CLAY MINERAL VARIATION IN A PENNSYLVANIAN UNDERCLAY

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This report presents the results of a detailed study of the clay mineral composition of a Pennsylvanian underclay which was made while the author was attending the University of Illinois. The underclay crops out along the southeast bank of the Salt Fork Creek, W ½ sec. 31, T 19 N, R 13 W, near the town of Fithian, Vermilion County, Illinois. It occupies a stratigraphic position below the Flat Creek Coal (J. A. Simon, personal communication). This underclay was selected for study since it is the type location for Fithian illite, a standard reference clay mineral (American Petroleum Institute, 1949-50); and also, because it displays features found in many Pennsylvanian underclays.

Following is a description of the stratigraphic sequence and sample positions:

Description	*Thickness in inches*
Shale, black, very hard, fissile, no fossils	8
Shale, black, soft, fissile, contains fossil hash	13
Limestone, dark gray, fossiliferous.	0-6
Coal (Flat Creek)	8
Underclay, dark gray, noncalcareous (sample B7)	5
Underclay, gray, noncalcareous (sample B6 just above iron-stained zone)	5
Iron-stained zone	1
Underclay, gray, calcareous nodules (sample B5 just below iron-stained zone)	10
Underclay, gray, calcareous nodules (sample B4)	10
Underclay, gray, calcareous nodules (sample B3 at base of underclay).	24
Underclay, sandy, calcareous (sample B2 in transition zone)	3
Siltstone, gray, calcareous, thin bedded, micaceous (sample B1 in upper 2 inches of siltstone)	60

Clay Mineralogy

Samples were obtained from freshly cleaned outcrop surfaces. Clay samples from the same stratigraphic sequence were also obtained one-half mile upstream from the type location. Their x-ray traces are similar to those in Figure 1. Each clay sample was dispersed in distilled water and fractionated by sedimentation to remove the < 2 micron size. Oriented aggregates were prepared for x-ray analysis. A General Electric XRD-5 diffraction unit with copper radiation was used. The x-ray traces of unheated, glycolated, and heated samples from the type location are shown (Fig. 1). Samples were heated to 475°C for thirty minutes to distinguish chlorite from kaolinite.

The underlying siltstone is very micaceous, thus giving the intense, well defined peak at 10 a.u. on the x-ray trace. Kaolinite and chlorite are very abundant in the siltstone and decrease as the siltstone grades upward into the base of the underclay (samples B1, B2, B3). The contact between the siltstone and un-

