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GEOLOGY AND PETROLOGY OF THE ANVIL ROCK SANDSTONE OF SOUTHERN ILLINOIS

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ABSTRACT

The Pennsylvanian Anvil Rock Sandstone occurs at the base of the McLeansboro Group in the Illinois Basin. This sandstone fills channels that have been eroded above, and in places through, No. 6 Coal, the principal minable coal in Illinois. The morphologic and petrologic properties of the Anvil Rock Sandstone were studied to determine the nature of the channels. Distribution and occurrence of these channels may be important in exploration and exploitation of No. 6 Coal in Illinois.

The Anvil Rock Sandstone in the southern portion of the Illinois Basin in Illinois, Indiana, and Kentucky was mapped in subsurface. Two morphologic elements were determined: a sheet phase and a channel phase.

The conformable sheet phase of Anvil Rock deposition is confined to the more rapidly subsiding portions of the Illinois Basin and does not occur on the western shelf area, but the channel phase of deposition shows no clear relation to differential subsidence. Study of sand and clay fractions indicates negligible mineralogical difference between the sheet and channel phases of sand deposition. The sandstones of both phases are subgraywackes, but the channel phase is distinguished by greater thickness, coarser grain, better sorting, and more prevalent cross-bedding.

The sheet phase is probably a regressive marine sandstone, whereas the erosional channels are considered to be of subaerial origin and to be dominantly filled with fluvial sandstones and shales. Subsurface channel pattern harmonizes with the dip direction of cross-bedding to demonstrate a general south-southwestward orientation of the ancient drainage system. An immature terrain to the north and northeast appears to have been the major source of sediments.

Although the evidence is inconclusive, it appears that the channel phase is younger than the sheet phase.

INTRODUCTION

Most of the sandstones of the Pennsylvanian System in the Illinois Basin have thick, massive phases that are local thickenings of a more widespread sandstone. Because the thick phases commonly occupy relatively narrow sinuous valleys or channels of erosional origin, they have been called "channel sandstones" (Weller, 1930; Wanless, 1931). This report deals with one such stratigraphic unit, the Anvil Rock Sandstone in the lower part of the McLeansboro

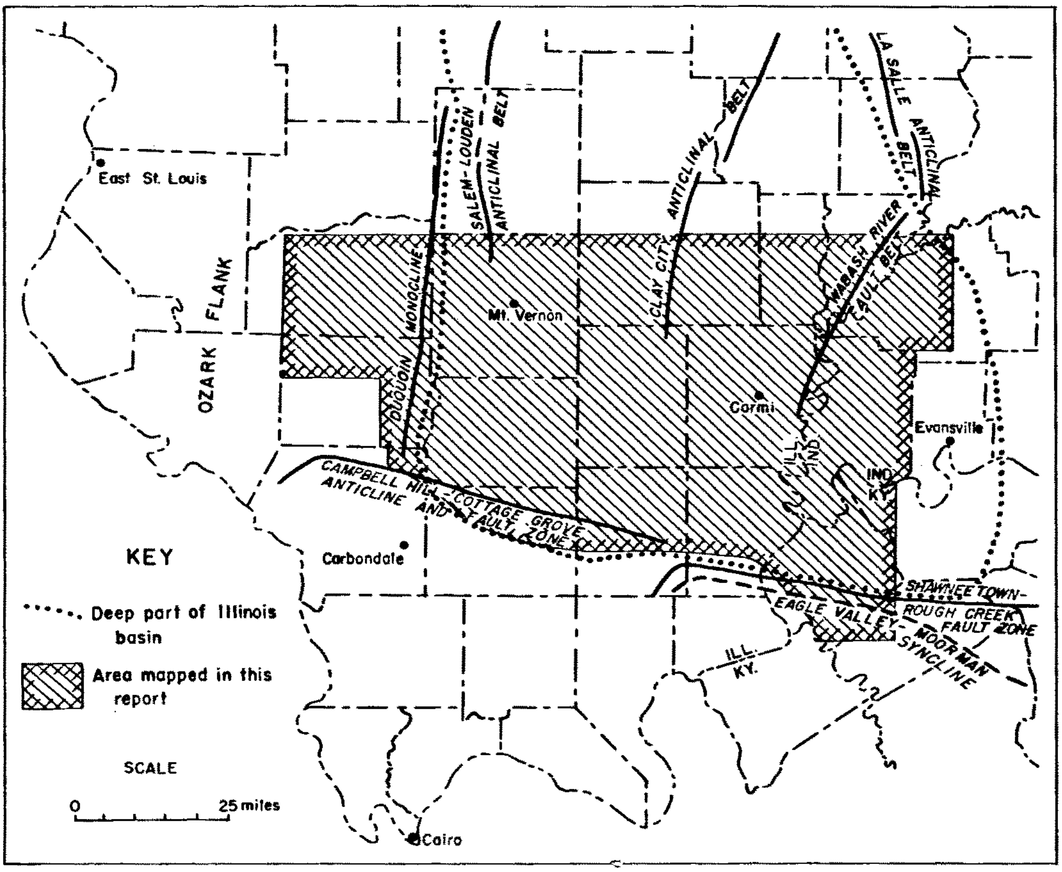

Fig. 1. - Index map showing principal structural trends and study area.

Group of the Illinois Basin. Although not everywhere well developed, the Anvil Rock Sandstone is present throughout most of the Illinois Basin. The Copperas Creek Sandstone is considered the equivalent of the Anvil Rock Sandstone in northern and western Illinois.

That the Anvil Rock occurs in channels has been known for some time, and channel trends have been recognized in some areas. At many places in Illinois where the Herrin (No. 6) Coal has been eroded, the resultant channel is filled with Anvil Rock Sandstone.

This study of the Anvil Rock Sandstone was made to 1) delineate the known Anvil Rock channels, 2) show its thickness distribution over a large part of southern Illinois and parts of Indiana and Kentucky, 3) infer the direction of sediment transport, 4) suggest a source for the sand, 5) propose a theory of how the channels developed and the sand was deposited, and 6) show the effects of channels on coal mining operations.

To achieve these objectives a combined field and laboratory study was necessary. This report presents the results of detailed mapping of the subsurface of the southern portion of the basin (fig. 1), field study of sedimentary structures, and laboratory study of mineralogical and textural characteristics.

Acknowledgments

This report is adapted from a doctoral dissertation completed at the University of Illinois, based on research work done at the Illinois State Geological Survey. I am indebted to Dr. Harold R. Wanless, Professor of Geology at the University of Illinois, for his guidance and many valuable suggestions.

Many members of the Illinois State Geological Survey have contributed time and effort to this study. Special thanks are due to Paul Edwin Potter, Raymond Siever, and Jack A. Simon for their many helpful suggestions and for their critical reading of the manuscript, and to H. D. Glass for his aid in the clay mineral analyses and interpretation. Able field assistance from Frank Andrews and M. E. Ostrom also is acknowledged.

GENERAL PROPERTIES OF PENNSYLVANIAN SANDSTONES

Some of the most important properties of the Pennsylvanian sandstones of the Illinois Basin are closely related to the cyclical behavior of Pennsylvanian sedimentation. The cyclic nature of Pennsylvanian rocks in the Illinois Basin was first noted in 1912 by Udden. Weller (1930) described these cycles and their significance and separated the ideal cycle into the following units:

10. Gray shale, marine fossils near base, sandy near top
9. Marine limestone
8. Black shale
7. Marine limestone
6. Gray shale, few marine fossils
5. Coal
4. Underclay
3. Nonfossiliferous limestone
2. Sandy, gray shale
1. Sandstone, unconformable at base

Each cycle was considered to be separated from the next by the unconformity at the base of each sandstone. Weller stressed the importance of this unconformity in the subdivision of the rock column. The cyclical nature of these rocks is much more apparent in the Carbondale and McLeansboro Groups than in the underlying Caseyville and Tradewater Groups, where marine limestones and coal beds are not as numerous.

The unconformable base is readily apparent in the channel phase of the sandstone. However, where the sandstone unit is thin,this unconformity may be absent and member 10 (sandy shale) of the next cycle then grades into the overlying sandstone. Near the top of a cycle, the sandy shale in many places contains thin sandstone beds that increase in number and thickness toward the top and that may or may not grade into a sandstone, the basal unit of the next cyclothem above.

The channel phase of sandstone deposit has received much attention and has been recognized in outcrop at many horizons. Ekblaw (1931) was able to trace one deep, narrow channel in the western Illinois outcrop. Rusnak (1957) recently published a petrologic and fabric study of the sandstone that fills this channel.

The nature of such channels also has been studied in connection with major minable coals. Ashley (1899, p. 385) early described such a channel (Coxville Carboniferous river) and Savage in 1918 published a mine map showing where the Rock Island (No. 1) Coal had been eroded. Payne (1941), Payne and Cady (1944), Siever (1950), Harrison (1951), DuBois (1951), DuBois and Siever (1955), and Cady et al. (1952, 1955) have published maps showing areas in Illinois where the No. 6 Coal has been eroded and its stratigraphic position occupied by the Anvil Rock Sandstone. Friedman (1955) shows a channel sandstone interpreted as the result of a stream flowing through a coal swamp in Vigo County, Indiana, and Weir (1953) has mapped a channel cutting out Indiana V Coal. Mueller and Wanless (1957) show trends of seven channels of Carbondale and McLeansboro age in Jefferson County, Illinois.

In the Western Interior Coal Field, similar channels have been observed. Hinds and Greene (1915) have described several channel sandstones in Missouri, the most notable being the Moberly and Warrensburg Sandstones. Mudge (1956) has described numerous channels in upper Pennsylvanian and lower Permian sediments of Kansas and has interpreted these channels as being dominantly filled with fluvial sediments. A broadly similar environment for the Tonganoxie Sandstone of northern Kansas was inferred by Lins (1950). Busch (1954) has made a detailed study of the subsurface of some of the lenticular Pennsylvanian sandstones of east central Oklahoma, some of which exhibit a dendritic pattern that he interprets as delta distributaries flowing in a southerly direction.

In addition to the intra-Pennsylvanian channels, there is in the Illinois Basin a channel system at the base of the Pennsylvanian System. Siever (1951) and Wanless (1955) have shown the distribution of channels cut during the development of the unconformity separating the Mississippian and Pennsylvanian Systems. Siever's study includes southern Illinois and adjacent parts of Indiana and demonstrates a dendritic pattern draining to the southwest (Siever, 1951, fig. 9). Wanless (1955, p. 1772) reports, in addition to the southwest-trending channels in southern Illinois, relatively shallow valleys draining southeast from the western Illinois shelf into the deeper Illinois Basin, and a southwest-trending system situated to the east of the LaSalle anticlinal belt.

The sedimentary structures of channel-fill deposits of the Pennsylvanian sandstones of the Illinois Basin are dominantly those of shallow turbulent water. Cross-bedding and ripple marks are common, slump structures are rare, and graded bedding is virtually nonexistent.

The petrography of Pennsylvanian sandstones has been investigated by Willman (1928), MacVeigh (1932), Siever (1949), Berman (1953), Siever and Potter (1956), Siever (1957), Rusnak (1957), and Potter and Glass (1958). In general, orthoquartzites in the Caseyville Group grade upward to less mature subgraywackes in the Tradewater, Carbondale, and McLeansboro Groups.

STRATIGRAPHIC POSITION OF ANVIL ROCK SANDSTONE

The Anvil Rock Sandstone lies at the base of the lower McLeansboro Group in the Illinois Basin. In the standard midcontinent section, the Anvil Rock Sandstone would lie near the middle of the Marmaton Group of the DesMoinesian Stage.

The Anvil Rock Sandstone was first named by David D. Owen (1856, p. 45) for two large, conspicuous, anvil-shaped float blocks (fig. 2) located about 1½ miles northwest of Dekoven, Union County, Kentucky. The float blocks had fallen from an abrupt bluff that overlooks the Ohio River Valley to the west. Owen stated:

Fig. 2. - Anvil-shaped float block of channel phase of the Anvil Rock Sandstone near Dekoven, Union County, Kentucky, 2750 F.E.L., 1100 F.S.L., N-17 (Carter Grid)

> "The lower coal measures are separated from these upper coal measures by a massive sandstone formation, which is universally known in southwestern Kentucky by the name at the "Anvil Rock". It has received this appellation on account of the resemblance to an anvil at two conspicuous masses of this formation, situated on its northern escarpment, on Hines Creek.
>
> "From this local appellation the name has been extended to the range of this sandstone formation, and serves as a popular and well understood term in Union County, Kentucky, by which to distinguish this prominent capping member of the lower coal measures, lying between it and the conglomerate or pebbly sandstone, which may be regarded as the base of the productive coal measures."

Stratigraphically, the Anvil Rock is the first sandstone above Kentucky No. 12 Coal, which is equivalent to the Jamestown Coal of Illinois (fig. 3B) (Weller and Wanless, 1939). Its lower surface defines the base of the Lisman Formation in Kentucky and the base of the McLeansboro Group in Illinois (Wanless, 1956). A few feet above the Anvil Rock Sandstone in Illinois is the Bankston Fork Limestone, which has not had official recognition in Kentucky but which I have observed there.

A possibility exists that the sandstone at the Anvil Rock type locality may actually be a channel phase of a higher sandstone, i.e., the first sandstone above the Bankston Fork Limestone. This sandstone has been observed on electric logs and in diamond drill cores from Union and Webster counties, Kentucky. Recent coal prospect drilling north of Wheatcroft, Webster County, has revealed a narrow erosional channel filled with this sandstone. In one core the sandstone

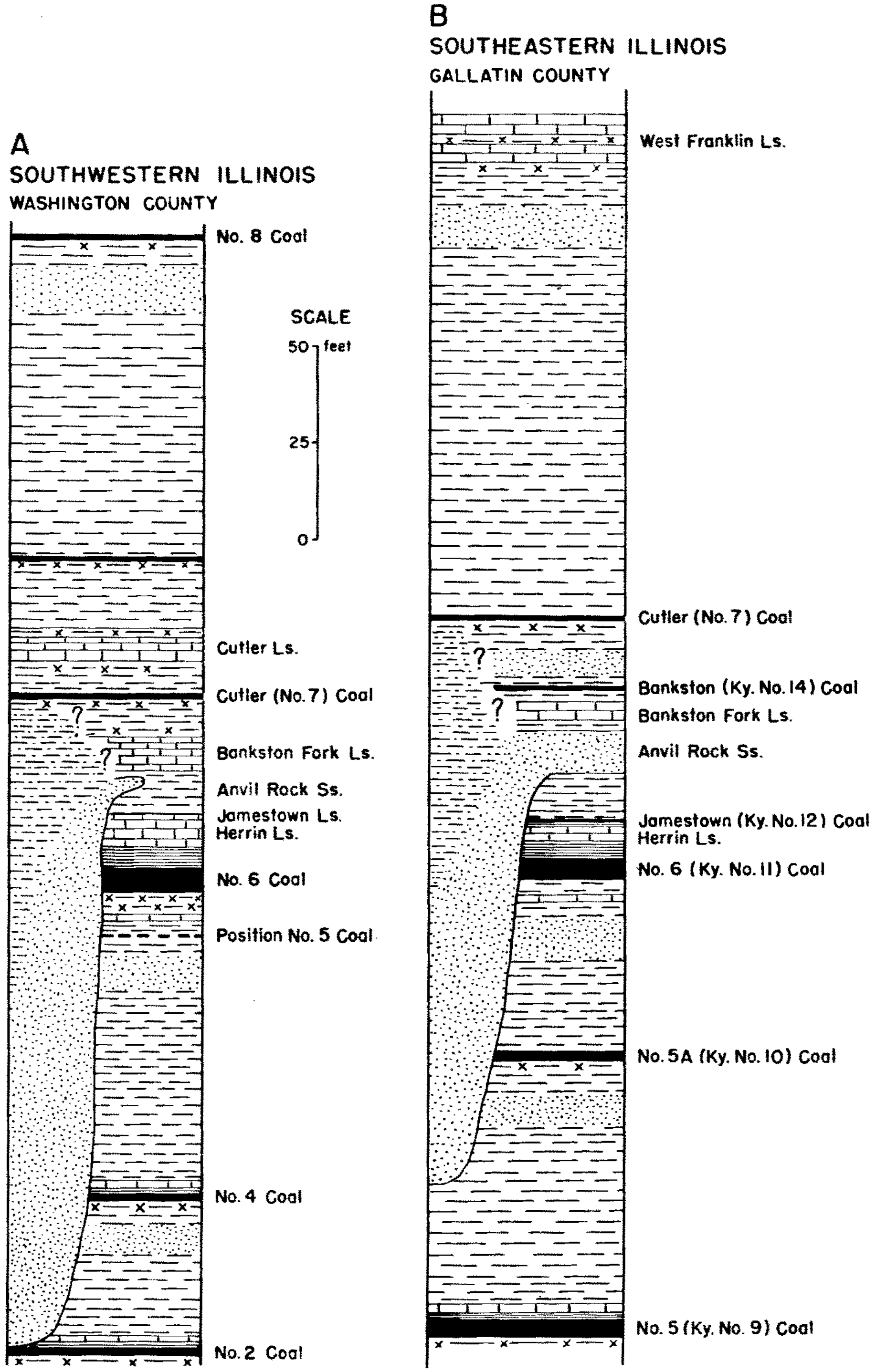

Fig. 3. - Generalized stratigraphic sections of upper Carbondale and lower McLeansboro strata in southwestern and southeastern Illinois.

"cut out" all but about two inches of the No. 14 Coal, which immediately overlies the Bankston Fork Limestone, whereas in others the sandstone extended several feet below No. 11 Coal. Detailed core drilling in the area of the type outcrop is needed to confirm or deny the possibility that the type Anvil Rock is stratigraphically higher than the sandstone termed "Anvil Rock" in Illinois.

The probable correlative of the Anvil Rock Sandstone in western Illinois is the Copperas Creek Sandstone (Wanless, 1956), which underlies the No. 7 Coal and overlies the Brereton Limestone. In southern Illinois there are two sandstones in this interval, one below the No. 7 Coal and above the Bankston Fork Limestone, and the Anvil Rock Sandstone below the Bankston Fork. Figure 3 shows the stratigraphic relationships of the interval containing the Anvil Rock Sandstone.

AREAL DISTRIBUTION AND THICKNESS OF ANVIL ROCK SANDSTONE

Collection of Data

The original sampling plan called for examining one well per section, but only about half of the square-mile sections had reliable records. Some 2500 subsurface control points were examined from an area of approximately 5000 square miles. Plate 1 shows the resultant sampling pattern.

Approximately 80 percent of the subsurface control was obtained from electric logs of oil tests. The spontaneous (self) potential (SP) curve was used to measure sandstone thickness. Sample studies and descriptions of cores from nearby diamond drill holes were correlated with electric logs to compare the lithologic character of the Anvil Rock Sandstone and related beds with their expression on the electric log. Core descriptions were used whenever they were available to determine thicknesses; drillers logs and sample studies were not used for this purpose unless necessary.

Thickness changes were found to be too abrupt to be represented by conventional arithmetic contours on the isopach map (pl. 1). A geometric interval was employed and because of the abrupt changes not all intervals between points were shown. Thus on the map an area characterized by 41 to 80 feet of sandstone may lie adjacent to an area 0 to 20 feet thick with no intervening thickness interval shown. This method of expressing thickness of the sandstone represents more clearly the abruptness of the changes.

