PETROLOGY OF THE DRY BRANCH, GEORGIA, KAOLIN DEPOSITS

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ABSTRACT

Samples from kaolin deposits in the Dry Branch, Georgia, area were examined in oriented thin section, by X-ray diffraction, and as carefully disaggregated sand-sized grains. The object was to determine the orientation of kaolinite crystals with respect to any gross stratification in the deposits and with respect to their mineral precursors.

Large muscovite grains show a preferred horizontal orientation which produces a noticeable stratification in some soft kaolins in which they are relatively abundant. Interleaved kaolinite is oriented with its cleavage parallel to that of the remaining unaltered muscovite and is of the *b*-axis disordered variety. Pseudomorphs of kaolinite after feldspar occur in both the soft kaolins and the associated sandstones. These show no preferred orientation and are well-crystallized kaolinite. Authigenic kaolinite growing as vermicular "books" in the kaolin deposits and sandstones shows no preferred orientation direction and is well-crystallized also.

These observations lead to the conclusion that these Georgia kaolin deposits were not sedimented in still-standing waters as the mineral kaolinite. Major mineral constituents of the original sediment were muscovite and feldspar. Post-depositional alteration of these minerals has occurred as well as recrystallization of some of the kaolinite.

INTRODUCTION

IN another paper in this symposium Professor Bates has reviewed the theories of origin of the sedimentary kaolins of the southeastern part of the United States. The first investigations in this area were mainly large-scale geological studies concerned with the areal and stratigraphic distribution of the deposits (Kesler, 1956; Smith, 1929; Veatch, 1901). More recently these have been augmented by studies of their clay mineralogy and chemistry (Bates, 1952; Murray, 1954; Bates, 1959). With only a few exceptions, there has been little petrographic work on kaolin deposits reported in the literature (Ross and Kerr, 1930).

The standard thin-section examination of the rock is not strikingly rewarding because of the fine-grained nature of its major constituent. Only a few grains of quartz and muscovite and traces of other minerals occur along with the kaolinite. The most spectacular features of the rocks

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are the vermicular "books" or worm-like aggregates of kaolinite crystals which are seen in a view parallel to the kaolinite (001).

This paper supplies some of the petrographic information that can be useful in determining the details of sedimentary process and depositional environment, character of originally deposited material, and nature of any post-depositional changes.

MATERIALS AND TECHNIQUES

Because of the fine-grained nature of the rock and the consequent limited usefulness of thin-sections study, new techniques were designed to provide information on the size, shape, and orientation of the kaolinite crystals. Large uncrushed samples that were representative of the various lithologies containing kaolinite were collected. Each sample was marked so as to retain the orientation of the horizontal plane in relation to the sample. All samples were taken in the Dry Branch, Georgia, area and included hard and soft kaolins, sand kaolin, kaolins of different crystallinity, and kaolins contaminated with montmorillonite.

Polished sections were cut in both the horizontal and vertical directions. The technique that was used was designed to preserve the orientation of all mineral particles in the sample. Slabs were cut in the desired orientation using a fine-toothed hacksaw blade. One surface was smoothed on emery cloth. These two steps were carried out without wetting the clay surface. The sections were then treated with a concentrated solution of Lakeside cement in acetone.

The solution was slowly dropped onto the surface where it readily soaked into the clay. Time was allowed for each successive application of the solution to penetrate as deeply as possible into the clay. A slab of clay 3/16 in. in thickness could easily be saturated with the solution. When the solvent evaporated the clay was effectively waterproofed by the impregnating cement. The surface was then polished down to a level that has not been touched by the preliminary cutting and smoothing. This final surface grinding was done with carborundum powder and water on a glass plate.

X-ray diffraction records for the several fine-grained minerals in these samples were then obtained using a spectrogoniometer with direct intensity measurement. Diffraction studies were made to determine the orientation of fine-grained minerals in standard thin-sections to which no cover glasses had been attached. The orientation of kaolinite was judged on the basis of the relative intensities of (002) at $d=3.56$ Å and (020) at 4.45 Å. Whenever muscovite was present the intensities of (002) for both kaolinite and muscovite were compared directly for the horizontal and vertical sections.