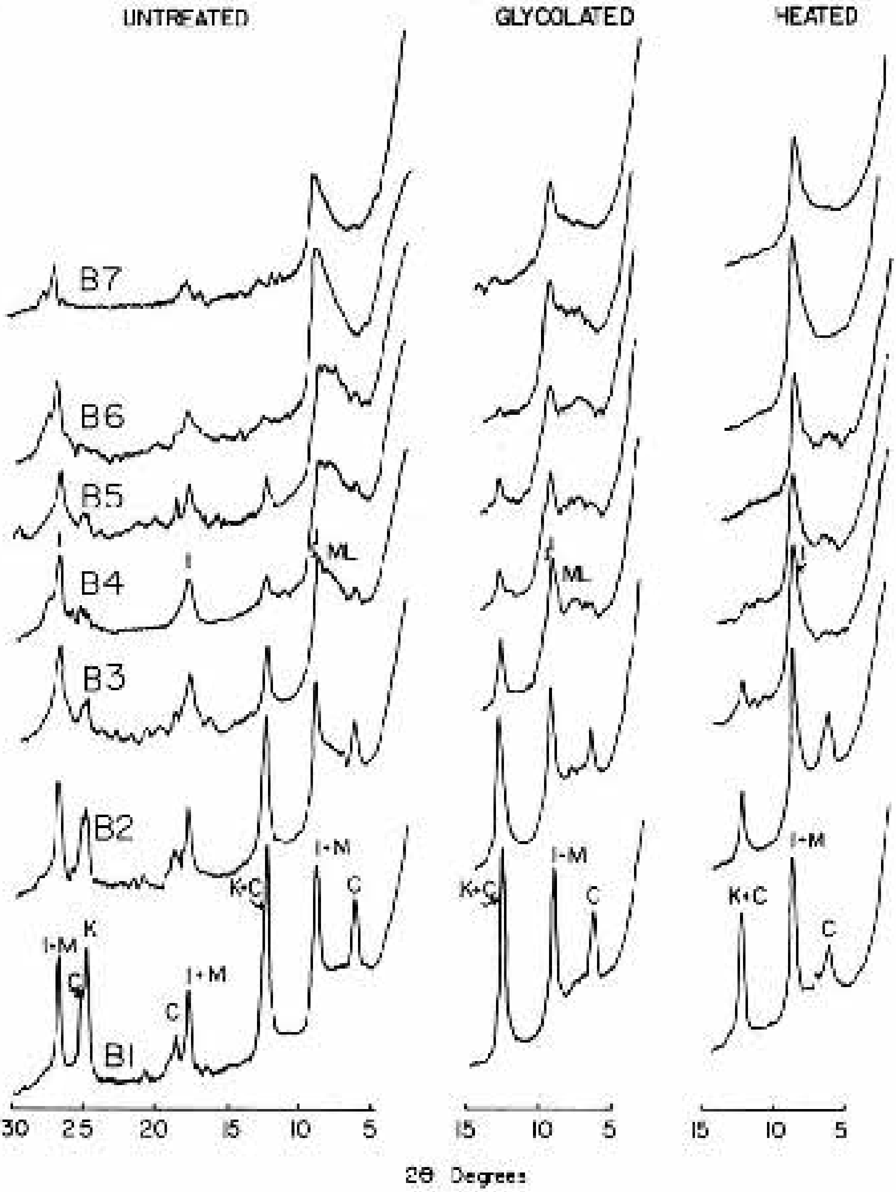

FIGURE 1.—X-ray diffraction traces of oriented clay mineral aggregates arranged in order of stratigraphic position. C, chlorite; I, illite; K, kaolinite; ML, mixed-layer; M, mica.

derclay is transitional as reflected in gradual vertical lithologic and mineralogic changes.

The x-ray traces (Fig. 1) indicate a decrease in the amount of kaolinite and chlorite vertically in the underclay. Illite and mixed-layer minerals dominate. Mixed-layer material slightly decreases in amount vertically, while illite increases. The illite in the noncalcareous zone is not greatly degraded as indicated by an intense and sharp peak at 10 a.u. (Fig. 1, samples B7, B6). An abrupt change in the kaolinite and chlorite content is noted at the iron-stained zone. Below the zone (sample B5), the clay is calcareous and contains mixed-layer minerals, abundant illite, with a minor amount of kaolinite and chlorite. Above the zone (sample B6), the clay is noncalcareous and contains only illite and mixed-layer minerals.

Interpretation

Several explanations accounting for the variation in clay mineral composition are as follows: (a) underclay could represent a fossil soil produced by weathering and leaching (Weller, 1956) which would alter the clay minerals in the same manner as in recent soils; (b) the underclay may have had a detrital origin and the composition variation reflects diagenetic changes; (c) the basin of underclay deposition may have been supplied by various source materials of different composition with no changes produced in the clay material during underclay accumulation.

Many investigators have studied the vertical distribution of clay minerals in soil profiles. Frye, Willman, and Glass (1960) studied profiles in Illinoian till and found an alteration sequence from chlorite and biotite-type micas through vermiculite-chlorite, vermiculite, mixed-layer clay minerals to expandable vermiculite; kaolinite is unaffected and may even be augmented. In buried Sangamon profiles on Illinoian till and outwash, the original illite and chlorite are altered completely in the upper part to montmorillonite (Brophy, 1959). Murray and Leininger (1956) found that illite and chlorite in unweathered parts of Illinoian and Wisconsin tills alter to montmorillonite in highly weathered parts. Droste, Bhattacharya, and Sunderman (1962) found that in soil profiles on glacial till, loess, and limestones the chlorite of the parent material is changed completely to montmorillonite with intermediate stages of random mixed-layers of chlorite-vermiculite-montmorillonite. They stated that kaolinite may be produced as a weathering product or remain unchanged from the parent material.

