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Relation of Petroleum Accumulation to Clay Minerals In Some Lansing and Kansas City Group (Pennsylvanian) Cores of Western Kansas

by

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RELATION OF PETROLEUM ACCUMULATION TO CLAY MINERALS IN SOME LANSING AND KANSAS CITY GROUP (PENNSYLVANIAN) CORES OF WESTERN KANSAS

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B.S., Kansas State University, 1958

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of the requirements for the degree
of Master of Science.

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ABSTRACT

Fifty four shale samples were obtained from Lansing and Kansas City Group (Pennsylvanian) oil well and dry hole cores from western Kansas. The clay minerals were identified and the quantity of each was estimated from x-ray diffractometer diagrams. The clay minerals from all shales are similar and consist of illite, random mixed-layer illite-montmorillonite, and chlorite, in that order of abundance. Montmorillonite is here defined as the mineral that expands to 17.8 A on glyceration.

There seems to be no definite variation in kind or amount of clay minerals stratigraphically through the Lansing and Kansas City Group sections. Further, no general differences can be detected geographically from one area to another.

The x-ray diagrams from raw oriented samples of shales directly below zones of petroleum accumulation exhibit similarities and are different from those of all other shales. In these diagrams, the 10 A illite peak is lower and broader and the apex of the peak is normally not as sharp as in diagrams of other shale samples. Further, the ratio of illite: random mixed-layer illite-montmorillonite is considerably lower in these samples.

An attempt is made to explain the above described differences on the basis of differences in the amount or variety of original montmorillonite present in the sediment.

This explanation requires the following assumptions: (1) montmorillonite was probably more abundant in the original sediment than it is now; (2) either the amount or the variety of montmorillonite varied considerably within the sediment geographically; (3) montmorillonite changes to illite in ancient marine sediments, (4) some varieties of montmorillonite adsorb organic material and act as a catalyst in petroleum formation, and (5) the adsorbed organic material retards the diagenesis of montmorillonite.

INTRODUCTION

Some new work has been done in the area of clay mineralogy and petroleum origin and accumulation especially by Ralph E. Grim (1947) at the University of Illinois and Charles A. Weaver (1959). Weaver made a study of 20,000 clay samples from the major United States oil producing basins and found a reasonably good direct relationship between the amount of reservoir oil and the expansible clay mineral content. Grim suggests that certain clay minerals have played a significant role in the origin of petroleum by serving as a catalyst for the transformation of organic material into petroleum.

This thesis is a detailed study of clay minerals in the shales obtained from Lansing and Kansas City Group (Pennsylvanian) oil well and dry hole cores in western Kansas. The area covered by this study is much smaller and the amount of detail much greater than that done by Weaver.

The occurrence of petroleum, or its absence, in each potential zone of accumulation is compared to the nature and composition of the clay minerals in all surrounding shales.

ACKNOWLEDGMENTS

My sincere gratitude is given here to all those who have helped make this thesis possible.

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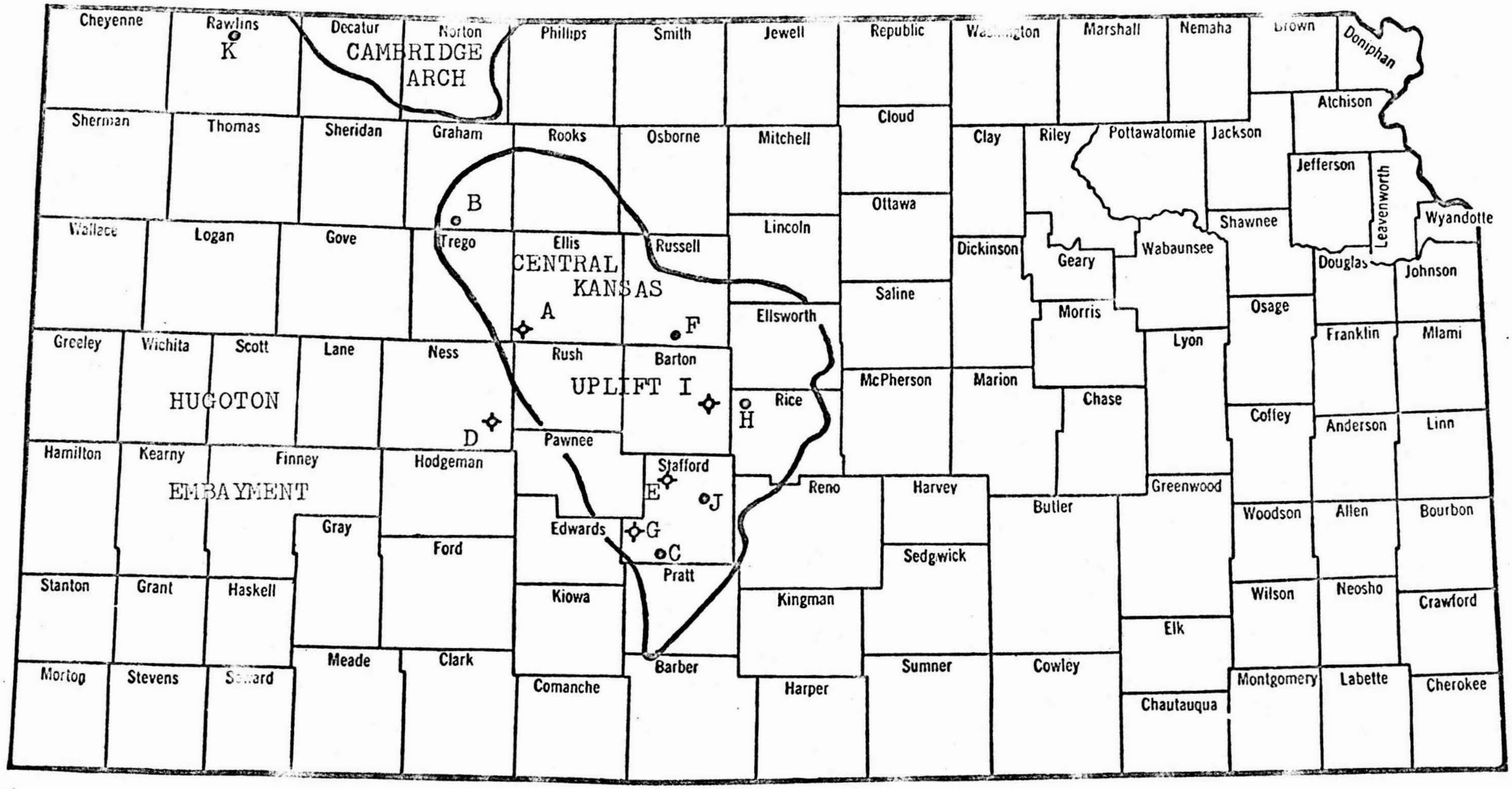
The State Geological Survey of Kansas provided financial assistance and also the cores used in this study.

Those instrumental in obtaining the needed information concerning the cores were Mr. V. Jean Taylor of Wichita, Kansas, Dr. Dan F. Merriam, and many oil company representatives.

I wish to thank my wife, Virginia, for her time and concern in typing the thesis. Dr. M. P. Bauleke is also given special thanks for his time spent in maintenance of the x-ray diffraction unit.



STATE OF KANSAS

Figure 1. Index map showing major western Kansas structural elements (Jewett, 1951) and locations of well cores used in this study.

● producing oil well ⌖ dry hole

STRATIGRAPHY AND STRUCTURE

The Lansing and Kansas City Groups (Missourian Stage) are similar lithologically, have a conformable contact, and for convenience are generally considered as one group in the western Kansas subsurface. The top of the Lansing Group and base of the Kansas City Group in most of western Kansas are readily recognized in electric and radioactive logs.

As a whole, the Lansing and Kansas City Groups are characterized by relatively thick, persistent limestones. Between the limestones are shales of varying thickness, light to dark colored, and calcareous to sandy in composition. A few thin and persistent black, platy shales are easily recognized in radioactive logs throughout the western Kansas subsurface.

