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Clay Mineralogy of Pre-Pennsylvanian Sandstones and Shales of the Illinois Basin

Part III. – Clay Minerals of Various Facies of Some Chester Formations

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ABSTRACT

Clay mineral suites of approximately contemporaneous sandstone and shale deposits were studied to determine whether their differences were such that clay minerals could be used in the determination of the environment of deposition of sediments. Differences were noted to be present. Suites from the sandstones were found to be divisible into two facies, the high-kaolinite and the low-kaolinite. Two facies also were generally discernible in the shales, the illite and the mixed-layer facies. The illite facies in shales and the low-kaolinite facies of sandstones both represent sediments deposited farther from shore than the sediments represented by the high-kaolinite sandstone facies and mixed-layer shale facies.

Differences in clay minerals other than kaolinite are due in part to alterations that occur in them during and soon after deposition, and these alterations are functions of rate of deposition and/or water composition. The investigation indicates that kaolinite is concentrated near the shore.

Clay mineral facies in several stratigraphic units are mapped, using ratios of the several minerals to each other. These maps conform in a general way to environmental facies charts.

INTRODUCTION

This report is the third part of the study of the clay mineralogy of pre-Pennsylvanian sandstones and shales of the Illinois Basin and is concerned with the facies-to-facies variation in the clay mineral suites of approximately contemporaneous rocks. Part I dealt with the relation of permeability to clay mineral suites. Part II was concerned with clay mineral variations between oil-bearing and non-oil-bearing sandstones.

If the clay mineral suites are different in rocks that represent different environments of deposition, clay minerals may be useful criteria for determining the environment of deposition of sediments, unless the differences in the clay mineral suites are due to subsequent alteration. Clay mineral analyses were made of approximately 150 samples representing various facies of ten Chester formations

(Mississippian System) from the Illinois Basin. The results have been used to construct charts that indicate how the clay mineral suites vary from facies to facies in a given time-rock unit.

Part of the data included in this report is taken from my "Clay Mineralogy of the Pre-Pennsylvanian Sandstones and Shales of the Illinois Basin," a thesis submitted to the University of Illinois in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Professor R. E. Grim, University of Illinois, provided valuable suggestions and counsel throughout the course of this investigation. Dr. W. F. Bradley and Dr. D. H. Swann, Illinois State Geological Survey, gave similar help, and Dr. F. M. Wahl, University of Illinois, offered many helpful suggestions regarding the presentation of the material.

SAMPLES

Approximately 90 percent of the samples used are from cores and 10 percent are from cable-tool cuttings. All of the samples were identified stratigraphically by the members of the Illinois State Geological Survey or of the Indiana State Geological Survey.

A limited number of samples was chosen to represent the widest geographical spread possible for several different stratigraphic units. This was done on the assumption that the wide spread would insure sampling many of the environments of deposition for each unit. As facies variations were reflected in lithologies, samples were chosen that ranged from orthoquartzites to shales. Carbonate contents varied, but very calcareous samples were avoided when practicable.

Although it has been recognized that post-lithification alteration has, in many instances, affected the composition of clay mineral suites in permeable sediments (Smoot, 1960; Smoot and Narain, 1960), it is thought that these suites in part reflect the clay mineral suites of the originally deposited sediment. Therefore, samples from both permeable and impermeable sediments were included in the study.

The samples were prepared in a manner described in Part I of this study (Smoot, 1960). The shale samples were gently disaggregated by mortar and pestle, and the less than 2-micron fraction was separated by sedimentation. Sandstone samples were gently crushed and further disaggregated in an ultrasonic generator. The less than 2-micron fraction was then drawn off.

CLAY MINERALS PRESENT

A detailed description of the clay minerals and subgroups encountered in the samples appeared in Part I of this study (Smoot, 1960). However, a brief summary of the mineral groups found and a brief definition of mineralogical terms used follow.

Five clay mineral groups are recognized in the samples: 1) the illite group, 2) the chlorite group, 3) the kaolinite group, 4) the montmorillonite group, and 5) the group composed of mixed-layer (undifferentiated) material. The illite group comprises two subgroups: a) well crystallized illite, and b) a poorly ordered, at least partially expandable subgroup referred to as illite plus mixed-layer material. Similarly, two subgroups compose the chlorite group: a) a well crystallized subgroup referred to as chlorite, and b) a mixture of chlorite and, at least in part, expandable material referred to as chlorite plus mixed-layer material. The term "all mixed-layer material," as used here, refers to all of the illite plus mixed-layer material, chlorite plus mixed-layer material, montmorillonite, and mixed-layer (undifferentiated) material that is present in a sample as a single assemblage.

Quantitative Estimates

A detailed explanation of the methods used in making quantitative estimates of the clay minerals was presented in Part I (Smoot, 1960). To summarize briefly, two methods were used.

The shales, dominantly composed of illite and chlorite, were estimated quantitatively, using the system outlined by Johns et al. (1954). This system is based on a comparison of intensities of the first-order peaks of the clay minerals present. The method employed, dealing with samples containing a dominant proportion of mixed-layer components, was based on a system suggested by W. F. Bradley (personal communication, 1958). By this system, the intensities of the first-order peaks of illite, chlorite, glycol-expanded montmorillonite, and the third-order peak of kaolinite were compared to comparable peak intensities of "pure" samples of each of these minerals. Use of this method gave more accurate estimates of the relatively abundant, poorly ordered components than did comparison by the method outlined by Johns et al. (1954). The latter method gave the best results in samples dominated by well ordered clay minerals.

Variations in the Clay Mineral Suites of Various Facies

The clay mineral suites deposited under different environmental conditions differed in relative abundance of the various clay minerals. In general, it was found that illite (and possibly chlorite) were relatively more abundant in the facies deposited under normal marine conditions, whereas the deposits representing facies nearer to the shore had relatively higher proportions of kaolinite and all mixed-layer material.

The term "high-kaolinite facies," as used here, must be defined loosely so that it can be used in all of the stratigraphic units chosen. In the Degonia-Clore-Palestine unit, the lowest kaolinite proportion is nearly as high as the highest kaolinite proportion of the Aux Vases Formation. However, samples from each stratigraphic unit show a range in kaolinite proportions, and the term "high-kaolinite facies" is used with limits appropriate to the differing ranges in each unit. It seems probable that the Degonia, Clore, and Palestine represent sediments deposited nearer the shore than most of the Aux Vases samples, but in both units the differences in the clay mineral suites are similar in nature.

The facies in the sandstones generally containing lesser proportions of kaolinite and greater proportions of mixed-layer material are referred to as the low-kaolinite facies. Probably the low-kaolinite facies generally represent slightly brackish to normal marine conditions in areas where the rate of sedimentation was to some degree slower than in areas where the high-kaolinite facies rocks are found.

The shale samples investigated contained little, if any, kaolinite. However, facies analogous to those described for the sandstones were discernible in the shales. The most readily noticeable differences in clay mineral suites between normal marine shales and shales deposited in nearer shore environments are in the proportionate amounts of illite and mixed-layer material. The highest proportions of illite (and generally the lowest proportions of mixed-layer material) generally are found in normal marine shales. The highest mixed-layer proportions (and generally lower proportions of illite) are found in shales thought to have been deposited closer to the shore.

