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LATE MISSISSIPPIAN SANDSTONES OF ILLINOIS

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ABSTRACT

Sandstones, one of the distinctive lithologies of the late Mississippian sediments of the Illinois Basin, constitute approximately one-fourth of the section. The sandstones consist chiefly of well sorted and moderately well rounded, mineralogically stable detrital grains and their chief sedimentary structures are cross-bedding and ripple marks.

The sandstones occur as sheets and as four types of elongate sand bodies: pods, ribbons, dendroids, and belts.

Detailed local maps showing the thickness of sand of the Degonia, Waltersburg, and Cypress Formations and regional maps for the Degonia, Palestine, Waltersburg, and Hardinsburg Formations display the recurring types of sand bodies and emphasize the essential similarity of all the late Mississippian sandstones. This similarity is a basis for better understanding and improved prediction of sandstone trends.

Data gained from the study of the sandstones integrates well with other known features relative to paleogeography of late Mississippian time.

INTRODUCTION

Sandstones are an important constituent in the late Mississippian rocks of the Illinois Basin. They occur not only in the Chesterian (Upper Mississippian) Series but also in the upper part of the Valmeyerian (Middle Mississippian) Series. The sandstone-bearing sediments in both series have been placed in the Pope Megagroup by Swann and Willman (1961), but are generally referred to in this paper as late Mississippian. These rocks underlie nearly 20,000 square miles in Illinois or about 35 percent of the area of the state (fig. 1). The sandstones of this sequence, primarily through their oil production, have contributed importantly to the economic well-being of the state.

This study summarizes present knowledge of late Mississippian sandstones in Illinois, emphasizing sedimentary petrology and texture, sedimentary structures, the basic types of sand accumulation, and local and regional patterns of sand deposition. Regional maps show the thickness of sandstone in the Degonia, Palestine, Waltersburg, and Hardinsburg Formations.

Maximum thickness of nearly 1,400 feet of Chesterian sediments occurs in southern Illinois near the outcrop in Johnson County. Northward, the Chesterian sediments thin, in part the result of deposition but principally because they were truncated by pre-Pennsylvanian erosion. The erosion exposed progressively older formations to the north and also developed a clearly defined dendritic pattern of valleys (Siever, 1951; Wanless, 1955, fig. 2). The valleys interrupt facies maps of many Chesterian formations, particularly near their subcrop.

The Pope Megagroup (the sandstone-bearing late Mississippian sequence) is approximately one-half shale, one-quarter limestone, and one-quarter sandstone.

Lithologically the sandstones consist of two basic types. One type tends to occur in beds less than 1 foot thick, commonly is argillaceous, has a calcite cement, is greenish gray, occurs in bodies less than 20 feet thick, has poor permeability, and is not always well defined on electric logs. The second type occurs in thick sections, at places as thick as 100 feet, has more permeability and porosity, is somewhat coarser than the first type, and gives good definition on electric logs. Fossils are rare except for plant debris that tends to occur in the upper part of some of the thick sandstones.

The late Mississippian limestones include both calcarenites and calcilutites and usually have a relatively small clay content. With few exceptions limestone units in the basin thicken southward.

Coal beds, from a fraction of an inch to a few inches thick, occur locally in most of the sandstone formations, commonly toward the top. The coals associated with the Tar Springs, Cypress, and Bethel Formations appear to be more continuous than those in the Degonia, Palestine, Waltersburg, and Hardinsburg Formations. Underclays with stigmarian rootlets range from a few inches to more than 12 inches thick.

The late Valmeyerian and Chesterian sandstones, shales, and limestones are imbedded in a cyclical arrangement that has been commented on by many writers. This cyclical arrangement of clastic elements alternating with carbonate elements provides the basis for differentiating the sequence into many relatively thin, widespread, stratigraphic units that can be mapped in both subsurface and outcrop.

Nomenclature of Chesterian and late Valmeyerian sediments used in this paper is shown in figure 2. Good general descriptions of this sequence in outcrop are given by Lamar (1925, p. 26-77), Weller and Sutton (1940), and Baxter et al. (1962). Cross sections by Swann and Atherton (1948) and Siever (1954, pl. 1) show the subsurface variations in the sequence. Workman (1940) and Swann and Bell (1958) provide a general description of these sediments in the basin.

