The Clay Minerals in Some Glacial Lacustrine Sediments of Indiana[1]

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Introduction

During the Pleistocene epoch many areas in Indiana were sites of glacial lakes. The glacio-lacustrine deposits are of two origins. According to Thornbury (9, 10) a system of ice-marginal lakes resulted from the ponding of southwestern drainage by the lobe of Illinoian ice that extended into southwestern Indiana. A second system of lakes, Wisconsin in age, was formed south of the Shelbyville moraine owing to ponding of tributary valleys by extensive valley trains along streams carrying large amounts of outwash from the Wisconsin ice.

Lacustrine deposits are composed mainly of calcareous silts and clays. Some deposits, depending on their location within the lake boundary, contain sand and gravel. Many deposits are laminated or varved and may contain calcareous concretions .Well records indicate that lacustrine deposits may be as much as 150 feet thick in some areas (1).

The primary purpose of this investigation was to determine the clay mineral content in some of the lacustrine deposits. No previous study has been made of any clay minerals in the Pleistocene lacustrine deposits of Indiana. Measurements of pH were made, size analyses by the hydrometer method were obtained, and minerals other than the clay minerals were identified by means of X-ray diffraction and the petrographic microscope.

Samples for this study were collected from the following counties in Indiana: Allen, Sullivan, Owen, Monroe, Gibson, Pike, Perry, and Franklin (Fig. 1). Sample sites were selected by considering the age of the section, the degree of weathering, and the geographic location. Lacustrine sediments of both Illinoian and Wisconsin age were collected. A 5-pound representative sample was obtained from each lithologic unit by means of the channel sample method. A total of 28 samples was collected from 9 locations in Indiana.

Methods of Investigation

Samples were prepared for analysis by drying them for 24 hours at 60° C.; after they had been dried the samples were disaggregated in cloth bags with a wooden mallet. Care was exercised to ensure that only aggregates were broken and actual particle size was not reduced. A few tough aggregates which resisted disaggregation by the above method were broken down by use of a mortar and rubber pestle.
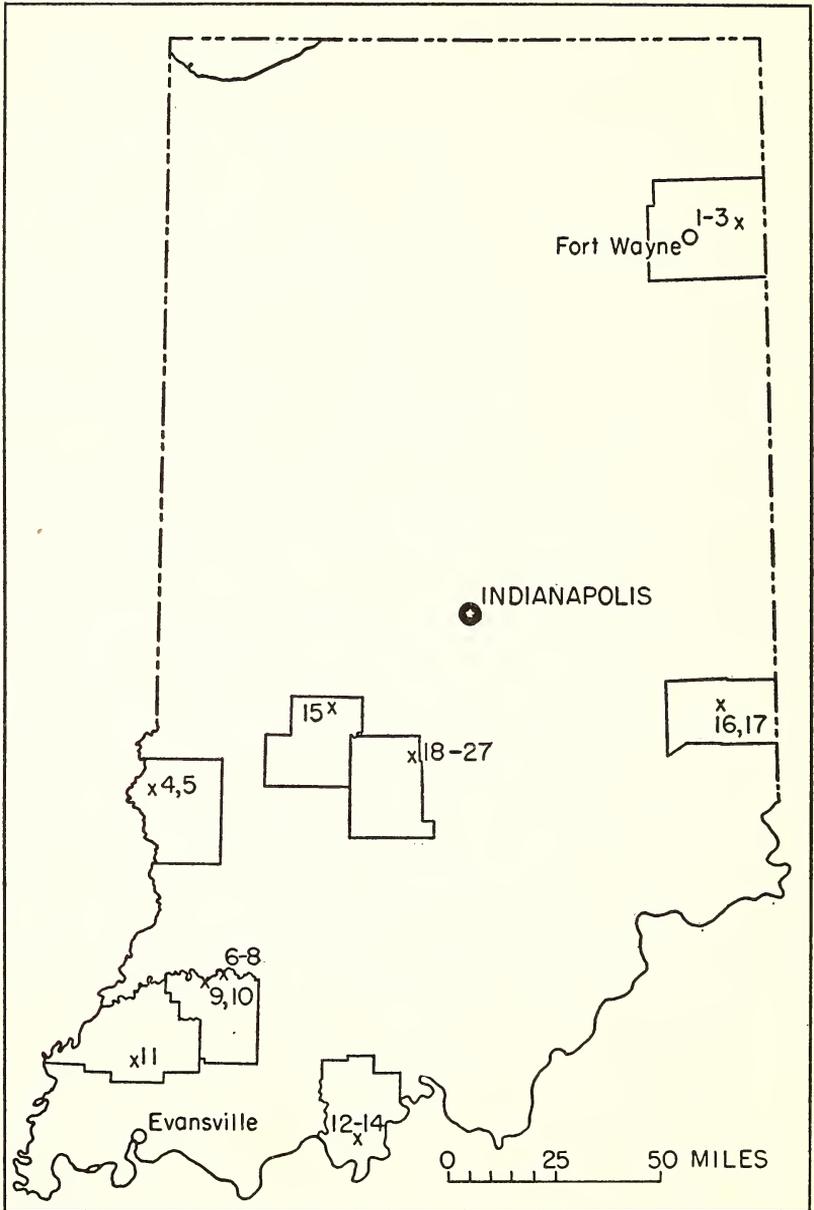
Figure 1. Map of Indiana showing collecting localities and sample numbers of glacial lake clays.

