

EFFECT OF WEATHERING ON CLAY MINERALS¹

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ABSTRACT

Types of clay minerals have been determined in samples from three profiles in Indiana: (1) a residual soil from limestone; (2) a Pleistocene till of Illinoian age; (3) a Pleistocene till of Wisconsin age. The type of clay minerals varies with depth from the surface because of degree of weathering. In the residual soil from limestone, montmorillonite is the dominant clay mineral; the entire profile is highly weathered. Likewise montmorillonite is dominant in the highly weathered portion of both the Illinoian till and the Wisconsin till. The relatively unweathered portion of both tills contains illite and chlorite as dominant clay minerals. The factors of the weathering process in central and southern Indiana evidently favor the development of the clay minerals having expanding lattices. The mechanism for changing chlorite and illite to montmorillonite seems to include oxidation of the iron in the lattice and subsequent leaching of magnesium and potassium.

When surface clays are eroded and transported by streams into a marine environment, the expanding-lattice clay minerals may revert readily to the original type, either chlorite or illite.

INTRODUCTION

One of the most adequate interpretations of weathering is that by Jackson and Sherman (1953) who define weathering as the changes in degree of consolidation and in composition which take place in the earth's crust within the sphere of influence of atmospheric and hydrospheric agencies. Keller (1955) has recently published an article elucidating the principles of chemical weathering and has reviewed much of the literature on the subject. The purpose of this study is to determine the effects of the chemical agents of weathering on clay minerals in the environment of surficial profiles.

Agronomists and soil chemists have done the most detailed work on weathering and much of the available literature on weathering concerns soils and soil development. Jackson at the University of Wisconsin has been a most ardent worker on this subject. Jackson and others (1948) have worked out a weathering sequence of clay-size minerals which consists of thirteen stages; the more soluble and easily weathered substances appear in the first five stages. The results that are presented in this paper emphasize the minerals in Jackson's intermediate stages 7 through 9: illite type, interstratified minerals and chlorite, and montmorillonite.

Three profiles were chosen for detailed chemical and mineralogical study. This report treats only the clay minerals; chemical and additional mineralogical data will appear at a later date. The three profiles studied represent three stages of weathering which for temperate climate can be classified as immature, inter-

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mediate, and mature. The immature weathering profile has developed on glacial till of Wisconsin age over a period of 18,000 to 19,000 years, according to radio-carbon dates (Horberg, 1955). The intermediate weathering profile has developed on glacial till of Illinoian age over a period of approximately 140,000 years (William Thornbury, oral communication). The mature weathering stage is represented by a residual soil developed on Mississippian limestones over millions of years.

Jackson and others (1948) have indicated that weathering rates are controlled by intensity and capacity factors operating as functions of time. The intensity factors are temperature, rate of water movement, acidity of solutions (proton intensity, H^+), biotic activity, and the degree of oxidation (electron intensity) and its fluctuation (oxidation-reduction, Δe^-). Capacity factors are the specific surface of the particles and the specific nature of the minerals being weathered. The samples that represent the immature, intermediate, and mature stages were all obtained within 60 miles of each other. The samples utilized for study were the less than 75μ fraction and the clay-size fraction separated by sedimentation. X-ray diffraction techniques were used for identification of clay-mineral types. Glycolation and heating tests were performed on all clay-size fractions to aid in identifying montmorillonite, vermiculite, and chlorite.

DESCRIPTIONS AND MINERALOGY OF SAMPLED SECTIONS

Residual Soil

A residual soil on limestone was sampled near Bloomington in Monroe County, Indiana. The soil is 5.5 feet thick; composite samples were collected from each 0.5 foot. The entire profile was leached and oxidized. Figure 1 shows diffractometer traces from the clay minerals observed in the maturely weathered profile. As can be seen in the figure the minerals do not change appreciably from top to bottom. Montmorillonite is the dominant clay mineral, along with minor amounts of chlorite, kaolinite, illite, and mixed layer materials.

