STATE OF ILLINOIS
WILLIAM G. STRATTON, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
VERA M. BINKS, *Director*

Differentiation of Caseyville (Pennsylvanian) and Chester (Mississippian) Sediments In the Illinois Basin

Elwood Atherton
Grover H. Emrich
Herbert D. Glass
Paul Edwin Potter
David H. Swann

DIVISION OF THE
ILLINOIS STATE GEOLOGICAL SURVEY
JOHN C. FRYE, *Chief* URBANA

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DIFFERENTIATION OF CASEYVILLE (PENNSYLVANIAN) AND CHESTER (MISSISSIPPIAN) SEDIMENTS IN THE ILLINOIS BASIN

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ABSTRACT

Differentiation of Caseyville and Mansfield (Pennsylvanian) from Chester (Mississippian) clastics in the Illinois Basin is complicated by the many properties they have in common. Criteria that distinguish between these sediments are reviewed and evaluated. These criteria are based on the stratigraphic sequence, lithology, mineralogy, and geophysical logs.

Some of the most reliable indices of the Caseyville clastics are quartz pebbles, siderite, minable coals, conspicuous mica, and siltier shales with higher resistivity. Reflecting the greater importance of marine sedimentation in the Chester are such typical characteristics of Chester clastics as detrital carbonate, red and green shales, marine fossils, and less kaolinite.

Although these and other criteria have basin-wide applicability, regional variations in both Caseyville and Chester sedimentation in a number of areas within the basin make recognition of the unconformity locally difficult.

Several problems associated with the development of the Mississippian-Pennsylvanian unconformity and its control over basal Pennsylvanian sedimentation are pointed out.

INTRODUCTION

The Mississippian Chester Series in the Illinois Basin is overlain by Pennsylvanian sediments (fig. 1). In southern Illinois and Kentucky the principal basal Pennsylvanian unit is the Caseyville Formation. In Indiana the Mansfield Sandstone at the base of the Pennsylvanian is largely equivalent to the Caseyville but includes some younger beds.

Although separated by a major unconformity, Caseyville and Chester clastics can be difficult to distinguish because they were derived from the same general source area and deposited in broadly similar environments. Paleontologic criteria have been of little help in many parts of the Illinois Basin where the position of the unconformity is doubtful. Recognition commonly depends on lithologic criteria. This study evaluates both published (Mylius, 1927, p. 69-71, 76-77; Siever, 1951, p. 544-549) and new criteria commonly used for differentiation of the two units and recognition of the unconformity.

Northwest of the area in which the Caseyville is found, later Pennsylvanian sediments directly overlie the Chester and, as these generally have characteristics less like those of the Chester, the unconformity is more easily recognized.

DEPOSITION OF THE SEDIMENTS

Chester sediments, coming into the area from the northeast, accumulated on a coastal plain and shallow marine shelf that sloped to the southwest. Direction of cross-bedding, orientation of sand bodies, and distribution of carbonates all indicate such an environment (Potter et al., 1958).

Following Chester deposition, the LaSalle Anticlinal Belt and other structures in the Illinois Basin were uplifted, whereas the deeper portion of the basin was downwarped along a north-south axis. A cycle of erosion produced widespread regional truncation of Chester and older sediments in the northern part of the basin. A later

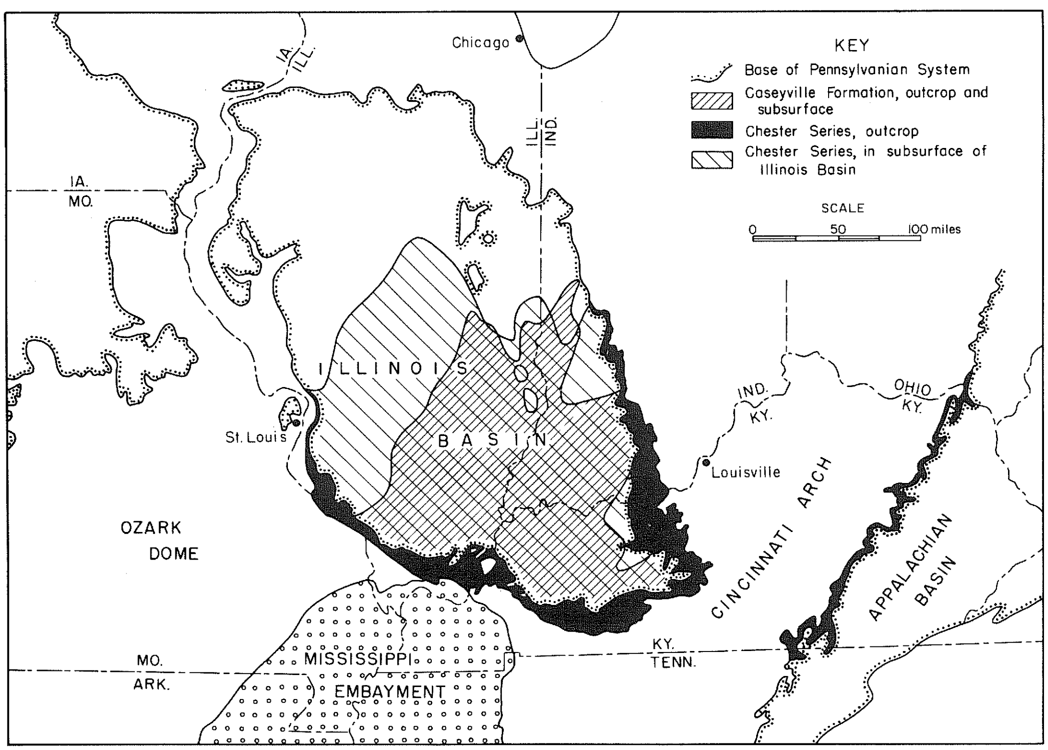

Fig. 1 - Illinois Basin showing Caseyville and Chester sediments and the base of the Pennsylvanian. Generalized Caseyville boundary modified from Wanless (1955, fig. 3).

cycle caused deep entrenchment of streams flowing to the southwest across the beveled structures of the old erosion surface (Siever, 1951, p. 574-575). Some of the channels were as much as 200 feet deep and two to three miles wide.

During early Pennsylvanian time, Caseyville sediments entered the basin, filled the valleys, and covered the interstream areas with clastics, in some places to a depth of two to three hundred feet. Studies of cross-bedding (Potter and Siever, 1956, p. 225-244) show that the paleoslope of the Caseyville and Mansfield sediments was similar to that of the Chester.

STRATIGRAPHIC SEQUENCE AND CLASTIC FACIES

The stratigraphic sequence is the key to the proper use and interpretation of other criteria for differentiating Caseyville and Chester sediments. A generalized stratigraphic section of the southern part of the Illinois Basin showing Chester, Caseyville, and higher Pennsylvanian sediments up to the widely recognized Colchester (No. 2) Coal appears in figure 2.

The Chester Series is an interbedded sequence of shale, limestone, and sandstone that attains a maximum thickness of about 1400 feet along the south side of the basin. It is roughly 50 percent shale, 25 percent limestone, and 25 percent sandstone.

In contrast, Pennsylvanian sediments below No. 2 Coal are almost entirely clastic. The Sellers Limestone Member, two feet thick and known only from a single outcrop (Wanless, 1936, p. 36), is the only limestone in the Caseyville or the overlying Abbott Formation in either Kentucky or Illinois. Limestones occur in the next higher formation, the Spoon, but even there are volumetrically insignificant. Coals are much less important than at higher levels in the Pennsylvanian. In the Indiana, Kentucky, and southernmost Illinois parts of the basin, the Pennsylvanian below No. 2 Coal averages about 50 percent sandstone and more than 40 percent shale, but farther northwest in central Illinois the proportion of shale is much higher. Maximum thickness of the Caseyville Formation exceeds 400 feet, that of the overlying Abbott Formation is about 400 feet, and that of the still higher Spoon Formation is about 350 feet.

The younger formations that overlap the Caseyville and lie on the Chester (fig. 1) contrast more markedly with the Chester because they are petrologically less mature. Clean quartz sandstones and siltstones from the Chester and Caseyville resemble each other but differ strikingly from the highly micaceous feldspathic sandstones of the Spoon Formation and even from those of Abbott, which are intermediate in character. Difficulty arises in Chester-Abbott differentiation only when electric logs are the sole type of information available.

Although the Caseyville Formation and the correlative part of the Mansfield have been subdivided in several areas, the locally recognized units are not easily traced far from their type sections. Lack of persistent marker beds and the lenticular character of the sandstones make the internal stratigraphy of the Caseyville difficult to determine both in outcrop and in subsurface.

The simplest and most effective way to locate the base of the Pennsylvanian System is to apply what is known of Chester stratigraphy. Because limestones are the most widespread, uniform, and persistent units of the Chester, they are the key stratigraphic elements for locating the position of the unconformity. As limestones are absent in the early Pennsylvanian, the highest carbonate bed in the region of the

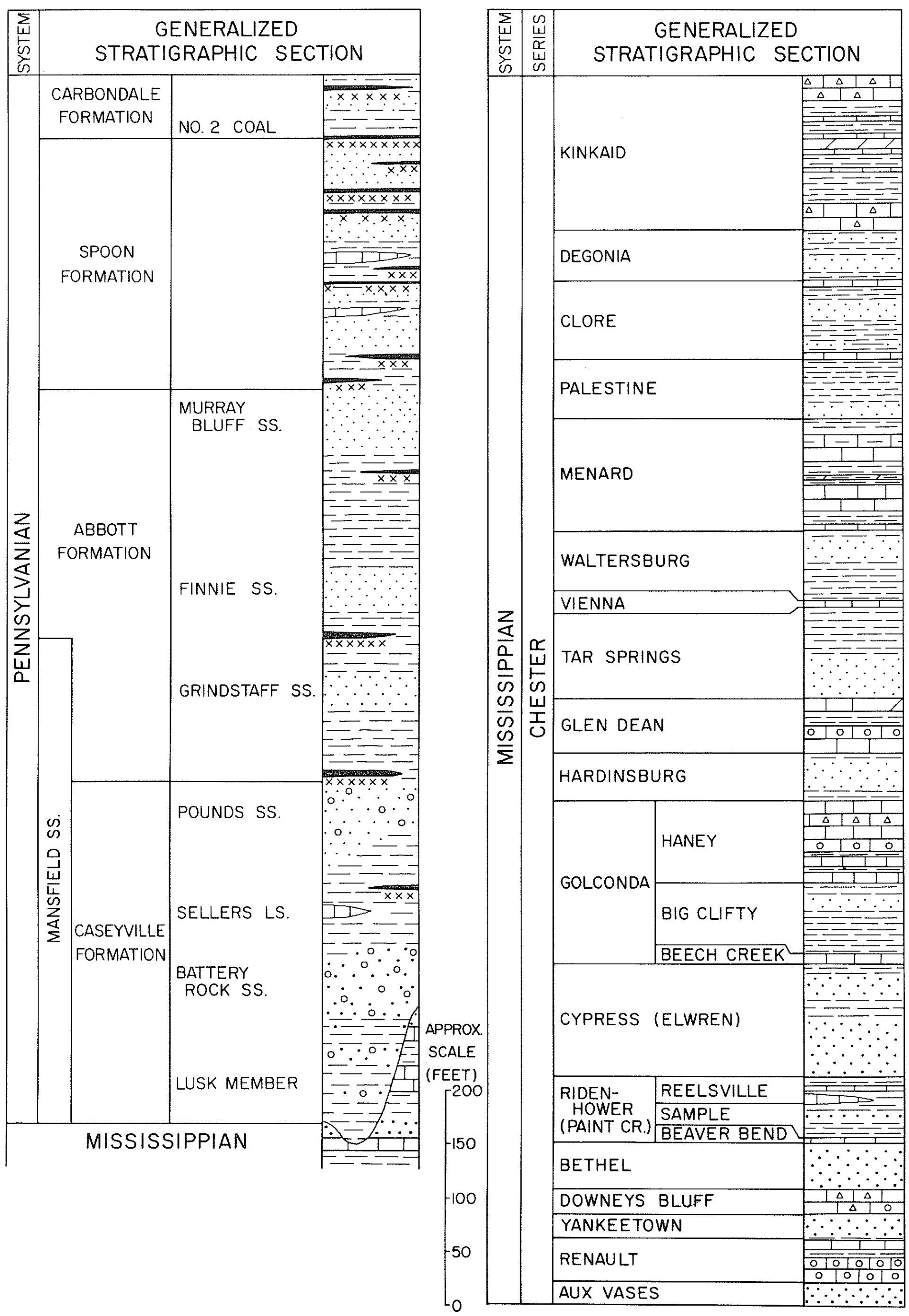

Fig. 2 - Generalized stratigraphic section of the lower part of the Pennsylvanian System and of the Chester Series in the southern part of the Illinois Basin.

unconformity may be considered Chester. The contact therefore occurs above the highest preserved Chester limestone and beneath the position the next higher limestone would occupy. Whether the clastics overlying the Chester limestone are Chester or Caseyville must be decided from other criteria. As clastic Chester sequences may be as much as 200 or more feet thick, there is possibility of considerable error, but more commonly only a few tens of feet of strata will be involved.