The material filling the channels is not all sandstone. A considerable thickness of argillaceous siltstone may occur above a more or less massive sandstone body, especially in the major channels. The isopach map (pl. 1) does not include this material above the sandstone; only the actual sandstone thickness is indicated. Siltstone and shale interbeds occur within the more massive sandstone body but generally are quite subordinate and were included in the total sandstone thickness on the map.

Distribution of Sheet Sandstone

The widespread, relatively thin Anvil Rock Sandstone in this report is termed the sheet sand or sheet phase. It ranges from 0 to 20 feet thick. Areas of sandstone thicker than 20 feet belong to the channel phase.

Figure 4 and plate 1 indicate several areas where no sandstone is present at the position of the Anvil Rock. In most of Washington, Perry, Jefferson, and

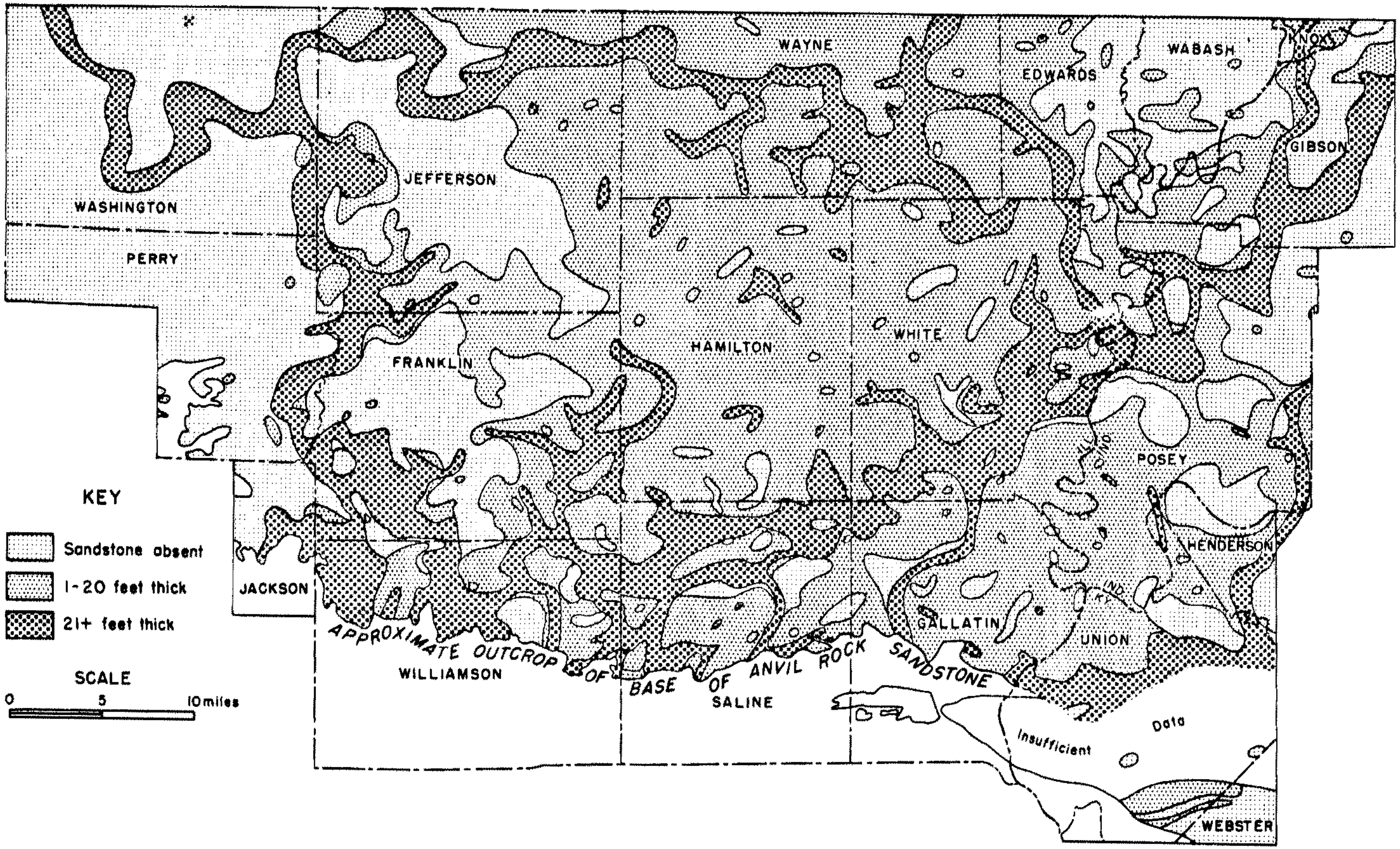

Fig. 4. - Generalized distribution and thickness of Anvil Rock Sandstone in southern Illinois, southwestern Indiana, and western Kentucky.

Franklin counties the channel phase is prominently developed, but no sheet phase is recognized away from the channels. In Edwards and Wabash counties, Illinois, and Gibson and Posey counties, Indiana, although both phases are generally present, there are substantial areas where no Anvil Rock Sandstone is recognized.

This distribution may be explained by the relationship of the sandstone to the principal structural trends shown on figure 1. The area with no sandstone in the western part of the region studied lies mainly in the shelf region (Ozark Flank on map). This shelf is separated from the Illinois Basin by the DuQuoin Monocline (cross section B-B', pl. 2). These structures were formed at various times during the Pennsylvanian Period. East of the monocline there is an abrupt increase in thickness of lower Pennsylvanian sediments and a moderate increase in thickness of middle and upper Pennsylvanian sediments, including the Anvil Rock Sandstone (Siever, 1951; Brownfield, 1954). The northeastern part of the area shown on the map, in which there are several large patches where no sheet sandstone is present, is also characterized by more positive structural elements.

In the deeper part of the Illinois Basin, the Anvil Rock Sandstone can more properly be called a sheet sandstone in the strict sense. It is continuous over most of Wayne, Hamilton, Saline, White, and Gallatin counties, an area of approximately 2000 square miles. Its continuity is broken only here and there by small areas where it is absent or where the channel phase is present. The small patches where the sandstone is absent bear no apparent relation to structure. Thus it appears (pl. 1) that the sheet phase of the Anvil Rock Sandstone was best developed in the more rapidly subsiding portion of the basin.

Distribution of Channels

Erosional channels filled with Anvil Rock Sandstone are widely distributed throughout southern Illinois and adjacent Kentucky and Indiana (pl. 1 and fig. 4). Channels were mapped on the basis of sandstone thickness. The thicker sandstone appears as long sinuous bodies, in some cases in typical dendritic patterns and in others as an anastomosing network. There is at the base and along the margins (fig. 5) a sharp lithologic break from the underlying beds, and the thickening is for the most part at the expense of the older rocks (cross sections, pl. 2).

The pattern exhibited by this network of channels is a composite one of erosion and deposition over a considerable span of time when stream courses were constantly changing. Recent channel-fill deposits along the Mississippi River have somewhat the same pattern (Fisk, 1947). Generalized stream courses for all of Anvil Rock time are shown in figure 6, which includes, in addition to the area of detailed mapping, occurrences of Anvil Rock channels in Illinois known at the time of this study.

One of the purposes of making this map was to trace the major channel as far as possible. It is shown ending in Shelby County, but control in this area is poor and it is probable that the sandstone could be traced farther east or north to the outcrop. Thick sandstone, possibly Anvil Rock, has been reported in wells in Douglas and Coles counties (Kenneth Clegg, personal communication). What may be a major channel is found in northern Illinois in Putnam County where the No. 6 Coal has been eroded and its place taken by sandstone (Cady, 1915; Cady et al., 1952).

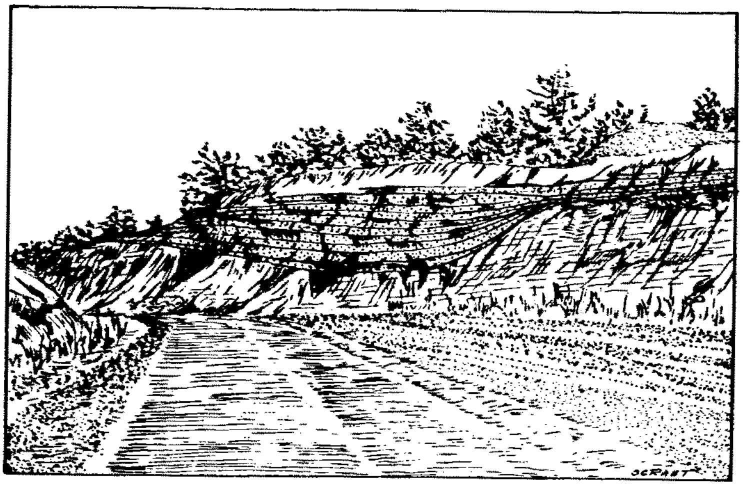

Fig. 5. - Base of Anvil Rock Sandstone showing unconformity. Highwall of Vogue mine, about 11 miles east of Madisonville, Kentucky.

The stream courses, as shown in figure 6, are divided into major and minor courses. Differentiation was based on: 1) sandstone thickness and depth of erosion, normally greater in the major course, 2) the fact that the major channel with few exceptions is a well defined single channel, and 3) the erosion of the No. 6 Coal, occurring in large areas along only the major channel.

Major Channels

Sandstone and siltstone are the predominant materials filling the channels. Sandstone may fill the entire channel or occur only in its lower part, especially in the major channels where a considerable part of the upper fill may be siltstone (cross sections, pl. 2). Average values for thickness along a major channel are presented in table 1.

Table 1. - Average Percentage of Sandstone and Siltstone in a Major Anvil Rock Channel

County area	Control points	Sandstone (%)	Siltstone (%)	Sandstone and siltstone thickness (ft.)
Washington	46	60	40	131
Jefferson (east-west channel)	45	45	55	99
Wayne	34	58	42	117
Edwards	13	68	32	142
White	38	52	48	122
Grand average		57	43	122

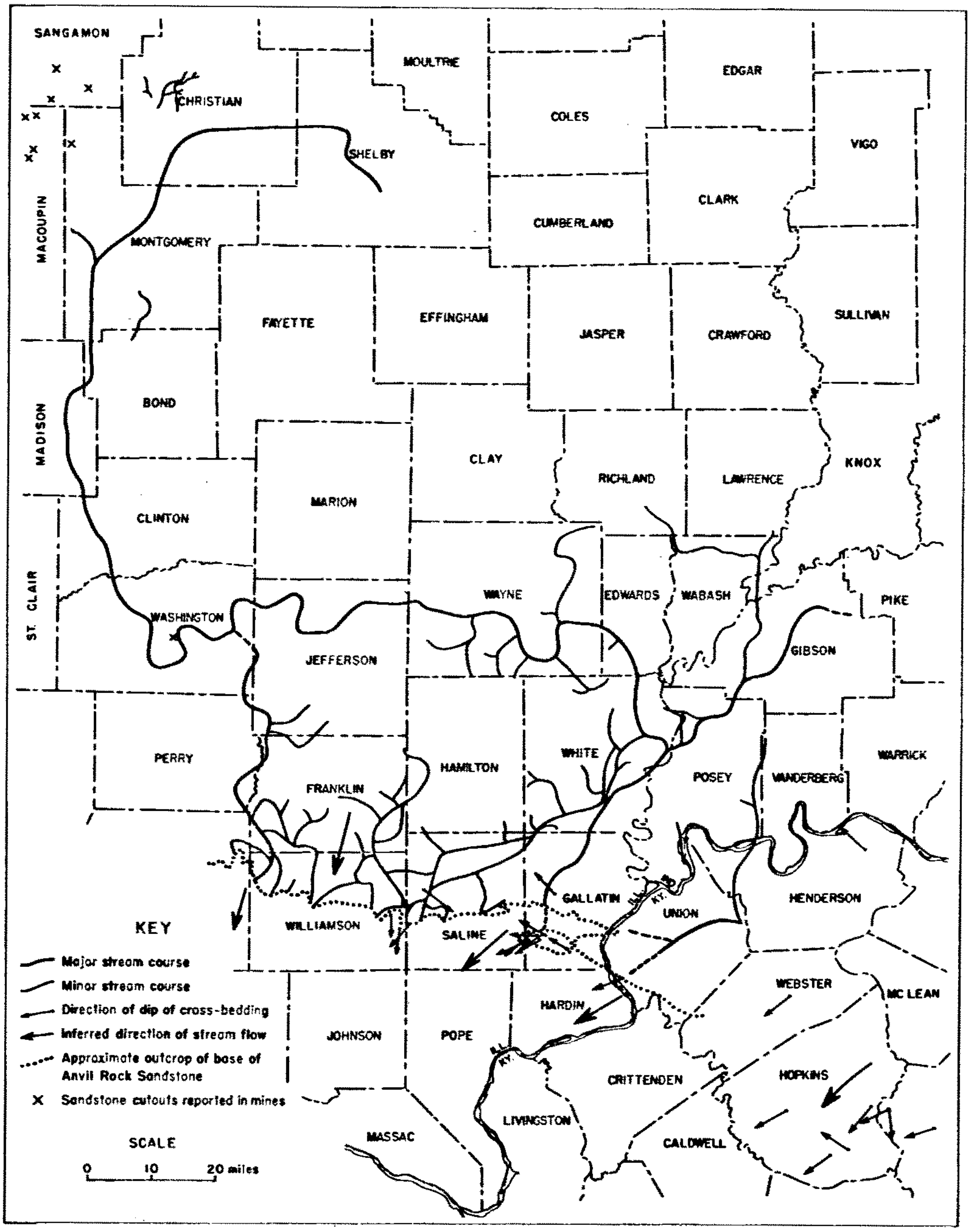

Fig. 6. - Generalized stream courses during channel cutting with cross-bedding dip directions as measured along outcrop.

As table 1 indicates, the total thickness of the channel fill varies considerably, and this variation is mainly in the coarser rock, the sandstone. Although local variations do occur (pl. 2), siltstone thickness averages are remarkably uniform along this major channel.

Maximum recorded thickness of the channel fill is 216 feet (Washington County, sec. 3, T. 1 S., R. 4 W.), of which 116 feet is sandstone overlain by 100 feet of siltstone. The greatest sandstone thickness found during this study, 210 feet in sec. 5, T. 3 S., R. 3 W., also occurs in Washington County. That this is all Anvil Rock could be questioned. One possible explanation for such high thickness values might be that two sandstones are measured here. It is quite possible that an Anvil Rock channel extends down into an underlying sandstone and two sandstones have been measured as one. Trends and occurrences of the Cuba Sandstone, which underlies the No. 6 Coal, are not known in this region, although in the next county to the east, Jefferson County, the trend of a Cuba Sandstone channel has been mapped (Mueller and Wanless, 1957). Several wells in T. 3 S., R. 3 W., and adjacent areas are about 200 feet thick, however, and it is considered probable that this is all Anvil Rock.

Average thickness of channel-fill deposits for the major channel in the five counties mentioned in table 1 is 122 feet, of which 70 feet is sandstone and 52 feet is siltstone. In general, the thickest sandstone occurs on the outside of major bends where current activity was greater and deposition of coarser material occurred when alluviation took place (pl. 1). In present streams we find alluviation occurring on the inside of bends, but if the entire valley were alluviated, coarser material would finally come to rest more to the outside where stronger currents were present.

Throughout most of the area mapped, width of the major channels averages about two miles. Where the channels are relatively straight for a considerable distance, channel width is about one mile, but where junctions and bends are numerous the width increases to as much as five miles.

Variation in thickness of sandstone is much greater than variation in stratigraphic depth of erosion (that is, the position of the base of the sandstone with reference to underlying key beds), which would seem to indicate that the channel bottom is relatively flat in cross section (pl. 2). In western Illinois the deepest stratigraphic position reached by erosion is a short distance above No. 2 Coal (fig. 3), but in the Illinois Basin to the east, where intervals between marker beds are greater, in only a few places has erosion cut below No. 5A Coal.

It has been noted by several students of Pennsylvanian stratigraphy (Weller, 1930; Wanless, 1952; Cross, 1952) that over wide areas many channel sandstones extend down to the top of the coal bed but have not replaced any of the coal, probably, they thought, because when the channels were cut the peat from which the coal was formed was leathery and tough, offering greater resistance to erosion than the associated sediments. Siever (1957), however, pointed out that information about the subsurface indicates that coal beds are commonly cut out and that there are many exceptions to the generalizations concerning their resistance to erosion.

It was noted during this study that coal beds are commonly cut out in the Anvil Rock channels, especially in the major channels. It should be mentioned that in a few places electric log study suggests that the sandstone does rest on the coal bed, but it is impossible to tell from the logs whether or not the coal has been eroded. Sandstone roof is reported for a number of mines in Macoupin and Montgomery counties, but in these mines the coal commonly has been partly or completely eroded. Throughout a considerable area in southern Illinois, minor channels (cross section E-E', pl. 2) extend down to the Jamestown Coal, which is only 2 to 3 inches thick. A short distance away the sandstone has been observed in diamond drill cores and outcrops to rest on a dark smut streak present at the position of the Jamestown Coal. The theory of resistance to erosion by compact peat cannot be offered as an explanation of the base level in this case because the base of the sandstone is at the same level whether it rests on the coal or the smut streak. It is more likely that the local base level simply coincides with the position of the Jamestown Coal.

That leathery peat might offer greater resistance to erosion than other sediments may be true, but relationship of the Anvil Rock Sandstone to the underlying coal generally does not support this idea. Perhaps coalification prior to cutting of these channels had proceeded beyond the leathery peat stage and the coal was more brittle and more easily eroded.

There is no clear-cut relationship between Anvil Rock channel distribution and structure. The northeast-southwest trend of the channel pattern through Gallatin and White counties, Illinois, and Posey and Gibson counties, Indiana, is subparallel to the Wabash River fault belt. The north-south channel in Williamson, Perry, and Franklin counties, although sinuous and complex, is essentially parallel to the DuQuoin Monocline. Most of this channel is on the basin side of the monocline to the east, but in northeastern Perry County it crosses the structure. The genetic relationship of the channels to structure is not fully understood.

To the east of the DuQuoin Monocline in Franklin and Jefferson counties is a large area where a gray shale up to about 60 feet thick lies above No. 6 Coal and below the Herrin Limestone. Also in this area the No. 6 Coal may be split by numerous gray shale partings, some as much as 30 to 40 feet thick, that make the coal unminable. The only association between the major Anvil Rock channel and this split-coal area is that the unstable nature of this area probably was responsible for the occurrence of the split coal, the thick gray shale, and finally the stream responsible for the channel.

The major east-west channel crosses the DuQuoin Monocline at right angles, seemingly with little change in direction or in thickness.* The channel fill (table 1) is, however, thicker in Washington than in Jefferson County in both over-all and sandstone thickness. The monoclinal axis lies on the county line, Washington County on the shelf side and Jefferson on the basin side. The greater sandstone thickness in Washington County could be explained by the fact that deeper erosion took place in this more positive area during channel cutting. Edwards County also has a greater than average sandstone thickness in the major channel in the 13 wells studied. Correlation with structure is not apparent here. The channel, however, appears to be narrow and fairly straight.