Illinoian Till

Many geologists and agronomists have been impressed by the marked weathering zones which are apparent in vertical exposures of glacial drift that blankets the upper Mississippi Valley and Great Lakes region. Leighton and MacClintock (1930) were the first to study these zones in detail. Figure 2 is a diagrammatic representation of a profile developed on an Illinoian glacial till. This till is exposed in the high wall of a coal strip mine near the town of Staunton, in Clay County, Indiana. The total thickness of the till profile is 26 feet; composite samples of each 0.5 foot were collected. One can observe definite color demarcations and changes in angle of repose which identify the zone boundaries. In this particular section 8 feet of soil and loess overlie a partially weathered till. Below this is 8.5 feet of leached and oxidized till in which the crystalline rock particles have disintegrated and decomposed. In this zone organic matter and ferrous iron have been oxidized. In the field this zone is detected by use of dilute hydrochloric acid, with which the material does not react, thus indicating that all calcium carbonate has been leached out. Figure 3 is a plot of percent

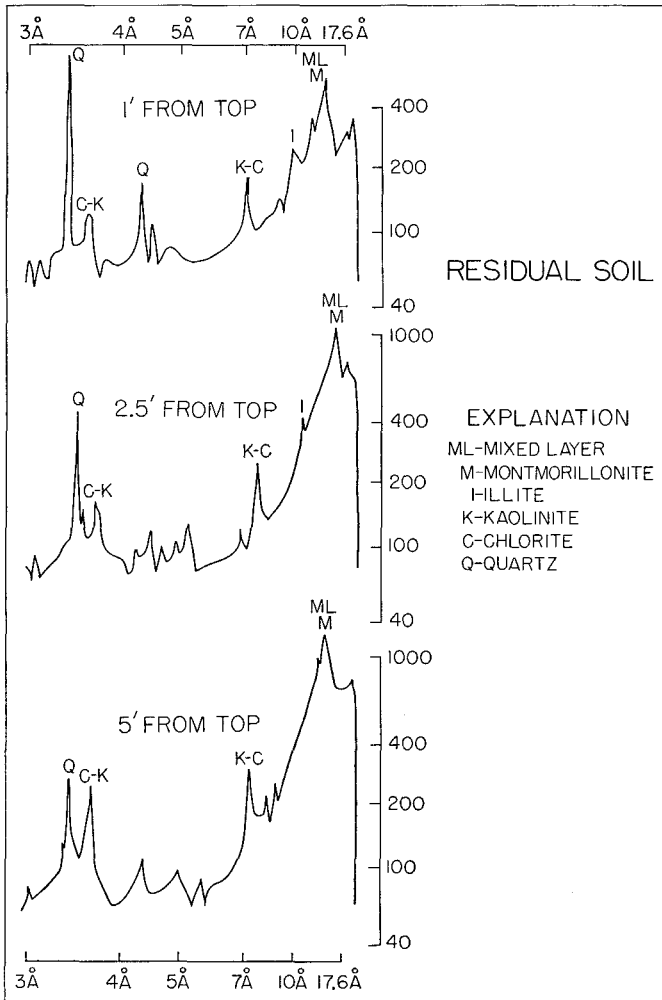


FIGURE 1.—X-ray diffractometer traces of residual soil samples.

carbon dioxide (determined by acid evolution) versus depth for the Illinoian till profile. Very little if any carbonate exists in the loess and leached zones. Original and secondary carbonate occur in the unleached, oxidized zone. Original carbonate less that converted to sulfate occurs in the so-called unweathered zone.

Below the leached and oxidized zone (Fig. 2) is a 7-foot zone which has been oxidized but not leached of carbonate. The junction of the leached and unleached zones is sharp. The lower blue-gray zone is the so-called "unweathered" zone which has been neither leached nor oxidized. The lower part of the un-

weathered zone closely approximates the original mixture of rock flour and coarse materials which was laid down by the glacier in a thickness equal to the entire till section. This type of profile of weathering provides an excellent opportunity for study of changes in the clay minerals in zones of different intensities and duration of attack by agents of weathering.

