

LATERAL CLAY MINERAL VARIATIONS IN CERTAIN PENNSYLVANIAN UNDERCLAYS

by

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ABSTRACT

X-ray diffraction techniques were used to identify the clay mineral assemblages of Pennsylvanian underclay samples taken mainly from beneath the Colchester (No. 2) and Herrin (No. 6) Coals of Illinois and the Middle Kittanning Coal of Ohio. The clay minerals present are kaolinite, illite, chlorite, vermiculite, montmorillonite, and mixed-layer clay minerals. The minerals are not restricted to any particular stratigraphic unit, and their areal distribution is related to paleogeographic position in the original basin of deposition. Kaolinite shows a decrease in abundance from near shore to more basinward areas; illite is not present in near shore regions, becomes common basinward, and then shows a decrease with increasing distance from shore; chlorite is not found in near shore or in extreme basinward areas but is most common slightly basinward of the illite maximum; montmorillonite is fairly rare but is prominent in the most basinward positions; vermiculite is uncommon but usually occurs where kaolinite is the dominant mineral; mixed-layer clay minerals are present in all samples, constituting a small fraction of the clay minerals in the near shore regions but increases to the major constituent in the most basinward areas.

Clay minerals entering the basin of deposition during underclay formation were mainly kaolinite and mixed-layer clay minerals. As the mixed-layer clays were carried basinward into waters of increasing salinity, some of the mixed-layer clays, formed from weathered illite and chlorite, preferentially adsorbed potassium and magnesium and were regraded. Mixed-layer clay minerals that had undergone severe structural damage during weathering were not regraded and were deposited further basinward.

Maps showing lateral variation of clay minerals in an underclay also show the paleogeography. These maps may be used in outlining positive areas and deltas, or specific types of clay deposits.

INTRODUCTION

UNDERCLAYS associated with coals of Pennsylvanian age may or may not contain kaolinite. It has been generally accepted that underclays occurring below the Colchester (No. 2) Coal in Illinois frequently contain appreciable amounts of kaolinite, whereas those clays in younger Pennsylvanian formations usually do not. This generalization is not always true for the kaolinite content may vary locally even in the same underclay unit.

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The clay mineral content of several underclay units was studied to determine whether a regional distributional pattern of the clay minerals existed. The underclay of the (No. 2) Coal was sampled throughout the Eastern Interior Basin because in Illinois this underclay indicated the boundary between the highly kaolinitic underclays and the low kaolinitic underclays (Grim and Allen, 1938).

Two other underclays, those of the Herrin (No. 6) Coal of Illinois and the Middle Kittanning (No. 6) Coal of the Ohio and Pennsylvania region from younger Pennsylvanian units, were also studied after an orderly lateral variation in the clay mineral content was noted in the underclay of the No. 2 Coal.

The Colchester (No. 2) Coal of Illinois correlates with Coal IIIa of Indiana, the Schultztown Coal of western Kentucky, and the Croweburg Coal of Missouri, Iowa, Kansas, and Oklahoma (Kosanke *et al.*, 1960). The No. 6 Coal of Ohio is believed to be equivalent to the Middle Kittanning Coal of Pennsylvania (Sturgeon, 1958, p.48; G.S.A. Guidebook, 1959).

REVIEW OF LITERATURE

A variety of opinion on the origin of underclays exists and there is little agreement concerning the processes producing this type of sediment. Logan (1842), Worthen (1866, p.59), Potonie (1910), Baker (1962), and Duff and Walton (1962) considered underclays to be fossil soils. Stout (1923), McMillan (1956), and Sensius (1958) felt that underclays formed in a manner similar to gleys. Weller (1930) and Huddle and Patterson (1961) believed that underclays were formed in place and represent evidence of a poorly drained weathering profile. Stevenson (1911-1913), Grim and Allen (1938), Spencer (1955), Weller (1956), and Parham (1958) considered this type of sediment to be transported with no alteration after deposition. Stout (1931), Schultz (1954), Wahl (1957) and Wanless *et al.* (1923) also believe that underclays were transported but that there had been some alteration after deposition. Karstrom (1951) and Webb (1961) felt that underclays were transported sediment deposited in both marine and non-marine waters.

DESCRIPTION OF UNDERCLAY

Pennsylvanian underclays are fine grained, argillaceous, non-bedded, sedimentary rocks, generally gray and normally found directly below coal beds. Organic material is usually more abundant in the upper few inches, giving this zone a darker color. Underclays commonly contain well-developed slickenside surfaces with random orientation. Weathering destroys the slickensides but in mines and active stripping operations,

some extend through the underclay. Root traces of plants, when preserved, are generally more abundant in the upper portion. Some underclays are noncalcareous; others are calcareous in their lower portions; still others are calcareous throughout. The contact between coal and underclay is sharp, whereas the contact of underclay and the sediment below is normally gradational. The sedimentary rock type beneath the underclay is variable.

Underclays are common in Pennsylvanian sediments of Illinois and are cyclic with the other lithologies (Fig. 1). The sediments represented comprise a complete cycle of sedimentation repeated throughout the Pennsylvanian rocks of Illinois. The cycle has been named cyclothem (Weller, 1930). Some of the individual lithic units may be missing or poorly developed in a given cyclothem. Underclay is one of the most persistent lithic types of Pennsylvanian cyclothem, some being traced from Pennsylvania to Kansas.

Cyclothem lithologies upward from the sandstone to and including the coal are non-marine, and those lithologies above the coal but below the next sandstone are marine (Weller, 1930). As Pennsylvanian beds are traced to the eastern United States, marine units thin out and disappear; moving westward into the midcontinent area many of the non-marine units behave in a like manner. The thinning and pinching out of lithologies results in a cyclic sequence in which underclay may rest upon any other sedimentary rock type (Wanless, 1947).

