

# A DISCUSSION ON THE ORIGIN OF CLAY MINERALS IN SEDIMENTARY ROCKS

*By*

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## ABSTRACT

X-ray analyses of the clay minerals from thousands of sediments indicate that any of the major clay minerals can occur in abundance in any of the major depositional environments and there is no consistent coincidence between specific clay minerals and specific depositional environments. It is concluded that the great majority of clay minerals in sedimentary rocks are detrital in origin, strongly reflect the character of their source material, and are only slightly modified in their depositional environments.

The most common process acting on the clay minerals in marine environments is cation adsorption. The modifications produced by this process are secondary but because of the overemphasis of names rather than processes, they have been considered fundamental changes and the process has been called diagenesis. From the geologist's viewpoint, the basic clay mineral lattice, which is inherited from the source material, is the most significant parameter of the clay minerals and modifications caused by the adsorbed cations are secondary, derived parameters reflecting the character of the depositional environment. This concept of dualism is essential to the understanding of clay genesis, and the significance of the two parameters must be understood before a genetic classification can be constructed and before clays can be used for geologic interpretation.

## INTRODUCTION

Clay petrology has finally come of age and can boast the development of widely divergent viewpoints such as characterize some of the older geologic disciplines; e.g., granitization and the graywacke confusion. The most important area of disagreement or speculation in clay petrology concerns the origin of the clay minerals in sediments; are they primarily detrital or diagenetic in origin? Millot (1949, 1953), Grim (1953), Powers (1957), and others have ably presented the case for diagenesis or neoformation. Rivière (1953) appears to have been the only one to attempt a defense of the "detrital" concept. In general the prevailing opinions are based upon rather scant data.

During the past few years, in connection with various investigations, x-ray diffraction analyses of the clay from thousands of sedimentary rocks have been available for interpretation. The purpose of collecting these data has been the geologic interpretation of argillaceous sediments and in all cases the clay mineral data have been closely integrated with all other available geologic information. The intent of this paper is to present some of the preliminary ideas obtained from examining this mass of data. The overwhelming impression gained from examining the clays from such a large number of rocks is that the majority of the clay minerals in sedimentary rocks are detrital in origin and strongly reflect the character of their source area.

## RELATION OF CLAY MINERALS TO DEPOSITIONAL ENVIRONMENTS

*General Observations*

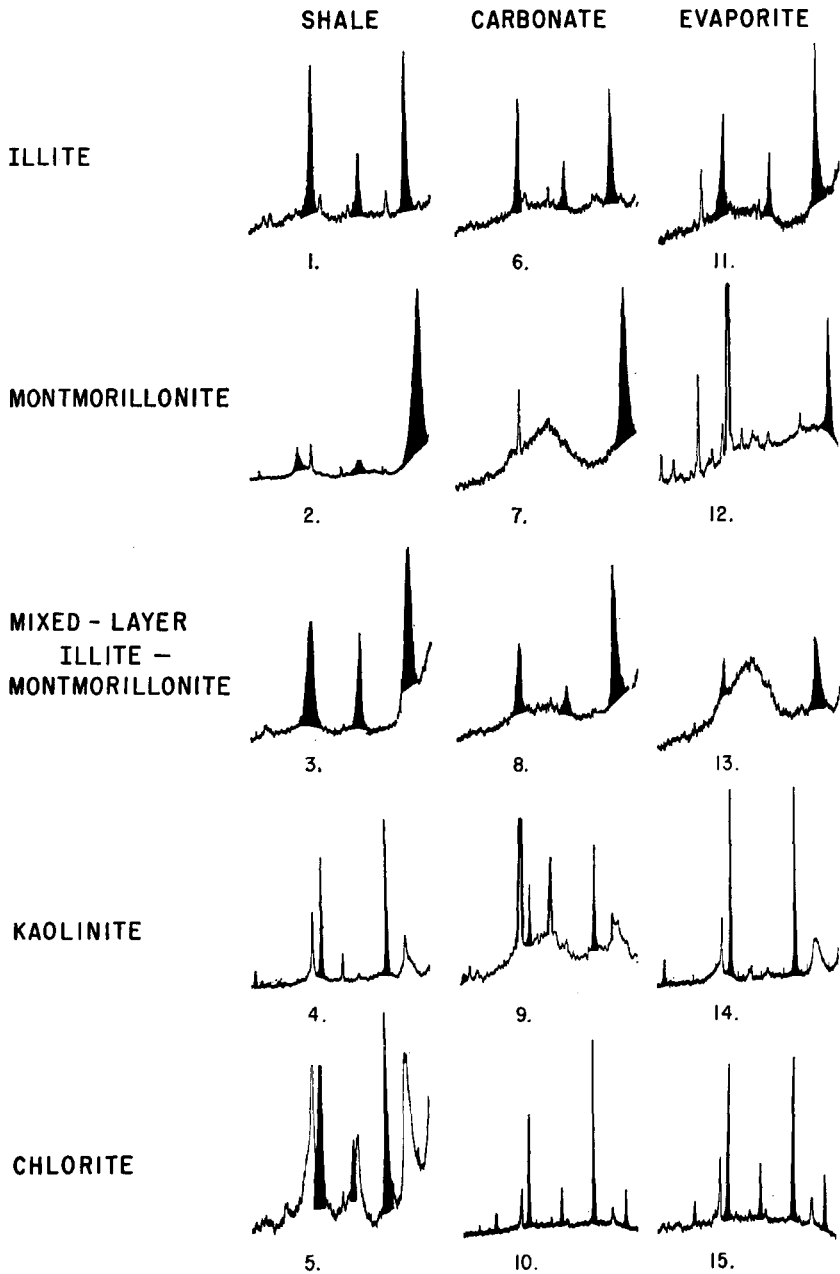
Figures 1 and 2 illustrate the variety of clay minerals found in sediments deposited under similar environmental conditions and also the variety of environments in which the same clay minerals can occur. All samples are of ancient rock and are not selected freak samples but are representative of tens or hundreds of samples. Although an attempt was made to select examples in which one type of clay predominates, many other examples could have been chosen to show various mixtures of clay minerals which occur in sediments deposited under widely differing environmental conditions.

