.2	.5	1.1
Bumelia lycioides	.3	.1	.5	.9
Quercus spp.	.3	.1	.5	.9
Quercus muehlenbergii	.2	----	.5	.7
Staphylea trifolia	.3	.2	.2	.7
Euonymus americanus	.2	.1	.3	.6
Unknown spp.	.1	.2	.3	.6
Aralia spinosa	.1	.2	.2	.5
Liriodendron tulipifera	.1	.1	.3	.5
Smilax spp.	.2	.1	.2	.5

Table 2.—(Continued)

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Berchemia scandens	.1	......	.3	.4
Calycanthus fertilis	.1	.1	.2	.4
Crataegus spp.	.1	....	.2	.3
Robinia psuedo-acacia	.1	....	.2	.3
Smilax hispida	.1	......	.2	.3
Vitis labrusca	.1	....	.2	.3

...... Less than 0.05%

Table 3. Herb layer of thick loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Rhus radicans	25.5	37.3	12.2	75.0
Carex spp.	15.7	7.3	9.8	32.8
Polystichum acrostichoides	.9	12.0	2.3	15.2
Arundinaria gigantea	2.3	6.3	2.3	10.9
Bignonia capreolata	3.3	2.6	4.7	10.6
Ampelopsis arborea	2.3	3.1	4.9	10.3
Nemophila microcalyx	6.0	1.2	3.0	10.2
Cystopteris fragilis	5.2	2.5	2.3	10.0
Viola spp.	3.0	2.4	4.1	9.5
Panicum spp.	4.2	1.1	2.8	8.1
Sanicula gregaria	2.9	1.3	3.9	8.1
Unclassified grasses	3.4	2.0	2.3	7.7
Erigeron pulchellus	3.8	1.3	2.1	7.2
Viola walteri	3.8	.8	1.1	5.7
Acer negundo	2.4	.6	1.7	4.7
Arisaema dracontium	.9	.9	2.6	4.4
Stellaria pubera	2.4	.5	1.5	4.4
Solidago caesia	.9	.8	2.3	4.0
Fraxinus americana	.4	1.2	2.1	3.7
Tilia spp.	.3	1.8	1.5	3.6
Quercus nigra	.5	1.0	2.1	3.6
Ulmus alata	.5	1.0	2.1	3.6
Oxalis spp.	1.2	.6	1.7	3.5
Lithospermum spp.	.8	1.0	1.5	3.3
Eupatorium coelestinum	1.1	.5	1.5	3.1
Galium aparine	.6	.5	1.5	2.6
Viola septemloba	.6	.5	1.5	2.6
Trillium stamineum Harbison	.5	.5	1.5	2.5
Desmodium spp.	.2	1.0	1.1	2.3
Ulmus rubra	.2	1.0	1.1	2.3
Prunus serotina	.2	.4	1.1	1.7
Cerastium spp.	.4	.3	.9	1.6
Carya cordiformis	.2	.3	.9	1.4
Osmorhiza claytoni	.2	.3	.9	1.4
Ruellia humilis	.2	.3	.9	1.4
Asplenium platyneuron	.1	.3	.9	1.3
Duchesnea indica	.4	.2	.7	1.3
Cornus florida	.2	.2	.7	1.1
Aster spp.	.4	.2	.4	1.0
Hydrangea quercifolia	.1	.2	.7	1.0
Smilax bona-nox	.1	.2	.7	1.0
Podophyllum peltatum	.6	.1	.2	.9
Arisaema quinatum (Nutt.) Schott.	.1	.2	.4	.7
Lindera benzoin	.1	.2	.4	.7
Parthenocissus quinquefolia	.1	.2	.4	.7

Table 3.—(Continued)

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Polygonum spp.	.1	.2	.4	.7
Ranunculus recurvatum	.4	.1	.2	.7
Unknown	.1	.2	.4	.7
Arisaema triphyllum	......	.4	.2	.6
Acer rubrum	.1	.2	.2	.5
Hydrocotyle spp.	.1	.1	.2	.4
Liquidambar styraciflua	.1	.1	.2	.4
Asplenium spp.	......	.1	.2	.3
Bumelia lycioides	......	.1	.2	.3
Corydalis flavula	......	.1	.2	.3
Geranium spp.	......	.1	.2	.3
Hieracium spp.	......	.1	.2	.3
Oxalis grandis	......	.1	.2	.3
Phytolacca americana	......	.1	.2	.3
Pinus taeda	......	.1	.2	.3
Poncirus trifoliata	......	.1	.2	.3
Sambucus canadensis	......	.1	.2	.3
Quercus falcata var. *pagodaefolia*	......	.1	.2	.3
Sonchus spp.	......	.1	.2	.3
Stellaria media	......	.1	.2	.3
Verbena spp.	......	.1	.2	.3

...... Less than 0.05%

Table 4. Tree layer of thin loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Fagus grandifolia	20.8	22.6	17.7	61.1
Nyssa sylvatica	13.5	15.3	12.7	41.5
Quercus velutina	9.4	13.0	10.1	32.5
Carya tomentosa	8.3	13.6	8.9	30.8
Ostrya virginiana	14.6	3.2	12.7	30.5
Quercus alba	6.3	9.9	6.3	22.5
Oxydendrum arboreum	8.3	3.6	8.9	20.8
Liquidambar styraciflua	5.2	7.0	6.3	18.5
Sassafras alibidum	3.1	2.8	3.8	9.7
Cornus florida	3.1	1.5	3.8	8.4
Carya glabra	2.0	3.5	2.5	8.0
Liriodendron tulipifera	1.0	2.7	1.3	5.0
Ulmus americana	1.0	0.9	1.3	3.2
Hamamelis virginiana	1.0	0.5	1.3	2.8
Quercus falcata var. *falcata*	1.0	0.4	1.3	2.7
Quercus falcata var. *falcata*	1.0	0.3	1.3	2.6