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* Since completion of this report, a major channel has been discovered trending southwestward from the vicinity of Nashville in Washington County to the outcrop in Perry County. This channel joins the main channel, shown on figures 4 and 6 and plate 1, near the southwesternmost point of the loop in T. 3 S., R. 3 W.

Several geologists have noted that the cut-out area of No. 6 Coal in Jefferson and Wayne counties crosses over or near the crest of a number of anticlines and that there may be some genetic relationship between the structure and the channel trend. On the No. 6 Coal structure map of parts of Jefferson, Wayne, and nearby counties (Siever, 1950, pl. 1b), a striking relationship seems to exist between occurrence of the major Anvil Rock channel (No. 6 cut-out area on Siever's map) and a number of oil pools that are structural traps producing from Mississippian rocks. The Anvil Rock channel crosses the following oil pools: Irvington, Boyd, Dix (now in Salem Consolidated), Dix South, Divide West, Divide, Divide East, Coil West, Coil, Coil East. and Keenville. The No. 6 Coal structure map of Wayne County (DuBois and Siever, 1955, pl. 2) shows that the same channel crosses parts of the Johnsonville Consolidated, Clay City Consolidated, and Barnhill oil pools. The channel crosses structural lows between the highs with no change in thickness or direction. When all pools in the Illinois Basin are plotted on a map showing channels no relation is apparent. The east-west trend in pools from Dix on the west to Keenville on the east and the similar Anvil Rock trend are regarded as coincidental.

Minor Channels

Minor channels in some areas were difficult to trace. However, where close control was available, areas in which the sandstone is more than 20 feet thick show up in plan view as channels, even though they are as much as three miles wide.

Minor channels in Franklin, Williamson, Saline, and White counties were particularly difficult to map. They are a complex system of anastomosing, relatively wide and shallow channels. The average thickness of the sandstone is about 40 feet, its maximum thickness 100 feet, and the maximum channel width about three miles. In only a few scattered occurrences has the No. 6 Coal been eroded in these channels. That the minor channels also are erosional channels and not just a sandstone facies of the gray shale overlying the Jamestown Coal is evident in strip mines to the south where the sandstone has cut out about 30 feet of the gray shale.

Interpretation of these features as stream-cut channels presents a problem when the great width-to-depth ratio is considered. Therefore, a comparison of these channels with modern valleys in the Gulf Coastal Plain was made. Several large rivers have essentially no valley walls, especially near their mouths, and relief of less than 30 feet for several miles from the river is common. Other streams have well defined valleys several miles wide but commonly less than 50 feet below the upland. If the channels of the Anvil Rock are comparable to the entire modern valley, then the size relationships, that is, the very wide and shallow nature of the channels, need not be a problem. Thickness of alluvial material in these valleys was not known and would tend to reduce the apparent shallowness of these valleys, but it is felt that the comparison with Anvil Rock channels is justified.

The siltstone that overlies the sandstone in the major channels is not well developed in the minor channels (fig. 7). In Williamson County (cross section E-E', pl. 2) the channels become even more difficult to trace because of a facies relationship with siltstone. Near the center of the N½ sec. 28, T. 9 S., R. 4 E., in the north highwall of the Delta Collieries strip mine, a sandstone-

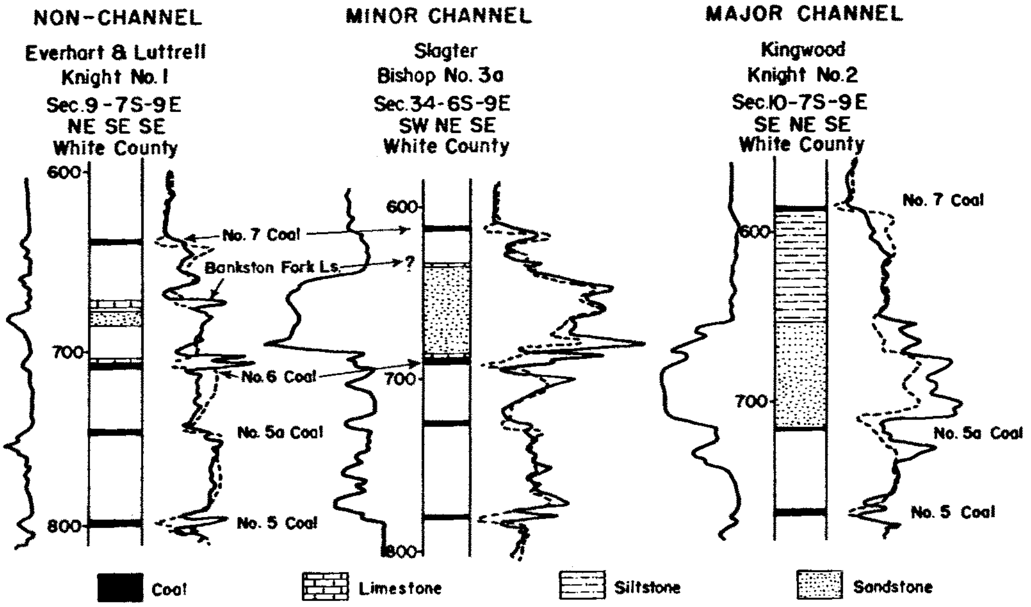


Fig. 7. - Representative electric logs in White County, Illinois, showing non-channel, minor, and major channels.

filled channel cuts down about 30 feet to within about 6 feet of the No. 6 Coal. When traced eastward for about 600 feet along the highwall, massive sandstone grades into thin-bedded sandstone and then into finely laminated siltstone. The eastward extent of this channel is not known.

To the north and west in T. 8 S., R. 3 E., the section immediately above the Jamestown Coal and Jamestown Limestone and below the Bankston Fork Limestone consists of varying amounts of sandstone, siltstone, shale, and shale with siltstone and/or sandstone interlaminations. Most of the shales in this section contain a few fossils; pelecypods and brachiopods have been noted.

A thin coal 1 to 4 inches thick occurs 10 to 15 feet below the Bankston Fork Limestone and may be separated from it by either sandstone or shale. This coal, sometimes referred to as the "sub-Bankston, " is not continuous but occurs sporadically in northeastern Williamson and southeastern Franklin counties. Megascopically the coal consists of bony coal and scattered bands of normally bright coal. The bony coal contains numerous leaf remains of Cordaites. It is interbedded and associated with dark gray to black shale containing numerous Cordaites leaf impressions. Underclay, which is typical of most autochthonous bright-banded coals in the Pennsylvanian, is not present below this coal. Running essentially north to south through T. 8 S., R. 3 E., is what is interpreted, on the basis of sandstone thickness, as a channel. All above mentioned strata occur in this channel. The relationships of these strata make it very difficult to discriminate between channel and non-channel phases of the sandstone.

Some minor channels appear to be tributaries of larger ones. This is particularly evident in Wayne County, Illinois, and Gibson County, Indiana, where the channels have the same general shape and size as the minor channels in

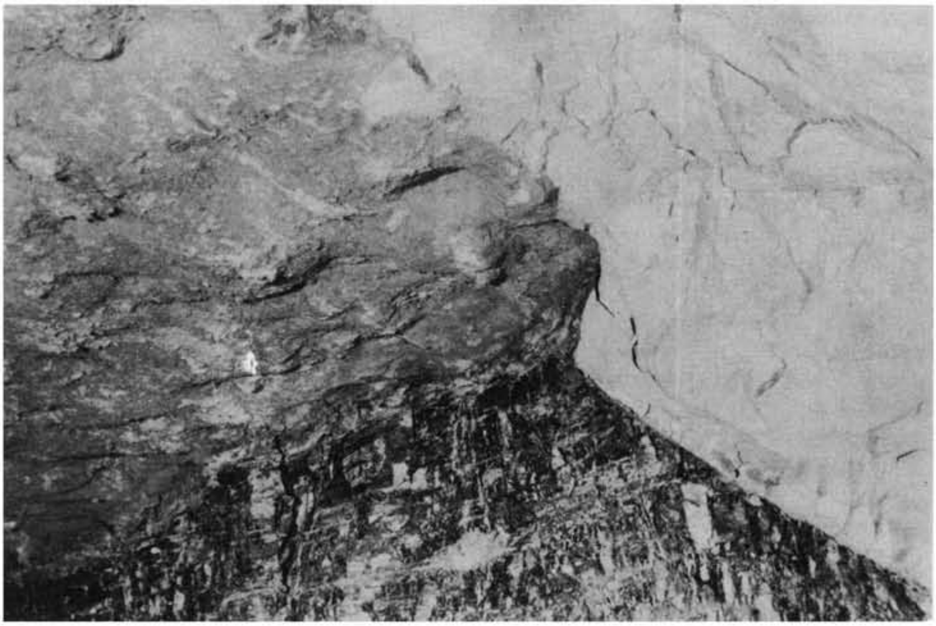


Fig. 8. - High-angle truncation of the Herrin Limestone and the underlying No. 6 Coal by the Anvil Rock (?) Sandstone in an underground mine in Christian County, Illinois.

Williamson County but in which facies conditions have not been recognized. Depth of erosion in these tributaries is less than that in the major channels. In only a few places has the No. 6 Coal been eroded, one notable occurrence being in a portion of the minor tributary in Gibson County, Indiana, Ts. 1 and 2 S., R. 12 W., where sandstone at two wells is 100 feet thick and the coal has been eroded for a distance of more than five miles along a prominent bend in the channel.

STRATIGRAPHIC RELATIONS OF CHANNEL FILL

No natural outcrops of the lateral margins of channels were observed, but in underground and strip mines the relationships along the margins and bottoms of the channels could be studied. An erosional unconformity was always observed because flat-lying subjacent beds have been truncated at angles as high as 35° from the horizontal. The high-angled, knife-edged contact is shown in figure 8, a photograph taken in an underground mine in Christian County.

Rapid thickening of the sandstone at the expense of underlying beds was established in adjacent wells 660 feet apart. Even with this amount of control it was impossible to obtain a good approximation of the angle of dip of the unconformable surface, and it should be noted that the steep angle of dip of channel margins shown on the cross sections (pl. 2) is merely inferred and that the vertical scale also is exaggerated.

The bottoms of the channels have been observed in outcrops, strip mines, and cores. There is always a sharp lithologic break at this contact. Conglomerates composed of shale, clay-ironstone, limestone, and coal pebbles imbedded in a sandstone matrix are present locally at the base and in the lower portion of the sandstone.

At the top of the channels no sharp lithologic break occurs and the sandstone grades upward into siltstone and shale. Grain-size analyses (fig. 12) show a gradual decrease from base to top even in the lower sandstone portion of the Anvil Rock. This gradation also is apparent in electric logs where the self-potential curve of the typical sandstone gradually approaches the self-potential curve at the typical shale (or siltstone) above the sandstone.

In addition to eroding older rocks, the sandstone channels also have an effect on overlying rocks. The following are somewhat generalized lithologic descriptions of cores, one from a non-channel area and one in the major channel in Gallatin County.

Non-channel Section
(sec. 4, T. 9 S., R. 9 E.)

Lithologic description	Thickness Ft.	Thickness In.
Cutler (No. 7) Coal		
Coal, normally bright-banded	1	10
Shale, greenish gray, micaceous, carbonaceous, stigmarian in upper 3 inches, grades into	1	3
Siltstone, gray, plant fossils and coal particles, interlaminations of fine-grained sandstone, grades into	3	9
Shale, dark gray, micaceous, carbonaceous, interlaminations of light gray siltstone, grades into	3	6
Siltstone, gray, micaceous, carbonaceous, faintly calcareous	8	0
Shale, dark gray to black, carbonaceous, canneloid near middle		9
Shale, black, carbonaceous, pyritic, with numerous ostracodes (coal horizon?)		9
Clay shale, gray, slickensided, grades into	1	4
Siltstone, gray, micaceous, grades into	1	2
Shale, gray	1	8
Bankston Coal		
Coal, thin-banded		2
Underclay, gray, carbonaceous and stigmarian in upper half, slickensided, calcareous in lower half, small buff limestone nodules in lower 6 inches	3	1
Bankston Fork Limestone		
Limestone, light gray to buff, argillaceous, nodular at top, inclusions and partings of gray shale in lower half, sparingly fossiliferous with crinoids and brachiopods.	6	0
Shale, dark gray, carbonaceous, greasy luster, slickensided, grades into		3
Siltstone, gray, irregular sandstone interlaminations, brown siderite nodules	1	9

Lithologic description	Thickness Ft.	Thickness In.
Anvil Rock Sandstone		
Sandstone, light gray, fine-grained, interbedded dark greenish gray shale (about 80% sandstone), sideritic, grades into	7	10
Shale, gray to dark gray, micaceous, few light gray siltstone interlaminations, fossiliferous in lower 3 feet	17	0
Herrin Limestone		
Limestone, dark gray, carbonaceous, argillaceous, thin shaly partings, very fossiliferous with brachiopods, crinoids, and fusulinids	2	0
Shale, black, hard, "slaty, " few fossils	1	3
Herrin (No. 6) Coal		
Coal, normally bright-banded, a 2-inch gray shale band 13 inches from base	4	5
Underclay, gray, slickensided, stigmarian	1	2

Section in Major Channel
(sec. 26, T. 8 S., R. 8 E.)

Lithologic description	Thickness Ft.	Thickness In.
Cutler (No. 7) Coal		
Coal, normally bright-banded	2	0
Shale, dark gray, stigmarian, massive	1	3
Shale, gray, carbonaceous, micaceous, plant remains	1	3
Anvil Rock Sandstone		
Siltstone, gray to dark gray, very carbonaceous, pyritized plant remains	9	0
Shale and sandstone (60 and 40%, respectively), sandstone beds up to 4 feet thick, light gray, fine-grained, micaceous, carbonaceous, some oil staining, calcareous in part; shale, gray, silty, carbonaceous plant remains, micaceous	22	0
Siltstone, gray, fine-grained carbonaceous plant material, scattered shaly zones and sandstone interlaminations	12	0
Sandstone, light gray, medium- to coarse-grained, micaceous, generally massive, some cross-bedding, few shale and siltstone partings, calcareous in part, heavily oil stained in upper 16 feet, abrupt and irregular contact at base	32	6
Herrin (No. 6) Coal		
Coal, normally bright-banded		8
Underclay, greenish gray, stigmarian	1	7

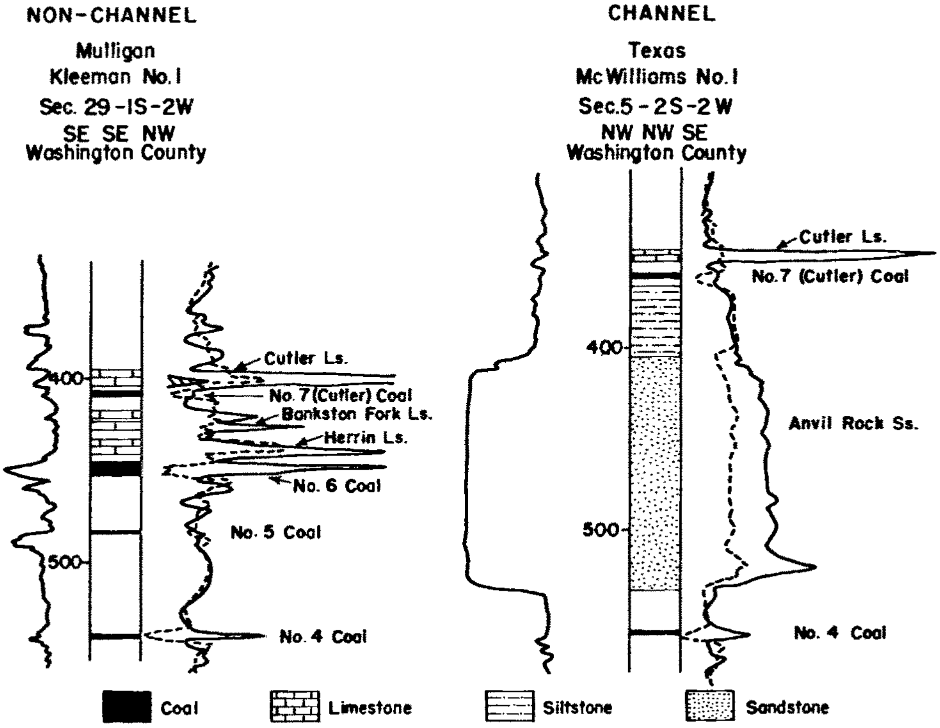


Fig. 9. - Representative electric logs from the Ozark flank area, showing non-channel and channel sections.

Relation to No. 7 Coal

Of the two key beds (Bankston Fork Limestone and No. 7 Coal) which closely overlie the Anvil Rock Sandstone, only the No. 7 Coal can positively be identified above the major channels. This key bed is persistent throughout the entire area studied. The interval from the No. 7 Coal to the first continuous marker bed under the Anvil Rock Sandstone increases in the channel areas (fig. 9). In the above core descriptions the interval from the base of No. 6 to the base of No. 7 Coal increases from 66 to 79 feet. Cross sections, based on a datum plane below the sandstone, make the top of the Anvil Rock Sandstone appear as a convex surface. The relatively minor compaction of the sandstone in the channels versus the greater compaction of the more shaly section away from the channels results in the convex top.

Relation to Bankston Fork Limestone

The Bankston Fork Limestone, which lies below the No. 7 Coal and over the Anvil Rock Sandstone, is not a continuous deposit over the area. It is absent over most of the area of both major and minor channels, and in a few localities away from the channels. There are three explanations offered for its absence. First, it may not have been deposited over the channels because they were topographic highs due to differential compaction of underlying strata. A second possibility is that the limestone is in part contemporaneous with the upper part of the channel fill, siltstone or sandstone having been deposited in the channels and limestone at the sides. A third possible explanation is that some of the major channels are of post-Bankston Fork age and the limestone had been removed by erosion.

The Bankston Fork Limestone is present, however, in many wells penetrating the major channel running north to south through Williamson, Perry, Franklin, and Jefferson counties. In that area its occurrence is erratic and seems to bear no consistent relationship to the channel. In many of the wells drilled through what are termed minor channels, the Bankston Fork Limestone is present a few feet above the Anvil Rock Sandstone. In other wells it is either absent or thin. This limestone can be identified positively in electric logs only when it is at least 3 or 4 feet thick.

Over some of the minor channels (fig. 7) a thin limestone is locally present, even where the underlying sandstone is as much as 40 feet thick. A study of samples in southern White County showed this thin limestone to be of different lithologic character than typical limestone of the Bankston Fork in nearby wells in the non-channel area. Normally, the Bankston Fork is a light gray to tan ferroan-dolomite (Siever and Glass, 1957) that contains marine fossils. Under the binocular microscope it is light gray and dense. The thin limestone present over the minor channel in White County is a fine-grained, reddish brown, impure limestone. It has not been determined whether this is a facies of the Bankston Fork or is another limestone near the position of the Bankston Fork.