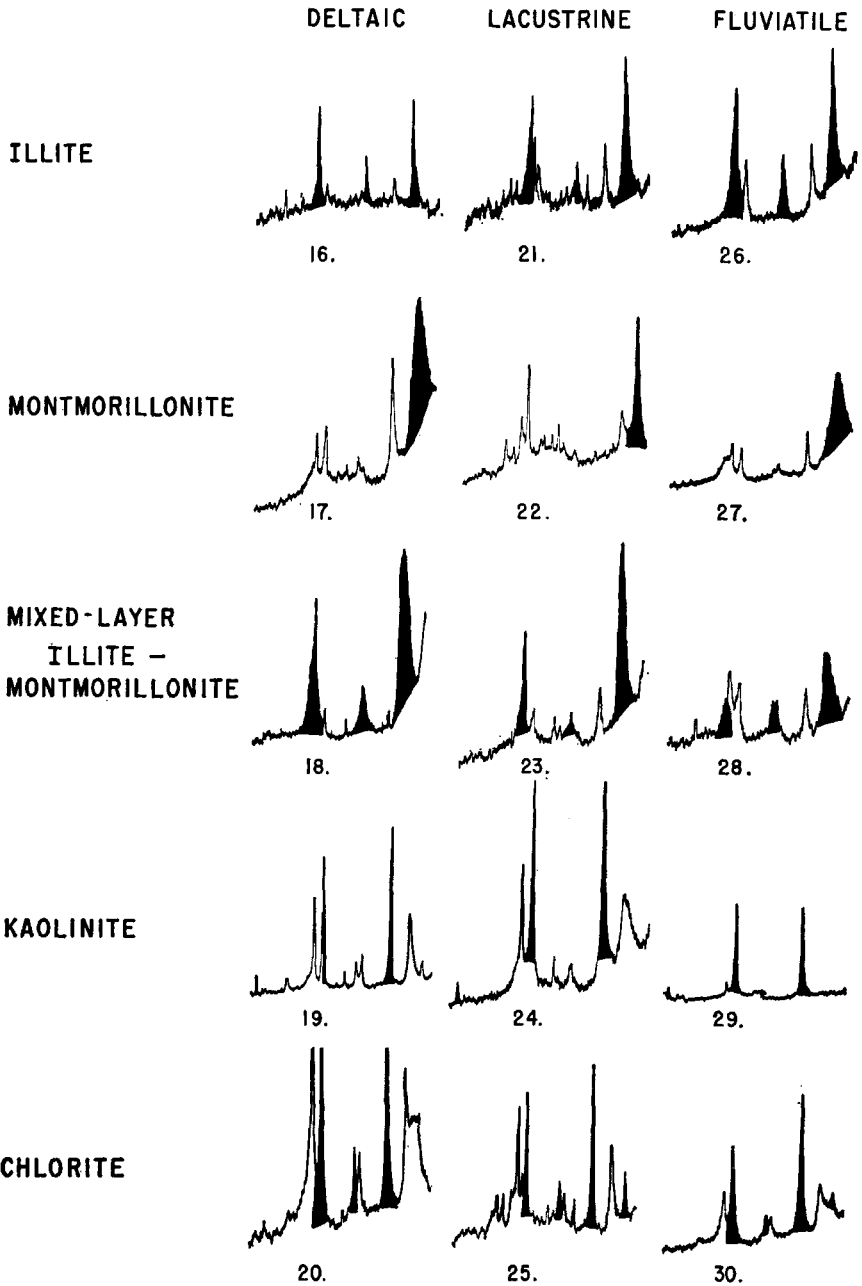
Postdepositional alteration of the clay minerals in porous and permeable sandstones is relatively common; for this reason only x-ray patterns of the clay from shale and carbonate samples are shown in Figures 1 and 2. Figure 3 is a series of x-ray powder-diffraction patterns of organic and pyrite-rich black shales. Again, all the major clay mineral types, except chlorite, occur as dominant minerals in these shales that represent similar chemical environments. Some of the inferences that can be made from these data and the bulk data from which they are drawn are: (1) no particular clay mineral is restricted to a particular environment; (2) illite, montmorillonite, and mixed-layer illite-montmorillonite can occur in abundance, frequently as the only clay minerals present, in any of the major depositional environments; (3) kaolinite is dominant mainly in fluvial environments although it occurs in abundance in all environments; (4) chlorite is seldom if ever a dominant clay mineral; (5) nonmarine shales are seldom if ever monomineralic.

