Clays and Clay Minerals, 1968, Vol. 16, pp. 257–264. Pergamon Press. Printed in Great Britain

ORIGIN OF THE WOODSTOWN, NEW JERSEY, MACRO-KAOLINITE

WAYNE C. ISPHORDING and WILLIAM LODDING

Department of Geology, University of South Alabama, Mobile, Alabama, and Rutgers, The State University, New Brunswick, New Jersey

(*Received* 26 *October* 1967)

Abstract—A kaolin bed in which many of the individual kaolinite platelets exceed 0·2 mm in size occurs in the immediate vicinity of the base of the middle-Miocene Kirkwood Formation, near Woodstown, New Jersey. These platelets appear to have resulted from breakdown of pre-existing illite and montmorillonite coupled with concurrent epitaxial growth and diagenetic growth of primary kaolinite. The alteration of the clay minerals is thought to be a product of upward leaching (dialysis) by groundwaters in the underlying Vincentown Sand. This is further evidenced by abnormally high percentages of clay-size kaolinite in the clays that lie above the Vincentown Sand but beneath the macro-kaolinite horizon. Growth of the macro-kaolinite was facilitated by face-to-edge sedimentation and the resultant high permeability of the stratum.

INTRODUCTION

Location

NEAR the base of the middle-Miocene Kirkwood Formation, in southern New Jersey, lies a distinctive horizon which has been described as a "micaceous, talc-like clay" (Ries, Kummel, and Knapp, 1904). Actually, the material that composes this horizon contains relatively little true mica and is completely lacking in the mineral talc. The soft, talc-like texture results from the presence of unusually large grains of kaolinite, in random orientation, some of which are larger than 0·2 mm in size (Fig. 1).

Description

Stratigraphic investigation disclosed that this bed is confined to the immediate vicinity of the up-dip limit of the marine clay unit of the Kirkwood Formation known as the Alloway Clay Member (Isphording, 1966). No evidence of this horizon was found elsewhere in the formation in other parts of the State, either outcropping or down-dip. Outcrops of the horizon, even in the vicinity of Woodstown, New Jersey, are uncommon because it erodes rapidly on exposure, but well records and extensive searching with hand auger have shown that its total areal extent is probably about 5 square miles (Fig. 2). The maximum thickness of this unit is about 10 ft, but usually is much thinner. The macro-kaolinite bed was found to occur invariably within 10 ft of the bottom of the formation. The clays lying beneath it, but above the base of the formation, are characterized by anomalously high percentages of kaolinite when compared with the remainder of the Alloway Clay Member.

STRATIGRAPHY

The Alloway Clay Member of the Kirkwood Formation outcrops over a wide area of southern New Jersey (Fig. 2) and rests, unconformably, on the lower Eocene Vincentown Sand and, locally, on the Paleocene Hornerstown Marl. The sediments that comprise the Kirkwood Formation were deposited during the early middle-Miocene transgression on a highly eroded surface which is commonly called the Schooley peneplane. The Alloway Clay Member is, stratigraphically, the lowest unit in the Kirkwood Formation and is contemporaneous, at least in part, to the lagoonal silts and clays of the Asbury Park Member which occurs in the northeastern portion of the State (Isphording, 1966). Both of these members appear to be overlain, with local disconformity, by the upper unit of the Kirkwood Formation, a sequence of fine sands and silts, known as the Grenloch Member. The macro-kaolinite horizon was not found in either the Grenloch or the Asbury Park Members, and is restricted completely to the Alloway Clay Member.

MINERALOGY

Mineralogically, the clays of the Alloway Clay Member consist of a homogeneous mixture of illite, kaolinite, montmorillonite, and mixed-layer clays, consistent with the marine origin of this member. The percentages of these clay minerals were found to be relatively constant in abundance