Underclays normally are a few feet thick but may locally attain a thickness of 15 to 20 ft. (These thicker underclays may actually be composites of more than one underclay.) They may be absent from the position beneath the coal and in such cases the plant root traces may be found in other rock types. An underclay may change in thickness from inches to ten or more feet within 10 or 15 yards. The underclay thickness is not related to the thickness of the overlying coal.

SAMPLING PROCEDURE

Underclays were obtained mainly from outcrops, a few from underground coal and clay mines, from coal and underclay stripping operations, and from diamond drill cores. The complete thickness of the underclay was sampled where possible. The loose weathered surface was removed from outcrops and a channel sample taken to minimize any vertical mineralogical variation.

METHODS OF STUDY

The clay mineral composition of the < 2 micron fraction was determined by X-ray diffraction from oriented aggregates on glass slides using a General Electric XRD-5 unit with $\text{CuK}\alpha$ radiation. The oriented clay

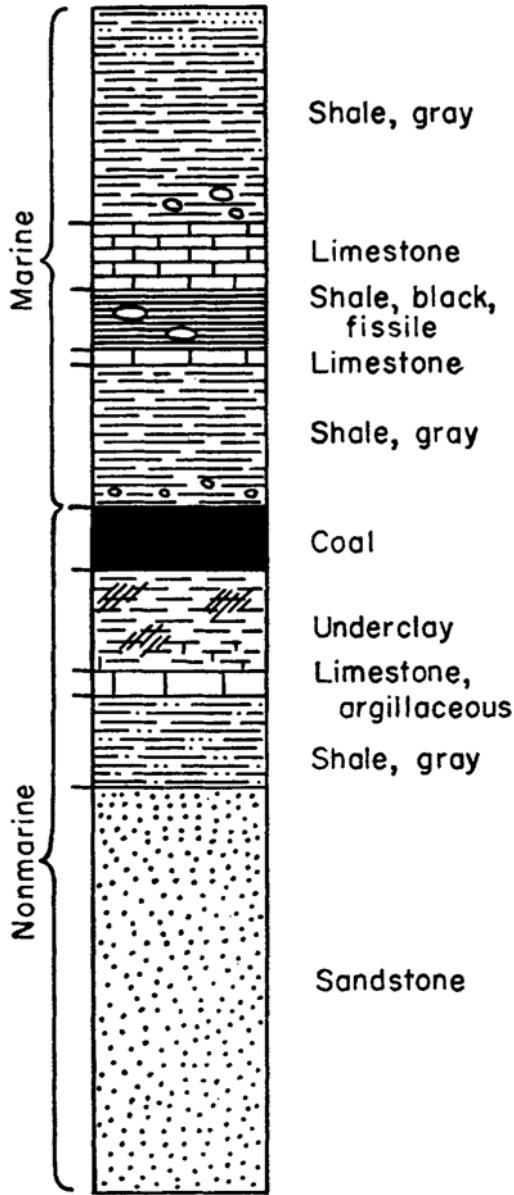


FIGURE 1.—Ideal Pennsylvania Cyclothem (after William and Payne, 1942, p.86).

aggregates were run at room temperature, after ethylene glycol treatment, and after 1 hr heating at 350°C. Quantitative estimates of the clay mineral components for all samples used in this study are listed in an Illinois Geological Survey Circular now in preparation.

X-RAY IDENTIFICATION OF CLAY MINERALS

The clay minerals in the Pennsylvanian underclays are kaolinite, illite, chlorite, vermiculite, montmorillonite, and mixed-layer material.

Kaolinite

Kaolinite is identified by its (001) reflection of 7.15 Å at 12.4° 2θ and (002) reflection of 3.57 Å at 24.9° 2θ. When chlorite is present, the (001) reflection of kaolinite approximately coincides with the (002) reflection of chlorite and the (002) reflection of kaolinite is more desirable for identification.

Illite

Illite, identified by a first order reflection of 10 Å at 8.8° 2θ and a second order reflection of 5 Å at 17.8° 2θ, does not expand with ethylene glycol treatment.

Chlorite

Chlorite is identified by the (003) reflection of 4.6 Å at 18.7° 2θ and the (004) reflection of 3.5 Å at 25.1° 2θ. The (001) reflection of chlorite falls at the same location as (002) vermiculite and the (002) reflection of chlorite coincides with the (001) of kaolinite. In many samples the amount of chlorite is small and the (004) reflection forms only a shoulder on the high angle side of the (002) kaolinite peak. This shoulder is used as the peak intensity for (004) chlorite.

Vermiculite

Vermiculite is identified by the abnormally intense (002) peak of 14 Å at 6.1° 2θ. Although this reflection coincides with the (001) of chlorite, vermiculite is recognizable by the intensity of the (002) reflection and by the absence of some of the higher orders corresponding to high orders for chlorite (Brindley, 1951). Heat treatment at relatively low temperatures, i.e. 200°C to 300°C, produces a gradual collapse of the vermiculite and a shift of the (002) reflection toward the 10 Å position, and diminishes the intensity of the (002) peak. Ethylene glycol treatment shifts the (002)

reflection from $6.1^\circ 2\theta$ to $5.9^\circ 2\theta$. Chlorite and vermiculite did not occur in the same samples, and vermiculite was found to be rare.

Montmorillonite

Any distinct diffraction peak at $5.0^\circ 2\theta$ of 17.6 \AA spacing after ethylene glycol treatment is called montmorillonite.