These data indicate that (1) as a whole, clay minerals do not originate *in toto* in their depositional environment, and (2) generally they are not strongly modified by the depositional environment. This suggests that the process of diagenesis is not as effective as is commonly thought and that clay minerals are predominantly detrital in origin and reflect primarily the character of their source area. There is strong evidence that clays are altered (usually degraded) to some extent in fluvial and subaerial continental environments, but in the other major environments there is little direct evidence to indicate that alteration in the basin of deposition is a major factor in determining the ultimate mineralogic character of the clay suite.

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FIGURE 1.—Types of clay minerals occurring in marine environments: (1) Wills Creek, Upper Silurian, Pennsylvania; (2) Soda Lake, Lower Miocene, California; (3) Soda Lake, Lower Miocene, California; (4) Soda Lake, Lower Miocene, California; (5) Fayetteville, Upper Mississippian, Arkansas; (6) Lebanon, Middle Ordovician, Tennessee; (7) Upper Cretaceous, Florida; (8) Nolichucky, Upper Cambrian, Virginia; (9) Magdalena, Lower Pennsylvanian, Texas; (10) Smackover, Upper Jurassic, Louisiana; (11) Seven Rivers, Upper Permian, Texas; (12) Upper Cretaceous, Florida; (13) Lower Cretaceous, Florida; (14) Glen Rose, Lower Cretaceous, Texas; (15) Lytton, Upper Devonian, Montana.





The rarity of monomineralic deltaic shales probably results from the rapid dumping type of deposition which occurs in deltas. The deltaic locus of sedimentation is an environment where there is little winnowing or chemical sorting.

Powers (1957) has presented some fairly convincing evidence that chlorite may form in a marine environment, but even here it is postulated that the basic lattice is detrital in origin and that only the interlayer material is authigenic. That chlorite is seldom a dominant mineral in shales and limestones can be explained by the fact that chlorite is rather easily weathered and seldom is the dominant mica in any of the common source rocks. If chlorite is commonly formed authigenically under normal marine conditions, it should frequently form the bulk of a clay mineral suite. Actually, it appears that chlorite may be more abundant in clays deposited in brackish and fresh-water environment than in those deposited under open marine conditions.

The investigators of Recent marine muds indicate that diagenesis is an important process in determining the mineralogic character of the clay mineral suite. Direct proof of the relative effectiveness of the diagenetic and detrital processes is extremely difficult and in nearly all studies of Recent and ancient sediments only indirect evidence can be cited. In most cases the data obtained from the clay petrology of a large number of formations and basins were best integrated into the over-all geologic history by assuming that the clay mineral suites were largely detrital in origin. Again the evidence is indirect but from the standpoint of coincidence there is consistently a greater coincidence between the bulk clay suite and source than between the bulk clay suite and depositional environment.

