Pleistocene geology and soils in southern Iowa

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UMI
Pleistocene Geology and Soils
In Southern Iowa

by

Karl A. Riggs, Jr.

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
Doctor of Philosophy

Major Subjects:  Geology
                Soil Morphology and Genesis

Approved:

Signature was redacted for privacy.

In Charge of Major Work

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Heads of Major Departments

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Dean of Graduate College

Iowa State College
1956
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INTRODUCTION

Throughout Iowa there are insufficient reserves of gravel and rock products available to meet the present and future roadbuilding needs of the state. Although some localities have sufficient reserves at the present time, in the future the shortage will affect the whole state. One solution to this problem is to develop ways to use the readily available materials.

Since loess and glacial materials occur at or near the surface throughout the state, these are the logical materials to study. Consequently a project entitled "An Investigation of Loess and Glacial Till Materials in Iowa" is in progress at the Engineering Experiment Station, Iowa State College.

To date work has been done on the loess of southwestern Iowa, east-central Iowa and northeastern Iowa. At present work is in progress on the sands of east-central and northeastern Iowa, the loess of northwestern Iowa, and on the loess and till of southern Iowa. This is a report on the progress of the southern Iowa study. Originally the southern Iowa area included the two southern-most tiers of counties starting with Page and Montgomery counties and extending eastward to Wayne and Lucas counties. In addition some information is included on work now in progress in Adair, Madison, Warren and Marion counties which clarifies findings in the original study area.

This study has the following objectives:

1. To determine by field and laboratory studies the areal and
stratigraphic variation of the loess and glacial till materials which are significant for the interpretation of engineering soil properties.

2. Develop working hypotheses, where needed, which more adequately explain the origin and characteristics of soils and Pleistocene deposits. This will increase the prediction value of engineering soil properties, aid in the application of soil stabilization techniques, aid in the location of materials beneficial to soil stabilization, and help predict the location of conventional aggregates.

3. Improve our understanding of geologic and pedologic processes especially where they have application in the theory and design of engineering structures. This will permit the most efficient use of earth materials for structures and foundations, and in many cases reduce the size, the strength or even eliminate structures requiring scarce aggregates.

These objectives involve the following specific problems:

1. Set up a sampling system which will produce rapid, efficient and representative sampling. The system must be flexible enough so that the intensity of sampling can be increased to meet the needs of future research and economic projects. This will make it possible to directly compare the data of future projects with the data in this report. It must also permit comparison with previous work in southwestern and northeastern Iowa.
2. Determine the regional, local and stratigraphic variations in petrography. At present, the most important aspect of petrography in engineering seems to be particle size distribution, clay mineralogy and the dominant minerals in the silt and sand fractions.

3. Determine how soil properties correlate with the common soil series and their horizons. This will make the published soil maps more valuable to the engineer.

4. The geologic and pedologic problems involved are:
   a. Mechanism of landscape evolution and its effect on the sedimentation, distribution and variation of soil materials.
   b. Origin of the loess, till and gumbotil from the viewpoint of sedimentation, weathering, diagenesis, deformation and relative age.
   c. Origin and composition of the clay fraction within the till, gumbotil, loess and soil horizons.
   d. Nature and mechanism of weathering because the soils and Pleistocene deposits are thought to be strongly influenced by weathering.
   e. The basic explanation for the distribution of soils and soil association areas.

This report summarizes the progress on investigation of the till, loess and gumbotil soils in southern Iowa. To date, 120 loess samples from 20 different sites, 50 till samples from 12 different sites and 7 gumbotil samples from 7 different sites have been studied.
Except where indicated otherwise, the particle size classification of the United States Department of Agriculture (Soil Survey Staff, 1951, p. 207) is used.
REVIEW OF LITERATURE

Pleistocene Geology

A vast amount of literature is available on the region but little of this is directly applicable to the major objectives of the study. Most of it includes little or no information on texture and mineralogy of the unconsolidated sediments.

One of the earliest reports which included comments on the Pleistocene deposits and soils of Iowa was written by D. D. Owen (1852). Among much other material, this report made a few general statements about the glacial drift, the loess and the soils of the region. Another early generalized description was given by White (1870).

In the succeeding years numerous papers were published on the area. The report by Miller and Kay (1941) is especially interesting to the present study. It reviews and quotes extensively earlier ideas concerning Pleistocene deposits in Iowa. Mechanical analyses and lithologic analyses are given for gravels from all over the state.

A large number of county geologic reports were made by members of the Iowa Geological Survey. Among these were reports by Bain (1898), Calvin (1901), Arey (1910; 1920), Tilton (1920), Lugn (1927), and Wood (1941).

None of these presented information of direct interest to the present study. Bain (1898, p. 292-293) and Arey (1910, p. 227-228) pointed out that the gumbotil was more closely related, stratigraphically,
to the loess in some exposures and more closely related to the till in others. Numerous other studies, which have little or no direct bearing on this study, are published in the national scientific journals and in the Proceedings of the Iowa Academy of Science. Most of this material has been summarized by Kay and Apfel (1928, p. 70-133; 1944, p. 70-133). A bibliography of the Pleistocene of Iowa is included in the work of Kay et al. (1944).

Kay and Apfel (1928, p. 40-45) recognized the broad flats of southern Iowa, and noted that the regional trends of these flats were gently sloping toward the Missouri, Des Moines, and Mississippi Rivers. They also noted that the flats were least dissected in the east. They interpreted the flat-topped divides as remnants of a former glacial drift plain.

Kay and Apfel (1928, p. 63-65) considered the topography 3 to 20 miles east of the Missouri to be the direct result of thick loess deposition. They state that the Missouri River is the chief source of the loess.

Kay and Apfel (1928, p. 109) considered the gumbotil to be the product of weathering because of the decrease downward of aluminum oxide and a pronounced increase downward of calcium oxide and magnesium oxide. However, some gumbotils contain carbonate concretions (Kay 1944, p. 143-146). No absolute criteria are given by Kay for distinguishing between Kansan and Nebraskan gumbotils, but elevations and thicknesses of the gumbotils are relied on heavily. The Kansan gumbotils average 11 feet in thickness and the Nebraskan average 8 feet. Kay and Apfel (1944,
p. 141) state that Nebraskan till is definitely distinguishable from Kansan till only when Nebraskan gumbotil separates them. They include many stratigraphic descriptions, and give data on the particle size distribution of various till, gumbotil, loess and interglacial strata. Some petrographic data on the gravel fraction of these strata is presented.

**Loess and Soils**

A bibliography of the loess has been compiled by Davidson, Chu and Sheeler (1951).

Kay and Graham (1944, p. 156-203) report that the mechanical analysis of the loess indicates a decrease of particle size toward the east. There is a decrease in thickness east from the Missouri River. As the Mississippi River is approached from the west, the loess increases in thickness again. Heavy mineral analyses of the till and loess are similar; so, the till was inferred to be the ultimate source of the loess.

The literature on the origin of the loess has been surveyed by Russell (1944). In the same publication he reports on his studies of the lower Mississippi valley loess. He restricts the term loess to massive silts which are rich in carbonate concretions and gastropods and concludes that it is a backslope deposit which has crept downslope, accumulated carbonates, incorporated snails and developed all of the other loessial characteristics.

Handy (1953) has reported on the properties of the loess of southwestern Iowa. His traverses ran northwest to southeast primarily in a
belt adjacent to the Missouri River valley. His data indicate: loess becomes less permeable with increasing distance from the Missouri valley, depth of oxidation is shallower on hillsides, in-place density increases with distance from the east valley wall, in-place density increases with depth, moisture holding capacity of the loess increases with depth and distance from the Missouri valley, clay content increases with increasing distance from the traverse origin, clay mineralogy is uniform, and mixed layer illite-montmorillonite dominates the clay fraction. Included chemical data indicates that the clay has a cation exchange capacity of approximately 60 milliequivalents per 100 grams for clay finer than 2 microns. The unleached loess has pH values of approximately 8.5, and the leached loess has pH values of approximately 7.

Swanson (1938) made a microscopic study of the soil structure of Marshall and Shelby soils. This included microscopic descriptions, staining tests and pH measurements. His work reveals that the Marshall has a more porous ground mass throughout the profile than the Shelby. The Marshall ground mass was found to be rather uniform throughout the profile whereas the Shelby increased in density with depth. Staining tests indicated that each soil is high in silica colloids and low in iron and alumina colloids. Colloidal material was found to increase with depth. This colloidal material is concentrated more in the ground mass than in the connecting channels. Carbonate crystals were observed projecting from the sides of channels.
The pH ranges from approximately 5 to 8 in both soil series. The B horizon of the Marshall has a pH of approximately 6 and the B horizon of the Shelby was approximately 5.

Regional studies of loess-derived soils in southern Iowa by Hutton (1948) and Ulrich (1949) are of special interest. Working with the Brunizem soils along two northwest-southeast traverses, Hutton concluded that the coarser loess was deposited near the source area, loess thickness decreases with increasing distance toward the southeast, soils on thick loess have slight profile development in the B horizon, and soils on thin loess have strong profile development in the B horizon.

Ulrich worked with Brunizem, Wiesenboden and Planosol soils in the same area as Hutton. Working along two southeast traverses, he established the following relationships with increasing distance from the Missouri River: increase of clay content in the B horizon, increase of volume weight, and decrease of aeration, total porosity and permeability.

Numerous other soils investigations have been conducted within the area. Among these are the Soil Survey Reports by Hall et al. (1918), O'Neal et al. (1919), Lounsbery et al. (1920), O'Neal et al. (1924; 1926), Elwell et al. (1927), Simonson (1941), and Scholte et al. (1954). These plus numerous other local studies indicate that the soils are primarily developed from glacial till, loess and alluvium. By far the dominant type are the members of the Brunizem Great Soil Group. The characteristics and genesis of the Brunizems have been summarized by Smith, Allaway and Riecken (1950).
The Gray-Brown Podzol Great Soil Group is second in importance. The Gray-Brown Podzols are most common on the highly dissected uplands adjacent to the major streams. They cover an important part of the landscape only in Decatur and Lucas counties.

The properties of the various soil series are summarized by Simonson, Riecken and Smith (1952, p. 63-69, 78-88, 91-94, 107-110). The boundaries of the soil associations as outlined by them are shown in Figure 2.

Simonson (1954) has written on the fossil soils of the area. He considers the gumbotil to be a buried soil horizon, and gives data to support the theory.

Concept of Pedimentation

Since the literature on the pediment landform and its formation is so vast, no attempt is made to completely outline the history of the concept. However, a brief review of some of the essential developments will adequately develop the concept for the uninitiated.

Gilbert (1877) was the first to mention the landform now called the pediment. However, McGee (1897) first proposed the term. The intermontane surfaces described by McGee were cut in bedrock and covered with little or no alluvium. He believed that the plane surfaces were cut by sheetflood erosion under desert conditions. Bryan (1923) considered the pediment as a slope of transportation between the mountain slope and the alluvial plain. He thought the pediment was cut by streams formed by convergence of sheet wash. He also emphasized the importance of slope retreat. Bryan (1935, p. 766) gives the following: "Pediments,
by definition, are plains of erosion and therefore develop through time within the area available and with relation to a baselevel that may be static, changing continuously or fluctuating”.

Thornbury (1954, p. 286-296) presented a brief resume of the major developments of the pediment concept in arid landscapes. Hunt (1940) compiled a bibliography on pediments and pedimentation. Tator (1952; 1953) reviewed the characteristics and terminology of pediments which had been proposed by various workers. Sharpe (1940, p. 361-362) reviewed typical examples of pediments and the proposed mechanisms of pedimentation. He concluded that the dominant process of pedimentation would depend on geologic, climatic and topographic conditions.

Bryan (1940, p. 266) suggested that slope retreat is the dominant process of landscape evolution in all climates. He also implied that pediments would form under all climates. Frye and Smith (1942) described surfaces similar to pediments on the high plains of Kansas. These surfaces were developed in a semi-arid climate but differed from arid pediments only in scale, geographic setting and their areal pattern. They considered slope retreat and lateral corrasion by minor streams to be the dominant processes. King (1948) advanced pediplanation as the mode of continental planation. This involved the extensive retreat of slopes and the survival of planed remnants called pediments which eventually coalesced to form pediplains. King (1950) went so far as to explain the major plain and plateau surfaces throughout the world by the process of pediplanation.
Ruhe (1956) made regional and detailed studies of erosional surface in the Belgian Congo. He demonstrated that these surfaces were formed by pedimentation under a humid tropical climate. Ruhe (1956, personal communication) reports that detailed studies in Pottawattamie, Cass, and Adair counties, Iowa reveal that slope retreat and consequent formation of pediments is the dominant process of landscape evolution in that area.
PETROLOGY OF SOILS

Introduction

The purpose of studying the petrography of the loess and till is to explain the regional variations in the engineering properties, the vertical variation in the till and loess soils, and the mechanism of soil development. It is also desired to use mineralogy as a tool in deciphering the relative ages and the origin of till and loess.

For the regional studies mechanical analysis and differential thermal analysis seem most rapid and important. Many engineering and agronomic properties of soils are determined by particle size distribution. Likewise many genetic factors are revealed by mechanical analysis. Differential thermal analysis seems to be a good approach to regional mineralogy for two reasons. First engineering properties are strongly influenced by the type of clay minerals present. Secondly the clays constitute a major fraction of the soils and therefore differential thermal analysis provides a mineralogical comparison for a large portion of the particle size range.

In addition detailed mineralogy of the soil profile and parent materials of a till and a loess Brunizem is desired. These tend to indicate the mineralogical changes taking place in the profile as weathering and soil formation proceed. Furthermore, it indicates any great mineralogical differences that may exist between the loess and the till. This will aid in the interpretation of soil stabilization data, help to decipher the geology of the region, and help interpret agronomic data.
To achieve these ends a sampling technique had to be developed. Actually this is no small problem in itself. Practical considerations limited the time, funds and the number of samples that could be used, and yet samples, which would be representative, had to be obtained. Since knowledge of direct application to the present project was almost nonexistent, a technique had to be used which would circumvent the need for previous knowledge. Furthermore the available knowledge had been acquired with different practical and/or philosophical goals in mind. Therefore it could be expected to emphasize some phenomena of little interest and overlook phenomena of vast significance to the present study.

