MICROSCOPIC MINERALS OF THE CLAYS OF MIDDLESEX COUNTY, NEW JERSEY

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During the detailed microscopic study of the clays and accompanying sands of the Cretaceous Raritan formation in Middlesex County, New Jersey, by the senior author of this paper, numerous interesting crystallized minerals have been observed. Search for their possible genesis and place of origin forms part of a fascinating problem in sedimentary petrography and stratigraphy, concerning which more will be published in the future.

This research has been done with a Leitz petrographic microscope, using a magnification, for the most part, of 331 diameters. Various representative clays from the Raritan formation have been elutriated by washing through three containers having different known rates of water flow. Thus the sand and heavy minerals have been separated from the clay which carried them, and the quantitative amounts and relative abundance of the various minerals in each clay determined. It is within the scope of this paper merely to describe the minerals which are present in the clays and associated sands.

The sands of this region of the inner part of the coastal plain belong to the Cretaceous series and alternate with the clays beds. The grains of the sand, which are mostly quartz, (though one sand lens was locally almost a pure dolomite), are found to vary in size from 0.05 mm. to 1 mm., with some which are larger. The sand grains are remarkably angular and show little attrition. Some sands are full of tiny plates of muscovite in practically unaltered condition. There are lenses in the uppermost sand containing microcline, and even granitic fragments still clinging together; and an origin in the granite gneisses of the highland belt of New Jersey and southern New York is plainly indicated. A very few grains of plagioclase, of the acid type, are rarely found. The lower sand, though for the most part pure quartz, contains splintery magnetite fragments, and ilmenite in plates and angular pieces of all sizes, but usually about 1/10 the size of the quartz grains which are with them. There are also magnetite grains which are spherical and look like shot. Where the sands are dry, fresh pyrite in beautiful little crystals is quite abundant; where water is present, the sand is full of colloidal limonite. Chlorite is frequently noted, and a few grains of hornblende in some strata; epidote in broken fragments is encountered at times, and even perfect green octahedrons of spinel, probably derived from the crystalline limestones of the Franklin Furnace-Amity belt. Red hematite in translucent plates; zircon which is colorless, pink, or brown; tourmaline, in small crystals, and fragments of larger ones; also tourmaline crystals which are still in quartz or mica grains; rusty biotite, and carbon, all are present. Garnets are practically absent, apparently because garnets are brittle and break up during transportation or change to limonite; those which have been found are dodecahedral or trapezohedral.

The study of the elutriated residues from the clays shows that the size of grain of the sandy material in the clay is from 0.01 mm. to 0.05 mm. in diameter, with very little that is coarser. Thus the finer grades of fire clay contain no grit of size large enough to be clearly felt between the fingers. On the other hand, there are, of course, gradations from pure clays through sandy clays to clay-bearing sand. The mineral grains here described are usually of a diameter like that given above. The shape of the grains of quartz and of the heavy minerals is remarkably angular and there are few signs of any prolonged attrition; quiet deposition is clearly indicated.

The plastic clay body is composed of kaolin in grains of the order of 0.001 mm. in diameter. With the kaolin is a variable amount of micaceous material in tiny grains and shreds, often making up nearly 50% of the clay body. This mica is partly muscovite and partly a hydrated mica, the ratio being 50%, more or less, of each.

The minerals found in the elutriated clay residues are of numerous species, representing those of all of the rocks of the region within perhaps 200 miles to the north and west of Middlesex County. Some of the best examples of those in crystalline form are illustrated in Plate I. They are as follows:

Magnetite (Fig. 1) is occasionally seen in small, sharp octahedrons. Some of these may possibly be chromite derived from the serpentines. Most of the magnetite, however, is in splinters and fragments. It is common in the lower sand (sand No. 1) and in the Raritan fire clay below this sand, but is uncommon in the Woodbridge fire clays and in the upper sand (sand No. 2) above the latter clays.