Table 5.—Shrub layer of thin loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Nyssa sylvatica	25.3	23.3	10.4	59.0
Ostrya virginiana	9.7	11.9	10.4	32.0
Hamamelis virginiana	6.1	8.7	4.2	19.0
Carya glabra	5.8	5.1	7.0	17.9
Quercus alba	5.3	5.4	6.3	17.0
Ulmus alata	7.5	3.1	5.6	16.2
Quercus velutina	3.1	7.9	2.8	13.8
Vaccinium arboreum	3.9	4.7	2.8	11.4
Prunus serotina	3.1	1.7	6.3	11.1
Cornus florida	2.8	2.5	5.6	10.9
Sassafras albidum	1.4	5.0	2.1	8.5
Halesia spp.	2.8	3.4	2.1	8.3
Carya tomentosa	2.5	1.5	4.2	8.2
Morus rubra	3.1	1.7	2.8	7.6
Quercus spp.	1.9	1.1	3.5	6.5
Callicarpa americana	1.4	.1	3.5	5.0
Fraxinus americana	1.4	.6	2.8	4.8
Aralia spinosa	1.7	2.0	.7	4.4
Oxydendrum arboreum	.6	2.3	1.4	4.3
Vaccinium spp.	1.4	1.2	1.4	4.0
Vitis rotundifolia	1.1	.7	2.1	3.9
Quercus marilandica	.6	1.8	1.4	3.8
Vaccinium spp.	1.4	1.0	1.4	3.8
Smilax glauca	1.1	.3	1.4	2.8
Fagus grandifolia	.8	.5	1.4	2.7
Acer rubrum	.8	.3	1.4	2.5
Liquidambar styraciflua	1.1	.4	.7	2.2
Hydrangea quercifolia	.6	.8	.7	2.1
Vaccinium spp.	.3	.3	.7	1.3
Smilax bona-nox	.3	.2	.7	1.2
Cartaegus spp.	.3	.2	.7	1.2
Ilex opaca	.3	.2	.7	1.2
Berchemia scandens	.3	.1	.7	1.1
Lyonia ligustrina	.3	.1	.7	1.1

Table 6. Herb layer of thin loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Hordeum pusillum	31.2	19.1	5.5	55.8
Arundinaria gigantea	9.9	19.6	6.1	35.6
Mitchella repens	13.8	7.9	6.7	28.4
Panicum spp.	8.2	9.0	8.5	25.7
Carex spp.	8.4	3.8	4.9	17.1
Polystichum acrostichoides	1.2	7.6	4.3	13.1
Unclassified grasses	6.4	3.8	2.4	12.6
Aster spp.	1.8	4.8	3.7	10.3
Solidago spp.	2.0	3.6	3.7	9.3
Desmodium spp.	1.1	3.6	3.7	8.4
Rhus radicans	2.0	1.6	2.4	6.0
Quercus spp.	.7	1.6	3.0	5.3
Ulmus alata	.9	1.9	2.4	5.2
Bignonia capreolata	1.5	.6	3.0	5.1
Smilax spp.	1.1	.7	3.0	4.8
Uvularia perfoliata	.9	1.3	1.8	4.0
Quercus phellos	.7	.9	2.4	4.0
Cornus florida	.6	.4	2.4	3.4
Fraxinus americana	.5	.4	2.4	3.3
Carya glabra	.4	.7	1.8	2.9
Acer rubrum	.7	.3	1.8	2.8
Viola spp.	.4	.3	1.8	2.5
Ostrya virginiana	.4	.7	1.2	2.3
Carya spp.	.4	.4	1.2	2.0
Aristolochia serpentaria	.5	.2	1.2	1.9
Quercus alba	.2	.4	1.2	1.8
Ruellia humilis	.2	.3	1.2	1.7
Unknown	.2	.2	1.2	1.6
Prunus serotina	.2	.2	1.2	1.6
Nyssa sylvatica	.2	.2	1.2	1.6
Elephantopus carolinianus	.2	.6	.6	1.4
Parthenocissus quinquefolia	.2	.6	.6	1.4
Unknown	.1	.6	.6	1.3
Vaccinium spp.	.1	.6	.6	1.3
Sanicula gregaria	.2	.3	.6	1.1
Phlox divaricata	.4	.1	.6	1.1
Smilax tamnoides var. *hispida*	.4	.1	.6	1.1
Smilax bona-nox	.3	.1	.6	1.0
Celtis laevigata	.2	.1	.6	.9
Lysimachia spp.	.2	.1	.6	.9
Quercus marilandica	.1	.1	.6	.8
Liquidambar styraciflua	.1	.1	.6	.8
Oxalis spp.	.1	.1	.6	.8
Passiflora lutea	.1	.1	.6	.8

Bundy, William T. in geology
Brown, Gordon E. in geochemistry
Christmas, J.Y. Jr., biochemistry
Crow, James W., in mathematics
Hallford, Charles R. in geology.
Harvey, Ira W., in physics
Loflin, Frank W. in physics
Mory, John L., in physics
Whatley, Richard S., geology

These students and their supervisors wrote three papers which appear in the 1965 Journal of the Mississippi Academy of Sciences.

Harvey, Ira W., Hendee, William R., and Priddy, Richard R., Electrical studies of Vicksburg loess.

Harvey, Ira W., Morey, John W., Christmas, J. Y., III., Crow, James W., Bundy, William T., Jr., Hendee, William R., and Priddy, Richard R., Record of loess and soil intervals in a 108-foot hole, Vicksburg, Mississippi.

Mory, John L. and Hendee, William R., Design and construction of a radiocarbon dating system.

Another paper was prepared for delivery at the November 19-20, 1964 Annual Meeting of the Geological Society of America at Miami Beach, Florida, pp. 156-157 of Program.

Priddy, Richard R., Hendee, William R., and Harvey, Ira W., Electrical device for detecting blankets of loess in fresh roadcuts.

Although the National Science Foundation sponsorship of loess investigations ended in May 1965, students and faculty of the Millsaps Geology Department continued the work on a limited basis through the academic years 1965-66, 1966-67, and 1967-68. There was a huge backlog of chemical and physical data to analyze, photographs to take in order to show progressive stages in weathering of loess roadcuts, snails and fossil carbon to collect for additional radiocarbon dating, and extensive X-ray and radiograph analyses to make of the hundreds of samples collected and stored in the Millsaps laboratories. Except for this extensive summary report of loess investigations, there has been but one small published contribution on the loess since May, 1965. It is in the Journal of the Mississippi Academy of Sciences for 1966, pages 130-131.

Priddy, Richard R., Snowden, J. O., Jr., and McDowell, L. L., Radiocarbon stratigraphy of Vicksburg loess.

Christmas, James Yancey, III (Sophomore, biology major) — processed maps and samples, helped drill holes, collected & cleaned snails, helped measure electrical conductivity. Plotted highway department physical data on loess.

Cupit, Thomas Lapell (Junior, biology major) — research in methods of flame photometery for Na and K analyses. Modified existing procedures.

Harvey, Ira Wilford (Junior, physics-chemistry major) — correlation of the several blankets of loess by means of differences in voltage and resistivity. Correlated lithology & conductivity.

Morrow, John Henry, III (Sophomore, ex-physics major) — with Chaney developed a method of measuring permeability of loess. Helped start electrical conductivity project.

Mory, John Louis (Junior, chemistry major) — rebuilt an old X-ray machine to perform C-14 analyses. Helped with electrical conductivity in the field.

Ward, Julia Griffith (Freshman, history major) — acted as secretary for project, collected and cleaned snails, prepared samples for flame photometry. Colored charts showing the chemical analyses of the loess.