Moore (1949) described the Lansing and Kansas City Groups as having regularities of sequence denoting both cyclothems and megacyclothems. According to Moore, these marine beds contain invertebrates interpreted as representing a very near-shore assemblage (inarticulate brachiopods, calcareous brachiopods, thick-shelled clams, snails, and some bryozoans), to those representing an off-shore assemblage (particularly the fusulinids). Algal limestones occur at the top of several limestone formations and evidently represent the shallow-water deposits of retreating phases of marine inundations.

These algal limestones produce local thickenings, or "reef-ups", in southeast Kansas and are thought to be responsible for some local thickenings in the subsurface of western Kansas which may serve as oil traps (Merriam, 1961). Other local thickenings are due to local structural warping during deposition. Merriam (1961) also called attention to some "stray" limestones occurring within predominantly shaly formations. Some limestone units of the Lansing-Kansas City Group pinch out in northwest Kansas and give way to thick shale sections (Walton, 1960).

The major structural element in western Kansas is the Central Kansas Uplift with its northern counterpart, the Cambridge Arch. West of this lies the broad Hugoton Embayment of the Anadarko Basin which includes many north-northwest-trending anticlines and synclines.

Pre-Kansas City history of western Kansas has been described by Merriam (1961). During Lansing-Kansas City deposition, the Central Kansas Uplift and Cambridge Arch were gradually rising while the Hugoton Embayment was subsiding. The Cambridge Arch has been uplifted continually until Mid-Cretaceous time. During this same time interval, the Central Kansas Uplift shows evidence of southeast tilting during the first half of the Permian, and, starting with Mid-Permian, shows southwest tilting up to Mid-Cretaceous time. From Mid-Cretaceous to the end of Tertiary both arches were tilting to the northwest and, starting with Quaternary, both exhibit eastward tilting.

Almost all Lansing-Kansas City oil and gas production is from closed anticlines and domes on the Central Kansas Uplift, the Cambridge Arch, or in the Hugoton Embayment. All but two of the cores used in this study came from the Central Kansas Uplift proper. The core from Ness County (D) is on the western flank of the uplift and the core from Rawlins County (K) is on the western flank of the Cambridge Arch.

In 1962 Kansas ranked sixth in oil production in the United States. Although the Lansing-Kansas City Group is not the most prolific producer in the state, it has been reported productive in more oil fields than has any other zone. Most Lansing-Kansas City oil wells produce from oolitic porosity in the limestones, or less commonly, from intergranular or intercrystalline porosity. Undoubtedly fracture porosity has a larger effect than generally realized.

Because of difficulty in correlating over long distances, most oil companies use an alphabetical index on the limestones of the Lansing-Kansas City Group (Morgan, 1952). Subsurface correlation of this group is complicated by intercyclic erosion, which has upset the orderly sequence of beds (Lee, 1956). Parkhurst (1959) correlated the surface outcrop in eastern Kansas with the subsurface through western Kansas. Figure 2 shows the relation of the alphabetical designation and Parkhurst's results (Merriam, 1961).

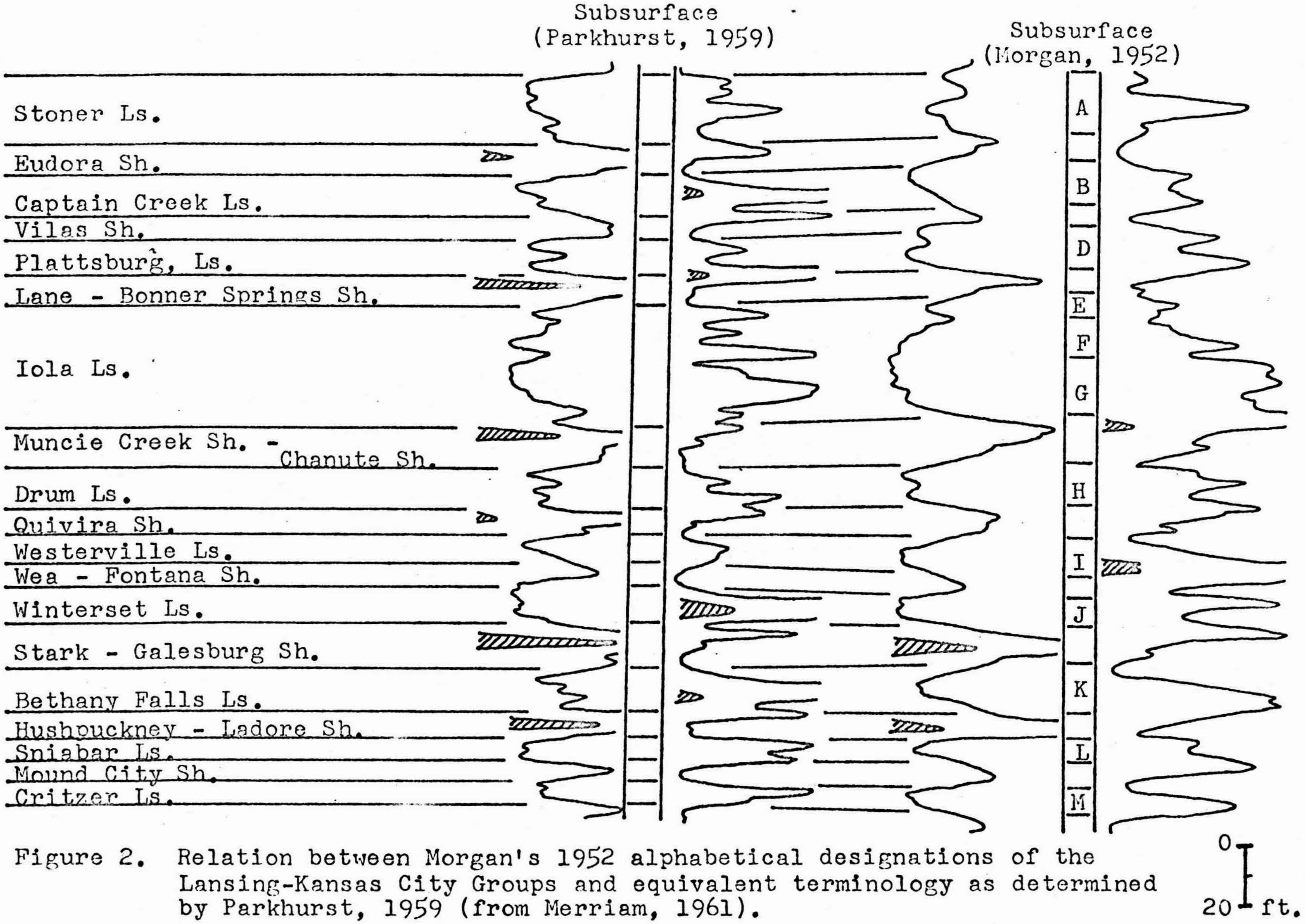


Figure 2. Relation between Morgan's 1952 alphabetical designations of the Lansing-Kansas City Groups and equivalent terminology as determined by Parkhurst, 1959 (from Merriam, 1961).

TECHNICAL PROCEDURE

Selection of Samples

The shales examined in this study were selected from eleven oil well and dry hole cores penetrating all or part of the Lansing-Kansas City Group in western Kansas. The shale portions of these cores were sampled at one-foot intervals and, in most cases, the samples from one shale unit were combined into one sample. When lithological or color changes were found in the thick shales, the one-foot samples were combined into two or three representative samples. Fifty-four samples were obtained from these cores (Figures 3 through 13).

Each sample was selected from the inside of the core so that the effect of drilling mud infiltration would be held to a minimum.

Depths indicated on the core boxes were checked against electric or lithologic logs to eliminate any discrepancies.