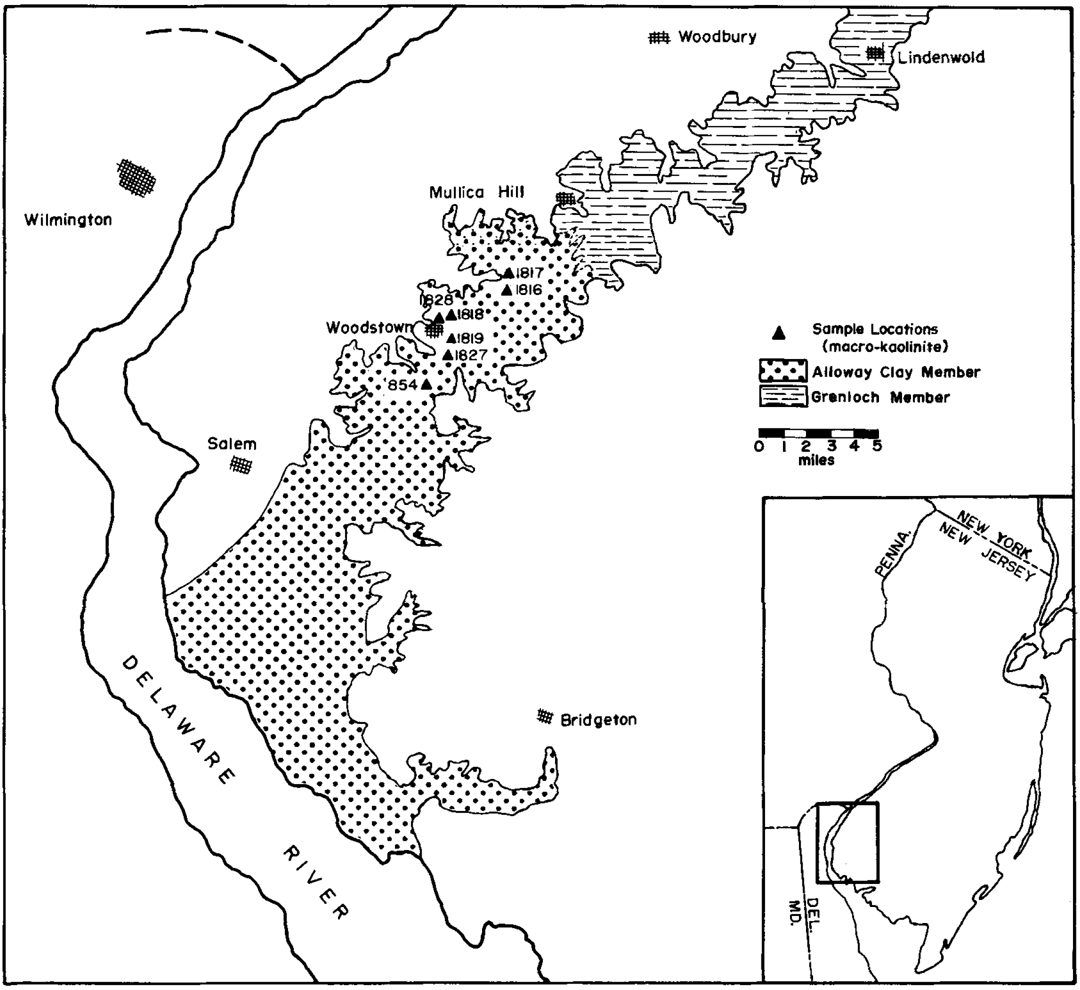

Fig. 2. Outcrop map of the Alloway Clay member showing locations where macro-kaolinite horizon was found.

within this member both laterally and vertically in the section. Table 1 shows the approximate percentages of the above minerals present in the $-2\ \mu$ fraction, based on analyses of nine fresh samples. The percentages of clay minerals were determined by first treating the clay fraction with sodium dithionite to remove soluble iron (see Black *et al.*, 1965), followed by magnesium saturation and removal of soluble salts. The clays were then sedimented on three glass slides and subjected to X-ray diffraction analysis using a Norelco diffractometer with copper $K\alpha$ radiation. One of the three slides was treated with glycerol; one was heated at 300°C, and another at 550°C. Percentages of minerals were computed from X-ray intensities using empirical correction factors for the 10 and 14 Å minerals. Representative diffractograms of this member are shown in Fig. 3.

In the immediate vicinity of the macro-kaolinite horizon, a marked deviation occurs from the average composition shown in Table 1. Figure 4 is a cross-section of a representative hole augered through the macro-kaolinite horizon (unit "*c*"), and the mineralogy of the various units is shown in Table 2. A marked enrichment in kaolinite, at the expense of illite and montmorillonite, is seen to occur in units *c*, *d*, and *e* while units *a* and *b* apparently are unaffected. Enrichment of kaolinite thus appears to have occurred from the base of the formation upward in the section.