Undifferentiated Mixed-layer Material

A region of broad diffuse reflections occurs commonly starting on the low angle side of the first order illite reflection and ranging to $2^\circ 2\theta$. Upon ethylene glycol treatment these reflections generally shift to a smaller

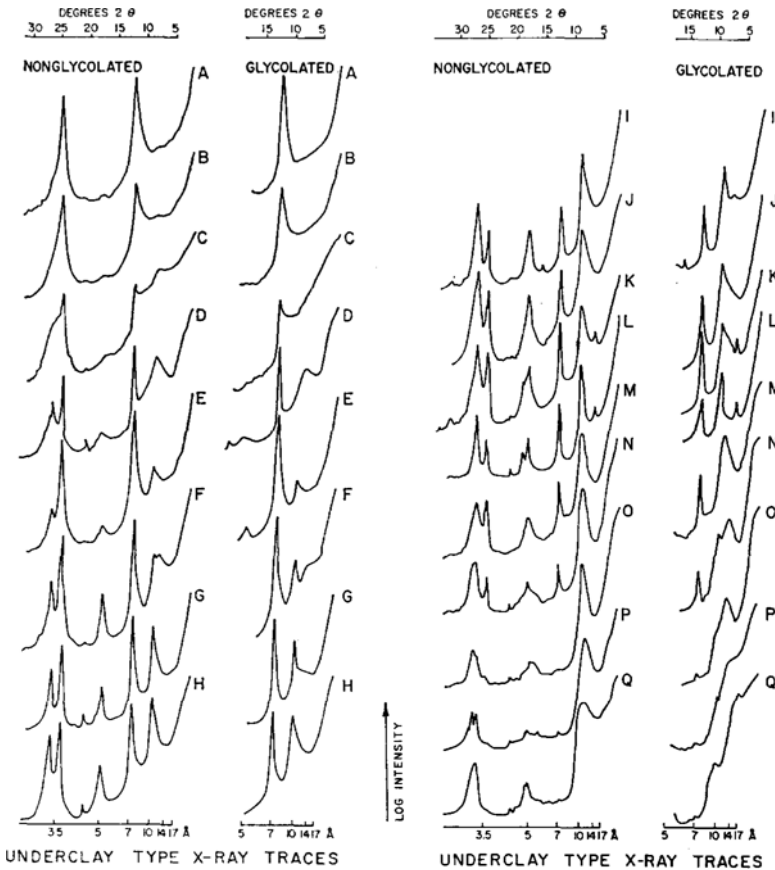


FIGURE 2.—Underclay type X-ray traces A through Q.

2θ angle. This area is commonly in the range of 6° to $8^\circ 2\theta$, but in certain cases broad reflections are found around the region of $2^\circ 2\theta$ to $4^\circ 2\theta$. Such diffraction effects are attributed to undifferentiated mixed-layer material.

CLASSIFICATION OF X-RAY TYPE CURVES

Clay mines in which the kaolinitic underclay of the Colchester (No. 2) Coal is exposed are generally located around the fringe of the Illinois Basin in western Illinois and southeast of the Kankakee Arch along the La Salle Anticline in northern Illinois. The kaolinite content of this underclay decreases away from these two regions in a basinward direction (W. Arthur White, Illinois Geological Survey, personal communication).

X-ray traces representing a continuous series of underclay samples are shown in Fig. 2 and are labelled Type A, B, C, . . . , Q in order of decreasing kaolinite content. X-ray traces of each sample are compared to the Type set and assigned the most closely matching letter value. Values for samples are listed in an Illinois Geological Survey Circular now in preparation.

Description of Type X-ray Traces A through Q

- Type A: Predominantly kaolinite with a small amount of mixed-layer material.
- Type B: Predominantly kaolinite with a larger amount of mixed-layer material than Type A.
- Type C: Predominantly kaolinite with larger amounts of mixed-layer material than Type B. Some illite may be present.
- Type D: Predominantly kaolinite and a mixed-layer component that is approaching the spacing of illite.
- Type E: Kaolinite is the major component. Less mixed-layer material and slightly more illite present.
- Type F: Kaolinite is still dominant but with a greater amount of illite than Type E. Some mixed-layer material is present.
- Type G: Slightly more kaolinite than illite.
- Type H: Kaolinite and illite are approximately equal.
- Type I: Illite is dominant and kaolinite found in lesser amounts.
- Type J: Similar to Type I except that chlorite is present.
- Type K: Illite remains about the same amounts as in Type J. Chlorite has increased in amount relative to kaolinite.
- Type L: Similar to Type K but with larger amount of chlorite.
- Type M: Chlorite decreases in relation to kaolinite. The basal reflections of illite broaden and ethylene glycol treatment indicates mixed-layer components in the range of 2° to $3^\circ 2\theta$ and 7.5° to $8.0^\circ 2\theta$.

- Type N: Chlorite is absent and the mixed-layer material after ethylene glycol treatment forms broad reflections near $7^{\circ} 2\theta$ and $2^{\circ} 2\theta$ to $3^{\circ} 2\theta$.
- Type O: Kaolinite has reached trace quantities. Three blunt, intense reflections are present near the positions of illite's basal reflections.
- Type P: Similar to Type O; the mixed-layer component produces reflections after ethylene glycol treatment at approximately $6.4^{\circ} 2\theta$, and near 2° to $3^{\circ} 2\theta$. Some illite is present.
- Type Q: The mixed-layer component shows broad intensity maxima for an illite-montmorillonite mixed system. After glycolation it develops maxima near $9^{\circ} 2\theta$, $6^{\circ} 2\theta$ and 2° to $3^{\circ} 2\theta$. No separate illite features are evident, but some unmixed montmorillonite could be present.