### *Specific Approach*

A specific example of the influence of source on the distribution of clay minerals in a thick shale formation is shown in Figure 4. A thin glauconitic sandstone is used as a datum line. The distribution of the clay mineral facies and additional geologic data indicate that a montmorillonitic (chlorite and kaolinite also present) delta was forming in the western part of the basin at the same time as an illite (kaolinite, chlorite, and mixed-layer illite-montmorillonite also present) delta was forming in the eastern part of the basin. The clays between these two deltas are a mixture of the two clay suites with each suite gradually losing its original character away from its respective delta. Eventu-

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FIGURE 2. — Types of clay minerals occurring in continental environments: (16) Catskill, Upper Devonian, Pennsylvania; (17) Springer, Upper Mississippian, Oklahoma; (18) Soda Lake, Lower Miocene, California; (19) Atoka, Lower Pennsylvanian, Texas; (20) Cantuar, Lower Cretaceous, Saskatchewan; (21) Green River, Middle Eocene, Utah; (22) Green River, Middle Eocene, Utah; (23) Green River, Middle Eocene, Utah; (24) Miocene, Venezuela; (25) Cantuar, Lower Cretaceous, Saskatchewan; (26) Cantuar, Lower Cretaceous, Saskatchewan; (27) Fountain, Lower Pennsylvanian, Colorado; (28) Cantuar, Lower Cretaceous, Saskatchewan; (29) Cantuar, Lower Cretaceous, Saskatchewan; (30) Cantuar, Lower Cretaceous, Saskatchewan.

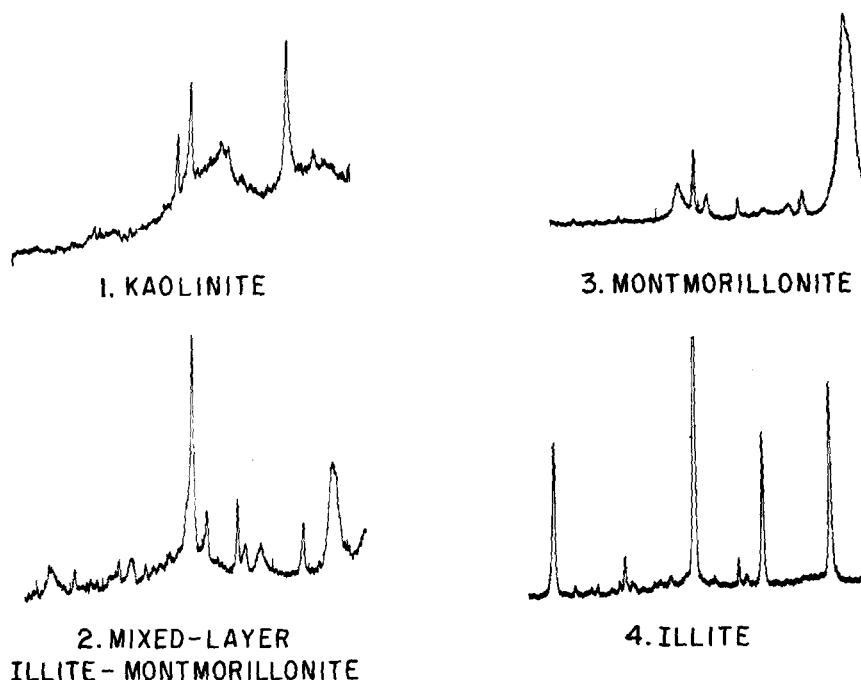


FIGURE 3. — Types of clay minerals occurring in black shales: (1) Cretaceous, Saskatchewan; (2) Devonian, Saskatchewan; (3) Eocene, California; (4) Ordovician, Oklahoma.

ally the basin was nearly filled; deposition ceased in the western, montmorillonitic delta and there was renewed uplift in the source area of the eastern, illitic delta. The illite facies spread westward over the montmorillonitic delta, reworking the underlying sediments (the deltaic sodium montmorillonite was altered to a calcium montmorillonite during weathering and reworking), and forming a thin zone of mixed sediments as it migrated to the west. The glauconitic sandstone is usually associated with this shallow-water, mixed zone.

In connection with source areas, it is of interest to note something of the erosional processes which produce the detrital clay material. Samples of the clay in flood water, taken at the crest, from the Susquehanna River and two of its major tributaries, Pine Creek and Loyalsock Creek, contain illite and chlorite. The streams in this region derive most of their detritus from the surrounding Devonian, Mississippian, and Pennsylvanian sediments which are predominantly illite and chlorite shales. The flood waters of a small tributary to Pine Creek which had eroded deep gorges through a series of Mississippian shales contained only illite and chlorite. The shale forming the sides of the gorges also contained only illite and chlorite; however, the heavily vegetated forest soil surrounding the stream contained mixed-layer illite-montmorillonite, kaolinite, and a small amount of illite. The illite-to-chlorite ratio, 9:1, in the

streams is similar to that in the surrounding shale formations. It is apparent that, as in the V-shaped granitic canyons described by Krynine (1949), most of the clays in these mountainous streams at flood stage are derived from mechanical disaggregation of relatively fresh shale material while the weathered soil material contributes very little to the stream load. In this situation it is possible to obtain two clay suites from one source area.