The macro-kaolinite horizon deserves additional discussion because of its unusual nature. The

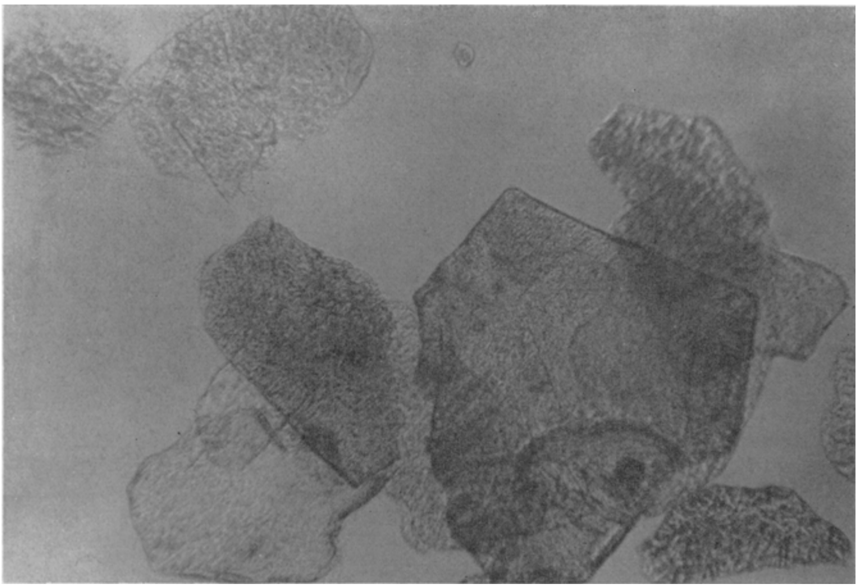

Fig. 1. Sand-size kaolinite platelets from macro-kaolinite horizon (× 185).

[*Facing page* 258]

Table 1. X-ray analyses (in per cent) of unweathered samples of the Alloway Clay Member (minus 2-μ fraction)

Sample No.	Montmorillonite and mixed-layer clays	Illite	Kaolinite	Quartz
K-12-1	21	52	14	12
K-12-2	29	43	16	12
K-12-3	25	45	17	13
K-12-5	22	43	23	12
K-53-3	15	39	29	16
1180-A	17	52	29	2
1180-B	25	47	24	4
1180-C	25	48	25	2
1180-D	26	52	20	3
Average	23	47	22	8