The pattern of deposition of sandstone bodies in the Caseyville differs little if at all from that of the Chester sandstones. In each there are both sheet and channel phases. Individual sandstone bodies of the sheet phase are rarely more than 20 feet thick, have transitional bases, and are finer grained and thinner bedded than the channel phase, which normally does not exceed 140 feet thick. However, as much as 200 feet of a single sandstone sequence in the Caseyville has been observed in the fill of a major pre-Pennsylvanian erosional channel. The channel sandstone phases of both Chester and Caseyville are markedly linear, whereas the sheet phases are more widespread and uniform. Only where the channel phase of one is in contact with the sheet phase of the other do marked contrasts result. Because of this similarity, the distribution patterns of the sandstone bodies of the Caseyville and Chester provide no satisfactory basis for distinguishing Caseyville from Chester clastics nor for locating the position of the Mississippian-Pennsylvanian unconformity.

SANDSTONES

The properties that distinguish sandstones of the Pennsylvanian from those of the Chester actually occur to some degree in both. However, a number of these megascopic and binocular properties are virtually confined to one age, and the others, appearing in different degrees of abundance or magnitude in the Pennsylvanian or Chester, can be considered definitely more characteristic of one than the other.

Characteristic Megascopic Pennsylvanian Properties

Quartz granules and pebbles are almost certain indicators of the Pennsylvanian. Subrounded to rounded quartz granules and pebbles are, with perhaps two exceptions, found only in Pennsylvanian sandstones and are therein virtually restricted to the Caseyville and Mansfield Formations. Commonly, they are best developed in the channel fill of the Mississippian-Pennsylvanian unconformity. In many outcrops, however, they are not prominent. The only two occurrences of quartz granules and pebbles known in the Chester sandstones are one near the base of the Bethel Sandstone and a possible one in the Degonia Sandstone. Even there they occur only where the formations are unusually thick.

Visible siderite also is nearly certain to indicate Pennsylvanian sandstone. Either as concretions or cement it is abundant in the Pennsylvanian, rare in the Chester. Siderite was observed, disseminated between the larger detrital sand grains as small anhedral crystals and spherules, in thin sections of about one-third of all carbonate-bearing sandstone cores from the Caseyville. It was not observed in similar thin sections from the Chester, although minor amounts were noted in x-ray diffraction patterns of some Chester sandstones.

Also indicative of Pennsylvanian sandstones are certain weathering phenomena. Weathering of a siderite-cemented sandstone produces a buff to reddish brown appearance. Liesegang banding and iron oxide boxworks develop readily as such sandstones weather. Although examples of such phenomena are found in the Chester, they are much more abundant in the Pennsylvanian.

Coarse-grained sandstone is very likely of Pennsylvanian age, and very coarse-grained sandstone with or without quartz pebbles is definitely so, for, although the finer sand sizes of the Caseyville are duplicated in the Chester, the coarser ones are not. Caseyville sandstones range from very fine to very coarse, the latter occasionally containing well rounded quartz granules and pebbles. In contrast, Chester sandstones range from very fine to fine and in only a few places reach full medium grain size, for example, in the basal part of the Bethel Sandstone of the western Kentucky and southern Illinois fluorspar district.

Caseyville sandstones appear to be somewhat less well sorted than Chester sandstones.

Conspicuously micaceous sandstone is more likely to be of Pennsylvanian than Chester age. Observation by hand lens, binocular microscope, and thin section indicate that mica flakes are more abundant in Caseyville than Chester sandstones. Because of its rarity (approximately one mica flake to a few thousand other grains) mica generally does not appear in thin section counts of 200 grains. Detrital mica, noted in nearly three-fourths of the thin sections of both Caseyville and Chester, was nearly always more abundant in the Caseyville sections. Observations with the binocular microscope indicate that many mica flakes in the Caseyville are larger than those in the Chester.

Caseyville sandstones also contain noticeably more megascopic carbonaceous material — wholly or partially carbonized and macerated plant remains, coal partings, and coal fragments — than do the Chester sandstones.

Also more common in the Caseyville than in the Chester are the iron sulfides, pyrite, and marcasite, according to studies made with the binocular microscope.

Quartz overgrowths appear more conspicuous in the Caseyville than in the Chester sandstones. Petrographic microscope estimates of the abundance of rounded quartz grains were not made because outlines were modified by secondary quartz overgrowths, but more angular grains have been used, though with caution, in some binocular microscope studies to distinguish the Caseyville.

Characteristic Megascopic Chester Properties

An almost certain indicator of Chester age is the red or green admixed argillaceous material in the finest sandstones — those bordering on siltstones. Shale pebble conglomerate containing red and/or green shale also very strongly indicates a Chester age.

Carbonate oolites formed on either quartz or carbonate nuclei have been observed only in Chester sandstones. Although oolitic grains are by no means common, they provide definite evidence of Chester age and reflect the closer affinity of Chester sandstones to marine environments.

Detrital microcrystalline carbonate aggregates of sand size also have been noted only in Chester sandstones. Essentially all the carbonate in Caseyville sandstones is nondetrital cement.

Although not common, marine fossils, if present, strongly indicate a Chester age.

Petrography

Mineralogical composition of the sandstones was evaluated from both published and new data (Siever and Potter, 1956, p. 321-324; Potter and Glass, 1958, p. 28-32; Potter and Pryor, in press). Figure 3 shows the distribution of sample localities. Table 1 gives the average petrographic composition of the well and outcrop samples and shows that Caseyville and Chester clastics are both mature and that in terms of major constituents there is very little difference between the two.

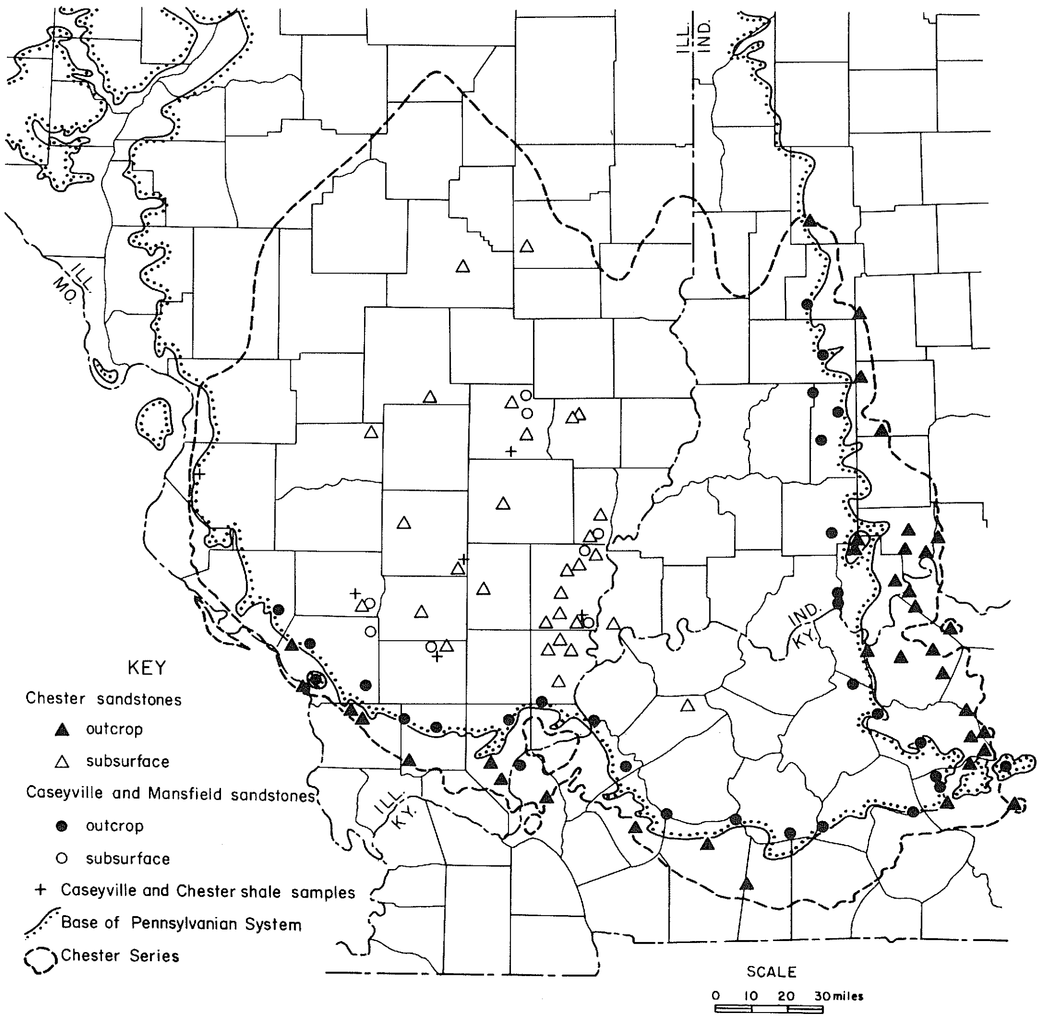

Fig. 3 - Localities sampled for petrographic and clay mineral analysis (see appendices A and C).

TABLE 1. - AVERAGE PETROGRAPHIC COMPOSITION OF CASEYVILLE AND CHESTER SANDSTONES

Age	Type of sample	Quartz (%)	Matrix (%)	Carbonate (%)	Feldspar (%)	Mica (%)	Chert (%)	Rock fragments (%)	Misc. (%)	No. of analyses
Caseyville*	Outcrop	90.7	7.8	0.0	0.7	†	0.7	0.1	-	30
	Well	82.3	6.0	9.4	0.4	†	0.6	1.3	-	11
Chester‡	Outcrop	84.5	8.1	3.9	0.4	0.2	0.2	1.3	1.4	26
	Well	82.6	7.0	7.2	0.7	0.2	0.2	1.4	0.7	31

* Taken from Siever and Potter, 1956, table 2A; Potter and Glass, 1958, table 4.
† Mica included in matrix.
‡ From Potter and Pryor (in press).

Nor is there major contrast in heavy mineral composition. Both the Caseyville and Chester have essentially identical heavy mineral suites. Zircon and tourmaline are the dominant heavy minerals and often constitute more than 90 percent of the nonopaque, nonmicaceous heavy minerals. Apatite is also fairly common, as is barite locally. Minor amounts of rutile, anatase, brookite, and garnet also are present. Although a few other nonopaque, nonmicaceous minerals can be found, they are exceedingly rare. Of the micaceous minerals larger than 62 microns, muscovite is predominant. Minor amounts of biotite and occasional flakes of detrital chlorite are present.

The abundance of polycrystalline quartz and rounded tourmaline also was evaluated, previously published data (Siever and Potter, 1956, p. 321-324; Potter and Glass, 1958, p. 28-33, and Potter and Pryor, in press) providing most of the information. Appendix A displays the tourmaline data. Appendix B provides the details of the methods and indicates that rounded tourmaline is more effective than polycrystalline quartz in distinguishing the Caseyville from the Chester sandstones. The amount of rounded tourmaline also correlates closely with that of rounded quartz and zircon grains (Potter and Pryor, in press).

Figure 4 shows two cumulative curves of rounded tourmaline in 135 Caseyville and Chester samples from the Illinois Basin. Caseyville samples had an average of 27.6 percent rounded tourmaline grains, and Chester samples averaged 44.2 percent rounded grains. The Kolomogorov-Smirnov two-sample test (Siegel, 1956, p. 127-136) showed the two distributions are significantly different at .001 level; Caseyville sand grains are thus generally less well rounded than Chester grains, and grain roundness is a definite aid in distinguishing the two groups of sandstones. However, as shown by the overlap of the two distributions, this contrast did not extend to every individual sample.

As as additional test, roundness was investigated in several profiles. In figure 5, round grain determinations are plotted against stratigraphic position in the Forester core of Perry County, Illinois. Just above a limestone bed in the Clore Formation a sharp break occurs in the amount of rounded tourmaline. The average for nine Caseyville samples is 32 percent rounded grains whereas that for 15 Chester samples is 50 percent. In this core, rounded tourmaline data fitted other geologic data and effectively distinguished the Caseyville and Chester.