A few generalizations may be made on the mineralogy. From the composition at Type A of kaolinite and mixed-layer material, in the increasing amount of accessory, the mixed-layer component gradually decreases as illite increases. Chlorite appears in Type J, persists to Type M, and is no longer distinguishable in Type N. Prominent mixed-layer components appear at Type M and are present through Type Q.

Mineralogical maps were constructed for the underclays of the Colchester (No. 2) Coal of Illinois and surrounding States, the Middle Kittanning No. 6 Coal of Ohio and Pennsylvania, and the Herrin (No. 6) Coal of Illinois by plotting the Type letter of each sample at its geographical location and then contouring sets of letters. The sets of letters were grouped depending on the amount of control. As there are more control points for the underclay of the Colchester (No. 2) Coal in La Salle and Knox Counties, Illinois, maps were made of these smaller areas.

CLAY MINERAL FACIES

Kaolinite is most common in nearshore sedimentary rocks and less abundant in offshore sections (Weaver, 1958; Kossovskaja, 1958; Groot and Glass, 1960; Pryor and Glass, 1961; Rateev, 1961; Waagé, 1961; Zkhus, 1961; Hayes, 1963). Some studies of recent sediments have shown that kaolinite content decreases as sediment is carried from fresh to marine waters (Brown and Ingram, 1954; Powers, 1954). Kaolinite decreases seaward in the Gulf of Mexico (Griffin, 1962) and in the Gulf of Paria (Hirst, 1962). The underclay of the Colchester (No. 2) Coal in north central La Salle County, Illinois, is highly kaolinitic at or near its feather edge (near shore region). If the kaolinite content for a given underclay is plotted with highest quantity in the "shore" direction and lowest quantity "basinward", and the average amount of other clay minerals plotted with reference to the amount of kaolinite, a facies chart may be constructed for the underclay (Fig. 3).

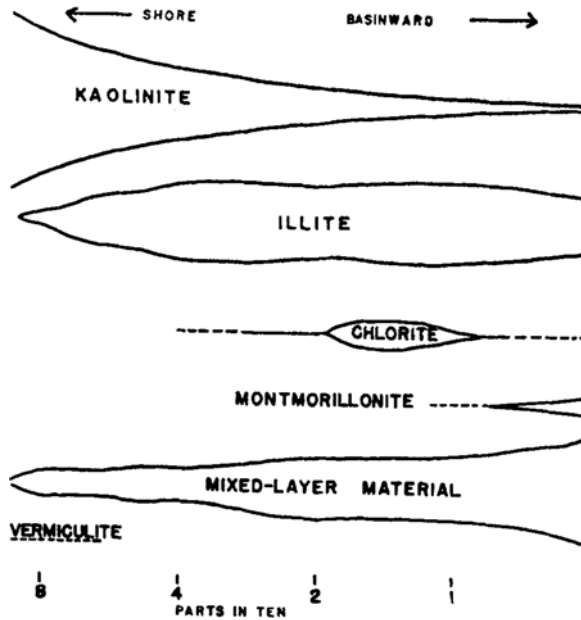


FIGURE 3.—Clay minerals facies chart.

Illite is absent in the very near shore zone, increases in abundance basinward and reaches a maximum of 4.0 to 4.5 parts in ten, then shows a progressive decrease to 3.0 parts in ten further basinward.

Chlorite is first observed shortly before illite reaches its maximum, reaches maximum values basinward of the illite maximum, and is absent or present in trace amounts further basinward.

Montmorillonite is first inferred after chlorite has reached its maximum. It increases only slightly in amount toward the center of the basin and is found only in small amounts if at all.

Vermiculite occurs in small quantities and is only found associated with high amounts of kaolinite. Unifferentiated mixed-layer material averages about 0.3 parts in ten very near shore and gradually increases to approximately 6.0 parts in ten in a basinward direction. Furthest basinward, montmorillonite is the major component of the mixed-layer material.

CLAY MINERAL CHANGES

Clay mineral facies maps (Figs. 4–8) and the distribution of clay minerals shown by the facies chart (Fig. 3) suggest an orderly lateral variation of clay minerals in these underclays. Various factors may have contributed to this distributional pattern.

Changing Source Areas

Land areas that existed during underclay deposition must have been subject to weathering and erosion, providing a source for some material that made up the underclay deposits. Many Pennsylvanian underclays and some coal persists for hundreds of miles, indicating that climatic conditions varied slightly over large areas in North America. The underclay of the Colchester (No. 2) Coal has been traced from Oklahoma to Indiana, and possibly was continuous with the underclay of the Lower Kittanning Coal of the Ohio and Pennsylvania region.

The fine grain size of underclays implies that nearby land areas were low-lying as no underclays were observed grading laterally into other rock types. Rocks of low-lying land areas that supplied sediment, probably contained a variety of clay minerals, feldspars, and other silicates and the variation of rock types probably exerted little effect on the weathered product formed under uniform climatic conditions in an acid, leaching environment (Hosking, 1957; Choux, 1961).

Ground-water Action and Present-day Weathering

If down-dip movement of ground water through underclays alters clay minerals to produce the observed facies, different underclays in the same region should show similar facies distribution patterns. However, the facies distribution pattern of the underclay of the No. 2 Coal eastward from the Ozark region is the reverse of that for the underclay of the No. 6 Coal, indicating that a ground-water origin for lateral clay mineral variations is untenable.

Samples from weathered outcrops and nearby drill holes or active pits show no marked differences in clay mineral composition indicating that present-day weathering is not the cause of observed clay mineral variation.