Dalton, Swineford, and Jewett (1958) studied the clay minerals in a fossil soil zone at a Desmoinesian-Missourian disconformity in southeastern Kansas. The soil zone is developed on top of a marine shale which contains predominantly illite, chlorite, quartz, feldspar, and a very small quantity of kaolinite. The results of alteration in the soil zone show a hydration of illite, characterized by the broadening of the basal reflections, production of "soil" chlorite (i.e., chlorite whose basal spacings are destroyed at 450°C), sporadic increase in kaolinite, and modification and destruction of normal chlorite (basal reflection retained after heated to 575°C) with production of mixed-layer and vermiculite minerals.

Ostrom and Potter (1961) studied the clay composition of a weathered zone in the Kinkaid Formation at the Mississippian-Pennsylvanian contact in the Illinois Basin. Their evidence indicated that the zone represented a truncated pre-Pennsylvanian weathering profile. The illite in the unaltered part of the formation was found to decrease vertically commensurate with an increase of mixed-layer material. The indication of a structural breakdown of illite to produce the mixed-layer component is used as evidence by Ostrom and Potter to support the existence of a weathering profile.

There are several factors controlling weathering processes which influence soil development: parent rock, topography, vegetation, time, and climate (Grim, 1953). The factors existing during the formation of the underclay of the Flat Creek Coal may have been similar to those influencing soil profile development at the Desmoinesian-Missourian disconformity in Kansas and the Mississippian-Pennsylvanian contact in the Illinois Basin, since the geologic conditions were probably similar in many parts of the Mid-Continent during the Pennsylvanian Period. The latter two profiles formed on dominantly kaolinitic, chloritic, and illitic rocks (a composition similar to the siltstone below the underclay of the present investigation). Since the parent rock and other soil producing factors were probably reasonably similar throughout the mid-continent, the clay mineral composition of the three examples should resemble each other. However, the variation of underclay composition is markedly different from that found in the two examples known to be fossil soils.

There is no indication of a weathering profile similar to that found in Pleistocene deposits. X-ray data of the underclay indicate a decrease upward in the kaolinite and chlorite content, no indication of a hydration or decrease of illite, and no formation of montmorillonite or other three-layer minerals. The mixed-layer component decreases in abundance. The sharp, well-resolved illite peak indicates a lack of degrading which would result under alteration. Grim and Allen (1938) determined the base-exchange values of the Fithian illite underclay and found no similarity to values obtained in a vertical sequence of samples from recent soils showing a profile. The clay minerals in the underclay do not appear to have been altered to produce the composition of these soil profiles formed during the Pleistocene or Pennsylvanian Periods, thus suggesting that the variation in composition probably did not result from the soil forming process.

The underclay may have formed as clay material was deposited in a basin prior to coal swamp development. The clay mineral variation may reflect chemical changes in the environment of deposition, also evidenced by the variation of the calcareous content of the underclay. Kaolinite and chlorite are present in the calcareous part of the underclay but absent in the noncalcareous section. A number of investigators have found that chlorite increases in a sedimentary environment as the salinity of the water increases (Johns and Grim, 1958; Brown and Ingram, 1954; Powers, 1954). As the source material first comes in contact with more saline water, cation exchange reactions result in the acceptance of K and Mg ions in exchange position. With increasing magnesium content and pH, protons would be subtracted from the water and the brucite configuration would develop. A definite, though poorly crystallized, discrete chlorite phase would develop with increasing brucite growth (Grim and Johns, 1953). The calcareous part of the underclay could have been deposited in a more saline environment in which chlorite could form. Chlorite development probably diminished as the water became fresher, thus indicating why it is absent in the noncalcareous portion.

The variation in underclay composition may be due also to the deposition of source material of different compositions in which less kaolinitic, chloritic, and mixed-layer material were deposited during the accumulation of the upper part of the underclay. The gradual decrease of kaolinite, chlorite, and mixed-layer minerals upward may simply reflect a diminishing of supply of these particular minerals. The supply of illite may have changed only slightly. Thus the variation in composition also may be purely a primary sedimentation feature.

Summary

A detailed clay mineral investigation of the Fithian illite underclay indicates a vertical variation in clay composition. Illite and mixed-layer clay minerals are abundant throughout. Kaolinite and chlorite decrease in amount toward the top of the unit. Clay mineral evidence does not indicate the presence of a profile of a fossil soil. A detrital origin may account for the variation in composition.

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