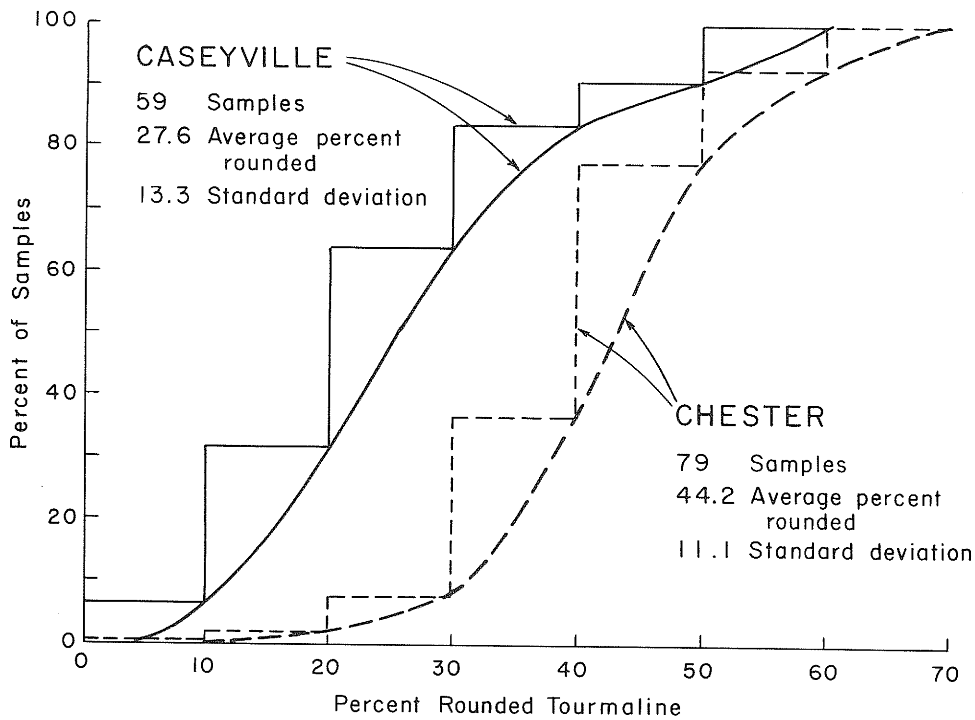

Fig. 4 - Step and smooth cumulative curves of rounded tourmaline in Caseyville and Chester samples.

Determinations of rounded grains also were made in eastern Hardin County, Illinois (fig. 6). Although the Caseyville samples have a lower average of rounded grains (40 percent) than the Chester sandstones (46 percent), the test method does not effectively distinguish individual samples of Chester age from samples of the Lusk and Battery Rock Sandstone Members of the Caseyville. The Lusk and Battery Rock here occur in the deeply entrenched pre-Pennsylvanian Evansville channel (Wanless, 1955, p. 1763), which may be responsible for this lack of contrast. Local reworking, induced by channel erosion or possibly by local post-Chester-pre-Caseyville structural movements can nullify the usefulness of roundness data.

SHALES

The shales of the Caseyville are easier to distinguish from those of the Chester than are the sandstones because the color, texture, organic content, physical properties, and mineralogy of the shales have a wider range of variation. They generally can be differentiated by hand lens or binocular microscope, but some lithologically similar shales do occur.

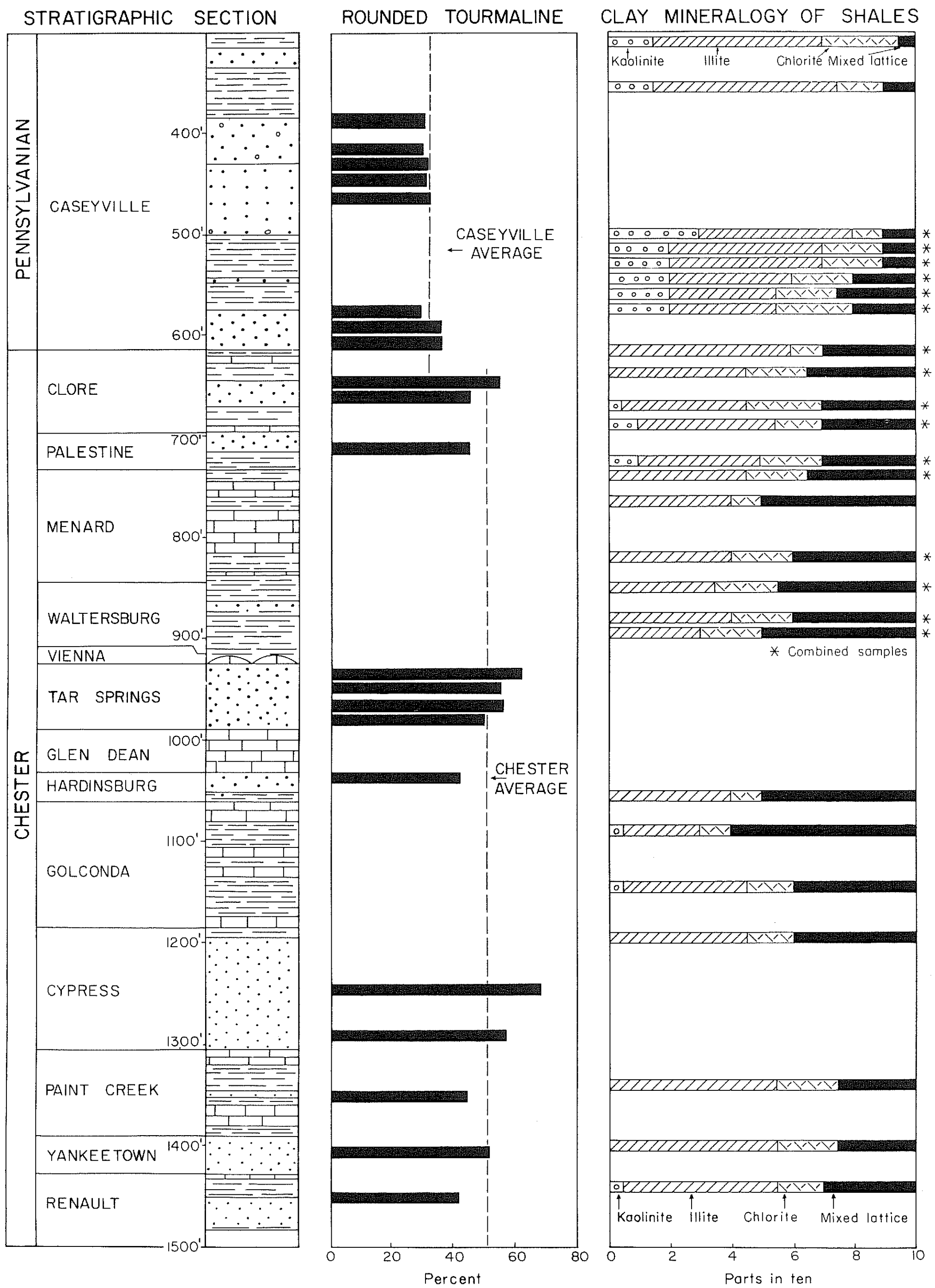

Fig. 5 - Amount of rounded tourmaline and the clay mineralogy of shales in core of J. H. Forester, No. 1 fee, sec. 5, T. 6 S., R. 1 W., Perry County, Illinois. Note discontinuity in both amount of rounded tourmaline and clay mineral composition at the Caseyville-Chester contact.

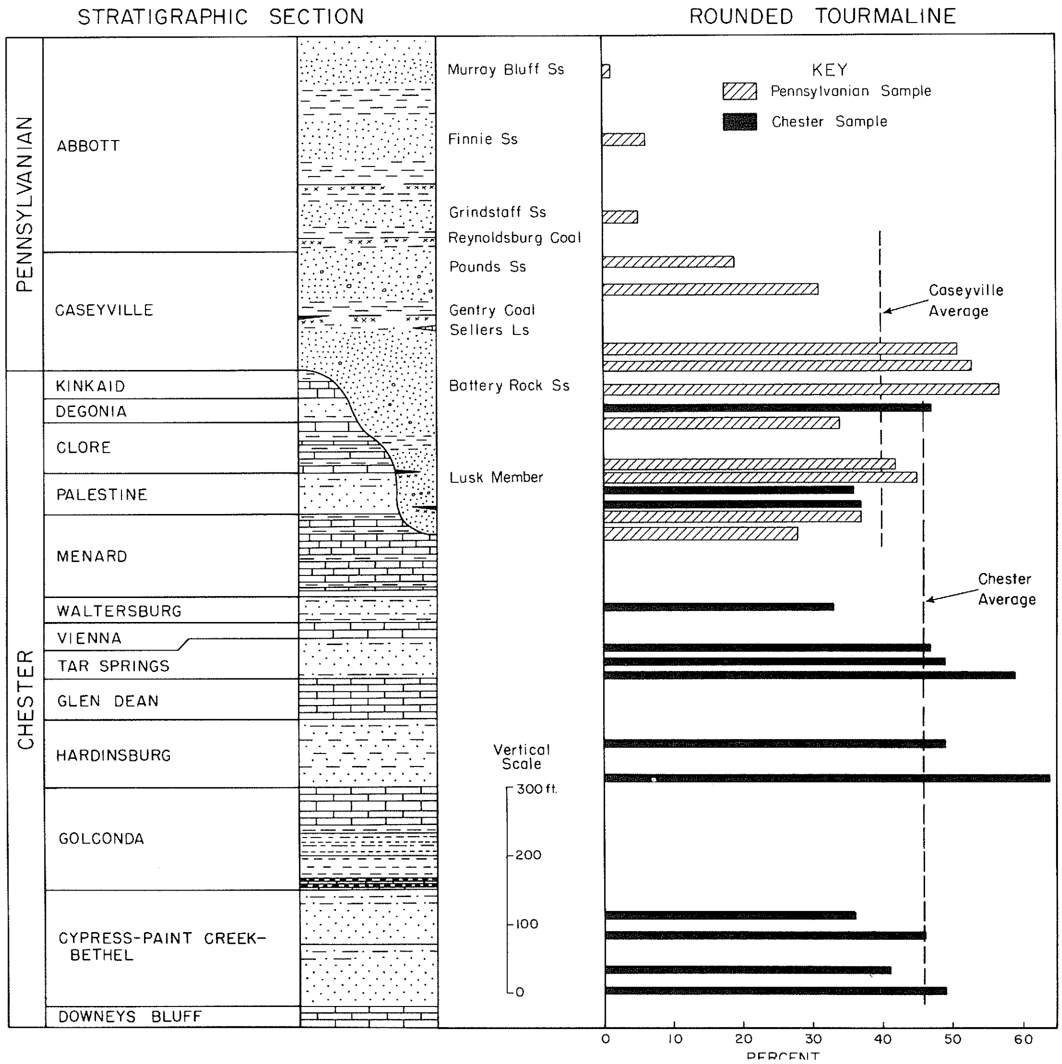

Fig. 6 - Rounded tourmaline in sandstones in the Pennsylvanian and Chester in eastern Hardin County, Illinois.

Table 2 summarizes some easily determined shale characteristics ranked according to their usefulness in distinguishing Caseyville or Chester age and to their reliability. The table lists first those properties that are most definitive of Caseyville age. If a shale is either a nonlaminated mudstone, or is very dark gray to black, or contains clay ironstone concretions or iron carbonate spherules and granules, the probability that it is Caseyville is very high. As in the sandstones, the presence of siderite is one of the most useful indicators of Caseyville age. If a shale is either conspicuously micaceous, silty, or carbonaceous, a Caseyville age is favored, but with less certainty. The carbonaceous material of Chester shales is commonly finer and more macerated than that in the Caseyville.

TABLE 2. - DISTINGUISHING FEATURES OF CASEYVILLE AND CHESTER SHALES*

	Caseyville	Chester
Nonlaminated	XXXXX	X
Very dark gray to black	XXXXX	X
Iron carbonate	XXXXX	X
Micaceous	XXXX	XX
Silty	XXXX	XX
Carbonaceous	XXXX	XX
Noncalcareous	XXX	XXX
Gray to dark gray and greenish gray to dark greenish gray	XXX	XXX
Slickensided	XXX	XXX
Nonsilty	XXX	XXX
Slakes in water	XX	XXXX
Red or green color	X	XXXXX
Calcareous	X	XXXXX
Invertebrate fossils	X	XXXXX

* Number of X's is proportional to the reliability of the criteria.

The middle portion of the table lists those properties that have little discriminating value. If a shale is noncalcareous, gray to dark gray, slickensided, or nonsilty, there is little basis for deciding upon a Chester or Caseyville age.

The lower portion of the table lists the best indications of a Chester age — red or green color, marine fossils, carbonate content, and slaking in water. However, these properties must be studied with caution in well cuttings, because of possible contamination from sediments above the Caseyville.

Many of the characteristics of shales are similar to those of the sandstones. The relative coarseness of the Caseyville sandstones is paralleled by the relatively high silt content in Caseyville shales. A greater amount of very dark gray and black shale and carbonaceous material in the Caseyville reflects the more abundant plant material in the Pennsylvanian sediments, while calcareous shale and invertebrate fossils reflect the greater role of marine environments in the Chester.

Several other properties not listed in table 2 deserve mention. Pennsylvanian shales are rarely as brittle or fissile as Chester shales. Chester shales appear to be somewhat more subject to caving than Caseyville shales.

The shapes of the shale fragments in well cuttings differ in the two systems. Although irregular tabular shapes occur in both, splinter- or lath-shaped fragments are usually conspicuous in samples of cuttings from Chester shales but usually absent in Caseyville cuttings (fig. 7).