Preparation of Samples

Approximately 3 grams of each combined sample was crushed to pass through a 61-micron screen. This powder was packed in an x-ray sample holder for an "unoriented" powder pattern.

An additional 10 to 20 grams was crushed and placed in a 500 ml Erlenmeyer flask containing distilled water and a few drops of NH_4OH. The contents were shaken vigorously in a wrist-action shaker for 8 hours to deflocculate the clay. The suspension was transferred to a 600 ml beaker, the beaker filled with distilled water, and allowed to settle for 4 hours. Clay finer than 2 microns was gathered by a medicine dropper 5 cm below the fluid surface and transferred onto 4 glass microscope slides. The slides were allowed to dry at room temperture.

One oriented slide from each sample was treated with a small amount of glycerine and allowed to stand for approximately two days. Thirteen slides from selected representative samples were heated to 575 degrees C and allowed to remain at that temperature for 30 minutes. Of these selective samples, eight slides were heated to 450 degrees C and allowed to cool without delay.

An additional 30 gram portion of one representative sample was crushed, passed through a 61-micron screen, and boiled for 5 minutes in dilute hydrochloric acid to test for kaolinite. The sample was then washed in distilled water, deflocculated, and the minus 2 micron fraction put on a glass slide as in the above described manner.

X-ray Diffraction

An "unoriented" powder pattern, a dry raw oriented pattern, and a glycerated oriented pattern were obtained for each of the 54 samples. In addition, 13 patterns of 575 degree C-heated slides, 8 patterns of 450 degree C-heated slides, and 1 HCl-treated slide were run.

The machine used was a General Electric XRD-3 x-ray diffraction unit, with nickel-filtered copper radiation. The x-ray beam passed through a 1 degree beam slit, 3 degree sollar, and 0.2 degree detector. The diffractometer scan speed was 0.2 degrees per minute. The unit operated at 45 kilovolts and 15 milliamperes.

NON-CLAY MINERAL COMPOSITION

The non-clay minerals were identified from the minus 61 micron fraction. The d-values and other identifying characteristics were obtained from Brindley (1951).

Quartz is the dominant non-clay mineral and is present in all 54 samples. The characteristic peaks for quartz appear at 4.21 A and 3.34 A.

Calcite occurs in the great majority of samples and is identified by the peak at 3.03 A. Calcite is not present in samples 11, 13, 25, 26, 27, 30, 36, 41, 46, and 48.

Feldspar is also a common constituent and is identified by the single or double peak at approximately 3.18 A. Feldspar is absent from samples 7, 11, 17, 32, 33, and 43.

Dolomite, which gives a strong peak at 2.88 A, is identified in samples 7, 8, 13, 51, 52, 53, 54, and 60.

The identification of mica in these samples is somewhat uncertain. Samples 5, 10, 11, 16, 26, 30, 35, and 38 give a fairly intense 10 A peak which is partly obscured by mixed-layer material. The corresponding hkl peaks cannot be distinguished from those of illite. It is difficult or impossible, in these samples, to distinguish a true mica from a well crystallized illite.

Crystallinity is here defined as the degree of order and regularity of molecules in the mineral lattice. Crystallinity increases with increasing completeness in the lattice and with decreasing lattice distortion.

CLAY MINERAL COMPOSITION

The clay minerals were identified from information in Grim (1953), Brindley (1951), and MacEwan etal.(1961). The minus 2 micron fraction was used to determine the clay mineral composition.

All samples are similar and are predominantly illite, chlorite, and seemingly illite-montmorillonite random mixed-layer material.

Illite is the dominant clay mineral and is present in all 54 samples. The characteristic illite peak is at 10 A. Each 10 A peak shows asymmetry in that it spreads on the low-angle side. This low-angle spreading is due to the mixture of illite with randomly mixed-layer material (Figure 3). In general, the high-angle side of the peak is normal and smooth. When the clay is glycerated, the 10 A peak becomes less intense and more symmetrical. The greater symmetry would suggest that the mixed-layer material has expanded slightly and has separated from the relatively pure illite to some degree. Upon heating to 575 degrees C, the illite peak becomes slightly more intense.

The intense 10 A peak in samples 5, 10, 35, 46, and 48 suggests well crystallized illite. Samples 7, 13, 28, 47, and 50 have low and broad 10 A peaks which suggest poorly crystallized illite. Other samples exhibit patterns everywhere in between these extremes. Where the patterns are clear and sharp, it is possible to suggest that the $2M_1$ polymorph seems to exist (Bradley and Grim, 1961). Most patterns, however, were not clear enough to give this distinction.

Chlorite also is a constituent of each sample. It gives a distinct peak at 14 A. The 14 A peak becomes slightly less intense with glyceration (probably because of dilution) and remains almost unchanged when heated to 575 degrees C for 30 minutes. Boiling the sample in dilute hydrochloric acid for 5 minutes destroys the 14 A and 7 A peaks. The chlorite peak also is generally asymmetrical, however the high-angle side shows the spreading in this case. Glyceration increases this asymmetry.

It was not possible to determine the variety of chlorite in these samples.

The material between the 14 A and 10 A peaks is presumably an illite-montmorillonite random mixed-layer material for the most part. Some chlorite also may be present in the mixture. Montmorillonite is here defined as the mineral that expands to 17.8 A on glyceration. The glycerated patterns show that some of this mixture moves away from the low-angle side of the 10 A peak and toward the high-angle side of the 14 A peak.

Some patterns exhibit broad, indistinct peaks within the random mixed-layer pattern. In two instances (samples 25 and 31) a small peak is developed around 6.6 A with no lower or higher order peaks distinguishable.

In samples 1, 3, 15, 27, and 43, a small peak at about 17.3 A is accompanied by a larger peak at about 7.6 A.

Heating to 575 degrees C makes the small 17.3 A peak move toward the 14 A chlorite peak. Glyceration has very little effect on this peak. These two reflections at 17.3 A and 7.6 A seemingly indicate a randomly mixed-layer mineral.

Talc was tentatively identified in sample 13. The mineral gives a first order peak at 9.3 A and second and fourth orders at 4.6 A and 2.3 A. The 9.3 A spacing was not expanded by glycerine and was not affected by heating to 575 degrees C for 30 minutes.