It was readily apparent that some system of random sampling would solve this problem very easily. Actually two different techniques were used to locate the sample sites of the glacial till and the loess. However, the same philosophy served as a basis for both techniques.

Both the till and the loess sampling systems proved to be simple, efficient and rapid methods of selecting sites. It is difficult to imagine how the previous training and experience of the worker could bias the results. It certainly met the practical needs of the project.

**Sampling Procedure**

**Purpose of the till procedure**

One of the main objects of the procedure is to reduce the influence of the operator in the selection of the sample sites. The writer wanted to determine the nature of a typical till in the area as a check on
observations made by previous workers. This meant that the sample site would have to be selected largely without the use of previous training and experience.

It was desirable to determine the relationship between the properties of the till sediment and the different sola developed from it. Only three major types of sola are developed from till in the area. These types are classified in the Regosol, the Brunizem, and the Gray-Brown Podzol Great Soil Groups. The engineering properties of the Regosols could be inferred satisfactorily from the A and C horizons of the Brunizems; therefore, they were eliminated from consideration. A number of series are now recognized in the Brunizem and Gray-Brown Podzol groups; however, on most published soils maps these are mapped as Shelby or Lindley soils respectively. In the present study these two subdivisions are sufficient and so it is convenient to use Shelby and Lindley as series names throughout the report.

Since the data would be used in soil engineering studies, it was desirable to concentrate the sampling where till soils might be important in the design of structures. This would determine the expectable local variations. However, it was also important to determine the regional variation since till soils are encountered to some extent throughout the area. The need for large quantities of samples for engineering tests, meant that deep roadcuts were preferred.

Locating till sites

First an outline map of the area was prepared. This was drawn to show the counties and also to show each group of four sections as one
square supersection. These supersections were numbered.

Next the total acreage of all Brunizems (Shelby) and Gray-Brown Podzols (Lindley) developed from till were estimated for each county from the literature (Hall et al., 1918; O'Neal and Rhodes, 1919; Lounsbury et al., 1920; O'Neal and Devereaux, 1924; O'Neal and Boatwright, 1926; Elwell and Moran, 1927; Simonson, 1941; Simonson et al., 1952; Scholtes et al., 1954).

Available funds limited the effort to 12 sample sites. Therefore, it seemed best to represent the two series by selecting 8 Shelby sites and 4 Lindley sites. This gave the Lindley proportionately higher representation, but it seemed that this was necessary to fulfill the practical goals of the project.

The region was divided into 4 areas and 2 Shelby sites were assigned to each area. The first area consisted of Adams, Montgomery, Page, and Taylor counties. The second included Ringgold and Union counties. The third group included Clarke and Decatur counties. Lucas and Wayne counties made up the fourth.

The Lindley sites were assigned to Clarke, Decatur, Lucas and Wayne counties because Lindley soils are sparse in the other counties.

Next the appropriate number of supersections was selected for each group of counties. To insure that these selections would be free of bias, the supersections were picked using a table of random numbers. As soon as a supersection was picked, the published soil map was checked for the desired series. If the desired series was absent another selection was made. Furthermore alternates were selected as a precaution.
in case field study revealed there were no suitable sites. If there was no published soil map, a larger number of alternates was selected.

Next each supersection was visited in the field. All roadcuts on the east and south sides and within the supersection were plotted on a sketch map. Roadcuts on both sides of the road were plotted and therefore visiting the roads on the north and east sides would have resulted in a theoretical duplication. The roadcuts were selected for depth, lack of slumping, minimum apparent erosion of topsoil and minimum apparent disturbance of the solum. If there were several equivalent sites within the same supersection, numbers were assigned to them and the number selected by drawing from a freshly shuffled pack of playing cards.

The sites selected are given in Table 1 and shown in Figure 1.

**Purpose of the loess procedure**

The underlying philosophy in this procedure was to minimize the influence of the operator also.

In addition there was a desire to obtain more information about the origin of the loess, the possible source areas of the loess, the relationship of loess properties to the solum developed from the loess, and the dependence of engineering properties on these basic geologic factors. It was also desirable to collect the samples in such a way that the results could be correlated with the previous work of Hutton (1948), Ulrich (1949), Davidson and Handy (1952), and Lyon et al. (1954).

Furthermore deep cuts exposing the base of the loess and its underlying materials were desired. One reason was a large amount of sample
Figure 1. Map of area showing sampling sites.

was needed for the engineering tests. Secondly it was desired to determine the vertical variations in the loess both for engineering purposes and theoretical purposes. Third, but by no means of less importance, it was hoped that the stratigraphic relationships of the loess, till and gumbotil might shed some light on the origin of the loess and gumbotil.

**Locating loess sites**

It was decided that a series of traverses would be most appropriate because previous studies seemed to indicate that the loess properties were gradational over the area.

First the northwest-southeast traverses of Hutton (1948, p. 424) and Davidson et al. (1952, p. 250) were extended into the area. Then the southwest-northeast traverses of Lyon et al. (1954, p. 291) were extended into the region. Finally additional traverses were added approximately parallel and at approximately the same interval as the extended traverses so that the area was covered with a grid pattern.

At each intersection of the grid lines, a sample site was established. If the potential site proved to be near a major stream valley, another site was selected further away from the valley before field investigation. Each one of these sites was visited in the field. First a four square mile area was investigated around the point determined by the grid. If this did not locate a satisfactory exposure, the eight square mile area around the point was investigated. In this manner a larger and larger area was searched until a suitable site was located. In most cases a site could be established within the area of four square miles. In all
cases the first suitable site discovered was used.

The only criteria used in the selection of cuts were: completeness of exposure, lack of slumping, minimum apparent erosion of topsoil, and minimum apparent disturbance of the solum. The sites selected are given in Table 1 and shown in Figure 1.

Petrographic Reconnaissance

Mechanical analysis

Till. Mechanical analysis was performed on all till samples collected. The actual procedure of mechanical analysis is presented in Appendix C.

Taking the region as a whole, the particle size distribution of the till is remarkably uniform. The small regional variation is shown by Figure 4. It is important to point out that there does not seem to be any regional trend in the distribution of texture. In fact the maximum variation exists between the texture of samples 403 and 404. The sites are approximately a mile and a half apart in Lucas County (Fig. 1).

Likewise, as far as the till itself is concerned, the vertical variation in particle size distribution is slight. This is well illustrated in Figure 3. The only major variation is where there is a gravel, sand, silt or clay lens. In other words, the major vertical variations can be readily estimated in the field.

Using Trask's sorting coefficient, the till is very poorly sorted. This arises primarily because the high clay content gives a very small
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<th>Sample site</th>
<th>Section</th>
<th>Tier &amp; range</th>
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<th>County</th>
<th>Soil series</th>
<th>Parent material</th>
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Table 1 continued

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<td>Clinton</td>
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Figure 3. Vertical variation in the particle size distribution of (a) three typical till, and (b) three typical loess soils in southern Iowa. Some gravel is included with sand in till soils. See figure 1 for locations of sample sites.
equivalent diameter for the third quartile.

The till itself seems to have a characteristic size distribution which produces a flat, gently curving cumulative distribution on semi-logarithmic graph paper (Fig. 4). In many cases the distribution is bimodal.

Furthermore there does not seem to be any major difference between the particle size distribution of the subsoil for a Gray-Brown Podzol and the subsoil of a Brunizem. Although there is some variation within these two groups, there is less variation between the subsoil of the Gray-Brown Podzols and the Brunizems than there is within the classes.

Gumbotil. The gumbotils are thought to be weathered till and therefore should have a particle size distribution similar to till except for the high clay content. Most of the gumbotils sampled in this study seem to be loess with an exceptionally high clay content. Since these were taken from cuts originally chosen for loess by random selection, this seems to be quite significant. In the field these have all of the properties of gumbotil. Figure 5 summarizes their particle size distribution.

Loess. Taking the region as a whole, the particle size distribution of the loess is remarkably uniform. Figure 6 shows the variation. This variation is essentially systematic across the area. In general the clay content increases to the south and east with the maximum clay content in the southeast. The amount of clay in the B horizon depends primarily on the Great Soil Group and the topographic position. However, for the same Great Soil Group, the maximum clay content in the B horizon increases to the east and to the south. In other words the B horizons
Figure 4. Range of particle size distribution of till samples. All are composite samples of the calcareous till.

Figure 5. Particle size distribution of umbrelle, till-like Kumholtsw 500-7, 501-0, 51-17, Kumholtsw 501-8.

Figure 6. Range of particle size distribution of Loess samples. All data are for air-dried samples taken 2 to 3 feet below the top of the C horizon.
in the southeastern part of the area tend to have the highest clay content.

The loess is uniform in texture from near the base of the loess up to the base of the solum. This is illustrated in Figure 3. However, at the base of the loess there is always a sandy layer which is approximately 6 inches thick. The range in its texture is shown in Figure 8.

Using Trask's sorting coefficient, the loess is very poorly sorted. This arises primarily because the high clay content gives a very small equivalent diameter for the third quartile.

The sand content is very low. In fact most of the sand over 0.074 mm. is actually small, black and/or brown concretions.

Comparison of till and loess. One of the most interesting features is that the C horizon of the loess and the C horizon of the till have about the same range in clay content. The till ranges from 27-36% material finer than 0.002 mm. and the loess ranges from 27-37% material finer than 0.002 mm.

It may also be significant that the range of particle size distribution below 0.005 mm. is almost the same for till and loess (Fig. 7).

The particle size distribution of the loess is distinctly different from the till above 0.005 mm., however. The most noticeable difference is the low sand content of the loess as compared to the high sand content of the till. Furthermore the loess, although poorly sorted, is much better sorted than the till.

One of the most interesting relationships between the loess and till is illustrated by Figure 8. This shows a complete gradation between the particle size distribution of the A horizon of the till and the sandy
Figure 7. Comparison of particle size distribution of till and loess. All till samples are composite samples of calcareous till. All loess samples are six inch samples taken 2 to 3 feet below the top of the C horizon loess.

Figure 8. Range of particle size distribution for A horizon of till soils and for sandy basal loess.
base of the loess. This becomes even more interesting when it is compared with Figure 7. From the two sets of data it is observed that, as far as range is concerned, there is a complete gradation from loess, sandy basal loess, A horizon of till and till itself. It should be noted, however, that this is for samples from different sites. The overlapping of textural composition is not necessarily true for any one sample site. In the field there usually is a gradational contact between the till, the sandy basal loess and the loess.

**Differential thermal analysis**

**Procedure.** All samples were air dried and gently ground. That portion passing the U. S. #40 sieve was further ground and sieved through a U. S. #325 sieve. This material, finer than 44 microns, was placed in an atmosphere of 50% humidity for at least two weeks. Then the sample was heated to approximately 1000° C using the apparatus described in Appendix C. If excessive organic matter was present, the analysis was run in a nitrogen atmosphere. All of the A horizon samples were run in a nitrogen atmosphere for clay mineral identification.

**Till.** The curves (Figs. 9, 10) suggest that illite and montmorillonite are the dominant clay minerals in the samples. Illite appears to be the dominant clay in most samples simply because of the pronounced and clear-cut endothermic reaction at 550° C. The initial curve at 100° to 115° C on occasion implies that montmorillonite is the dominant clay. The dominance of montmorillonite is more often indicated in the B horizon and the non-calcareous till than in the A horizon or the calcareous...
Figure 9. Differential thermal analysis curves of till and loess Brunizems. 409-1, A horizon of Shelby; 409-2, B horizon of Shelby; 409-3, calcareous till; 512-1, A horizon of Grundy; 512-2, B horizon of Grundy; 512-4, non-calcareous loess. See figures 1 and 3.

Figure 10. Differential thermal analysis curves. 405-1, A$_1$ horizon of Lindley; 405-2, A$_2$ horizon of Lindley; 405-3, B horizon of Lindley; 405-4, non-calcareous till; and 405-5, calcareous till. See figures 1 and 3.
till. Even without the X-ray data, the curves suggest a mixed-layer type of clay, and it is more a matter of deciding whether montmorillonite or illite dominates in the clay grains. A slight deflection of the dehydration curve at 175° to 200° C suggests the presence of vermiculite. This effect is noticed in all horizons from soils in Adams and Page counties. It is also observed in various samples from other horizons and counties. It could be merely the effect of a hydrated divalent cation between the layers of montmorillonite. At any rate the vermiculite, if present at all, constitutes less than 4% of the total sample.

Another interesting feature of many curves is a very broad and flat endothermic reaction starting at approximately 600° or 650° C and extending to 850° or 900° C. This often grades into the endothermic reaction which illite and the montmorillonites give at 850° to 900° C. The reaction at 850° to 900° C is always very diffuse and in many cases is not indicated at all. Likewise the exothermic reaction which is commonly reported from 900° to 950° C is very poorly represented by a broad exothermic hump.

It may be significant to pedogenesis that the broad endothermic reaction from 600° to 900° C is poorly defined in all of the A horizon samples. This reaction persisted in a sample which had been leached with 1N HCl. Furthermore it occurs in non-calcareous samples as well as calcareous samples; therefore, it is not a carbonate reaction. A sample was heated to 600° C for 15 minutes without leaching and the endothermic reaction occurred again when the sample was heated above 600° C.

A well defined quartz endothermic peak occurs in many samples at approximately 575°C. This reaction is strongest in the A horizon samples.
Calcite is strongly indicated in all calcareous till samples.

By far the most intense reaction is the organic matter reaction. The interesting feature is that in some instances there are two exothermic peaks and in others there is only one. If two exothermic peaks are present, they may be unequal or subequal. Even when there are two exothermic peaks, the valley never approaches the reference level. At most it only declines one third of the peak height. The organic reaction starts at approximately 200°C and ends at approximately 500°C. The A horizon always has an extremely strong organic matter reaction. Most of the B horizon samples also have a low, broad exothermic reaction interpreted as organic matter. Rarely is this pronounced enough to necessitate a nitrogen atmosphere.