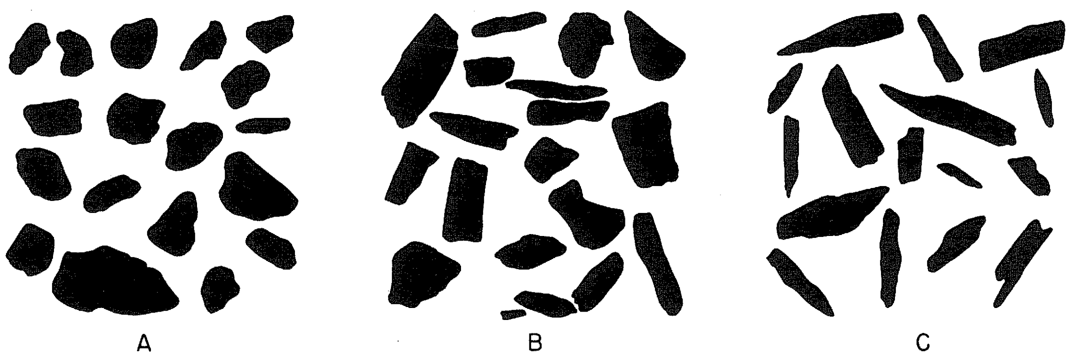

Fig. 7 - Shapes of shale fragments in well cuttings: A – Caseyville, B – Chester, C – Selected lath-shaped Chester.

The clay mineral composition of Caseyville and Chester shales was studied to evaluate its usefulness as a basis for discrimination. To supplement published analyses (Grim et al., 1957; Potter and Glass, 1958, table 8; Smoot, 1960), 143 new clay mineral determinations were made. Altogether, 92 analyses were used for Chester shales and 70 for Caseyville shales. Shale samples were prepared for x-ray spectrometer analysis using oriented aggregates on petrographic glass slides and were treated with ethylene glycol to test for expandable clay minerals. Because of the clay mineral alterations induced by outcrop weathering (Potter and Glass, 1958, p. 40-43; Glass, 1958, p. 237-240), only core samples were used. Appendix C gives sample locations and compositions. Most of the samples come from the structurally deeper portion of the basin (fig. 3), which subsided more rapidly.

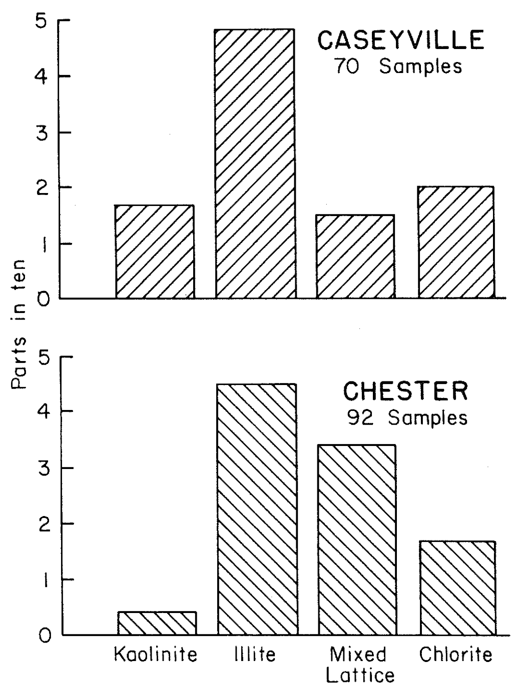

Fig. 8 - Average clay mineral composition of shales from the Caseyville and Chester.

Figure 8 shows the average clay mineral composition of shales from the Caseyville and Chester. Illite and chlorite dominate the clay minerals of both in about the same abundance. In contrast, the amounts of kaolinite and mixed-lattice clay minerals differ markedly between the two. The average composition of a Chester shale includes nearly eight times as much mixed-lattice material as kaolinite, whereas shale in the Caseyville has approximately equal parts of both. On the average, shales from the Caseyville have almost four times as much kaolinite as Chester shales and less than half as much mixed-lattice materials.

The ratio of kaolinite to mixed-lattice material effectively distinguishes the great majority of Caseyville and Chester shales in the structurally deeper portion of the basin (fig. 9). If the ratio of kaolinite to mixed-lattice materials exceeds 0.5, a Caseyville age is indicated. Only 5 percent of Chester shale samples studied have a ratio greater than 0.5. If the ratio is less than 0.5 a Chester age is very strongly indicated since only one Caseyville analysis lies in this range. Outside the structurally deep part of the basin, the kaolinite to mixed-lattice ratio may be appreciably less effective as a distinguishing criterion.

Detailed studies of two diamond drill cores demonstrate the above relationships in the southern part of the basin. Figures 5 and 10 plot clay mineral composition against stratigraphic position. There is noticeably more kaolinite and less mixed-lattice material in the Caseyville than in the Chester shales of both cores.

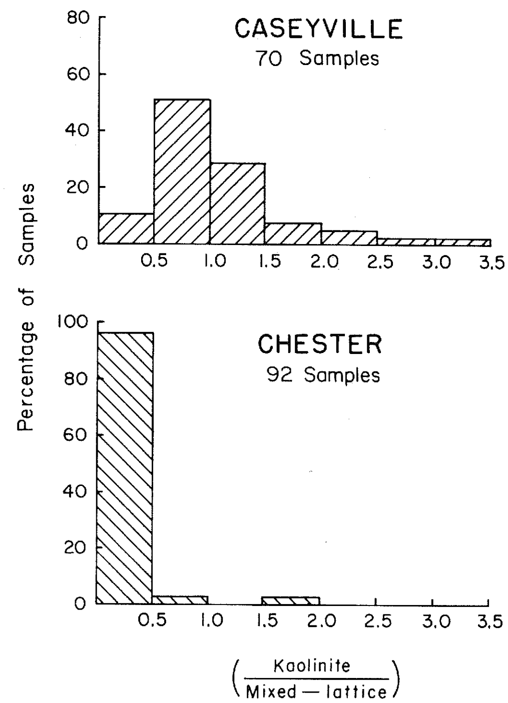

Fig. 9 - Ratios of kaolinite to mixed-lattice clay minerals in shale from the Caseyville and Chester.

If differing organic contents or textures reflect somewhat differing depositional environments, the clay mineralogy of the different shale types might be expected to differ. An evaluation of this hypothesis is given in table 3, which lists the clay mineral compositions associated with eleven shale features. As shown by this table, whether a Caseyville or Chester shale is micaceous, silty, calcareous, or is green or red makes little difference in its average clay mineral composition. Moreover, the differences in clay minerals between the Caseyville and Chester are of the same magnitude, with no regard to types of shales. Thus, as demonstrated by table 3, average clay mineral compositions of Caseyville and Chester shales not only are consistently different but, to a remarkable degree, also are surprisingly independent of the various shale types we sampled.

One of the diagnostic characteristics of Chester shales, as opposed to Caseyville shales, is their much greater slaking in water. Clay mineral composition provides the explanation for this behavior because the mixed-lattice clay minerals that promote slaking are twice as abundant in Chester shales as in Caseyville.

Judged by the data gathered from subsurface samples, clay mineralogy of shales provides an effective means of separating Chester from Caseyville. Because they can be made relatively quickly, clay mineral determinations should prove to be an effective supplement to binocular microscope study in long shale sections. The method may not be as effective with outcrop samples because weathering can be expected to blur rather than heighten the clay mineral contrasts.

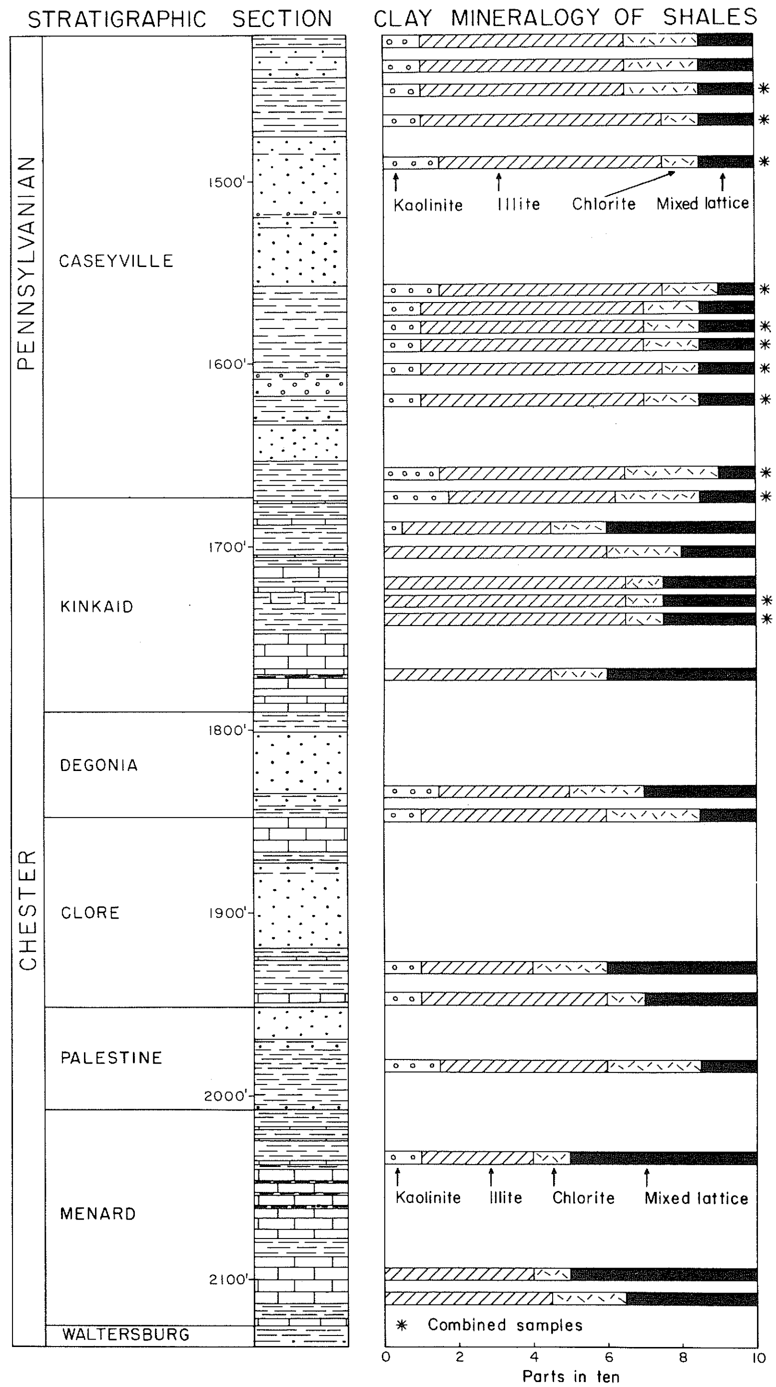

Fig. 10 - Clay mineralogy of shales in core of Madison Coal Company, No. 25, sec. 12, T. 8 S., R. 4 E., Williamson County, Illinois. Note discontinuity of kaolinite and mixed-lattice minerals at Kinkaid-Caseyville contact.

TABLE 3. - SHALE TYPES AND THEIR AVERAGE CLAY MINERAL COMPOSITION
(parts in ten)

Shale Types	Caseyville					Chester					Combined				
	Kaolinite	Mica	Mixed lattice	Chlorite	No. of samples	Kaolinite	Mica	Mixed lattice	Chlorite	No. of samples	Kaolinite	Mica	Mixed lattice	Chlorite	No. of samples
Mudstone	2.1	4.2	1.6	2.1	8	-	-	-	-	-	-	-	-	-	-
Micaceous	1.7	4.1	1.8	2.4	15	0.3	4.1	3.5	2.1	5	1.4	4.1	2.2	2.3	20
Silty	1.6	4.7	1.7	2.0	33	0.6	4.1	3.2	2.1	14	1.3	4.5	2.1	2.1	47
Nonsilty	1.5	5.2	1.5	1.8	26	0.4	4.4	3.5	1.7	61	0.7	4.7	2.9	1.7	87
Carbonaceous	1.7	4.7	1.5	2.1	17	0.4	4.2	3.3	2.1	11	1.1	4.6	2.2	2.1	28
Calcareous	-	-	-	-	-	0.2	4.7	3.5	1.6	29	-	-	-	-	-
Noncalcareous	1.6	5.0	1.6	1.8	59	0.6	4.1	3.4	1.9	46	1.1	4.6	2.4	1.9	105
Slakes in water	-	-	-	-	-	0.4	4.3	3.8	1.5	9	-	-	-	-	-
Very dark gray to black	1.5	4.7	1.4	2.3	16	-	-	-	-	-	-	-	-	-	-
Gray to dark gray and greenish gray to dark greenish gray	1.6	5.1	1.6	1.7	40	0.5	4.2	3.5	1.8	59	1.0	4.5	2.7	1.8	99
Red, green, or red and green mottling	1.3	3.8	2.8	2.0	3	0.3	4.7	3.5	1.5	15	0.5	4.5	3.4	1.6	18

SILTSTONES

Siltstones and siltstone-shale interlaminations probably are the most difficult of all lithologies to separate. Because of the fineness of siltstone grains, many of the criteria that differentiate sandstones fail in the siltstones. The best way to distinguish Chester from Caseyville siltstone-shale interlaminations is by the color of the incorporated or associated argillaceous material. If either the siltstones or the shale interlaminations have a greenish or reddish color, a Chester age is indicated. If gray prevails, discrimination is difficult, and the best procedure is to examine the shale partings and laminations for the diagnostic features listed in table 2.