## SOURCE VERSUS DIAGENESIS

### *Kaolinite*

In discussing diagenesis, Grim (1951) has noted that kaolinite is relatively less abundant in ancient sediments than in younger sediments and concluded that it must therefore be changed to some other clay mineral. Gilluly (1949) reported that "The record of the coarser clastic border zones is much more liable to be destroyed by erosion than is that of the basin center. Statistically, we should expect that the older the period, the more likely it is to be represented by offshore deposits." Because kaolinite is most abundant in continental and near-shore sediments, a more reasonable explanation of the decrease in kaolinite might be that these kaolinite-rich, border zone sediments are poorly represented in the older geologic record.

Millot (1953), in building his case for marine diagenesis, reported that marine sediments, poor in calcite but rich in organic matter and sulfides, are relatively rich in kaolinite and concluded that kaolinite is formed by an acid reaction in an anaerobic medium. Data from the Chattanooga, Woodford, Lodgepole, Tesnus, Caney, Heebner, Polk Creek, Fernie, Exshaw, Banff, Bak-

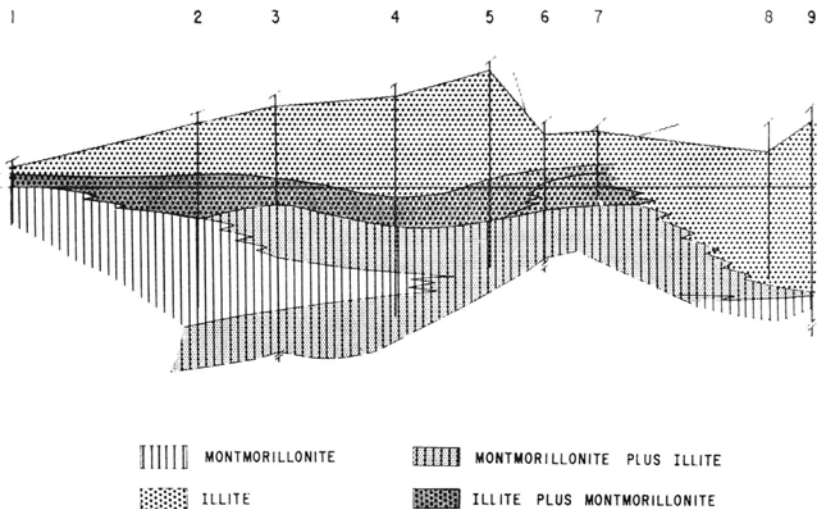


FIGURE 4.—Northwest-southeast cross section showing the distribution of clay mineral facies.

ken, and Duvernay formations indicate that marine black shales are dominantly composed of illite or mixed-layer illite-montmorillonite and usually contain no kaolinite or less than 10 percent.

### *Montmorillonite*

Grim (1951) also stated that there is relatively less montmorillonite in ancient sediments and suggested therefore that it is changed by diagenesis to some other clay mineral. There is some doubt that time diagenesis has any effect on montmorillonite, as it is quite common in Jurassic, Permian, Pennsylvanian, and Upper Mississippian rocks (locally 5000 feet thick), and is present as mixed-layer chlorite-montmorillonite in Middle and Lower Ordovician and Upper and Middle Cambrian sediments. Volcanic material is the major source of montmorillonite and it appears that there may have been less volcanism during the early Paleozoic than the Tertiary. Further, much of the older Paleozoic bentonitic material appears to have been altered by regional metamorphism (volcanic slates of the Appalachian Mountains).

### *Illite*

Illite is the dominant mineral in limestones and it is generally believed that there is some relation between a calcareous environment and the diagenesis of illite. However, the data summarized in Figure 1 indicate that any of the clay minerals, with the possible exception of kaolinite, may exist in abundance in carbonate rocks. Although illite is the most abundant mineral in carbonate rocks, it is also the most abundant mineral in shales and the present data indicate that it is not noticeably more abundant in limestones than in shales. In sections where limestones and shales are interbedded, there is little difference between the clay mineral suites. Although the clay mineral in older Paleozoic limestones is predominantly illite, illite is also the predominant clay mineral in the older Paleozoic clastic sediments and its abundance apparently is a reflection of source material and type of weathering rather than environmental diagenesis.