Influence of Topographic Highs

In this investigation, no detailed outcrops or subsurface data were found to establish the relationship between channels and the presence or absence of the Bankston Fork Limestone. If the idea that topographic highs prevented its deposition is correct, then the limestone should either thin out or show facies relationships with shallow-water sediments above the channels. This has been neither demonstrated nor disproved. Compaction of the more shaly section in the non-channel area would have begun shortly after deposition and would have continued as the shale deposits were buried. The No. 7 Coal, however, does extend over the channels. If a topographic high had existed at the time of accumulation of No. 7 Coal, some effect of the high might be expected to appear in the coal thickness, but apparently there is no change in character or thickness.

Then, too, in the western part of the area studied, on the shelf region, the Cutler Limestone lies a few feet above the No. 7 Coal (fig. 3). This limestone is present over most of the channels and shows no consistent relationship to the thickness of the sandstone (fig. 9). If compactional highs prevented the deposition of the Bankston Fork Limestone over the channels, it is difficult to see why deposition of the Cutler Limestone, which lies only about 15 feet above the channel deposits and 15 to 20 feet above the Bankston Fork in the non-channel areas, was not affected. The only definite result of differential compaction evident is that in its present attitude the Cutler Limestone rises over the channels. This, however, could be the result of compaction during post-Cutler time and not during or prior to Cutler deposition.

The presence of the Bankston Fork Limestone over the minor channels in many wells casts doubt on the compaction theory. Thickness of sandstone in minor channels is at some places as great as that in main channels, and differential compaction prior to Bankston Fork time should have created topographic prominences over the minor as well as major channels. The fact that no break occurs in sedimentation at the top of the major channels until the No. 7 Coal is reached also makes the compaction theory doubtful. The upper 50 feet or so of the major channel fill is argillaceous siltstone, which should have compacted almost as much as shale.

Possible Contemporaneity

Up to this point all the sandstone and siltstone occurring in the major channels has been referred to as channel fill and the convex upper surface as the result of differential compaction. There is a possibility that the upper portion (siltstone) of the so-called channel fill was not deposited in the channel but <u>over</u> the channel after submergence of the area. The possibility of contemporaneity of the siltstone with the Bankston Fork Limestone must be considered. If the two are not in part contemporaneous, and if the major channel fill is pre-Bankston Fork, then there must be a hiatus between the siltstone and the sandstone of the major channel fill. As mentioned above, the only abrupt break in character of sediments over the channels is the change at the base of the coal. Below this there is no evidence of any marked break in lithology until the base of the sandstone is encountered.

One might expect a calcareous zone in the siltstone if it were contemporaneous with the Bankston Fork Limestone, but no such occurrence has been recognized in the course of this study. Nor do the meager data available on lithologic character of the Bankston Fork Limestone adjacent to major channels point to its becoming more silty or more argillaceous as one approaches the channels, as would perhaps be the case if the idea of contemporaneity were correct. The thin limestone found in some wells over the minor Anvil Rock channels (fig. 6) may indicate a change in lithology of the Bankston Fork Limestone but is not definitive.

Possibility of Post-Bankston Fork Deposition

A simple explanation of absence of Bankston Fork Limestone in major channel areas is that the sandstone is post-Bankston Fork. If this were true, the limestone would have been removed by erosion during channel cutting, and the sand and silt later deposited to fill the channel. Two lines of evidence, however, make this idea highly unlikely. First, some of the minor channels that join the major channels like tributaries are overlain by Bankston Fork Limestone, so that channel deposits must antedate the Bankston Fork. Second, the siltstone at the top of the channels occupies essentially the same lithostratigraphic position as Bankston Fork and beds below No. 7 Coal, whereas the sandstone portion occupies the stratigraphic position of the sheet phase of the Anvil Rock down to the base of the unconformity.

Of the alternatives cited, I favor contemporaneity of a portion of the upper channel fill, especially in the major channels, with the Bankston Fork Limestone. A combination of contemporaneity and differential compaction could have acted to keep this limestone from being deposited over the channels, but I feel that evidence is stronger for contemporaneity. This implies that during Bankston Fork time the channels were still serving as a medium for transportation and

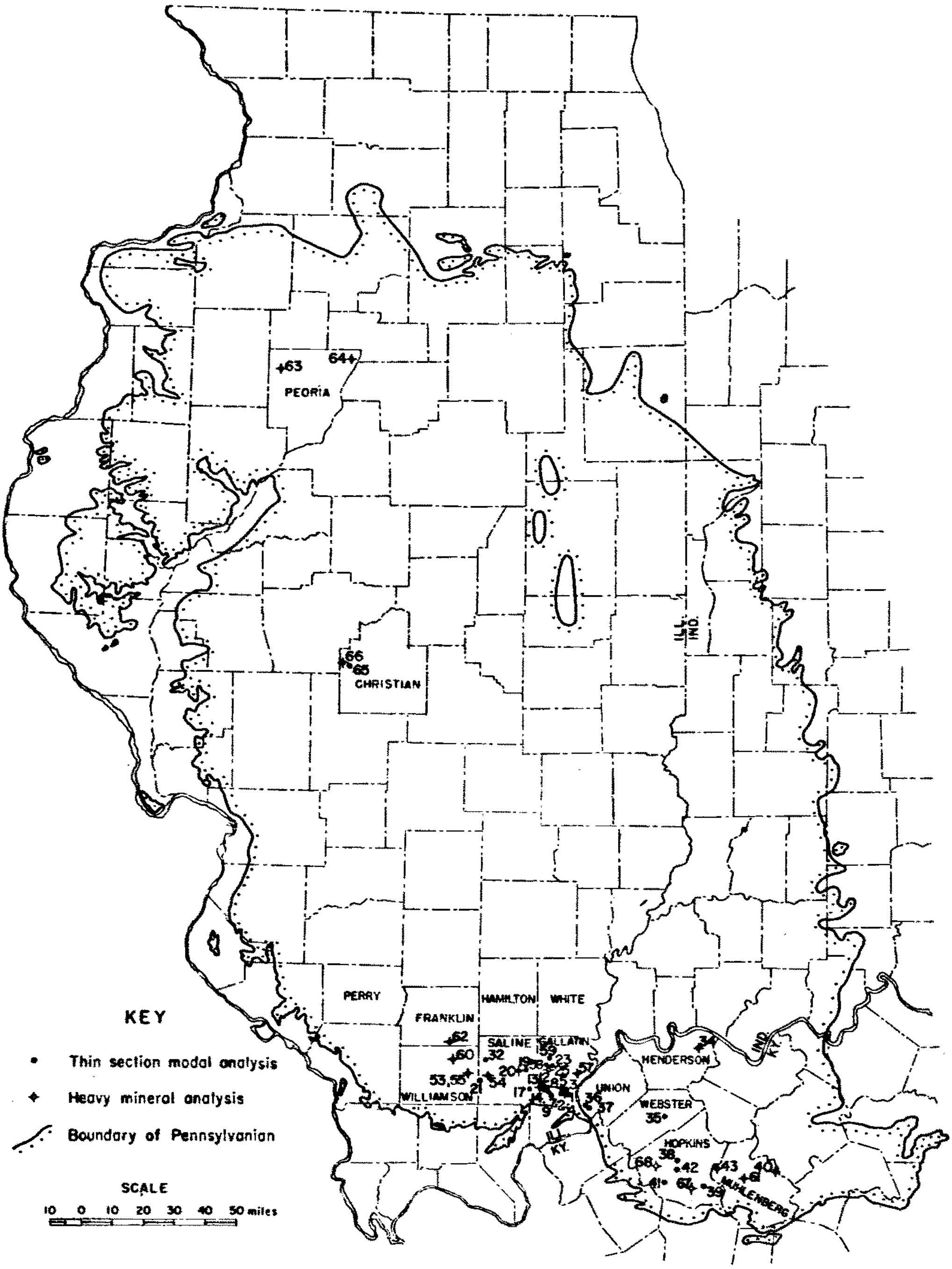


Fig. 10. - Index map showing sample locations.

deposition of fine-grained clastic material that was not spread over a wide area but concentrated in the channels.

PETROLOGY

The petrologic phase of this study was directed primarily toward differentiating the channel from the sheet phases of Anvil Rock deposition. Figure 10 indicates locations from which samples were obtained.

Petrographic study of the sandstone consisted of: 1) modal analyses of 70 thin sections, 2) heavy mineral determinations, 3) clay mineralogy of the interbedded shale and clay fraction of the sandstone, and 4) grain size analyses. The point counter was used in making modal analyses. Two hundred grains were counted per thin section for the gross mineralogy, and another 200 quartz grains per section were counted to differentiate "igneous," "metamorphic," and "metamorphic quartzite" (polycrystalline) grains.

The following minerals were identified in thin section: quartz, plagioclase, twinned and non-twinned potash feldspar, interstitial matrix clay, siderite and calcite, chert, rock fragments, muscovite, biotite, and chlorite. No quantitative determinations were made of limonite, heavy minerals, and carbonaceous shreds.

Table 2 tabulates the data from 70 analyses of thin sections taken from cores and outcrops located largely in southern Illinois, but including eight samples from central Illinois (Christian County) and two samples of Copperas Creek Sandstone from western Illinois (Peoria County). With the exception of three vertical series (samples 57, 58, and 59), these samples were collected randomly from outcrops and cores with no attempt to collect from any particular zone in the sandstone.

Heavy minerals were separated with bromoform (specific gravity 2.87) after careful disaggregation. The samples were jaw-crushed to about ½ inch in diameter, ground with a mortar and pestle to about 1/8 inch in diameter, hand ground with steel "rolling pin" or the palm of the hand, and inspected with binocular microscope to see whether disaggregation were complete. If the samples were high in calcium carbonate, hydrochloric acid was added to dissolve the cement. After disaggregation the sample was treated with boiling HCl to clean the quartz grains and separate heavy and light minerals more completely. The fact that apatite, if present, would be lost by this method was recognized. Table 3 summarizes the resultant data.

In addition to determining mineralogical composition, measurements were made with a micrometer-ocular to estimate maximum, modal, and minimum size of quartz grains. Thin-section estimates were supplemented by 44 sieve analyses (table 4). Average roundness for the modal class was estimated by using the Krumbein (1941) chart.

Clay minerals were identified by the X-ray diffraction method on oriented aggregates of particles less than 2 microns in diameter.

Mineralogical Composition

Light Minerals

Quartz. - In addition to determining the total percentage of quartz present in the samples, three quartz varieties were differentiated and counted - "igneous quartz," "metamorphic quartz," and "metamorphic quartzite." Although the

Table 2. - Constituent Minerals and Modal Analyses of Thin Sections of Anvil Rock Sandstone (see fig. 12 for map showing locations)

		Percentage of Minerals in thin sections													Grain size (mm.)			
		Quartz				Feldspar												
							Potash											
Location number	Location Sec-T-R	"Igneous"	"Metamorphic"	"Meta-quartzite"	Total	Plagio-clase	Non-twinned	Twinned	Total	Clay	Carbonate C = Calcite S = Siderite	Chert	Rock Fragments	Mica	Maximum	Minimum	Mode	Average roundness
						GALLATIN COUNTY												
59-2^{a}	26-8S-8E	77.0	19.0	4.0	57.5	2.0	1.0	0.5	3.5	25.5	5.0CS	1.0	3.5	4.0^{b}	.50	.02	.12	.4
59-3^{a}		70.0	23.0	7.0	56.0	2.0	3.0	1.0	6.0	20.5	10.5CS	T	3.0	4.0^{b}	.36	.02	.12	.4
59-4^{a}		80.0	17.5	2.5	65.5	1.5	0.5	-	2.0	19.5	5.0CS	-	3.0	5.0	.44	.03	.14	.4
59-5^{a}		72.5	18.0	9.5	58.5	1.5	4.5	-	6.0	25.0	1.5CS	0.5	7.0	1.5^{b}	.60	.02	.14	.4
59-6^{a}		71.5	21.0	7.5	64.5	2.5	2.0	0.5	5.0	20.5	1.5C	1.5	2.0	5.0	.44	.02	.20	.4
59-7^{a}		78.0	18.5	3.5	55.5	0.5	2.5	T	3.0	34.5	0.5C	-	1.5	5.0^{b}	.40	.02	.10	.4
59-8^{a}		72.0	21.0	7.0	59.5	2.0	3.0	T	5.0	26.5	2.0CS	-	3.0	4.0^{b}	.64	.03	.16	.4
59-9a^{a}	Sample No. 59, vertical profile, 80 foot core section	80.0	15.0	5.0	70.0	1.0	0.5	T	1.5	21.0	3.5CS	T	2.5	1.5	.52	.02	.20	.4
59-9b^{a}		71.0	21.5	7.5	56.5	2.0	2.0	T	4.0	28.5	7.5CS	0.5	2.5	1.5	.60	.02	.20	.4
59-9c^{a}		73.5	19.0	7.5	64.0	1.5	4.5	0.5	6.5	22.0	3.5CS	1.0	2.0	1.0	.70	.02	.24	.4
59-10^{a}		73.0	17.0	10.0	65.0	2.5	3.0	T	5.5	22.0	2.0CS	T	3.0	2.5^{b}	.64	.02	.16	.4
59-11^{a}		71.5	19.0	9.5	61.5	3.5	3.0	0.5	7.0	25.5	2.0C	-	2.0	2.0	.66	.03	.16	.4
59-12^{a}		78.0	18.0	4.0	64.0	2.5	2.0	T	4.5	24.0	2.0CS	0.5	2.5	2.5	.56	.03	.24	.4
59-13^{a}		72.5	20.5	7.0	62.0	2.0	2.5	0.5	5.0	23.5	3.5CS	-	2.5	3.5^{b}	.48	.02	.20	.4
59-14^{a}		74.5	20.0	5.5	67.5	1.5	3.5	T	5.0	17.0	4.0CS	-	3.0	3.5^{b}	.54	.03	.22	.4
59-15^{a}		71.0	20.0	9.0	56.0	0.5	3.5	1.0	5.0	23.0	13.5CS	0.5	1.0	1.0^{b}	.72	.03	.22	.4
59-16^{a}		70.0	20.5	9.5	58.0	2.5	4.5	0.5	7.5	21.5	5.5CS	-	3.5	4.0	.58	.02	.18	.4
59-17^{a}		72.0	20.0	8.0	65.0	3.5	1.5	T	5.0	22.0	3.5CS	1.0	2.5	1.0	.66	.03	.24	.4
59-18^{a}		71.0	22.5	6.5	59.0	0.5	3.5	T	4.0	25.0	8.0CS	1.0	2.0	2.0^{b}	.66	.02	.20	.4
59-19^{a}		70.0	23.0	7.0	64.5	3.0	1.5	T	4.5	25.0	0.5C	-	3.5	2.0^{b}	.80	.02	.26	.4

58-1[a]	3-9S-8E	72.5	15.5	12.0	74.0	2.0	1.5	0.5	4.0	13.0	4.5CS	1.0	3.0	0.5[b]	.68	.02	.30	.5
58-2[a]		72.0	20.0	8.0	72.5	2.5	4.0	1.5	8.0	4.5	11.5CS	0.5	2.5	0.5	1.27	.03	.60	.6
58-3[a]		73.0	19.5	7.5	76.0	3.0	1.5	1.0	5.5	11.0	5.0C	1.0	1.0	0.5	.96	.03	.30	.5
58-4[a,c]		79.5	13.0	7.5	33.5	1.0	1.5	1.0	3.5	13.0	9.0C	1.5	38.5	1.0	34.0	.02	.50	.6
FRANKLIN COUNTY																		
62	27-7S-3E[g]	75.0	21.5	3.5	55.0	2.0	2.0	0.5	4.5	14.0	17.0C	-	3.5	6.0[b]	.64	.02	.18	.5
60	26-8S-3E[g]	78.5	13.5	8.0	45.0	T	1.5	-	1.5	4.0	45.0CS	T	1.5	3.0[b]	.64	.02	.18	.4
WILLIAMSON COUNTY																		
53[d]	22-9S-4E	74.0	17.5	8.5	66.0	2.0	1.5	0.5	4.0	17.5	9.0C	-	2.5	1.0[b]	.50	.03	.18	.5
55[d]	22-9S-4E	75.0	21.0	4.0	63.0	2.5	2.0	1.5	6.0	29.0	TC	-	1.5	0.5[b]	.72	.03	.26	.5
SALINE COUNTY																		
21c[d]	30-9S-5E	75.5	20.0	4.5	70.5	1.5	1.0	0.5	3.0	20.0	0.5C	1.0	4.0	1.0[b]	.52	.03	.20	.4
21a	30-9S-5E	72.0	21.5	6.5	73.5	1.5	2.0	-	3.5	19.0	-	-	3.0	1.0	.62	.02	.18	.4
54[e]	28-9S-5E	66.0	27.0	7.0	66.5	1.5	2.5	T	4.0	22.5	1.5	0.5	2.5	2.5[b]	.56	.02	.12	.4
32[d]	33-8S-5E	74.5	20.5	5.0	71.5	2.0	1.5	0.5	4.0	21.0	-	0.5	2.5	0.5	.68	.02	.20	.5
20	19-9S-7E	71.0	19.0	10.0	63.5	2.5	2.0	-	4.5	27.0	-	T	4.0	1.0	.68	.03	.30	.5
19	22-9S-7E	65.5	24.0	10.5	65.0	-	2.0	-	2.0	29.5	-	T	2.5	1.0	.58	.02	.12	.4
17	11-10S-7E	73.5	24.5	2.0	66.5	0.5	0.5	-	1.0	30.5	-	-	1.0	1.0	.46	.02	.14	.4
GALLATIN COUNTY																		
13[a]	7-10S-8E	66.0	24.5	9.5	72.5	-	-	-	-	23.0	-	-	3.0	1.5	.70	.02	.26	.4
14[a]	9-10S-8E	73.5	15.0	11.5	76.5	T	-	-	T	21.0	-	-	2.5	-	1.00	.04	.40	.6
12[a]	4-10S-8E	67.0	23.0	10.0	74.0	-	0.5	T	0.5	23.0	-	-	2.5	T	.80	.04	.22	.4
8	3-10S-8E	71.0	22.0	7.0	64.5	3.0	1.5	T	4.5	25.0	0.5C	-	3.5	2.0[b]	.80	.02	.26	.4
9[f]	10-10S-8E	63.0	25.0	12.0	68.5	0.5	2.0	T	2.5	27.5	-	0.5	0.5	0.5	.90	.04	.40	.5
7[f]	13-10S-8E	68.0	21.0	11.0	71.5	-	0.5	T	0.5	24.0	0.5S	1.0	1.5	1.0	1.14	.04	.40	.5
23[f]	2-9S-8E	72.5	19.5	8.0	61.0	0.5	2.5	1.0	4.0	13.0	20.0C	-	1.5	0.5	.98	.03	.20	.5
5[e]	8-10S-9E	75.0	23.0	2.0	60.5	2.0	1.5	-	3.5	32.5	-	0.5	1.5	1.5	.22	.02	.10	.4
3[f]	9-10S-9E	76.5	16.0	7.5	69.5	1.5	2.5	T	4.0	20.5	0.5S	0.5	3.5	1.5[h]	.48	.02	.12	.4
2	21-10S-9E	68.5	20.0	11.5	62.0	1.0	1.0	-	2.0	31.5	2.5CS	1.0	-	1.0	.62	.04	.28	.4
1[e]	26-10S-9E	66.5	20.5	13.0	69.0	0.5	3.0	-	3.5	20.5	4.0S	2.0	-	1.0	.98	.04	.34	.4
57-1[e]	19-9S-10E[g]	78.0	18.5	3.5	64.0	1.0	2.5	T	3.5	28.0	-	-	3.0	1.5[b,h]	.54	.02	.16	.4
57-3[e]	Top[g]	77.5	20.0	2.5	65.0	0.5	1.5	T	2.0	19.0	9.5CS	1.0	-	4.0[h]	.48	.04	.14	.5
57-4[e]	Base[g]	73.0	20.0	7.0	69.0	2.5	2.0	0.5	5.0	16.0	8.0CS	-	-	1.5[h]	.64	.04	.26	.4