COALS AND UNDERCLAYS

Although coal beds and underclays occur in both the Chester and the Caseyville, the coal horizons of the Caseyville are much more conspicuous. Caseyville coals such as the Wayside, Battery Rock, and Main Nolin locally are more than 24 inches thick and have been mined in both Kentucky and Illinois. Although coal beds have been reported at seven or eight stratigraphic horizons in the Chester, they are commonly only a fraction of an inch to a few inches thick and are less widespread. Chester and Caseyville underclays have essentially similar appearances.

CHARACTERISTICS ASSOCIATED WITH THE UNCONFORMITY

Three distinctive characteristics are sometimes associated with the unconformity: a green color of the underlying shale, a zone of iron sulfide concentration, and a siderite concentration in the Caseyville.

Although essentially identical in appearance to other green shales in the Chester, the shale beneath the unconformity differs in distribution and origin from those shales whose green color is related to original sedimentation and occurs at positions normally occupied by other shales. This coloration in Chester shales is therefore of post-Chester origin and appears to be the result of weathering during the Mississippian-Pennsylvanian interval. Color and lowered electrical resistivity are the primary expressions of this alteration zone. Thicknesses in excess of 5 feet are rare.

The presence of iron sulfide and siderite in the various sediments on either side of the unconformity was tabulated for sample studies. Iron sulfide marks the unconformity at approximately one well in ten and can occur on either side of it. The iron sulfide generally occurs as crystals and anhedral masses disseminated in the host rock. Approximately one-third of all wells studied had a siderite zone at the base of the Pennsylvanian section. Concentrations up to eight feet thick have been reported, and some of fifteen or twenty feet are suggested in electric logs. Subaerial weathering alters such sideritic zones into limonitic ores that have been noted in outcrops (Gray et al., 1957) at the base of the Pennsylvanian and have been mined locally. This basal zone in the Illinois Basin resembles the Harrison Member "iron ore" found at the base of the Pennsylvanian in Ohio.

GEOPHYSICAL LOGS

Electric logs are the principal means for locating the Pennsylvanian-Chester contact in the subsurface. Other geophysical logs are either uncommon or are poorly adapted to such use. Recent studies of the base of the Pennsylvanian in the subsurface (Lowenstam, 1951, fig. 5; Siever, 1951; Wanless, 1955, fig. 2) have relied largely on electric log data.

The first approach to finding the Chester-Pennsylvanian contact on an electric log is stratigraphic. The major Chester limestone sequences are identified, and the contact is selected at the top of or above the uppermost limestone and beneath the position of the first missing limestone. As the resistivity patterns of the major limestone-bearing formations are recognized readily, the method is quick. It is not precise, however, for the successive sequences thus recognized may be from 50 to 200 feet apart. Precision can be increased somewhat in many areas by using not only such major readily recognized limestone sequences as Kinkaid, Menard, and Glen Dean, but also minor or local limestone sections such as those in the middle part of the Degonia, the upper and lower parts of the Clore, or the Vienna.

With many logs, no approach other than the broad stratigraphic one is possible. The tendency in ambiguous logs is to place the contact at the top of the limestone formation rather than within the overlying clastics where it may actually occur. This results in limestone-bearing formations' being put at the top of the Chester in a very high proportion of logs.

The area of overlap in the electrical properties of Chester and Pennsylvanian shales is large. However, in favorable circumstances a few characteristics will differentiate them. Most of the diagnostic features are shown in figure 11, a log in southwestern White County, Illinois, in the south-central part of the Illinois Basin. These features are shown more clearly on this log than on the average one (figs. 12, 13), but even on figure 11 the assignment of a seven-foot zone is uncertain.

On the self-potential curve there is commonly a slight shift in the shale base line at the Pennsylvanian-Chester contact. The self-potential opposite Chester shales is 2 to 8 millivolts negative (shifted to the left) compared with the potential opposite Pennsylvanian shales. This is contrary to the normal "drift" of the shale line to the right with increasing depth. The shift at the contact tends to be masked by the normal drift on logs where any considerable thickness of other lithologic types separates the respective shales. Moreover, the shift is so small that in many cases it lies within the margin of error of determining a shale base line. The criterion is of little help on logs run in relatively salty mud because the self-potential curve is flatter and more generalized as mud resistivity decreases.

The self-potential varies only a millivolt or so in many Pennsylvanian shales, resulting in a "straight-edge" curve, whereas Chester shales in which the self-potential does not fluctuate rapidly with depth through a range of two to five millivolts are rare. This criterion is useful only on logs with quite detailed self-potential curves, run in moderate- to high-resistivity mud, with little dampening and with no interference from extraneous potential sources. Some Pennsylvanian shales have variable potential curves whereas some Chester shales have straight potential curves (2010' - 2038' on fig. 12) similar to those of Pennsylvanian shales. A shale sequence in the Kinkaid Formation, a short distance above the lower limestone member, is particularly difficult to distinguish from Pennsylvanian shales except where it is overlain by distinctive Chester shales and limestones.

Many Chester shales have lower resistivity than any Caseyville or Abbott Formation shales. In the central, southern, and eastern parts of the basin, any shale bed near the contact that is more than two feet thick and has a resistivity less than 8 or 10 ohmmeters is almost certain to be Chester. Resistivity of both Chester and Pennsylvanian shales is lower in the northwestern part of the basin and electric logs must be used with more caution and the discrimination limit lowered to 7, 6, or even 5 ohmmeters.

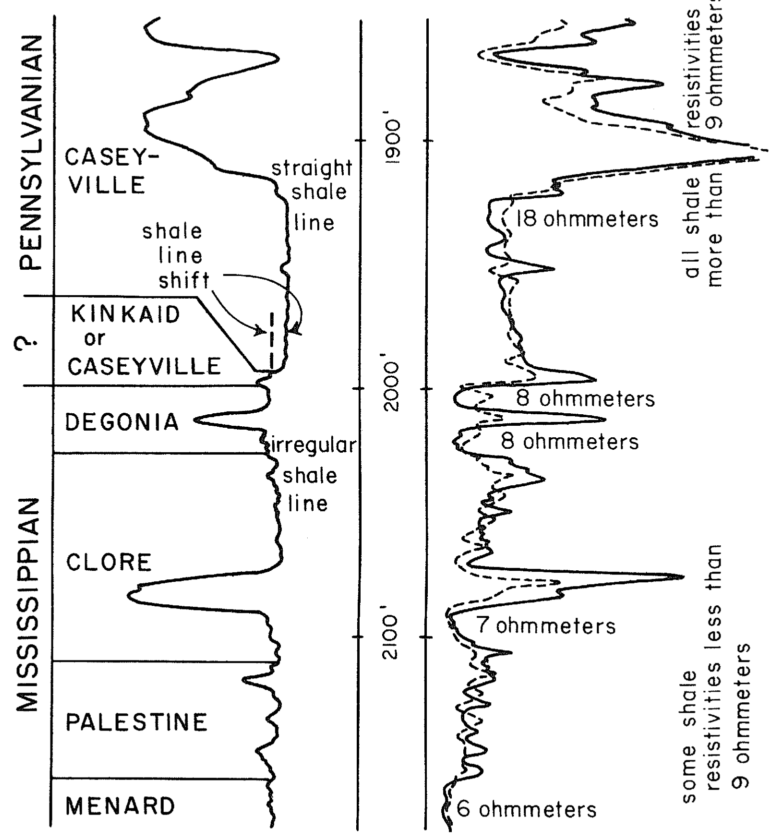

Fig. 11 - Electric log of Herndon Drilling Company, No. 1 Turner, sec. 13, T. 6 S., R. 8 E., White County, Illinois, showing distinguishing characteristics of shales of the Caseyville and Chester.

Electrical properties of Chester and Pennsylvanian sandstones have essentially identical ranges of variation. Some heavily siderite-cemented Pennsylvanian sandstones have lower porosity and resulting higher resistivity than Chester sandstones, but they overlap Chester limestones in these respects.

Use of a combination of approaches — stratigraphic and geographic as well as lithologic or electric — often allows the definite assignment of rocks to one system where a single approach would fail. Stratigraphic and geographic positions limit the potential range of variations in both Chester and Pennsylvanian rocks. In a specific area, differentiation is not as difficult as it is when the whole basin is considered. The geologic control is normally such that only one or two Chester formations could possibly be involved, and the geographic location may limit the number of facies of those formations. For instance, because massive sandstone is not known in the Waltersburg Formation (Chester) in Randolph County, Illinois,

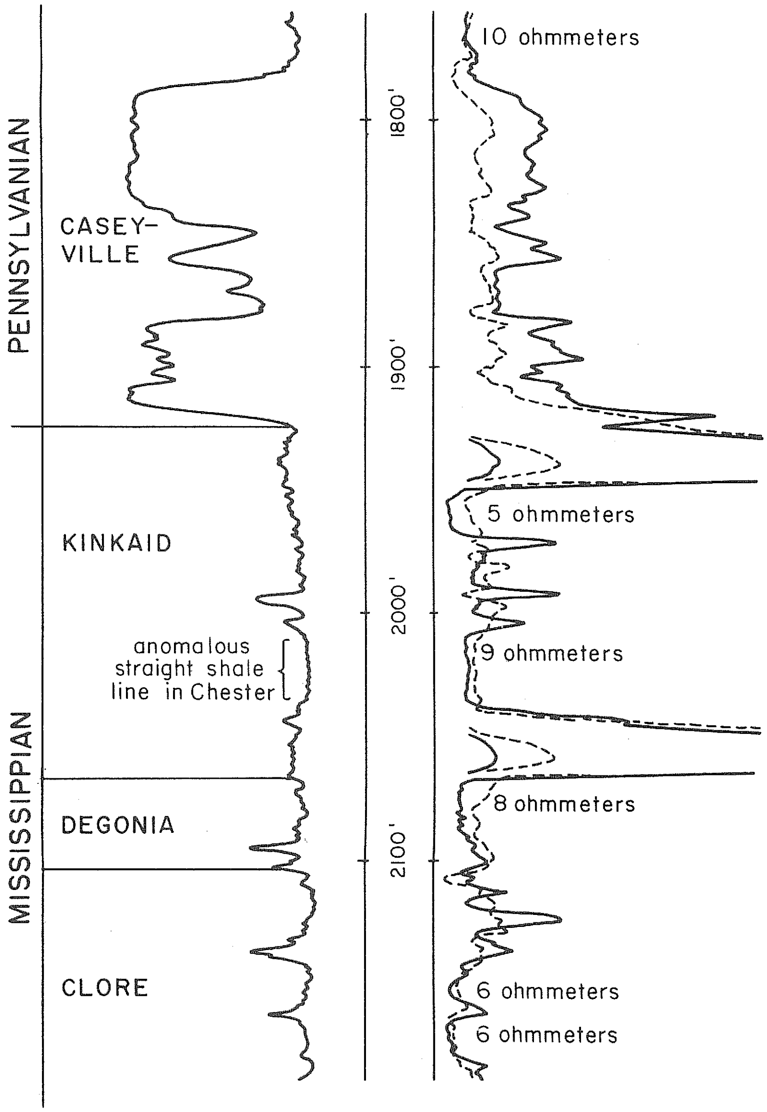

Fig. 12 - Electric log of Oil Management, Inc., No. 2 Moore-Leach, sec. 36, T. 6 S., R. 5 E., Hamilton County, Illinois, illustrating a shale bed in the Chester having Pennsylvanian properties (2010 to 2138 feet).

a 10-foot bed of sandstone found a short distance above the Vienna Limestone in this region could be accepted as Pennsylvanian, whereas the same unit in the same stratigraphic position in Knox County, Indiana, would be indeterminate. Again, a 60-foot bed of sandstone a short distance above the Menard Limestone in Wabash County, Illinois, might be in either the Palestine or the Caseyville, but several