Williams, James Aubrey (Senior, chemistry major) — research in flame photometry and control of flame's intensity. Compared K and Na content with the geochemical analyses of previous years.

These students, a few other students who were interested in the project, and the supervisors published four papers in the 1964 Journal of the Mississippi Academy of Sciences.

Morrow, J. H., Harvey, I. W., Cheney, E. L., and Hendee, W. R., Permeability measurements on loess from the Vicksburg area.

Priddy, Richard R., Bundy, William F., Jr., and Brown, Gordon E., An unusual fault, U.S. Highway 61, North, near Vicksburg.

Priddy, Richard R., Christmas, J. Y., III, and Ward, Julia G., Pseudoanticlines in Vicksburg loess.

Priddy, Richard R., Lewand, Raymond L., and McGee, Edward H., Several loess blankets in the Vicksburg hills.

PARTICIPANTS, THEIR DUTIES, AND THEIR PUBLICATIONS 1964-1965

The fifth (and last) year of the National Science Foundation sponsored Millsaps studies of the loess was titled "Stratigraphy of the Loess in West-Central Mississippi". Nine students worked on the investigation, five in geology and one in mathematics guided by Dr. Richard R. Priddy and three in Physics under the direction of Prof. Charles B. Galloway. The work was about evenly divided between the field and laboratory. In the field snails and fossil carbon was collected for radiocarbon dating, samples were collected from power driven test holes, and electrical measurements were made of (1) these holes and of (2) hand-auger holes which had been drilled in previous years and capped, and of (3) highway roadcuts. In the laboratories chemical analyses were correlated with physical analyses. Some radiocarbon analyses were performed. The student participants were:

Grissom, Charles Edgar (Senior) — retrapped species of **Peromyscus** in sufficient numbers to estimate population densities. Discovered that population patterns do not suggest either species affinity or seasonal response to surface water supply.

McDaniel, David Bordon (Sophomore) — helped in the program of establishing population densities in both loess and non-loessal areas.

Tangible evidence of student accomplishment in 1962-1963 are the following ten papers which summarize specific studies by the biologists and introduce the findings of the geologists. All have been published in the 1963 Journal of the Mississippi Academy of Sciences.

Caldwell, R. D. and Bell, Rondal E., A comparison of climatic factors of some forest communities in loess and loessal soils of West-Central Mississippi. Part II.

Caplenor, Donald, Scott, Alice, Ware, Stewart, Wells, Melanie, Some affinities of the forest communities of West-Central Mississippi.

Priddy, Richard R., National Science Foundation loess program at Millsaps College.

Bundy, W. Thomas, Pulmonate gastropod species in the loess of the Vicksburg-Jackson area.

Brown, Gordon E., Significance of perched water tables in the loess of Vicksburg-Jackson area.

Lewand, Raymond L., Grain size zonation in the loess of the Vicksburg-Jackson area.

Snowden, J. O., Jr., The heavy minerals of the loess of the Vicksburg-Jackson area.

Bellew, J. E., Caldwell, R. D., Grissom, C. E., and Bell R. E., A study of a population of **Peromyscus** species related to surface water supply.

Bell, R. E., Bellew, J. E., Caldwell, R. D., and Grissom, C. E., A sound-triangulation method for counting barred owls.

Grissom, C. E., Bellew, J. E., Caldwell, R. D., and Bell, R. E., A checklist of the birds of the loess hills of Warren County, Mississippi.

PARTICIPANTS, THEIR DUTIES, AND THEIR PUBLICATIONS, 1963-1964

The 1963-1964 Millsaps/National Science Foundation project was for a single year. It was a study of the Geology of the Loess in West-Central Mississippi. Only nine students were involved in the investigation, two in chemistry, three in geology, and four in physics. The students operated in the laboratory as teams but pooled their efforts for field work. Dr. Clifton Mansfield supervised the chemical work in flame photometry, Dr. Richard R. Priddy was in charge of geological investigations, and Dr. William R. Hendee guided the physics students.

Bundy, William Thomas (junior, geology major) — processed maps & samples, drilled hand-auger holes, collected & cleaned snails, helped measure electrical conductivity.

Chaney, Edward Larette (Junior, physics major) — helped construct a permeameter to measure permeability and resistivity of loess & loessal soils. Started electrical conductivity methods.

Coleman, Lawrence Arnold (Senior) — analyzing for Ca and Mg by successive titrations with ethylene diamine tetracetate (EDTA).

Lamb, William G. (Sophomore) — analysis of Fe, Al, Ca, Mg, and Si in loess and loessal soils. Used a resin-exchange column to devise a rapid EDTA-titrimetric method for Al which worked well with soluble aluminum but not for that aluminum which is a constituent of insoluble mineral grains.

Parker, Fred Gulton II (Sophomore) — analysis for the elemental constituents in loess and loessal soils.

Williams, James Aubrey (Junior) — processed loess and loessal soils for analyses of the following constituents: ferric oxide, alumina, silica, lime, and magnesia.

Student participants of the Geology Team in 1962-1963.

Directed by Richard R. Priddy, Prof. and Chairman, Dept. of Geology and J. O. Snowden, Jr., Instructor in Geology.

Brown, Gordon Edgar, Jr. (Sophomore) — studied perched water tables in loess, collected and cleaned pulmonate gastropods for x-ray diffraction and for radioactive-time studies, helped record and assess geochemical analyses. Wrote and delivered a paper.

Christmas, James Yancey, III (Freshman) — helped determine size of mineral grains in the loess by hydrometer method, helped make mounts of clay fractions for x-ray analysis, and helped separate the heavy minerals in the coarsest size fraction by suspending in tetrabromethane. Helped write a paper.

Williams, David Bass (Junior) — recorded physical, chemical, x-ray, and other radiation data in color on charts for the various hand-auger holes and various outcrops.

Student participants in the Mathematics Team in 1962-1963.

Directed by S. R. Knox, Statistician, Prof. and Chairman of the Mathematics Department.

Owen, Davis Lee (Junior) — worked with the biologists in their population studies. Made a theoretical study of a probability distribution that might apply to a population, the factors being finite population, fixed number of traps, and constant probability of being trapped. The team also continued analyzing meteorology data in order to determine water constants of loess derived soils and non-loessal soils.

Student Participants in the Zoology Team in 1962-1963.

Directed by R. E. Bell, Assistant Prof. of Biology.

Bellew, James Edgar (Junior) — trapped small mammals in order to ascertain population densities in loess and non-loess areas, as governed by surface water supply. Helped construct a parabolic sound amplifier for counting barred owls, as a means of determining small mammal population.