The thin-sections were then studied in the usual manner. Orientation studies of the kaolinite and muscovite using the petrographic microscope were limited necessarily to relatively large aggregates of these minerals.

The samples were also carefully disaggregated to obtain grains whose external shapes may be recognizable. Vigorous agitation of some kaolinites fails to break down the aggregates. On the other hand, some aggregates are quite delicate and begin to break down at the slightest disturbance. The most gentle treatment that was devised involved dropping water onto a block of clay rock until it began to "melt". Large aggregates could then be separated and washed as units onto the bottom of the container where they were dried for further inspection.

THIN-SECTION PETROLOGY

The sandstone associated with the kaolin deposits surrounds them and interleaves with them. Quartz, muscovite, and kaolinite are the main constituents. Quartz grains in sand size are frequently subangular and are in advanced stages of embayment and wedge splitting. Plate 1A shows one large grain split into several smaller angular pieces. These pieces are all in the same optical orientation, suggesting that the splitting took place after deposition. Also several embayed grains are visible in this photomicrograph.

The extreme angularity usually characteristic of the quartz grains of these sediments is mainly a result of the post-depositional splitting caused by kaolinite crystal growth. The actual shape of the detrital quartz grains can only be judged in thin section before the split grains have been disaggregated.

Muscovite can be seen in all stages of conversion to kaolinite. The conversion appears to begin at muscovite crystal edges resulting in a frayed appearance. Plate 1B illustrates several different stages in the conversion process.

The orientation of muscovite flakes was random in some specimens and showed a preference for the horizontal in others. Whenever the kaolin rock appeared to have a small-scale stratification it was always caused by large quantities of orientated muscovite.

Orientation on a gross scale of either the fine-grained kaolinite or the vermicular growths could not be detected with the microscope. Only longitudinal sections of the vermicular growths of kaolinite were observed. Even in samples containing large numbers of these growths there was no hint of the shape of the transverse section. It was concluded that the appearance of the aggregate in transverse section is identical with that of the fine-grained matrix in which it is embedded.

X-RAY DIFFRACTION OBSERVATIONS

The bulk of the kaolinite consistently showed no preferred orientation by X-ray diffraction. In specimens in which the muscovite was oriented and showed some conversion to kaolinite a small preference was shown for kaolinite to orient horizontally. It was discovered by separating the partially altered muscovite flakes for diffraction that the interlamellar kaolinite (001) is parallel to muscovite (001) in which it crystallized. All of the kaolinite orientation that was ever observed was directly attributable to the parent muscovite orientation.

Interlamellar kaolinite was also separated from its muscovite progenitor for powder diffraction analysis. This kind of kaolinite showed all the diffraction characteristics of the *b*-axis disordered variety. In general, those kaolins that contained a large amount of muscovite were poorly crystallized. The close association of clay mica with *b*-axis disordered kaolinite has been noticed by Glass (1954) and by Robertson, Brindley, and Mackenzie (1954).

OBSERVATIONS ON DISAGGREGATED SPECIMENS

Disaggregation of the kaolins produced four main kinds of kaolinite.

1. Interstital fine-grained kaolinite which is difficult to separate without contamination by the other types. Little can be said about this type except what is judged of its character by comparing the bulk characteristics of mixtures with known characteristics of the more easily separable kaolinite types.
2. Kaolinite that has been developed directly from large muscovite crystals and is closely associated with them.
3. Sand-sized kaolinite aggregates with hexagonal cross-section characteristic of the vermicular growth.
4. Sand-sized kaolinite aggregates with feldspar morphology.