Although illite is usually the dominant clay mineral in all shales, it is convenient to refer to the illite facies as contrasted to the mixed-layer facies in shale samples.

In both the sandstone facies and the shale facies, I mentioned nearer shore, fresh, brackish, and normal saline environments. I realize that the distance from shore in miles may be insignificant and that the important factors are two — the rate of sedimentation, and the salinity of the water. Therefore, the distances from the mouths of the streams that fed the sediments to the basin are probably much more significant than the distances from the strand lines. Figure 1 depicts the idealized relationship between the various facies described and their environments of deposition. Even on such an idealized diagram, the upstream extent of the high-kaolinite facies is problematical.

The facies used here are only comparative terms. The sediments investigated probably have been studied as thoroughly as any similar group of rocks reported in the literature. Therefore, I was working with sediments whose environments of deposition were at least superficially known. The comparison of samples from the various facies brought out generalities that resulted in the use of these

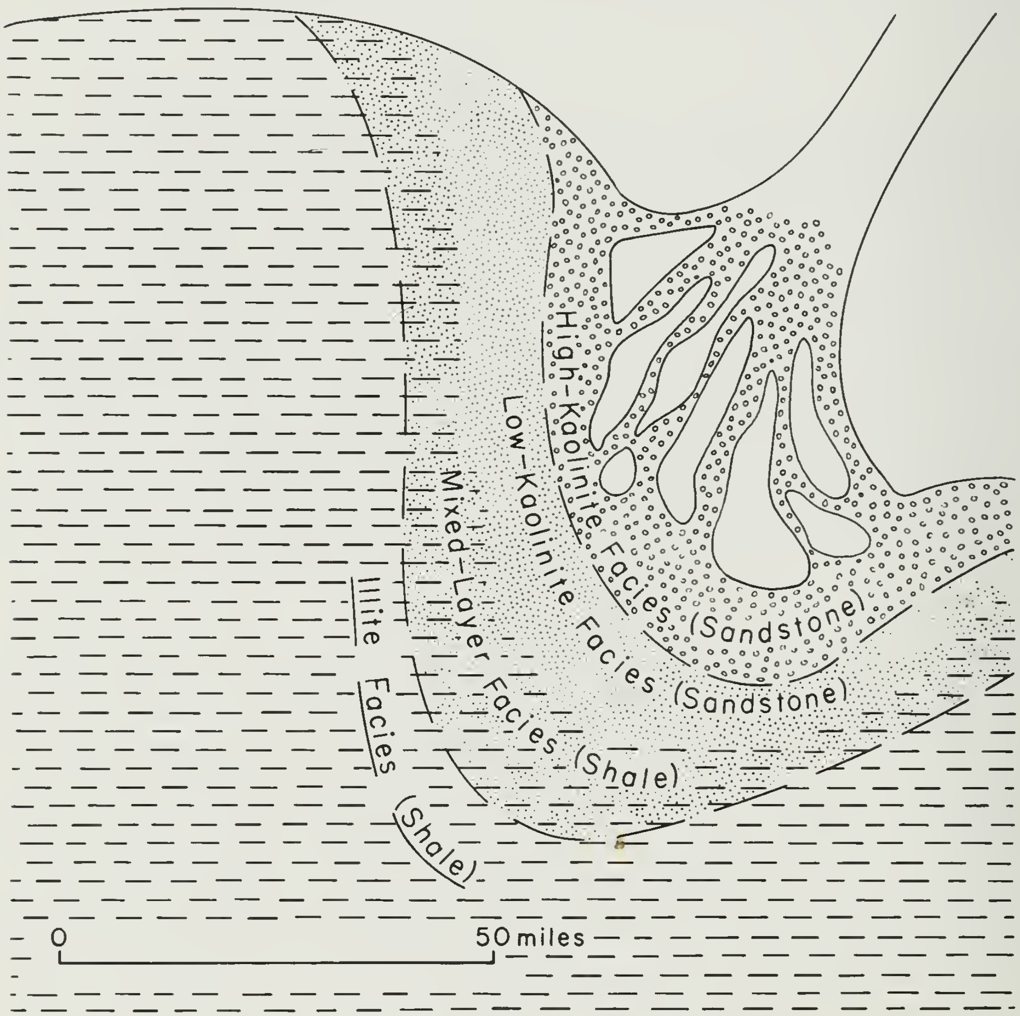

Fig. 1. Idealized relation between clay mineral facies.

facies terms. A sample representing one environment would have little or no value in environmental interpretation unless there were another sample for comparison. The greater the number of comparisons, the more apparent is the validity of these generalities, and they are most valid when groups of samples, representing various facies, are compared.

During Chester time the Illinois Basin underwent many fluctuations, and each sandstone and shale formation therefore generally contains, in vertical sequence, sediments deposited under several environmental conditions. Several formations probably contain repeated sequences of environmental conditions. Consequently, although in a given area a certain formation typically may be composed of sandstones of the high-kaolinite facies, an individual sample may exhibit very little or no kaolinite. Similarly, a relatively low-illite shale sample may come from an area where high illite proportions are common. The fact that some samples representing a time-rock unit in a general area are noticeably different from the average composition in that area may well be attributed to original variability in sedimentation.

STRATIGRAPHY

Ten formations from the Chester Series (Mississippian System) were sampled. The limited number of samples and the short time available for the study has permitted a separate investigation of only two formations, the Cypress and the Aux Vases; others are discussed in groups of two or three formations somewhat similar in duration and environment of deposition and in source area.

Environment of Deposition

A wealth of geologic information has been published about the Illinois Basin. Although specific statements concerning the environments of deposition are rare, much of the reported data can be used in interpreting the environments.

Workman (1940) presented cross sections and isopach maps of the Chester Series that show a general increase in thickness toward the southern part of the basin. The thickest sediments were shown to be in the Gallatin County area. Subsequent cross sections have been in general agreement with Workman's.

Swann et al. (1951) presented an east-west cross section of the Eastern Interior Basin (now Illinois Basin). This cross section indicates that the Chester Series thins gradually from the central part of the state to the eastern edge of the basin and rapidly from the center to the Mississippi River.

Potter et al. (1958), in reporting the cross-bedding and sandstone trends of the Illinois Basin, concluded that the source area for the Chester sediments was north and northeast of the basin. They also presented evidence suggesting that the upper Chester sandstones have channel phases and possible distributaries and recognized a coupled low coastal plain and shallow marine shelf as the major physiographic feature. Such an area, with six or seven marine invasions during the deposition of the Chester sediments, likely would have deltaic deposits, shallow marine shelf deposits, and open marine deposits.

Swann and Bell (1958) presented maps that show clastic ratios, total clastic thickness, total thicknesses, and sand-shale ratios of portions of the Chester Series of the Illinois Basin. Their data indicate a northeast-southwest trend for the clastic sediments, a decrease in detrital size averages toward the southeast, and an increase of carbonates toward the southeast.

Potter et al. (1958, fig. 15) showed that the limestones included in the section between the base (Aux Vases Sandstone) and the top (Tar Springs Sandstone) of the Chester Series are thickest in the southeastern part of the basin. On their map, southwestward and southeastward thickenings are particularly noticeable. According to Swann (personal communication, 1959), the part of the Chester Series of the Illinois Basin having the greatest proportion of limestone extends approximately from central Kentucky southwestward.