Gumbotil. The thermal analysis curves for the gumbotil samples (Fig. 11) reveal that the gumbotil clay is similar to the clay of other till horizons. In fact the range of variation of gumbotil and till samples is the same. There is more variation between gumbotil samples than there is between the gumbotil and the other horizons of the till.

Loess. The curves (Figs. 9, 11, 12) suggest that illite and montmorillonite are the dominant clay minerals in all the horizons of the loess. These are probably combined in a mixed-layer clay. Judging from the endothermic dehydration peak at 100° to 110°C, the dominant micelle may be montmorillonite. The endothermic peak at 550°C is never as strong in the loess samples as it is in the till.

In a few C horizon loess samples, an endothermic peak occurs at 175° to 200°C which may suggest the presence of vermiculite. However, it
Figure 11. Differential thermal analysis curves for sandy basal loess and gumbotil. Samples 500-7, 502-6, and 512-6 are sandy basal loess. Samples 500-8, 501-8, 502-7, 504-6, and 506-7 are gumbotil. See figure 1 for locations of samples.

Figure 12. Differential thermal analysis curves. 500-1, A horizon of Marshall; 500-2, B horizon of Marshall; 500-4, non-calcareous loess or C horizon of Marshall; and 502-1, A horizon of Ladoga; 502-2, B horizon of Ladoga; 502-5, non-calcareous loess or C horizon of Ladoga. See pages 1 and 3.
could merely be due to the dehydration of a divalent cation in montmorillonite. This reaction appears in about one third of the samples.

In most samples an endothermic reaction takes place between 600°C and 900°C. This reaction is identical, apparently, to the reaction of this range that occurs in the till. However, it is never so pronounced as in the till. In some instances this reaction does not appear when the sample is run in a nitrogen atmosphere even though it does appear when the sample is run in a natural atmosphere.

Except for the organic matter reaction, no significant differences exist between curves for samples from the A horizon, B horizon, C horizon and the sandy base of the loess.

The organic matter reaction is pronounced only in the A horizon. The organic matter content in the other horizons never is sufficient to make the mineral reactions. In fact only a few B horizon samples have a significant organic exothermic reaction. There is no significant organic matter reaction for the sandy base of the loess. The organic matter reaction of loess is always one single broad peak. It is never double-peaked as in some till samples.

An endothermic reaction at 575°C, interpreted as a quartz lattice inversion, is present to some degree in all loess samples.

Detailed Petrography

Procedure

Composite samples were taken of the A, B and C horizons of a typical loess-derived Brunizem and a typical till-derived Brunizem. These were
air-dried and split on a Jones' sample splitter. Part of the sample was used for mechanical analysis and part was used for mineral analysis. The mechanical analyses are illustrated in Figures 3, 13 and 15.

The soil samples were elutriated according to the procedure presented by Handy, Davidson and Chu (1955, p. 15-18). The coarse fraction was sieved on U. S. sieve numbers: 270, 140, 60, 20, and 10. The material coarser than 0.5 mm. was studied under the binocular microscope without being mounted in Canada Balsam. Each fraction under 0.5 mm. was mounted in Canada Balsam and studied under the petrographic microscope. An oil immersion lens was necessary for the 5 to 10 micron fraction.

At least 300 mineral identifications were made for each size fraction. These were converted to percent and then recalculated as percent of the whole sample using the mechanical analysis data. The results are expressed graphically in Figures 14 and 16. In Tables 2 and 3, the total mineral composition of each horizon is indicated. The group referred to as miscellaneous light minerals consists primarily of muscovite. Altered feldspar includes all feldspar in which over 5% of the grain is converted to some alteration product. All minerals which could be expected to sink in bromoform (sp. gr. = 2.87) are included in the heavy minerals group.

X-ray spectrometer data were collected for the till sample and the loess sample studied in detail. The data were needed to supplement the clay determination made by differential thermal analysis, and to determine mineral composition finer than 5 microns. Only a limited number of samples could be analyzed because of the inaccessibility of the X-ray equipment. However, the size distribution, differential thermal analysis and the
Figure 13. Particle size distribution of the Shelby profile.

Figure 14a. Mineral composition by weight for A horizon of Shelby.

Figure 14b. Mineral composition by weight for B horizon of Shelby.

Figure 14c. Mineral composition by weight for calcareous till of Shelby.
color of these samples represented an average of the samples throughout the area. Therefore it is thought these data reveal the essential features of the typical clays in the region.

Some trial samples were run on material sieved through a U. S. #325 sieve (0.044 mm.), material less than 0.44 mm. and ground for 4 hours, less than 0.005 mm. material obtained by elutriation and less than 0.002 mm. material obtained by sedimentation. The less than 0.044 mm. material was inadequate for clay mineral identification although clear cut peaks for quartz and feldspar were obtained.

The material finer than 0.005 mm. gave fair data for the identification of clays; however, they could be understood best only after the less than 0.002 mm. material had been run. The material finer than 0.002 mm. was most valuable for determining the composition of the clays. Both untreated samples and samples treated with ethylene glycol were run.

Till

Profile. On the basis of field description, mechanical analysis and differential thermal analysis, sample site 409 appears to be a typical till Brunizem which is classified as Shelby in this report. Site 409 is located in a roadcut in the SW¼ of SW¼ of SE¼, section 23, T68NR31W, Benton Township in Ringgold County. The profile is as follows:

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<th>Horizon</th>
<th>Depth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
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<td>A₁</td>
<td>0-10 inches</td>
<td>Very dark brown (10YR2/2 moist) clay loam.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Granular structure. No reaction with dilute hydrochloric acid.</td>
</tr>
<tr>
<td>Horizon</td>
<td>Depth</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>B₁</td>
<td>10-17 inches</td>
<td>Yellowish brown (10YR5/4 moist) clay. Granular structure. No reaction with dilute hydrochloric acid.</td>
</tr>
<tr>
<td>B₂</td>
<td>17-27 inches</td>
<td>Yellowish brown (10YR5/4 moist) clay. Fine to medium blocky structure. No reaction with dilute hydrochloric acid.</td>
</tr>
<tr>
<td>B₃</td>
<td>27-54 inches</td>
<td>Yellowish brown (10YR5/4 moist) clay. Poorly developed medium blocky structure. No reaction with dilute hydrochloric acid.</td>
</tr>
<tr>
<td>C</td>
<td>4.5-10.5 feet</td>
<td>Light yellowish brown (10YR6/4 moist) clay loam. Medium blocky structure. Violent reaction with dilute hydrochloric acid. Carbonate, brown (limonite), and black manganese oxide concretions are very common.</td>
</tr>
</tbody>
</table>

**Petrography.** The gravel content is very low in all three horizons. Its petrography was not determined because it is minor.

All of the miscellaneous rock types occur in material coarser than 0.5 mm. A great variety of rock types exist in the 0.5 mm. to 2 mm. fraction, but the most important are: various granites and granodiorites, quartz sandstone, graywacke, gneiss, schist, greenstone, shale, quartzite and slate.

The iron oxide concretions are noticeably higher in the A and C horizons than in the B horizon. The concretions are typically rounded
to ovoid masses which are easily scratched with a knife. Under the microscope, they seem to consist of masses of silt grains and opaque material. Some are quite hard and apparently siliceous. Presumably the opaque material consists of hematite, limonite, manganese oxides and clay.

The carbonates are present in both the B and C horizons; however, they are important only in the C horizon. They constitute less than one percent of the B horizon. The carbonates are evenly distributed throughout the size fractions from 5 microns to 2 mm. in the C horizon, but they occur from 0.25 up to 2 mm. in the B horizon. Some carbonate grains have well developed crystal faces.

Muscovite and biotite are concentrated in the 5 to 10 micron fraction in all three horizons. Some flakes have partially developed crystal faces. In the B horizon an interesting mica-like material exists in the 5 to 10 micron fraction. This material seems to have properties similar to a mica, but it has a slight greenish tint. Partially developed pseudo-hexagonal crystal faces occur on some of the grains. It may be exceptionally large grains of illite or some similar mineral.

The heavy minerals are concentrated in the 5 to 10 micron fraction and the 10 to 20 micron fraction ranks second for the total heavy mineral fraction. The total quantity of heavy minerals is nearly equal in all three horizons, but if the differences are significant, they are slightly more abundant in the A horizon.

The composition of the heavy mineral suite is approximately the same in all three horizons. The dominant minerals are: zircon, tourmaline, titanite, rutile, brookite and amphibole. The heavy minerals of secondary
Table 2. Mineral composition

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</tr>
</tbody>
</table>
importance are pyroxene, monazite, garnet, spinel, staurolite and chlorite. However, many other minerals occasionally occur including grains of fluorite.

An examination of Table 2 reveals that the feldspar content is approximately equal in all three horizons. Furthermore quartz is highest in the A horizon and lowest in the B horizon. It is interesting to note that there is only three percent difference in the quartz content between the A and C horizons.

In the B horizon (Fig. 14b) a definite secondary mode occurs in the 5 to 10 micron fraction. It is interesting to note that there is a net increase in the amount of unaltered feldspar in this fraction as compared to fractions coarser than 20 microns.

One of the most interesting features is the occurrence of alteration products within the feldspars. The alteration products are useful to help distinguish feldspar from quartz, and they may have considerable significance which will be clarified later. Invariably, if there is any pattern at all, the alteration products appear to line up parallel to possible cleavage planes. Furthermore the alteration products are highly birefringent and therefore apparently crystalline. There is a complete gradation from perfectly clear, unaltered feldspars to grains almost completely altered.

As the mineral analysis was conducted, careful attention was devoted to the roundness and sphericity of the grains. The grains ranged from well rounded to highly angular in all size fractions of all horizons. As a refinement of this evidence, sphericity and roundness were estimated
visually from the comparison charts of Krumbein (1941, Pl. 1) and Rittenhouse (1943, p. 80-81, Fig. 1) for the 0.074 mm. to 0.105 mm. fraction. A count of 50 grains was made for both the A and C horizons. The values for sphericity are 0.77 and 0.79, and for roundness are 0.29 and 0.30 respectively for the A and C horizons. There does seem to be a difference between the roundness for quartz and feldspar, however. The roundness for quartz for the A and C horizons are 0.25 and 0.27 respectively. The roundness for feldspar is 0.34 in both the A and C horizons. In other words feldspar is slightly more rounded than quartz, but there is no profile variation in roundness and sphericity. Quartz and feldspar grains with perfect and imperfect crystal faces occur in minor amounts in all three horizons.

Loess

Profile. After the mechanical analyses and differential thermal analyses had been run, sample site 512 appeared to be a typical loess soil and was centrally located within the boundaries of the project area.

Sample 512 is a typical upland Brunizem which would be called a Grundy silty clay loam in the current classification. This was taken in a roadcut at the southeast corner of the NE^1 of NE^1, section 4, T71NR27W, Doyle Township, Clark County. The profile is as follows:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-12 inches</td>
<td>Very dark grey (10YR3/1 dry) silty clay loam. It has a granular structure. No reaction with dilute hydrochloric acid.</td>
</tr>
<tr>
<td>Horizon</td>
<td>Depth</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>-------------------------------------------------------</td>
</tr>
<tr>
<td>B2</td>
<td>12-26 inches</td>
<td>Dark gray (10YR4/1 moist) with strong brown (7.5YR5/6 moist) mottles. Silty clay. Fine to medium blocky structure with clay skins. No reaction with dilute hydrochloric acid.</td>
</tr>
<tr>
<td>B3</td>
<td>26-46 inches</td>
<td>Olive gray (5Y5/2 moist) with strong brown (7.5YR5/6 moist) mottles. Silty clay loam. Coarse angular blocky structure with clay skins. No reaction with dilute hydrochloric acid.</td>
</tr>
<tr>
<td>C</td>
<td>46-100 inches</td>
<td>Gray-brown (2.5Y5/2 moist) with strong brown (7.5YR5/6 moist) mottles. Silty clay loam. Medium to coarse blocky structure. No reaction with dilute hydrochloric acid. Black concretions 1-2 mm. in diameter. Worm and root channels.</td>
</tr>
</tbody>
</table>

**Petrography.** The total content of brown and/or black concretions is about the same in all three horizons. However, most of the material greater than 0.074 mm. is composed of concretions. Apparently the concretions consist of mixtures of hematite, limonite, manganite, clay, silt and perhaps silica. In the A horizon over 90% of the material coarser than 0.25 mm. is composed of the concretions. In the B horizon, almost all of the material over 0.105 mm. is made up of the concretions. In the C horizon approximately two-thirds of the material coarser than 0.105 mm.
Figure 15. Particle size distribution of the Grundy profile.

Figure 16a. Mineral composition by weight for A horizon of Grundy.

Figure 16b. Mineral composition by weight for B horizon of Grundy.

Figure 16c. Mineral composition by weight for non-calcareous loess of Grundy C horizon.
consists of these concretions.

The carbonate content is negligible throughout the profile. Most of the grains have crystal faces.

The muscovite content is similar throughout the profile. However, it is strikingly higher in the 5 to 10 micron fraction than in any other. It is approximately twice as abundant, percentagewise, in the 5 to 10 micron fraction as it is in the 10 to 20 micron fraction. In the same sense, it is twice as high in the 10 to 20 micron fraction as it is in all coarser fractions. Its percent fluctuates throughout the other size fractions, but it is essentially constant.

The heavy mineral content is similar in all horizons but it may be significantly lower in the A horizon. The dominant heavy minerals are amphibole, pyroxene and biotite. The other important heavy minerals are: zircon, tourmaline, monazite, rutile, garnet and staurolite. A large number of other minerals are present in trace amounts.

The amount of amphibole is approximately the same in all three horizons. There is much less pyroxene in the A horizon than in the other horizons. Apparently its decrease explains most of the lowering of the total heavy mineral content in the A horizon. Conversely there seems to be a slight increase of relatively resistant rutile in the A horizon.