Caldwell, Richard Dale (Senior) — helped trap small mammals to ascertain population densities. Made monthly visits to NSF-Loess meterology station. Kept micro-climatic data. Helped count barred owls in predator-prey investigation.

Dodge, William Howard (Junior) — helped trap small mammals to determine population density by capture-recapture methods.

Meadows, David Leigh — trapline collecting. Made a survey by questionnaires of all counties in the State to determine the distribution of native mammals.

Wilkerson, George Edward — trapline collecting. Helped Meadows make questionnaire survey.

Tangible evidence of student accomplishment in 1961-1962 are the following papers:

Brook, Judith Lynn. 1962. Present vegetation on loess in West-Central Mississippi. Jour. Miss. Acad. Sci.

Caplenor, Donald, Brook, Judith, and Regan, Anne. 1962. Upland plant communities on deep loess, shallow loess, and clay soils in West-Central Mississippi. (Abs.) Assoc. Southeastern Biologists Bulletin Vol. 9, page 31.

Regan, Anne. 1962. The original forests of the Mississippi loessal hills. Jour. Miss. Acad. Sci.

Coleman, L. A., Mozingo, J. R., Price, J. B. 1962. Complexometric titrations for calcium and magnesium. Jour. Miss. Acad. Sci.

Alexander, A. H. D., Bullock, C., Cain, C. E. 1962. Chemical Analysis of loess and loessal soils. Undergraduate Research Symposium, University of Mississippi, April 20, 1962.

PARTICIPANTS, THEIR DUTIES, AND THEIR PUBLICATIONS 1962-1963

Student Participants of the Botany Team in 1962-1963.

Directed by C. Donald Caplenor, Prof. and Chairman, Department of Biology.

Scott, Alice Brunson (Junior) — comparing the plant communities of loessal and non-loessal soils of Central Mississippi in order to determine the effect of soil type and water supply.

Ware, Steward Alexander (Junior) — studying the plant communities of relatively undisturbed forests on loessal soils and comparison of these forests with other communities on non-loessal soil with respect to differences in these various communities and the reasons for the difference.

Wells, Carmen Melanie (Senior) — establishing the differences between flora on loessal and non-loessal soils, based on dominance, density, and frequency of the various species.

Student Participants of the Chemistry Team in 1962-1963.

Directed by C. Eugene Cain, Associate Prof. of Chemistry, assisted by R. A. Berry, Jr., Assistant Prof. of Chemistry, and J. B. Price, Professor and Chairman, Department of Chemistry.

Bullock, Cal Wilson, Jr. (Senior) — analyzed loess and loessal soil for attached water, water of hydration-carbonaceous content, and carbonate, lime and magnesia by gravimetric methods. Experimented with various photometric and titrimetric methods for speeding the analyses.

Calvert, William Ernest (Junior) — modified existing gravimetric methods for determining aluminum, iron, and calcium-magnesium content of some loess and loessal soils.

Student participants in the Chemistry Team in 1961-1962.

Directed by Joseph B. Price, Prof. and Chairman, Dept. of Chemistry and C. Eugene Cain, Assoc. Prof. of Chemistry.

Alexander, Albert H. D. (Senior) — helped determine water hydration, carbonate, iron, and silica content, delivered a paper in chemistry symposium on "Chemical Analyses of Loess & Loessal Soils".

Bufkin, William Jackson (Senior) — helped analyze for iron, calcium, and magnesium.

Coleman, Lawrence Arnold (Junior) — helped in varied analyses, co-authored with Mozingo & Price on "Complexometric Titrations".

Drais, John Harlan (Senior) — helped work out analytical procedures in 1960-1961 and 1st semester 1961-1962.

Mozingo, James Robert, Jr. (Senior) — complexometric titration for Ca and Mg using EDTA and checking iron by cerric sulfate redox titrations.

Student participants in the Geology Team in 1961-1962.

Directed by Richard R. Priddy, Prof. and Chairman, Dept. of Geology and Director of the NSF projects.

Alleman, Herbert Jackson (Sophomore) — helped drill hand-auger holes, made scaled, glass tube models of scaled samples of loess, tested for hygroscopic moisture, checked fluorescence.

Catlette, Dorothy Gray (Freshman) — kept Grant's report books & kept publicity. Helped make charts comparing physical, chemical, and geological data.

Doggette, Billy Carroll (Sophomore) — helped drill hand-auger holes, sieved samples, bottled size fractions.

Neitzel, Sara C. (Freshman) — helped make charts comparing physical, chemical, and mineral data. Filed reports.

Smith, Dean Edward (Sophomore) — helped drill holes. Collected pulmonate gastropods, made plastic apparatus and plastic models of minerals. Helped in microphotography.

Williams, David Bass (Sophomore) — helped drill holes and process the samples in the laboratory. Mimeographed data sheets.

The Mathematics Team in 1961-1962.

Directed by S. R. Knox, Prof. and Chairman Dept. of Mathematics.

Leggett, Robert Nelson, Jr. (Senior) — statistical analysis of microclimatic data furnished primarily by Caldwell, the student meteorologist.

Student participants in the Zoology Team in 1961-1962.

Directed by Rondal E. Bell, Assoc. Prof., Dept. of Biology.

Grissom, Charles Edgar (Sophomore) — trapline collecting of small mammals populating the loess areas, especially small mice. Analyzing populations.

McCaddon, Donald Miles — trapline collecting and preparing of specimens. Made a study of natural history of genus **Peromyscus**, a genus of mice.

Student Participants of the Geology Team 1960-61.

Directed by Richard R. Priddy, Prof. and Chairman, Dept. of Geology.

Alleman, H. Jackson — Freshman — Drilling, sample preparation and gross analysis, model preparation.

Lyons, Russell H. — Junior — Drilling, sample preparation, and gross analysis.

Moore, Willard S. — Junior — Drilling, sample preparation, log analysis.

Poole, Rex D. — Junior — Drilling, preparation of samples for microanalysis and microphotography.

Smith, Charles W. — Freshman — Drilling, sample preparation, microphotography.

Thompson, Don H. — Senior — Drilling, stenographer, and draftsman.

Tangible evidence of student accomplishment are the following papers prepared in March and April, 1961, presented at the April meeting of the Mississippi Academy of Sciences, and published in the Academy's 1961 Proceedings.

Libby, David R. and Bell, Rondal E. A comparison of climatic factors of some forest communities on loess and loessal soil of West-Central Mississippi.

Brook, Judith, Caplenor, Donald, Hughes, Charles, and Regan, Anne. Comparison of some forest communities on loess and loessal soils of West-Central Mississippi.

Ward, Robert P. and Ross, Vernon F. A home-range study of **Peromyscus** spp. as indicated by capture-recapture methods.

Ward, Robert P. and Woods, John E. An inexpensive live-trap for capturing small mammals.