Plate 1C is a photomicrograph of the vermicular growths of kaolinite in a hard kaolin sample. They are quite small and occur only in those hard kaolins that give the diffraction effects characteristic of a medium to high degree of crystallinity. Their orientation within the kaolin is random. The intertwined appearance and fragility can only be explained on the basis of crystallization in place. There was obviously no void space in this rock to allow free growth of crystals from introduced mineral material. More reasonably, they could be considered to have grown by a process of recrystallization of the kaolinite that was already there. Vermicular growths of kaolinite in other deposits were likely to have involved recrystallization also. Coarser sediments with available void spaces allowed

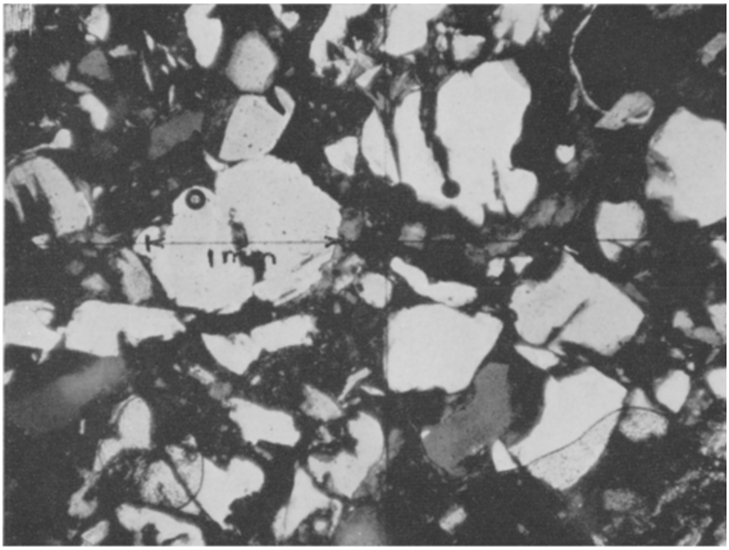

PLATE 1A.—Photomicrograph of the sand from a thin layer within a soft kaolin deposit.

Quartz grains are deeply embayed and split into angular pieces which maintain uniform optical orientation.

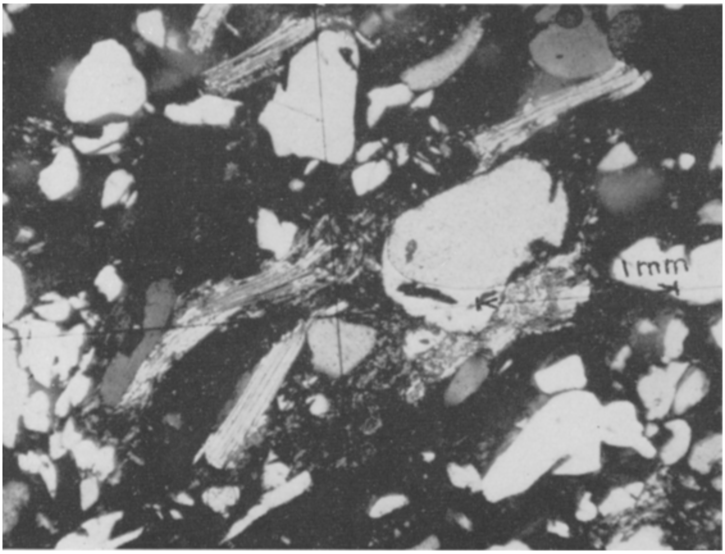

PLATE 1B.—Photomicrograph of large muscovite flakes in several stages of conversion to kaolinite. Conversion is marked by fraying of the edges and crystallization of layers of kaolinite between the separated muscovite layers.

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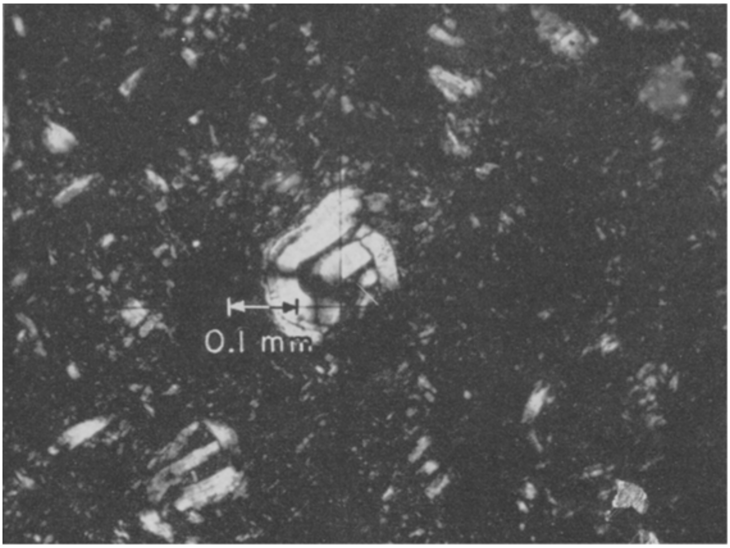

PLATE 1C.—Photomicrograph of vermicular kaolinite growth in a hard kaolin.

