

Geology 570

ORIGIN AND DEPOSITIONAL ENVIRONMENT
OF SOME
CENTRAL OHIO DEVONIAN BLACK SHALES

Based on Clay Mineralogy

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Abstract

The clay mineralogy of an outcrop of the lower Ohio Shale sequence near Worthington, Ohio has been studied by x-ray diffraction. Illite was found to be the dominant clay mineral. Both illite and kaolinite vary in abundance as a function of stratigraphic position and clay particle size. Theories of the origin and depositional environment of this shale are reviewed. It is suggested in this paper, according to the results of this study, that the Ohio Shale originated from parent soils displaying similar clay mineralogy characteristics. This type of soil would have developed best on a topography of low relief. The shale was deposited by the reworking of these soils by the transgressing Devonian sea west and northwest of the Appalachian geosyncline. Deposition occurred in the deepening water to the east of the western edge of this sea.

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INTRODUCTION

Shales of Devonian and Mississippian age are among the most geologically and economically important strata in Ohio, occurring in over half of the counties and outcropping or lying directly beneath surficial deposits in about one-fourth of the counties. This Devonian-Mississippian shale sequence thickens and dips to the east in Ohio at a slow rate. The sequence is underlain by limestone in all outcrops of the contact, and is overlain by sandstone where sufficient depth allows a complete section. Subdivision of the Devonian-Mississippian shales is based on lithologic characteristics. Of major importance in the sequence is the black carboniferous shale which is locally termed "Ohio" shale. The Ohio shale, which is Upper Devonian in age, is believed to be of the same origin as and stratigraphically equivalent with the New Albany, Chattanooga, Marcellus, Exshaw, Mountain Glen, Grassy Creek, Antrim, Woodford, Portage, and other locally named black shales extending along a belt roughly 300 miles wide from southern New York to Oklahoma and northern-most Texas.

The origin of depositional environment of the Devonian black shales has been a source of considerable controversy ever since the strata were studied and recognized. There have been many and varied ideas postulated about the paleoenvironment of this highly carbonaceous shale.