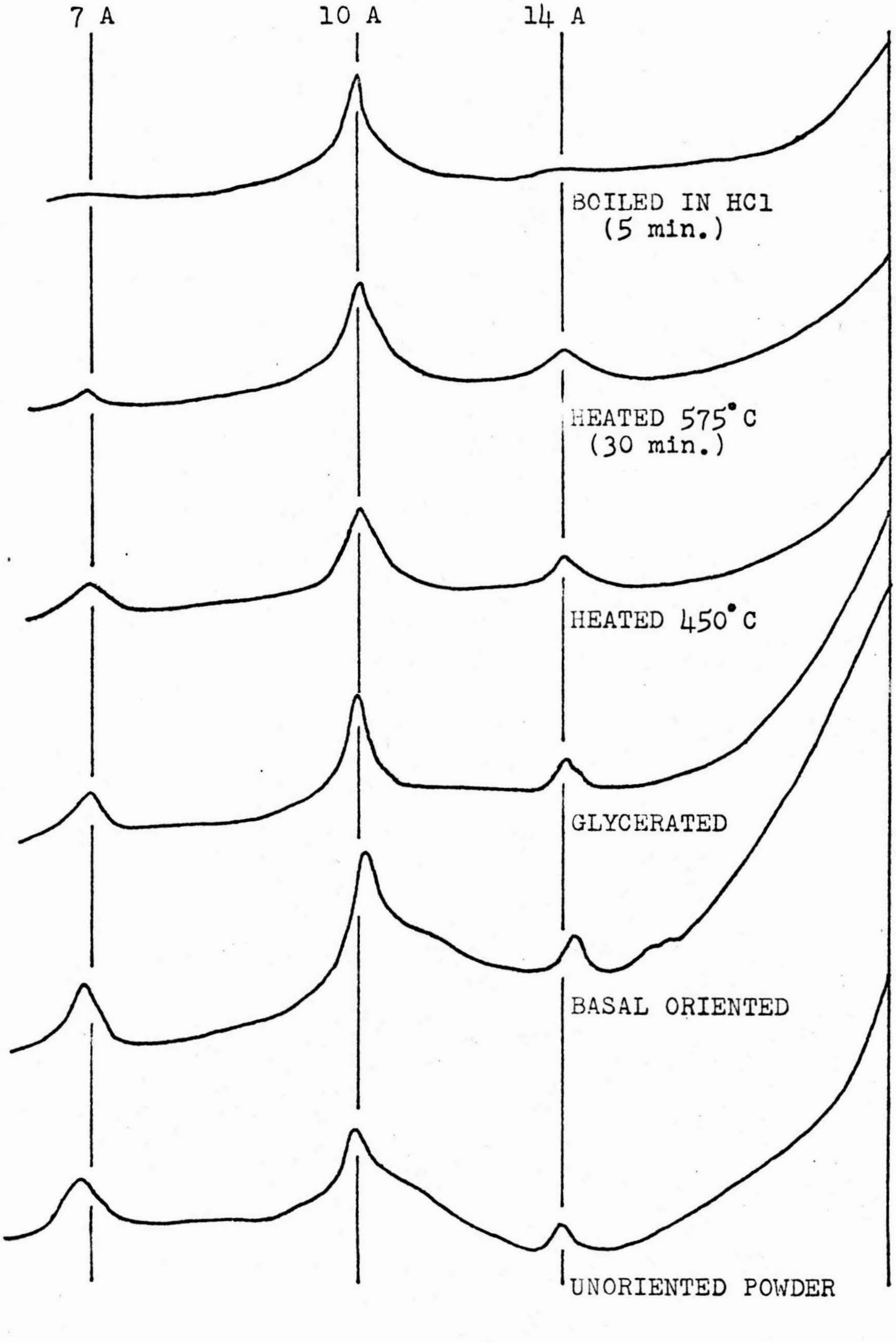


Figure 3. X-ray patterns of a representative sample (sample 38).

QUANTITATIVE ESTIMATION OF CLAY MINERALS

The estimation of the relative amounts of clay minerals from x-ray patterns is difficult and the results give only a rough picture.

Most previous workers have compared peak intensities or areas under the peaks. The diffracting power of the clay minerals (and therefore, the peak heights) is known to depend on such factors as the grain size, degree of orientation, and degree of crystallinity, as well as the composition. Further, different clay minerals have different reflecting coefficients. A sample containing equal amounts of illite and kaolinite, for example, generally gives a higher peak for the kaolinite portion in the x-ray pattern. For a detailed study of quantitative estimation, the reader is referred to Brindley (1961) and Johns et al., (1954).

Brindley (1961) states that the reflecting coefficients of illite and chlorite depend, to a large degree, on the variety of each. As it was impossible to determine the variety of minerals in this study, the heights of the illite and chlorite were compared directly. To obtain the relative amount of mixed-layer material in each sample, the area under the curve was compared directly with the areas under the illite and chlorite peaks.

Procter (1959) developed a procedure for converting peak heights to relative composition. The procedure used here is similar to that used by Procter but is adapted to include mixed-layer material which has no distinct peaks. A planimeter was used to measure the areas. The steps of conversion are as follows: (1) Divide the area under the mixed-layer curve by the total area under the illite and chlorite peaks and the mixed-layer curve. This gives a measure of percentage of mixed-layer material. The remaining percentage is presumably the amount of illite and chlorite present. (2) Multiply the illite peak intensity by the remaining percentage (step 1), and divide by the sum of the illite and chlorite peak intensities. This gives the percentage of illite. (3) Subtract the sum of the mixed-layer and illite percentages from 1.00. The remainder is the chlorite percentage. These percentages, although they have no actual validity, are useful for comparison of samples.

Table 1 lists the relative amounts of illite, chlorite, and mixed-layer material obtained from the 54 samples.

The percentage of illite generally ranges from 25 to 85 percent. Sample 13 contains 45 percent talc, apparently at the expense of illite (only 15 percent). Chlorite ranges from 5 to 35 percent. The mixed-layer material ranges from 10 to 60 percent.

Using the percentage of illite as unity, ratios of illite : chlorite : mixed-layer material were computed and are included in Table 1.

Table 1. Clay mineral analysis of 54 samples

Core	Sample No.		Depth	Percentage Composition			Ratios		
				Illite	Chlorite	Mixed-Lay.	Illite	Chlorite	Mixed-Lay.
A	1		3312 to 3319	36	18	46	1.0	0.5	1.3
	2		3364 to 3372½	59	19	22	1.0	0.3	0.4
	3		3424 to 3431	38	29	33	1.0	0.8	0.8
	4		3437 to 3457	55	16	29	1.0	0.3	0.5
	5		3480 to 3486	62	10	28	1.0	0.1	0.4
	6		3501 to 3509	50	14	36	1.0	0.3	0.7
B	7	*	3761 to 3769	46	19	35	1.0	0.4	0.8
	8	*	3778 to 3785	37	19	44	1.0	0.5	1.2
	9	*	3795 to 3804	35	15	50	1.0	0.4	1.4
C	10		3681½ to 3687	88	3	9	1.0	0.1	0.1
	11		3694 to 3698	49	19	32	1.0	0.4	0.7
	12		3701 to 3704	59	18	23	1.0	0.3	0.4
	13	+ *	3914 to 3918	15	8	32	1.0	0.5	2.1

* Shale samples directly below slight to good shows of oi

\+ Also contains 45% talc (9.3 A).

Table 1. (continued)

Core	Sample No.		Depth	Percentage Composition			Ratios		
				Illite	Chlorite	Mixed-Lay.	Illite	Chlorite	Mixed-Lay.
D	15		3752 to 3755	50	18	32	1.0	0.4	0.6
E	16		3418 to 3419	42	24	34	1.0	0.6	0.8
	17		3549 to 3555	34	10	56	1.0	0.3	1.6
	18		3563 to 3564	53	16	31	1.0	0.3	0.6
F	23	*	3058 to 3062	49	19	32	1.0	0.4	0.7
	24		3098 to 3107	43	19	38	1.0	0.4	0.9
	25		3120 to 3122	44	16	40	1.0	0.4	0.9
	26		3130 to 3133	62	11	27	1.0	0.2	0.4
	27		3214 to 3217	33	17	50	1.0	0.5	1.5
G	28		3657 to 3662	50	19	31	1.0	0.4	0.6
H	30	*	2962 to 2965	40	20	40	1.0	0.5	1.0
	31		2965 to 2966	51	15	34	1.0	0.3	0.7
	32		3013 to 3020	60	13	27	1.0	0.2	0.5
I	33		3121 to 3122	73	12	15	1.0	0.2	0.2
	34		3126 to 3129	80	3	17	1.0	0.0	0.2

Table 1. (continued)

Core	Sample No.		Depth	Percentage Composition			Ratios		
				Illite	Chlorite	Mixed-Lay.	Illite	Chlorite	Mixed-Lay.
J	35		3314 to 3318	53	21	26	1.0	0.4	0.5
	36		3330 to 3333	62	14	24	1.0	0.2	0.4
	37		3336 to 3338	46	18	36	1.0	0.4	0.8
	38	*	3347 to 3357½	41	18	41	1.0	0.4	1.0
	39		3372 to 3375	48	11	41	1.0	0.2	0.9
	40		3380 to 3384	42	15	43	1.0	0.4	1.0
	41		3392 to 3395	46	17	37	1.0	0.4	0.8
	42	*	3424 to 3430	24	17	59	1.0	0.7	2.5
	43	*	3442 to 3444½	44	13	43	1.0	0.3	1.0
	44	*	3519 to 3522	36	15	49	1.0	0.4	1.4
K	46	*	3991 to 3993	51	13	36	1.0	0.3	0.7
	47	*	4000 to 4015	26	26	48	1.0	1.0	1.8
	48		4020 to 4028	49	17	34	1.0	0.3	0.7
	49	*	4038 to 4050	38	24	38	1.0	0.6	1.0
	50	*	4053 to 4078	25	29	46	1.0	1.2	1.8