The samples were split into two 30-gram and one 50-gram representative portions by means of a riffle sampler. A Bouyoucos type hydrometer was used to obtain size analysis. After the material had been completely dispersed in distilled water by the addition of sodium hexametaphosphate and vigorous stirring with a mechanical mixer, the hydrometer was introduced at selected time intervals. Cumulative curves of particle size distribution were plotted, and the sorting coefficient was calculated according to the method used by Trask (11).

A Beckman model-G battery-operated pH meter with extension glass electrodes was used to obtain the pH. A 30-gram sample was allowed to stand in distilled water in a 1,000 ml beaker for 60 hours before the pH was determined.

Grim (4) pointed out that a separation at 2 microns is generally the optimum size for a split of the clay minerals from the nonclay minerals in natural materials. According to Stoke's law, particles greater than 2 microns settle out of an 8-inch column of water after 6 hours. In order to obtain the less than 2-micron portion, the samples were stirred vigorously with a mechanical mixer and then allowed to settle. Material which remained in suspension after 6 hours was siphoned off and was used to make oriented slides following the procedure outlined by Grim (2).

In addition to the slide of the less than 2-micron minerals a slide of the less than 0.5-micron portion was prepared by allowing the material to settle for 64 hours before inserting the glass slide. After the slides had been made, the water was evaporated from the beakers, and differential thermal analyses of less than 2-micron material were run. The apparatus used was similar to that described by Grim (3). A heating rate of approximately 10° C. per minute and a resistance of 20 ohms on the recording circuit were used.

The oriented clay minerals on the glass slides were identified by using a General Electric XRD-3 spectrogoniometer with nickel filtered copper radiation with settings of 50 kilovolts and 16 milliamperes.

In order to determine if material with a 14.2 Å spacing was montmorillonite or chlorite, the slides were treated with glycol and re-run. If montmorillonite was present, glycol, which is a polar organic compound caused the montmorillonite lattice to expand to approximately 17.7 Å. If the 14.2 Å spacing did not change, chlorite was indicated.

After the addition of glycol, the slides were heated to 450° C. for 1 hour. The loss of the 7 Å and the 3.5 Å reflections indicates the presence of poorly crystalline chlorite (6). If these reflections remain, the mineral is probably kaolinite.

X-ray powder diffraction data were obtained from the original material in order to identify nonclay minerals present. In addition, an optical microscope was used to identify minerals retained on the 300-mesh screen. Heavy minerals were not common enough to warrant a heavy mineral separation.

Results of Investigation

The pH values of the samples ranged from 6.99 to 8.69. A range of 8.0 to 8.4 was reported by Rankama and Sahama (8) for natural calcareous lake and river waters. In general, the upper samples in a section had lower pH values, as would be expected in zones where carbonates had been partly leached. The pH of the leached clays ranged from 6.99 to 7.88 and the average reading was 7.36. The pH of the unleached or calcareous clays ranged from 7.77 to 8.69 and the average was 8.21.