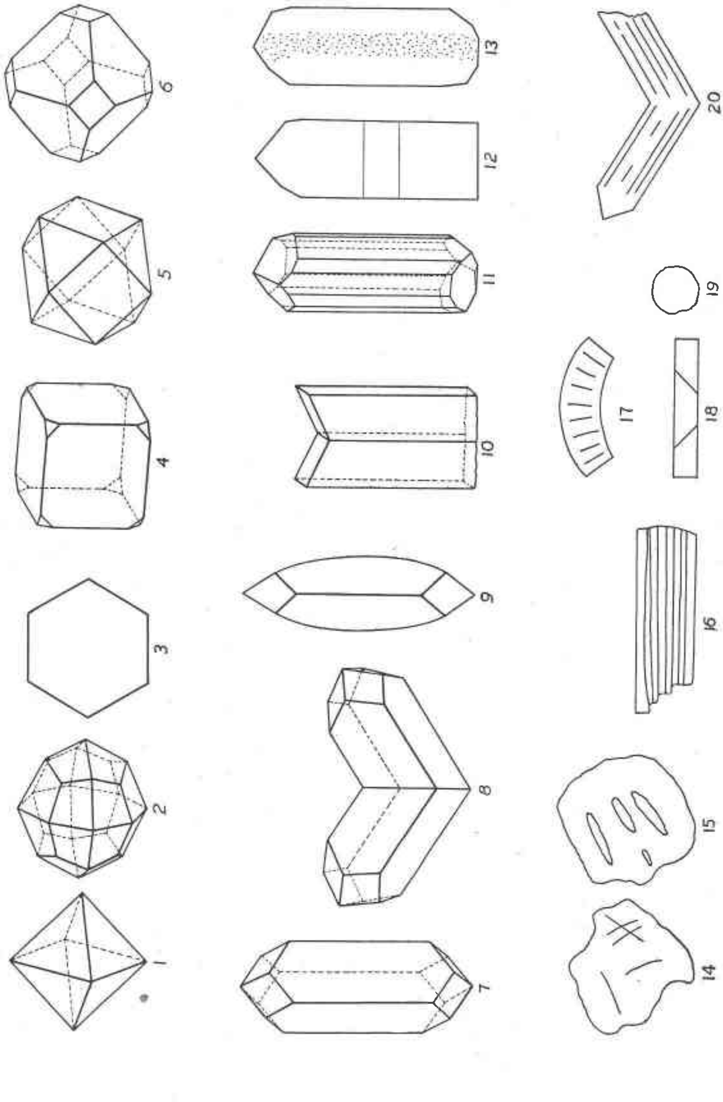

PLATE 1

Garnet (Fig. 2) is uncommon in all of these clays and sands; some grains and crystals are found in the Raritan fire clay at the base of the series. The figure shows such a crystal with the form of the trapezohedron (211); it is also occasionally present in dodecahedrons. Its origin is in the various crystalline rocks which are garnetiferous, including the ancient schists of the Manhattan belt and the granite gneisses of the highlands.

Hematite (Fig. 3) often has a clear red color, and plates with a sharply defined hexagonal outline are not uncommon. Part of it at least has been of secondary origin in the clays.

Pyrite (Figs. 4, 5, 6) is a secondary mineral in the clays. Forms observed include the cube, the octahedron, and various combinations between these. Combinations as well as simple cubes and octahedrons, may occur together in one small clay sample. This is true of the clay from the Quigley property on the south side of the town of South River (pyrites visible under high power only). The pyritohedron is a rare form on pyrite from these clays, having been but once observed (pyritohedron *e* (210)) on pyrite from Sayreville. In this case the form was a small modification on a cubo-octahedron. In some cases, tiny balls and crystals of pyrite are regularly oriented on the edges, or corners, or both, of hematite or ilmenite plates. Marcasite, though found as spearhead twins a half inch long in the Woodbridge fire clay in the vicinity of Parlin, has not been identified among the microscopic minerals.

Zircon (Figs. 7, 8, 9) can be found in the clays and sands in microscopic crystals and grains of three distinctly different kinds, viz.: There are colorless crystals (Fig. 7), always showing the first order prism with the second order pyramid (malacon type). Fig. 8 shows a twin, and Fig. 9, a tapering crystal. Examination of the rocks of the surrounding area shows that the zircon crystals of the Manhattan schist series have these characteristics; and it is to this source that their occurrence in the clays must be due. An interesting fact is brought to light by the common occurrence in the clays of zircon grains of this type whose shape is subangular, much rounded, or even spherical. In the absence of any signs of rounding of the quartz grains, it has been difficult to understand why grains of a mineral with such superior hardness, as zircon, should be so rounded. But upon careful examination of the zircon crystals in the original rock, it was found that most of them were incompletely formed, and that, therefore, the shape of the zircon grains in the clays is not due to wear through transportation, but to the original shape of the grains, which were often rounded. There are brown zircon crystals, showing a combination of the first order unit prism with the first order unit pyramid *p*, and often also the acute first order pyramid *u*(331). These crystals are plainly of the type which occur in the crystalline granite gneisses of the highlands, often in the proximity of the magnetite ores. Pink zircon crystals also are not uncommon, which are made up of a combination of the first order prism and unit pyramid; the origin of these crystals has not yet been ascertained.