Figure 4 shows diffractometer traces from the clay minerals in the weathering profile developed on Illinoian till. The unweathered till contains chlorite, illite, mixed-layer materials, and kaolinite. The oxidized-unleached zone contains the same mineral assemblage. In every sample from the oxidized-unleached zone more mixed-layer materials were found, and the illite and chlorite peaks were diminished in intensity relative to the same peaks for the unweathered samples. In the leached zone, montmorillonite is the dominant mineral; the amounts of illite, kaolinite, chlorite, and mixed-layer materials are much diminished in comparison with the other two zones.

Wisconsin Till

The sampled section of glacial till of Wisconsin age is located near the town of Kingston in southern Parke County, Indiana. The sampled section is 30 feet thick; composite samples were collected from one-foot intervals. The oxidized-leached zone is 5 feet thick and the oxidized-unleached zone 12 feet thick.

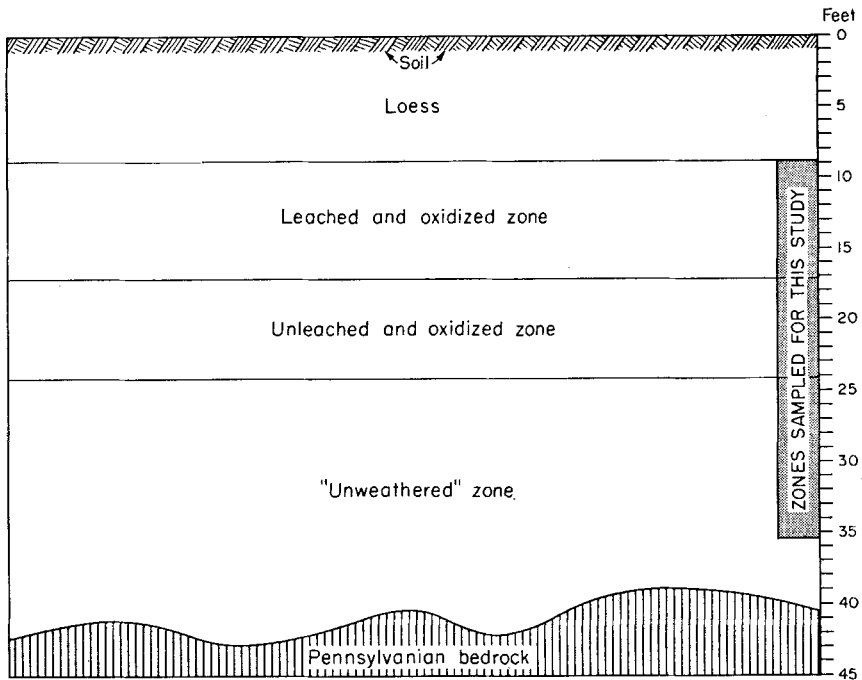


FIGURE 2. — Sketch of Illinoian till profile.