The heavy minerals are highest in the 10 to 20 micron fraction in the B and C horizons and in the 20 to 53 micron fraction in the A horizon. They decrease in importance as the particle size increases and above 53 microns they are negligible.
An examination of Table 3 indicates that the feldspar content is a maximum in the C horizon and lowest in the B horizon. Furthermore, the altered feldspar is a maximum in the A horizon and approximately the same in the B and C horizons. The altered feldspars are most abundant in the 20 to 53 micron fractions of the A and C horizons. However, altered feldspars are most abundant in the 10 to 20 micron fraction of the B horizon. The secondary maximum of altered feldspar in the A and B horizons is the 10 to 20 micron fraction. The alteration products in the feldspar tend to be lined up parallel to apparent cleavage planes. Most of the grains are highly angular and seem to have a sphericity similar to the till. No profile or size fraction variations seem to exist for sphericity and roundness. Some feldspar and quartz grains in the 5 to 53 micron fractions of all horizons have imperfect and well-developed crystal faces.

The quartz content is lowest in the B horizon and approximately the same in the A and C horizons.

X-ray study of the clay fraction

The X-ray data indicates that the clay mineralogy of these two profiles is the same and that a mixed-layer clay dominates both the till and the loess. Therefore the results for both the till and loess profiles are discussed together.

The following information is based primarily on data obtained from the samples finer than 0.002 mm, and secondarily on data obtained from samples finer than 0.005 mm. The clay peaks are very subdued in the samples finer than 0.005 mm. The results are shown in Figure 17.
Table 3. Mineral composition

<table>
<thead>
<tr>
<th>Grundy soil</th>
<th>% by weight</th>
<th>% by recalculation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizon</td>
<td>A 512-9</td>
</tr>
<tr>
<td>Sample number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartz</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>Total feldspar</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Miscellaneous light</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Heavy minerals</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Carbonates</td>
<td></td>
<td>T</td>
</tr>
<tr>
<td>Iron oxide concretions</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Clay (minus 0.005 mm.)</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>Clay (minus 0.002 mm.)</td>
<td></td>
<td>38</td>
</tr>
<tr>
<td>Altered feldspar</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Quartz/feldspar (ratio, not %)</td>
<td></td>
<td>1.9</td>
</tr>
</tbody>
</table>
Figure 17. Spectrometer curves for X-ray diffraction of the minus 2 micron clay. Numbers above curves are spacings in Angstrom units. Shelby samples are: 409-1, A horizon; 409-2, B horizon; and 409-3, calcareous till. Grundy samples are: 512-9, A horizon; 512-10, B horizon; and 512-11, C horizon loess.
The broad reflection from this group ranges from approximately 10Å to 16Å. In most samples the 10Å peak is sufficiently separated from the main bulge to suggest that at least some illite is present as a distinct species.

Furthermore superimposed on the main hump are several minor peaks. These could be accidental but they are consistent enough to suggest that there may be some chlorite, vermiculite, and/or montmorillonite present as distinct species. This broad reflection is shifted to a slightly higher basal spacing when a sample treated with ethylene glycol is run; therefore, there must be some montmorillonite present in the mixed layer micelle. At any rate the X-ray data and differential thermal reactions both indicate that the mixed layer clay is composed predominantly of illite and montmorillonite micelles.

Kaolinite is the third most important clay in the samples; however, it probably does not exceed 10 or 15%. It is slightly more abundant in the till samples. There are no major differences in the clay mineral composition between the A, B and C horizons of either the loess or the till.

Quartz is indicated to some extent in all samples finer than 0.002 mm. However, quartz would hardly exceed 10% in the material finer than 0.002 mm. The material finer than 0.005 mm is somewhat different. In this fraction, the quartz peaks are well developed and apparently quartz constitutes approximately 20% of the sample.
Discussion of Petrology

Sampling

The sampling technique proved to be very practical. In the till soils it gave the local and regional texture range. Examples of minimal, medial and maximal profiles were obtained for both the Brunizems and the Gray-Brown Podzols. Likewise soils developed from both calcareous and non-calcareous till were represented. In the loess sampling, the various Brunizem series and the Gray-Brown Podzol series were adequately represented.

The number of samples used in this study is adequate where it is desired to determine the expectable variations and trends. However, in some types of design and construction, where local variations are important, it will be desirable to use a larger number of samples.

Texture

The results indicate that the till of southern Iowa tends to have a particle size distribution which can be established between broad limits. This range is indicated in Figure 4. The local variations within a mile or so exceed the regional variations of the till. The vertical variation at any one site is minor within the till itself; however, such obvious anomalies as gravel, sand and silt lenses create a tremendous local variation in the drift. As far as soil stabilization is concerned the vertical variation will be insignificant at most localities. There does not seem to be any correlation between the subsoil texture and the solum developed from it; therefore, the agronomic series for till soils will
not correlate very well with the engineering properties of the subsoil.

The loess has a particle size distribution which seems to be distinctive from that of the till. It is poorly sorted, but this is due solely to the large amount of material which is finer than 5 microns. In other words if most of the clay has been formed since deposition, then the loess was well sorted when first deposited. The loess has a very low sand content. In fact most of the sand actually measured is due to concretions which could easily have formed since deposition.

In contrast to the till soils, there is a close correlation between the texture of the loess and the solum developed from it within any one Great Soil Group. Therefore agronomic soil maps will be quite valuable to the engineer by giving an approximate measure of the texture of the loess. Since the loess soils cover the greater part of the area, engineers and geologists will find agronomic soil maps quite useful.

Many gumbotils may not be due to weathering of till. Random sampling revealed that 5 out of 7 gumbotils were actually a loess-like material with a high clay content. Since previous workers rigorously selected their gumbotils as ideal examples, the earlier ideas about gumbotil may prove to be an oversimplification.

The sandy basal loess has a range in particle size distribution intermediate between the loess and the A horizon of till derived soils. Since a gradational contact normally exists between the gumbotil, the sandy basal loess and the loess, the sandy basal represents the zone of mixing between the till material and the loess. This mixing is a product of mass creep of the loess.
Significance to stabilization

As a group, the differential thermal curves for till, loess, gumbotil and all soil horizons are very similar. This suggests that the bulk clay mineralogy of all of these materials is the same. This is extremely valuable information because it means that clay composition is a variable that can be largely ignored. At least within the area of the present study, clay content is a much more important factor.

The X-ray data indicate that a mixed-layer illite montmorillonite dominates the clay fraction. The slight shift of the peak (Fig. 17) suggests that illite is the predominant type of micelle in the mixed-layer clay. The minerals of secondary importance in the clay fraction are illite, kaolinite and quartz. Therefore the exchange sites on these clays will occur primarily on the surfaces and edges of the micelles. For this reason determination of surface area will be valuable in the development of stabilization techniques.

Because of disturbance and mixing by construction, the variation of total feldspar and quartz content between the various horizons of the soil profile probably will not be of importance in either the till or the loess. However, comparing the data in Tables 2 and 3 with the data obtained by Handy (1953, p. 69, Table 4) indicates that there may be more variation in quartz and feldspar content between different loess soils in the region than between till and loess soils. The differences between loess and till in total content of quartz and feldspar may be important because of the differences in size distribution of the predominant minerals.
The mineralogy of the soils are similar and the particle size distributions are similar at least in the finer fractions. Therefore the same basic techniques of soil stabilization will apply to all horizons of the till and loess. The variation in clay content, silt content and silt mineralogy may necessitate variations in amount of stabilizing agent on a local as well as a regional scale. This may be especially true when the till soils are used.

Because the texture is related to the soil series in most cases, agronomic maps should prove to be useful in soil stabilization.

The gumbotils differ from the till and loess primarily in the total clay content. Therefore their undesirable characteristics seem to be related primarily to poor drainage and a high moisture retaining capacity. Control of the drainage and minor variations in the method of stabilization should make them perform satisfactorily as foundation and road materials.

Till

The quartz/feldspar ratio in the A, B and C horizons seems rather anomalous. It would seem legitimate to think that the A, B and C horizons had about the same composition originally. However, the raw data implies that quartz grains have been added to the A horizon and subtracted from the B horizon.

Theories of soil formation for the soils of this area consider the B horizon as the zone of clay accumulation (Hutton, 1948, p. 89; Ulrich, 1949, p. 132). This concept suggested arbitrarily recalculating the
composition of the B horizon on the basis of 37% less than 5 micron clay instead of the measured content of 50%. The A and C horizons are also recalculated on the basis of 37% minus 5 micron clay since the A horizon has 37% finer than 5 microns. This does not reproduce the original minus 5 micron content, but it serves as a basis for comparison (Table 2). Doing this reveals that the B and C horizons have about the same quartz content and the A horizon has a higher quartz content than the B or C. Likewise the heavy mineral content in the B and C horizons is approximately the same whereas the heavy mineral content is approximately 0.5% higher in the A. Since mineral analyses are correct to plus or minus one percent, this is hardly significant.

The other constituents are present in such small amounts that recalculation does not affect their percentages significantly.

Pursuing this further, it is noticed that the A and C horizons have about the same feldspar content whereas the B horizon has approximately 3% feldspar than the A or the C.

Looking at Figure 14, other relationships are noticed. First of all most of the feldspar above 20 microns in the B horizon and above 53 microns in the A and C horizons is altered. However, the feldspar finer than 10 microns is not altered in any of the horizons and the feldspar content in the 5 to 10 micron fraction is nearly equal in all three horizons. The B horizon has a secondary mode in the 5 to 10 micron fraction.

Other interesting relationships arise if we assume that the A and C horizons were originally identical. Comparing quartz, muscovite, feld-
spar and total heavy minerals of the A and C horizons suggests that these minerals have been, or at least tend to be, fractured into finer fractions. Presumably a similar process would occur in the B. This may explain the secondary mode in the 20 to 30 micron fraction of the A horizon and the secondary mode in the 5 to 10 micron fraction of the B horizon.

It may also explain why the 5 to 20 micron fraction of the A horizon is slightly higher than the 5 to 20 micron fraction of the C horizon.

The A and C horizons have approximately the same percent of material finer than 5 microns, but the distribution is quite different. This suggests that the minus 5 micron clay tends to decompose into finer clay.

All of these phenomena suggest that weathering is more intense near the soil surface.

Several facts already described are also worth noting. One is the presence of clay micelles within the feldspars. Another is the greater roundness of feldspars as compared to quartz. A third is the presence of crystal faces on a few feldspar and quartz grains.

The following hypothesis is advanced to explain these relationships. First, weathering of feldspars is considered to be partially a surface reaction as indicated by laboratory experiments (Correns and von Engelhardt, 1938). Dissolution of the grain boundaries should produce a gradual rounding of the grains, and therefore the higher roundness of the feldspars suggests that they are more readily dissolved than quartz. Next, the presence of clays within the feldspars suggests that clay growth splits the feldspar grain down into finer particles. This produces smaller feldspar grains and clay particles. This may also explain the
changes in particle size distribution of micas and some heavy minerals. The fine feldspars and clays may then be carried into the subsoil by downward seeping ground water, through root channels, dessication cracks and other large soil pores. The evidence for this latter hypothesis is in the higher clay content of the B horizon, perhaps the secondary feldspar mode in the B and the clogged soil pores of Shelby soils as reported by Swanson (1938, p. 61).

However, the secondary feldspar mode, if real, could also be explained by the formation of authigenic feldspar in the B horizon. The mechanical analysis of samples from different levels in the B horizon suggests that the secondary mode actually exists in the lower portion of the B.

The presence of feldspars with crystal faces may be additional evidence of such a phenomenon. Likewise this may explain why the feldspar content in the 5 to 10 micron fraction is the same in all three horizons and why the feldspars in the 5 to 10 micron fraction are clear and unaltered. Boswell (1953, p. 87-105) has reviewed the literature on authigenic minerals and especially feldspars. Baskin (1956) reviews the literature on authigenic feldspars in sediments and contributes to the chemical understanding of the phenomenon.

Authigenic formation of feldspar is favored by a high pH. Swanson (1938, p. 59) reports that the pH of Shelby B horizons is usually lower than the pH of the A or C horizons. Since the calcareous till underlies the B horizon at this site, it is conceivable that capillary waters could rise into the B horizon from a high water table. Under these con-
ditions it is conceivable that the higher pH might temporarily favor the formation of feldspar in the B horizon. However, fresh water moving downward would readily flush away any carbonates or salts that might tend to form from the alkaline ground waters. This interpretation may be favored by the fact that carbonates coarser than 0.25 mm do occur in the B horizon.

Another major question appears to be whether feldspar splitting, feldspar solution or feldspar growth is the dominant process. Continuing with our assumption that this is a typical Shelby profile, it would appear that feldspar splitting is the dominant process in southern Iowa. The difference in roundness is so slight that it does not seem possible that solution could be the major process. The slight increase of feldspar in the B horizon and the presence of feldspars and quartz with crystal faces suggests that some feldspar growth may occur, but it certainly is not the dominant process in this profile.

Assuming for the moment that the hypothesis of feldspar splitting is the correct one, a mechanism must be presented. The hypothesis presented by Frederickson (1951, p. 221-223) seems to explain the actual observations and the laboratory studies of McClelland (1950) may provide supporting evidence.

In brief, hydrogen ions are free to migrate through holes in the feldspar lattice. Since the hydrogen ion has a relatively large charge per unit area as compared to sodium or potassium, the hydrogen ion can replace the alkali ion and force the alkali ion to migrate from the lattice.
This is possible primarily because of two basic chemical conditions. First, the hydrogen ion can only have a coordination number of two; consequently, it is highly attracted to two oxygens. The remaining oxygens are partially repelled by the charges of their neighbors. This causes an expansion of the crystal lattice so that the alkali ions can leave the lattice.

Secondly, the alkali ions migrate toward the interface because of the high concentration within the lattice and the low alkali concentration outside of the lattice. The expansion of the lattice permits the process to proceed at a faster rate. Furthermore, the expansion of the lattice strains some of the SiO₄ bonds and so the SiO₄ units are chemically more reactive.