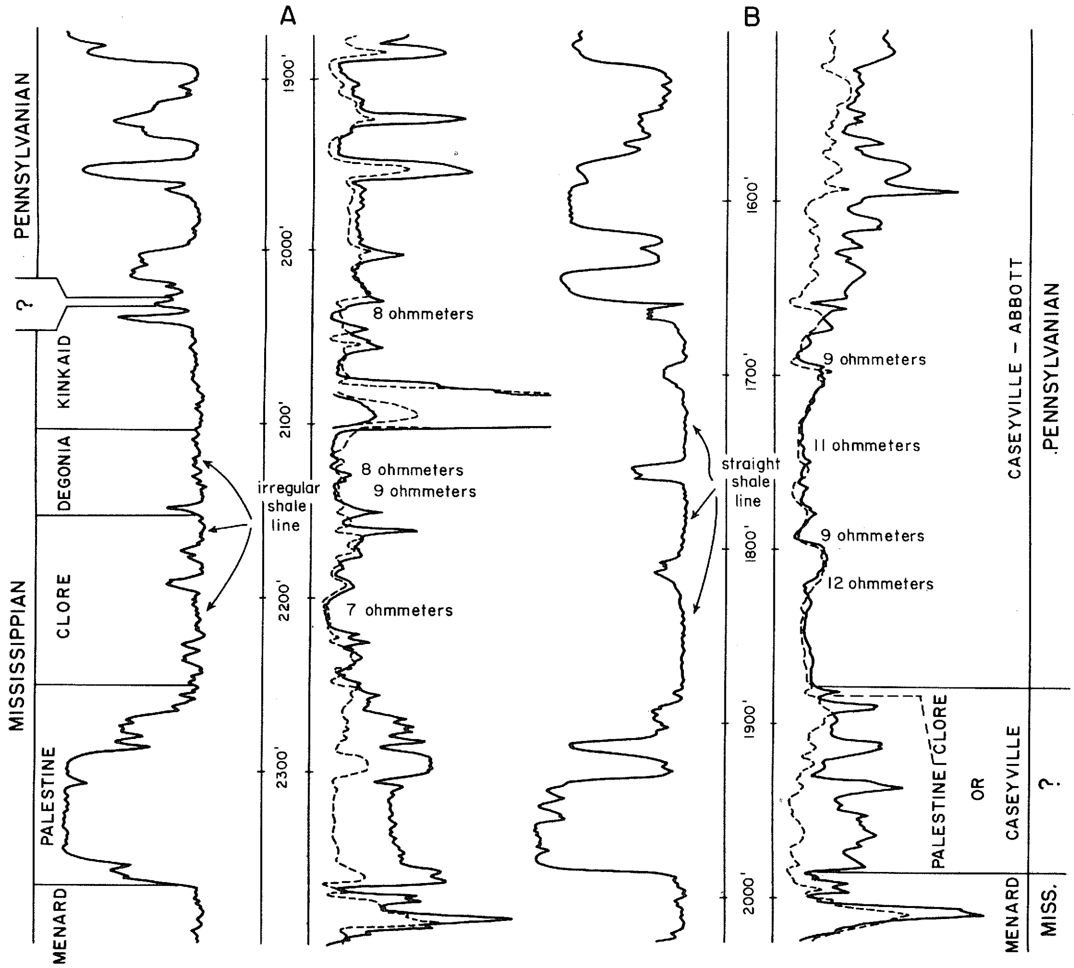

Fig. 13 - Electric logs illustrating problem of correlating channel sandstones. A. - O. W. Minton, No. 1 Adkinson, sec. 11, T. 7 S., R. 5 E., Hamilton County, Illinois, and B. - Youngblood et al., No. 1 Schmidt, sec. 18, R. 2 S., T. 13 W., Wabash County, Illinois.

feet of very dark gray shale here could be accepted as indicating Pennsylvanian age. Finally, a 5-foot bed of shale with a resistivity of 7 ohmmeters a few hundred feet below the commercial coals could safely be called Chester in Posey County, Indiana, but might be in either the Pennsylvanian or Chester in Montgomery County, Illinois.

Detailed knowledge of the stratigraphic succession contributes to the solution of many such specific problems.

By use of many closely spaced logs, the position of the contact may be worked out,whereas this would be impossible were the logs taken singly. In this manner it is sometimes possible to differentiate sheet phase clastic rocks of the Chester from those of Pennsylvanian. Although they are quite similar, there is less continuity of minor lithologic units — especially thin siltstones and silty shales — in the Caseyville and Abbott sheet phase clastics than in those of the Chester. Electric logs, and particularly the self-potential curves of Chester sheet phase clastics, are very similar within a few miles of each other, whereas minor early Pennsylvanian units, perhaps two to six feet thick, seldom can be traced as far as two or three miles.

The differentiation of Pennsylvanian and Chester sediments by electric logs is particularly difficult when both the basal Pennsylvanian and the Chester units are in a channel sand phase. Figure 11 shows that a sheet phase of the Palestine Sandstone (Chester) lies upon a 22-foot low-resistivity shale, the same shale that was removed prior to the deposition of the Palestine channel phase shown in figure 13A. The channel sandstone is overlain by 200 feet of evident Chester, but the similar sandstone of figure 13B is overlain by a shale of definite Pennsylvanian age. The well shown on the log in figure 13B is located where the channel phase is to be expected at both stratigraphic positions. The correlation of the sand body, therefore, cannot be established, and the base of the Pennsylvanian in figure 13B might be at 1880 feet, 1986 feet, or any of several positions between unless criteria other than electrical properties are applied.

The lithologic types associated with the unconformity often can be recognized on electric logs. Sideritic cementation increases downward to the very base of the Pennsylvanian both in silty shales or siltstones (fig. 11) and in sandstones (fig. 12), and the resulting increase in resistivity may be very helpful. A shale two to five feet thick and of relatively low resistivity may develop at the contact, particularly over flat upland portions of the pre-Pennsylvanian surface. Although identical electrically to many Chester shales, it may be at a position in the column where no low-resistivity Chester shales are recorded and thus will serve to mark the contact. This low-resistivity shale is probably the green shale noted earlier that lies immediately beneath the unconformity. A zone of iron sulfide concentration at the base of the Pennsylvanian can give anomalous chemical self-potential values at the contact, presumably from oxidation by the drilling mud.

Certain black shales in the Pennsylvanian have much higher gamma radioactivity than any in the Chester. The more persistent of these radioactive shales are higher in the Pennsylvanian sequence, but some are low enough to be helpful in a few localities.

REGIONAL VARIATIONS AFFECTING RECOGNITION OF THE UNCONFORMITY

Because the nature of the sediments varies throughout the basin, most of the discriminating criteria will be more useful in some areas than in others.

In the northern part of the basin, the Chester limestones are thinner and more erratic in their occurrence than to the south. Thus, clastic-on-clastic contacts are more frequent and the proportion of doubtful picks from subsurface data is higher.

In the northwestern part of the basin the difficulty is aggravated by the local lack of thick sandstones in the basal part of the Pennsylvanian sequence, which makes contacts of shale and shaly sand on shale and shaly sand common. The basal Pennsylvanian shales also contain less silt and their resistivity contrast with Chester shales is therefore greatly reduced.

The Caseyville is marked by prominent thick sandstones along the present southern limit of the basin from Murphysboro, Illinois, to beyond Mammoth Cave, Kentucky. Moreover, the best development of most of the Chester sandstones extends from the fluorspar district in southeastern Illinois and adjacent Kentucky northeastward along the Wabash River Valley. In such areas of optimum sandstone development in both the Caseyville and Chester, electric logs will sometimes show as much as 300 to even 400 feet of sandstone at the position of the unconformity (fig. 3), making electric log identification of the unconformity difficult.

A fourth difficult situation prevails northward from the southeastern corner of the basin. There sandstones in the Caseyville or Mansfield are only occasionally well developed and massive. Chester sandstones also are less well developed. Poorer Pennsylvanian sandstone development, low regional dip, and mature dissection minimize physiographic contrasts between Caseyville and Chester sediments. The wide belt of mature dissection that spans both outcrops results in many isolated sandstone outcrops difficult to identify.

Different areas in the basin will require different combinations of criteria for successful placement of the Mississippian-Pennsylvanian contact. Internal consistency will nearly always reinforce rather than weaken a conclusion. In general, the more criteria used, the more reliable the answer. Because Caseyville and Chester sediments are closely related, difficult mapping problems can arise. Knowledge of the stratigraphic sequence and geophysical logs can provide the solution to many problems, but in other instances techniques using the binocular or petrographic microscope or x-ray diffraction equipment are required. If cuttings, cores, or outcrop samples are available, there are very few lithologic types of Chester and Caseyville sediments that cannot be distinguished.

PROBLEMS ASSOCIATED WITH THE UNCONFORMITY

The problems associated with the unconformity include its morphology, its effect upon the sediments beneath, and its control over the trend and type of basal Pennsylvanian sediments.

By far the most important feature of the unconformity is its morphology, knowledge of which depends largely on detailed mapping of the subsurface. With the exception of a few scattered local studies, only Siever (1951) has published a detailed map and Wanless (1955, fig. 2) a broader reconnaissance map.

Ancient soils have been found at unconformities in rocks ranging in age from Precambrian through Quaternary (Richmond and Frye, 1957, p. 758-759). To judge from the literature, however, weathered zones are not commonly preserved in pre-Quaternary rocks. The Mississippian-Pennsylvanian unconformity in the Illinois Basin appears to depart but little from this pattern. Extensive outcrop mapping and a few diamond drill cores through the unconformity have failed to reveal any buried soils at the top of the Mississippian. Except for some sink hole development, even leached zones on Mississippian limestones are not commonly reported. Ancient soils are most likely to be preserved on areas of flat pre-Pennsylvanian upland overlain by fine-grained Pennsylvanian clastics.

The relief of the unconformity, especially the erosional channels, has exercised important controls on basal Pennsylvanian sediments. Locally, of course, the channels controlled the transport direction of their sediment fill. Regionally, the transport direction of the basal Pennsylvanian grossly parallels this channel system. Erosional channels also influenced the type of sediments that formed the basal Pennsylvanian strata. The sediments that filled the old erosional channels are dominantly thick, channel-phase sandstones that generally contain the coarsest conglomerates. This is especially apparent away from the major areas of Caseyville sandstone deposition. In such areas the channel phase is commonly restricted to the erosional channels of the unconformity, and sheet-phase deposition predominates elsewhere.

Opportunities for outcrop study of this behavior are especially good at a number of points along the eastern edge of the basin in the southeastern corner near Mammoth Cave (Weller, 1928, p. 151-168; Potter and Siever, 1956, fig. 6) and at several points in southern Illinois. Subsurface and outcrop mapping of the erosional channels of the unconformity and their control on the basal facies of Pennsylvanian sediments would help to clarify the stratigraphy of the basal units and predict possible stratigraphic oil traps.

SUMMARY

The broad similarity of both source-area contributions and depositional environments has led to similar Caseyville and Chester clastics. However, it is generally possible to distinguish successfully the age of all but a very few clastic types.

The stratigraphic succession is the starting point for discrimination of Chester and Caseyville sediments. The clastic sediments of the Chester, in contrast to those of the Caseyville, are interbedded with widespread marine carbonates whose succession can be identified. Recognition of the position of the unconformity in the clastic section between the highest preserved limestone and the position that would be occupied by the first missing one is the main problem.

Sandstones in the Caseyville are best distinguished from Chester sandstones by occurrences of quartz granules and visible siderite and coal partings. Chester sandstones are most surely identified when marine fossils, detrital carbonate sand, red or green shale pebble conglomerates, or similarly colored matrix materials are present. Oolites and detrital carbonate grains are virtually restricted to the Chester. Tendencies toward coarseness, poorer sorting, more carbonaceous matter, and more mica are relative indicators of the Caseyville. Although exceptions do exist, Caseyville sand grains are generally more angular than Chester.

The shales of the Caseyville and Chester are more readily distinguished than the sandstones. If a shale is either nonlaminated, very dark gray to black, or contains clay ironstone concretions or iron carbonate, Caseyville age is strongly favored. If a shale is micaceous, silty, or carbonaceous, Caseyville age is indicated, but with less assurance. The most effective criteria of Chester age are red or green color, carbonate content, and marine fossils. Slaking in water and splinter- or lath-shaped shale particles also are indices of a Chester age. Chester shales are also more brittle and cave easier than those of the Caseyville. Shales in the Caseyville contain more kaolinite and less mixed-lattice material than Chester shales. These contrasts prevail even where megascopic characteristics differ. The greater amount of mixed-lattice materials in the Chester is responsible for their greater slaking in water. More radioactive black shales occur in the Caseyville than in the Chester.

Caseyville and Chester siltstones are probably the most difficult of all lithologic types to distinguish. The best criterion for siltstone discrimination is that of color. If the admixed and interlaminated argillaceous materials are a greenish or reddish hue, a Chester age is indicated.

Although coals and underclays occur in both, coals are more widespread and thicker in the Caseyville than in the Chester.

The position of the unconformity is at some localities marked by the green color of the underlying shale, a zone of iron-sulfide concentration, and a siderite zone.

Electric logs can be used successfully to distinguish shales in the Chester from those in the Caseyville. Caseyville shales generally will have a somewhat greater resistivity. The self-potential varies only a millivolt or so in many Pennsylvanian shales, resulting in a "straight edge" curve. No such distinction is possible in the sandstones, for the electrical properties of Pennsylvanian and Chester sandstones have essentially similar ranges of variation. In some wells the rock types associated with the unconformity are recognizable on electric logs. Closely spaced groups of electric logs are much more effective in determining the position of the unconformity than are individual logs.

Caseyville clastics are best distinguished from Chester clastics by using combinations of the above closely related criteria, which are even more effective when combined with knowledge of the regional variations and supplemented by specific stratigraphic information.