Three general conclusions pertaining to the environments of deposition of the pre-Pennsylvanian rocks of the Illinois Basin can be drawn from the aforementioned reports.

1) The northern part of the basin was nearer to the strand line and more frequently continental than the southern part. Sedimentation in the southern part was more frequently marine and farther off shore than in the northern part.

2) During Chester time the strand line in the Illinois Basin was especially variable, with many regressions and progressions. Deltaic deposits, near-shore shallow marine-shelf deposits, off-shore marine deposits, and, possibly, fluvial deposits were being formed simultaneously at various places within the boundaries of the basin.

3) The general direction of flow of sediment was from north to south or from northeast to southwest.

If the clay mineral suites of various facies are a function of the facies, then in general they should change in mineral composition from the northern part of the basin to the southern or southwestern portion.

Studies of rocks representing limited periods of time indicate that deviations from the above generalities are numerous. However, when rocks representing large portions of Chester time are investigated, the results agree very well with these generalities. Following are discussions of clay mineral variations found in different facies of various Chester units.

Degonia, Clore, and Palestine Formations

The seventeen core samples from the three upper Chester formations, the Degonia, the Clore, and the Palestine, are dominantly sandstones and orthoquartzites. The total amount of clay in any of the sandstone samples rarely exceeds one percent, and all are quite highly permeable.

The environment of deposition of these sediments has been assumed to be near-shore, deltaic, and/or terrigenous. The evidence for this, although meager, is convincing, as shown below.

Siever (1954) characterized the upper Chester sandstones as having been deposited in environments ". . .that varied from sublittoral turbulent waters to a terrestrial coastal plain." He also reported abundant stigmarian roots and a thin coal bed in the Palestine.

Workman (1940) indicated that the Degonia is thickest in the western portion of the basin. Potter et al. (1958) showed that the modal cross-bedding direction of the Degonia falls between 201° and 240° azimuth.

Workman (1940) also indicated that the Clore Formation thickens to the south, but Potter et al. (1958) showed the modal cross-bedding direction of the Clore falling between 241° and 280° azimuth. Assuming that the greatest thicknesses of sediment are accumulated in the deeper (hence, farther off shore) parts of a basin, it seems that the off-shore facies of the Clore are in the southern parts of the basin and that the sediments were introduced from the northeastern edge of the basin.

The Palestine is thickest along the eastern part of the basin (Workman, 1940); the modal cross-bedding direction of the Palestine is between 161° and 200° azimuth (Potter et al., 1958). Hence, it seems that the Palestine sediments were introduced into the basin by a stream system, perhaps deltaic in nature, that flowed into the eastern part of the basin.

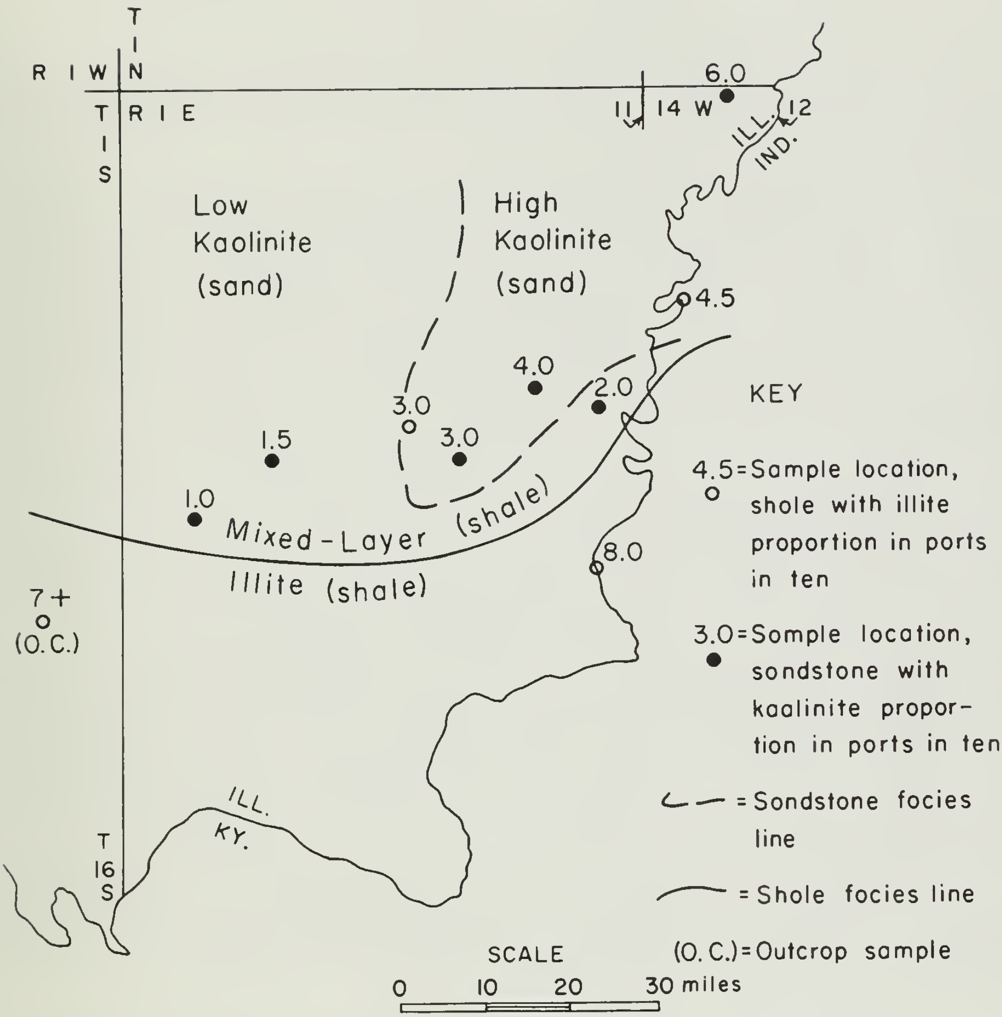

Fig. 2. Proportions of kaolinite in sandstone and shale samples and of illite in in shale samples from Degonia, Clore, and Palestine Formations.

Figure 2 shows a) the kaolinite content of the sandstone samples from the Clore, Degonia, and Palestine Formations, and b) the illite content of the few shale samples available. It is apparent that sediments with the higher kaolinite contents occur in a belt trending northeast-southwest and that the kaolinite proportions decrease to the south and away from this belt. A broken line has been drawn between the high-kaolinite facies and the low-kaolinite facies of the sandstone samples.

The shale samples indicate that the highest proportions of illite are found in samples from the southern areas. The solid facies line in figure 2 separates the samples exhibiting high illite proportions from those with lower proportions. The relatively low-illite bearing samples have two and three-plus parts of kaolinite and two and four parts of mixed-layer material, compared with values of less than one for the high-illite bearing samples. Therefore, a mixed-layer facies can be recognized along with the illite facies.