Differential Flocculation of Clay Minerals

Clay minerals deposited in quiet waters of increasing salinity settle in the following order; illite (most rapidly), chlorite, kaolinite, and montmorillonite (Whitehouse and McCarter, 1958; Whitehouse, Jeffrey, and Debbrecht, 1960). This sequence does not parallel the clay mineral distribution in underclays and thus differential flocculation, under the experimental conditions observed above, does not appear to be responsible for the lateral clay mineral variations.

A decrease in the surface area of clay particles during transport resulting from a contraction in the interlayer spacings due to cation fixation might cause particle drop-out while current velocity remained the same.

Effect of Coal Forming Processes on Underclay

Chemical alteration of underclay caused by growing plants in the coal swamp should have caused similar clay mineral changes throughout the swamp. Under such conditions the effect of growing plants should not cause the orderly lateral variation in clay mineral composition observed. An assumption that where coals are thicker acid action of the coal swamp on the sediment below would have been greater and consequently more kaolinite produced is not warranted. The No. 6 Coal of Illinois is about 4 to 7 ft thick where mined and is underlain by underclay with a low kaolinite content, whereas the No. 2 Coal of Illinois, ranging from 2 to 3 ft in thickness, is underlain in many instances by underclay high in kaolinite. Thus, thickness of coal and clay mineral composition of underclays are not related and in areas favorable for thick accumulation and preservation of plant debris the acid swamp condition was not a significant factor in producing the clay mineral assemblage in the sediment below. Certainly, any life plant will alter material in which it is growing to some extent; we must assume therefore that there was some alteration of the underclays by coal-forming plants. Only plants that partake sparingly of nutrients can survive in present-day bogs. Peat forming in bogs draws ground water upward permitting growth of more plants on the bog surface (Deevey, 1958). Assuming that water movement was upward in Pennsylvanian coal swamps, and that plants that grew there were of the variety that could survive on little nutrients, there would be little likelihood of the clay minerals in underclays having undergone appreciable alteration.

Suggested Cause for Lateral Clay Mineral Variation in Underclays

Kaolinite, mixed-layer clay minerals, and occasionally vermiculite are the only clay minerals contained in underclays surrounding Pennsylvanian low-lying lands. It is assumed that when illite and chlorite occur further from shore, they developed from mixed-layer material. Changes and distribution of clay minerals in recent sediments transported from fresh to marine water show strong similarities to the distribution of clay minerals in underclays (Brown and Ingram, 1954; Powers, 1954; Johns and Grim, 1958; Whitehouse and McCarter, 1958; Nelson, 1960). A gradual increase in common cation content in rainwater occurs as it moves from lakes, streams, and rivers into bodies of marine water (Conway, 1942; Gorham, 1961; Carroll, 1962). A transition usually exists from shore → seaward in a large body of water from less saline water to true marine water (Hatch, *et al.*, 1950; Pritchard, 1950; Powers, 1954; Dunbar and Rogers, 1957, p. 149). A similar gradient would be expected in the large bodies of water in which underclays were deposited.

Changes in the clay mineral distribution pattern in underclays suggest that as the mixed-layer material was slowly carried farther out into shallow

waters of increasing salinity, some portion that had been illite stripped of much of its potassium, was able to regrade by absorption of potassium ions. The $\text{Na}^+ : \text{K}^+$ ratio for underclays is smaller than for other argillaceous Pennsylvanian rocks and a slow rate of sedimentation is believed to be responsible for this (Nicholls and Loring, 1960).

K^+ and Mg^{++} are removed from clays in acid waters but under the alkaline environment of seawater are regained first as exchange ions; later, K^+ is held firmly on illite interlayer sites and precipitation of brucite layers in chloritic material fixes Mg^{++} (Bradley, 1953).

Illite's maximum development (Fig. 3) is shoreward of chlorite's maximum and is in agreement with findings of Grim and Johns (1958) on clays of the Mississippi delta.

The regradable components would decrease as the sediment travelled further basinward and a point would be reached where little or no chlorite and illite would develop. Basinward, only highly disordered, non-regradable weathered clay material would be deposited.

Kaolinite would not be effected by salinity changes and would be distributed with its coarser particles near shore and smaller ones further from shore. Montmorillonite's presence in Type Q traces might be due to some primitive rebuilding of the highly disordered clays in a more alkaline environment.

Salinity values prevailing during deposition of underclays just prior to the appearance of vast coal swamps probably never reached concentrations of modern oceans. The lateral clay mineral sequence in underclays has been spread out over large distances, probably because of the gentle salinity gradient, and is more clearly resolved than similar changes in recent sediments. The change from fresh to marine water takes place in a relatively short distance in many areas of recent sedimentation. There is a strong suggestion that a close relationship exists between the steepness of salinity gradient and rate of diagenesis (Powers, 1954). Perhaps the slow travel time of clays through waters of low salinity could have compensated for the lower salinity and have resulted in the same changes that take place today as clays are carried from fresh water across steep salinity gradients to marine water.

Underclays of Type J to Q are frequently calcareous in the lower portion. Nicholls and Loring (1962) feel that this is merely the result of progressive sedimentation of silts and clays in waters of slowly decreasing pH and need not imply that the upper part had undergone leaching.

Environmental conditions necessary for formation of one Pennsylvanian underclay probably were not much different from conditions necessary for formation of any other. Kaolinite should show a decrease in offshore regions, regardless of which underclay is studied, and regardless of the shape of the basin of deposition. Thus, changes in kaolinite content in underclay should aid in reconstructing ancient basins of deposition.