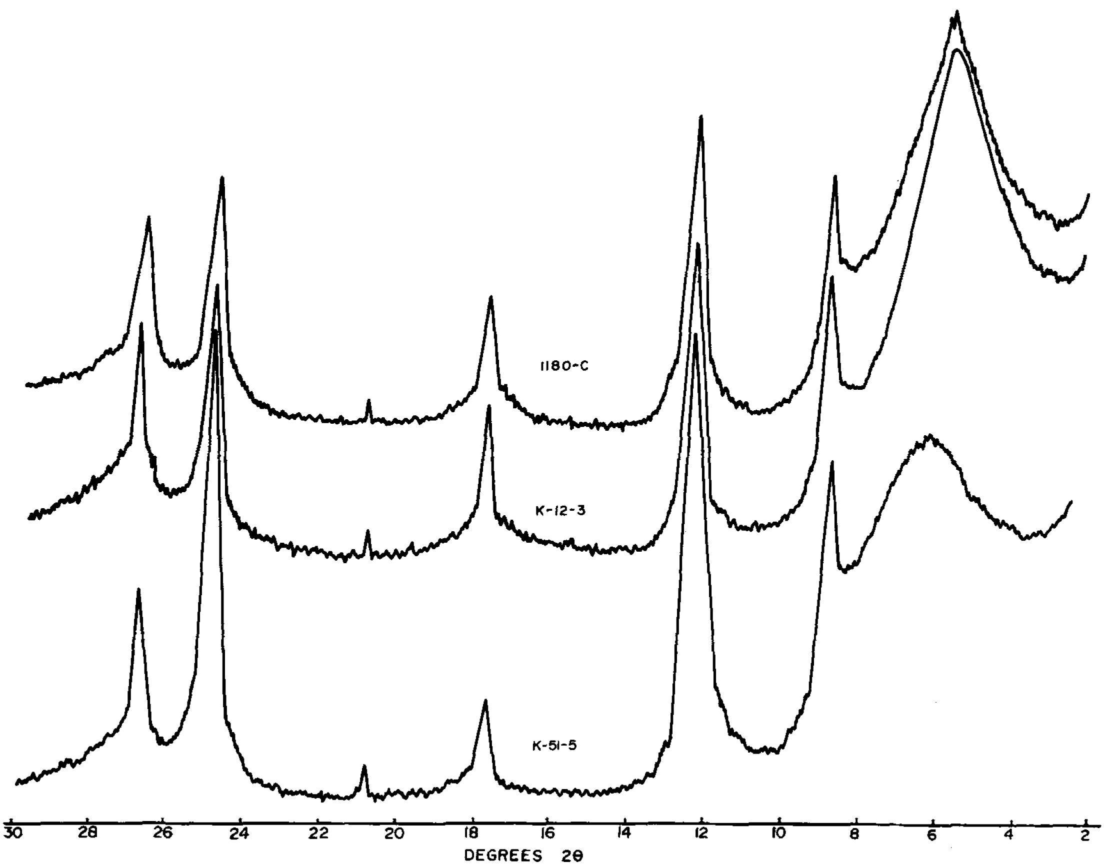

Fig. 3. Diffractograms of minus 2-μ fraction, Alloway Clay Member.

https://doi.org/10.1346/CCMN.1968.0160308 Published online by Cambridge University Press

Table 2. Mineral composition of minus 2-μ fraction for units at Location 854 (in per cent)

Unit	Depth (ft)	Kaolinite	Illite	Mixed-layer and montmorillonite	Gibbsite	Quartz	Feldspar
A	1–6	30	35	30	1	2	1
B	6–7	30	35	30	—	2	1
C	7–9	60	25	10	2	1	1
D	9–11	65	25	5	2	1	1
E	11–16	60	20	10	3	1	1
F*	16–19	20	35	20	3	20	2

*Note: unit "F" represents the upper 3 ft of the Vincentown Sand at this location.

mineralogy and texture of this unit have been discussed previously by Lodding (1965) but will be summarized briefly here. Textural analyses indicate that the largest kaolinite grains in this unit are on the order of 65 mesh (0·2 mm) but that most are between 100 mesh (0·149 mm) and 200 mesh (0·074 mm) in size. Sieve and hydrometer analyses, together with X-ray analysis, disclosed that kaolinite occurs in greatest relative abundance in two size intervals: (i) the $-2\ \mu$ fraction, with a mode at approx. 0·5 μ and (ii) a coarser, silt-sized fraction, with a mode at approximately 15 μ (see Fig. 5). Mansfield and Bailey (1967, personal communication) have studied over 50 of the sand and silt-sized kaolinite platelets by X-ray single-crystal methods and found that all are twin crystals, rotated ±120° about the normal to the cleavage. Representative DTA thermograms for this unit are shown in Fig. 6. The endotherm occurring at approximately 280°C results from the presence of geothite; no evidence of gibbsite was found in the macro-kaolinite horizon. X-ray diffractograms are presented in Fig. 7.

DISCUSSION

Related work

A search of the literature failed to reveal a discussion of any clay deposit of similar texture, attesting to the uniqueness of this horizon. Any theory regarding the origin of this horizon must

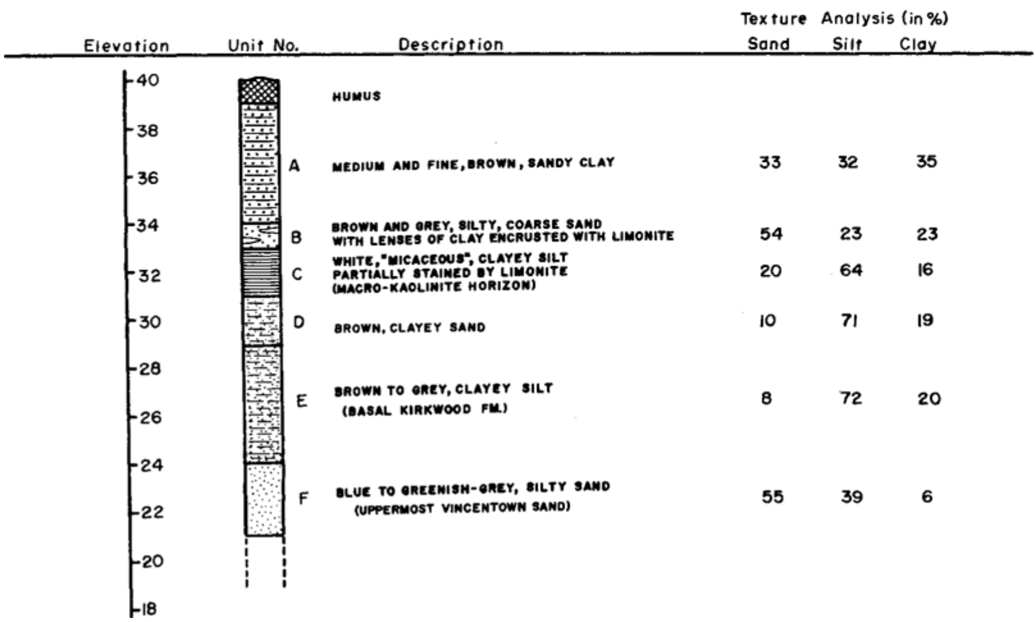

Fig. 4. Auger hole penetrating macro-kaolinite horizon (location 854).