Waltersburg and Tar Springs Formations

The Waltersburg and Tar Springs Formations are represented by 20 core samples, 18 from sandstones and 2 from shales. The sandstone samples are from only 14 locations, so average proportions are given for locations represented by more than one sample.

These two formations compose a very sandy part of the column. The Tar Springs is the most uniformly widespread sandstone in the Chester of Illinois (Swann and Bell, 1958). The Waltersburg is characterized by sandstone bodies extending northeast-southwest that Siever (1954) suggested are the result of marine current action. Potter et al. (1958) showed that both units contain very similar cross-bedding characteristics. Their figures 11 and 12 showed, by isopach intervals, elongate sandstone bodies extending from northeast to southwest in both formations in Gallatin, Saline, Williamson, and Johnson Counties. Limestones are rare in these formations.

Interpretation of this information seems to indicate that the southeastern part of the basin during much of Waltersburg and Tar Springs time was an area very near shore, possibly deltaic in part. Most of the samples studied are from the southeastern part of the basin, which is the part where the sandstone proportions of these formations are the highest and where oil reservoirs are found. According to the above evidence, most of the few samples that come from localities north of Saline and Gallatin Counties may represent terrestrial facies.

Most of the samples represent very porous and permeable sandstones that probably would have been subject to extensive post-lithification alteration of the clay mineral suites. However, the pattern exhibited by the kaolinite proportions of the samples on figure 3 suggests that they also reflect original environmental conditions. A facies line therefore has been constructed that separates the high-kaolinite facies from the low-kaolinite facies. The average kaolinite proportion for all samples of each facies is given.

The northern samples have an average kaolinite value considerably greater than that of the southern samples. In a very general way this indicates that the off-shore sediments were deposited to the south, and this agrees, again in a very general way, with the conclusions drawn from previous investigations.

Cypress Formation

The Cypress Formation is represented in this study by 15 sandstone samples from rather widely separated localities.

The environment of deposition of the Cypress Formation was variable. Swann and Atherton (1948) reported that the formation is thickest in the south-central part of the Illinois Basin, that it is predominantly a sandstone with some siltstone and shale, and that two thin coal beds occur locally near the top of the formation. The Cypress rests unconformably on lower formations, except possibly in the extreme northeastern part of the basin.

Potter et al. (1958) reported that the greatest thickness of sandstone is found near the south margin of the basin along the Kentucky-Illinois state line. Their figure 11 showed, by isopach intervals, a strong northeast-southwest trend of the sand bodies, a conclusion strengthened by Swann's more recent studies (personal communication, 1959). Their paper also indicated that the cross-bedding data suggest the sediments were deposited by a southwestward-moving agent of transportation that entered the basin at its northern and eastern edges.

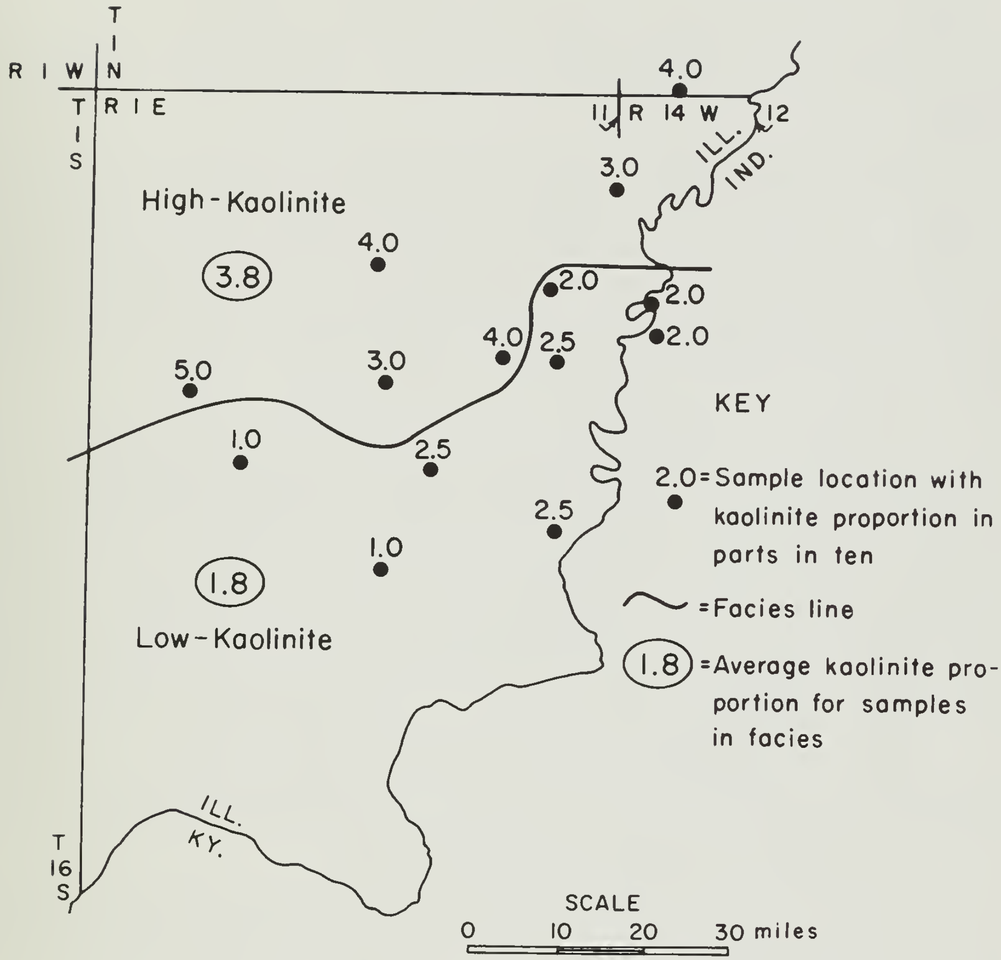

Fig. 3. Proportions of kaolinite in sandstone samples from the Waltersburg and Tar Springs Formations.

Swann and Bell (1958, figs. 11, 12) showed that the Cypress-Bethel sequence has the highest proportion of sandstone in the area along the Indiana-Illinois and Illinois-Kentucky boundaries and that the area of highest proportion of carbonate of this sequence is in the extreme southeastern part of the Illinois Basin in central Kentucky. They also indicated that the proportionately highest sandstone content is in the extreme southern part of the basin. This is anomalous to other data presented in that if the sediments came from the northeast there should be more coarse sediment in the northeastern part of the basin than elsewhere.

Swann (personal communication, 1959), commenting on this anomaly, suggested that the sampling technique used was such that the sandiest sections, which are also the thickest, tended to be automatically excluded in the northern part of the basin where an abnormally thick column was more likely to have been partially removed by pre-Pennsylvanian erosion than was a shorter column. Farther south the pre-Pennsylvanian unconformity did not cut as deep, and the sandiest, thickest sections were as likely to be sampled as the shalier, thinner ones. Thus the sand-shale ratios in the northeastern part of the basin (including Clark, Crawford, Jasper, and Lawrence Counties, Illinois, and Vigo, Sullivan, Green, and Knox Counties, Indiana) should be higher than was shown in figures 11 and 12 of Swann and Bell (1958).