Under these circumstances the writer visualizes the regrouping of the ions into the octahedra and tetrahedra of a phyllosilicate. Furthermore, along an incipient cleavage plane sufficient irregularities may exist to permit the entrance of water molecules themselves. However, it is conceivable that water could form in the feldspar lattice by the union of migrating hydrogen ions and oxygen ions released by the breakdown of the lattice. At any rate the cleavage planes would tend to be less stable chemically than other zones in the lattice and so in many cases phyllosilicates would tend to grow parallel to them.

Loess

Using the same assumptions as in the till, the loess composition was recalculated on the basis of 42% material finer than 5 microns because that is the minus 5 micron content of the C horizon (Table 3).
On this basis the heavy mineral content for the B and C horizons is approximately the same. The heavy mineral content remains lower in the A horizon. Furthermore the quartz content in the B and C horizons is nearly the same but it is several percent higher in the A. The feldspar content remains nearly the same in the A and B horizons, but it is about 2% higher in the C. This may not be significant but it could indicate that authigenic feldspar is crystallized from ions in solution in soil water. This would explain the feldspars with crystal faces. Authigenic feldspar is normally reported from an alkaline environment and all horizons of loess are neutral to acidic (Ulrich, 1949, p. 290-291). On the other hand, water of capillary rise, a perched water table or a high water table may produce a temporary alkaline environment in the loess. This temporary condition might exist for a few weeks at a time and at least once a year. The feldspar content of the C could also mean that ground water in the C horizon slows down the weathering rate.

Apparently the loess has been weathered enough so that the relative content of quartz has been slightly increased in the A horizon. Likewise weathering appears to have gone far enough so that the feldspar in the A and B horizon has been slightly reduced, much of the pyroxene has been eliminated from the A horizon, and a slight relative increase of rutile has been achieved in the A horizon.

The origin of clay in the loess and loess-derived sola is an interesting problem. The work of Ulrich (1949) indicates decreasing porosity, permeability and total aeration, and increasing volume weight as the clay content increases to the southeast. The decreases in porosity and per-
meability, and increase in volume weight are most prominent in the profiles where the clay content is highest. This implies that the clay has been added into the interstices. This could be by weathering or by some other mechanism. However, it does not seem that sedimentation would create these porosity and permeability relationships.

Hutton (1948) concluded that at least some of the clay was due to migration of clay finer than 0.2 microns. He considered this to be a product of weathering. The rest of the clay he concluded was deposited with the loess. Undoubtedly some of the clay is from initial deposition, and some is from weathering.

It is extremely improbable that the trend in clay contents reflect sedimentation. In fact Handy et al. (1954, p. 285, Fig. 8) found that aeolian dust from a Kansas dust storm of 1954 had a higher clay content near Great Bend, Kansas than it did at Ames, Iowa. If experimental error is considered, then there was no change in clay content by transportation and deposition over a distance of approximately 300 miles.

Let us also consider the possibility that the clay is transported as aggregates. Then one could consider the possibility of gravity separation. Birch (1942, p. 7-13) gives the density of the minerals of interest. The densities range from 2.5 to 3.0 gm/cm³. There is a complete overlapping of the density range of the alkali feldspars, quartz and the clay minerals. If anything, the clays should be deposited near the source area. However, anyone who has tried to separate minerals of widely different densities, for example orthoclase and rutile, in an undisturbed heavy liquid will appreciate the improbability of such a
mechanism. The slightest disturbance of the liquid results in an imperfect separation and deliberate stirring as the liquid drains results in little or no separation. As the particle size becomes smaller, these tendencies become more pronounced. Since the air does move and has to move by turbulent flow in order to transport dust (Bagnold, 1941, p. 46-47, 97-98), the mechanism can hardly be of significance.

If the clay is due to deposition plus weathering from the same source area, it should be reflected in the petrography. Both Hutton (1948) and Ulrich (1949) concluded that the loess of southern Iowa came from the Missouri River valley on the basis of profile development and particle size distribution. Therefore, the feldspar content of the Grundy soil should be less than the feldspar content of the less weathered loess near the Missouri River valley. Handy (1953, p. 69) found a maximum feldspar value of 25% a short distance east of the Missouri River.

Let us assume for the sake of discussion that all of the material finer than 5 microns is the product of the weathering of feldspar. Then the quantity of minus 5 micron material can be added to the present feldspar content to give an extreme upper limit for the original feldspar content.

If the total minus 5 micron content of Handy’s samples is added to the total feldspar content, then the initial quantity of feldspar in the loess was on the order of 45%. However, the total of feldspar and minus 5 micron clay in the Grundy C horizon indicates that the initial feldspar content could have been as high as 61%. The actual maximum of 25% feldspar in Handy’s samples and 19% in the Grundy might serve to indicate
that the Grundy is more highly weathered than western Iowa loess. However, if the quartz to feldspar ratio is a measure of weathering, then the Grundy C horizon is not weathered as much as the loess samples nearer the Missouri River. The quartz to feldspar ratio in the Grundy C horizon is 1.44. In Handy's (1953, p. 69; 1955, p. 234) sample 55-1, the ratio is 1.65; in sample 20-2, it is 2.65; in 26-1, it is 3.0; and in 43½-1, the quartz to feldspar ratio is 3.0. Either the Grundy soil is developed from a loess of different source, authigenic feldspar has been added, quartz weathers more rapidly than feldspar, or all of the minus 5 micron clay in the Grundy has not been formed by weathering.

Let us consider these possibilities. First, if the Grundy is from a different source, then the increasing clay content toward the southeast cannot be explained by deposition nor by weathering. Some local and regional factors and processes must be determining the clay content in spite of the distance from the source area and clay formation by weathering.

Second, it is conceivable that some authigenic feldspar has been formed by precipitation from solution, and the evidences for this have already been suggested. However, authigenic feldspar is more likely to form in an alkaline environment, and the loess tends to be neutral to slightly acid.

Third, presumably from geologic experience, quartz can be considered stable as compared to feldspar.

The fourth and final consideration is that the minus 5 micron clay in the Grundy has not been formed by weathering. This can be surmised
from a semiquantitative comparison of the till and the loess mineralogy. In the loess, the only major weathering loss appears to be a decrease of 3% feldspar in the A and B and a 1% loss of pyroxene in the A horizon. From this, it is conceivable that the 11% minus 5 micron clay excess in the B could have been formed by weathering. On a semiquantitative basis, this appears to be largely formed in place in the B horizon. However, it is difficult to conceive that 42% minus 5 micron clay throughout the profile could have been formed by weathering either during or since deposition if only 11% excess minus 5 micron clay has accumulated in the B since deposition. Furthermore, the till mineralogy suggests that the till is more highly weathered and yet it has less minus 5 micron clay than the loess.

From these considerations it is apparent that the cause of the regional trends of clay content in the loess is a major problem. Many detailed studies will be needed before the origin of the clay is established.

Since the heavy mineral suite and the quartz to feldspar ratio is entirely different for the till and loess, it appears that they are unrelated in age and perhaps in source as well. The mineralogy suggests that loess is not as old as the till. This is suggested by the importance of pyroxene and amphibole in the heavy mineral fraction of the loess and the importance of rutile, zircon, etc. in the heavy mineral fraction of the till.

Apparently the till and the loess are experiencing the same process of weathering. At least there is no appreciable rounding, and the alteration products within the feldspars are very obvious.
Pleistocene Stratigraphy

Introduction

Two major drift sheets have been established within southern Iowa. The oldest of these is called the Nebraskan and was proposed by Shimek (1909, p. 408). The youngest is called the Kansan which was first proposed by Chamberlin (1895). Occurring within the till mass throughout the area are a number of deposits of gravel, sand, silt, clay, peat beds and clay rich zones known as gumbotil. Some of these have been reported in the literature as recording interglacial conditions and therefore assigned to the stratigraphic unit called the Aftonian.

The writer has visited all of the southern Iowa localities of Nebraskan, Aftonian and Kansan deposits cited in the literature. Many of these were no longer exposed because of more recent construction, burial by slumping or deposition, or stream erosion. Many other exposures, not reported in the literature, were also studied.

In all of the available exposures, it seemed that the non-till portion of the section could best be explained as ice-marginal deposits formed during local shifting of the ice margin. Therefore, it is concluded that the establishment of two separate drift sheets, as previously recognized, is unjustified. However, future studies may very well distinguish more than one drift sheet in southern Iowa when more refined tools are applied.
At the top of the drift, a clay rich zone known as gumbotil is present. In the past it has been interpreted by most workers as the B horizon of a paleosol; however, this may be an oversimplification.

Above the gumbotil occurs a silt which tends to be sandier than the overlying loess. Ruhe (personal communication) has named this the pedisediment. This in turn grades upward into the loess which is considered to be a Wisconsin formation.

In this study, stratigraphic features were used primarily as aides in deciphering the alteration, diagenesis and deformation of the soil mass. Stratigraphic features also proved to be valuable in the derivation of geomorphic processes.

Glacial till

**Occurrence.** In general the till outcrops on the flanks of the loess-capped hills. How far up the flank of the slope the till is exposed depends mainly on the thickness of the loess, the amount of apparent loess creep, and the local development of the intermittent drainage system. In areas near the major river valleys where the incision of topography is at an advanced stage, the till is exposed at the crests as well as on the flanks of the hills.

Till-derived soils tend to become more common at the surface as one goes from the west end of the region to the east. Likewise they tend to be more common in the southern part of the region than in the northern. Till derived soils are especially abundant in some parts of Decatur, Wayne, and Lucas counties.
General features. The glacial till seems to be quite homogeneous considering the region as a whole although locally it may vary from a heavy clay to a clayey sand. Typically it is a clay loam with an appreciable quantity of gravel. The till mass is composed of blocky peds whether the till is wet or dry. The only till that lacks structure is the exposed material puddled by rain and sheetwash. There is a crack between peds even when wet but the cracks are wider when the soil is dry.

The gravel fraction is composed of a great variety of materials but quartz, granite and pegmatite fragments always predominate.

Quite commonly gravel, sand or clay lenses occur. These may be over fifty feet in length or they may be only a foot in length. Occasionally one sees a cut in till where small pockets of sand are scattered throughout. The small pockets are typically about a foot thick and two feet long. They may be irregular in shape but they are usually squarish or oval. It may be well to note that similar lenses of sand or gravel occur in over half of the randomly selected till sites which suggests that the lenses are a common feature and not just rare phenomena that impress one because of their distinctiveness.

Both the sands and the gravels typically have a clay content, which is undesirable for most engineering purposes. In the gravels a large amount of limonitic material is typically disseminated and in some instances it occurs as abundant small concretions.

Rock types. Although no quantitative studies were attempted, large numbers of field observations were made throughout the area on the gravel
fraction. As a whole, the gravel fraction has a uniform composition although locally appreciable differences could be noted. In general the dominant rock types are red and white quartzites, various varieties of pegmatites and aplites, assorted granites and granodiorites and various types of chert. In addition there are weathered schists, weathered gneisses, quartzose sandstone, graywacke, greenstone, slate, shale and many others. Pebbles of a distinctive red quartzite, exactly like the Sioux Quartzite of northwestern Iowa, occurs throughout the area.

**Color.** The till is essentially the same color throughout the area except it appears to be browner in the southern part.

Specifically the calcareous and non-calcareous till, when dry, is usually yellow or yellow with mottles of strong brown. When wet, it is a light yellowish-brown and sometimes has strong brown mottles. Occasionally a gray till with or without mottles of brown occurs.

**Special features.** Some special features of the till are of considerable interest to this study. These are iron oxide concretions, carbonate concretions, polygonal color patterns and cracks.

The iron oxide concretions occasionally resemble the pipestem concretions occurring in the loess, but most are rounded irregular masses. Field criteria indicate they are composed of iron oxides, clay and in some instances disseminated chert and chalcedony. These are most interesting when they become concentrated in lenses which are exposed along the lower flanks of valley walls and terraces. The lenses rarely exceed 4 feet and most are about 2 feet in length. Typically they are
about a foot thick. The lenses are made up of ordinary gravel, and sand with some silt and clay. However, the great concentration of angular ironstone concretions makes them very striking. The lenses rarely extend into the gumbotil and examples extending into the loess have not been discovered.

The carbonate concretions are the most obvious secondary structure. They normally have dimensions on the order of an inch but occasionally one finds concretions up to six inches in size. Typically the concretions are rounded, irregular-shaped masses but some are botryoidal or even discus-shaped. They are similar to the loess kindchen which occur in western Iowa loess. When they are broken open, one finds radiating cracks. When dilute hydrochloric acid is placed on them, a vigorous reaction ensues and a muddy residue accumulates. Judging from the hardness, some of these contain varying amounts of disseminated chert or chalcedony.

In roadcuts the upper surface of the zone of carbonate concretions is subparallel with the surface although it invariably outcrops on the flank of the hill.

The occurrence of the carbonate concretions around sand, gravel and silt lenses in the till is especially striking. Invariably the concretions completely outline the more porous lens. The concretions rarely occur in the more porous bed, but rather, they are confined to the till. Furthermore, the till itself is highly calcareous whereas the silt, sand or gravel lens is non-calcareous.
A very obvious brown or red band one to three inches wide usually outlines the silt, sand or gravel lenses. The carbonate concretions tend to be most abundant within these bands.

Likewise a polygonal pattern of brown bands is especially common within the till. The bands range from one to four inches wide. Frequently a gray band occurs in the middle of the thicker brown bands. The polygonal pattern is enhanced and made very obvious where carbonate concretions are concentrated within the bands. The concretions are more concentrated within the gray band if it is present. In the center of the polygon the till is yellow, brown or gray mottled with brown depending apparently on the moisture content.

The polygons outlined by the color bands may range from one to four feet in dimensions. They are a subsurface phenomena, but they remind one of the so-called soil polygons. From numerous exposures it is concluded that the till mass is often composed of three-dimensional polygons of till with lines of concretions concentrated between the polygons. The writer has never discovered any crack between the polygons. Usually along the lines of the inferred contacts between polygons, there is no textural difference which can be observed in the field. In a few instances, the till is noticeably sandier along a band about an inch wide between polygons.