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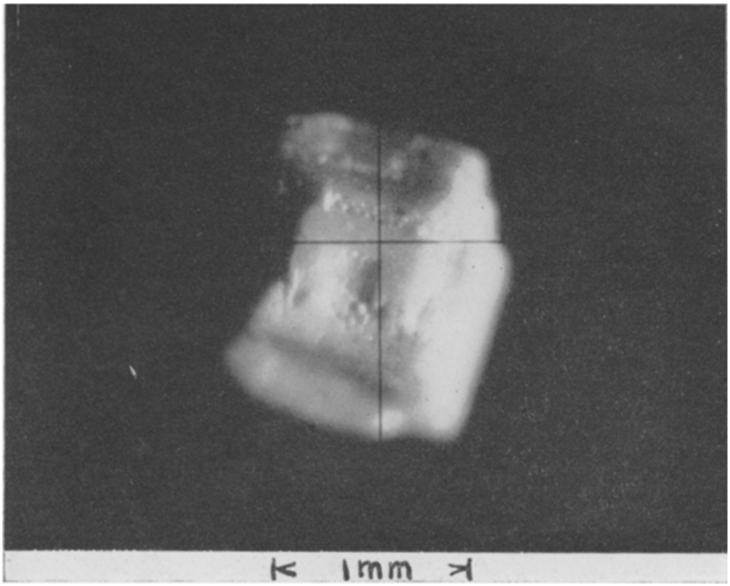

Plate 2A.—Coarse-sand sized kaolinite vermicular growth from a soft kaolin deposit. Top surface is an hexagonal prism face showing compound crystal growth.

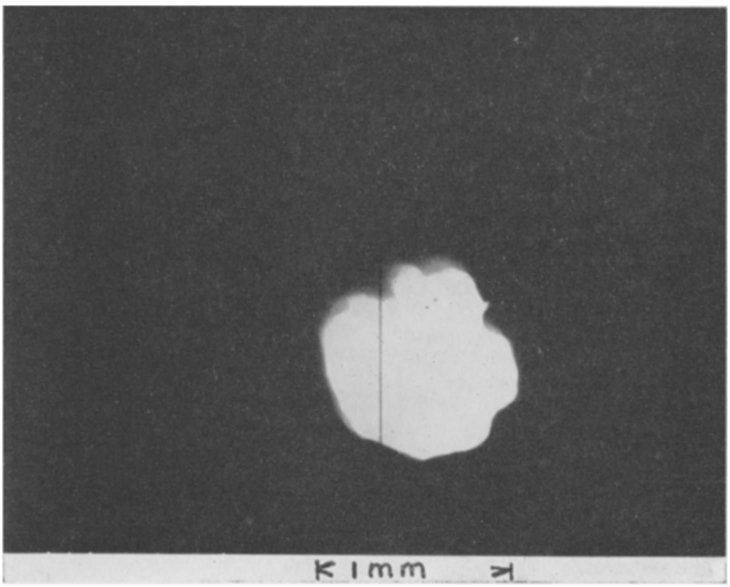

Plate 2B.—Coarse-sand sized kaolinite vermicular growth from soft kaolin. This view of the (001) surface illustrates the compound nature of the crystals formed by the recrystallization process.