According to Swann (personal communication, 1958), the Cypress Formation is at least in part continental, even in the southernmost outcrops in Kentucky. In the lower part of the Cypress (included in the Paint Creek Formation by some investigators) a few marine limestone beds are known to be present. These beds, along with sandstones near the base of the formation that contain marine fossils and the coal beds near the top, are essentially the only parts of the formation that exhibit strong evidence concerning the environment of deposition. The sandstones and the few shales in between are variable and furnish no reliable evidence concerning their environments of deposition.

However, the evidence outlined above suggests the following generalities. The lower part of the Cypress Formation probably was deposited in areas farther off shore than either the middle or upper portion; the upper part probably was deposited closer to shore than either the lower or middle parts and was at least partially terrestrial material. Furthermore, all the sandstone sequences above these limestones probably are mostly near-shore, if not actually terrestrial, deposits, as attested to by their cut-and-fill structures, the elongate nature of the sand bodies, the clastic nature of the sediments, cross-bedding, and, indirectly, by the sand-shale ratios. Although conditions varied, near-shore and terrestrial conditions probably prevailed during most of Cypress time, especially in the southeastern part of Illinois.

As most of the samples investigated came from oil wells, they are from the highest sandstone part of the Cypress, which is generally the position of oil accumulation. If the above generalities are valid, the samples investigated were dominated by near-shore and terrestrial deposition.

Figure 4 shows the sample locations and the kaolinite proportion (in parts in ten) of the clay mineral suite of each sample. The highest kaolinite proportions are concentrated in the northern and eastern samples. The average kaolinite proportion of these samples is approximately 3.1 parts in 10 of the clay fractions and these samples compose the high-kaolinite facies.

The low-kaolinite facies is separated on figure 4 from the high-kaolinite facies by a solid line. The average kaolinite proportion of the 10 samples composing this facies is approximately 1.2 parts in 10. A dashed line separates the low-kaolinite facies into two parts — one with relatively higher proportions (average 1.9 parts in 10) and one with relatively low proportions (average 0.7 parts in 10). This dashed line can be considered as an alternate line separating the high- from the low-kaolinite facies or could be considered as a subfacies line, although such a subdivision is hardly justified. It is included here mainly to accentuate the gradational nature of these facies.

The high-kaolinite facies certainly corresponds to the area of near-shore deposition delineated by previous investigators. The southern and western samples generally correspond to the areas that would have been farther from shore.

Paint Creek, Bethel, and Renault Formations

Samples from the Downeys Bluff, Ridenhower, Shetlerville, and Yankeetown, as well as those from the Paint Creek, Bethel, and Renault Formations are referred to this sequence. As correlation in the sequence is difficult, it is convenient to

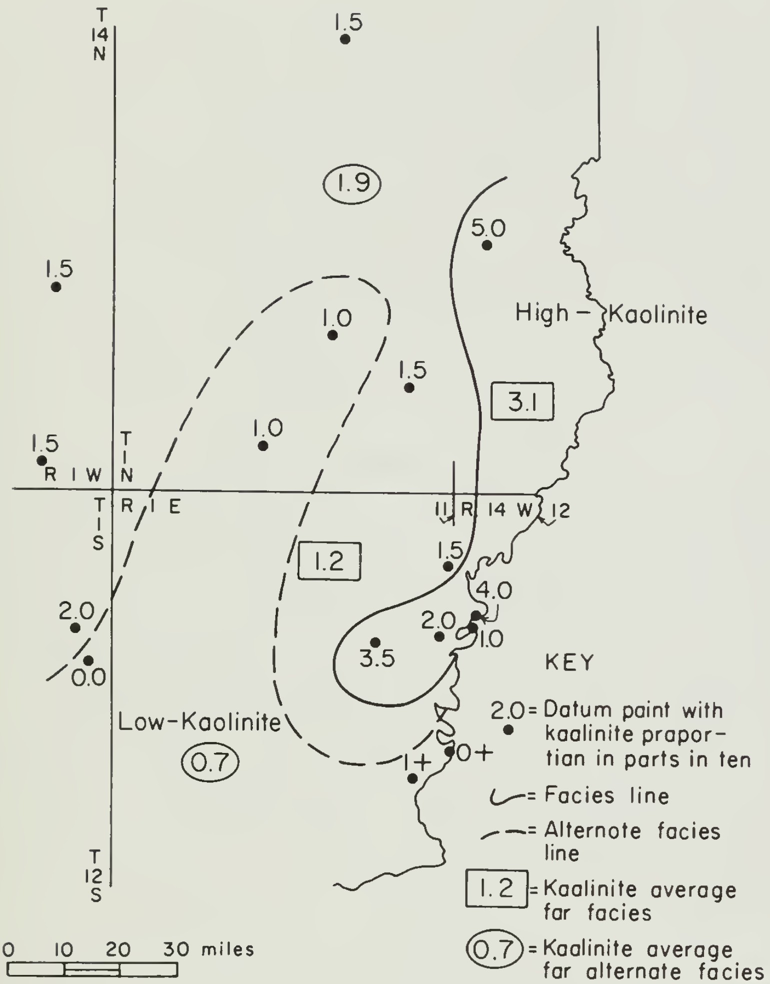

Fig. 4. Proportions of kaolinite in samples from the Cypress Formation.

study these formations as a unit. Although the number of samples available is too small for a satisfactory study of individual formations, they are numerous enough and have wide enough geographical distribution to be significant in a study of the sequence as a whole.

The pattern of lithologic facies in the upper part of this sequence resembles that in the Cypress (Swann and Bell, 1958) in that the major sandstone bodies lie near the Wabash River. Lesser amounts of sandstone extend to the east margin of the basin but little or no sandstone is found near the west edge of the basin. Cross-bedding measurements of the sandstones (Paint Creek, Sample, Mooretown, Bethel) show sediment flow to the southwest and west, the 201° to 240° and 241° to 280° intervals being equally preferred (Potter et al., 1958). Limestone in this part of the sequence is best developed at the southeastern and southwestern corners of the basin.

The pattern in the lower part of this sequence differs in that sandstone is practically confined to the western half of the basin where cross-bedding measurements of sandstones in the Yankeetown (Benoist, "western Bethel") and Renault Formations show flow dominantly to the south (Potter et al., 1958). This part of the sequence contains only a little limestone at the southwestern corner of the basin, is dominantly limestone in most of Indiana and Kentucky, and is entirely limestone in a few Kentucky counties at the southeastern corner of the basin.

As a whole, the sequence shows the usual Chester pattern of sediment source to the north and more marine conditions to the south. The details superposed on this broad pattern are quite complex, but in general the clastics of the upper part of the sequence were introduced from the northeast, whereas those of the lower part were introduced from the northwest. Thus lines separating near-shore and off-shore domains for the upper part of the sequence should tend to run northwest-southeast, whereas those for the lower part of the sequence should trend northeast-southwest.

In this study, these formations are represented by 25 subsurface samples representing rather a wide distribution (fig. 5). Most of the samples are shales, although some have rather high silt and sand contents and others are calcareous. The 19 samples from Illinois are from cores and the 8 samples from Indiana are sample chips from cable-tool bores.

Because the samples represent shales, comparisons between proportions of illite and mixed-layer material best define their differences in mineralogical composition. Therefore, for each sample a value was computed for the ratio of illite to the total mixed-layer component. These values are shown in figure 5.