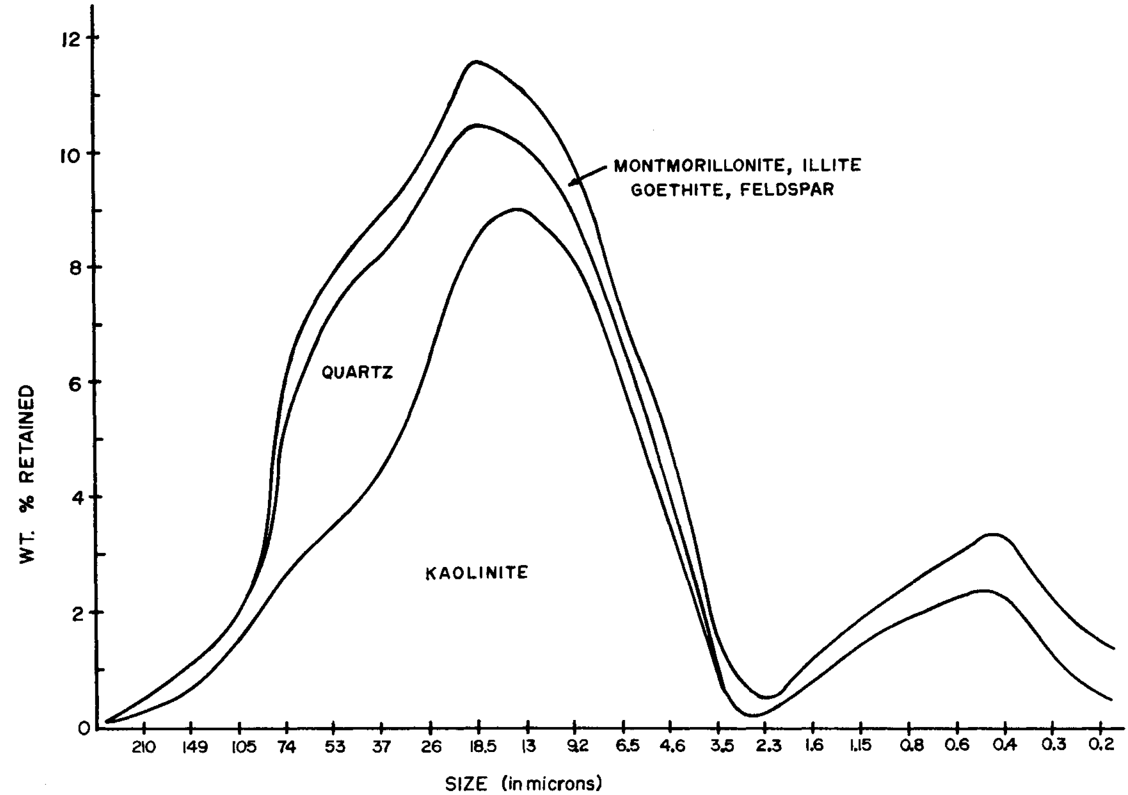

Fig. 5. Size distribution and mineral composition of macro-kaolinite horizon.

account not only for the unusual size and size distribution of the mineral grains, but also for the upward enrichment in kaolinite occurring beneath the macro-kaolinite horizon. Both are undoubtedly related in origin.

In his discussion of the flint clays of southeast Missouri, Keller (1956) has proposed upward leaching and the process of dialysis to explain the inverse relations between illite and upward increasing kaolinite in the weathering profiles. He has further specified that evidence indicates that conversion of illite to kaolinite took place under non-marine conditions by leaching with strongly acid groundwaters, which stripped cations from the illite structure and subsequently formed kaolinite.

Altschuler, Dwornik, and Kramer (1963) have also used the mechanism of upward leaching by ground water, under non-marine conditions, to explain the origin of the kaolinitic sediments of the Citronelle Formation of peninsular Florida, and to account for upward increasing kaolinite in the weathering profile. In addition, they propose that the parent material, chiefly montmorillonite, was transformed into kaolinite, *in situ*, by initial intracrystalline leaching of the inter-layer cations, followed by subsequent lateral epitaxy, which formed and enlarged the end product, kaolinite.