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CLASSIFICATION OF SAND BODIES

Late Mississippian sandstones have less lateral continuity than the shales and limestones. Elongate sandstones, in part discontinuous, have pronounced variation in thickness and are the disruptive elements of the sequence. For example, sediments have been eroded at the base of nearly all thick elongate sand bodies. Differential post-depositional compaction between sandstone and shale accentuates initial differences in thickness.

Figure 3 shows some of the common map patterns of the late Mississippian sandstones as revealed by subsurface mapping. The classification of sand bodies associated with these patterns is applicable to similar facies elsewhere, but is not intended to be a general one.

There are four types of thick elongate sand bodies: pods, ribbons, dendroids, and belts. Pods refer to small, isolated, slightly elongate sand bodies. With increase in length pods grade into ribbons which are relatively straight but generally isolated sand bodies. Widths in excess of several miles are unusual. Narrow elongate sand bodies, from a few hundred feet to several miles in width, with meandering outline and either tributaries or distributaries, are termed dendroids. With increasing width, dendroids grade into belts which may be as wide as 25 to 35 miles. Such belts nearly always contain "islands" in which no permeable sandstone is found.

Sheet sand bodies have less distinctive map patterns. In subsurface they may consist of relatively small sand bodies of limited extent and irregular pattern. Preferred orientation is not apparent. At other places, sheet sand bodies may be more widespread.

Sheets may be the lateral equivalents of ribbons and belts, but they also may occur on top of elongate sand bodies, and in this position they represent the waning phase of sand deposition in an upward transition to shale.

Although the high walls of some quarries provide cross sections of smaller sand bodies, cross section is best determined in subsurface in areas of dense drill-hole control. The elongate sand bodies are generally lenticular in cross section, as demonstrated both in outcrop and in subsurface cross sections, especially if underlying marker beds are progressively replaced by sandstone. Differential compaction of sandstone and shale accentuates the biconvex character of lenticular cross section in the subsurface. The sheet sand generally has planar bounding surfaces. Figure 4 shows idealized cross sections of the sheet and elongate sand bodies.

In outcrops, it is not generally possible to distinguish between pods, ribbons, and dendroids, but the distinction between the sheet and elongate sand bodies is quite apparent. Table 1 summarizes this distinction in terms of eight attributes.

1) Basal Contact.—Basal contact is best observed in outcrop. It is always sharp and disconformable beneath elongate sand bodies. It is commonly conformable and transitional beneath sheet sand bodies.

2) Thickness.—The elongate late Mississippian sand bodies commonly range from 20 to 125 feet in thickness, although thicker sections are known. The sheet sand bodies are rarely more than 20 feet thick.

3) Texture.—Every grain size of a sheet sand body may be duplicated in elongate sand bodies, but the converse is not true. Typically, sheet sand bodies are fine to very fine-grained whereas those of the ribbons and belts are

somewhat, but not a great deal, coarser. Thickness of bedding parallels these contrasts in grain size. Individual beds of sandstone in the sheet phase are rarely more than one foot thick, whereas thicker beds are more common in the elongate sand bodies.

4) Conglomerates.—Occasional pebbles and cobbles of limestone and chert may be found in elongate sand bodies, but only rarely are they conspicuous. Shale pebble conglomerates may be well developed. The only conglomeratic elements of the sheet sand bodies are small (generally less than one inch) clay pellets and galls derived from the interlaminated shales and shale partings.

5) Mineralogy.—For comparable size grades, sheet and elongate sand bodies exhibit little or no difference in detrital mineralogy. Because the sheet sand bodies are finer, however, there are some size-linked differences in the heavy minerals, especially those that have contrasting densities such as tourmaline and zircon. There is relatively more zircon in the sheet bodies. Some contrast in clay minerals, related to contrast in permeability, may exist between sheet and elongate sand bodies but is probably minor.

6) Structures.—The late Mississippian sandstones and their associated siltstones and shales of the Illinois Basin exhibit practically every known sedimentary structure reported from sandstones, but only a few structures are common.