On several occasions cracks were observed in the till. Since most observations were made in roadcuts or similar excavations, the only cracks that could be considered natural were those running transverse to the exposed face. These happened to be in wet till. They were approximately 1 inch wide, at least 3 feet high from top to bottom and extended into the till an unknown distance.
Significant stratigraphic exposures. Some typical features of the brown and gray bands and the carbonate concretions are well exposed in a roadcut at the SW\(\frac{1}{4}\) of NW\(\frac{3}{4}\), section 22, T72N R33W, Prescott Township, Adams County. In this cut the brown color bands and their associated carbonate concretions form a crude quadrilateral pattern. The linear trends which are inclined transverse to the hillslope tend to curve toward the horizontal in the upper part. The till away from the bands is yellow-brown. The concretions vary from less than 0.5 inch up to 4 inches, but most are 1 or 2 inches in diameter. At the lower flank of the hill the concretions are present, but there are no lines of concretions or color bands. These relationships are illustrated in Figures 18 and 19.

Another example of banding and concretions is in a roadcut in SW\(\frac{1}{4}\) of SW\(\frac{1}{4}\), section 8, T67N R26W, New Buda Township, Decatur County. Here the trends of concretions curve upwards toward the surface and form distinct concave arcuate lines. Color bands are associated with the lines of concretions in much the same manner as in the previously described exposure. They seem to suggest a concave plane extending toward the flanks of the ridge. There are concretions forming trends essentially transverse to the concave planes. Figure 20 suggests these relationships in a generalized manner.

Some interesting relationships between carbonate concretions and sand deposits exist in a roadcut at the SW\(\frac{1}{4}\) of SW\(\frac{1}{4}\), section 34, T72N R27W, Troy Township, Clark County. Here two pockets of coarse to medium sand are outlined by concretions. The sand itself is not calcareous but the
Figure 18. Quadrilateral pattern of carbonate concretions, gray bands, and brown bands, Guthrie County.

Figure 19. Sketch illustrating relationships between quadrilateral pattern of concretions and topography, Adams County.

Figure 20. Sketch of concave arcuate concretion bands, Decatur County.
till is calcareous. The concretions are in the till. The till is a deep brown, but the sand is buff. The relationships are shown in Figures 21 and 22.

A similar relationship between till and silt occurs in a roadcut in NW4 of SW4, section 2, T67NR30W, Middle Fork Township, Ringgold County. A lens of clayey silt with carbonate concretions occurs within the till. The silt lens is approximately 40 feet long and 4 feet thick. Concretions are scarce but most are concentrated around the margin but within the silt. Concretions in the till also outline the silt lens. In addition a 6 inch deep-brown band of till, commonly called ferreto, outlines the silt lens. The till has many more concretions which are lined up in intersecting lines. Figure 23 illustrates the features described.

In a roadcut in SW4 of section 28, T70NR32W, Platte Township, Taylor County, till overlies an alluvial silt. The till extends out over the alluvium a distance of approximately 20 feet. The alluvium at the contact is approximately 15 feet above the modern flood plain. This alluvium under the till is identical in character and continuous with the modern alluvium. The upper end of the till-alluvium contact is jagged, convoluted and interfingered.

Gumbotil Occurrence. The most persistent occurrence of the gumbotil is at the top of the till. In addition to the typical stratigraphic position between the till and loess (Fig. 24), there are other heavy clay-rich sediments within the till mass which have all of the field properties of the gumbotil occurring at the till-loess contact. The gumbotils
Figure 21. Sketch of concretions outlining sand deposits in till, Clark County.

Figure 22. Photograph of concretions outlining sand pocket. See figure 21.

Figure 23. Relationships between carbonate concretions, till and silt lens, Ringgold County.
which are closely associated with and included within the till mass and modern alluvium appear to be stream deposits.

General features. The gumbotil is typically a clay with a very well-developed, angular, blocky structure. It is typically 2 to 4 feet in thickness. Normally the clay content varies from top to bottom in a manner identical to that in a typical mature B soil horizon. That is, the clay content is at a maximum near the top of the gumbotil, and then decreases gradually with depth as it grades into the till. Typically it contains a minimum of sand and gravel as compared to the till. Some examples have little or no sand and gravel and therefore are similar to the loess except for the high clay content.

The peds are typically coated with smooth, waxy clay coatings known as clay skins. Even when the peds are wet a thin crack exists. When dry the cracks between peds are much wider. The color of the gumbotil varies greatly, but it is usually brown, olive gray, or dark gray. The brown gumbotil is called ferreto gumbotil by the writer.

Within some gumbotils, surfaces with very pronounced slickensides occur. The character of these surfaces is illustrated in Figure 25. The surfaces are smooth, have parallel trends of lineations, and have small streamlined swells and rises.

Many cases can be cited where the gumbotil is partially altered to a ferreto gumbotil. A good example is the section exposed in NW^4 of NW^1, section 5, T68N R33W, Clayton Township, Taylor County. Loess overlies a gumbotil which occurs at the top of the till. The deep-brown gumbotil is 1 to 2 feet thick. Concentrations of hematite occur within this layer.
In some instances the concentrations become almost dense enough to form a concretion. This deep-brown gumbotil grades through a mottled brown and gray gumbotil into gray gumbotil. The gray gumbotil is 2 to 3 feet thick. These relationships are illustrated in Figure 26.

Another interesting feature closely associated with the gumbotil is a concentration of pebbles called the stoneline. Typically this occurs at the top of the gumbotil and at the base of the loess. However, on occasion it occurs within the gumbotil layer. The stoneline is often redder than the adjacent till or gumbotil. The stoneline is composed of the same materials as the gravel fraction of the till. The materials on either side of the stoneline often become redder as the stoneline is approached. The stoneline is illustrated in Figure 27.

Inclusions of loess within the gumbotil are also known. One of these is exposed in a roadcut in the NW\(^1/4\) of NW\(^1/4\), section 22, Lincoln Township, T75NR28W, Madison County. Loess lenses one and two feet long occur approximately a foot below the top of the gumbotil. Furthermore, distinct undulations occur at the top of the gumbotil. Several stages are illustrated between the initial infolding of loess in gumbotil and the final pinch-out of a loess lens. The gumbotil appears to be a typical gumbotil. Figure 28 should be consulted.

**Loess**

**Occurrence.** The loess occurs as a blanket on the flat divides and at the crests of the higher knolls throughout the area. In Page and Montgomery counties, it is almost a continuous blanket from the margin
Figure 24. Loess, gumbotil, and till relationships, Ringgold County.

Figure 25. Slickensides on gumbotil. Sample site 502, Taylor County.

Figure 26. Sketch depicting relationships of loess, ferreto gumbotil, gray gumbotil and till, Taylor County.
Figure 27. Above, stone-line overlain by colluvial sediment, Adams County. Below, close-up of stone-line overlain by colluvial sediment, Adams County.

Figure 28. Above, photograph showing relationships between loess, infolded loess, and gumbotil in Madison County. Below, sketch showing relationships between loess, infolded loess, and gumbotil in Madison County.
of the valley to the hillcrest. However, even in these areas, some till outcrops on the flanks of the hills. This is especially true near the major valleys where the topography is highly dissected.

As one goes eastward from the Missouri River or southward from the Wisconsin drift border, the loess tends to become thinner. It is thinnest in the southeastern part of the area. In Wayne and Decatur counties, fairly extensive areas exist where loess is absent. However, it is only in areas where the topography is highly dissected that loess is absent on the hilltops. On the broad flat divides, loess is always present.

**General features.** The loess is a very homogeneous deposit composed almost entirely of silt and clay. Its sand (over 0.074 mm.) content is very low except at the base of the loess. At the base of the loess a gray sandy layer almost always occurs. The loess grades into the sandy layer and usually the sandy layer grades into the gumbotil below. This sandy zone is typically 6 inches thick.

The color of the loess is quite homogeneous throughout the region. It is typically a light gray-brown; however, other shades of brown occur. Commonly it is lightly mottled with some shade of gray. The lower portion of the loess is often gray. This gray zone varies from 6 to 18 inches in thickness.

One of the more interesting features of the C-horizon loess is the platy structure. These plates are approximately 0.5 cm. in diameter and 1 mm. thick. They are very friable and easily broken. When placed in water, they disintegrate immediately; however, even in the wet loess,
the peds are distinct and are separated by minute spaces. Sometimes
a crumb structure is developed instead of a platy structure. The crumbs
are also approximately 0.5 cm. in diameter.

Occasionally well developed jointing occurs in the loess. The
joints are bordered by red and gray bands just as in the till. However,
they are not common. A few examples of well developed vertical jointing
are known to exist. This type of jointing is rare compared to the
occurrence of vertical jointing in western Iowa.

In a few exposures cracks run back into the loess near the bottom
of roadcuts. At first they were considered dessication cracks, but
examination of some of the sites, when the loess was wet, indicated
some other cause. They thinned vertically and were about an inch wide
at the base.

Small, bead-like, black concretions also occur. Presumably they
are composed of manganese oxides with small amounts of other materials.
"Pin holes" and vegetative shards are typical features present in almost
all exposures.

Special features. A characteristic type of brown concretion is
present in almost all of the loess. These are quite soft, non-calcareous,
and typically have a concentric structure. Commonly the concretions are
so well developed that a concretion resembling a segment of a pipestem
is formed. The concentric structure is readily recognized in the pipe-
stems and usually they have a small hole approximately a millimeter in
diameter through them. In other exposures, the concretions are only
poorly developed. In fact they should really be called banded iron
segregations. In many exposures, a complete range of examples exists from banded segregations to pipestem concretions. In some exposures, iron concretions and concentrations are especially common in the lower foot or so of the loess.

The loess in this area of study is completely free of carbonates, carbonate concretions and gastropods.

Occasionally wavy red bands run through the lower part of the loess. The red bands are essentially parallel with the base of the loess. They may be a millimeter or up to 2 or 3 centimeters in thickness.

Woody zones occur occasionally also. All observed examples have the woody zone in the lower part of the loess. Invariably the loess surrounding the woody zone is gray and has a higher content of sand than the material overlying it.

Materials similar to loess. In addition to the upland silts, there are a large number of other deposits whose properties are quite similar to the loess but which are atypical in one respect or another. Some of them occur frequently whereas others are rarely observed.

One of the most abundant of these materials is floodplain alluvium. Much of the alluvium has almost all of the properties of the loess. The major differences are that the alluvium usually has a higher sand content, the alluvium is often black, and iron concretions and concentrations are rare or absent. Some of the alluvium is stratified, but some is as unstratified as the loess itself.

The loess-like alluvium is quite extensive in the flood-plains and also in the small drainage-ways and swales. In the small tributaries,
however, it may be only a foot or so in thickness.

Closely related to the alluvium are terrace and bluff-forming deposits of loess-like materials. Some are obviously terrace deposits as indicated by their topographic position and by minor stratification.

These terrace deposits are composed primarily of silt and clay. The sand content is sometimes as low as in the loess; however, some have a noticeable amount of sand. Unlike the alluvium, the deposits have a color and structure identical to the loess and some have concretions. It is not unusual to find 4 or 5 feet of this loess-like material between two thin stringers of sand or gravel. In other exposures no stringers of sands or gravels are present at all.

The bluff deposits are especially interesting. They occur along under-cut bluffs of small permanent streams. They are identical to the loess except that they are usually much thicker than the upland loess in the region. They may be 5 to 20 feet thick, have well developed vertical jointing, and are buff colored. Also small "pin holes", shards of vegetation and pipestem concretions occur.

There is a sand deposit in Ringgold County which is well exposed in a sand pit in the NW\(\frac{1}{4}\) of SW\(\frac{1}{4}\), section 11, T67NR31W. It is associated with the loess in a very interesting manner. Approximately a quarter of a mile south of the valley wall, three bedded sand deposits occur as lenses within the silt. The lenses are approximately 400 feet in diameter. In some beds a distinct graded bedding is found. The sand has sharp contacts with the silt at some places, but at others the sand grades both vertically and laterally into the silt. At one point a
bedded sand, 3 feet thick, grades laterally into silt over a distance of 4 feet (Fig. 29).

The banding in the sand is produced by layers of buff sand and red silty-sand. In some places assymmetrical and symmetrical ripples are present at the top of the silty sand layers. The ripples have a wavelength of approximately one foot. The sand has a mode of 0.5 mm. and is poorly sorted.

Fortunately aerial photographs are available which were taken before the sand pits were opened. They reveal that the sands are included within the area of erosional topography and therefore appear to have been deposited before the present upland drainage system developed.

In many places the till is so highly weathered that at first glance it appears to be loess. In these instances, it is fine-grained, buff colored, non-stratified and has a well developed vertical jointing. However, closer examination reveals that it grades down into the underlying till. Furthermore, gumbotil and sandy basal material is absent. Very close examination reveals that it has a higher sand content than the loess and occasionally pebbles occur. Materials of this type are usually only three or four feet in thickness.

Geomorphology

Introduction

The geomorphic analysis was carried out by means of field observation, study of aerial photographs, published soil maps, published topographic maps and also by using topographic profiles along several major
highways.

At least three major elements can be recognized in the topography. These are the broad upland flats (Figs. 30, 31, 34), the rolling or hilly areas (Fig. 32), and the major flood plains (Fig. 33).

**Upland flats**

Broad flats occur in most of the divide areas and in some instances extend for a distance of several miles. These large flat areas are especially common in Decatur and Wayne Counties and tend to be more common in the eastern part than in the western part of the area. Typically they have less than five feet of relief and tend to be poorly drained.

The flats end rather abruptly at the margins of the rolling areas. However, the margins are definitely rounded or sloping. Furthermore, near the margins of these flats the A horizon is higher in clay and the B horizon appears to thin in the downslope direction.

Ravines scallop the margins of the flats (Fig. 35). Oftentimes a shallow drainage swale will extend headward from the ravine. In general the drainage swales appear to be the sole originators of relief on the flats. Rarely does the relief associated with a swale exceed five feet.