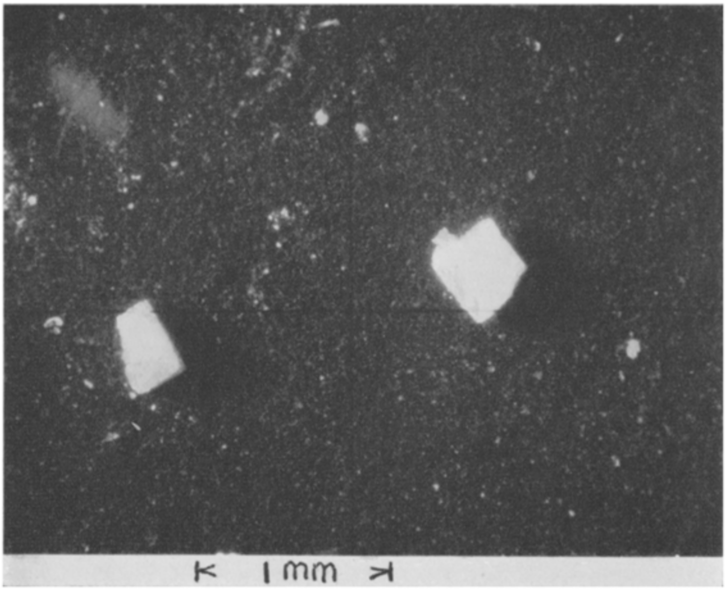

Plate 2C.—Kaolinite pseudomorphs after feldspar from soft kaolin. The rectangular cross-section is shown by these two grains which are resting on (001) cleavage surfaces of the kaolinite.

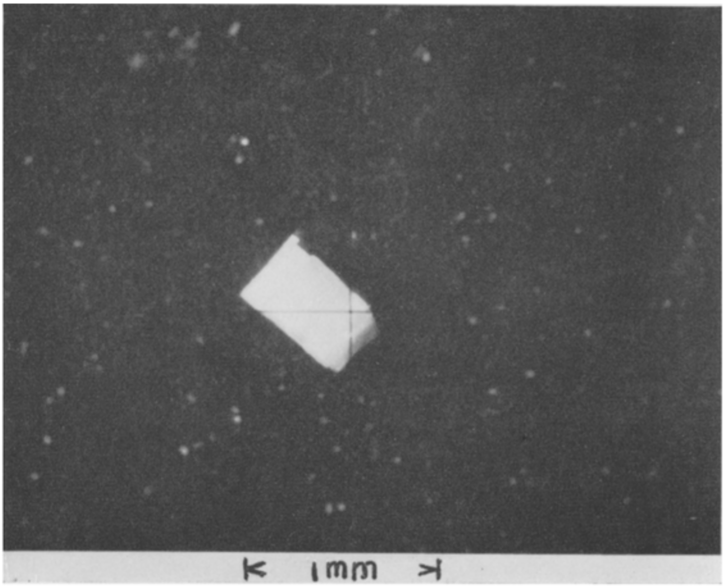

Plate 2D.—Kaolinite pseudomorph after feldspar which is in the process of degrading to an hexagonal cross-section.

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much larger crystal growth. On the other hand, these crystals are able to grow against rather high confining pressures judging from the quartz grain splitting that is so common.

Those hard kaolins that are composed of poorly crystallized kaolinite do not contain vermicular growths. The vermicular growths are always well-crystallized kaolinite. Recrystallization of the kaolinite in hard kaolin deposits has probably been the process which changed originally poorly-crystallized kaolinite to well-crystallized kaolinite. The recrystallization process, if it is related to circulating liquids in the rocks, would be less vigorous in deposits of as low permeability as the hard kaolins. The soft kaolins with much higher permeability would be much more easily recrystallized. This relation has already been noted by Kleinfelter and others (1943).

Plates 2A and 2B are illustrations of a coarse sand-sized grain of kaolinite separated from soft kaolin. The hexagonal prism face shows large numbers of re-entrants and evidence of extreme crystal compounding. The overall shape of the vermicular growth is hexagonal, but on large units it is obvious that they are compounded of many small crystallites having parallel (001) but otherwise not being related in crystallographic orientation. This lack of crystallographic orientation within the plane transverse to the axis of the vermicular growth produces optical properties similar to those of the fine-grained, randomly-oriented kaolinite that surrounds them. The outline of the transverse section is virtually impossible to determine. Because the grains that are easily washed from kaolin deposits frequently have a hexagonal outline, all of the grains viewed in longitudinal section in thin section have been assumed in the past to have an hexagonal shape. Some, of course, do, but others have quite different shapes.