Table 1. (continued)

Core	Sample No.		Depth	Percentage Composition			Ratios		
				Illite	Chlorite	Mixed-Lay.	Illite	Chlorite	Mixed-Lay.
K	51	*	4088 to 4095	38	24	38	1.0	0.6	1.0
	52	*	4095 to 4109	35	15	50	1.0	0.4	1.4
	53	*	4109 to 4114	53	13	34	1.0	0.2	0.6
	54	*	4114 to 4127	24	16	60	1.0	0.7	2.5
	55	*	4139 to 4144	31	27	42	1.0	0.9	1.4
	56	*	4144 to 4168	26	37	37	1.0	1.4	1.4
	57	*	4184 to 4195	33	25	42	1.0	0.8	1.3
	58		4197 to 4211	41	19	40	1.0	0.5	1.0
	59	*	4223 to 4232	31	20	49	1.0	0.6	1.6
	60		4236 to 4239	35	17	48	1.0	0.5	1.4
	61		4243 to 4247	28	16	56	1.0	0.6	2.0

DISTRIBUTION OF THE CLAY MINERALS

There appear to be no definite variations in relative amounts of clay minerals stratigraphically through the Lansing and Kansas City Group sections. Further, no general differences can be detected geographically from one area to another.

Generally, all samples are composed of illite, random mixed-layer illite-montmorillonite and chlorite in that order of abundance.

X-ray diagrams of the shales associated with petroleum appear different from those not associated with petroleum. Although there are exceptions, some general statements can be made.

Clay Minerals Associated with Petroleum

When x-ray diagrams of the air-dry oriented samples from shales directly below zones of petroleum accumulation are placed together, similarities are observed.

The 10 A illite peak is generally low and broad, and the apex of the peak is normally not sharp. In these shales the average ratio of illite : mixed-layer material is 1 : 1.35, considerably lower than in other shales.

Two notable exceptions to the above generalities are samples 46 and 53. Sample 53 is taken from the top 5 feet of an 18-foot shale section. The x-ray pattern from the lower 13 feet conforms well with the above generalities.

Clay Minerals Not Associated with Petroleum

Similarities are also observed in the diagrams of raw oriented samples of most shales either from between "dry" zones, or from directly below these zones. This category includes shales from directly above zones of petroleum accumulation.

These shales give a 10 A illite peak which is more intense and not as broad. The apex of the peak is normally sharper. The illite : mixed-layer material ratio is 1 : 0.76, almost double that of the other category.

Definite exceptions to these similarities include samples 17, 27, 60, and 61. It is interesting to note that samples 60 and 61 are from a well in which eight zones contain oil, but the zones above these two shales gave salt water in drill stem tests.

The possibility of oil migration must be considered here. The above four samples, for example, may have been below an oil zone in the past and the oil has now migrated to areas of higher elevation. Another complicating factor is the possibility that one of the shales is sufficiently fractured to allow oil from a lower source bed to pass through it.

The 14 A chlorite peak in x-ray diagrams of all 54 samples appears approximately the same. Samples from below petroleum accumulation seemingly contain the same amount of chlorite as those from below "dry" zones. The shape and sharpness of the chlorite peak cannot be differentiated into two or more general categories.

DISCUSSION

It has been established that the clay minerals in these 54 samples and their average relative quantities are as follows: Illite 45 percent, random mixed-layer illite-montmorillonite 40 percent, and chlorite 15 percent. Small amounts of chlorite also are thought to be scattered through the mixed-layer material. Kaolinite was not identified.

Investigations by Milne and Earley (1958), Grim et al., (1949), and others indicate that recent muds in a marine environment are of a more complex nature than that found in these samples. If these clay minerals were at one time more complex, what processes have changed them into shales containing only two or three essential minerals? Further, why do these samples, taken from eleven different cores across western Kansas, and from all major shales through the Lansing and Kansas City Groups, exhibit almost identical clay mineral content? It seems improbable that the source or the environment of deposition, or both, remained the same over such an area and for so long a time.

It was also established that the mixed-layer material is more abundant, at the expense of illite, below zones of petroleum accumulation. These particular illite peaks also lack sharpness in the x-ray diagrams, when compared to other samples. What mineralogic processes could be responsible for these differences?

Possible Diagenesis

Grim (1953) has found that parent rocks containing considerable quantities of potassium, as well as magnesium, under weathering conditions permitting the potash and magnesia to remain in the environment after break-down of the parent materials, will yield illite and montmorillonite as the alteration products. Studies of clays in the Gulf of California show that the clay minerals in recent sediments are mostly mixed-layer materials and are poorly crystallized before entering a marine environment (Grim et. al. 1949). Other studies confirm this generality.

It is suggested, therefore, that the clays in this study were once generally mixed-layer materials. Much of the relatively pure illite and chlorite probably was formed after the clay entered the marine environment. According to Weaver (1956) and Grim (1958), montmorillonite is a common product of present-day weathering under certain conditions. It is also abundant in recent marine sediments and in many Cenozoic and Mesozoic sediments.

The quantity of montmorillonite decreases considerably in sediments older than Mesozoic. Dodd et al. (1955) found that only a weak concentration of expansible clay (montmorillonite) is found in rocks older than Permian. Other studies, especially by Grim and Weaver, confirm this result. The small quantity of expansible material found in this study has probably diminished since deposition, and it may have been present in considerable quantity at that time.

Grim believes that the clay mineral composition of sediments is largely a result of conditions in the environment of deposition, such as alkalinity of the water, character of the dissolved salts, temperature, rate of accumulation, and kind and amount of organic material. Further, he believes that most diagenetic changes take place rapidly after the sediment arrives in the environment of accumulation. Most authorities disagree with each other as to the emphasis placed on each of these factors and some disagree with Grim as to the rate of early diagenesis.

The marine environment is alkaline and contains Ca^{++}, K^{+}, and Mg^{++} ions. As the mixed-layer and poorly crystalline material enters this environment, many changes may take place. As a result of weathering processes, illite is degraded and has a low potassium content. Upon entering the marine water, K^{+} and Mg^{++} ions are adsorbed and the crystallinity improved. The Ca^{++} and Mg^{++} ions favor the stability of montmorillonite and chloritic mica.

The shales of this study are all associated with limestones and most of them are calcareous to some degree. Kaolinite is a rare component of calcareous marine sediments, perhaps because the Ca^{++} ions tend to inhibit its formation (Millot, 1942). Robbins and Keller (1952) also find that kaolinite is more common in ancient nonmarine sediments than in marine sediments. Most kaolinite entering the marine environment, containing Ca^{++} ions, is thought by Grim (1953) to be converted to chloritic mica.

It seems probable from this discussion that, fairly soon after entering the marine environment, the clay minerals in these shales probably consisted mostly of expansible (montmorillonite-rich or degraded illite-rich) mixed-layer material, some relatively well crystallized illite, and a small amount of chloritic material. Other clay minerals were probably present in lesser amounts and in poorly crystallized form.

Weaver (1959) and others have found that the number of clay mineral types decreases with increasing age. According to Grim (1958), the early diagenesis of clay minerals is rapid, but further diagenesis is a slow process. The main effect of this later, slow diagenesis seems to be the conversion of other clay minerals to illite and chlorite.

As stated before, montmorillonite is rare in ancient marine sediments. Illite is the dominant clay mineral in most ancient marine shales and its origin may be due largely to diagenetic processes (Grim, 1947).