In all the cases encountered, loess covered the flat. The thickness of the loess on the flat is approximately equal to the expectable thickness for the area (Simonson *et al.*, 1952, p. 15). The writer never saw an extensive flat with till exposed at the surface.
Figure 29. Bedded sand and massive silt, Ringgold County.

Figure 30. Typical broad flat, Adams County.

Figure 31. View across a series of accordant level divides separated by small valleys, Madison County.

Figure 32. Typical view of rolling land in southern Iowa, Warren County.

Figure 33. View across a typical stream valley, Tarkio Creek in Montgomery County.

Figure 34. Typical drainage swale on flat divide, Madison County.
Rolling land

The rolling lands dominate the western counties. However, throughout the region the rolling land constitutes at least one-half of the total area of each county.

In Montgomery and Page Counties, the slopes are typically long, gentle and dominantly convex at the top and concave at the bottom (Fig. 36). However, as one comes eastward, the slopes tend to be shorter and steeper. It is also interesting to note that as the loess becomes thinner, the slopes tend to be shorter and steeper.

On the steeper slopes, catsteps and slumpblocks are especially noticeable (Figs. 37, 39 and 39). In the other areas one can find slumpblocks which seem to be masked with creep.

Ravines and gullies erode headward up the sides of many knobs. In general the ravines are more open and gentle where the loess mantles the topography.

Roadcuts

Roadcuts have proven to be a very valuable aid in deciphering the mechanism of geomorphic processes. Roadcuts which were new when the aerial photographs were made can be examined and the changes noted. Although there is a large amount of variation, in general 8 to 12 inches of topsoil accumulates on grassed roadcuts in 15 to 20 years. This appeared to be primarily translocated topsoil.

Another feature of interest is the presence of large cracks associated with slumping. The cracks may be up to 2 inches wide although
Figure 35. Intermittent stream showing how tributaries scallop a flat divide, Taylor County.

Figure 36. Advanced stage of divide dissection, Clark County. Note that the divide is still recognizable. Slopes are convex near the crest but concave near the base. The concave portion is underlain by colluvium. The incipient floodplain is underlain by alluvium.

Figure 37. Example of large slump along deeply entrenched stream, Page County. Note how creep has healed slump scar at left center of photograph.

Figure 38. Series of small slumps, Page County. Some are partially healed by creep.

Figure 39. Small gullies cutting headward into divide away from intermittent stream, Taylor County. Small slumps are between the gullies, but they do not show in the photograph.
normally they are approximately \( \frac{1}{4} \) inch in width. The cracks are known to be up to 5 feet in depth and 12 feet in length. Probably larger examples exist. Typically they are filled with a dark-colored structureless soil. Apparently it is material that has washed or fallen into the cracks.

Normally the cracks thin with depth, but in several cases, they become wider with depth. Invariably the cracks are associated with slump blocks and developing slump blocks. In some cases the slump blocks are masked by the creep of topsoil.

Smaller cracks also exist on roadcut slopes. These appear to be associated with creep and perhaps with smaller slumps. They too are usually filled with wash sediment.

**Regional trend**

Since good topographic maps were available only for parts of Lucas and Wayne Counties, it was necessary to compile several highway profiles to obtain some concept of the regional trend in relief and elevation (Pl. 1, 2).

The profiles were drawn along U.S. highways 2, 34, 69 and 148. The original surveys were redrawn with a vertical exaggeration of 100 times and with a horizontal scale of 1 inch equals 10,000 feet. This proved to be a very valuable form of topographic analysis.

In general the divides or hilltops tend to be at a lower elevation near the major rivers. A notable exception to this is the divide between the Missouri River and the West Nishnabotna River (Pl. 1). It is especially interesting to note that the divides gradually decrease in eleva-
tion toward the West Nishnabotna River valley, but the divides decrease in elevation abruptly toward the Missouri River valley. Furthermore, the highest divide between the Missouri and West Nishnabotna valleys has almost the same elevation as the divides near Corning and Bedford.

Another striking feature is that the divides of the Missouri River tributaries tend to be at a higher elevation than the divides of the Mississippi River and Des Moines River tributaries.

The highest divides on the east-west profiles occur near Creston and western Ringgold County. Examination of the drainage pattern of southern Iowa reveals that the drainage divide between the Missouri and Mississippi Rivers coincides with the higher elevations.

The published topographic maps of Missouri were examined and the average elevation of upland was estimated for each quadrangle. When these were plotted on a small scale map, the same trends were noted as obtained by the use of highway profiles.

In general then, the project area comprises the northern part of a broad topographic swell. This swell slopes toward the Des Moines River on the north and east, toward the Mississippi River on the east and toward the Missouri River on the south and west. Superimposed on this regional pattern are numerous other trends in which the divides gradually lower toward the river valleys.
Discussion

Sedimentation

The thickness of the loess as shown by Simonson et al. (1952, p. 15, Fig. 7) seems to be totally unrelated to the divide elevations revealed by the highway profiles. This suggests that the loess occurs as a blanket on old erosion surfaces of diverse degrees of development and dissection. The petrographic data and the field observations support this hypothesis. Therefore the upland loess of this area seems to be an aeolian deposit.

On the basis of numerous silt beds between thin sand and gravel lenses, it appears to be possible for streams to deposit thick, non-stratified silts provided a sufficient source of silt is present. These plus the lowland bluff silt-rich deposits and sands adjacent to some streams record alluviation of the drainage courses in southern Iowa. Detailed studies of these deposits will provide a clear understanding of drainage history. Since the field characteristics of these alluvial materials are very similar to those of the loess, it is quite probable that the techniques of soil stabilization developed for the loess will be successful for stabilizing these materials.

Field observations and loess thickness trends have led to the conclusion that the alluviated valleys of major streams were the chief sources for the loess. These alluviated valleys were probably much broader than revealed by cursory inspection of their modern equivalents.

The study of the drainage history of this region will have great practical application in the location of buried sand and gravel deposits.
Geophysical prospecting in the uplands adjacent to these alluviated valleys should also locate sand and gravel deposits. Fine sands probably will be the predominant aggregates, but coarser materials should be present as well. Where present the aggregates should be as little altered by accumulation of concretions, clay and iron oxides as the enclosing silts. Therefore they would be much more desirable than the clay and iron-rich aggregates known to be associated with the highly altered till.

**Regional pedimentation**

Several lines of evidence suggest that pedimentation is the dominant process of landscape evolution in the area. First, the region seems to be the northern portion of a topographic swell which slopes toward the major drainageways. Secondly, the divides are characteristically lower adjacent to the major tributaries. Third, the coincidence of a larger number of flats and lower elevations in the east suggests that lowering of elevations and development of flats are closely related. Therefore the flats appear to be remnants of pediments.

The pediment elevations imply that pedimentation is more advanced in the east than in the west. This could arise if the Missouri River and its tributaries were younger than the Mississippi River drainage system.

The highway profiles suggest that the Missouri Valley is younger than the Nishnabotna drainage system. This is partially indicated by the rise of divides very gradually from the Nishnabotna whereas the divides rise abruptly from the Missouri River bottom.
It is suggested that the major drainageway of the Missouri River may have been across the state of Iowa in Illinoian or Wisconsin time. Independently, Horberg and Anderson (1956, p. 108, 110) have made the same suggestion. If this is true, the channel may have been blocked by the advance of the Des Moines lobe, the Illinoian ice sheet or both. The damming of the valley would produce alluviation throughout the drainage system. With recession of the ice, the pediments would have been dissected by lowering of local base level. Presumably the latest regional cycle of dissection began in the Wisconsin when base level was lowered by the formation of continental ice sheets.

**Mechanism of pedimentation**

In the Ida-Monona-Hamburg Soil Association Area along the Missouri River, the evidence for slumping and soil creep is very striking. In some cases the sinuous divides are dune-like. Careful field observation of topography and soils suggests that the steep ridges are produced by slumping. If creep or sheet wash masks the slumps, the topography acquires a billowy dune-like character.

However, within the Marshall Soil Association Area, most slopes tend to be in equilibrium. Remarkably little evidence for slumping exists. The convex slope at the top of the hill is primarily due to creep. At the base is a concave slope composed of colluvium. This colluvium is considered to be partially deposited by water running off the slope and partially by mass wasting.

Through the other soil association areas toward the east and southeast both the convex slope and the concave slope tend to become shorter.
Furthermore slumps and slumps partially concealed by sediment are more obvious than in the Marshall Area.

The dominant mechanism in the retreat of slopes in southern Iowa appears to be slumping and soil creep (Figs. 36, 37 and 38). The evidence for slumping lies in the slump blocks and in sod steps where the surface mat has apparently crept over the slump blocks. The relative rapidity of soil translocation is easily recognized by the thick layer of topsoil which has apparently crept and washed over modern roadcuts.

Apparently sheet wash is important only locally. In the small drainage swales on the flats, sheet wash and soil creep appear to dominate. To a minor extent sheet wash helps form the convex slope at the margin of the flats. As the run off becomes concentrated at the margin of the flats, a rill or gully is gradually cut headward.

Gully and rill development determine to a large extent where creep and slump will occur. Ultimately this leads to dissection of the flat and a valley is formed. Thereafter a pediment is developed along the flanks of each stream as the slopes retreat primarily by slumping and soil creep. In this fashion the uplands are narrowed and the drainage system developed.

Mass movement

One of the most important features in the till is the polygonal pattern produced by the carbonate concretions. The examination and analysis of these patterns with relationship to topography have led to the conclusion that the till is a mass of three-dimensional polygons.
separated by lines of concretions and color bands. The till exposures which lack this feature are in a state of relatively rapid creep movement like most of the loess.

The significance of the lines of concretions and color bands may be revealed by similar relationships between bands, concretions and porous lenses.

Around sand, silt and gravel lenses a line of concretions is typically formed. Likewise the lenses are usually outlined by deep brown bands. If the more porous lenses were drained faster than the till, water might tend to move toward the lenses. On the other hand, the permeable sand or gravel may have a capillary potential lower than the clay-rich till. In this case water would flow from the sand or gravel into the till. If the sand were dry the water at the sand-till contact would partially evaporate and carbonates would be precipitated in the till near the contact. Apparently the deep brown band around the lenses implies that the till is more highly oxidized near the sand-till contact. The actual mechanisms of formation of these features will have to be elucidated by detailed field, petrographic and chemical studies. At any rate it appears to be directly or indirectly related to the greater porosity, permeability and perhaps aeration of the gravels, sands and silts.

Returning to the polygons, these lines of concretions and color bands can be explained if it is assumed that a slippage plane exists between each polygon. If there were a tendency for movement along these planes, voids would be created by irregularities of the slippage surfaces and perhaps rotation of grains. Once the zones of transmission were created,
all the chemical changes associated with the more porous interface would take place. These changes should be similar to those occurring at the margin of porous lenses.

Other phenomena exist which also can be explained as the product of mass movement. In the till, there are the occasional cracks in wet till, apparent overriding of recent alluvium by till creep, the blocky structure of the till and the occasional vertical jointing. In the gumbotil it is the convolutions of the loess-gumbotil contact, inclusion of loess lenses in gumbotil, slickensides in the gumbotil, the stone-line and the blocky structure of the gumbotil. In the loess it is the platy structure, cracks in the wet loess, the wavy red bands near the base of the loess and the vertical jointing so common in western Iowa loess. The gradational contacts between the loess, sandy base of the loess and the till signifies that the base of the loess is a mixture of till and loess formed as the loess moves downslope over the till. It would seem from the relative relief that in general the till would creep slowest, the loess would have an intermediate rate of creep and the surface soil would creep the fastest. Furthermore, the movement is not only in the lateral and downslope direction, but there is also a tendency for some downward movement.

The downhill massive movement of the till and loess provides a mechanism and cause for slumping on natural and artificial slopes. In this process it is visualized that the toe of the slope is relatively stable and that gradually the slope angle is increased by lateral movement. When a critical slope angle is reached, slumping will occur.
Needless to say undercutting by stream erosion also increases the slope angle and induces slumping. The stability of roadcuts and retaining walls may be partially influenced by how fast the materials move into this critical slope angle. If this could be expressed quantitatively perhaps more accurate formulae could be developed for predicting the stability of artificial slopes. This in turn will have important application in the theory and design of roadcuts, retaining walls and similar engineering problems.

**Chemical alteration**

The various types of concretions in the till, loess and other materials indicate that these materials are undergoing chemical alteration. The till is more highly altered than the loess which may be because it is older than the loess.

Initially the upper limit of the carbonate zone represents an equilibrium level between the modal level of the fluctuating water table and the depth of leaching. In most sites this should be above the mean level of the water table. This explains why the upper limit of the zone of carbonate concretions is sub-parallel with the surface. As a result of valley deepening and slope retreat, the zone of concretions tends to outcrop at the lower flanks of the hills.

As the landscape evolves by pedimentation, the upper limit of the zone of carbonate concretions is moved to a lower elevation by surface leaching. As the pediment is dissected, the water table tends to be lowered and consequently the upper limit of the zone of carbonate con-
cretions will be lowered.

From these considerations it can be seen that the depth of leaching is not a legitimate measure of the age of the Kansan drift as originally proposed by Kay (1931). It is primarily a product of local landscape evolution although many other factors may be involved to some extent. The average depth to carbonates in the Kansan is deeper than in the Wisconsin and Illinoian drifts primarily because the topography is more highly dissected.

The gravel lenses with angular ironstone concretions, occurring at the lower flanks of some slopes, are the result of ground water. As the water evaporates in the gravel, a crust rich in iron and silica tends to develop. The more soluble salts tend to be leached away as fast as they form. As deepening of the valley progresses the slope migrates toward the valley under the force of gravity, the crusts are broken up into angular fragments, and tend to be dislocated and slightly mixed with the original gravel constituents.