Origin of the macro-kaolinite

The previously described mechanism of upward leaching is thought satisfactory to explain the enrichment phenomena, which occur beneath the macro-kaolinite horizon in the Alloway Clay Member of the Kirkwood Formation. Groundwaters circulating through the porous and permeable sands of the underlying Vincentown Sand are the agents thought responsible for the leaching action. The macro-kaolinite lens, however, cannot be satisfactorily explained solely by the aforementioned diagenetic process. The loose, fluffy nature of this horizon almost certainly indicates depositional conditions different from that of the remainder of the Alloway Clay Member. The writers hypothesize that this horizon represents clays that were initially deposited in a fresh-water or brackish water environment, such as a small lagoon that received large amounts of runoff. The clays were

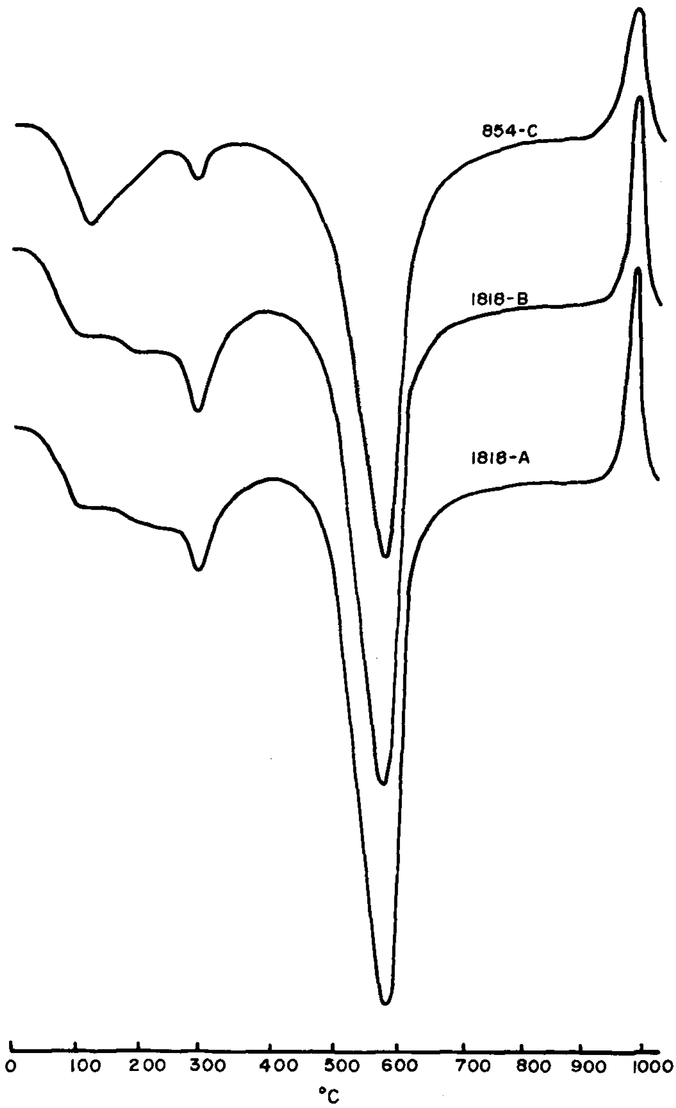

Fig. 6. Differential thermograms of macro-kaolinite platelets.

subsequently transformed to kaolinite by interlayer leaching and were enlarged by lateral epitaxy contemporaneous with the alteration which occurred beneath the horizon. Hinckley (1961) has shown that when kaolinite enters a saline environment it tends to flocculate crystal face-to-crystal face, yielding a dense clay deposit. In fresh water, however, the tendency is for flocculation to occur face-to-edge resulting in a more open deposit which has greater sedimentary volume and porosity. Such a deposit would, therefore, allow more effective leaching by meteoric and groundwaters. The large crystal size of the kaolinite grains in the macro-kaolinite horizon would seem to indicate an initially more open structure, which was conducive to crystal growth during diagenetic alteration. The bi-modal occurrence of kaolinite, hence, represents: (i) kaolinite grains that were deposited and subsequently enlarged, and (ii) montmorillonite and illite clays that were diagenetically altered to kaolinite. Some of the latter probably also underwent epitaxial growth.