Hydrometer readings were taken at intervals of half a minute, 1 minute, and 2, 4, 8, 15, and 30 minutes and at intervals of 1 hour and 2, 4, 8, 24, 36, and 48 hours. A Casagrande nomographic chart was used for calculating grain diameter of the samples. Cumulative curves showing results of the hydrometer analyses were plotted. Quartiles of particle size distribution were calculated according to the method of Krumbein and Pettijohn (7) and the sorting coefficient was calculated from the quartiles. The average sorting coefficient value was 1.94 well below the 2.5 value Trask indicated for a well-sorted sediment.
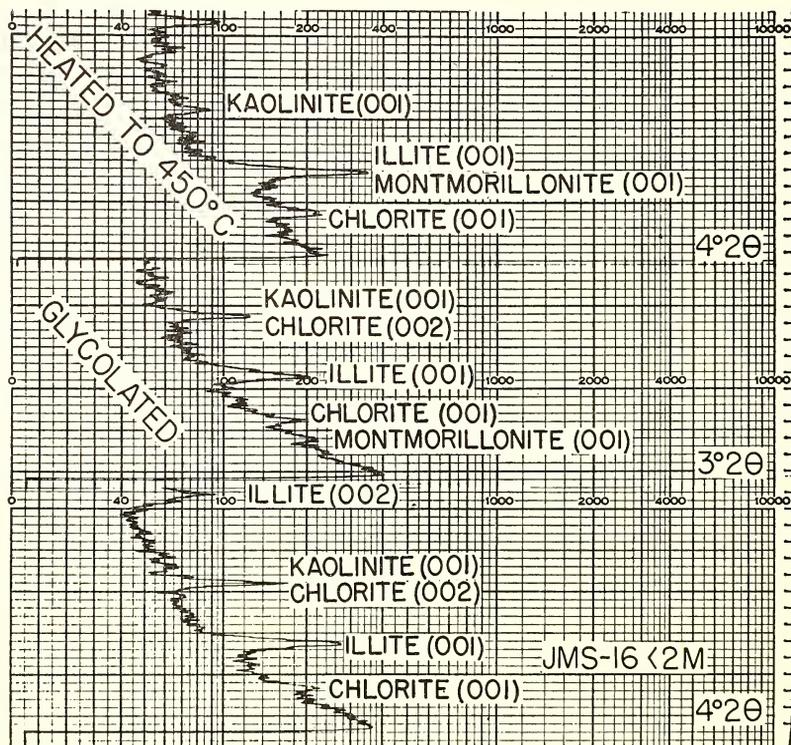

Figure 2. X-ray spectrogram of original sample JMS-16.

X-ray analysis of the original samples showed that quartz was the most abundant nonclay mineral and that calcite, dolomite, and feldspar were in most samples in varying amounts. Some samples contained small amounts of iron in the form of hematite. Figure 2 shows a typical X-ray spectrogram of an original sample.

Material retained on the 300-mesh sieve was examined with a polarizing microscope. Of the major components quartz was found to be the most abundant mineral and the carbonate minerals were the next most abundant. Feldspar was present in nearly all samples. Large amounts of organic material were found in most samples. Nearly half of the samples contained brown opaque minerals, some of which were magnetic and apparently coated with limonite. Minor constituents included a wide variety of both stable and unstable heavy mineral species.

X-ray diffraction data were obtained from untreated oriented slides of the less than 2-micron and less than 0.5-micron portions after they were saturated with glycol and heated to 450° C. Figure 3 shows a
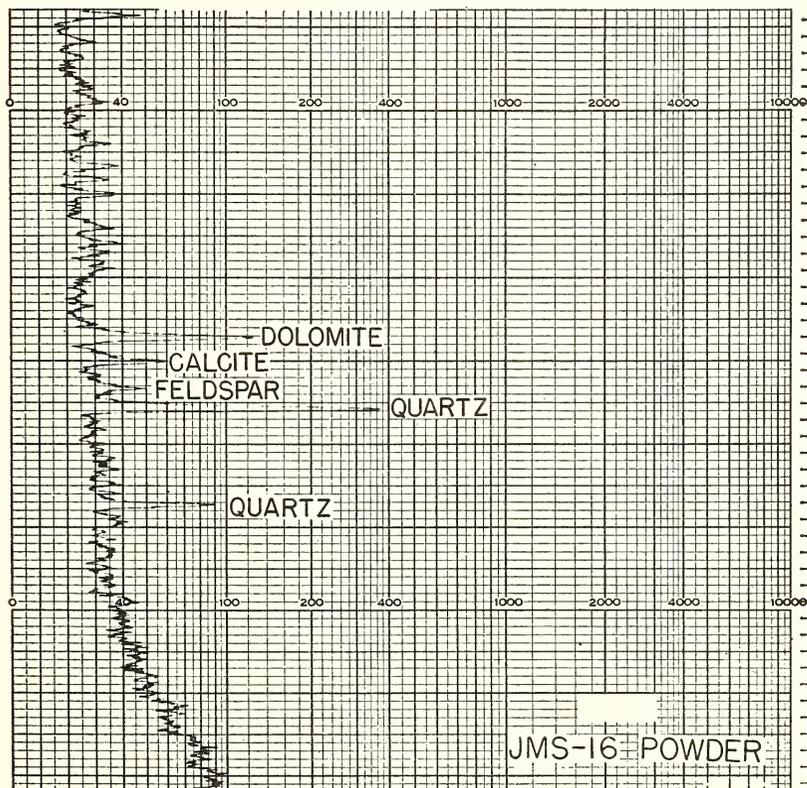