It seems that the only major chemical change that can be inferred in most terrace deposits is the apparent oxidation of organic matter so that it has much the same color and appearance of the upland loess. At least some of the relatively recent alluvial silts have sufficient organic matter and ferrous iron compounds to make them dark colored. Undoubtedly some chemical alteration is controlled by local variations in geomorphic development.

The color of the gumbotil is supposed to be an inherited feature resulting from pedogenesis; however, the vertical variation in color
of some gumbotils suggests that the ferreto and ferreto-gumbotil owe their present color primarily to the relatively recent geologic environment. As the evolution of the landscape proceeds by the dissection of flats, there is a tendency for the mean water table level to be lowered under the flat because of lateral drainage of ground water toward the valley. As dissection progresses the gumbotil would be under water less frequently and only when a perched water table existed above it or when the water table was especially high. When the water table drops below the loess-gumbotil contact, oxidation could very easily occur starting at the top of the gumbotil and proceeding downward.

The movement of iron into the gumbotil from a water table perched on the gumbotil may operate separately or in conjunction with the previous mechanism to produce brown or red gumbotils. In this case iron could move downward in solution and be precipitated by changing pH or concentration, or it could result from a crude type of liesegang phenomenon. The gray zone in the lower portion of the loess suggests a reducing environment and occasionally this gray zone is especially rich in iron oxide concentrations and concretions. This hypothesis may be supported by the oxidized ring around gravel, sand and silt lenses.

From these considerations it can be seen that color may be closely related to drainage or chemical composition. Color probably has basic practical significance in the direct application of soil stabilization techniques and in the understanding of the nature and variation of the soil materials used in stabilization. Much basic research is needed to clarify the causes of color and color changes.
Soil genesis

It remains to show how the previously developed concepts and hypotheses on stratigraphy, and geomorphology can be used to clarify the distribution of southern Iowa soils.

Soil creep and mass movement help explain some features of the soil profile. First the rapid accumulation of topsoil on roadcuts suggests that most of the topsoil of slope phase Regosol and Lithosols has been formed on the level surface above the slope and carried downslope by soil creep. Undoubtedly some organic matter is formed and accumulated on the slope and probably some is carried down by sheet wash but these are judged to be of less importance. Therefore it is suggested that the A horizon of Regosols and Lithosols exists whenever the rate of soil creep exceeds the rate of slope retreat. Obviously the actual process of slope retreat, soil creep, and subsidiary formation and accumulation of organic matter are complex processes to say the least. The B horizon develops on slopes only when the rate of slope retreat is less than the rate of soil formation.

In level upland soils, the irregular jagged boundary between the A and B horizons is mainly caused by the washing and falling of A horizon sediment into tension cracks. These tension cracks are primarily caused by the mass creep of the B horizon but desiccation is a contributing factor. At the margin of the upland, the B horizon often fades out or pinches out near or just below the crest of the slope. This is primarily caused by soil creep. Apparent pinch-out of a sedimentary horizon down-slope is a common phenomenon in topography developed from sedimentary
Likewise the structure of the B horizon is partially caused by soil creep. Ample evidence indicates that the type of structure and its perfection of development is related to clay content, organic colloid content, sesquioxide content, etc. In some soils these may be the only determining factors. The colloid content and perhaps the sesquioxide content in soils in southern Iowa play an important role in determining the shape, size and degree of perfection of soil peds because there is a wider space between peds when dry. However, the observation of wet peds at numerous sites in various materials indicates that a distinct space exists between peds even when wet. Consequently the actual mechanism of tension and compression is primarily initiated by soil creep and mass movement. In most topographic situations, tension should dominate.

Starting at the Missouri River and moving eastward, the first soil association is the Monona-Ida-Hamburg area. The apparent incision of the Missouri and a rapid rate of slope retreat is the fundamental explanation for this region. The rapid rate of downcutting by tributary streams leads to unstable slopes and this results in a rapid rate of slump and soil creep. Consequently only Regosols or immature Brunizems can dominate the area.

The Marshall area lies in a region which is inferred to have slopes which have attained their angle of equilibrium. Because of this most slopes tend to be stable and consequently retreat very slowly. The rate of soil formation exceeds the rate of slope retreat and a Brunizem soil
which extends from the lower portion of the slopes to the hillcrests dominates the Marshall area.

The remainder of the area is dominated by loess derived Brunizems which tend to have an increase in the clay content of the B horizon and the other horizons as the loess thins toward the southeast (Ulrich, 1949; Hutton, 1948). Relatively small areas of Wiesenbodens and Planosols are associated with the Brunizems on the flats. The Planosols and the Wiesenbodens are better developed and more common in the areas of thinner loess (Ulrich, 1949a).
CONCLUSIONS

In conclusion the following results, hypotheses and recommendations are presented:

Petrography

1. The loess and till have distinctive particle-size distribution above 5 microns, but their range of variation below 5 microns is the same.

2. The gumbotils have particle size distributions similar to both loess and till. Random samples from 7 sites gave 5 gumbotils with a particle-size distribution similar to loess.

3. The particle-size distribution of the surface soil layers differs significantly from the parent soil materials only in the total amount of organic and inorganic colloids.

4. The regional variation in clay content of the loess is systematic, especially within a Great Soil Group. The variation in the clay content of the till does not vary systematically through the region.

5. Differential thermal analysis of all samples and X-ray analysis of selected samples indicate that the clay mineralogy is the same in the till, loess, gumbotil, B horizon and the A horizon.
6. The dominant clay is a mixed layer illite-montmorillonite. X-ray data indicate that illite dominates in the mixed layer. Illite also occurs as a distinct species. Kaolinite and quartz are present but minor. The compositions of the minus 2 and minus 5 micron materials are similar, but the minus 5 micron material has a higher quartz content.

7. Quartz and feldspar dominate the material from 0.005 mm. to 2.0 mm. in both the till and the loess. The quartz and feldspar contents of the A, B and C horizons of both a till-derived Brunizem and a loess-derived Brunizem are very similar.

Hypotheses

1. Only one drift sheet, called Kansan, should be recognized at the present time. Its properties are determined by initial deposition, some weathering and addition of various minerals from ground water solutions.

2. As streams dissect the drift, the drift tends to creep toward the valleys. This tends to produce unstable slopes which favors slumping and soil creep.

3. Pedimentation is the dominant process of landscape evolution. This consists of parallel slope retreat laterally away from each drainageway. In southern Iowa slope retreat is caused primarily by slumping and soil creep although other erosive processes are involved.
4. Pedimentation explains:
   a. The broad topographic swell in southern Iowa and northern Missouri.
   b. The lowering of divide levels toward the major streams.
   c. The tendency to have a larger number of broad flats where the elevations are lower.

5. From the distribution of loess thickness on old pediments, it is concluded that the alluviated equivalents of modern and ancient major stream valleys were the chief source areas for the loess.

6. Since the loess thickness is independent of pediment elevations, the loess is younger than the pediment surfaces and therefore is considerably younger than the Kansan drift.

7. The upland loess was originally a homogeneous aeolian deposit. Subsequent to sedimentation, various concretions and clay have been formed, and downslope creep has occurred.

8. Weathering of silicates is primarily a fracturing process caused by the breakdown of the crystal lattice and the formation of alteration products within the grain. Each grain is considered an independent, but open, chemical system. Surface solution of silicates is minor under the climate of this region.
9. Weathering by chemical fracturing decreases with depth. Weathering losses may not explain the total clay content, clay mineralogy and the regional variations in clay content.

10. Some clay is from initial sedimentation, and some is the product of weathering.

11. There is a regional systematic variation in clay content in the loess because of initial uniformity, loess thickness and constant topographic position.

12. The regional non-systematic variation in clay content in the till is due to variations caused by transportation and sedimentation by glaciers, varying topographic position and perhaps drift sheets of different ages.

13. The Soil Association Areas are primarily, but indirectly, a function of geomorphic development and loess thickness. For example:
   a. The Monona-Ida-Hamburg Area is dominated by Regosols and immature Brunizems because of a rapid rate of slope retreat by slumping and creep.
   b. The Marshall Area seems to be a region where slopes are approaching equilibrium.
   c. The other association areas occur in a region of decreasing loess thickness toward the south and southeast and decreasing dissection of old pediment surfaces.
14. Soil creep is an important pedogenic process. It is the pre-
dominant cause and explanation for:

a. The mechanism of ped formation. The nature of the peds is
explained by the content of colloids and cementing agents.
b. The irregular, jagged boundary between the A and B horizons.
c. The thinning of the B horizon downslope from the crest of
an upland flat.
d. The A horizon of the slope phase Regosols and Lithosols.

Recommendations

1. The same basic chemical techniques of soil stabilization will
apply to all horizons of the till and the loess. This is
indicated by the uniform range in the clay content, clay
composition and the similar mineralogy of the silt fractions.
Furthermore, field observations on alluvial materials indicate
that most of these can be expected to react favorably to soil
stabilization techniques developed on upland soils.

2. The engineering behavior of soils can be expected to correlate
closely with the agronomic soil series. The modern detailed
soil maps will be especially useful. The greatest discrepancies
can be expected to arise in soils developed from till materials.
Agronomic soil maps are primarily important to the engineer be-
because they give some indication of total clay content in the
loess and indirectly reveal subsurface drainage conditions.
3. The gumbotils differ from the till and the loess primarily in the total clay content. Therefore the problem of the gumbotils is essentially a moisture problem. Control of the drainage and stabilization of the clay will make the gumbotils perform satisfactorily as foundation and road materials.

4. Geophysical exploration for subsurface aggregates will be most successful in uplands adjacent to the major river valleys and in the thin loess areas. Fine sand can be expected to be the dominant aggregate along the valleys, but the coarser aggregates will be of higher quality than the till aggregates. In the thin loess areas coarse and fine aggregates in the drift will be sufficiently close to the surface to be economically practical. The glacial drift aggregates can be expected to have a high content of iron oxides, clay and similar impurities.

5. A quantitative evaluation of the rate of mass creep of these materials will be of benefit in the theory and design of embankments, roadcuts and similar structures.


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Appendix A. Mechanical Analysis

Introduction

Mechanical Analysis was performed on all samples. For the most part, the procedure is similar to A.S.T.M. D422-51, but there is enough difference so that a separate description is warranted.

Preparation of sample

The sample was air-dried and carefully broken into lumps less than one-half inch in size. The total air-dried field sample was split on a Jones' Sample Splitter until a suitable amount was obtained.

Specific gravity

Specific gravity values were obtained by members of the staff of the Engineering Experiment Station Soil Research Laboratory. These were determined according to a standard procedure (A.S.T.M. D354-52). There was a small range in values, but it appeared that a value of 2.63 would be suitable for all samples.

Hygroscopic moisture

Approximately 10 grams of soil passing the U. S. number 10 sieve were used to determine the hygroscopic moisture. These were determined using the standard procedure designated A.S.T.M. D422-51.

Hydrometer analysis

Approximately 60 grams of air-dried soil were carefully ground past a U. S. number 10 sieve and weighed to 0.01 grams. This was placed in a liter sedimentation cylinder, and covered with 40 ml. of sodium meta-
phosphate solution and approximately 200 ml. of distilled water. The dispersing solution was prepared by dissolving 51 grams of sodium metaphosphate crystals in distilled water and filled up to 1 liter in a flask. After standing for 18 to 24 hours, the soil was dispersed with 25 pounds of air pressure for 5 minutes using a special air-jet apparatus (Chu and Davidson, 1953).

The dispersed soil was made up to 1 liter with distilled water and placed in a constant temperature bath. Then the suspension was mixed with a simple stirring rod (Krumbein and Pettijohn, 1938, p. 167) and the initial time recorded.

Hydrometer readings were taken to the nearest 0.5 gram periodically and the exact time recorded. The interval varied but typical reading intervals were: 2 minutes, 5 minutes, 30 minutes, 1 hour, 2 hours and 24 hours. All readings were taken with a standard hydrometer (Type A of A.S.T.M. D422-51). The temperature was taken periodically and recorded to the nearest 0.5°C.

The data were corrected for the effect of temperature and dispersing agent, and then the equivalent diameter was determined using the nomographic solution of Stokes' Law (Casagrande and Fadum, 1940, p. 15).

**Sieve analysis**

The suspension used for the hydrometer analysis was washed through a U. S. number 200 sieve (opening 74 microns). The residue retained on the sieve was washed into a pan and dried on a hot plate.

After drying, the material was sieved through a nest of sieves on a mechanical shaker. The actual sieves used depended on the amount of
sand and gravel, but typically U. S. sieve numbers 10, 20, 40, 60, 140 and 200 were used. Each fraction was weighed, and the weight expressed as a percent of the whole sample.

**Plotting of data**

The hydrometer and sieve analysis data were plotted on a cumulative basis according to the standard procedure outlined in A.S.T.M. D422-51.

**Appendix B. Differential Thermal Analysis**

**Theory**

Differential thermal analysis is a technique used to help identify clays, some minerals and other chemicals. Basically it consists of heating an unknown sample at a constant rate simultaneously with a specimen of inert material. By recording the temperature difference between the inert material and the unknown, the temperature and approximate intensity of various endothermal and exothermal reactions within the unknown can be determined. Needless to say, each mineral will experience characteristic reactions at certain temperatures. The theory is reviewed in greater detail by Caillere and Henin (1947), Arens (1951), and by Kerr et al. (1949).

**Apparatus**

The apparatus is patterned after that described by Kerr et al. (1949). It consists of a set of twin furnaces that can be alternately raised or lowered over the sample holders. The sample holders are an iron-nickel
alloy with two small holes drilled into the top. A thermocouple is
within each hole and one of the holes is packed with alumina. The other
sample hole is packed with the unknown. The recording unit is a Brown
electronic strip recorder. Further information about the apparatus can
be obtained from Handy (1953, p. 58-60) and Lyon (1955, p. 44-45).
PLATE 1 EAST-WEST PROFILES OF HIGHWAYS 2 & 34
Legend

Horizontal Scale: 1" = 10,000'
Vertical Scale: 1" = 100'

Architectural drawing with grid lines and labeled points: Indianapolis, Highway 69, Warren Co., Polk Co.