Recently Levinson (1955) and Yoder and Eugster (1955) have discussed polymorphism in illite minerals. The latter authors have demonstrated that the 1M and 1Md polymorphs are the stable low-temperature structures and that the 2M mica polymorph is the stable high-temperature form. Examination of a number of sedimentary illites has suggested that the 1M and 1Md types tend to be found as glauconites, illites formed by the alteration of feldspars, and mixed-layer illite-montmorillonites which have formed from montmorillonites. Samples of leached muscovite, which expand to 16.6Å when treated with ethylene glycol, still retain their original 2M structure. These data, along with the data of Yoder and Eugster (1955), strongly suggest that any sedimentary dioctahedral illite mineral which formed diagenetically from a mineral other than muscovite, or authigenically from solution, would have a 1M or 1Md structure. In view of the fact that the glauconite mineral, which is



considered to form diagenetically under marine conditions, appears to exist only as the 1M polymorph, it would be difficult to imagine that elsewhere in the marine environment the 2M mica polymorph was being formed from material that did not have a preexisting 2M structure. The only significant source of 2M illites is muscovite (most of which probably was formed by metamorphism of 1M illites and mixed-layer clays) and, as the 2M, 10A illites appear to be overwhelmingly more abundant than the 1M varieties in both shales and limestones, it appears that most of the illite in sediments was derived from muscovite and is therefore detrital in origin.

The nature of the marine environment and diagenetic changes in it are such that variations in the character of the source material are almost invariably reflected in the sedimentary accumulation. This does not mean that clay minerals cannot be used for environmental interpretation but that the effects of source should be understood and evaluated before an environmental interpretation is attempted.

## SEDIMENTARY PROCESSES AFFECTING CLAY MINERALS

### *Terminology of Sedimentary Processes*

A reexamination of the basic data indicates that many of the detrital vs. diagenetic differences are more apparent than real and may be in part a matter of semantics. Much misunderstanding is a result of the failure to separate and weigh objectively the clay mineral characteristics which are of detrital origin and those due to depositional environment. The dual character of the clay minerals is a result of the unsatisfied charge which exists in the basic lattice. The basic clay mineral lattice is fairly stable and its original character will not be materially altered except under relatively intense weathering and leaching conditions. The processes operative in marine environments do not appear to be sufficiently severe to alter appreciably the basic clay lattice except in volumetrically unimportant environments. However, the cations which are adsorbed on the surface of the clay sheets are only loosely held and are readily exchanged for other cations as the clay passes from one chemical environment into another. Some of these cations are more tightly bound than others, but even in the micas where they are most tightly bound, the bonding is much weaker than that within the lattice. This concept of the dual character of the clay minerals must always be kept in mind when discussing the sedimentary processes affecting clay minerals.

Before discussing the processes in which clay minerals participate, it is necessary to review the definition of some terms commonly used in connection with these processes. Clastic is "a descriptive term applied to a rock formed from the fragments of other rocks" (Rice, 1948). Chemical is defined as "... precipitates from solution ..." (Pettijohn, 1949). Pettijohn (1949, p. 476-478) defines authigenesis as "the formation of new minerals either by replacement or by recrystallization ... [and growth] on the spot," and diagenesis as "... the beginning of metamorphism ..." and in a more restricted sense, "the chemical rearrangements and replacements that occur while the

sediment is still on the sea floor. . . .” Thus, both clastic and chemical minerals can be modified after reaching the deposition environment. The processes of modification are called authigenesis if the change is fundamental; i.e., aragonite to calcite, silica gel to quartz. The direct precipitation of minerals from solution is also considered authigenesis but the process here is no different from that defined by the term chemical. The term diagenesis has been used to describe the very minor and least important changes which take place in preexisting minerals, such as base exchange. However, the term is also used to describe all types of modification extending up to low-grade metamorphism.

The term diagenesis is very broad in meaning and seldom means the same thing to any two people; as a result, the use of this term causes unnecessary misunderstanding. Diagenesis in general implies a more fundamental modification or alteration of a mineral than that caused by interchanging the adsorbed surface cations. Such an interchange most likely occurs with the few cations adsorbed on the surface of a clastic quartz grain when it shifts to different chemical environments. Certainly, changing a Na-montmorillonite to a Ca-montmorillonite should not be considered diagenesis. Yet it is this type of reaction which apparently accounts for much of the marine environmental modification of clay minerals. Perhaps it is the use of clay mineral names which implies changes greater than actually occur, which has caused the use of the term diagenesis. Thus, it is common to speak of the diagenesis of montmorillonite to illite under marine conditions. There is no evidence to suggest that the clay mineral montmorillonite, as defined by the structural and chemical character of its basic lattice, adsorbs potassium and becomes illite.