OPPOSING VIEWS OF ORIGIN

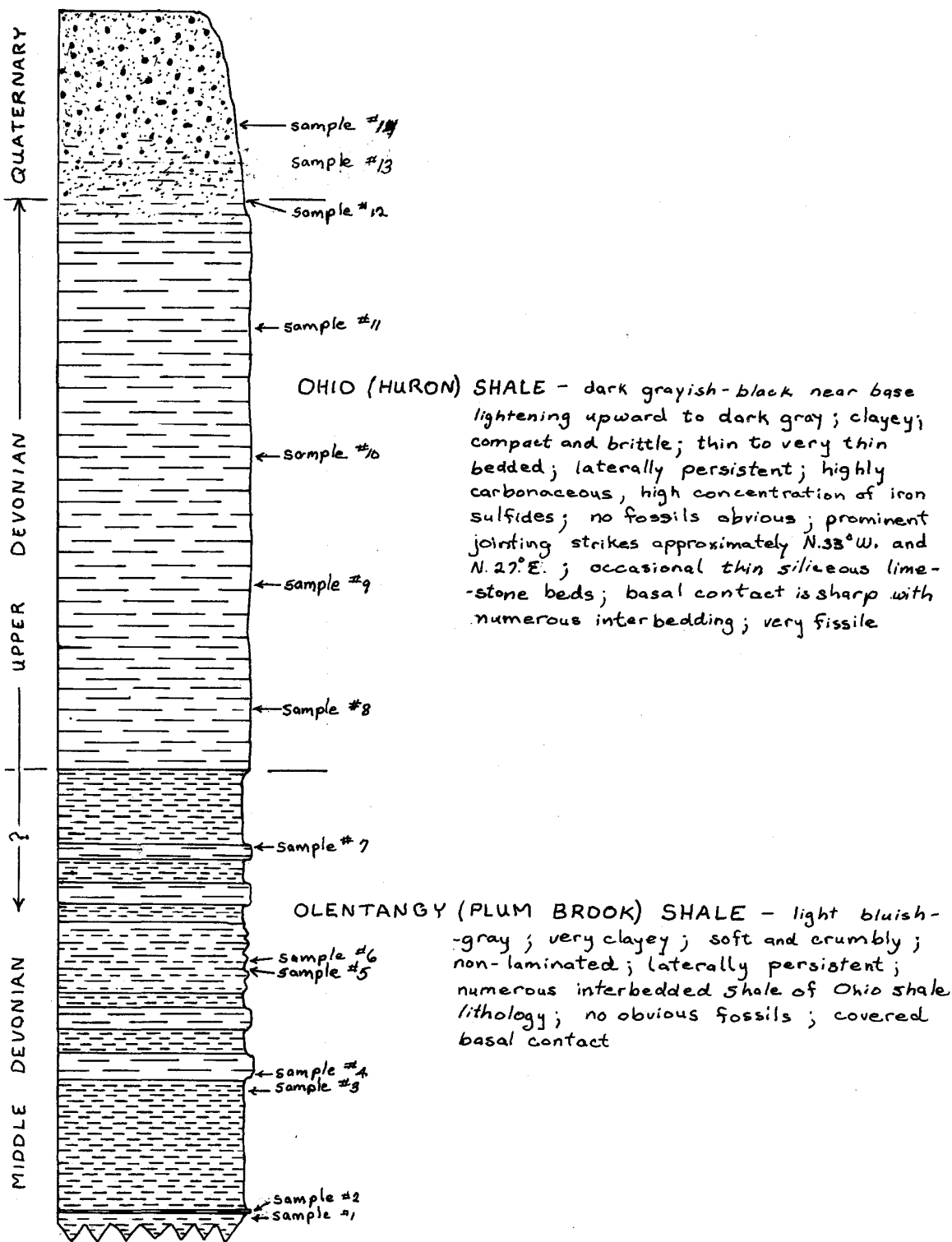
The prevailing interpretations of depositional environment, by those who have studied the black shale problem, can be divided into those that advocate a "deep-water" origin or transported shale, and those that advocate a "shallow-water" origin or residual shale. Clark (1903), Schuchert (1910), and Rich (1951) believe that the shales were transported from mountains to the east during the Acadian orogeny and then deposited as the western-most reaching material in a deep-water environment in the western part of the Appalachian geosyncline, where the lower water was quiet, stagnant, and toxic. Rich (1951) gives reasons for this interpretation. Thin, remarkably evenly-bedded, fine clays and carbonaceous material of low specific gravity indicate quiet water. Phosphatic nodules, some lag deposits and fifteen to one hundred feet of total Upper Devonian sediment in many places indicate slow sedimentation at a considerable distance from shore. The black, highly carbonaceous nature of the shale along with the pyrite content indicate a highly reducing ferrous sulfide bottom water caused by decaying organic material along with a lack of circulation and oxygen at depth. Only conodonts, various fish remains, pteropods, and orbiculoids, which were all free-swimming and could have existed above the toxic waters, have been found.

Occasional linguloid brachiopods and crinoids have been found but probably were rafted by floating logs.

Ulrich (1911), Graham (1917), Klepser (1937), and others, on the other hand, have advocated that the black shales are residual and essentially a "shallow-water" deposit of a transgressive sea, formed by the reworking of soil material by near shore conditions. According to Grabau (1917), under a so-called late stage of peneplanation, the relief of the land becomes quite low and the rock surface becomes mantled with products of subaerial weathering and decay. Prolonged exposure to this process results in the complete disintegration of the mineral constituents of the rocks. When the rock of the old land surface is a limestone, only the finest residual clay-soil will remain behind. The surface of the peneplain is characterized by obstructed drainage conditions, ultimately resulting in a paludal environment of decaying organic material, and the clay-soil becomes highly concentrated in carbonaceous material. When the sea enroaches upon such an area of residual soil, the basal formation of the resulting series of deposits will be black shale underlain with limestone. Grabau suggests that the Ohio and associated black shales are a result of this condition, but he points out that not all black shales should necessarily be attributed to this origin, such as lagoonal deposits.

The purpose of this report is to summarize a study of

GENERALIZED COLUMNAR SECTION OF OUTCROP



the presence, abundance, and distribution of clay minerals of a section of lower Ohio shale and upper Olentangy shale in central Ohio, and to suggest a probable origin and paleoenvironment of deposition based on interpretations of the results of this study.