UNION COUNTY																		
36[f]	Type Anvil Rock	71.0	14.0	15.0	61.0	0.5	0.5	T	1.0	35.0	-	0.5	2.5	T	.96	.04	.40	.4
WEBSTER COUNTY																		
37[f]	Dekoven, Ky.	70.5	16.0	13.5	69.5	-	-	-	-	28.5	-	0.5	1.5	T	1.16	.04	.36	.5
35[f]	Vic. Ortiz, Ky.	65.0	22.0	13.0	56.0	0.5	3.0	1.5	5.0	36.0	-	-	2.5	0.5	.76	.02	.28	.5
HENDERSON COUNTY																		
34[e]	Vic. Spottsville, Ky.	77.5	19.5	3.0	52.5	1.5	1.0	0.5	3.0	13.0	26.0C	0.5	2.0	3.0[b,h]	.50	.02	.12	.4
HOPKINS COUNTY																		
41[e]	Vic. Carbondale, Ky.	80.5	18.0	1.5	77.0	-	1.0	-	1.0	20.0	-	-	1.5	0.5[b]	.36	.02	.12	.4
39[e]	Vic. Nortonville, Ky.	79.5	18.5	2.0	87.0	-	0.5	T	0.5	10.0	0.5S	0.5	1.5	T	.38	.03	.18	.6
38[e]	Vic. Madisonville, Ky.	79.0	17.0	4.0	84.0	-	1.5	-	1.5	12.0	-	0.5	2.0	-	.56	.04	.26	.6
42[e]	Vic. Earlington, Ky.	73.0	22.0	5.0	78.5	1.0	1.5	T	2.5	18.0	-	T	1.0	-	.68	.04	.40	.4
MUHLENBERG COUNTY																		
43[f]	Vogue Mine, Ky.	86.0	8.0	6.0	75.5	T	1.5	T	1.5	22.0	-	T	1.0	-	.66	.04	.28	.5
61[f]	Duncan Mine, Ky.	82.5	17.5	-	69.5	-	0.5	-	0.5	28.5	-	1.0	0.5	-	.54	.02	.16	.4
40[f]	Vic. Paradise, Ky.	74.0	22.0	4.0	70.0	0.5	0.5	0.5	1.5	26.5	-	-	2.0	-	.48	.02	.12	.4

						CHRISTIAN COUNTY												
65-1d	18-13N-3W	74.5	18.0	7.5	70.0	3.0	7.5	1.0	11.5	16.5	-	-	1.0	1.0	.88	.03	.26	.5
65-2d		70.0	19.5	10.5	74.5	3.0	2.5	0.5	6.0	16.0	TC	1.0	2.0	0.5	.62	.02	.28	.5
65-3d	(underground mine samples)	69.5	22.5	8.0	71.5	2.0	3.0	0.5	5.5	19.5	-	1.0	0.5	2.0	.74	.03	.26	.5
65-4d	"	73.0	20.0	7.0	65.0	4.0	4.5	0.5	9.0	26.0	-	0.5	1.0	0.5	.64	.03	.18	.5
65-5d	"	74.0	16.5	9.5	71.5	3.5	5.5	0.5	9.5	17.0	-	0.5	1.0	0.5	.70	.03	.22	.5
66-3d	10-13N-4W	76.5	18.0	4.5	63.5	1.5	2.5	T	3.0	15.5	11.0C	T	6.0	1.0	.78	.03	.27	.5
66-4d	(underground mine samples)	74.5	15.5	10.0	47.5	T	1.0	-	1.0	2.5	47.5C	-	1.0	0.5	.70	.04	.24	.5
66-6d	"	70.0	20.5	9.5	66.0	1.5	2.0	1.0	4.5	26.0	1.0	-	2.0	0.5	.72	.03	.28	.5
						PEORIA COUNTY												
63i,f	13-10N-5E	77.0	21.0	2.0	56.0	0.5	1.5	-	2.0	35.0	-	0.5	2.5	4.0	.40	.02	.14	.5
64i,e	9-11N-9E	73.0	21.0	6.0	50.0	0.5	-	T	0.5	26.0	22.5C	-	0.5	0.5	.72	.02	.20	.5
AVERAGES:																		
Top 5 samples of major channel (Nos. 59-2 through 59-6)		74.2	19.7	6.1	60.3				4.5	22.2	4.7	0.6	3.7	3.9			.14	
Bottom 5 samples of major channel (Nos. 59-15 through 59-19)		70.8	21.2	8.0	60.5				5.2	23.3	6.2	0.5	2.5	2.0			.22	
All major channels (26 samples)		72.8	19.7	7.5	64.4				4.4	21.8	4.1	0.4	2.5	2.3			.23	
All channel samples (22 samples, excluding above 26)		72.9	18.7	8.4	67.3				3.7	22.6	3.3	0.4	1.9	0.6			.26	
All non-channel samples (10)		75.9	20.3	3.7	70.3				2.7	19.1	4.6	0.5	1.5	1.5			.19	

a/ = Major channel.
b/ = Chlorite and muscovite present.
c/ = Near base of major channel (core).
d/ = Minor channel.
e/ = Non-channel.
f/ = Channel.
g/ = Core.
h/ = Biotite and muscovite present.
i/ = Copperas Creek sandstone of western Illinois.

Table 3. - Non-Opaque Heavy Mineral Determinations

Location no. (see fig. 12)	Zircon	Tourmaline	Rutile	Garnet	Chlorite	Biotite	Others
63	F	VA	R	P	-	-	Kyanite? R
64	F	A	R	VA	P	-	Kyanite? R
66	A	A	R	F	-	-	Kyanite? R
62	F	F	R	P	VA	R	-
60	F	VA	P	P	VA	-	-
55	VA	VA	R	R	A	R	Kyanite? R
54	F	VA	P	-	P	-	-
20	F	VA	R	-	-	-	-
13	P	A	R	-	-	-	-
25	P	P	R	-	-	-	-
57	F	F	R	-	A	-	-
5	F	VA	-	-	P	-	-
4	F	F	R	-	-	-	Anatase R
36	P	A	-	-	-	-	-
35	F	A	P	-	-	-	-
34	A	VA	R	VA	P	-	-
68	A	A	R	-	-	-	-
67	F	A	R	-	-	-	-
43	VA	A	R	-	-	-	-
61	VA	P	A	-	-	-	-
40	A	A	-	-	-	-	-

F = flood; VA = very abundant; A = abundant; P = present; R = rare.

presence of strain shadows and sutured polycrystalline grains are not definitive criteria for differentiating igneous and metamorphic quartz, igneous quartz here includes all monocrystalline grains with no profound strain shadows, metamorphic quartz includes those grains that show definite strain shadows when rotated on the microscope stage between crossed nicols, and metamorphic quartzite fragments are polycrystalline grains that show sutured boundaries between the individual anhedral crystals and generally have pronounced strain shadows. Secondary overgrowths and interpenetration of the igneous quartz were observed but were not abundant. Distinct, worn secondary overgrowths were noted in a few slides. Quartz makes up from 33.5 to 87 percent of the sandstone.

Feldspar. - The most abundant feldspar noted in thin section was microscopically non-twinned potash feldspar. Any feldspar without multiple twinning was tabulated (table 2) as non-twinned potash feldspar, even though many of the crystals might be submicroscopically twinned. Some grains of plagioclase also were included in this category.

Almost as abundant as non-twinned potash feldspar are twinned plagioclase grains. Twinned potash feldspar is almost always present in minor amounts. Both weathered and unweathered grains were present in most slides and all gradations between fresh detrital grains and grains almost completely weathered to clay were observed. In some slides feldspar was either rare or absent, and clusters of kaolinite "books" were abundant. No authigenic feldspar was recognized. Feldspar composes from 0 to 11.5 percent of the sandstone.

Clay. - Any very fine-grained interstitial material was tabulated as clay and no attempt was made to differentiate the various clay minerals. Only the

Table 4. - Grain Size Analyses (by weight percent)

Sample location (fig. 12)	Coarse sand		Medium sand		Fine sand		Vy. fine sand		Silt and clay	Trask sorting coefficient	Median grain size (mm.)
	Grain Size (mm.)										
	1.0 to .707	.707 to .500	.500 to .354	.354 to .250	.250 to .177	.177 to .125	.125 to .088	.088 to .062	<.062 Pan		
Non-channel samples											
8-9S-5E Saline Co.		8.8	10.5	13.0	22.8	16.6	7.3	5.4	15.7	1.65	.190
62 Franklin Co.		7.5	10.6	10.3	9.8	14.0	15.5	11.7	20.6	2.10	.135
19 Saline Co.		6.8	13.7	16.7	14.3	15.5	10.6	7.4	15.0	1.80	.185
54 "		3.7	10.0	17.3	20.3	14.4	10.8	7.5	16.0	1.70	.184
42 Hopkins Co., Ky.			14.9	8.1	7.3	8.4	16.5	20.0	24.7	1.85	.097
53-1 Williamson Co.			T	3.5	7.0	11.8	30.4	17.9	29.4	1.55	.094
53-2 "			T	3.2	15.2	29.5	16.3	8.9	26.9	1.70	.124
53-3 "			T	4.0	16.0	25.6	16.4	10.4	27.6	1.70	.115
53-4 "				2.6	6.9	13.1	24.7	19.8	32.9	1.63	.086
53-5 "				6.9	20.7	22.8	16.4	8.7	24.5	1.65	.125
near 57-1 Gallatin Co.		4.6	6.8	16.9	16.7	12.5	9.2	8.4	24.9	2.05	.160
" 57-2 "		3.3	7.1	24.8	21.8	11.8	7.3	6.5	17.4	1.65	.210
" 57-3 "	0.8	5.4	7.9	24.0	17.7	10.5	7.2	6.7	19.8	1.90	.205
" 57-4 "		3.9	8.7	23.1	17.4	11.3	7.0	6.9	21.7	1.95	.197
Average, 14 non-channel samples	0.1	3.1	6.4	12.5	15.3	15.6	14.0	10.4	22.6	1.78	.150
Channel samples											
near 21-1 Williamson Co.	0.4	4.2	8.4	18.6	23.2	17.9	8.7	5.3	13.3	1.51	.185
" 21-2 "	T	1.8	15.5	39.2	16.2	7.2	4.2	3.6	12.3	1.30	.262
" 21-3 "	1.0	6.7	19.7	33.1	13.7	6.5	3.5	3.2	13.6	1.45	.290
" 21-4 "	1.3	10.1	45.0	20.8	4.8	3.5	2.6	2.5	9.4	1.25	.370
" 21-5 "	0.9	2.6	18.4	41.4	9.2	5.2	3.6	4.1	14.6	1.50	.310
" 21-6 "	1.7	9.6	40.8	21.3	5.0	3.7	2.6	2.6	12.7	1.34	.338
4-1 Gallatin Co.	T	5.2	18.8	30.4	12.9	7.5	4.4	4.3	16.5	1.65	.262
4-2 "	T	12.0	42.0	15.6	6.5	4.5	2.8	2.8	13.8	1.50	.370
4-3 "	T	9.3	42.0	17.3	7.1	4.9	3.1	2.8	13.5	1.52	.350
4-5 "	0.8	12.7	33.3	20.3	7.7	5.0	3.2	2.9	14.1	1.62	.340

4-6	"	T	14.2	36.6	18.5	6.9	4.7	3.0	2.7	13.4	1.51	.350
4-7	"	T	7.3	35.6	22.7	7.7	5.3	3.5	3.1	14.8	1.60	.330
4-8	"	T	4.1	27.2	28.9	9.8	6.8	4.5	3.7	15.0	1.60	.310
4-9	"	T	6.7	33.8	22.0	8.0	6.7	4.2	3.6	15.0	1.65	.320
43-1	Muhlenberg Co., Ky.		2.2	42.5	42.9	5.5	2.6	1.4	1.0	1.9	1.14	.340
43-2	"		0.7	6.6	56.3	27.7	4.5	1.2	0.9	2.1	1.11	.263
43-3	"		3.4	28.4	34.6	19.7	5.0	3.0	1.4	4.5	1.30	.283
43-4	"		0.8	18.3	64.3	8.6	2.4	1.4	1.1	3.1	1.13	.308
43-5	"		0.4	5.8	38.2	36.7	10.4	2.9	1.6	4.0	1.21	.298
43-6	"		0.6	5.9	32.1	34.6	14.4	4.8	2.4	5.2	1.26	.235
43-7	"	0.5	1.7	3.5	32.3	36.5	12.3	4.8	2.7	5.7	1.24	.225
43-8	"	0.4	1.2	2.0	15.0	46.5	20.5	6.3	2.9	5.2	1.22	.195
43-9	"	1.0	2.6	2.4	6.0	24.7	31.0	14.7	6.9	10.7	1.40	.160
68	Hopkins Co., Ky.		4.3	18.3	36.2	20.3	8.1	3.7	2.5	6.6	1.28	.268
10	Gallatin Co.		7.7	16.0	38.4	20.7	4.1	1.8	1.4	9.9	1.25	.270
36	Union Co., Ky.		9.6	22.8	32.3	11.8	5.1	3.1	2.6	12.7	1.34	.305
25	Gallatin Co.		37.2	34.6	7.4	4.8	3.0	1.5	1.1	10.4	1.28	.460
67	Hopkins Co., Ky.			18.8	44.3	22.6	7.2	1.9	0.8	4.4	1.25	.277
61	Muhlenberg Co., Ky.		3.3	15.9	41.9	21.0	6.2	3.7	2.7	5.3	1.17	.268
13	Gallatin Co.		9.3	24.3	35.1	10.5	4.8	2.9	2.6	10.5	1.35	.320
Average, samples	30 channel	0.3	6.4	22.8	30.2	16.4	7.7	3.8	2.7	9.8	1.36	.295

vermiculitic books of kaolinite were of sufficient size to be identified positively with the petrographic microscope. Matrix clay composes from 4 to 36 percent of the sandstone.

Carbonate. - Calcite and siderite were the only two carbonates recognized. Practically all the calcite occurs as a cement; only a few grains were detrital. Calcite had replaced practically every constituent of the rock, most commonly occurring at the expense of clay and, less prevalently, quartz and feldspar.

Siderite is not as abundant as calcite but occurs both as a cement and as small spherules about 0.05 mm. in diameter. Frequently the matrix is a sideritic clay similar to clay ironstone. Two samples (60 and 66-4) contain equal amounts of calcite and quartz and could almost be called limestones even though in hand specimen they look like sandstone. In these samples many quartz grains are "floating" in the calcite matrix. Whether this is an original depositional feature or the result of replacement of some of the quartz grains is not known, but there is some evidence to suggest the calcite was deposited along with the quartz. Carbonate composes from 0 to 47.5 percent of the sandstone.

Chert. - Detrital grains of chert were found in almost all thin sections but in small quantities. Chert as a cement was not noted. It makes up from 0 to 2 percent of the sandstone.

Rock fragments. - In addition to chert and metaquartzite fragments, argillaceous (and generally micaceous) rock fragments were almost ubiquitous in all the slides of the sandstone. These rock fragments are about the modal size of quartz grains. Many argillaceous rock fragments appear to have been either squeezed or otherwise disturbed until the grain outline was destroyed. Much of the clay in the sandstone could have been introduced as fragments and not as individual clay-sized material. Rock fragments were found to compose from 0 to 7 percent of the sandstone.

Mica. - The micaceous minerals recorded in table 2 include only large grains of muscovite, chlorite, and biotite. In only a few slides was mica absent. In all slides showing mica, muscovite was the most common, with chlorite next. Biotite was present in only a few samples. All these mica grains or flakes appear to be detrital. Mica makes up from 0 to 6 percent of the sandstone.

Other components. - In a few samples, a green microcrystalline anisotropic mineral, probably glauconite, occurred in very minor amounts, generally only a few grains per slide. Some grains appeared to be clastic with detrital outlines but other grains filled the irregular space between other constituents.

Limonite was common in thin sections of outcrop samples and appeared to be replacing the clay. Limonitic clay was tabulated in the clay category but where the clay-limonite relationship was not obvious the slide was discarded; if the quantity of limonite was very small, it was ignored.

Heavy Minerals

Heavy minerals make up a very small quantitative portion of the sandstone and were not quantitatively determined in thin-section analyses. Table 3 shows abundances of the various non-opaque heavy minerals from 21 samples. No grain count was made, but the abundance of each mineral was estimated.

Opaque minerals such as leucoxene (most abundant), magnetite, ilmenite, and, locally, pyrite are abundant but were not recorded. Non-opaque heavy minerals, making up less than 1 percent of the sandstone, include in relative order of abundance zircon, tourmaline, chlorite, rutile, garnet, and a few grains of kyanite (?) and anatase.

Table 5. - Clay Mineral Analyses[a]
In percent

Sample no.	Location no. on fig. 12	Description	Kaolinite	Mica	Mixed lattice	Chlorite
1	43	Clay seam interbedded in channel sandstone	35	45	20	0
4	68	Shale near top of channel, badly weathered	25	25	(50 montmorillonite and chlorite)	
6	21	Shale interbedded in sandstone	40	40	10	10
8	54	Shale interbedded in non-channel sandstone	25	50	10	15
10[b]	63	Shale interbedded in channel sandstone	20	30	10	40
11[b]	64	Shale interbedded in non-channel sandstone	20	30	10	40
12	59[c]	Shale 6 feet from top	20	45	10	25
13	"	Shale 19 "	20	45	10	25
14	"	Clay fraction of sandstone 25 "	40	30	5	25
15	"	Shale 32 "	20	45	10	25
16	"	Shale 45 "	20	40	15	25
17	"	Clay fraction of sandstone 49 "	40	30	5	25
18	"	Shale 52 "	20	35	20	25
19	"	Clay fraction of sandstone 61 "	40	35	5	20
20	"	Shale 63 "	20	45	10	25
21	"	Clay fraction of sandstone 65 "	45	25	5	25
22	"	Clay fraction of sandstone 80 "	45	25	5	25
23	66	Clay fraction of channel sandstone[d]	40	30	15	15
24	near 57	Clay fraction at base of non-channel sandstone[d]	30	30	15	25
25	"	Clay fraction of siltstone 5 feet above base[d]	35	35	20	10
26	"	Shale at top of non-channel sandstone[d]	20	35	20	25
	Averages					
		All sandstones (7 samples)	40	29	8	23
		All shales (13 samples excluding No. 4)	24	40	14	22
		All core shales (8 samples)	22	40	14	24
		All outcrop shales (5 samples excluding No. 4)	28	39	12	21
		Outcrop shales excluding No. 4 and Copperas Creek samples (3 samples)	33	45	13	8

a = Percentages are corrected to 100% to exclude quartz and feldspar, which were present in all samples.
b = Copperas Creek sandstone of western Illinois.
c = Vertical profile in major channel (core)
d = Core

In the heavy mineral separations, chlorite was pale green and had extremely low birefringence. Chlorite fragments have the same general size and shape as clastic muscovite flakes. Biotite was recognized in only a few samples and then it was generally quite altered. Garnet grains occurred in the western Illinois samples, the western three of the southern Illinois samples, and in one Kentucky sample. Kyanite (?) was present in four of the seven samples containing garnet.