Illite and muscovite can have some of their interlayer potassium removed and are then described as degraded illites (Grim, 1951), or can have potassium removed to the extent that water is adsorbed between the layers and the clay mineral superficially resembles a montmorillonite or vermiculite. When these clays are placed in a potassium solution, they contract to 10A (Brown, 1953; Kunze and Jeffries, 1953; Van der Marel, 1954; Rich and Obenshain, 1955; etc.). The basic lattice of these weathered minerals apparently is not seriously modified, for when a sample of this type was exposed to sea water it readsorbed potassium and was rejuvenated or reconstituted to 2M illite. This process superficially looks like diagenesis but is actually no more than an adsorption phenomenon. Much less is known about the formation of chlorite under marine conditions, but it is likely that much of the chlorite is formed from degraded chlorites or chlorites that have had most of the brucite layer removed and act as vermiculites.

Mixed-layer illite-montmorillonite appears to form by the alteration of montmorillonite under marine conditions (Weaver, 1953). Here again the change is magnified by the nomenclature. No mixed-layer illite-montmorillonite has been reported which has a basic lattice character near that of montmorillonite; i.e., predominantly octahedral lattice substitution. The mixed-layer clays have a larger total charge and larger amount of tetrahedral substitution.

Clays having basic lattices of this latter type are frequently found in continental deposits where they contain hydrated  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{Na}^+$  as exchangeable cations and are usually referred to as montmorillonites. If these clays are transported to a marine environment, the layers with the higher total and tetrahedral charge (mica-like basic lattice) would presumably exchange their  $\text{Ca}^{2+}$  for  $\text{K}^+$  and contract to a mica-like layer, whereas the lower and octahedral-charged layers would retain their water and remain expanded. Again the alteration is merely one of adsorption wherein the variously charged, detrital clay lattices come to equilibrium with their surrounding environment.

These same clays, on the basis of their lattice differences, are mixed-layer lattices even under continental conditions, but because potassium is not available, all the layers remain expanded and, because of the overemphasis of the features of expansion and contraction, they are commonly considered to be montmorillonites. With a classification based on the nature of the basic lattice, they would and should be mixed-layer clays regardless of the composition of the adsorbed cations. If such reactions are to be called diagenesis, the process involved must be more exactly defined. The term adsorption, prefixed by the cation involved, as K-adsorption or adsorption diagenesis, is a more realistic statement of the modification. Perhaps the term diagenesis should be restricted to include only alterations which modify the basic lattice.

Agronomists and chemists, who have long been interested in the chemical reactivity of the clay minerals, have tended to stress the role of the adsorbed cation, but to the geologist, who must be concerned with the whole mineral, the ephemeral adsorbed cations are of only secondary importance to the basic clay lattice.

### *The Effects of Sedimentary Processes on Detrital Material*

There is little question that clay minerals form by authigenesis and diagenesis under continental conditions; however, there is considerable disagreement concerning their formation under marine conditions. The following processes may occur in marine environments: (1) Clay mineral formed from glass, gel, or colloidal material; (2) clay mineral formed by altering the basic lattice of a preexisting mineral; (3) clay mineral altered by changing the type of adsorbed surface cation; and (4) clay mineral unaffected by chemical environment.

These first two processes may be considered as representing diagenesis; classifying the third process as diagenesis is questionable and the fourth can be considered as definitely detrital. Processes 3 and 4 appear to be the most important volumetrically.

Montmorillonite formed from volcanic material under marine conditions is a true example of Type 1 marine diagenesis, but even here it is likely that the ultimate character of the basic lattice of the montmorillonite will depend strongly on the chemical composition and semblance of structural order of the volcanic material.

Glaucanite, though volumetrically unimportant, is sometimes cited as an example of marine diagenesis of the second type. Glaucanite, an iron-rich illite, is essentially a femic mineral, and is frequently believed to have been derived largely from preexisting femic minerals such as biotite, augite, and olivine (Gallihier, 1935; Hendricks and Ross, 1941). Some of these minerals appear to have altered to glaucanite under marine conditions and may therefore represent diagenesis. In other cases much of the alteration could have been accomplished by subaerial weathering and only minor modifications were produced in the marine environment. Walker (1949) has shown that during soil weathering the composition of biotite tends to shift toward that of glaucanite. In any event glaucanite diagenesis is accomplished under perhaps the most ideal conditions for marine clay diagenesis: formed from easily altered femic minerals during times of slow or negative sedimentation and frequently with the aid of organic agents (Hendricks and Ross, 1941). Under these ideal conditions the more subtle features of the glaucanite mineral and the  $\text{Fe}^{3+}$  to  $\text{Fe}^{2+}$  ratio appear to be a function of the depositional environment, whereas the coarser feature of the glaucanite, a high iron content, is usually inherited from the detrital source material. If femic minerals can retain this much of their original identity, it is not surprising that the more silic minerals would be even less affected by diagenesis. Further, recent work has indicated that glaucanitelike pellets can be composed of iron-rich chlorite (thuringite?) and montmorillonite, which suggests that the type of glaucanite formed depends on the type of source material.