Ward, Robert P., Billups, William A. Jr., and Lewis, A. Carter. A preliminary checklist of mammals inhabiting areas of the loess of West-Central Mississippi.

Ward, Robert P., Boone, Gary, and Ross, Vernon F. A preliminary report on the population density of some small mammals inhabiting forest areas of Hinds and Warren Counties, Mississippi.

PARTICIPANTS, THEIR DUTIES, AND THEIR PUBLICATIONS — 1961-1962

Student participants of the Botany Team in 1961-1962.

Directed by C. Donald Caplenor, Prof. and Chairman, Dept. of Biology.

Brook, Judith L. (Senior) — plant sampling, data analysis, literature review, report writing, authored a paper.

Regan, Barbara Anne (Senior) — plant sampling, data analysis, literature review, report writing, authored a paper.

Caldwell, Richard Dale (Junior) — studied microclimate of the area June through August (Summer Grant) and through 1961-1962 academic year, based on periodic readings of thermometers, hydrographs, rain gauges, and determinations of moisture in 10 foot hand-auger holes.

PARTICIPANTS, THEIR DUTIES, AND THEIR PUBLICATIONS — 1960-1961

Student participants of the Botany Team in 1960-1961.

Directed by C. Donald Caplenor, Prof. and Chairman, Dept of Biology.

Brook, Judith L. — Junior — Plant sampling, data analysis, literature review and report writing.

Hughes, Charles E. — Senior — Plant sampling, data analysis, literature review and report writing.

Regan, B. Anne — Junior — Plant sampling, data analysis, literature review and report writing.

Student Participants of the Chemistry Team in 1960-1961.

Directed by Joseph B. Price, Prof. and Chairman, Dept. of Chemistry.

Davis, Woody D. — Junior — Devising methods for soil analysis and analysis of soil samples provided by geology team.

Perry, John R. — Senior — Devising methods for soil analysis and analysis of soil samples provided by geology team.

Ward, Frazier E. — Senior — Devising methods for soil analysis and analysis of soil samples provided by geology team.

Wells, Alice H. — Junior — Devising methods for soil analysis and analysis of soil samples provided by geology team.

Student participants of the Meteorlogical Team 1960-1961 *& Summer* 1961.

Directed by Rondal E. Bell, Assoc. Prof., Dept. of Biology

Libby, David R. — Senior — Collection and analysis of microclimatic data, report preparation.

Caldwell, Richard D. — Sophomore — Collection and analysis of microclimactic data (started in latter part of spring and continued gathering data during the summer).

Student Participants of the Zoology Team 1960-1961.

Directed by Robert P. Ward, Assoc. Prof., Dept. of Biology.

Billups, William A., Jr. — Junior — Field collection and preparation of specimens, checklist report preparation.

Boone, A. Gary — Senior — Field collection and preparation of specimens, analysis of population densities.

Lewis, A. Carter — Senior — Field collection and preparation of specimens, checklist preparation.

Woods, John E. — Senior — Field collection and preparation of specimens, analysis of trapping program.

bership is shown below for each of the five years. Since all students contributed in some measure to collecting the data used in this Bulletin their individual projects are shown, many of which are of unusual interest. Also, the tangible evidence of their work in the form of a list of publications helps summarize each year's activity. Most of the papers can be read in the Journal of the Mississippi Academy of Sciences: Vol. VII 1961, Vol. VIII 1962, Vol. IX 1963, Vol. X 1964, Vol. XI 1965, and Vol. XII 1966.

SUMMARY ACKNOWLEDGMENTS

As intimated in Acknowledgements, this study would not have been possible were it not for funds from the National Science Foundation which supported five years of undergraduate loess research at Millsaps. There were three separate grants and one amendment, all part of the Undergraduate Research Participation Program.

The first project, a three year investigation, was:

A Comparative Study of Loess and Loessal Soils of West-Central Mississippi: The Chemical and Physical Properties and Their Influence on the Biotic Community — EO/43-2330 for September 1960 through May 1963 was for $34,065.00

which grant was supplemented in the summer of 1961 to measure

Microclimatic Control of Plant and Animal Communities in Loess and Animal Communities on Loess and Loessal Soils of West-Central Mississippi — G13334 .... $ 1,230.00

The second project was a one year investigation:

Geology of the Loess in West-Central Mississippi — E 3-43-3884 for September 1963 through May 1964 .... $ 5,600.00

The third project was for another year (the fifth):

Stratigraphy of the Loess in West-Central Mississippi 5/50/5/410-0178 for September 1964 through May 1965 .... $ 5,600.00

Total Grants $46,495.00

As the grants were aimed primarily at training students in research, most of the investigations were performed by students, several members of the Millsaps faculty supervising. The criteria for participant selection were:

1. Desire and apparent capability of the candidate to pursue a career in some area of science.
2. Previous scholastic achievement of the candidate.
3. Suitability of the candidate to the particular team's project and possible benefit to be gained by participation.
4. Vocational preferences of the candidate. Students were chosen, other things being equal, on the basis of the following vocational choices, in order. (a) College teaching and research, (b) public school teaching, (c) applied science professions, and (d) science-related professions.

Each year the participants were organized as teams, as the nature of the work required; in Botany, Chemistry, Geology, Mathematics, Meteorology, Physics, and Zoology. The team mem-

Table 20. Summary of the importance values of species in the herb layer whose importance value in any community equaled or exceeded 10.

Species:	Thick Loess	Creek Bottom Non-loess	Thin Loess	Upland Non-loess
	Importance Value			
Rhus radicans	75	----	6	37
Carex spp.	33	60	17	19
Polystichum acrostichoides	15	1	13	----
Arundinaria gigantea	11	4	36	----
Bignonia capreolata	11	9	5	----
Ampelopsis arborea	10	1	----	----
Nemophila microcalyx	10	----	----	----
Cystopteris fragilis	10	----	----	----
Viola spp.	19	----	3	1
Uniola sessiliflora	----	41	----	52
Panicum spp.	8	29	26	24
Mitchella repens	----	22	28	----
Elephantopus caroliniamus	----	12	----	----
Hordeum pusillum	----	----	56	----
Aster spp.	1	7	10	19
Pinus taeda and/or *echinata*	0.3	1	----	20
Desmodium spp.	2	2	8	18
Solidago spp.	----	2	9	17
Scutellaria spp.	----	----	----	13

Table 19. Summary of the importance values of species in the shrub layer whose importance value in any community equaled or exceeded 10.