Clay Minerals

Twenty-one samples of shale interbedded in the sandstone and clay fraction of the sandstone (less than 0.002 mm.) were analyzed by standard X-ray diffraction methods, two analyses for each sample, one before treatment with ethylene glycol and one after treatment. Table 5 includes relative percentages of kaolinite, mica (illite), mixed-lattice minerals, and chlorite. Graphs showing averages for various groupings of samples are shown in figure 13.

Texture

The results of 44 sieve analyses are shown in table 4. Silt and clay fractions are lumped together in one column (pan) and were not separated into size grades. To calculate the Trask sorting coefficient, cumulative frequency curves were plotted for all samples, and eight of these curves are shown in figure 10. These eight samples were randomly chosen, four from each of the two groups of sieve analyses (channel and non-channel).

Discussion of Petrology

The Anvil Rock Sandstone is argillaceous, micaceous, sparingly feldspathic, and most closely corresponds to a subgraywacke. Siever (1957) reports that the other sandstones of the upper part of the Tradewater, the Carbondale, and the McLeansboro Groups in the Illinois Basin are subgraywackes. The petrographic analyses of the Anvil Rock Sandstone are very similar to most of the other higher sandstones (Siever, 1957, table 1).

The primary objective of the integrated petrographic analysis of the Anvil Rock Sandstone was to differentiate channel and sheet (non-channel) facies. Modal analyses (table 2) show little variation in composition between the two, the only noticeable difference being a slightly lower percentage of clay in the channel samples. The major conclusion to be drawn from the thin-section study is that the channel and sheet sandstones have petrographic homogeneity. Neither thin-section nor heavy-mineral study provides a basis for distinguishing between the two.

A significant difference in grain size between channel and sheet sandstone does exist, however. Thin-section modal size for ten sheet sandstone samples averaged 0.19 mm., and for 14 sieved samples the average median was 0.15 mm. Average thin-section mode for 48 channel samples was 0.24 mm., and average median for 30 sieved samples was 0.29 mm. There is, however, a distinct decrease in grain size from the base of a channel to the top (fig. 12), and as most of the random samples were collected in the lower part of the channel where outcrops are better, this should be considered before basing any conclusions on grain size.

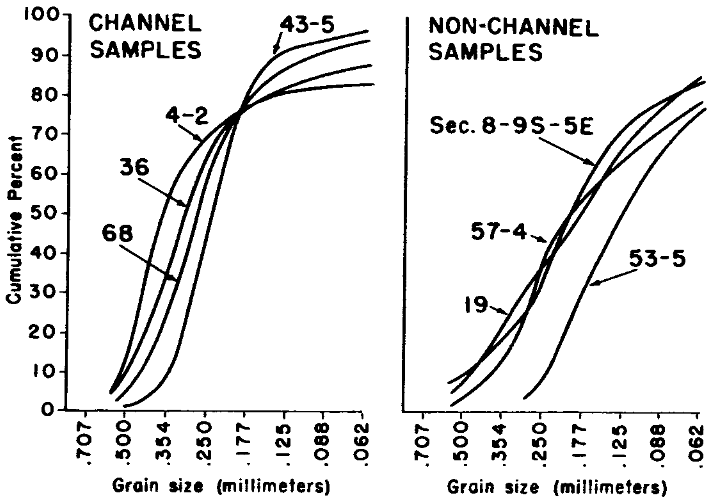


Fig. 11. - Cumulative grain-size frequency curves of channel and non-channel phases of the Anvil Rock Sandstone.

In addition to a difference in grain size between channel and sheet sand, an apparent difference shows up when cumulative frequency curves (fig. 11) of the two types are compared. Channel sands have lower sorting coefficients, indicating better sorting. Average sorting coefficient for 30 channel samples is 1.36 compared to 1.78 for 14 non-channel samples (table 4).

The paucity of heavy minerals, especially the meagerness in amounts of the varieties that are present, may be the result of post-depositional intrastratal solution of the less stable species, particularly the ferro-magnesian minerals. Supporting this view is the contrast between compositional immaturity of the Anvil Rock Sandstone as a whole versus the compositional maturity of.the heavy minerals.

Although the data are limited, there may be more garnet in western Illinois than elsewhere in the basin. Siever (1957) reports generally higher percentages of chlorite and garnet in western Illinois for sandstones of Pennsylvanian age. A few grains of kyanite (?) were found in four of the six garnet-bearing samples.

Effects of post-depositional diagenesis are the only clearly defined significant variations discernible in the clay minerals of the Anvil Rock Sandstone. Samples of thin shale lenses and interbeds in the sandstone, when compared to the clay minerals that make up the matrix of the sandstone, show significant variations (table 5). That these variations are due to post-depositional changes and not to differences in source or environment of deposition is a reasonable assumption because of the intimate association of the shale and the sandstone beds. This association is probably the result of local current intensity and not of changes in environment or source area.

Relative percentages of the component clay minerals (kaolinite, mica or illite, mixed-lattice minerals, and chlorite) are shown in table 5 and averages

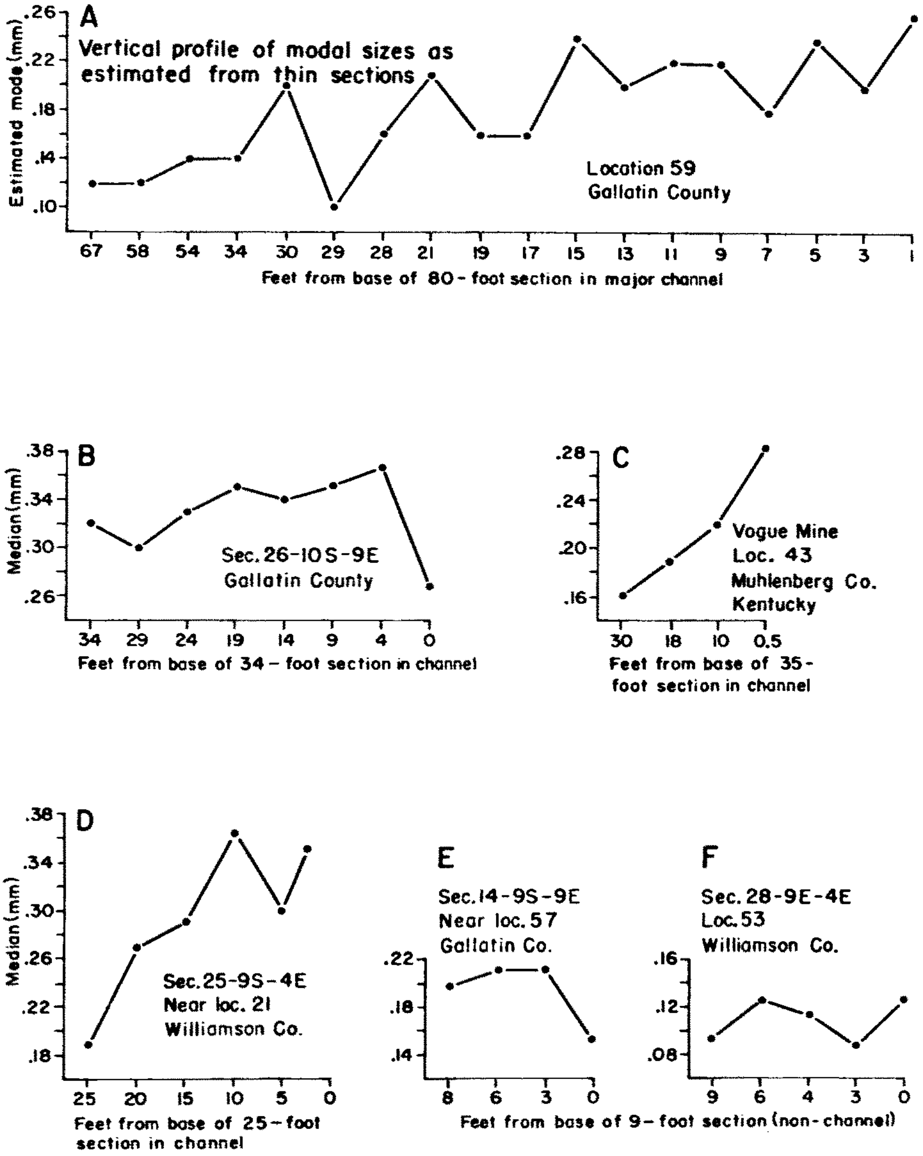
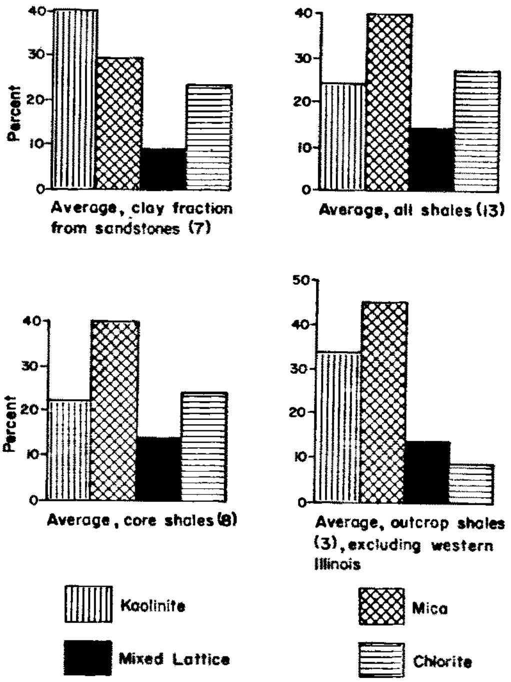


Fig. 12. - Vertical profiles of modal and median grain sizes from channel and non-channel phases of the Anvil Rock Sandstone.

are plotted on a graph (fig. 13). Clay minerals from the clay fraction of sandstone average 40 percent kaolinite, 29 percent mica, 8 percent mixed lattice, and 23 percent chlorite. The clay minerals from shale interbeds average 24 percent kaolinite, 40 percent mica, 14 percent mixed lattice, and 22 percent chlorite. These averages show a definite increase in relative amount of kaolinite and a decrease in mica in the sandstones. Shales are slightly higher in mixed-lattice minerals, but chlorite is essentially the same in both sandstones and shales.

As previously mentioned, nests of kaolinite books were common in the sandstone thin sections. Glass et al. (1956) reported the same occurrence in basal sandstones of Pennsylvanian age and pointed out that survival of these aggregates would be highly unlikely in the turbulent, rigorous environment of sandstone deposition, and that their presence is the result of post-depositional changes. As permeability is higher in the sandstones than in shales, movement of water and, consequently, diagenesis would be greater in the sandstones.


Average, clay fraction from sandstones (7)

Average, all shales (13)

Average, core shales (8)

Average, outcrop shales (3), excluding western Illinois

Fig. 13. - Results of clay mineral analyses of the minus 2-micron fraction of the Anvil Rock Sandstone and shale interbeds within the sandstone.

Effects of weathering can be seen when clay minerals of core samples are compared with those of outcrop samples (two lower histograms of fig. 13). Outcrop shales (excluding western Illinois) show a relative increase of kaolinite (22 to 33 percent) and a marked decrease in chlorite (24 to 8 percent), indicating that, in outcrop, acid leaching has resulted in the formation of kaolinite and the destruction of the original chloritic component.

These detailed studies of a single stratigraphic unit support the conclusion of Potter and Glass (1958, p. 35-42) that appreciable clay mineral contrasts can exist between outcrops and cores and between sandstones and shales.

PROVENANCE

Properties of sandstones useful in determining direction of sediment transport are: 1) cross-bedding, 2) gross sand-body form, 3) asymmetrical ripple marks, 4) contemporaneous deformation features such as slump structures, 5) load casts, 6) current lineation marks, 7) cut-and-fill structure if seen in three dimensions, and 8) internal sand fabrics. All of the above properties were observed in the Anvil Rock Sandstone but only cross-bedding measurement and gross form (channel trends) were found to be useful. Cross-bedding typical of that found in the channel phase of the Anvil Rock Sandstone is shown in figure 14.

The relationship between direction of cross-bedding and channels is shown in figure 6. Most of the cross-bedding data were obtained from the channel phase of Anvil Rock Sandstone. A comparison of cross-bedding in channel and non-channel sandstones could not be made because not enough non-channel measurements were available.

Direction of sediment transport in the basal Pennsylvanian clastics of the Illinois Basin is dominantly toward the southwest. This conclusion is based on the dominant southwesterly orientation of the erosional channels of the Mississippian-Pennsylvanian unconformity (Siever, 1951; Wanless, 1955). Cross-bedding direction in the basal Pennsylvanian sandstones is also dominantly to the southwest (Potter and Siever, 1956). In southern Illinois this southwestward cross-bedding direction persists through some 1800 feet of Pennsylvanian sedimentation to at least 150 feet above the position of the Anvil Rock Sandstone (Potter and Glass, 1958).

Fig. 14. - Cross-bedding in the channel phase of the Anvil Rock Sandstone, Gallatin County, Illinois.

Directions of sediment transport during deposition of the Anvil Rock Sandstone do not depart from this pattern. Cross-bedding dip directions, trends of channels, and junction angles of channels (fig. 6) lead to the conclusion that the currents responsible for the transportation and subsequent deposition of the sand were flowing in a southwesterly direction in southern Illinois. A glance at the major east-west channel that crosses Jefferson, Wayne, and Edwards counties, however, suggests that for a distance of about 65 miles the direction of flow was to the east before it resumed the southwesterly direction. Thus the transport direction of the Anvil Rock Sandstone closely conforms to the known directional pattern of other Pennsylvanian sediments in the basin.

Petrologically, the sandstones of the Carbondale and McLeansboro Groups are subgraywackes and, as shown by Siever (1957), are exceedingly homogeneous. As previously noted, the composition of the Anvil Rock Sandstone conforms closely to that of the other sandstones of the Carbondale and McLeansboro Groups in the basin. The detrital elements of the Anvil Rock Sandstone (tables 2 and 3) imply a source in which granitic and metamorphic rocks as well as pre-existing sediments were present. Siever (1957) suggested that the dominant source of the subgraywacke sandstones was to the northeast and north. Highlands to the east of the northern Appalachian Basin in New England and the southern portions of the Canadian Shield appear to have been the dominant source regions.

EROSIONAL AND DEPOSITIONAL HISTORY

Physiographic Setting

One of the most striking characteristics of the sediments of the Carbondale and McLeansboro Groups is the lateral persistence of the individual lithologic units. Coal beds, underclays, and limestones are most persistent,but many shales and sandstones have remarkable uniformity. Numerous oscillations of the strand line have been established for Pennsylvanian time, even if only alternation of coal and marine limestone is considered. Coupled with this alternation is the widespread distribution of the individual units, some of which are less than a foot thick. Thus we see a very low-lying surface with little relief subject to numerous invasions of shallow seas that, because of the low relief, affected wide areas.

Deposition of Sheet Sand

Previous workers have considered in broad outline the morphological and environmental implications of the Pennsylvanian sandstones in the Illinois Basin.

Weller (1930) regarded the sandstones as the result of stream deposition on an alluvial plain. According to this theory, after the streams aggraded their channels they were forced to spread over wide areas, depositing the sheet sand. Weller recognized, however, that transitional beds occur locally between the sandstone and the underlying marine shale. Study of hundreds of diamond drill cores taken from the Anvil Rock and other sandstones indicates that a gradational contact is at least as common as a sharp contact in areas where the sandstone is thin (non-channel phase).

Wanless and Shepard (1936) believed the sandstones were deposited by rivers in channels cut on a newly exposed delta plain. No difference in manner of deposition of the sheet versus the channel phase is implied.

Siever (1957) shows that there is much conflicting evidence on the nonmarine versus marine origin of the sandstones and concludes that petrographically similar sandstones were deposited in a variety of shallow-water, littoral, lagoonal, deltaic, and coastal plain alluvial environments.

In contrast to the above broad environmental judgments, comparatively little attention has been given to the possible difference in origin of the sheet and channel sandstones.

At least the lower part of the sheet phase of the Anvil Rock Sandstone is older at any one area than the channel sand and is considered the first sand deposited. As a sharp break in sedimentation is not the rule, the sheet phase may better be regarded as a coarse facies of the underlying gray shale. Marine fossils are present near the base of this shale, but become less numerous above the lower few feet and generally have not been observed in the upper part.

The environment of deposition of the sheet sand is considered to be nearshore marine under shallow-water conditions where current activity was low and conditions were more or less uniform, giving rise to the parallel bedding and lateral continuity that characterize this sandstone. Cut-and-fill structures and cross-bedding, both indicative of strong current action, are rare, whereas the most noticeable structures are an occasional ripple mark (both asymmetrical and symmetrical) and parallel bedding. Shale interbeds are common.

The beginning of sandstone deposition was the response to a relative fall in sea level that began at the onset of gray shale deposition. Streams draining from the source area (which lay mainly to the north and northeast) contributed detritus to the shallow sea. As the sea regressed toward the south and southwest, grain size of the detritus at any one place increased, resulting in the gradation from shale to sandstone that is present at the base of the sheet sandstone.

As detritus entered this near-shore area, weak currents would spread the material. No evidence of extensive reworking is present, so currents probably were not strong or persistent enough to effect segregation of the finer sizes from the sand-sized material. Local scouring of the muddy bottom would account for the abrupt contact with the shale seen at the base of the sheet sandstone at some places.

The sheet sand is thought not to be entirely regressive. After channel cutting, marine conditions again invaded this region. The sheet sandstone grades into the overlying shale, which is overlain by the Bankston Fork Limestone. Much of the sheet sand may have been slightly reworked or new sand may have been deposited during this transgression. Not enough vertical profiles of grain size analyses were made to show a decrease in grain size at the top and bottom of the sheet sand. Two profiles of median grain size are shown (E and F of fig. 11). Observations of outcrops and cores, however, do show the gradation that is even more apparent at the top of the sandstone than at the base.

The unconformity developed after regression is not visible. It would occur in the sandstone, but if the sand was not lithified slight reworking would destroy any trace of this unconformity.

Thicker and more uniform deposition of this sand occurred in the more negative part of the Illinois Basin. To the west of the DuQuoin Monocline the sheet sandstone is not present (fig. 4) and its position between the Jamestown (where present) and Bankston Fork Limestones is taken by gray shale or siltstone. No evidence exists of the unconformity that should occur between these two earlier beds if the sand had been deposited and subsequently removed.