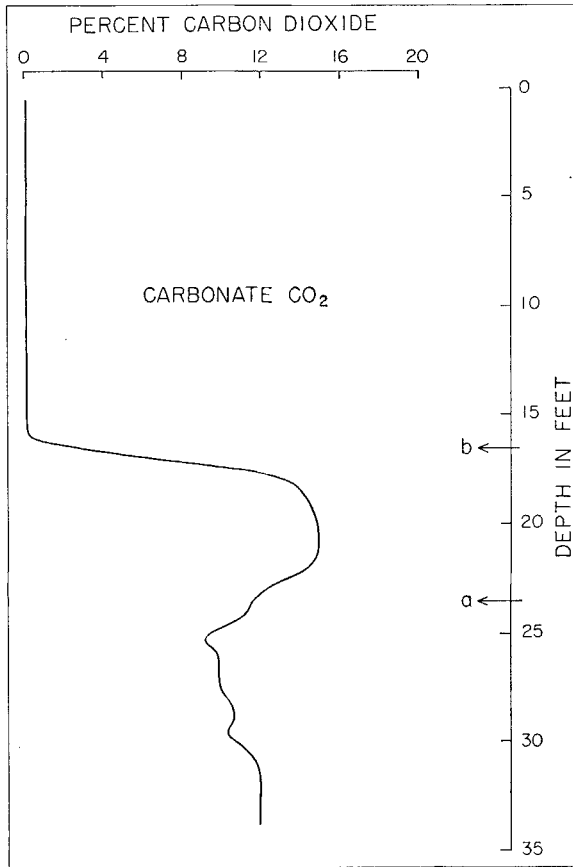


FIGURE 3.— Carbonate CO₂ versus depth, Illinoian till profiles: *a*, top of “unweathered” zone; *b*, top of unleached, oxidized zone.

Figure 5 shows diffractometer traces from the clay minerals present in the unweathered, oxidized-unleached, and oxidized-leached zones of the Wisconsin till. In the unweathered zone the clay minerals are chlorite, illite, interstratified or mixed-layer minerals, and kaolinite. In the oxidized-unleached zone these same minerals are present; the only differences observed were a diminishing intensity of the illite 001 peaks and relatively more interstratified material. In the oxidized-leached zone montmorillonite is the dominant component with minor amounts of illite, chlorite, and kaolinite along with mixed-layer components.

DISCUSSION OF RESULTS

A total of 109 samples were analyzed for the three profiles; definite changes in the clay minerals were observed resulting from differences in the intensity

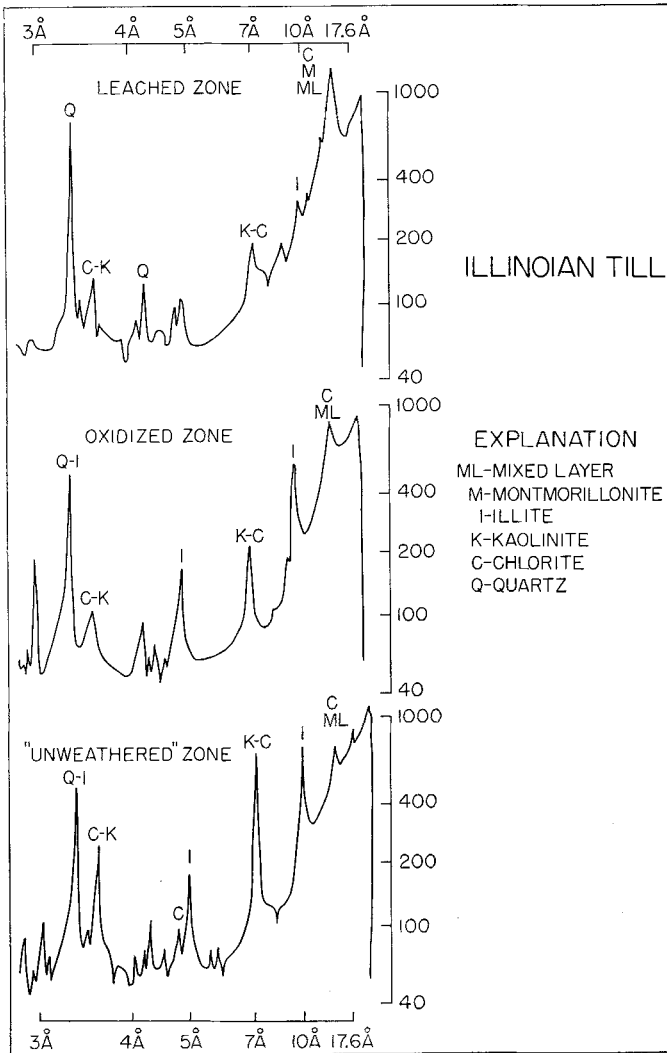


FIGURE 4.—X-ray diffractometer traces of samples from Illinoian till profile.

of weathering within the till profiles. The maturely weathered material represented by the residual soil profiles contains an abundance of montmorillonite. The most intensely weathered portions of both till profiles contain a dominance of montmorillonite. From this observation, montmorillonite is concluded to be the result of weathering of the particular intensity and capacity factors active in the geographic area where the samples were collected. Jackson and others