TABLE 1 — PROPERTIES OF ELONGATE AND SHEET SAND BODIES

Attributes	Elongate	Sheet
Basal contact	Erosional and disconformable	Conformable and commonly transitional
Thickness	Commonly 20 to 125 feet	Rarely exceeds 20 feet
Texture	Fine to occasional fine-to-medium sand; beds thicker than 1 foot common	Fine to very fine sand; beds generally less than 1 foot thick
Conglomerates	Occasional pebbles of limestone and chert plus shale pebbles	Small pebbles and pellets of shale
Mineralogy	High tourmaline-zircon ratio	Low tourmaline-zircon ratio; somewhat low kaolinite content
Structure	Cross-bedding and cut-and-fill structures predominate; some ripple marks	Ripple marks predominate
Lithology	Principally sandstone with very minor conglomerates and some shaly sandstone and siltstone; good self potential on electric log	Shaly sandstone, siltstone, and shale as well as some thin sandstone beds; generally poor self potential on electric logs
Fossils	Marine invertebrate fossils, generally reworked, may be present but unusual; some plant material	Marine fossils may be present but only rarely abundant; some plant material

The chief structures of the elongate sand bodies are cross-bedding and cut-and-fill structures. Ripple marks are the most abundant sedimentary structure in sheet sand bodies.

7) Lithology.—The principal component of the elongate sand bodies is sandstone. Less abundant are conglomerate, shaly sandstone, and siltstone. At a few places, siltstone is the principal type of rock. Typically, the elongate sand bodies have good self potential on electric logs.

In the sheet sand bodies, shaly sandstone, argillaceous siltstone, and shale may be interbedded and gradations between these lithologic types are common.

8) Fossils.—Marine invertebrate fossils, generally reworked, may be present but are unusual in elongate sand bodies. In the sheets, they may be present but only rarely are they abundant. Plant debris occurs in both types, but is finer in the sheets. Stigmarian roots may occur also in both types, especially toward their tops.

A relatively good correlation exists between the sand types shown in table 1 and the environment of deposition. In the late Mississippian sediments of the Illinois Basin, the majority of the elongate sand bodies are either fluvial or deltaic. However, some of the isolated and discontinuous pods and ribbons of sandstone appear to be of marine origin. Map pattern and cross section are most useful in distinguishing possible differences in the environment of deposition of the elongate sand bodies. Neither, however, is always as definite as might be desired. The sheet sand bodies have a closer affinity to marine environments than the elongate.

Lateral transitions from elongate sand bodies to either shale or the sandstone sheet sand bodies commonly are abrupt. Changes in thickness from zero to more than 60 feet of sandstone in horizontal distances of 660 to 1320 feet are not unusual.

Table 2 gives localities where examples of the sheet and elongate sandstone bodies can be observed in outcrop. Although sandstone sheets occur above many elongate bodies, the examples listed in table 2 are exposures of sheet sand bodies only. The use of the geologic maps listed in table 2 will facilitate identification of the sand bodies at these localities.

PETROLOGY AND TEXTURE

In contrast to the large number of published reports on late Mississippian stratigraphy and correlation, there are relatively few reports on the petrology and texture of sandstones of this age in Illinois.

In 1944, Pye published a detailed petrographic and textural study of the Bethel Sandstone, although much of his material was actually from the Yankeetown. Ten years later Siever (1954) presented a petrographic analysis and interpretation of the conditions of sedimentation of late Chesterian sandstones. In 1955, Biggs and Lamar reported on grain size, roundness, heavy minerals and chemical composition of the late Mississippian sandstones in southern Illinois, emphasizing their possibilities as an industrial mineral resource. Swann et al., (1959) also reported on the grain size of these sandstones. Smoot (1960, table 4) analyzed the clay mineral composition of some late Mississippian sandstones and their associated shales. Potter and Pryor (1961, appendix 2) extended Siever's petrologic studies.