Because Caseyville and Chester clastics are products of the same facies of sedimentation, difficult mapping problems arise. Knowledge of the stratigraphic sequence and geophysical logs alone can resolve many of these, but if they fail more refined techniques are available. If cuttings, cores, or outcrop materials are available, there are relatively few Caseyville and Chester clastics that cannot be successfully distinguished.

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APPENDIX A

LOCATION AND ROUNDED TOURMALINE CONTENT OF SAMPLES

Formation (M. = Member)	Sample number	Rounded tour-maline (%)	Location and depth (In Illinois unless otherwise noted)
Pennsylvanian System			
Abbott (Murray Bluff M.)	H-119	0	SW NW NW, 33-10S-9E, Gallatin Co.
Abbott (Finnie M.)	H-118	6	NW SE NW, 33-10S-9E, Gallatin Co.
Abbott (Grindstaff M.)	H-117	5	SE SE NE, 3-11S-9E, Hardin Co.
Caseyville	H-4	31	J. H. Forester, No. 1 fee, 5-6S-1W, Perry Co. (388 feet)
Caseyville	H-5	30	Same (423 feet)
Caseyville	H-6	32	Same (433 feet)
Caseyville	H-7	31	Same (451 feet)
Caseyville	H-8	33	Same (461 feet)
Caseyville	H-9	29	Same (588 feet)
Caseyville	H-10	40	Same (593 feet)
Caseyville	H-11	31	Same (594 feet)
Caseyville	H-12	36	Same (602 feet)
Caseyville	H-28	28	Top of cliff, 265 feet east of shelter house at Cliff View Park in Alto Pass, NW NE NE, 15-11S-2W, Union Co.
Caseyville	H-29	19	Same, nine inches below top
Caseyville	H-30	34	Same, 2 feet 7 inches below top
Caseyville	H-31	26	Same, 4 feet 5 inches below top
Caseyville	H-32	20	Same, 5 feet 5 inches below top
Caseyville (Pounds M.)	H-107	19	NE SW NE, 21-11S-10E, Hardin Co.
Caseyville (Pounds M.)	H-108	31	Same
Caseyville (Battery Rock M.)	H-109	51	SW NW SW, 18-11S-10E, Hardin Co.
Caseyville (Battery Rock M.)	H-110	57	Same
Caseyville (Battery Rock M.)	H-111	53	NE SE NW, 20-11S-10E, Hardin Co.
Caseyville (Battery Rock M.)	H-112	34	Same
Caseyville (Lusk M.)	H-113	52	NE NW NW, 19-11S-10E, Hardin Co.
Caseyville (Lusk M.)	H-114	37	Same
Caseyville (Lusk M.)	H-115	28	SE NE SE, 19-11S-10E, Hardin Co.
Caseyville (Lusk M.)	H-116	45	NE NW NE, 29-11S-10E, Hardin Co.
Mississippian System			
Chester Series			
Degonia	32	39	Madison Coal Co., No. 25, 12-8S-3E, Williamson Co. (1840 feet)
Degonia	51	17	Mississippi River bluff, NE NW SW, 24-8S-5W, Jackson Co.
Degonia	H-1	49	SW$\frac{1}{4}$, 33-7S-6W, Randolph Co.
Degonia	H-2	33	20-11S-1W, Union Co.
Degonia	H-3	31	Along line of secs. 10 and 11, 5S-1W, Perry Co., Indiana

Location and Rounded Tourmaline Content of Samples - Continued

Formation (M. = Member)	Sample number	Rounded tour-maline (%)	Location and depth (In Illinois unless otherwise noted)
Mississippian System - Continued			
Chester Series - Continued			
Degonia	H-33A	47	NW NW NW, 18-11S-9E, Hardin Co.
Clore	34	27	Madison Coal Company, No. 25, 12-8S-3E, Williamson Co. (1910 feet)
Clore	H-13	55	J. H. Forester, No. 1 fee, 5-6S-1W, Perry Co. (649 feet)
Clore	H-14	49	Same (658 feet)
Clore	H-15	40	Same (659 feet)
Clore	H-16	52	Same (666 feet)
Palestine	479	26	SW SE NW, 11-3S-3W, DuBois Co., Indiana
Palestine	4-326	40	Taylor, Byrd and Son, No. 1 J. L. Nelson, 18-7S-10E, White Co. (2086 feet)
Palestine	C-1319A	36	Superior, No. 1 Blood A, 1-3S-10E, Edwards Co. (2176 feet)
Palestine	H-17	45	J. H. Forester, No. 1 fee, 5-6S-1W, Perry Co. (714 feet)
Palestine	H-34A	37	NE NW NW, 18-11S-9E, Hardin Co.
Palestine	H-35A	36	NE NW NW, 24-11S-9E, Hardin Co.
Waltersburg	9	48	Carter, No. 1 Fuller, 11-7S-8E, White Co. (2166 feet)
Waltersburg	475	52	A.M.S. Oil Co., No. 1 Austin, 28-6S-9E, White Co.
Waltersburg	483	39	NW NE, 22-3S-3W, Perry Co., Indiana
Waltersburg	C-1488	50	Magnolia, No. 6 Stanhope, 2S-14W, Edwards Co. (2296 feet)
Waltersburg	H-36A	33	SE SW SE, 19-11S-10E, Hardin Co.
Tar Springs	474	39	Engle, No. 3 Sandefur, 14-N-24, Webster Co., Kentucky (approx. 1840 feet)
Tar Springs	476	52	Two miles west of Cloverport, Breckinridge Co., Kentucky
Tar Springs	C-1803	33	Magnolia, No. 3 Rotramel, 26-2S-14 W., Edwards Co. (2310 feet)
Tar Springs	C-2179	47	Nat. Assoc. Pet., No. 1 Sanders, 33-7S-9E, Gallatin Co. (2310 ft.)
Tar Springs	H-18	63	J. H. Forester, No. 1 fee, 5-6S-1W, Perry Co. (940 feet)
Tar Springs	H-19	55	Same (952 feet)
Tar Springs	H-20	56	Same (980 feet)
Tar Springs	H-21	50	Same (990 feet)
Tar Springs	H-37A	47	SW SE, 27-11S-10E, Hardin Co.
Tar Springs	H-38A	49	Diamond drill hole, NE$\frac{1}{4}$, 27-11S-9E, Hardin Co. (25 feet)
Tar Springs	H-39A	59	SW SE, 27-11S-10E, Hardin Co.

Location and Rounded Tourmaline Content of Samples - Continued

Formation (M. = Member)	Sample number	Rounded tour-maline (%)	Location and depth (In Illinois unless otherwise noted)
Mississippian System - Continued			
Chester Series - Continued			
Tar Springs	H-42	35	Adkins, No. 1 C.W. & F. Coal Co. K, 36-6S-2E, Franklin Co. (2098 feet)
Tar Springs	H-43	41	37 miles south of Crofton, on U. S. 41, Christian Co., Kentucky
Hardinsburg	370	37	One mile north of Hardinsburg, Breckinridge Co., Kentucky
Hardinsburg	473	32	Near base of formation in abandoned quarry on north side of Green River at Brownsville, Edmonson Co., Kentucky
Hardinsburg	575	40	10,500 feet from S line, 7050 ft. from E line of the quadrangle, 19-L-41, Grayson Co., Kentucky
Hardinsburg	H-22	43	J. H. Forester, No. 1 fee, 5-6S-1W, Perry Co.
Hardinsburg	H-40A	49	Diamond drill hole, NE$\frac{1}{4}$, 27-11S-9E, Hardin Co. (151 feet)
Hardinsburg	H-41A	64	Diamond drill hole, NE$\frac{1}{4}$, 27-11S-9E, Hardin Co. (222 feet)
Hardinsburg	H-44	44	3400 feet from W line, 1700 feet from N line, 5-H-42, Edmonson Co., Kentucky
Hardinsburg	H-45	44	3800 feet from N line, 1950 feet from W line, 5-R-38, Meade Co., Kentucky
Hardinsburg	H-46	51	550 feet from S line, 400 feet from E line, 11-S-37, Meade Co., Kentucky
Hardinsburg	H-47	44	6-7S-2E, Crawford Co., Indiana
Hardinsburg	H-48	28	Deep Rock, No. 1 Phipps, 29-5S-9E, White Co. (2647 feet)
Big Clifty	574	40	11,500 feet from E line, 3500 from S line of the quadrangle, 23-K-41, Hart Co., Kentucky
Big Clifty	H-49	50	2800 feet from E line, 9100 feet from N line of the quadrangle, 10-0-39, Breckinridge Co., Kentucky
Big Clifty	H-51	44	Approximately 3.5 miles north of Fairview, 8-E-27 or 9-E-27, Todd Co., Kentucky
Big Clifty	H-52	55	3000 feet from E line, 7800 feet from S line of the quadrangle, 20-M-40, Grayson Co., Kentucky
Big Clifty	H-53	48	5350 feet from S line, 10,900 feet from W line, I-44 Hart Co., Kentucky

Location and Rounded Tourmaline Content of Samples - Continued

Formation (M. = Member)	Sample number	Rounded tour-maline (%)	Location and depth (In Illinois unless otherwise noted)
Mississippian System - Continued			
Chester Series - Continued			
Cypress	371	39	NE NE, 14-14S-6E, Pope Co.
Cypress	426	48	Shell, No. 1 Montgomery, 14-1S-6E, Wayne Co. (3077 feet)
Cypress	427	34	Pure, No. 1 Harrell, 26-4N-9E, Richland Co. (2576 feet)
Cypress	H-23	68	J. H. Forester, No. 1 fee, 5-6S-1W, Perry Co. (1245 feet)
Cypress	H-24	57	Same (1296 feet)
Cypress	H-57	41	20-13S-2E, Johnson Co.
Cypress	H-103	36	Diamond drill hole, NE$\frac{1}{4}$, 27-11S-9E, Hardin Co. (426 feet)
Cypress	H-104	46	Diamond drill hole, NE$\frac{1}{4}$, 27-11S-9E, Hardin Co.
Cypress (Elwren)	481	48	SW SW NE, 20-8N-2W, Monroe Co., Indiana
Cypress (Elwren)	482	44	SW NE NW, 32-2S-1E, Crawford Co., Indiana
Cypress (Elwren)	573	9	5000 feet from W line, 7700 feet feet from N line, 6-P-39, Breckinridge Co., Kentucky
Cypress (Elwren)	H-54	33	21-13N-5W, Putnam Co., Indiana
Paint Creek	H-25	44	J. H. Forester, No. 1 fee, 5-6S-1W, Perry Co. (1370 feet)
Paint Creek	H-105	41	Diamond drill hole, NE$\frac{1}{4}$, 27-11S-9E, Hardin Co. (484 feet)
Paint Creek (Sample)	484	34	NE NW NE, 12-3S-2E, Harrison Co., Indiana
Paint Creek (Sample)	577	46	6-P-39, Breckinridge Co., Kentucky
Paint Creek (Sample)	H-55	64	8150 feet from W line, 8300 feet from N line of quadrangle, L-42, Grayson Co., Kentucky
Yankeetown (Benoist)	429	32	Townsend-Banks, No. 1 Clark, SE NE SE, 13-2S-1E, Jefferson Co., (2090 feet)
Yankeetown (Benoist)	H-26	53	J. H. Forester, No. 1 fee, 5-6S-1W, Perry Co. (1410 feet)
Bethel	372	42	30-13S-6E, Pope Co.
Bethel	373	29	SE SE, 29-6N-2W, Lawrence Co., Indiana
Bethel	374	63	Top of main Cedar Bluff quarry; 2.5 miles south of Princeton, Caldwell Co., Kentucky
Bethel	H-56	27	3-3N-2W, Lawrence Co., Indiana
Bethel	H-106	49	Diamond drill hole, NE$\frac{1}{4}$, 27-11S-9E, Hardin Co. (515 feet)

Location and Rounded Tourmaline Content of Samples - Continued

Formation (M. = Member)	Sample number	Rounded tour-maline (%)	Location and depth (In Illinois unless otherwise noted)
Mississippian System - Continued			
Chester Series - Continued			
Bethel (Mooretown)	448	60	Roadcut on south side of U. S. 60, approximately one-half mile south of Guston, 7-Q-40, Meade Co., Kentucky
Renault	H-27	42	J. H. Forester, No. 1 fee, 5-6S-1W, Perry Co. (1463 feet)
Aux Vases	368	50	11-34N-13E, Perry Co., Missouri
Aux Vases	480	44	NW SW NE, 21-9N-2W, Monroe Co., Indiana

APPENDIX B

ROUNDED TOURMALINE AND POLYCRYSTALLINE QUARTZ

Tourmaline grains were divided into two classes on the basis of roundness. Grains with roundness of 0.6 or more (Krumbein, 1941, p. 68-70) were classified as rounded, all others as nonrounded. Percentages were estimated for the size fraction. 0.062 to 0.5 mm. One hundred tourmaline grains per slide were classified.

Quartz grains composed of two or more crystals were defined as polycrystalline. These grains generally consist of 10 or more interpenetrating sutured anhedral crystals. One hundred loose quartz grains on glass slides were counted. In thin sections, 200 grains per slide were counted.