	Importance Value			
Species:	Thick Loess	Creek Bottom Non-loess	Thin Loess	Upland Non-loess
Carpinus caroliniana	37	56	----	----
Cornus florida	27	3	11	----
Ostrya virginiana	21	3	32	----
Fraxinus americana	18	15	5	----
Hydrangea quercifolia	17	----	2	----
Tilia spp.	17	----	----	----
Carya cordiformis	16	----	----	----
Carya glabra	13	16	18	8
Hydrangea arborescens	13	----	----	----
Asimina triloba	12	----	----	----
Ulmus rubra	12	7	----	----
Quercus nigra	8	23	----	3
Smilax spp.	1	23	4	5
Ulmus alata	7	18	16	15
Callicarpa americana	2	13	5	----
Halesia spp.	1	11	8	----
Crataegus spp.	0.3	11	1	13
Acer rubrum	2	11	3	8
Vitis rotundifolia	----	10	4	41
Nyssa sylvatica	----	3	59	6
Hamamelis virginiana	8	2	19	----
Quercus alba	3	----	17	3
Quercus velutina	2	1	14	3
Vaccinium arboreum	----	----	11	----
Prunus serotina	5	1	11	----
Rhus radicans	----	----	----	54
Pinus taeda	----	----	----	29
Quercus stellata	----	----	----	26
Diospyros virginiana	----	----	----	10

Table 18. Summary of the importance values of species of trees in each community whose importance value in any community equaled or exceeded 10.

Name of Species	Importance Value			
	Thick loess	Creek Bottom Non-loess	Thin loess	Upland Non-loess
Liquidambar styraciflua	49	38	18	7
Tilia spp.	21	----	----	----
Liriodendron tulipifera	19	4	5	----
Quercus nigra	19	6	----	----
Quercus falcata var. pagodaefolia	16	6	----	----
Ulmus rubra and americana	15	11	3	----
Carya cordiformis	14	1	----	----
Fagus grandifolia	8	34	61	----
Carpinus caroliniana	9	31	----	----
Pinus glabra	----	29	----	----
Pinus echinata	----	17	----	41
Carya tomentosa	5	15	31	24
Quercus laurifolia	----	15	----	----
Pinus taeda	6	12	----	100
Quercus alba	6	10	23	33
Nyssa sylvatica	----	1	42	----
Quercus rubra var. *borealis*	----	----	33	----
Quercus velutina	4	1	33	2
Ostrya virginiana	12	5	31	----
Oxydendrum arboreum	2	2	21	----
Sassfras albidum	7	----	10	----
Quercus falcata var. falcata	----	----	3	35
Quercus stellata	----	----	----	20
Quercus phellos	1	2	----	12
Fraxinus americana	6	5	----	11

Table 16. Average actual percentages of water in thick and thin loess on basis of dry weight of soil. Weekly sampling for 3", 12", and 18" depth, from 12/19/1960 to 12/28/1961. Weekly sampling for 10' depth from 6/9/1961 to 12/19/1961.

Depth of Sample	% water, dry weight of soil as basis.	
	Thick loess	Thin loess
3 inches	28.3—1.58%*	21.2—1.54%
12 inches	26.1—1.26%	17.4—0.73%
18 inches	28.1—1.16%	18.1—1.25%
10 feet	11.7—0.42%	8.3—0.64%

* Standard error of the mean

Table 17. Water coefficients of soils of the various communities, expressed as percentages of dry weight.

% water by dry weight

	Thick loess	C. B. non-l.	Thin loess	Upland non-l.
Field Capacity	30.8 ± 1.2	21.7 ± 1.0	18.7 ± 1.7	19.4 ± 1.6
Permanent Wilting Point	11.0 ± 0.45	6.9 ± 0.52	6.2 ± 0.66	11.5 ± 0.65
Available Water	19.8	14.8	12.5	7.9

Table 13. Summary of certain climatic factors in thick and thin loess areas Oct., 1960—May, 1962.

	Region	
	Thick loess	Thin loess
Average weekly maximum, Air temperature	81.9 ± 0.87°*F	82.2 ± 0.97°F
Average weekly minimum, Air temperature	40.2 ± 0.90°F	44.6 ± 0.91°F
Average weekly mean, Air temperature	61.0 ± 0.88°F	64.0 ± 0.71°F
Temperature range	16—87°F	16—90°F
Average maximum relative humidity	94.5 ± 0.33%	96.3 ± 0.49%
Average minimum relative humidity	29.9 ± 1.65%	29.3 ± 1.36%
Average mean relative humidity	62.4 ± 0.90%	62.3 ± 0.80%
Relative humidity range	18—100%	14—100%
Total precipitation (10/1/60—7/9/61)	69.3 in.	78.4 in.
Average prec./week	1.101 in.	1.191 in.
Average weekly soil temperature—		
3 inch depth	54.8 ± 1.87°F	63.3 ± 0.75°F
18 inch depth	54.8 ± 1.42°F	59.9 ± 1.60°F

* Standard error of the mean

Table 14. Summary of mean percentages of CaO, MgO, and Fe_2O_3 in soils of the various communities.

	Thick loess	C. B. non-1.	Thin loess	Upland non-1.
%CaO	2.00	0.61	0.51	0.43
%MgO	0.64	0.12	0.33	0.07
%Fe_2O_3	3.46	2.84	5.85	3.85

Table 15. Mean pH of the soils of the various areas.

Area	Thick Loess		Thin loess		Upland non-1.		C.B. non-1.
pH	6.85 ± 0.15*		5.08 ± 0.04		4.75 ± 0.09		4.92 ± 0.09
Probability of larger value, "t" test		<——> $P < 0.001$		<——> $P < 0.005$		<——> $P \sim 0.2$	

* Standard error of the mean.

Table 12.—(Continued)

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Bidens bipinnata	.1	.1	.4	.6
Carya glabra	.1	.1	.4	.6
Ampelopsis arborea	.1	.1	.4	.6
Crataegus spp.	.1	.1	.4	.6
Gelsemium sempervirens	.1	.1	.4	.6
Hamamelis virginiana	.1	.1	.4	.6
Liquidambar styraciflua	.1	.1	.4	.6
Parthenocissus quinquefolia	.1	.1	.4	.6
Polygonum spp.	.1	.1	.4	.6
Quercus phellos	.1	.1	.4	.6
Ruellia humilis	.1	.1	.4	.6
Sambucus canadensis	.1	.1	.4	.6
Sanicula gregaria	.1	.1	.4	.6
Stellaria spp.	.1	.1	.4	.6
Ulmus rubra	.1	.1	.4	.6