To the northeast in Edwards, Wabash (Illinois), Gibson, and Posey (Indiana) counties (fig. 4) the sheet sandstone is absent over large areas. Control here is largely based on electric logs. The lithology of the rocks between the Jamestown and Bankston Fork Limestones (where present) can be referred to only as "shale." Evidence for or against deposition of sheet sand over this entire region is lacking. However, isolated patches of sandstone as much as 15 feet thick are present, and might be interpreted to indicate that deposition originally took place over the entire area.

Both the region west of the DuQuoin Monocline and the northeastern part of the area mapped are tectonically positive; the shelf to the west is a homogeneous positive element, and the northeastern area has a more heterogeneous positive framework, the Wabash River fault belt.

Current intensity probably is the controlling factor in the distribution of the sheet sand. The positive areas may have been very near or even slightly above sea level during deposition of the sheet sand, while the deeper portion of the basin was open water subject to more uniform currents. No shore line deposits such as beaches and bars were recognized.

Development of Channels

Whether the channels were developed during or after regression is at present an unanswered question. If channel development kept pace with regression, channels would have extended themselves at their mouths, in a manner similar to the growth of a deltaic body, and the master stream would be connected to the original source. In classical geomorphology, drainage development on a newly raised coastal plain generally is considered in terms of the period after it is exposed to erosion and not in terms of the extension of pre-existing streams during the withdrawal of the sea. Lengthening of the streams during regression should result in poorly defined erosional channels, unless after maximum regression a period of erosion occurred and the streams were able to sculpture well defined valleys.

When stream erosion takes place on a newly exposed plain, headward extension of valleys is the rule. The new streams would not be connected with the ultimate source, in contrast to stream extensions formed during regression. Source of clastic material for the new streams would be the previously deposited sand now exposed on the coastal plain.

As far as can be established from thickness of channel fill and stratigraphic depth of erosion, no systematic gradient is discernable in the channels. With the exception of the slope of some of the short tributary channels, gradients must have been exceedingly low. This is in harmony with paleogeographic conditions throughout most of Pennsylvanian time on this part of the craton where low-lying lands and shallow uniform seas were the rule.

The following is considered the most logical sequence of events prior to and during channel development:

1) Deposition of sheet sand during regression.
2) Extension of a complex network of shallow, wide channels on a newly exposed coastal plain (minor channels).
3) Period of erosional development of the channels including short tributaries.

In the third stage, erosion was confined mainly to the channel areas and interfluves were not deeply incised, although some of the sheet sand was removed and carried to the channels. At the period of maximum regression, base level was further lowered and the major channels were cut. At this stage downcutting was predominant and the anastomosing character of the streams was lost, resulting in a more definite simple stream pattern. At the time of maximum erosion the location of the major channels was determined by the chance location of the trunk stream at this particular time. Only in eastern Washington County is there any suggestion of changing drainage patterns in the major channels (pl. 1). There the north-south channel joins the east-west channel. Subsurface control here is poor and the junction is only inferred. However, in every instance where control was present, continuity of the major channels was maintained, so that the joining of these two channels is probably justified. Major drainage at this time shifted from the east-west to the north-south channel or vice versa. Some type of stream piracy is inferred.

Sedimentation in Channels

Aggradation in stream channels may be the result of such factors as decrease in volume, increase in load carried, or obstructions to flow, most of which are impossible to assess in the ancient rocks. Modern geomorphic studies indicate that alluviation in most of our streams can be caused by such short term factors as climatic controls, overloads of sediment, and activity of man. In the geologic column, only long term changes such as diastrophism, relative rise and fall of sea level, and some climatic changes, can be deciphered.

Alluviation of Anvil Rock channels is considered a result of sea level change. A return to definite marine conditions after Anvil Rock time is evidenced by the Bankston Fork Limestone, a short distance above the Anvil Rock, which bears a marine fauna of brachiopods, corals, crinoids, and fusulinids. With a relative rise in sea level a graded stream would first deposit its load near the mouth and a wave of aggradation would extend upstream. A continual rise in sea level would give the same results, and the channels would be filled by either stream alluviation or marine deposition, depending on the balance of deposition of alluvial material and the rate of rise in sea level. In the absence of marine fossils, separation of these two environments would be difficult.

The question of how the tributaries were filled arose early in the study. Where was the source of the sand that filled tributary channels as much as 15 miles long? These tributaries appear to end a few miles from the principal "through-flowing" channels. If sheet sand had not previously been deposited, tributaries would have had no source of sand, as they cut through only shale and, at some places, coal and limestone.

It might be argued that erosion of the shale would supply sufficient sand to fill these channels. If this had happened it would have resulted in the removal of a large quantity of shale and the development of an unconformity extending beyond the channel area. The former requisite is difficult to assess, but the latter should be observable if present. The gradational nature of the base of the sheet sandstone was therefore studied and the findings indicated that the shale-erosion hypothesis of the source of sand filling the tributaries was untenable.

Relations at channel margins, however, fail to show that the channel sandstone is younger than the sheet sand. As a channel sandstone is traced laterally into the sheet phase, no surface of discontinuity separates the two. The only apparent change is in bedding, the sheet sandstone being more uniform and thinner bedded than the channel sandstone. If the sheet sand had been lithified. prior to channel filling, a surface of discontinuity would be apparent. However, if the channel was filled prior to lithification of the sheet sandstone, the contact between the two phases would be imperceptible, especially if marine currents had an opportunity to rework some of the material in the upper parts of the channel.

The hypothesis regarding relative age of sheet phases and channel phases that has been outlined is considered the one most consistent with the stratigraphy, gross form, sedimentary structures, and petrology of the sandstone. One assumption, however, that is critical to the hypothesis is that the channels were cut by subaerial streams.

Comparison with submarine valleys on continental shelves is informative. Such valleys as the Hudson channel, the Sunda "River, " the Elbe and Rhine channels, and many others are considered the result of normal stream erosion, with subsequent drowning due to a eustatic rise in sea level after the last glacial advance (Kuenen, 1950). The channels on the floor of the shallow (50 to 80 meters) Sunda Shelf between Sumatra and Borneo have a dendritic pattern, and most of the valleys start near mouths of large rivers on the adjacent islands (Kuenen, 1950, fig. 203).

Because of the geologically recent (late Pleistocene) eustatic rise of some 200 to 300 feet in sea level, results of marine erosion on continental shelves are difficult to evaluate. We do know that currents strong enough to erode weak sediments are present on the shelves, but the concentration of these currents into narrow channels in a dendritic pattern is somewhat hard to conceive unless the eroding agents are the narrow threads of dense currents issuing from the river mouths. That currents of this type were responsible for the long Anvil Rock channels is hardly conceivable. A narrow thread of current could not be expected to maintain such a long course on a flat shelf unless confined by a pre-existing channel. Nor could tributaries to the principal channels be so cut in consolidated rocks in areas far removed from river mouths and without appreciable slope.

The Pennsylvanian channels and the sandstones filling them cannot be compared to submarine canyons and the associated deep water deposits. Headward erosion by slumping and the generation of turbidity currents should leave some evidences in the form of slump structures and/or graded beddings, but such evidence is lacking. Moreover, depositional slopes were exceedingly low, not approaching the gradient of those associated with submarine canyons. Deep water deposition can be ruled out, for paleontological, sedimentological, and stratigraphic evidence all point to either shallow-water or to low-lying continental environments throughout Pennsylvanian time.

I favor the hypothesis that the channels have a dominant subaerial origin.

That the channels were filled by the same agent that formed them has been questioned. Lack of marine fossils and presence of land plants in most of the sandstones have been advanced as evidence for the terrestrial deposition of a nonmarine environment. However, all calcareous fossils easily could have been removed by post-depositional solution, or environmental conditions during deposition could have been unfavorable for abundant marine life. Presence of land plant fossils in these rocks indicates nothing more than that land plants were growing somewhere within transporting distance.

Deposition by valley alluviation combined with marine filling of the channels seems the most probable explanation of channel fill based on stratigraphic and petrographic relationships. A limestone environment, the Bankston Fork, shortly followed deposition of the sandstone in the non-channel areas and in several places over the minor channels. Over the major channels where the Bankston Fork Limestone is almost universally absent, siltstone was deposited, some of it probably contemporaneous with the limestone. Turbid water carrying silt and clay-size material would have deposited the clastic material at the mouth of the major stream, thus preventing the deposition of the Bankston Fork. A decrease in grain size from base to top of the channel fill (fig. 12) indicates a gradual decrease in competency of the currents, a situation that would result if the channels were subject to a gradual drowning by a transgressing sea. No marine fossils were observed in the siltstone of the major channels, but a thorough investigation of this lithology is not feasible as it has not been recognized in outcrop and only a few core holes have been drilled through it.

The difference in depth of erosion of the major and minor channels and the difference in their channel pattern suggest that channel formation and filling occurred at two more or less distinct times. The minor channels are believed to be the result of extension of pre-existing streams in the direction of the retreating strand line. Major channels developed subaerially as the major drainage system on the exposed surface after withdrawal of the sea.

Following Bankston Fork time, emergent conditions prevailed once again, culminating in the widespread coal-forming swamp that became the Cutler (No. 7)

Coal. Between this coal and the Bankston Fork Limestone is a sandstone and at least two other coal beds. Stratigraphic relations between the sandstone and the uppermost coal bed (a local, discontinuous coal) are not clear. However, the lower of the two coal beds, the Bankston Coal, occurs only a foot or two above the Bankston Fork Limestone and is persistent as a coal bed or a coal horizon (underclay plus a thin carbonaceous shale) over most of the outcrop belt in southern Illinois east of the DuQuoin Monocline. It attains minable thickness in parts of Union and Webster counties, Kentucky, where it is known as the Baker No. 14 Coal (Glenn, 1922).

Sedimentary conditions that gave rise to these rocks between the Bankston Fork Limestone and No. 7 Coal did not favor the deposition of these strata in the major channel areas. The sandstone in the channels restricted the distribution of both normal marine deposits and continental deposits.

In the Illinois Basin an abrupt topographic difference of as much as 20 to 30 feet between channel and non-channel areas was likely to affect distribution of sediment. The channels probably were not completely filled until deposition of the No. 7 Coal, which is the first bed that can be traced over both the channels and the non-channel areas. On a low-lying coastal plain repeatedly subjected to swampy conditions, negative relief of the postulated 20 to 30 feet would be enough to keep the channels filled with water and possibly not entirely interconnected as they had been when erosion and sand transportation were dominant. When siltstone had gradually filled up the channels, coal swamp conditions prevailed, permitting widespread development of No. 7 Coal.

ECONOMIC SIGNIFICANCE

Effects on Coal Mining

In Illinois, considerable importance has been placed on determining the extent of the Anvil Rock Sandstone because of its position above the No. 6 Coal, the most important commercial coal in the state. Structural maps of the subsurface have delineated long, relatively narrow areas where the coal has been removed by erosion and its place taken by the sandstone. These Anvil Rock channels have been partially mapped in the following counties: White (Harrison, 1951), Wayne (DuBois and Siever, 1955), Wabash (Cady et al., 1955), Madison, Clinton, Bond, Montgomery, and Shelby (Payne and Cady, 1944; DuBois, 1951). The coal resources map of the No. 6 Coal for the entire state shows known extent of cut-outs as of 1950 (Cady et al., 1952, pl. 2). Many of the above references show coal cutouts as isolated occurrences, but the present available data proves the major channels continuous.

In Putnam and Bureau counties, sandstone cutouts occur as far north as the limit of the No. 6 Coal. Cady (1915, p. 77) refers to cutouts in the No. 5 Coal in southeastern Putnam County. Subsequently this coal was found to be No. 6 (Cady et al., 1952, p. 58), suggesting that the sandstone is Anvil Rock (or Copperas Creek, the probable western Illinois equivalent). Distribution and size of the cutouts in this region are not known but there is some suggestion of a north-south trend as much as two miles wide.

Mining operations in the No. 6 Coal have encountered sandstone cutouts in several places west and northwest of the deep part of the Illinois Basin. The best known are those in the Taylorville district, Christian County (Payne and Cady, 1944) where trends have been established by extensive mining (fig. 6).

A large number of channels filled with sandstone, siltstone, and shale have been reported in mines in Sangamon, Montgomery, Macoupin, and Washington counties (fig. 6). All channels encountered in mining to date, with the exception of the Washington County occurrence, are small, varying from a few feet to over 1000 feet in width. The sandstone may extend onto, into, or through the coal.

In the area of detailed mapping, the mine of the Clarkson Coal and Mining Company, Nashville, Washington County, Illinois, is thought to have mined against a major channel. Miners reported a sandstone "fault" in the eastern part of the workings. Information on the subsurface in this area indicates that the Anvil Rock channel is the cause of this irregularity in the coal. In addition to a number of mines where cutouts are reported, sandstone roof is locally common in several other mines that have operated in this general region.

In many cases mining operations have stopped when a complete cutout was encountered and the coal was considered to be "faulted." A knowledge of the true nature of these sandstone channels would have been helpful in deciding whether to close part of the mine or to tunnel through the sandstone and resume mining.

Potter and Simon have mapped the Anvil Rock Sandstone in some detail in the counties in which mines have encountered channel cutouts of No. 6 Coal northwest of the area of the present study.

The spacing pattern of diamond drill holes used by most companies in prospecting for future underground mines in Illinois is generally too inadequate for use in delineation of these narrow channels. They may be missed entirely, even in a field where channels are subsequently found, during mining, to be common. Where the coal is missing in drill holes, proper evaluation of the rocks occurring at its position and the elevation of lower marker beds generally can establish whether the coal is absent because of non-deposition, cutout, or true faulting. When this has been ascertained, the drilling program should be modified accordingly. In the case of sandstone cutouts, delineation is difficult because of their sinuous pattern, and numerous drill holes may be required to outline the channel.

Mining operations must be modified considerably when cutouts are encountered during mining. Because of the meandering pattern of the channels, prediction of trends may be exceedingly difficult. By measuring the strike of the unconformable lateral margin, local trend may be established, but projection for any distance is unreliable. A combination of observations at the cutout face and planned diamond drilling should aid in delineating the channels.

Another problem created by the presence of channels lying over or cutting through the No. 6 Coal is that of water. The sandstone, especially the channel phase, may be permeable and water bearing. In planning mining operations, the quantity of this water and its chemical nature, primarily salinity, should be estimated. Considerable water from the Anvil Rock Sandstone has been reported in a few mines in Illinois and its removal has become a large economic factor in at least one case. Although salinity of water in this sandstone was not studied, the curves in the majority of electric logs examined showed definitely that the water could not be considered fresh. Obviously, this is to some degree a function of depth; above a certain depth the sandstone would yield fresh water.

Oil and Gas

In the Illinois Basin oil and gas are produced largely from Mississippian and older systems. Considerable production is obtained from the lower part of the Pennsylvanian column along the LaSalle anticlinal belt, and lesser amounts along the Wabash River fault belt (fig. 1). The upper part (Carbondale and McLeansboro Groups) is almost barren.

The author is aware of only one area where production has been obtained from the Anvil Rock Sandstone. A few wells in the Herald Consolidated pool have produced gas from this sandstone at depths of 670 to 750 feet in secs. 2 and 3, T. 7 S., R. 9 E., White County. The Anvil Rock in this area is about 45 feet thick and is the minor channel phase. Initial production was reported for six wells and open-flow capacity ranged from 200,000 to 3,250,000 cubic feet. Accumulation here is probably a function of structure as these wells are located on a faulted anticline (Harrison, 1951, pl. II).

SUMMARY AND CONCLUSIONS

The character of the Anvil Rock Sandstone was determined by mapping its subsurface distribution and making studies of its sedimentary structures and its petrology.

Subsurface mapping demonstrates that the Anvil Rock Sandstone has two primary morphologic elements: a sheet phase and a channel phase. The sheet phase is largely confined to the more rapidly subsiding portion of the Illinois Basin and is generally conformable with the underlying sediments. It rarely exceeds 20 feet in thickness, and is considered to be a dominantly regressive marine sandstone.

In contrast, the channel phase is considered to be dominantly fluvial. The channel phase has pronounced unconformity with underlying sediments and at some places is more than 200 feet thick. Although the evidence is not conclusive, the channel phase is considered to be younger than the sheet phase. The mapped pattern of the channels indicates a general southwesterly transport direction.

Texturally, the fill of the erosional channels at the base of the Anvil Rock Sandstone is coarser grained and better sorted than the sheet phase sandstones. Cross-bedding appears to be most abundant in the channel phase. In outcrop, cross-bedding direction indicates a transport direction to the southwest.

Petrologically, the sheet and channel phases of the Anvil Rock Sandstone are very similar. Moreover, their composition differs but little from the other subgraywacke sandstones of the Carbondale and McLeansboro Groups of the Illinois Basin. The subgraywacke composition of the Anvil Rock Sandstone indicates that a moderately immature source area contributed detritus to the basin. Both channel pattern and cross-bedding directions indicate that this detritus was dominantly transported across the basin from the northeast to the southwest.

Detailed information about the channel pattern and generalized transport direction of the Anvil Rock Sandstone and its relationship to the Herrin (No. 6) Coal is important in evaluating conditions that might be encountered in mining the coal.