CONCLUSION

The authors suggest that following deposition of a portion of the Alloway Clay Member of the

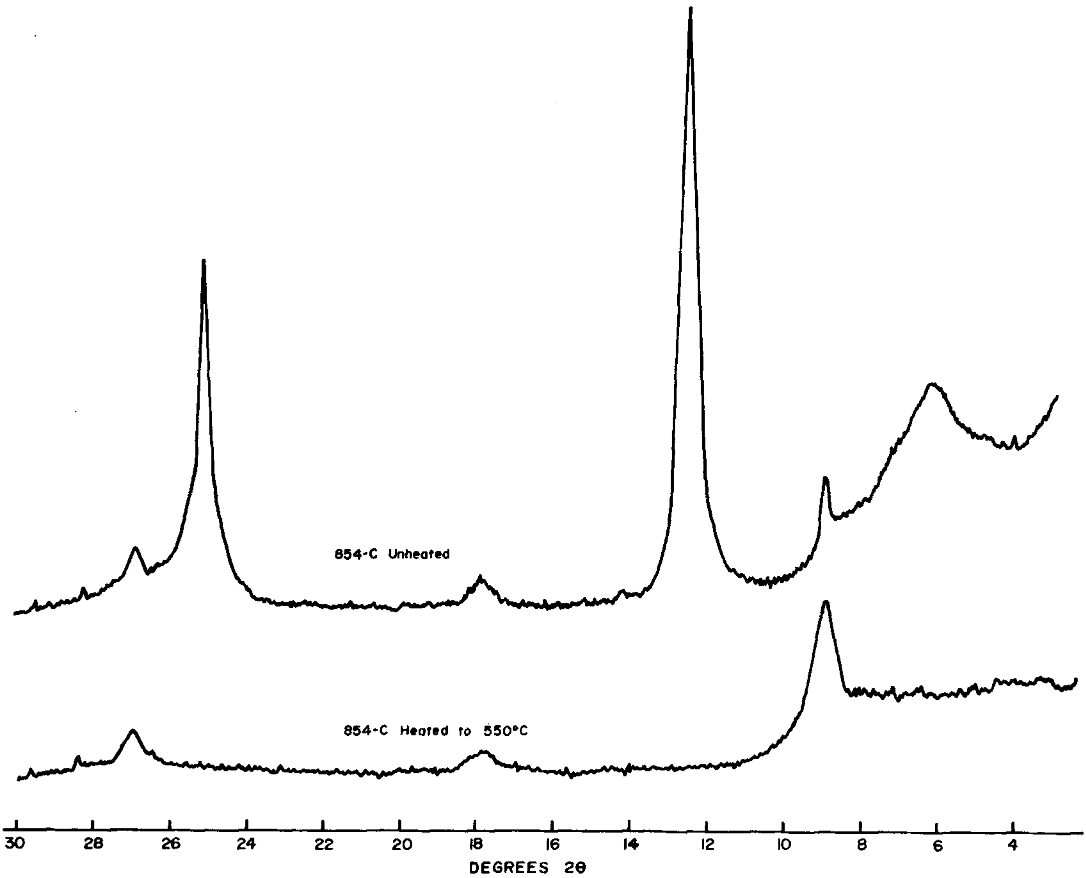

Fig. 7. Diffractograms of minus 2-μ materials from macro-kaolinite horizon.

Kirkwood Formation in lower middle-Miocene time, the sea withdrew briefly from the southern portion of the New Jersey Coastal Plain and exposed a limited portion of the recently deposited sediments. Local depressions and irregularities on the old sea floor may have been transformed into small backshore lagoons or lakes which continued to receive fine sediments. The argillaceous sediments deposited in the fresh water basins were probably identical to those that formed the bulk of the previously deposited portion of the Alloway Clay Member, containing approx. 20–25 per cent kaolinite. The tendency of this kaolinite to flocculate face-to-edge in fresh water would thereby explain the initial, less compact nature of this horizon. Following the brief interval of non-marine deposition, the seas again transgressed over the land surface and deposited a blanket of clays and sands above the original deposit. Final withdrawal of the sea is evidenced by the regressive, cross-bedded sands and gravels of the upper-Miocene (and lower Pliocene?) Cohansey Sand which overlies the Kirkwood Formation with minor disconformity.

The actual time at which diagenesis occurred forming the macro-kaolinite and transforming the clays beneath it is not known with certainty, but it seems reasonable to assume that it followed final withdrawal of the sea in upper Miocene or lower Pliocene time. Enlargement of the kaolinite is not thought to have occurred immediately following deposition because the delicate nature of this material makes it almost certain that it would have been rapidly removed and dispersed by the transgressing sea. More probably the upward leaching that transformed the illite and montmorillonite and enlarged the kaolinite grains occurred following the withdrawal of the sea in early Pliocene and prior to the cooling trend that began in late Pliocene and culminated in the glacial activity of the Pleistocene.