The third process, cation adsorption, has been discussed under the previous heading and, as suggested there, this process should not be considered as representing diagenesis. For the vast majority of clays in argillaceous rocks, the basic lattice can be considered to be detrital and to have retained most of the character it originally had in the source area, whereas the adsorbed cations can be classed as either authigenic, if they have been acquired in the depositional environment, or detrital if they are the original cations obtained at the source area (Type 4). Similar dualism is common in the coarser minerals; i.e., a quartz grain deposited under marine conditions is considered to be detrital but quartz overgrowths which form on the grain are authigenic.

The amount of clay material unaffected by the marine environment (Type 4) is quite large. Relatively unmodified muscovite, biotite, and chlorite are common in sand-size and finer sediments. If deposition is rapid, as in mio-geosynclines and eugeosynclines, and the nearby source areas have relatively high relief, the processes acting on the clay material are largely physical and there is little if any modification of the clay. Geosynclinal shales derived from nearby muscovite and chlorite schists frequently afford x-ray reflections as sharp and distinct as those obtained from the schist material.

#### NEED FOR A GENETIC CLASSIFICATION

The degree of contraction or expansion of a clay lattice is actually a derived parameter, one that is dependent upon the basic properties, for it is not the

potassium ion between the clay layers which causes a clay to contract but it is the type and amount of charge on the basic lattice which primarily provides the clay with its contractable character. A genetic classification of shales must include this fundamental concept of clay minerals. If clay minerals are classified on the basis of derived properties rather than basic properties, then there is little chance for establishing a genetic classification of shales. For example, if the belief persists that illites form from montmorillonites in a marine environment rather than from leached illites and muscovites, it will be difficult to develop a unified theory of clay or shale genesis. This does not necessarily imply any radical reclassification of the clay minerals, for the name illite is as usable as the name feldspar. It is the definition and the physical and chemical nature of the various illite clay minerals and how they react in given environments which need to be clarified.

Pettijohn (1949) states "... the basis of all sound taxonomic work must be selection of significant characters for classificatory purposes and avoidance of irrelevant peculiarities," and "the only test of significance is whether the characteristics are or are not basic to the understanding of origin." Thus, our present classification is not usable if we consider such things as the type of adsorbed cation and the amount of water between clay layers as the most significant characteristics. These are only local peculiarities of the immediate environment which are subject to subsequent change, whereas the character of the basic lattice is relatively unaffected by local modifications except under extreme conditions and is a more significant characteristic. At the present time, only a descriptive classification can be constructed. In developing a classification of this type, any number of descriptive parameters can be used but it would be wise to choose parameters that, on the basis of present data, afford the best prospects of ultimately having genetic implications. Certainly with present techniques it is easier to study and measure the derived properties than the basic properties but that is no excuse for altering their order of importance.

## SUMMARY

X-ray analyses of the clay minerals from thousands of sediments indicate that any of the major clay minerals can occur in abundance in any of the major depositional environments and there is no consistent coincidence between specific clay minerals and specific depositional environments. It is believed that many of the generalized theories concerning the diagenesis of clay minerals are based on inadequate and nonrepresentative data.

It is concluded that the great majority of clay minerals in sedimentary rocks are detrital in origin, and that they strongly reflect the character of their source material and are only slightly modified in their depositional environments.

A review of the terminology used to describe the origin of clay minerals and the processes affecting the clay minerals indicates that the most common process acting on the clay minerals in marine environments is cation adsorp-

tion. The modifications produced by this process are superficial but because of the overemphasis of names rather than processes, they have been considered fundamental changes and the process has been called diagenesis. From the geologist's and petrographer's viewpoint, the basic clay mineral lattice, which is inherited from the source material, is the most significant parameter of the clay minerals; and modifications caused by the adsorbed cations are secondary, derived parameters reflecting the character of the depositional environment. This dualism is essential to the understanding of clay genesis and the significance of these two parameters must be understood before a genetic classification can be constructed.

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