The transition from montmorillonite to illite requires that interlayer water be lost and K^+ ions adsorbed. Many investigators have shown that a material substantially like illite is produced by synthesis from montmorillonite when all the exchange positions are occupied by potassium and the material is dried at 110 degrees C (Grim, 1953).

The following is quoted from Grim (1953):

> It seems likely that diagenetic reconstruction degraded micas would take place quickly. Some illite probably forms from montmorillonite. It seems that this change would take place relatively slowly.
>
> It seems likely that metamorphic processes would cause the alteration of montmorillonite to a mica type of mineral, and, therefore, the mineral would tend to disappear in more ancient sediments. When the structure of montmorillonite is completely collapsed so that all water is removed, rehydration of the mineral is difficult, and the mineral has many of the attributes of mica. Further in the course of geologic time, montmorillonite would probably slowly pick up K^+ and Mg^{++} ions from ground water, which might in turn obtain such constituents from the disintegration of ferromagnesian minerals and feldspars.

The montmorillonite probably present in the original clay could, in this manner, be converted to illite either of the relatively pure type, or to that present in the mixed-layer type. It should be pointed out that the diagenesis of montmorillonite to illite probably does not take place at a constant rate. Montmorillonite is abundant in many Mesozoic sediments, and is relatively rare in earlier rocks. There seemingly has been a relatively rapid diagenesis near the Mesozoic-Paleozoic boundary possibly due either to time or to overburden pressure.

If some of the chlorite present is of diagenetic origin, then its formation may be due to the development of brucite layers between mica or illite-type layers. This process involves a structural change in the clay mineral and would conceivably be even more difficult than the change from montmorillonite to illite. Weaver (1959), however, visualizes the building blocks of all clay minerals as being free to change places in certain environments. He also has found evidence of possible brucite layer formation under a great depth of overburden, which possibly could produce the chlorite structure from other clay minerals.

Possible Explanation of Results

From the above discussion of diagenesis, it should be emphasized that montmorillonite very probably was more abundant in the original sediment (at least in some places stratigraphically and geographically) than it is now. This is an important factor to be considered in the following discussion.

The original source beds of petroleum are generally believed to have been shales, and in a few instances, highly organic limestones. If this is true, then what is the difference between oil-producing shale and all other shales? Further, where are these source beds located with respect to zones of accumulation? According to Clark (1934) migration of oil and gas does not generally take place over long distances. The source beds are usually sought very near the petroleum accumulation. Further, the source beds are not necessarily highly bituminous or carbonaceous at present.

In studying the history of Gulf Coast crude oils in 1934, Barton found two significant facts: first, the oil from sources of a certain geologic age also accumulates in reservoirs of that age, unless the trap rocks are extensively fractured; second, oils become progressively lighter in gravity with increasing age and depth. The heavier hydrocarbons are constantly being transformed into lighter ones.

Taylor, in 1929, examined 19 core samples from various locations and all associated with oil-bearing strata. He found that all the shales were alkaline and contained sodium clay as the main constituent. On the basis of these results, he (Taylor, 1930), proposed the hypothesis that the shales overlying oil-bearing strata had undergone cation exchange with sodium chloride solutions, resulting in the formation of sodium clays. Other investigations have not found his results to be valid. Case (1933), working in Oklahoma, found most overlying shales to contain more calcium than sodium.

The catalytic effect of some surface-active clays had long been known in some industries, but this effect had not been extended to include petroleum formation.

In 1946, Frost, without considering differences in clay minerals, proposed a hypothesis of petroleum formation employing clays as catalysts. The following is quoted from his hypothesis:

> It is shown that clays in contact with various organic compounds are capable of catalyzing, at relatively low temperatures, the following reactions: chemical dehydration of alcohols and ketones, polymerization and disproportionation of hydrogen by hydrogenation of other olefins, with the hydrogen lost by other constituents of the material to form heavier compounds low in hydrogen, which are adsorbed by the clay.

Grim (1947) proposed that the clay mineral montmorillonite (or some varieties of it) may be responsible for the catalysis of organic matter into petroleum. He also suggested that organic matter present in the clay would retard the transition of montmorillonite to illite by reducing its cation exchange capacity.

Grim explains that organic material is present in argillaceous sediments in two ways: as discrete particles, and as molecules adsorbed on clay mineral surfaces. Adsorption of organic compounds is probably due to surface structure, cleanness of the surface, and replacements within the lattice. Montmorillonite is much superior to other clay minerals in cation exchange capacity and surface activity. Grim points out, however, that only some varieties of montmorillonite have this property to an important degree.

Weaver (1959) also utilizes the properties of montmorillonite in explaining petroleum accumulation, but in a different way. Water is presumably necessary to move hydrocarbons from shales to the reservoirs. Montmorillonite not only holds more pore water (a factor of 10) than the non-expansible clays, but also a greater pressure is required to squeeze this water out. Assuming that considerable depth of burial is necessary for hydrocarbons to form, the water held by montmorillonite might be the only water available to force hydrocarbons into the reservoir. Weaver thinks this may explain why formations containing little expansible clay are oil shales rather than oil source beds for reservoirs. Weaver bases his hypothesis on a study of 20,000 clay samples from oil producing basins. He found a reasonably good direct relationship between the amount of reservoir oil in each geologic system and the expansible clay mineral content.

Brooks (1948) gives an excellent discussion of the chemical aspects of active-surface catalysts in petroleum formation. Chemical data completely substantiate active-surface clay (montmorillonite) as being the most probable catalyst in the formation of oil.

From this previous work, it can be summarized that the presence of certain varieties of montmorillonite in shales is probably an important factor in converting organic matter into petroleum, or in forcing petroleum into a reservoir, or both.

Narain (1959) studied clay minerals of certain producing and nonproducing Mississippian oil sands in Hamilton County, Illinois. The clay minerals in oil producing sands were comparatively less crystalline. It was discovered, however, that clay mineral crystallinity also depended on the type of rock. Crystallinity was higher in coarse grained sandstones and in argillaceous rocks. Lower crystallinity was found in fine grained sandstones. Narain did not define his usage of crystallinity, however it is presumed to have approximately the same meaning as in this paper.

In 1959, Procter made a study of clay minerals from the Mesozoic Vanguard and Blairmore formations in Southwestern Saskatchewan. This study indicated a relationship between the present structure and the distribution of clay minerals. Kaolinite was concentrated in structural "highs". Procter concluded that the processes involved are apparently post-diagenetic and may include circulation of formation fluids.

The sampling in this study should mostly eliminate the factors of structure and grain-size, as described by Procter and Narain. All samples are from shales; however the amount of sand and calcite in the shales does vary. In most cases, two or more shales from the same core were sampled, thus eliminating the structural factor. Two shales from the same Lansing and Kansas City Group core, one from below an oil zone and the other from below a "dry" zone, should have approximately the same structural affiliations.

In the original sediment, montmorillonite concentration probably varied from place to place in the same stratigraphic horizon, and the variety of montmorillonite possibly varied also. Organic material was deposited contemporaneously with the clay minerals, with more in some areas than in others. As bacterial action and ionic diffusion proceeded, some of the organic matter probably was being adsorbed by surface-active clay (montmorillonite), where present.

Upon deeper burial, illite and chlorite probably gained in crystallinity at the expense of montmorillonite and other clay minerals. The montmorillonite which had its cation exchange capacity decreased by adsorption of organic complexes was retarded in its transition to illite.

As overburden pressure over expansible shales became great enough, the water may have been squeezed from the montmorillonite structures and may have carried the catalyzed petroleum with it to the reservoir.

The illite peaks in samples from below petroleum accumulation are relatively broader and less intense, and the apex of the peak is less sharp. According to Brindley (1961), poor crystallinity and lattice distortion both broaden and diminish the reflected x-ray intensity. It is conceivable that illite that formed by the diagenesis of montmorillonite would not be as well crystallized as primary illite. The degree of diagenesis probably would depend on the availability of K^+ ions and the ability of ionic diffusion to make the necessary replacements.