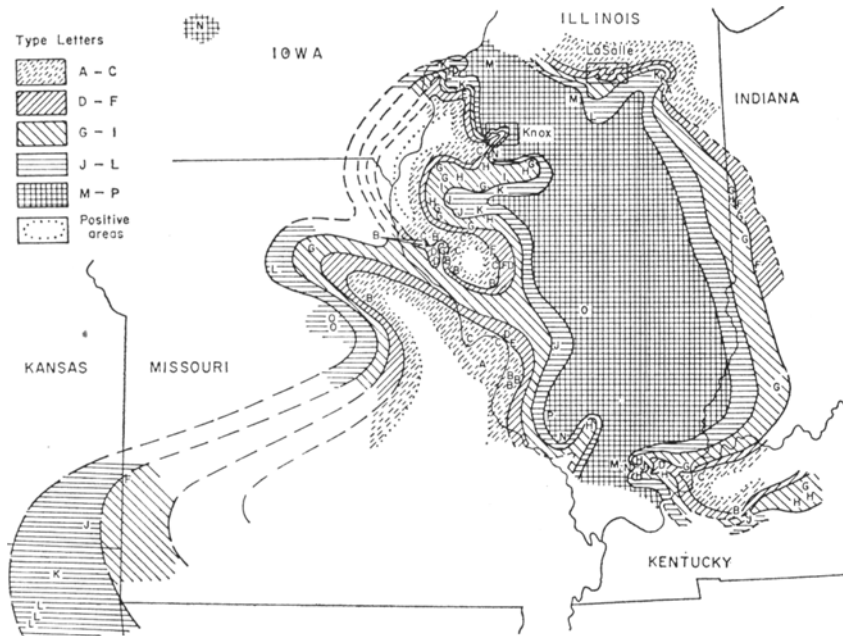


FIGURE 4.—Clay mineral facies map of the underclay of the Colchester (No. 2) Coal.

PALEOGEOGRAPHY

An increase in kaolinite content in one sample relative to another may be used as a directional property for locating land areas that existed during the underclay's deposition. Following is the paleogeography of each underclay studied.

Underclay of the Colchester (No. 2) Coal

Figure 4 suggests that the Ozark area was contributing sediment to the west, north, and east. (The La Salle and Knox areas are shown in greater detail in Figs. 5 and 6.) Sediment was being supplied to western Illinois from land north of the Ozark region. This is considered to be a spur of the Ozark Dome (Wanless and Weller, 1932). During deposition of this underclay there was a narrow waterway connecting Illinois and Missouri north of St. Louis. W. A. White of the Illinois State Geological Survey (personal communication) has noted places in western Illinois where Mississippian

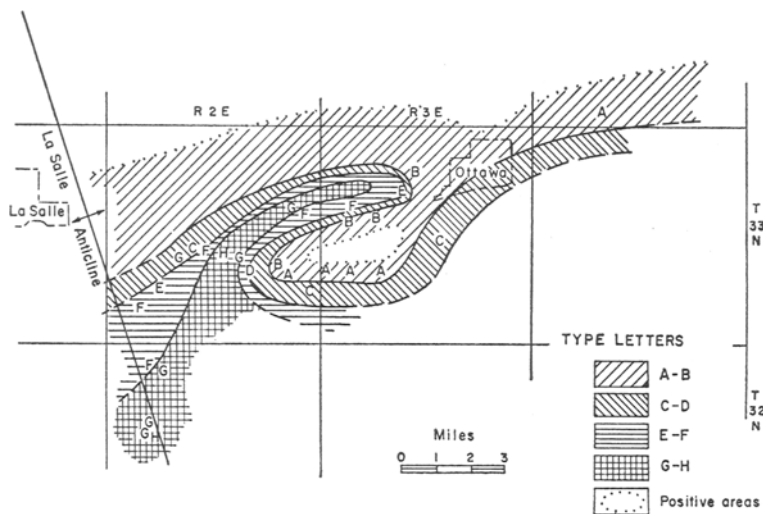


FIGURE 5.—Clay mineral facies map of the underclay of the Colchester (No. 2) Coal in La Salle County, Illinois.

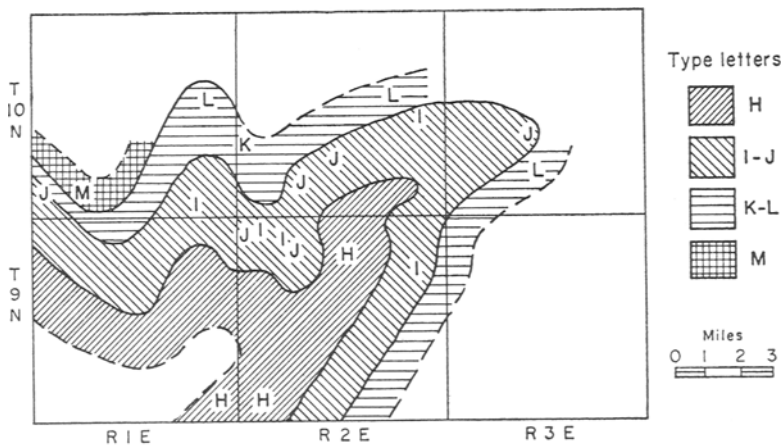


FIGURE 6.—Clay mineral facies map of the underclay of the Colchester (No. 2) Coal in Knox County, Illinois.

rocks are higher topographically than the Pennsylvanian sediments suggesting a remnant of this old source area. The Type N sample from central Iowa suggests that this land area did not extend far into Iowa or northern Missouri. The northern end extended to about Mercer or Rock Island County, Illinois, where a narrow waterway existed connecting Illinois and Iowa.