Gypsum (Fig. 10), more properly described as a pseudomorph of an unidentified mineral after gypsum. These crystals, comprising less than one per cent of the clays in which they occur, have been identified by their angles as measured under the microscope, as having been originally gypsum. They are flattened as usual on pinacoid *b*, and show in addition, prism *m*, unit pyramid *l*, and rarely base *c*. Swallow-tail twins are not uncommon, and also sheaf-like groupings typical of gypsum. But though these crystals polarize with colors, yet their internal structure may best be described as granular crystalline. The crystals appear monoclinic, yet their extinction is practically parallel to the nicols. This leads to the conclusion that the present crystals are either pseudomorphs, or else have changed in water content, and thus taken on the confused inner structure. The refractive indices of the present material are as follows: $\alpha = 1.490$, $\gamma = 1.530$. This shows no correspondence with any known calcium sulphate compound.

Tourmaline (Figs. 11, 12, 13) is probably the most interesting of all the clay minerals, from the point of view of crystallization. There are myriads of these crystals in the clays of Middlesex County, and most of them are of but one type and general size. They are normally about 0.1 mm. long and half to a quarter as wide, and can be seen in any of the clays with the aid of a microscope of very moderate magnifying power. Their crystal forms are prisms *m* and *a*, unit rhombohedron *r*, acute minus rhombohedron *o*, and base *c* (Fig. 11). Others are flattened, as in Figs. 12 and 13. They are green in color, some with yellow terminations, others with transverse bands which are colorless, yellow, blue, or brown (Fig. 12). Nearly all of them carry microscopic dusty black inclusions which are arranged lengthwise in the crystal (Fig. 13). Their uniform size and complete development suggest an origin in metamorphic schists; precisely similar tourmalines are present in great numbers in the Carboniferous schists of central Connecticut and Massachusetts, and in the many other dark colored phyllites and schists of New England, including the Ordovician rocks which were affected by the Taconic uplift in Vermont; hence this is considered to be the region of their origin. Judging by quantitative microscopic measurements of tourmaline content on the clays and the New England rocks, about 3% of the clay material was derived from the tourmaline-bearing schists and phyllites of New England. Thin, flat tourmalines within muscovite plates have been observed in the clay residues, and some of these are grayish blue indicolite, as found in western New Hampshire. A minor number of other small tourmaline crystals with other characteristics are found in clays and sands. There are fragments of larger tourmalines of green and brown colors, particularly in the sands.

Quartz (Figs. 14, 15) is usually in ragged, angular grains, although a relatively few rounded grains, and even a quartz crystal or two, have been observed. A great many of the quartz grains contain dusty inclusions, like those of the granite gneisses, and others contain cavities, often elongated, or needles of rutile or similar acicular minerals (Figs. 14, 15). Zircon and tourmaline crystals are sometimes found in these quartz grains, and in one case there was within the quartz a bright blue mineral, evidently azurite.

Muscovite occurs in the form of shreds and plates of all sizes Much of it is hydrated or otherwise altered.

Kaolin is often in the form of curved aggregates of plates (Fig. 17). These are typical of much kaolin, like that in the granite gneisses of the highlands, and sedimentary rocks derived therefrom, of many different ages. In this form the kaolin may be original or secondary.

Ilmenite, besides appearing in irregular grains, is occasionally seen in distinct plates, the most complete of which show base *c* with prism *m* and unit rhombohedron *r* (Fig. 18). Some ilmenite grains approach a perfectly spherical shape (Fig. 19), which does not appear to be due to abrasion, but to the original shape of the grain.

Rutile (Fig. 20) is in the form of prisms which appear deeply striated; a very few are twinned. The amount of rutile present, however, is very small in proportion to that of ilmenite, from which we conclude that the titanium in the clays is principally in the latter mineral.

Limonite and closely related hydrous iron oxides are present in clays and sands in great abundance; many of their forms are colloidal, while others are strongly crystalline. All stages of derivation from pyrite and the other iron minerals may be observed.

Other minerals which have been seen in a few instances are pyroxene, enstatite, hypersthene, monazite, staurolite, one sharp crystal resembling olivine, and several grains and aggregates occasionally encountered whose exact nature is uncertain. No definite zeolite has been identified.

With the exception of the pyrite crystals and limonite derived therefrom and from other iron bearing minerals, the kaolin aggregates, the gypsum crystals, and the crusts of melanterite and of alum which appear on clay surfaces, it does not seem probable that any of the mineral grains above described have been secondarily produced in the clays since the deposition of the latter.