Table 12. Herb layer of bottom land non-loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Carex spp.	30.8	18.9	10.0	59.7
Uniola sessiliflora	19.4	15.7	5.9	41.0
Panicum spp.	9.7	11.4	7.4	28.5
Mitchella repens	9.2	6.4	5.9	21.5
Rhus radicans	6.0	6.4	6.7	19.1
Unclassified grasses	8.9	3.2	3.7	15.8
Elephantopus carolinianus	1.5	6.0	4.8	12.3
Bignonia capreolata	1.5	1.7	5.6	8.8
Smilax spp.	1.0	1.4	6.3	8.7
Aster spp.	1.0	3.2	3.0	7.2
Rubus spp.	.6	3.7	2.2	6.5
Unknown spp.	.9	2.2	2.6	5.7
Arundinaria gigantea	.3	3.0	.7	4.0
Carpinus caroliniana	.5	1.6	1.8	3.9
Juncus effusus	2.1	.9	.4	3.4
Quercus nigra	.3	.9	2.2	3.4
Berchemis scandens	.3	.5	2.2	3.0
Acer rubrum	.3	.6	1.8	2.7
Aristolochia serpentaria	.4	.5	1.8	2.7
Botrychium dissectum	.3	.4	1.8	2.5
Euonymous americanus	.7	.6	1.1	2.4
Ilex opaca	.2	.6	1.5	2.3
Solidago spp.	.1	1.3	.7	2.1
Fraxinus americana	.4	.7	.7	1.8
Desmodium spp.	.2	.4	1.1	1.7
Acalypha virginica	.2	.3	1.1	1.6
Asarum ruthii	.2	.3	1.1	1.6
Vitis spp.	.3	.5	.7	1.5
Scutellaria spp.	.2	.5	.7	1.4
Callicarpa americana	.1	.5	.7	1.3
Carya cordiformis	.1	.5	.7	1.3
Lonicera japonica	.5	.4	.4	1.3
Acer negundo	.2	.3	.7	1.2
Eupatorium spp.	.2	.3	.7	1.2
Morus rubra	.1	.6	.4	1.1
Ulmus alata	.1	.3	.7	1.1
Celtis laevigata	.1	.2	.7	1.0
Oxalis spp.	.1	.2	.7	1.0
Pinus echinata	.1	.2	.7	1.0
Polystichum acrostichoides	.1	.4	.4	.9
Cornus florida	.1	.3	.4	.8
Lactuca spp.	.1	.3	.4	.8
Tovara virginiana	.1	.3	.4	.8
Commelina communis	.1	.2	.4	.7
Ascyrum stans	.1	.1	.4	.6

Table 11. Shrub layer of bottom land non-loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Carpinus caroliniana	10.0	35.6	10.2	55.8
Quercus nigra	8.8	6.4	8.0	23.2
Smilax spp.	7.9	6.7	8.0	22.6
Ulmus alata	6.3	5.3	6.5	18.1
Carya glabra	5.4	5.1	5.6	16.1
Fraxinus americana	5.4	3.8	5.6	14.8
Callicarpa americana	4.5	4.2	4.6	13.3
Halesia spp.	3.9	3.2	4.0	11.1
Crataegus spp.	4.5	1.8	4.6	10.9
Acer rubrum	3.6	3.5	3.7	10.8
Vitis rotundifolia	3.9	2.5	4.0	10.4
Liquidambar styraciflua	2.7	3.7	2.8	9.2
Berchemia scandens	3.3	1.1	3.4	7.8
Ilex opaca	3.0	1.4	3.1	7.5
Ulmus rubra	2.7	1.8	2.8	7.3
Celtis laevigata	2.4	.4	2.5	5.3
Carya cordiformis	1.8	.9	1.9	4.6
Pinus echinata	.9	2.1	.9	3.9
Bignonia capreolata	1.5	.5	1.6	3.6
Sambucus canadensis	1.5	.5	1.6	3.6
Symplocos tinctoria	1.5	.5	1.6	3.6
Unknown spp.	1.2	1.3	1.0	3.5
Nyssa sylvatica	.9	1.0	.9	2.8
Morus rubra	.9	.9	.9	2.7
Cornus florida	1.2	.2	1.2	2.6
Fagus grandifolia	.6	1.4	.6	2.6
Ostrya virginiana	.9	.8	.9	2.6
Hamamelis virginiana	.9	.4	.9	2.2
Quercus michauxii	.9	.4	.9	2.2
Acer negundo	.9	.3	.9	2.1
Sassafras albidum	.6	.7	.7	2.0
Rhus glabra	.3	1.1	.2	1.6
Liriodendron tulipifera	.6	.2	.6	1.4
Gelsemium sempervirens	.6	.1	.6	1.3
Hypericum spp.	.6	.1	.6	1.3
Morus alba	.6	.1	.6	1.3
Aralia spinosa	.3	.2	.2	.7
Ligustrum vulgare	.3	.2	.2	.7
Prunus serotina	.3	.1	.3	.7
Vaccinium spp.	.6	.3	.2	1.1
Rhododendron spp.	.3	.1	.2	.6
Carya tomentosa	.3	.1	.2	.6
Decumaria barbara	.3	.1	.2	.6
Quercus velutina	.3	.1	.2	.6

Table 10. Tree layer of bottom land non-loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Liquidambar styraciflua	12.6	14.1	11.5	38.2
Fagus grandifolia	10.1	14.4	9.4	33.9
Carpinus caroliniana	12.6	6.9	11.1	30.6
Pinus glabra	12.4	7.3	9.4	29.1
Pinus echinata	4.4	8.1	4.5	17.0
Carya tomentosa	5.4	3.8	5.9	15.1
Quercus laurifolia	4.4	8.2	2.4	15.0
Pinus taeda	3.1	4.4	4.9	12.4
Ulmus rubra and americana	4.1	1.6	5.2	10.9
Quercus alba	3.1	3.0	3.5	9.6
Carya glabra	2.3	4.4	2.8	9.5
Quercus michauxii	2.3	2.2	2.1	6.6
Ilex opaca	2.3	1.4	2.8	6.5
Celtis laevigata	1.3	3.7	1.4	6.4
Quercus nigra	1.8	1.6	2.4	5.8
Quercus falcata var. *pagodaefolia*	1.6	1.9	2.1	5.6
Fraxinus americana	1.6	1.4	2.1	5.1
Ostrya virginiana	2.1	0.9	1.7	4.7
Ulmus alata	1.8	0.4	2.1	4.3
Carya laciniosa	1.6	1.1	1.4	4.1
Liriodendron tulipifera	1.0	1.6	1.4	4.0
Quercus lyrata	1.0	1.9	1.1	4.0
Acer rubrum	1.0	1.1	1.4	3.5
Morus rubra	1.0	0.6	1.1	2.7
Cornus florida	1.0	0.2	1.4	2.6
Oxydendrum arboreum	0.8	0.7	0.7	2.2
Quercus phellos	0.5	0.6	0.7	1.8
Magnolia grandiflora	0.3	1.1	0.3	1.7
Prunus serotina	0.8	0.2	0.7	1.7
Hamamelis virginiana	0.5	0.3	0.7	1.5
Nyssa sylvatica	0.4	0.3	0.5	1.2
Aralia spinosa	0.4	0.1	0.5	1.0
Magnolia virginiana	0.3	0.4	0.3	1.0
Carya cordiformis	0.3	0.2	0.3	0.8
Quercus velutina	0.3	0.2	0.3	0.8
Acer negundo	0.3	0.1	0.3	0.7
Quercus shumardii	0.3	0.1	0.3	0.7