Plate 2C shows sand-sized grains of kaolinite that have a rectangular cross-section. These grains can be washed out of the soft kaolin deposits with gentle disaggregation techniques. They resemble the kaolinite pseudomorphs after feldspar found in the sandstones associated with kaolin deposits which have been reported by Kesler (1952). A considerable part of some of the soft kaolins is made up of these grains.

Each grain is an aggregate of small kaolinite crystals which have parallel alignment of their (001) faces. The rectangular section is identical with that of feldspars in recent river sands. The grains have shapes resulting from the two feldspar cleavages (001) and (010) which are approximately at right angles.

The shape of the feldspar pseudomorphs is remarkably unstable. The grain illustrated in Plate 2D is in the process of being eroded and would eventually be reduced to an hexagonal cross-sectional shape. At least a part of the hexagonal plates and books separated from kaolins by vigorous disaggregation methods are partly worn and eroded feldspar pseudomorphs. Considering the similarity of structure between the recrystallized growths and feldspar pseudomorphs, it is reasonable to assume that the pseudomorphs serve as nuclei for subsequent crystal development into vermicular growths.

DISCUSSION

As a result of the petrographic observations that have been described, the following conclusions have been reached:

1. Pseudomorphs of kaolinite after feldspar occur in the kaolin deposits as well as in the surrounding sandstones.
2. There has been considerable rearrangement of materials that made up the original sedimentary deposits to convert them into the kaolin as we know it today. Much of the original sediment was probably minerals other than kaolinite.
3. Each of the morphological types of kaolinite when separated and purified is either well-crystallized or poorly-crystallized. No intermediate degrees of crystallinity are observed except in samples known to be mixtures of two or more types.
4. Lack of kaolinite orientation supports the concept that the kaolin deposits were not formed by sedimentation of kaolinite.

Abundance of feldspar pseudomorphs, extent of kaolinite recrystallization, and partial chemical solution of quartz grains all demonstrate that post-depositional changes have taken place in all of the kaolin deposits and the associated sandstones. A knowledge of the character of the deposits at the time of deposition would be of great assistance in reaching valid conclusions concerning their origin.

It appears that feldspar and muscovite may have been major constituents in the original sediments that are now kaolin deposits. Muscovite is observed in some kaolins to have a relatively uniform orientation indicating that depositional conditions were such that if crystals of kaolinite were being deposited they could have assumed a horizontal orientation also. The general lack of kaolinite orientation in the deposits can be attributed either to kaolinite not having been present during deposition or to recrystallization which destroyed the sedimentation texture.

Even in the hard kaolins that show least evidence of recrystallization there is no kaolinite orientation. Hard kaolins are generally characterized by their massiveness and conchoidal fracture. For this reason, it is questionable if there was any kaolinite in the original sediment at all. Feldspar grains, on the contrary, would not be expected to prefer any special orientation during sedimentation. Even if there is a unique orientation of kaolinite with respect to the feldspar from which it is converted, the resulting kaolin from a mass of feldspar grains would not show any preferred kaolinite orientation.

Kaolinite derived from post-depositional conversion of feldspar is the well-crystallized variety. That kaolinite that has undergone recrystallization is also of the well-crystallized variety. The conversion of muscovite to kaolinite produces the *b*-axis disordered variety. It appears that the interstitial kaolinite can be either the well-crystallized or poorly-crystallized variety. Although hard kaolins are frequently composed of poorly-crystallized kaolinite, they can be well-crystallized if they have been subjected to recrystallization. The fact that they are not often recrystallized is probably related to their low permeability. Those hard kaolins that have undergone recrystallization produce small vermicular growths of kaolinite. Soft kaolins with intermediate permeability produce somewhat larger vermicular growths, but the largest growths are found in the highly permeable sandstone .

Conversion of feldspar and muscovite to kaolinite and recrystallization of kaolinite as well as the partial dissolving of quartz are probably brought about by the same chemical environment. Each reaction rate will be different, and the overall accessibility to the chemical environment which is related to the permeability of the original sediments controls the progress of the reactions.

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