Figure 3. X-ray spectrogram of untreated glycolated and heated slide, JMS-16, less than 2-micron portion.

typical X-ray spectrogram of the less than 2-micron portion.

Because of the similarity of the clay minerals found in this study to those in Recent sediments, the procedure for quantitative estimates of amounts of clay minerals present in the samples, suggested by Johns, Grim, and Bradley (6), was followed in the interpretation of results.

Illite was found in all samples and was the predominate clay mineral in all but 6 samples; in these 6 chlorite was the most abundant clay mineral. Montmorillonite was found in minor amounts in nearly all samples and was predominant in one sample. Kaolinite was present in small amounts in nearly half of the samples analyzed. A few samples showed mixed layering of illite, chlorite, and montmorillonite, but the amount of each was very small and thus was not considered in the semiquantitative estimates. Colloidal quartz was present in varying amounts.

In general, the same minerals that were found in the less than 2-micron portion were predominate in the finer portion. However, a marked reduction in the amount of illite and an increase in the amount of chlorite occurred in the less than 0.5-micron portion. Montmorillonite and kaolinite were less common in the finer portion. Some samples showed mixed layering of illite and chlorite, but the amount of mixed-layered material was insignificant. Colloidal quartz also was present in varying amounts.

Differential thermal analysis supplements X-ray data and provides some information that cannot be derived from X-ray diffraction analyses. Organic material is not detectable by X-ray diffraction techniques but is indicated on differential thermal curves by a broad exothermic reaction that begins at approximately 200° C. and ends at about 500-600° C. Differential thermal reactions for the various clay and nonclay minerals were described by Grim and Rowland (5) and, therefore, are not discussed in detail in this report.

Illite was the major clay mineral indicated on more than half of the differential thermal curves. Chlorite although present did not give reactions diagnostic enough to be recognized. Organic material was present in amounts ranging from a trace to extreme abundance. Differential thermal analyses indicated the formation of a calcium silicate compound at 850° C. when colloidal $CaCO_3$ and SiO_2 were present in sufficient quantity. An X-ray powder photograph verified the formation of this compound $CaO._3(MgFe)0.4SiO_2$.

Discussion of Results

The data indicate that the clay minerals in the lacustrine deposits sampled are, in order of abundance, illite, chlorite, montmorillonite, and kaolinite.

The rocks which contributed detrital materials to the glacial lakes in Indiana are very diverse. The most important contributors of detrital materials to the lakes were the sedimentary rocks of Indiana. Some materials were derived from rocks on the Canadian shield and from rocks in areas crossed by glaciers south of the shield area. Within Indiana, the most important contributors to the lacustrine deposits

were the sedimentary rocks of Silurian, Devonian, Mississippian, and Pennsylvanian ages.

The Silurian system is composed mainly of limestones and dolomites. The Waldron shale (Silurian) may have contributed minor amounts of clay minerals to lacustrine areas in southeastern Indiana. The Waldron is composed predominantly of illite; kaolinite along with mixed-layer clay minerals is second in abundance. The Devonian system in Indiana is mainly dolomite and dolomitic limestones, but the top of the Devonian is composed of the thick New Albany shale which contains abundant illite and kaolinite. The Borden group (lower Mississippian) consists predominantly of shales and siltstones. The major clay minerals in the rocks of the Borden group, in order of abundance, are illite, chlorite, and kaolinite. The Meramec series is made up primarily of carbonate rocks and contributed very little clay to the Pleistocene lakes. The Chester series (upper Mississippian) is composed of alternating sandstone, shale, and limestone. These rocks contributed clays which in order of abundance are illite, kaolinite, chlorite, and mixed-layer minerals. Pennsylvanian sedimentary rocks are now found only in southwestern Indiana; these rocks are soft and easily eroded. The Pennsylvanian rocks contain far more clay minerals than do the rocks of any other system in Indiana. These rocks are cyclic in nature and are composed of sandstones, siltstones, shales, underclays, coals, and thin limestones. The Pennsylvanian sedimentary rocks contributed large amounts of clay minerals to the glacial lacustrine areas of southwestern Indiana. The clay minerals found in these rocks are in order of relative abundance: illite, kaolinite, chlorite, and mixed-layer minerals.