These values make it readily apparent that the south-central samples have much higher proportions of illite than of mixed-layer material. In figure 5 they have been separated from the other samples by a solid facies line. The average ratio value for the six southern samples is 6.3. They compose the illite facies.

The 19 northern samples that make up the mixed-layer facies have an average ratio of illite to mixed-layer material of 1.9. These samples have been subdivided into general groupings by a broken line (fig. 5) that is subparallel to the solid facies line. Such a subdivision seems justified when the average ratio values of the two subgroups are compared—the northernmost 9 samples have an average ratio value of 0.7, whereas the 10 intermediate samples have an average ratio value of 2.2. Here, as in the subdivision of the low-kaolinite facies of the Cypress samples, the subdivision of the mixed-layer facies of these samples is not meant as an attempt at subfacies classification. The broken line could be chosen as the facies line between the illite and mixed-layer facies and it indicates the gradational aspect of the mineralogical differences between these groups of samples.

In the vicinity of the southern part of the Indiana-Illinois border, three or four low-ratio values extend the mixed-layer facies southward into the area of the illite facies (fig. 5). I interpret this as a function of the dual sedimentation pattern represented in the group composed of the Paint Creek, Bethel, and Renault Formations. As pointed out above, in Renault time the off-shore direction should have been southeastward; in Paint Creek and Bethel time the off-shore direction should have been southwestward. Therefore, the sediments deposited along the Indiana-Illinois border should have been under near-shore conditions more often than those farther to the east or to the west of them.

The ratios indicate that the illite facies of these sediments are found in the areas where off-shore deposition would have been expected and that the mixed-layer facies represent rocks deposited under conditions closer to shore, as prior investigations have noted.

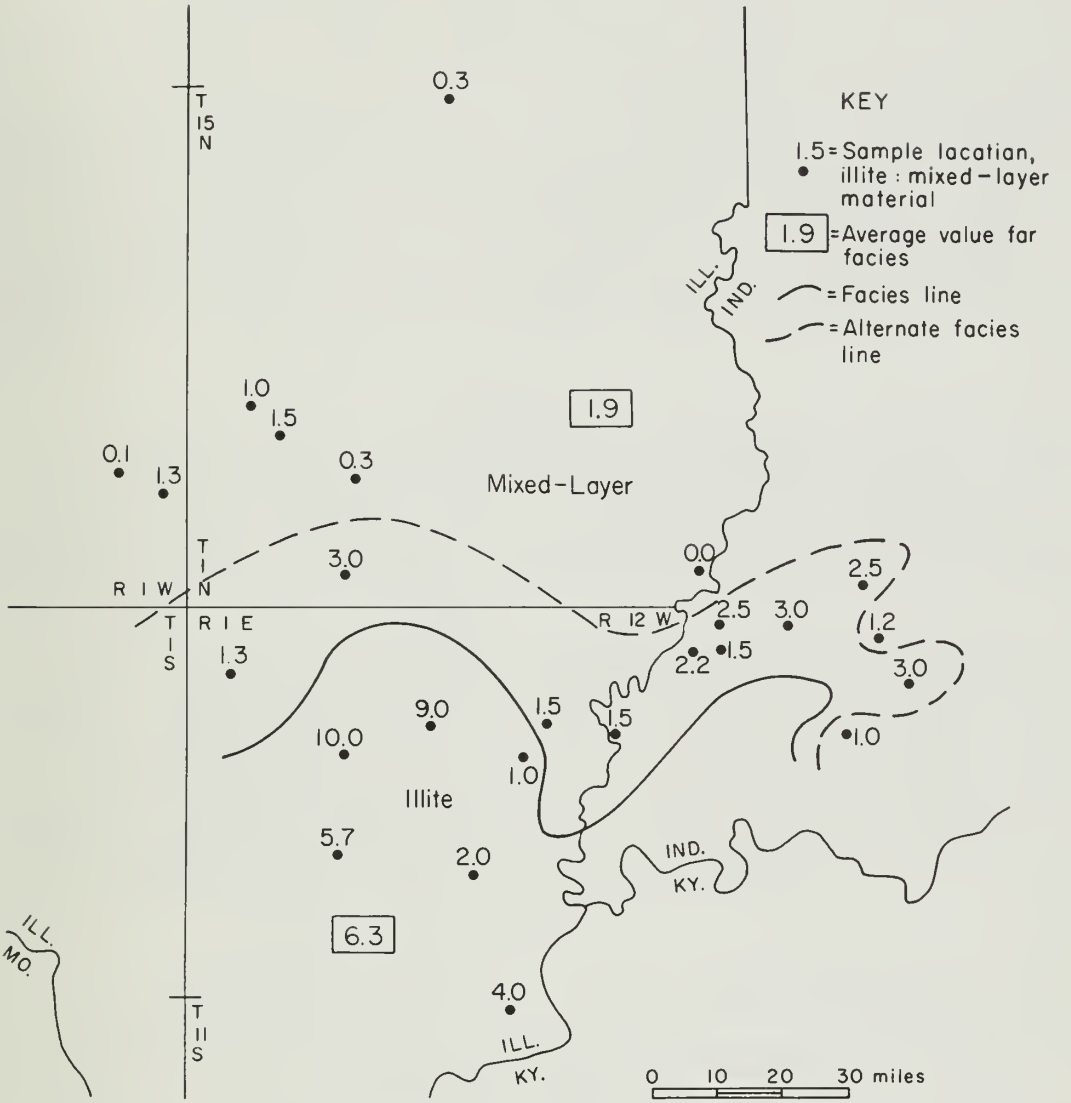

Fig. 5. Ratios of illite to mixed-layer material for samples from the Paint Creek, Bethel, and Renault Formations.

Aux Vases Formation

The Aux Vases Formation is dealt with as a separate unit because of the comparatively large number of samples available, their fairly widespread geographical distribution, and the fact that various facies are known to exist in the formation. The basal part of the Aux Vases in White, Edwards, Wabash, Gallatin, and parts of other southeastern counties is known to have rather thick marine limestone beds, whereas in the northern part near-shore deposits are thought to be present.