REFERENCES

Altschuler, Z. S., Dwornik, E. J., and Kramer, H. (1963) Transformation of montmorillonite to kaolinite during weathering: *Science* **141**, 148–152.

Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E., and Clark, F. E. (1965) *Methods of Soil Analysis, Part 1*: American Society of Agronomy, Madison, Wis.

Hinckley, D. N. (1961) Mineralogical and Chemical Variations in the Kaolin Deposits of the Coastal Plain of Georgia and South Carolina: Ph.D. Thesis, The Pennsylvania State University.

Isphording, W. C. (1966) Petrology and Stratigraphy of the Kirkwood Formation: Ph.D. Thesis, Rutgers University, New Brunswick, New Jersey.

Keller, W. D. (1956) Clay minerals as influenced by environments of their formation: *Bull. Am. Assoc. Petrol. Geol.* **40**, 2689–2710.

Lodding, W. (1965) Kaolinite macro-crystals from near Woodstown, New Jersey: *Am. Mineralogist* **50**, 1113–1114.

Ries, H., Kummel, H. G., and Knapp, G. N. (1904) The Clays and Clay Industry of New Jersey: *New Jersey Geol. Survey Final Report Ser. State Geol.* **6**.

Résumé—On trouve un lit de kaolin dans lequel l'épaisseur de plusieurs plaquettes individuelles de kaolin est supérieure à 0,2 mm. dans la proximité immédiate de la base de la formation Kirkwood du miocène moyen, près de Woodstown, New Jersey. Les plaquettes semplent résulter de la désintégration d'illite et de montmorillonite préexistantes, et, simultanément, d'une croissance épetaxiale et d'une croissance diagénétique de kaolinite primaire. On attribue l'altération des minéraux d'argile à l'épuisement vers la haut (par dialyse) causé par les eaux souterraines d'une sous-couche de sable Vincentown. Les pourcentages anormalement élevés de kaolinite de taille d'argile dans les argiles qui se trouvent au-dessus du sable Vincentown mais sous l'horizon macro-kaolimique contribuent à prouver la véracité de cette thèse. La croissance macro-kaolinitique a été facilitée par la sédimentation de la face au bord et l'importance de la perméabilité de la strate qui l'a accompagnée.

Kurzreferat—Eine Kaolin Lagerstätte, in der die Grösse vieler der einzelnen Kaolinitplättchen einen Wert von 0,2mm übersteigt, befindet sich in der unmittelbaren Nachbarschaft des Sockels der Mittel-Miozän Kirkwood Formation in der Nähe von Woodstown, New Jersey. Diese Plättchen scheinen das Ergebnis eines Zerfalls von vorher vorhandenen Illit und Montmorillonit in Verbindung mit gleichzeitigen epitaxialem und diagenitischem Wachstum von Primärkaolinit zu sein. Die Umwandlung der Tonminerale wird einer nach oben gerichteten Auslaugung (Dialyse) durch Grundwasser im darunter befindlichen Vincentown Sand zugeschrieben. Ein weiterer Beweis hierfür sind die abnormal hohen Anteile der Kaolinite von Tongrösse in den oberhalb des Vincentown Sands, aber unterhalb des makro-kaolinitischem Horizonts gelegenen Tonarten. Das Wachstum des Makro-Kaolinits wurde durch die Fläche und Kante Ablagerung, und die sich daraus ergebende hohe Durchlässigkeit der Schicht, gefördert.

Резюме—Пласт каолина, в котором многие из отдельных каолинитовых листочков превышают 0,2 μ по размеру находится при самой подошве миоценовой формации Кирквуд, поблизости Вудстаун в штате Нью-Джерси (США). Листочки эти являются повидимому следствием разрушения исходно существующего иллита и монтмориллонита с одновременным эпитаксиальным и диагенетическим ростом первичного каолинита. Изменение в глинистых минералах считают следствием восходящего выщелачивания (диализа) грунтовой воды в лежащих под этим пластом песках Винсенттаун. Доказывается это также ненормально высоким процентным содержанием каолинита размера как глина в тех глинах, которые лежат над песками Винсентаун, но под макро-каолинитовым горизонтом. Выращивание макро-каолинита облегчается осаждением поверхности к краю и последующей высокой проницаемостью пласта.