Table 9. Herb layer of upland non-loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Uniola sessiliflora	23.4	23.6	5.1	52.1
Rhus radicans	13.6	13.7	9.7	37.0
Pinus taeda and/or echinata	8.1	3.6	8.7	20.4
Carex spp.	7.6	6.2	5.6	19.4
Aster spp.	4.7	7.7	6.6	19.0
Desmodium spp.	4.9	4.4	8.7	18.0
Solidago spp.	6.2	6.2	4.6	17.0
Panicum spp. (Eupanicum)	6.6	4.9	5.1	16.6
Scutellaria spp.	4.1	2.8	6.1	13.0
Unknown spp.	2.5	2.6	3.1	8.2
Panicum spp. (Dichanthelium)	1.9	1.8	3.6	7.3
Grass (unclassified)	1.2	2.1	2.5	5.8
Eupatorium album	1.9	2.3	1.5	5.7
Vitis rotundifolia	1.9	1.3	2.5	5.7
Lespedeza spp.	1.3	2.3	1.5	5.1
Ruellia humilis	1.2	1.3	2.0	4.5
Houstonia spp.	.7	.7	2.0	3.4
Rubus spp.	.4	1.6	1.0	3.0
Gelsemium sempervirens	.7	.7	1.5	2.9
Silphium integrifolium	.4	1.0	1.5	2.9
Quercus phellos	.6	.5	1.5	2.6
Cirsium spp.	.2	1.6	.5	2.3
Elephantopus carolinianus	.4	.8	1.0	2.2
Berchemia scandens	.4	.5	1.0	1.9
Stylosanthes spp.	.6	.3	1.0	1.9
Quercus falcata	.5	.3	1.0	1.8
Sanicula gregaria	.4	.8	.5	1.7
Galium spp.	.4	.2	1.0	1.6
Oxalis spp.	.3	.3	1.0	1.6
Cyperus spp.	.3	.3	1.0	1.6
Quercus stellata	.2	.8	.5	1.5
Agrimonia spp.	.3	.2	.5	1.0
Acer rubrum	.2	.2	.5	.9
Botrychium virginianum	.2	.2	.5	.9
Cocculus carolinus	.2	.2	.5	.9
Crataegus spp.	.2	.2	.5	.9
Fraxinus americana	.2	.2	.5	.9
Potentilla canadensis	.2	.2	.5	.9
Quercus alba	.2	.2	.5	.9
Smilax spp.	.2	.2	.5	.9
Smilax bona-nox	.2	.2	.5	.9
Campsis radicans	.2	.2	.5	.9
Ulmus alata	.2	.2	.5	.9
Viola spp.	.2	.2	.5	.9

Table 8. Shrub layer of upland non-loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Rhus radicans	33.9	13.2	6.6	53.7
Vitis rotundifolia	23.4	9.7	8.3	41.4
Pinus taeda	6.9	14.2	7.7	28.8
Quercus stellata	6.5	13.0	6.3	25.8
Fraxinus americana	3.5	5.4	8.3	17.2
Ulmus alata	3.9	4.0	6.6	14.5
Crataegus spp.	2.4	5.0	5.4	12.8
Diospyros virginiana	1.3	3.6	5.4	10.3
Liquidambar styraciflua	1.5	5.2	2.9	9.6
Quercus falcata	1.9	3.8	3.7	9.4
Acer rubrum	1.6	3.1	3.2	7.9
Carya glabra	1.1	3.9	2.9	7.9
Nyssa sylvatica	.8	2.4	2.8	6.0
Carya tomentosa	.6	2.4	2.9	5.9
Vaccinium spp.	1.7	1.3	2.9	5.9
Osmanthus americanus	.6	1.8	2.3	4.7
Quercus phellos	.8	.9	2.9	4.6
Quercus velutina	.4	1.3	1.7	3.4
Ilex spp.	.9	1.0	1.2	3.1
Amelanchier arborea	.5	1.3	1.2	3.0
Gelsemium sempervirens	1.4	.4	.9	2.7
Quercus alba	.3	.8	1.4	2.5
Quercus nigra	.4	.4	1.7	2.5
Smilax rotundifolia	.7	.4	1.2	2.3
Smilax spp.	.6	.4	1.2	2.2
Quercus spp.	.3	.3	1.4	2.0
Ascyrum hypericoides	.3	.1	1.4	1.8
Berchemia scandens	.3	.1	1.4	1.8
Unknown	.1	.1	1.2	1.4
Cornus alternifolia	.2	.1	.6	.9
Smilax bona-nox	.2	.1	.6	.9
Ulmus americana	.1	.2	.6	.9
Pinus echinata	.1	.2	.3	.6
Kalmia latifolia	.1	.1	.3	.5
Parthenocissus quiniquefolia	.2	-----	.3	.5
Rosa spp.	.1	-----	.3	.4
Sassafras albidum	.1	-----	.3	.4
Vitis labrusca	.1	-----	.3	.4

----- Less than 0.05%

Table 7. Tree layer of upland non-loess area.

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Pinus taeda	33.0	42.6	24.7	100.3
Pinus echinata	12.0	16.2	12.9	41.1
Quercus falcata var. *falcata*	11.2	9.3	14.2	34.7
Quercus alba	11.2	10.3	11.7	33.2
Carya tomentosa	8.8	7.3	7.7	23.8
Quercus stellata	8.0	3.2	9.0	20.2
Fraxinus americana	3.2	3.0	5.2	11.4
Quercus phellos	4.0	3.7	3.8	11.5
Liquidambar styraciflua	3.2	1.5	2.5	7.2
Acer rubrum	1.6	1.3	2.5	5.4
Carya glabra	1.6	0.4	2.5	4.5
Quercus lyrata	.8	1.4	1.2	3.4
Quercus velutina	.8	0.2	1.2	2.2

Table 6.—(Continued)

Name of Species	Percent Total Density	Percent Total Dominance	Percent Total Frequency	Importance Value
Vitis rotundifolia	.1	.1	.6	.8
Ascyrum hypericoides	.1	.1	.6	.8
Crataegus spp.	.1	.1	.6	.8
Fagus grandifolia	.1	.1	.6	.8
Halesia spp.	.1	.1	.6	.8