LITHOLOGIC SECTION, PROCEEDURE, AND RESULTS

The shale section studied is located in northern Franklin County, Ohio, approximately one-fourth mile west of the Interstate 270-High Street of Columbus interchange on the north side of the I-270 highway cut. The lower portion of the section (see figure) is considered to be a transitional zone between the Olentangy and Ohio shales. It consists of the soft, bluish-gray, clayey, Olentangy shale interbedded with the compact, black, and fissile Ohio shale. The upper portion is Ohio shale, which grades into surficial material near the top of the section. In central Ohio, the Olentangy shale is thought to be a gradational, basal phase of the Ohio shale by some. Samples were collected at approximately five foot intervals starting at the base of the outcrop. Two samples of the two shales for each interval in the lower portion where interbedding is present were taken at the nearest contact of the two dissimilar lithotypes. At the surficial transitional zone, samples were taken at smaller

TABLE 1

RELATIVE ABUNDANCES
2 Micon Size Fraction

Sample*	Illite	Kaolinite	Montmorillonite	Chlorite	Quartz
1-A**	3.3***	1.1	0.5	0.3	1.8
2-B	3.5	1.1	0.6	0.4	2.6
3-A	4.1	0.9	0.5	0.4	2.7
4-B	2.3	0.5	0.4	0.2	1.5
5-A	3.0	0.7	0.6	0.8	2.1
6-B	1.6	0.3	0.4	0.2	1.1
7-B	2.4	0.5	0.5	0.3	2.6
8-B	2.7	0.5	0.6	0.3	2.8
9-B	2.4	0.5	0.5	0.3	2.6
10-B	2.7	0.4	0.5	0.3	2.4
11-B	3.4	0.3	0.7	0.3	2.7
12-B	4.9	0.2	1.1	0.2	3.6
13-B	2.8	0.3	0.8	0.5	2.2
14-B	3.2	0.1	0.7	0.3	3.0

* see figure

** A= light lithotope

B= dark lithotope

*** values in arbitrary units (inches)

intervals to help establish the source material of this glacial till. The samples were disaggregated and deflocculated by preliminary crushing with a mortar and pestle, and then in a high speed blender with distilled water and hexametaphosphate as a dispersant. A fine, silt-sized fraction (approximately eight microns) and a clay-sized fraction (approximately two microns) were obtained from each shale sample by the pipette method.

These size fraction samples were then applied to glass slides and allowed to oven dry at 35-40 degrees centigrade. Mineral analysis was accomplished by x-ray diffraction analysis using General Electric equipment operating at 45 kvp and a current of 15 ma with a copper target, 1° and 0.1° collimators on the emission and detector tubes, respectively. The goniometer and chart scanning rate was $1^{\circ} 2\theta$ per inch.

Illite, kaolinite, montmorillonite, chlorite, and quartz were recognized as the major constituents of the samples. The strongest single peak of each particular mineral (at the same d-spacing and 2θ values) was measured in the arbitrary units of inches for comparison of the relative abundances of these minerals (see tables). The two different size fractions analyzed are represented in separate tables. A quick overall glance shows that illite and quartz are dominant for all samples represented. There tends to be a greater relative abundance of illite in

TABLE 2

RELATIVE ABUNDANCES
8 Micron Size Fraction

Sample*	Illite	Kaolinite	Montmorillonite	Chlorite	Quartz
1-A**	6.9***	2.2	0.8	1.0	8.9
2-B	3.6	0.8	0.6	0.4	4.4
3-A	5.4	1.4	0.4	0.6	6.8
4-B	1.3	0.5	0.4	0.3	4.9
5-A	5.4	1.7	0.7	0.6	7.0
6-B	1.5	0.6	0.4	0.2	4.9
7-B	3.7	0.9	0.6	0.3	4.3
8-B	1.4	0.4	0.4	0.3	1.6
9-B	1.8	0.4	0.6	0.3	1.7
10-B	4.0	0.4	0.6	0.4	4.1
11-B	4.1	0.2	1.0	0.5	4.3
12-B	2.6	0.3	0.5	0.5	3.4
13-B	3.3	0.2	1.0	0.5	3.6
14-B	3.7	0.2	0.8	0.5	3.6

* see figure

** A= light lithotope
B= dark lithotope

*** values in arbitrary units (inches)

the light (Olentangy lithology) shale than in the dark (Ohio lithology) shale in the 2 micron fraction and even more so in the 8 micron fraction. This generalization also holds true for kaolinite in both size fractions, and for quartz in the 8 micron fraction. There is a definite overall decline in the relative abundances of kaolinite in both size fractions of both light and dark shales taken individually, in an upward direction. The data for montmorillonite, chlorite, and quartz, do not seem to reveal any major overall increase or decrease in relative abundances through the section, but only minor fluctuations. The broadness of the peaks relative to their heights gives an approximate indication of the degree of crystallinity of the minerals. A sharper peak indicates better crystallinity.