Swann and Bell (1958, figs. 9 and 10) showed that sand-shale ratios decrease from the northwest to southeast in belts that strike slightly north of northeast. Potter et al. (1958) showed that the modal cross-bedding class interval of

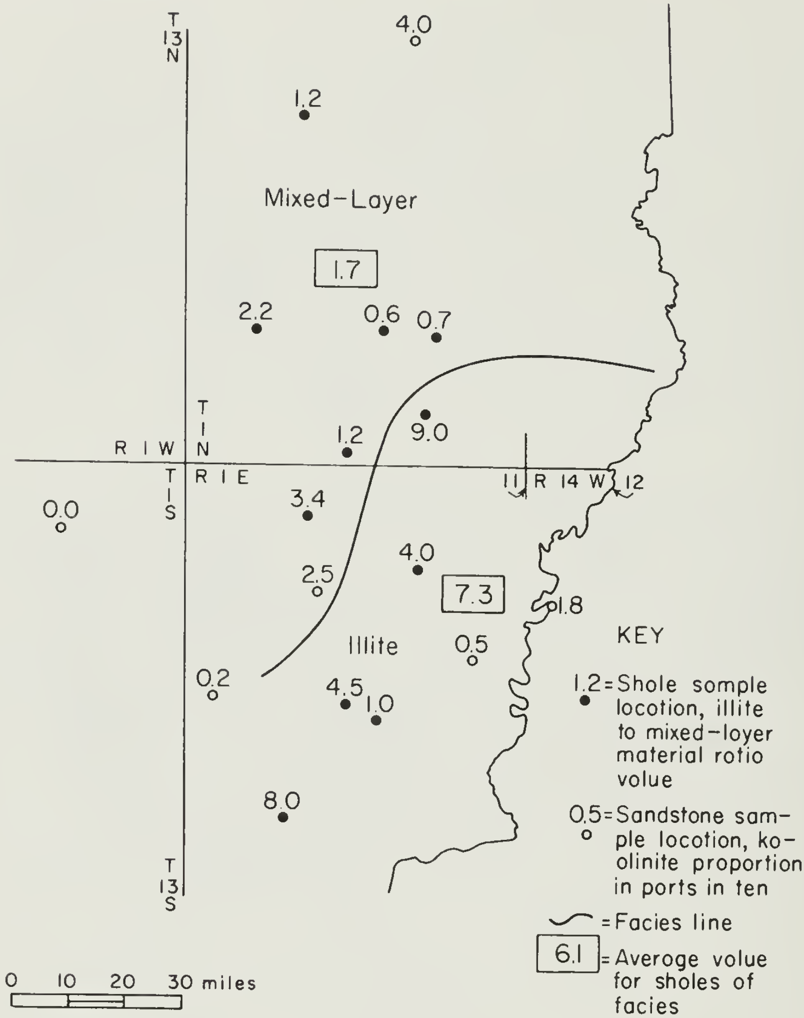

Fig. 6. Ratios of illite to mixed-layer material for shale and sandstone samples from Aux Vases Formation.

the Aux Vases is between 161° and 200°. Workman (1940) reported that the Aux Vases is thickest in the southwest part of the basin, thinning toward its eastern edge. Swann and Atherton (1948) noted the presence of lateral variations between fine-grained sandstones and oolitic sandstones or sandy oolitic limestones as well as variations between sandstone, shale, and limestone. Such variations probably indicate extremely variable conditions and environments of deposition.

The Aux Vases Formation is represented by 18 samples from rather widely distributed locations; 12 are from shales or very argillaceous sandstones; the remaining 5 samples are from sandstones that contain minor to trace amounts of argillaceous matter.

The shale samples are shown on figure 6 by the solid dots, and the ratio of illite to mixed-layer material of each shale sample appears at its location. The open dots represent the sandstone samples and the accompanying number is the kaolinite proportion (in parts in 10) of the clay fraction of the sample.

The line drawn on figure 6 separates the mixed-layer facies from the illite facies and pertains to the shale samples only. No kaolinite facies line has been constructed because the number of sandstone samples is too small to provide data for such a division.

The average ratio of illite to mixed-layer material for the six shale samples composing the mixed-layer facies is 1.7. This facies occupies the northwestern part of the basin, that part which would represent deposits closer to shore than the southeastern deposits do, according to the investigations cited above.

The illite facies, represented by 5 shale samples, has an average ratio of illite to mixed-layer material of 7.3. These samples are from the southeastern part of the basin, and the highest ratio value (11.0) represents a sample from an area that contains a marine limestone member at the base of the Aux Vases Formation.

Chester Shales

It seems probable that the post-lithification alteration of clay minerals is much more extensive in permeable sediments than in impermeable sediments. Therefore, the clay mineral suites of shales and of very argillaceous, impermeable sandstones should reflect the nature of the clay mineral suites as they were before or during lithification. Figure 7 shows the ratios of illite to mixed-layer material for the Chester shale and for low-permeable, argillaceous sandstone samples from cores from the entire Chester Series.

The low values have been separated from the higher values by an equal-value line, the value chosen being 4.0. The average ratio of illite to mixed-layer material for the shale samples below 4.0 is 1.7; for those samples with values of 4.0 or above, the average value is 6.5. The average value for all samples is 3.3.

Samples with ratio values less than 4 in the southern and eastern part of the basin (fig. 7) represent upper Chester formations. During the deposition of these deposits, it is probable that this area was deltaic and/or terrestrial. The higher values are concentrated in the southern portions of the basin where, during Chester time, the depositional environments were generally off-shore.

DISCUSSION

It seems likely, on the basis of the evidence presented here, that, in general, the mineralogical composition of the clay mineral suite varies as the sedimentary environment varies — and that the clay mineral facies vary as do environmental facies. To find the reason for this relationship, the nature of the clay minerals that originally were introduced into the sedimentary basin must be determined. By comparison of the minerals now composing the rocks (especially shales in which post-lithification alteration would have been minimal) and the minerals that originally were available, the factor or factors controlling the areal differentiation might emerge.

Character of Clay Minerals Introduced into Sedimentary Basins

Studies of clay minerals in Recent soils (such as that by Alexander, Hendricks and Nelson, 1939), and of fluvial, lacustrine, and marine sediments (such as those by Johns and Grim, 1958; Grim et al., 1949; Milne and Earley, 1958; and Milne and Shott, 1958) have shown that montmorillonite, degraded chlorite, degraded illite, and kaolinite commonly are present in Recent sediments and soils. Clay minerals exhibiting all degrees of degradation and variations in crystallinity are likely to be present as constituents of the clay mineral suites of Recent sediments because of the complexity of the source areas supplying the sediments.