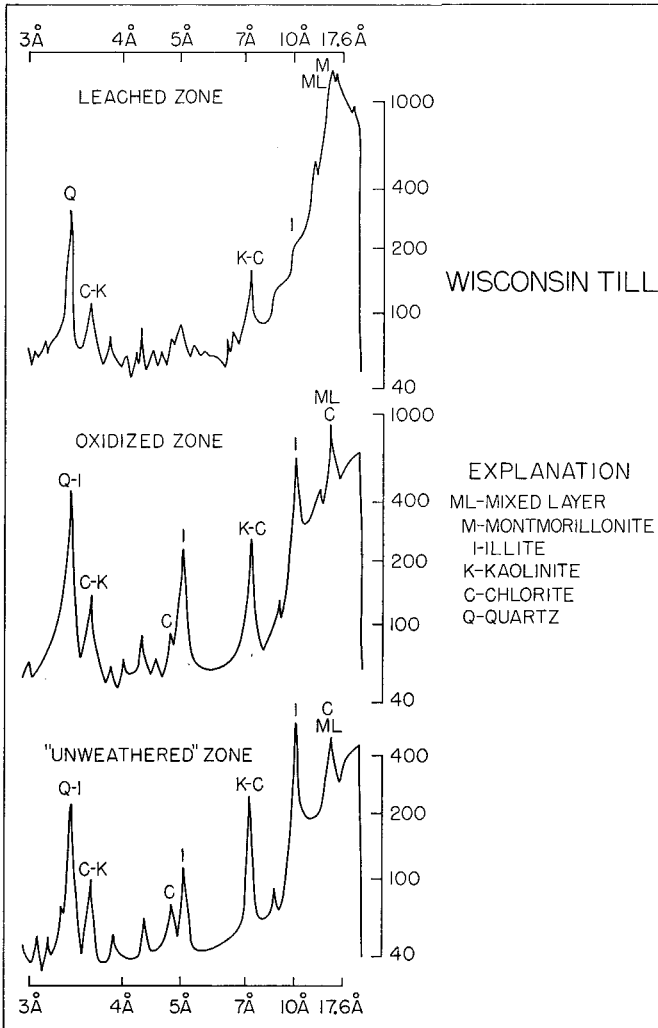


FIGURE 5.—X-ray diffractometer traces of samples from Wisconsin till profile.

(1948) indicated that the next stage of weathering is the formation of kaolinite; no evidence of kaolinite development was observed in these particular profiles.

Montmorillonite is the most abundant clay mineral in the most highly weathered portion of the profiles; illite and chlorite are the most abundant clay minerals in the unweathered portions of the till profiles; illite and mixed-layer materials are the clay components of the limestone on which the residual soil has developed. The remaining components change also, but chemical and mineral determinations indicate that montmorillonite developed from the illite and

chlorite minerals. A suggested initiation of the mechanism for this change is oxidation. Some ferrous iron is undoubtedly present in the octahedral layers of chlorite and illite. When this iron in the octahedral positions becomes oxidized, the structure is somewhat disrupted as is evidenced by the decrease in intensity and broadening of x-ray diffractions from the basal planes of illite and chlorite. The oxidation of the iron causes a change in the net charge. The bonds between the sheets are weakened, thus allowing the introduction of solutions and/or water which could then remove potassium ions from illite—or iron, magnesium, and/or hydroxyl ions from chlorite. This mechanism would produce an expanding-type clay mineral. The authors believe that the initiating mechanism for the change from chlorite and illite to montmorillonite is oxidation of ferrous iron in the octahedral layers.

When these weathered clays are eroded and transported into streams and are subsequently carried into the marine environment, the clay minerals will tend to revert back to their original types; i.e., illite and chlorite. Bradley (1954) has indicated that during diagenesis clays that have been changed during weathering tend to revert back to their original types because their skeletal structures persist; these structures accommodate ferrous iron, magnesium, and/or hydroxyl ions when available from the marine environment.

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