DISCUSSION OF RESULTS

The depositional environment of a particular sedimentary rock cannot be readily determined solely from the presence of a particular clay mineral or clay mineral suite. Kaolinite, montmorillonite, and illite, the three most common clay minerals, have been found in marine and fresh water sediments of both shallow and deep water origins. Knowledge of the clay mineralogy, however, along with other information can be helpful in determining the

depositional environment of the deposits. It must be remembered first that detrital clays strongly reflect their composition of their source soils which, in turn, is determined by the parent rock and the environmental conditions; and second that they are only slightly modified in the depositional environment (Weaver 1958). The most advantageous approach, then, for determining the depositional environment by clay mineralogy, lies in first establishing the nature of the soil from which the detrital clay came; second, inferring a set of morphologic conditions necessary in the development of this soil; and finally, postulating an erosional and depositional environment compatible with these conditions.

If the shales had been deposited in the Appalachian geosyncline, the major contributing source area for these deeper deposits would have been the higher relief area to the east where uplifting by the Acadian Orogeny had been occurring. The soils of this source area would have been well leached because of the orographic rainfall and efficient drainage resulting from the topography. This would mean an absence of metal ions (Ca, Mg, Na, Fe, and K) because of solution and oxidation, occurring within the soil. Also, the pH of this soil would tend to be acidic. These conditions are exceedingly favorable for the formation of kaolinite relative to montmorillonite and illite. Although it is true that some kaolinite may be lost after

deposition in a marine environment, any substantial change in a clay mineral composition would likely be slow, and loss, therefore, would be slight and the change in abundance of this dominant mineral would not be very significant. (Grim, 1958).

The results, however, show a distinct dominance of illite over kaolinite and montmorillonite. The abundance of illite relative to kaolinite and montmorillonite indicate that the soil from which this shale was derived, was most probably abundant in illite and deficient in kaolinite and montmorillonite. The chemical factors necessary for the formation of illite and montmorillonite and not kaolinite are the retention and concentration of the metal ions (Ca, Mg, Na, Fe, and K) in the soil, and a neutral or basic soil pH. A considerable concentration of K ions, as well as a high Al to Si ratio in the soil provide the condition for the formation of illite in lieu of montmorillonite. The most likely physiographic conditions which will provide these factors are low topographic relief which will result in poor drainage, and moderate rainfall. The lack of efficient drainage will prevent for the most part, the leaching away of the metal ions by water solution, and it will set up a condition whereby the evaporation of water solutions can occur, concentrating the metal ions. Also, the soil pH will tend to remain neutral or basic.

As a result of the low relief, the source area under subaerial erosion would only provide a negligible amount of material to the sea. By erosion by a transgressing sea, however, the soil could be eroded in sufficient quantity to produce a large deposit. This low relief source area was most likely present west of the Appalachian geosyncline where uplift was not occurring. As the Devonian sea in this area expanded, it transgressed over the source area to the west, eroding the soils by wave action and scattering this material gradually into deeper water below wave base where deposition could take place. The differences in abundances of the clay minerals between the carbonaceous shale and the non-carbonaceous shale suggest that the carbonaceous material was a constituent of the parent soil rather than originating from some other independent source. These factors also imply that there were two parent soils which were selectively eroded possibly by fluctuations in the sea level forming the interbedding present in the section. The overall decrease in some of the clay minerals in an up-section direction may mean that there is a gradual decrease in the degree of development of the soil away from the sea.

CONCLUSION

The clay mineralogy of the Olentangy and Ohio shales are distinctly abundant in illite relative to kaolinite and montmorillonite. Based on this fact, the parent soils from which the shales were derived probably displayed nearly similar relative concentrations of clay minerals. The soils then, probably had developed ultimately on a plain of low relief. The most likely area with conditions suitable for the formation of this type of clay mineralogy would have been the flatter topography in the area west of the Appalachian geosyncline. The transgressing Devonian sea slowly covered this area as it expanded westward. The soils of this area would then have been eroded by wave action and gradually dispersed into deeper water below wave base where the material accumulated. Variations in the clay mineralogy reflect the changes of eroded soil material due to variations in the clay mineralogy over the source area resulting from particular weathering conditions, and the selective effect of the higher energy area of the transgressing sea moving over these areas one at a time. Fluctuations in sea level and onlap would account for the numerous interbedding present in the sequence of shales, as well as the possibility that there were two distinct sources.

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