Two preliminary tests were made to determine the validity of these procedures — fraction analyses and operator experiments.

Fraction Analyses. - Two pairs of fraction analyses from Caseyville and Cypress (Chester) sandstones are shown in figure 14. In this comparison the tourmaline roundness of the Cypress exceeds that of the Caseyville in every size class. For the entire size range, about 54 percent of the Cypress tourmaline grains were judged to be rounded, whereas only 33 percent of the Caseyville tourmaline grains were rounded. Noteworthy is the greater roundness exhibited by even the finer Cypress size classes, indicating that the sands of Chester age had a much longer abrasion history than those of the Caseyville.

Amount of polycrystalline quartz shows a much closer relationship to grain size, and in most size classes the differences between the two samples are not pronounced. Although the relative abundance of polycrystalline grains increases rapidly in the larger grain sizes, in the size classes with the most grains polycrystalline grains account for only six percent in the Caseyville and three percent in the Chester sandstones.

Operator Experiments. - Two operator experiments evalued the joint effects of operators, slides, and the two geologic systems. The tourmaline roundness experiment produced definitive results. Each operator not only could clearly distinguish between the two systems but between the different samples within each system. On the other hand, the operators failed to distinguish between the two systems and generally between the samples within a system when polycrystalline quartz grains, either in thin section or as loose grains, were studied.

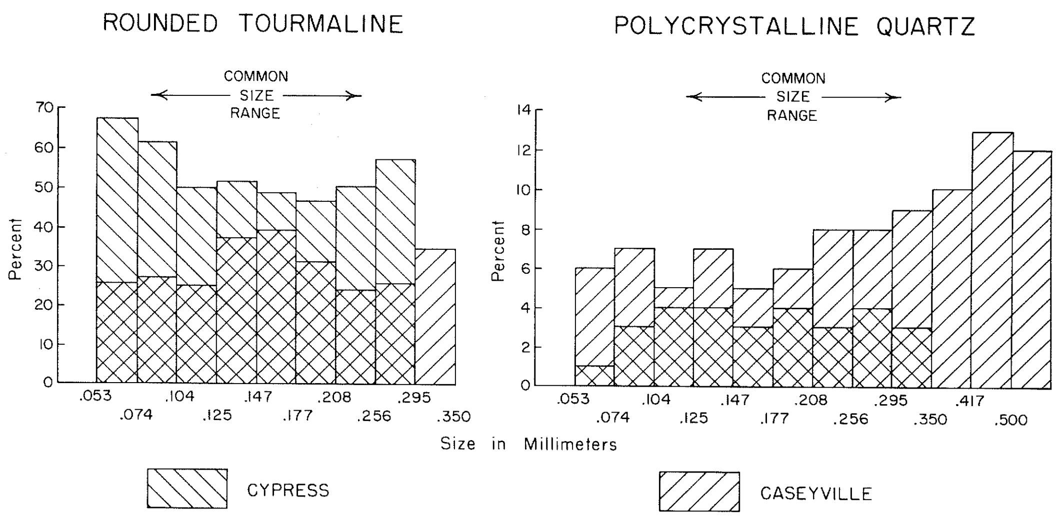

Fig. 14 - Rounded tourmaline and polycrystalline quartz in size separations from an outcrop of Cypress (Chester) Sandstone in NW cor. SE¼ NW¼ sec. 20, T. 13 S., R. 2 E., Johnson County, Illinois; and from a core of Caseyville from a depth of 491 feet in the core of the J. H. Forester, No. 1 fee, sec. 5, T. 6 S., R. 1 W., Perry County, Illinois. No analysis could be made for Cypress tourmaline roundness coarser than 0.295 mm, nor for polycrystalline quartz coarser than 0.350 mm.

APPENDIX C

CLAY MINERAL ANALYSES OF SHALES
(parts in ten)

Depth (feet)	Kaolinite	Illite	Mixed lattice	Chlorite	Stratigraphic unit
		Benedum and Trees, No. 1 Nugent 21-2N-5E, Wayne County, Illinois			
2773	1	4	3	2	Cypress
2776	1	4	3	2	Cypress
2784	1	4	3	2	Cypress
2798	0	4	4	2	Paint Creek
2803	0	4.5	3.5	2	Paint Creek
2806	0	6	1.5	2.5	Paint Creek
2827	0.5	4	3.5	2	Paint Creek
2878	0.5	4.5	3	2	Renault
2880	0.5	4	3.5	2	Renault
2884	0	4.5	3.5	2	Renault
2920	0	5	2	3	Aux Vases
		Benedum and Trees, No. 1 Valbert 12-2N-6E, Clay County, Illinois			
2972.5	0.5	3.5	4	2	Renault
3008	0	5	4	1	Aux Vases
3015	0	6	3	1	Aux Vases
3023	0	5.5	2.5	2	Aux Vases
3029	0	5.5	2.5	2	Aux Vases
		J. H. Forester, No. 1 fee 5-6S-1W, Perry County, Illinois			
308	1.5	5.5	0.5	2.5	Caseyville
353	1.5	6	1	1.5	Caseyville
500.5	3.5	4.5	1	1	Caseyville
501.5	2	5.5	1	1.5	Caseyville
506	2	5	1	2	Caseyville
510	2	5	1	2	Caseyville
512	2	4.5	1.5	2	Caseyville
518	1.5	5.5	1	2	Caseyville
523	1.5	5.5	1	2	Caseyville
525	1.5	5	1.5	2	Caseyville
526.5	1.5	5	1.5	2	Caseyville
530	2	4.5	1.5	2	Caseyville
537.5	2.5	4	1.5	2	Caseyville
538.5	1.5	5.5	1	2	Caseyville
539	2.5	4	1	2.5	Caseyville
549.5	2.5	3.5	2	2	Caseyville
550	3	2.5	2.5	2	Caseyville
552	2.5	3.5	2	2	Caseyville
555	2.5	3.5	2	2	Caseyville
558	2	3.5	2.5	2	Caseyville
560	2.5	3	2.5	2	Caseyville
560.5	2	3	2.5	2.5	Caseyville
567	2.5	2.5	2.5	2.5	Caseyville
572	1.5	3.5	2	3	Caseyville

CLAY MINERAL ANALYSES OF SHALES - Continued

Depth (feet)	Kaolinite	Illite	Mixed lattice	Chlorite	Stratigraphic unit
		J. H. Forester, No. 1 fee - Continued			
574	2	3.5	2.5	2	Caseyville
575	2	3	2.5	2.5	Caseyville
576	2.5	2.5	2.5	2.5	Caseyville
606	2.5	2.5	2	3	Caseyville
613.5	1	3.5	3.5	2	Caseyville
614	0.3	5.2	3.5	1	Clore
615	0	6	3	1	Clore
616.5	0	6.5	2.5	1	Clore
618	0	7	2	1	Clore
619	0	6.5	2.5	1	Clore
620	0.3	6.2	2.5	1	Clore
625	0	6	2	2	Clore
630	1	5	2	2	Clore
635	0	3	6	1	Clore
640	0.3	3	4.7	2	Clore
645	1	4.5	2	2.5	Clore
672	1	2	2	2.5	Clore
676	0	3.5	4	2.5	Clore
684	1	3	4	2	Clore
687	1	3.5	3.5	2	Clore
688	1	4.5	2.5	2	Clore
691	0.5	5	2.5	2	Clore
694	0.5	5	3	1.5	Clore
700	0.5	5.5	2	2	Palestine
705	0.3	5.7	3	1	Palestine
711	0.5	5	2.5	2	Palestine
723	1	4.5	2.5	2	Palestine
728	1	5	2	2	Palestine
734	1	5	2	2	Menard
740	1	3	4	2	Menard
750	0	4	5	1	Menard
766	0	4.5	3.5	2	Menard
772	0	4	4	2	Menard
775	1	2	5	2	Menard
798	0	5.5	2.5	2	Menard
805	0	4.5	3.5	2	Menard
814	0	4.5	3.5	2	Menard
816	0.3	3	4.7	2	Menard
846	0	3	5	2	Waltersburg
850	0	4	4	2	Waltersburg
858	0.3	4	4.7	1	Waltersburg
862.5	0	3	5	2	Waltersburg
868	0	3.5	4	2.5	Waltersburg
872	0.3	3.7	4	2	Waltersburg
878	0	3	5	2	Waltersburg
883	0	3	5	2	Waltersburg
886	0	3	5	2	Waltersburg
1058	0	4	5	1	Hardinsburg
1092	0.5	2.5	6	1	Golconda
1143	0.5	4	4	0.5	Golconda
1195	0	4.5	4	1.5	Cypress

CLAY MINERAL ANALYSES OF SHALES - Continued

Depth (feet	Kaolinite	Illite	Mixed lattice	Chlorite	Stratigraphic unit
		J. H. Forester, No. 1 fee - Continued			
1340	0	5.5	2.5	2	Paint Creek
1396	0	5.5	2.5	2	Yankeetown
1442	0.5	5	3	1.5	Renault
		Madison Coal Co., No. 2 24-1N-9W, St. Clair County, Illinois			
260	1	1	6	2	Cypress
265	0.5	4	4.5	1	Cypress
269	0.5	4.5	5	?	Cypress
312	1	2	4	3	Cypress
329	1.5	1.5	5	2	Paint Creek
341	?	2.5	5	2.5	Paint Creek
378	?	3	5	2	Paint Creek
		Madison Coal Co., No. 25 12-8S-3E, Williamson County, Illinois			
1420	1	5.5	1.5	2	Caseyville
1438	1	5.5	1.5	2	Caseyville
1445	1	5.5	1.5	2	Caseyville
1450	1	5.5	1.5	2	Caseyville
1455	1	5	2	2	Caseyville
1456	1	5	2	2	Caseyville
1462	1	5.5	2	1.5	Caseyville
1467.5	1	7	1	1	Caseyville
1471	1.5	6	1.5	1	Caseyville
1474	1	6	2	1	Caseyville
1480	1	6	1.5	1.5	Caseyville
1490	1	6	2	1	Caseyville
1492	1.5	6	1.5	1	Caseyville
1557	1.5	6	1	1.5	Caseyville
1562.5	1.5	6	1	1.5	Caseyville
1572	1	6	1.5	1.5	Caseyville
1578	1	6.5	1.5	1	Caseyville
1581	1	6	1.5	1.5	Caseyville
1587	1	6	1.5	1.5	Caseyville
1593	1	6	1.5	1.5	Caseyville
1600	1	6	1.5	1.5	Caseyville
1604	1.5	7	1.5	?	Caseyville
1620	1.5	5.5	1.5	1.5	Caseyville
1621	1	6.5	1.5	1	Caseyville
1664	1.5	5.5	1	2	Caseyville
1667	1.5	5	1	2.5	Caseyville
1669	1.5	5	1.5	2	Caseyville
1673	2	3.5	1.5	3	Caseyville
1687	0.5	4	4	1.5	Kinkaid
1693	1	5.5	1.5	2	Kinkaid
1698	0.5	5.5	1.25	2.5	Kinkaid
1704	?	6	2	2	Kinkaid
1721.5	?	6.5	2.5	1	Kinkaid
1727	?	6.5	2.5	1	Kinkaid
1733	?	6.5	2.5	1	Kinkaid

CLAY MINERAL ANALYSES OF SHALES - Continued

Depth (feet)	Kaolinite	Illite	Mixed lattice	Chlorite	Stratigraphic unit
		Madison Coal Co., No. 25 - Continued			
1738	?	6.5	2.5	1	Kinkaid
1738.5	?	7.5	1.5	1	Kinkaid
1744.5	0	6.5	2.5	1	Kinkaid
1770	?	4.5	4	1.5	Kinkaid
1831.5	1.5	3.5	3	2	Degonia
1846	1	5	1.5	2.5	Clore
1930	2	3	1	4	Clore
1931	1	3	4	2	Clore
1946	1	5	3	1	Clore
1984	1.5	4.5	1.5	2.5	Menard
2034	1	3	5	1	Menard
2082	0	7.5	1.5	1	Menard
2096	?	4	5	1	Menard
2111	?	4.5	3.5	2	Menard
		Taylor, Byrd and Son, No. 1 J. L. Nelson, "New Haven Core" 18-7S-10E, White County, Illinois			
1594	2.5	4	1	2.5	Caseyville
1594.5	1.5	5	1	2.5	Caseyville
1606	2	4.5	1	2.5	Caseyville
1611	1.5	5	1	2.5	Caseyville
1615	2.5	4	1	2.5	Caseyville
1615.5	1.5	4	1.5	3	Caseyville
1630	1.5	4	1.5	3	Caseyville
1635	2	4	1.5	2.5	Caseyville
1645	1.5	5	1.5	2	Caseyville
1646	1.5	4.5	1.5	2.5	Caseyville
1663	1.5	5	1.5	2	Caseyville
1738	1.5	5	1	2.5	Caseyville
1744.5	1.5	4	1.5	2.5	Caseyville

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