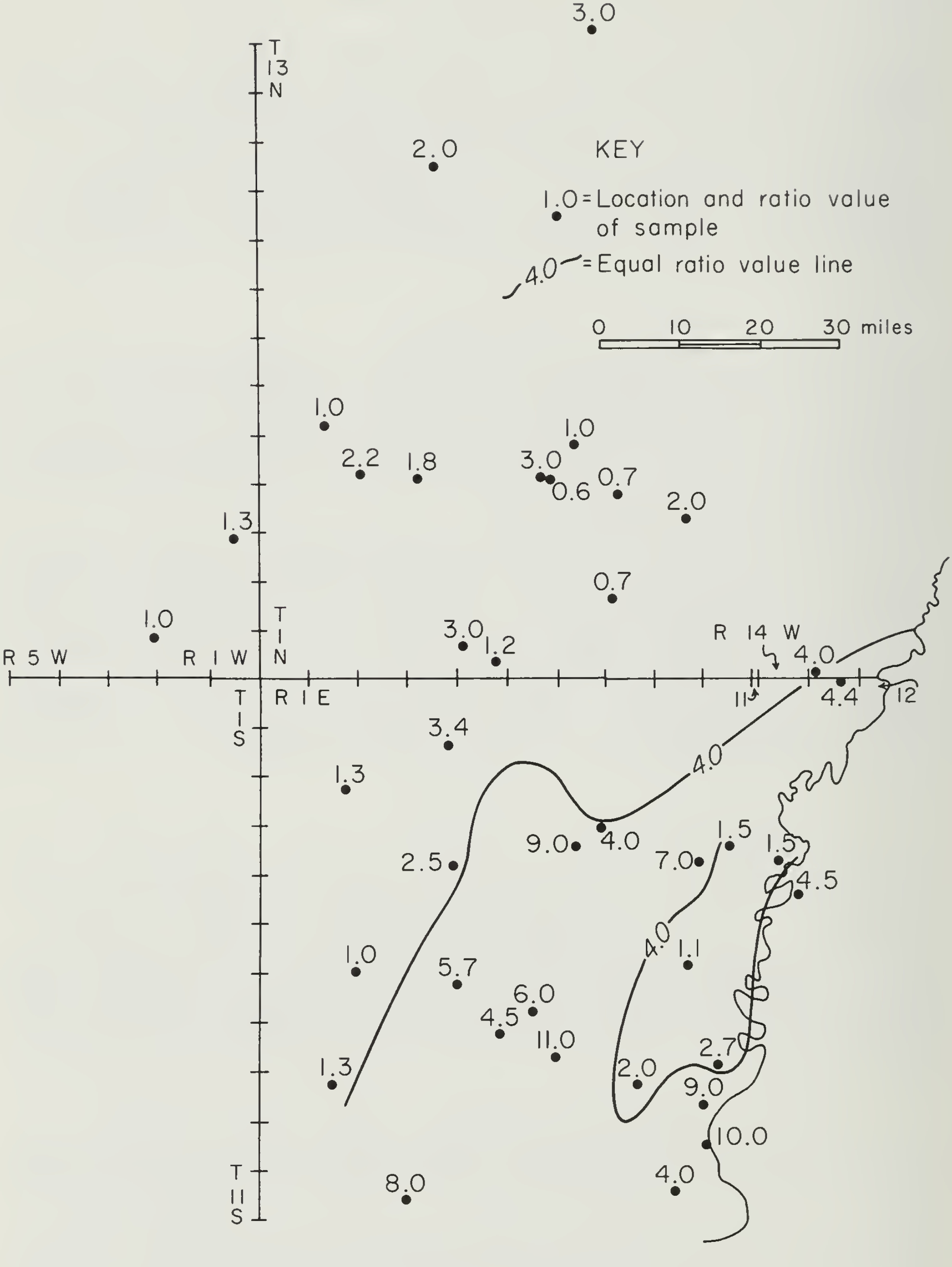

Fig. 7. Ratios of illite to mixed-layer material in shale samples from the Chester series.

Weathering products would be expected to form a major part of the sediments supplied to the area of accumulation from highly vegetated, low-relief areas. Hence, degraded illite, degraded chlorite, montmorillonite, and/or kaolinite would be the likely dominant clay minerals supplied by such an area. From areas of high relief with minor covers of vegetation, erosion products would be the dominant constituents of the sedimentary load. Therefore, relatively well crystallized clay minerals probably would be the dominant constituents of the clay minerals supplied by such an area. If it is assumed that little or no degradation takes place in the area of accumulation, clay minerals such as degraded illite and degraded chlorite, montmorillonite, and/or kaolinite that apparently are formed essentially as weathering products would be absent unless they had been supplied by the eroded bedrock of the source area.

On the basis of previous investigations concerning the Chester Series of the Illinois Basin, it can be assumed that most of the sediments of the series came from a relatively low-lying land mass dominated by a temperate climate. In such an area, products of weathering should have been a major constituent of the sedimentary load supplied to the basin. As these minerals appear now as only minor constituents of the clay mineral suites, it must be assumed that either areal differentiation or crystallographic alteration has occurred between the time the detrital clay minerals were introduced into the basin and the present.

One reason that the stratigraphic units used herein were chosen was that the formations composing each unit seemed to have had essentially the same source areas. The differences that existed between the northern, northeastern, and northwestern parts and the southern and southeastern parts of the basin are, therefore, essentially differences in the environments of deposition and rates of accumulation.

The kaolinite content of contemporaneous sandstone deposits is variable. It has been shown that the high-kaolinite facies constitute sandstones probably deposited nearer to the shore than those made up of the low-kaolinite facies. W. E. Parham and W. A. White, both of the Illinois State Geological Survey, have convincing evidence that this generality also is demonstrable in Pennsylvanian shales and underclays (personal communication, 1959). The best explanation for these concentrations seems to be that the kaolinite was flocculated when it came in contact with sea water.

As differences between the clay mineral suites of essentially contemporaneous shales do exist and these differences seem to be essentially controlled by the environments of deposition or rates of accumulation, it would be helpful to sedimentologists if the reason or reasons for these changes could be ascertained. The following explanations for such changes have been in part gathered from rather recent literature of clay mineralogy. Following each suggestion is an indication of its applicability to the data presented herein.

1) Weaver (1958, p. 260) states, "Yoder and Eugster's (1955) studies on the synthesis of illite and the writer's study on naturally occurring illites indicates that there are low-temperature and high-temperature illite polymorphs. As most of the illites in limestones (and shales) are the high-temperature polymorphs, it is unlikely that they were formed by marine diagenesis and more likely that they are detrital and were derived from muscovite or illite in the source area."

If Weaver's idea were correct, then either Stokes' law or differential speed of flocculation must be called upon to explain the relationships observed. The former would be difficult to use as it must be assumed that high-temperature muscovite particles would be better ordered and larger sized, thus permitting the muscovite to settle out closer to the shore while the finer grained material went farther out. This is the reverse of what is found. Preliminary experiments made by the author suggest that in concentrations of 30,000 to 120,000 ppm NaCl, well ordered illite seems to flocculate faster than poorly ordered, mixed illite. Therefore, according to rates of flocculation, the well ordered illite would be closer to shore than the poorly ordered illite. Again, the reverse is found.

2) Well crystallized illite is the result of an alteration connected with temperature and pressures brought to bear on detrital and/or precipitated material during burial. The greater the depth of burial, the higher the degree of crystallinity and the greater the chance for all available material to reach this equilibrium phase.

The data at hand, although inconclusive, tend to discredit this possibility. If this idea were correct, it would be suggested that the highest illite proportions would be found in the thickest (and deepest buried) part of the basin. As all Chester formations in the Illinois Basin are thickest along the southern outcrop belt, it seems reasonable to think that during Chester time the deepest buried sediments were much farther south than the present outcrop belt. There is much evidence indicating that illite increases from north to south but there are also some data that suggest the highest illite values are found not in the deepest buried sediments but farther northwest.

3) Degraded illite introduced into a marine sedimentary basin becomes regraded to better crystallized, more ordered illite by the fixation of potassium as rates of accumulation decrease. Therefore, as the degraded illite is carried out farther from shore, the proportion of regraded illite developed from degraded illite increases and the amount of other detrital material decreases. Very little of the degraded illite trapped in rapidly deposited sandstones had the chance to be regraded.

The data at hand seem to support this idea. In every stratigraphic group investigated, maximum illite proportions are from facies thought to represent offshore environments; minimum illite proportions are from facies thought to represent near-shore, deltaic, or terrestrial environments. Where the near-shore facies are composed of sandstones, the predominance of mixed-layer and degraded material, though in part due to post-depositional changes, also reflects an originally unregraded, inherited clay mineral suite.

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