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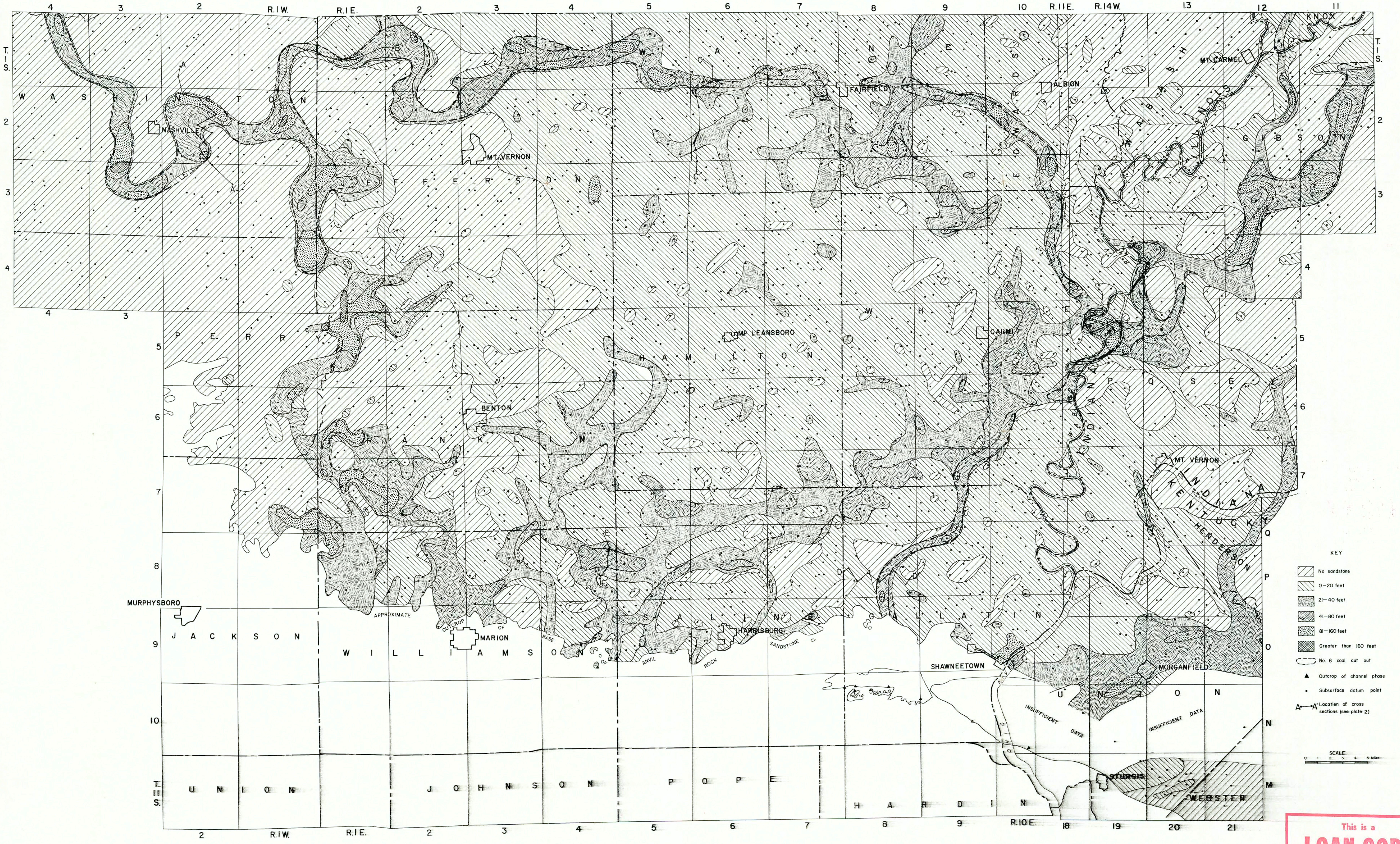

THICKNESS OF ANVIL ROCK SANDSTONE

M. E. HOPKINS

1955

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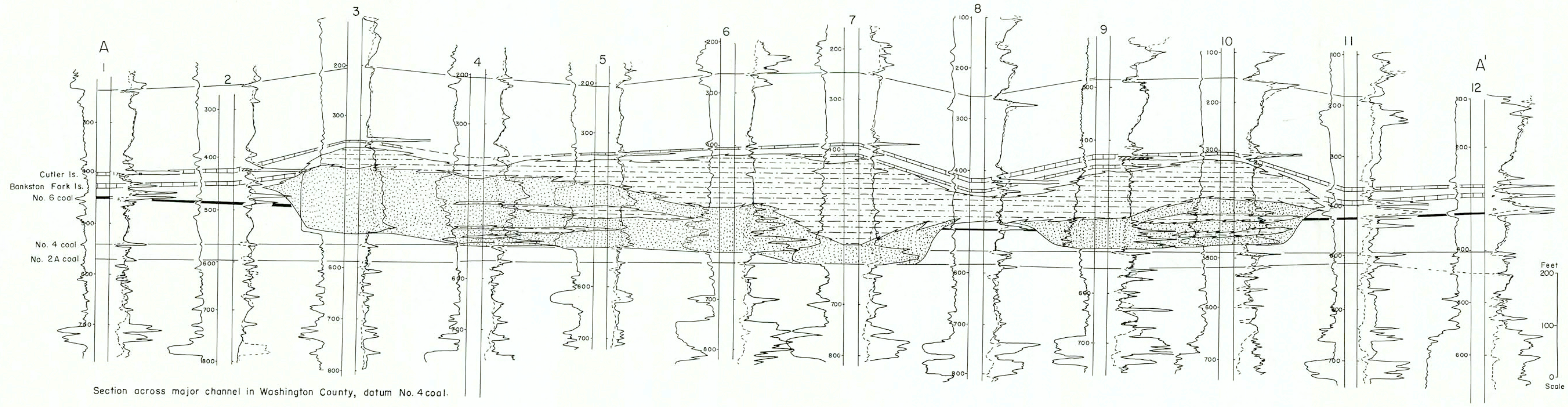
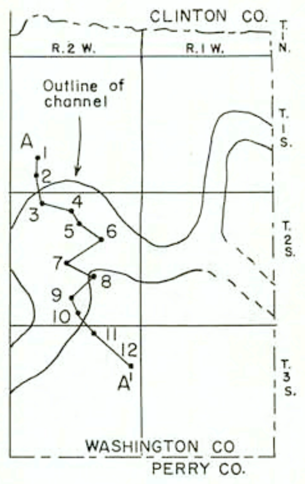


Section across major channel in Washington County, datum No. 4 coal.



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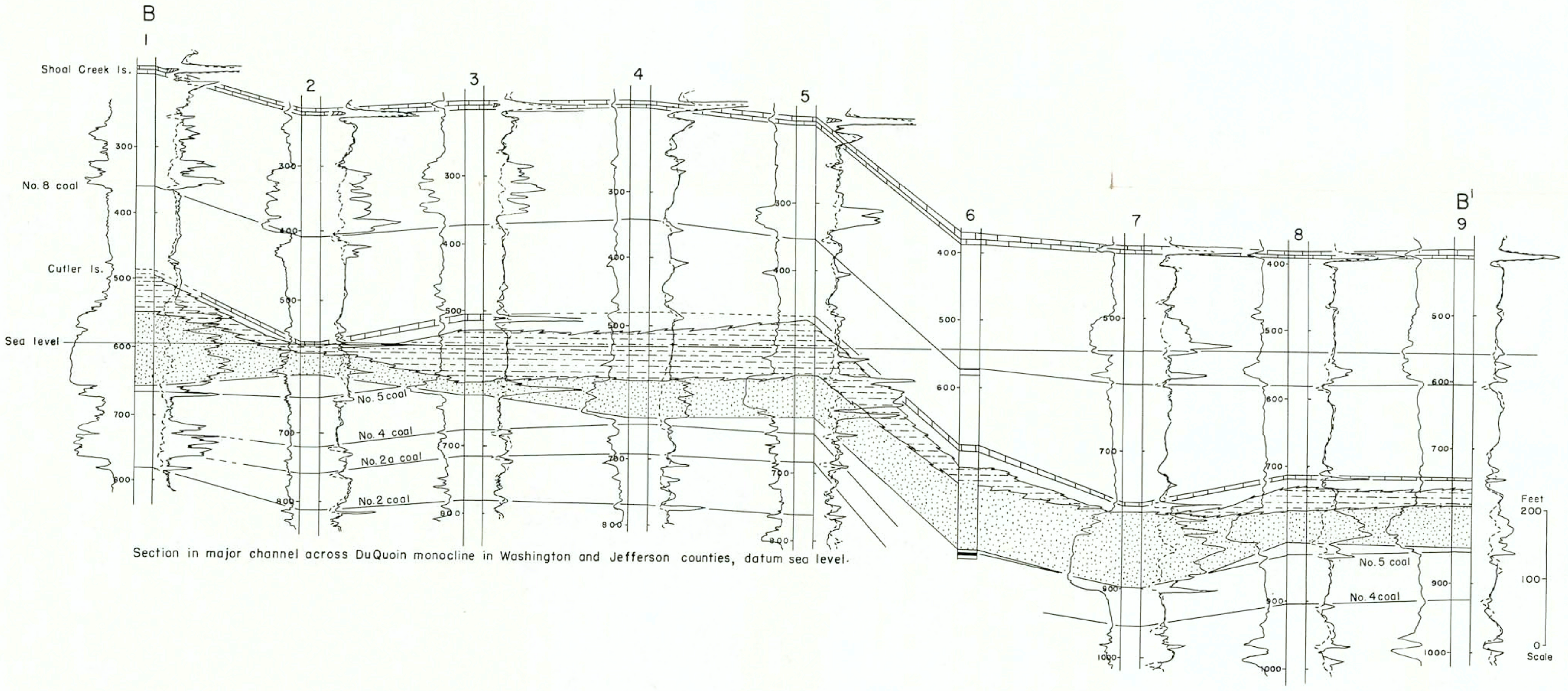
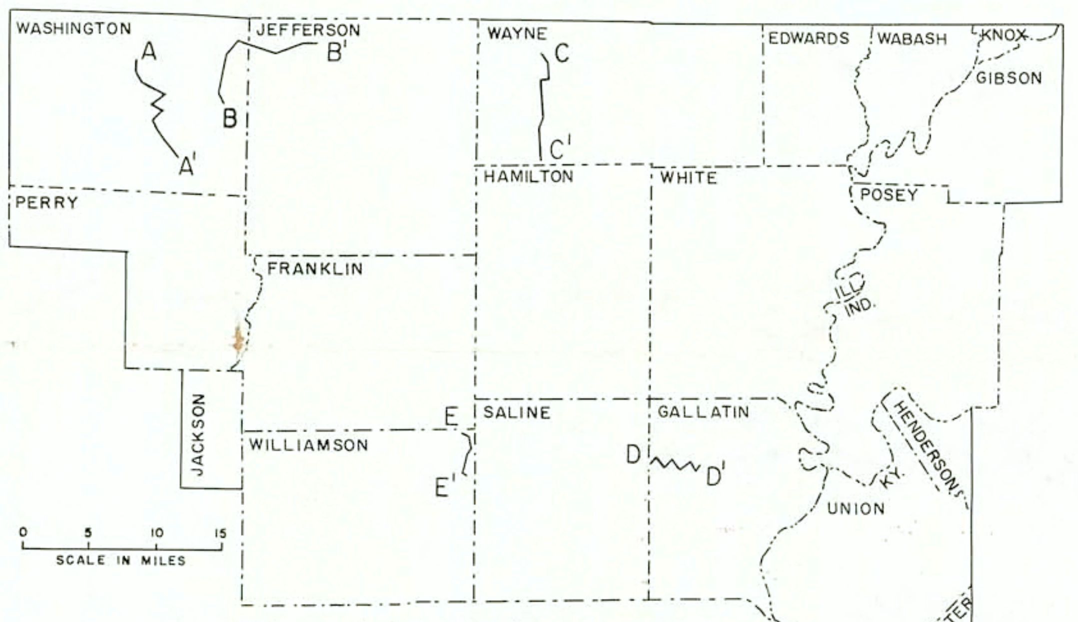
2. Sec. 32, SE NW NW

T.2S., R.2 W.
3. Sec. 5, NW NW SE
4. Sec. 4, SE SE SE
5. Sec. 10, SE SW NW
6. Sec. 14, SE NW NW
7. Sec. 21, NW NE NE
8. Sec. 22, SE NE SE
9. Sec. 28, NE SE SE
10. Sec. 34, SW SW NW

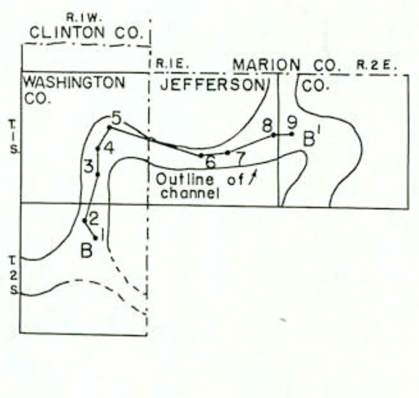
T.3S., R.2 W.
11. Sec. 3, SE NE NE
12. Sec. 12, NE SW SE



Section in major channel across DuQuoin monocline in Washington and Jefferson counties, datum sea level.



Index map showing location of cross sections (see plate 1 for relation to distribution of channels)



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4. Sec. 22, SW SE
5. Sec. 14, SW SW NW

T.1S., R.1E.
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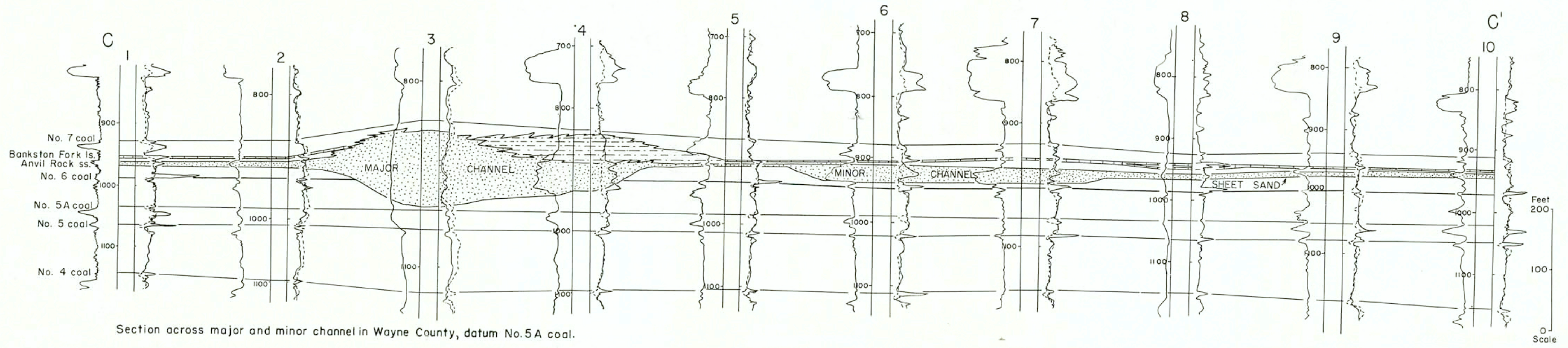
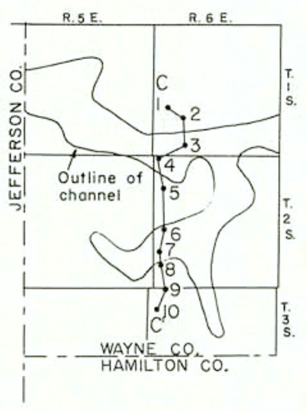
7. Sec. 22, NE NW SE
8. Sec. 13, SW NE SE

T.1S., R.2E.
9. Sec. 18, SW NW SE



Section across major and minor channel in Wayne County, datum No. 5A coal.



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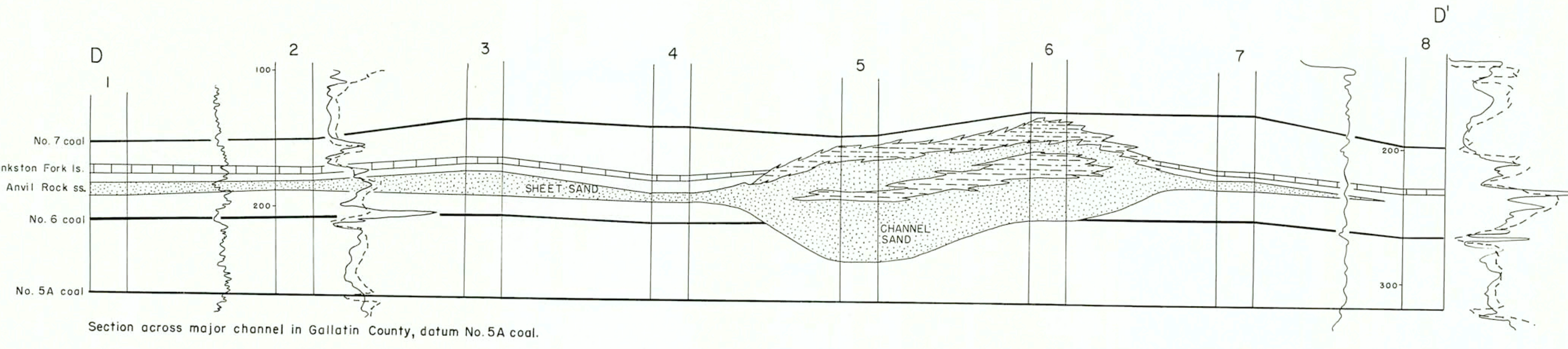
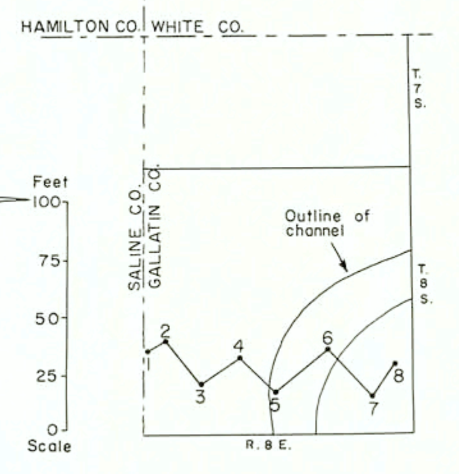
3. Sec. 32, Cen. NW SE

T.2S., R.6E.
4. Sec. 6, W1/2 NE NW
5. Sec. 7, SW NW SE
6. Sec. 19, W1/2 NW SE
7. Sec. 30, SE SW NW
8. Sec. 31, NW NE NW

T.3S., R.6E.
9. Sec. 6, NW NW NE
10. Sec. 7, NW NE



Section across major channel in Gallatin County, datum No. 5A coal.



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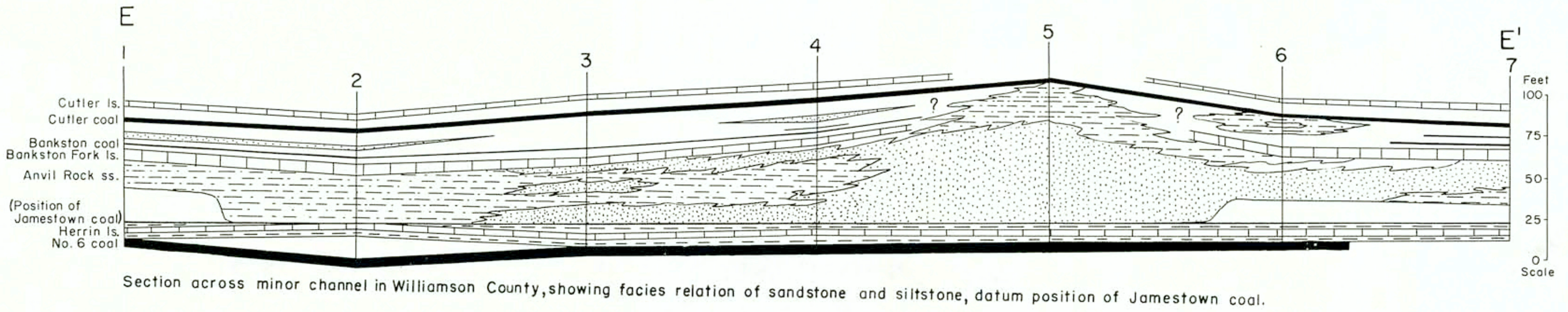
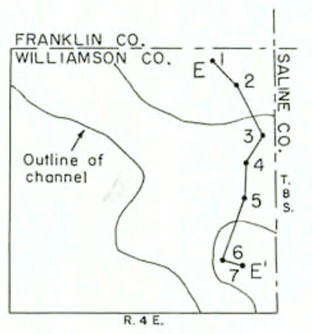
6. Sec. 26, NW/C
7. Sec. 36, NW/C SW NW
8. Sec. 25, NW NW SE



Section across minor channel in Williamson County, showing facies relation of sandstone and siltstone, datum position of Jamestown coal.



T.8S., R.4E.
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2. Sec. 1, NE SW SW
3. Sec. 12, SE SW SE
4. Sec. 13, NE NE SW
5. Sec. 24, NE SE NW
6. Sec. 26, NE SE SE
7. Sec. 25, SW SE SW

KEY

▨ Sandstone
▤ Siltstone (sandy)
▦ Limestone
▤ Black Shale
■ Coal

CROSS SECTIONS - ANVIL ROCK CHANNEL

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