It is possible, also, that the differences are in the variety of montmorillonite. Some varieties are much less active and adsorb very little organic material. The cation exchange capacity thus is not seriously reduced, and the transition to illite may be nearly complete.

It was also found that shales below petroleum accumulations had a lower ratio of illite : mixed-layer material. The relatively smaller amount of illite also can be explained by a higher concentration, or the presence of a certain variety, of montmorillonite. First, it must be assumed that any montmorillonite in these shales had adsorbed considerable organic complexes. Certain varieties, if variations did exist, had adsorbed much more than others. When organic adsorption took place, most deficiencies in the lattice surfaces were either filled or covered and the activity of the mineral was greatly reduced. Very little relatively pure illite could result diagenetically from such a mineral.

When overburden pressure became great enough almost to collapse the montmorillonite structure and presumably force the oil and water out, the resulting mineral possibly was only slightly more crystalline than it was when deposited. With the hydrocarbons flushed out, the mineral may be able to adsorb K^+ or Mg^{++} ions to some extent and some poorly crystalline illite might result.

On the other hand, clay minerals containing little montmorillonite, or other varieties of it, would adsorb only a small amount of organic material and would retain most of their ion exchange activity. It should be remembered, however, that these minerals would not be of the high activity type and the diagenesis to illite may be rather slow.

It does not seem probable that areas devoid of petroleum accumulation had a lesser concentration of organic matter. The black, so called carbonaceous, shales are as prevalent in dry holes as in oil wells.

It does seem likely that there would be varying degrees of illite concentration and crystallinity depending on the amount of original montmorillonite, its variety, and therefore, the amount of organic complexes adsorbed into the clay. No such correlation could be made, however, with the nature of the clay minerals in these shales and the varying amounts of petroleum accumulation above the shales.

Two major assumptions were made concerning the original sediment: (1) montmorillonite was more abundant in the original sediment than it is now, and (2) either the amount or the variety of montmorillonite varied considerably within the sediment geographically. Both of these assumptions have support in studies of recent sediments.

The differences in the nature of the clay minerals, these assumptions made, can be explained reasonably by employing three generalities, as stated by Grim: (1) montmorillonite changes to illite in ancient marine sediments, (2) some varieties of montmorillonite adsorb organic material and are thought to act as a catalyst in petroleum formation, and (3) the adsorbed organic material retards the diagenesis of montmorillonite.

Significance of This Study

The study of these 54 shale samples indicates that correlation by clay mineral differences within the Lansing and Kansas City Groups of western Kansas is impossible. It is further indicated that the identification of specific shales stratigraphically within these two groups is not possible by clay mineral analysis.

The clay mineral differences between shales associated with petroleum and those not associated with petroleum seemingly can be explained by differences in the amount or type of original montmorillonite present. The assumptions required for this explanation seem to be well founded.

The similarity of clay minerals in shales below zones of petroleum accumulation in this study perhaps suggests that the source beds of petroleum are directly below the reservoir zones.

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APPENDIX

Tables of abbreviated logs of cores A through K showing where samples were taken.

Abbreviations used in these tables:

Ls.	-Limestone	crm.	-cream
Sh.	-Shale	gy.	-gray
Ss.	-Sandstone	gn.	-green
dns.	-dense	bn.	-brown
f.	-fine	wh.	-white
xlln.	-crystalline	blk.	-black
chty.	-cherty	dk.	-dark
ool.	-oolitic	scat.	-scattered
ooc.	-ooliclastic	por.	-porosity
calc.	-calcareous	stn.	-stain
fos.	-fossiliferous	sat.	-saturated
vug.	-vuggy	gd.	-good
mica.	-micaceous	strks.	-streaks
sdy.	-sandy	vsso	-very slight show oil
gran.	-granular	sw.	-salt water
concret.	-concretions	bopd	-barrels oil per day
sl.	-slightly	M.	-thousand cubic feet

Table 2. Abbreviated log of core A showing where samples were taken.

Stanolind, #1 C. M. Wann, NW SW SE, Sec. 12-15S-20W, Ellis County, Kansas; Pool Wildcat, Completed 8-1-35, Elev. 1990', Potential D&A; Lans. 3298, B/Kc. 3538, T.D. 3716.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
3300	Top core Ls., crm.-gy., dns.-f. xlln., chty.	Stoner Ls.	
3312	Sh., gy.	Eudora Sh.	1
3319	No core		
3350	Ls., crm., f. xlln.	Plattsburg Ls.	
3356	No core		
3364	Sh., gy.	Lane-Bonner Sp. Sh.	2
3372½	Ls., crm., f. xlln.	Iola Ls.	
3377	No core		
3407	Ls., crm.-gy., dns., sl. chty., scat. ool. por. at top.	Iola Ls.	
3424	Sh., gy.	Chanute Sh.	3
3431	Ls., crm., f. xlln.	Drum Ls.	
3437	Sh., gy., calc., w/ chty. ls. seams.	Quivira Sh.	4
3457	Ls., gy.-buff, f. xlln., fos.	Westerville Ls.	
3471	Ls., crm.-gy., f. xlln., chty.	Winterset Ls.	
3480	Sh., gy.	Galesb.-Stark Sh.	5
3486	Ls., crm.-gy., dns.	Bethany Ls.	
3501	Sh., gy.	Ladore-Hushpuckney Sh.	6
3509	Ls., crm., f. xlln., fos., sl. shty., scat. ool. por.	Sniabar Ls.	
3531	Base core		

Table 3. Abbreviated log of core B showing where samples were taken.

Magnolia, #4 Steve Nemechek, SE NW SW, Sec. 28-10S-23W, Graham County, Kansas; Pool Happy, Completed 7-8-55, Elev. 2363 rb, Potential 319 bopd; Lans. 3605, T.D. 3868.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
3758	Top core		
3761	Ls., crm., oil stn.	Drum Ls.	
	Sh., gy.	Quivira Sh.	7
3769			
	Ls., crm.-gy., ool. por., oil sat.	Westerville Ls.	
3778			
	Sh., gy.	Fontana-Wea Sh.	8
3786			
	Ls., crm., ool. por., gd. oil sat.	Winterset Ls.	
3795			
	Sh., gy.	Galesburg-Stark Sh.	9
3804			
	Ls., gy.-buff, f. xlln., ool. por., gd. oil sat.	Swope Ls.	
3821	Base core		

Table 4. Abbreviated log of core C showing where samples were taken.

Skelly, #1 H. C. Kipp "A", SE SE NE, Sec. 27-25S-14W, Stafford County, Kansas; Pool Kipp, Completed 1-22-37, Elev. 1981', Potential 1265 bopd + 961 M gas; Lans. 3681, B/Kc. 3906, T.D. 4250.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
3680	Top core		
3681½	Sh., dk. gy.		
	Ls., gy., fos., strks. calc. sh.	Stoner Ls.	10
3687	Ls., gy., dns., sl. por., no oil stn.		
3694	Sh., gy.-gn., sdy.	Eudora Sh.	11
3698	Ls., gy.-bn., f. xlln., 3' gy. sh. at mid.	Captain Creek Ls.	12
3707	No core		
3900	Ls., gy.-bn., por. & oil sat., flow 5 boph & 200 M gas.	Sniabar Ls.	
3914	Sh., gy.-gn.		13
3918	Base core		

Table 5. Abbreviated log of core D showing where sample was taken.

Sinclair-Prarie, #1 Wilhelm, C SW SW, Sec. 16-19S-21W, Ness County, Kansas; Pool Wildcat, Completed 1-25-33, Elev. 2215', Potential D&A; Lans. 3737, B/Kc 3982. T.D. 4777.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
3735	Top core Sh., dk. gy. & red.		
3737			
	Ls., gy. buff, dns.-f. gran., chty., dolo.	Stoner Ls.	
3752			
	Sh., red & gy.	Eudora Sh.	15
3755	Base core		

Table 6. Abbreviated log of core E showing where samples were taken.