Other sources of clay for the glacial lakes were preglacial soils which resulted from the weathering of bedrock. Reworked Illinoian glacial materials were important sources for Wisconsin lake sediments in some areas. In addition, wind-blown materials are found in a few of the lacustrine deposits.

According to Grim (4) the chief clay mineral components found in calcareous sediments (including dolomites) are illite and montmorillonite. Grim also states that in the weathering of kaolinite clays, such as some Pennsylvanian underclays in which there is no appreciable content of alkalies or alkaline earths, illite and montmorillonite cannot be formed because potash and magnesia are necessary for their formation. Muscovite and biotite can change to illite by a slight structural rearrangement without any breakdown to ionic or colloidal components (4).

Data from Grim (4) indicate that in sediments of lacustrine origin where salts and carbonates are likely to accumulate, the dominate clay mineral components are illite and montmorillonite.

A general study of source materials for the lacustrine areas in Indiana indicates that the following minerals are present in order of abundance: illite, chlorite, kaolinite, and montmorillonite.

Sample analyses show a slight enrichment of chlorite or reduction in the amount of kaolinite, for these two minerals are present in approx-
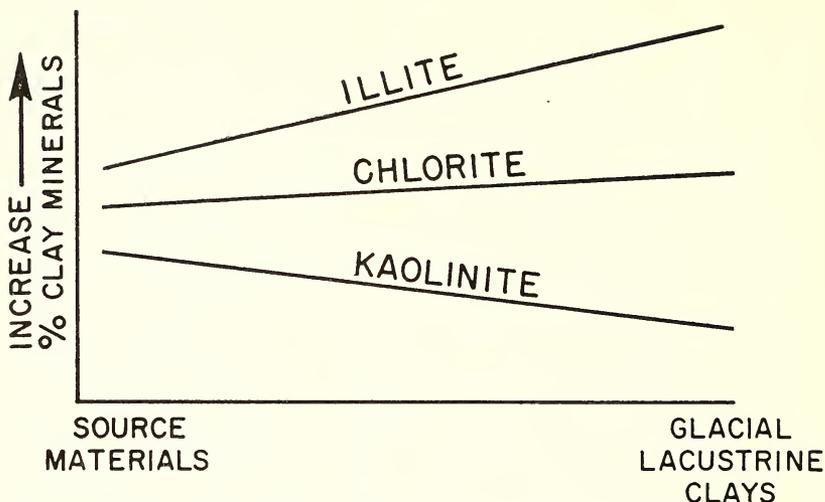
Figure 4. Diagram showing relative abundance of clay minerals in source materials and lacustrine clays.

imately equal proportions in the source rocks. Figure 4 shows a generalized diagram showing relative abundance of clay minerals in source materials and in the lacustrine deposits. No explanation to account for this difference in amounts of clay minerals in source materials and in lacustrine deposits is readily apparent unless a source area north of Indiana may have contributed a large amount of chlorite. Illite is more abundant in the lacustrine sediments than in the source rocks. Enrichment of illite can be explained in part by the breakdown of micas found in the source rocks to illite. Moreover, if potassium ions were available in the lake waters, illite could have been produced by the adsorption of K^+ by montmorillonite. K^+ has the lowest ionic potential of any ion that would be in solution and therefore might be adsorbed preferentially. Colloidal quartz in the samples may represent colloidal silica produced by weathering of the source rocks.

The great variability of rock types in the possible source areas and the complexity of the transporting agents make conclusions regarding provenance of the glacial lacustrine clays very difficult. The following generalizations may be made regarding the clay minerals:

1. Nearly all the clays are detrital except for some montmorillonite which is a weathering product.

2. The size and shape of clay minerals permit them to be carried great distances without deposition or change in character. These clay minerals may have been deposited and re-eroded many times before deposition at their present location.

3. No pronounced differences were observed between clay minerals in the sediments of Illinoian and those of Wisconsin age.

4. The source-rock constituents were the main controlling factors in the type of clay minerals deposited in the lacustrine areas. The transporting agent or environment of deposition apparently had little influence on the clay minerals, probably because these sediments were deposited rapidly in relatively short-lived glacial lakes.

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