The waterway was bounded on the north by the Wisconsin or the Kankakee Arch indicated by high kaolinite content in samples from La Salle and Kankakee Counties. The Type letter lines cross the La Salle Anticline (Fig. 5) indicating that this structure was not supplying material for formation of the underclay of the No. 2 Coal. The influence of the Kankakee Arch is noted from samples in western Indiana, where values from Type D to Type I predominate.

South of where the boundaries of Illinois, Indiana, and Kentucky join is a region high in kaolinite which does not correspond to any known structural feature. Wanless (personal communication) suggests that it is possibly the reflection of a delta distributary that carried sediment from the east and that existed shortly before deposition of the underclay of the No. 2 Coal. Potter (1962) has shown that crossbedding in Pennsylvanian sandstones of this region shows a general east to west trend.

West of this area and east of the Ozark region there was an opening of the Illinois Basin to the south that possibly connected with Warrior Coal Basin of Alabama. Sandstone crossbedding studies show a north to south trend in this region (Potter, 1962). There are no coals found in the Alabama region as young as the No. 2 Coal of Illinois (Wanless, personal communication).

Pennsylvanian underclays of Alabama tested for refractoriness were found to have a maximum PCE (pyrometric cone equivalent) of 28 and generally fell into the range of PCE 20 to 28 (McVay and Toulmin, 1945). The refractoriness of an underclay or its PCE value are directly related to the sample's kaolinite content; the greater kaolinite content the more refractory the underclay will be and the higher PCE value. Underclays tested from Illinois with PCE values of 28 would correspond most closely to Type E or F X-ray curves. One might suspect therefore that the exposed Alabama underclays were deposited in more basinward sites.

Underclay of the Herrin (No. 6) Coal

Figure 7 shows a pattern different from that of the underclay of the No. 2 Coal. Type letters O, P, and Q are predominant east of the Ozark region signifying a depositional site far from a positive area. The Ozark area was probably completely inundated and no longer served as a source for sediment. The No. 6 underclay is continuous from Illinois to Kansas across a large part of the Ozarks (Wanless *et al.*, 1963). The Illinois Basin still had an open end to the south and the same small positive feature that existed in southeastern Illinois during deposition of the underclay of the No. 2 Coal was present. Various underclays from the Herrin (No. 6) Coal to approximately 600 ft above the Witt Coal of the Bond Formation from a diamond drill core from Union County, Kentucky, range in composition from Type G to N. The wide spread of Type letters through this time

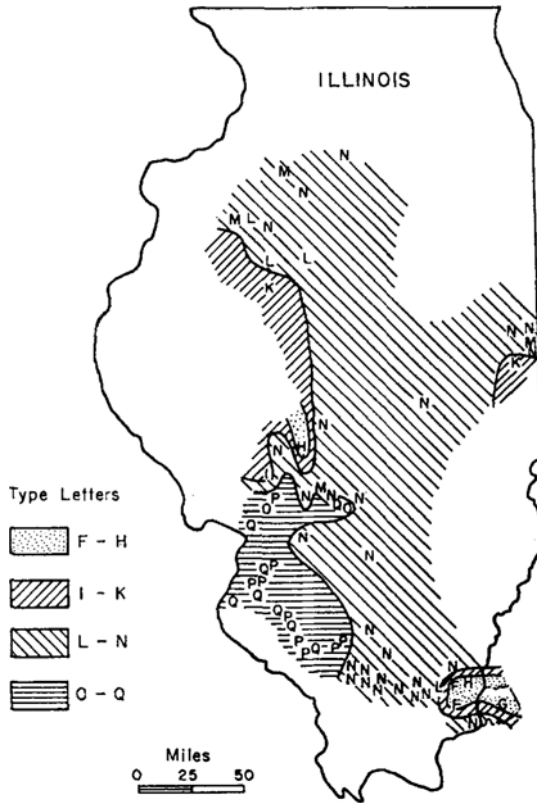


FIGURE 7.—Clay mineral facies map of the underclay of the Herrin (No. 6) Coal in Illinois.

interval suggests that this land area was present from time to time. This is near the position of a pre-existing westward draining delta or distributary of a delta that had existed shortly before formation of the underclay of the No. 6 Coal (Wanless *et al.*, 1963).

There may have been a small positive area in western Illinois or eastern Iowa as indicated by Type letters. Type letters in northern Illinois suggest that deposition of this underclay may have been continuous between the Illinois and Michigan Basins. However, there are no coals as young as the No. 6 of Illinois found in the Michigan Basin (Wanless, personal communication).

Underclay of the Middle Kittanning Coal

Figure 8 shows a parallelism between Type letters and the approximate position of the ancestral Appalachians. Sediment was probably trans-