Cities Service, #1 Shilling, C NW SW, Sec. 26-21S-13W, Stafford County, Kansas; Pool Gates, Completed 9-22-34, Elev. 1876, Potential D&A; Lans. 3330, T.D. 3755.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
3400	Top core		
	Ls., gy., f. xlln. w/ thin gy. sh. strks.	Plattsburg Ls.	
3418 3419	Sh., dk. gy.	Lane-Bonner Sp. Sh	16
	No core		
3549 3555	Sh., varicolor. w/ ls. concret.	Ladore-Hushpuckney Sh.	17
	Ls., gy., f. xlln. w/ gy. sh. strks.	Sniabar Ls.	
3563 3564	Sh., varicolor. Base core	Mound City Sh.	18

Table 7. Abbreviated log of core F showing where samples were taken.

Cities Service, #1 Sellens, NE SW SW, Sec. 30-15S-13W, Russell County, Kansas; Pool Trapp, Completed 1-16-37, Elev. 1839, Potential 1823 bopd (from Arbuckle only); Lans. 3027, B/Kc. 3265, Arb. 32[illegible], T.D. 3276.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
3027	Top core		
	Ls., wh.- crm., chty., ool, & ooc. por.	Stoner Ls.	
3044	No core		
3046	Ls., buff, sl. show oil in fos. por.	Captain Creek Ls.	
3058	Sh., gy.	Vilas Sh.	23
3062	Ls., gy., por., ooc., chty., no stn.	Plattsburg Ls.	
3077	No core		
3091	Ls., crm., dns.	as above	
3098	Sh., gy.	Bonner Springs Sh.	24
3107	Ls., gy., por.-no stn.		
3110	No core		
3115	Ls., w/dk. sh. strks.	Iola Ls.	25
3122	No core		
3129	Ls., w/dk. sh. strks.		26
3133	No core		
3190	Ls., crm., ooc. & por. on top to dns. at base, no stn.	Westerville Ls.	
3214	Sh., gy.	Fontana-Wea Sh.	27
3217	Ls., crm., dns., chty.	Winterset Ls.	
3220	Base core		

Table 8. Abbreviated log of core G showing where samples were taken.

Cities Service, #1 O'Connor, NE NE NE, Sec. 17-24S-15W, Stafford County, Kansas; Pool Macksville, Completed 3-29-37, Elev. 2033, Potential D&A; Lans. 3653, T.D. 4130.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
3645	Top core Ls., crm., sl. chty., ooc. por., no stn.	South Bend Ls.	
3657			
3662	Sh., gy.-gn. Base core	Rock Lake Sh.	28

Table 9. Abbreviated log of core H showing where samples were taken.

Hollow Drilling, #3 Stout "A", CN/2 SW NE, Sec. 6-18S-10W, Rice County, Kansas; Pool Bloomer, Completed 1-20-40, Elev. 1788, Potential 4400 bopd (from Arbuckle only); Lans. 2939, Arb. 3218, T.D. 3224.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
2955	Top core Ls., gy., top ooc. por. w/sl, oil stn.	Stoner Ls. 3 ft.	30
2962	Sh., gy.-gn.	Eudora Sh.	
2966	Ls., crm., chty.	1 ft. Captain Creek Ls.	31
2970	No core		
3000	Ls., gy.-buff, dns., fos. in part.	Iola Ls.	
3013	Sh., gy.-buff, calc.	calc. sh. in Iola Ls.	32
3020	Base core		

Table 10. Abbreviated log of core I showing shere samples were taken.

Bridgeport, #1 Drews "A", SW NE NE, Sec. 16-18S-11W, Barton County, Kansas; Pool Ames, Completed 8-8-47, Elev. 1786 df, Potential D&A; Lans. 3058, T.D. 3360.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
3121	Top core		
	Sh., gy.-gn.	Lane-Bonner Sp. Sh.	33
3122	Ls., gy.-buff, dns.-f. xlln. w/5 ft. lt. gy.-gn. sh.	Iola Ls.	34
3140	Base core		

Table 11. Abbreviated log of core J showing where samples were taken.

Stanolind, #3 J. Denker, NE NW SW, Sec. 10-22S-12W, Stafford County, Kansas; Pool Max, Completed 10-26-49, Elev. 1864 kb, Potential 3000 bopd; Lans. 3297, B/Kc. 3519.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
3301	Top core Ls., brn., dns., vsso.	Stoner Ls.	
3314	Sh. dk. gy., mica.	Eudora Sh.	35
3318	Ls., gy.-brn., dns., vsso.	Captain Creek Ls.	
3330	Sh., blk. 6" beds w/ brn. dns. ls.	Vilas Sh.	36 37
3338	Ls., gy., dns., vug. w/sl. oil show.	Plattsburg Ls.	
3347½	Sh., blk., fos., ls. nodules	Lane-Bonner Springs Sh.	38
3357½	Ls., gy., vsso.	Iola Ls.	
3365-7	Sh., gy.		39
	Ls., buff, vsso.		
3370-2	Sh., gy.		40
	Ls., brn., vsso.		
3376-7	Sh., brn., silty.		41
	Ls., buff, fos., por. at top w/show oil.		
3424	Sh., dk. gy., fos.	Chanute Sh.	42
3430	Ls., buff, ool. por. w/g. show oil.	Drum Ls.	
3442	Sh. gy.	Quivira Sh.	43
3444½	Ls., pink-buff, most f. xlln., few thin gy. sh. seams, scat. ool. por. & g. shows oil.	Westerville, Winterset, Bethany, and Sniabar Ls.	
3519	Sh., blk.-dk.gy.		44
3522	Base core		

Table 12. Abbreviated log of core K showing where samples were taken.

Skelly, #1 Bartosovsky, SE SW SW, Sec. 9-1S-34W, Rawlins County, Kansas; Pool Cahoj, Completed 8-22-59, Elev. 3104 df, Potential 3000 bopd; Lans. 3976, B/Kc. 4243.

Depth	Core Description	Name (Parkhurst, 1959)	Sample No.
3976	Top core		
	Ls., buff, vug., oil	Stoner Ls.	
3991	Sh., gn., sdy., calc.	Eudora Sh.	46
3993	Ss., calc., bleed. oil	Captain Creek Ls.	
4000	Sh., red-gy., sdy-calc	Vilas Sh.	47
4015	Ls., buff, f. xlln.	Plattsburg Ls.	
4020	Sh., red-gy., calc-fos.	Lane-Bonner Sh.	48
4028	Ls., buff, vug., oil		
4038	Sh., gn.-gy.-red, calc.		49
4050-1	Ls., crinoid, fair stn.	Iola Ls.	
.	Sh., red-gy., calc.		50
4078	Ls., vug., bleed oil.		
4088	Sh., dk. gy.	Muncie Creek Sh.	51
4095	Sh., calc., gy., fos.	Paola Ls.	52
4109	Sh., dk. gy.-gn.		53
4114	Sh., red-gy., calc.	Chanute Sh.	54
4127	Ls., vug., bleed oil.	Drum Ls.	
4139	Sh., dk. gy., fos.		55
4144	Sh., red & gy.	Quivira Sh.	56
4168	Ls., buff, vug. por., bleed oil	Westerville Ls.	
4184	Sh. gy.	Fontana-Wea Sh.	57
4194-5	Ls., gy., no oil		
	Sh., gy.-red.		58
4211	Ls., buff, g. show oil	Winterset Ls.	
4223	Sh., red, hard	Galesb.-Stark Sh.	59
4232	Ls., buff, dns., sw.	Bethany Ls.	
4236	Sh., red-gy., soft.	Ladore-Hush. Sh.	60
4239	Ls., buff, dns., sw.	Sniabar Ls.	
4243	Sh., red-gy. banded		61
4247			