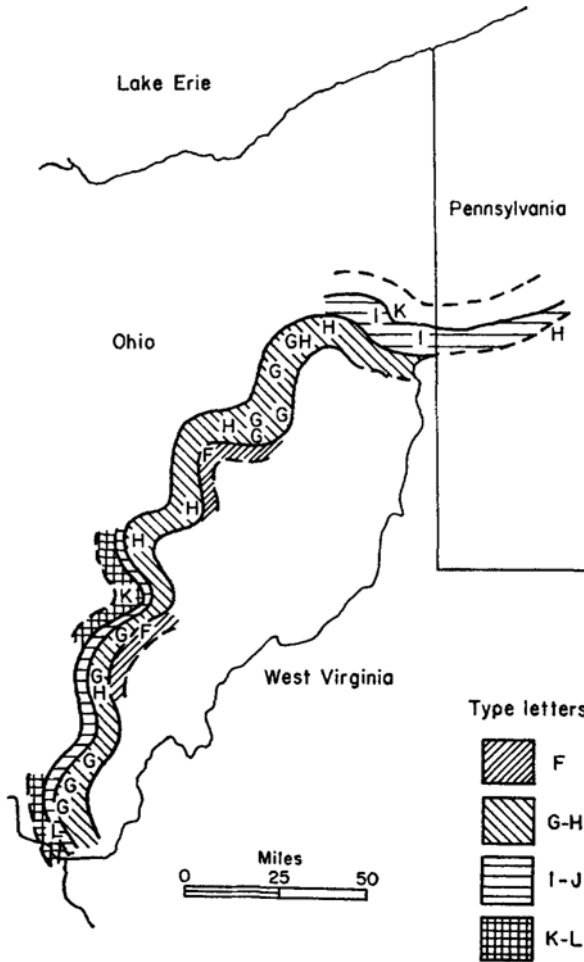


FIGURE 8.—Clay mineral facies map of the underclay of the Middle Kittanning Coal of Pennsylvania and Ohio.

ported from the southeast. However, the present-day dip of rocks of the Kittanning Formation in Ohio is to the east and southeast, probably indicating that movement of the Cincinnati Arch reversed the original dip direction. There is no increase in kaolinite content toward the Cincinnati Arch, indicating either that at that time the Arch was not serving as a source for sediment, or that all of the underclay with higher kaolinite content has been removed by erosion.

GENERALIZED UNDERCLAY CLAY FACIES

It is apparent that clay mineral variations exist both above and below the underclay of the No. 2 Coal and that kaolinite just as any other of the clay minerals can be found in fair quantity above or below this bed. An underclay in eastern Illinois, associated with the West Franklin Limestone several cycles higher than that containing the No. 2 Coal, is kaolinitic and best represented by Type B, C, and D curves. Another, associated with the Danville (No. 7) in Grundy County, Illinois, is kaolinitic, whereas elsewhere in Illinois this unit is not. There probably are remnants of edges of some other upper underclay units preserved in a few places. A generalized diagram of the succession of underclays and their clay mineral content found in the Illinois Basin is shown in Fig. 9. Erosion of edges of

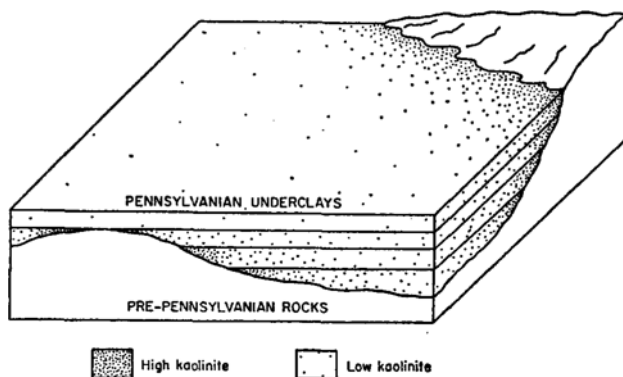


FIGURE 9.—Generalized diagram of the succession of underclays in the Illinois Basin and their kaolinite content.

upper units would at the same time expose lower ones, and would give the impression that a sharp clay mineral break developed at some stratigraphic position during Pennsylvanian times. This accounts for the apparent clay mineral break at the underclay of the No. 2 Coal in Illinois.

McCue *et al.* (1948) sampled most underclays of the different coals of West Virginia and tested them for possible industrial uses. Each underclay unit was represented by a few scattered samples. Figure 10 is based on the average fired color of each underclay unit; the lightness of fired color is directly related to kaolinite content.

The West Virginia underclays dip westward, and were probably derived from the southeast or east. If this is true, the edges of the upper units of underclays in West Virginia should have been eroded more completely than edges of stratigraphically lower underclays. Exposed edges of under-

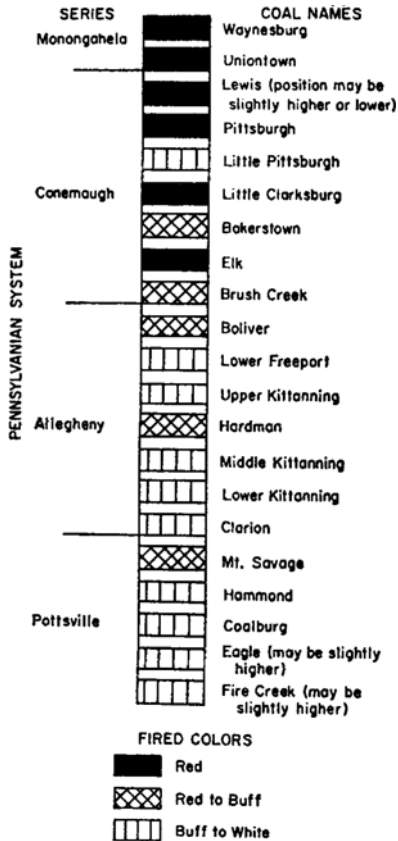


FIGURE 10.—Fired colors of underclays from West Virginia (after McCue *et al.*; 1948).

clays lower stratigraphically should be higher in kaolinite. Figure 10 shows, as expected, that there is a general lightening in fired colors in lower stratigraphic units. The only underclay that does not fall into place is that of the Little Pittsburgh Coal. McCue mentions, though, that at various places throughout the State this underclay has been used for sewer pipe (sewer pipe normally has a red firing color). The general concept of onlap in the Pennsylvanian in this region also gives a picture not unlike that of Fig. 9.

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