TABLE 2 - EXPOSURES OF SHEET AND ELONGATE SAND BODIES IN ILLINOIS

Unit	Type	Location $\frac{1}{4}$ Sec. T. R., County	Quadrangle Map and Reference
Degonia	Sheet	NW SE NE 30-11S-1E, Union	Carbondale (Lamar, 1925)
Degonia	Sheet	N$\frac{1}{2}$ SE 17-8S-5W, Randolph	Campbell Hill (Weller, 1939)
Degonia	Belt	N$\frac{1}{2}$ NE SE 2-8S-6W, Randolph	Campbell Hill (Weller, 1939)
Degonia	Elongate	SW 29-11S-1E, Union	Carbondale (Lamar, 1925)
Degonia	Sheet	SW NW SW 1-8S-6W, Randolph	Campbell Hill (Weller, 1939)
Degonia	Belt	SW SE SE 22-11S-1W, Union	Carbondale (Lamar, 1925)
Sandstone of Clore Fm.	Sheet	NW SW NE 3-12S-1E, Union	Carbondale (Lamar, 1925)
Sandstone of Clore Fm.	Sheet	SW SW SE 33-11S-1E, Union	Carbondale (Lamar, 1925)
Palestine	Sheet	NE SE SE 25-11S-1W, Union	Carbondale (Lamar, 1925)
Palestine	Elongate	NE SE SW 6-8S-5W, Randolph	Campbell Hill (Weller, 1939)
Palestine	Elongate	NW SE SE 31-13S-5E, Pope	Brownfield (Weller et. al., 1939)

TABLE 2 - EXPOSURES OF SHEET AND ELONGATE SAND BODIES IN ILLINOIS - continued

Unit	Type	Location ¼ Sec. T. R., County	Quadrangle Map and Reference
Palestine	Elongate	NE SW NE 6-11S-2W, Union	Alto Pass (Weller, 1940)
Palestine	Elongate	NW SW SE 34-11S-10E, Hardin	DeKoven (Baxter et al., 1962)
Waltersburg	Sheet	SE SW SE 19-11S-10E, Hardin	Saline Mines (Baxter et al., 1962)
Waltersburg	Sheet	SE SW NW 6-12S-1E, Union	Carbondale (Lamar, 1925)
Waltersburg	Elongate	NW 10-13S-4E, Johnson	Vienna (Weller, et al., 1939)
Waltersburg	Elongate	NW 11-13S-4E, Johnson	Brownfield (Weller et. al., 1939)
Waltersburg	Sheet	NW NW SE 15-11S-2W, Union	Alto Pass (Weller, 1940)
Waltersburg	Sheet	SE SW NE 8-13S-5E, Pope	Brownfield (Weller et. al., 1939)
Tar Springs	Belt	SE NW NW 15-14S-4E, Massac	Vienna (Weller et. al., 1939)
Tar Springs	Elongate	NE NE 17-13S-3E, Johnson	Vienna (Weller et. al., 1939)
Tar Springs	Sheet	SE NE NE 25-7S-7W, Randolph	Chester (Weller, 1939)
Tar Springs	Belt	N½ SE SW 15-11S-2W, Union	Alto Pass (Weller, 1940)
Hardinsburg	Belt	NW SW NW 19-13S-3E, Johnson	Vienna (Weller et. al., 1939)

TABLE 2 - EXPOSURES OF SHEET AND ELONGATE SAND BODIES IN ILLINOIS - continued

Unit	Type	Location ¼ Sec. T. R., County	Quadrangle Map and Reference
Hardinsburg	Belt	SE NE 36-13S-5E, Pope	Brownfield (Weller et. al., 1939)
Bethel	Belt	NE NE 14-14S-6E, Pope	Brownfield (Weller et. al., 1939)
Bethel	Belt	NE 17-12S-10E, Hardin	Repton(Baxter et al.,1962)
Bethel	Elongate	NW SW 1-14S-2E, Johnson	Vienna (Weller et. al., 1939)
Cypress	Belt	SW SW SW 4-12S-1W, Union	Dongola (Weller et. al., 1939)
Cypress	Sheet	SE SW SE 32-5S-8W, Randolph	Renault (Weller, 1939, Rexroad, 1957, fig. 9)
Cypress	Belt	NE NW SE 35-13S-3E, Johnson	Vienna (Weller et al., 1939)
Cypress	Belt	NW NW 9-12S-10E, Hardin	Repton (Baxter et al., 1962)
Renault	Sheet	SW NE SE 11-3S-9W, Monroe	Waterloo (Weller, 1939)
Renault	Elongate	SW NW NE 5-2S-9W, Monroe	Waterloo (Weller, 1939)
Rosiclare	Sheet	SE NW SE 34-11S-9E, Hardin	Saline Mines (Baxter et al., 1962)
Aux Vases	Belt	SW SW SE 26-5S-9W, Randolph	Renault (Weller, 1939)
Aux Vases	Belt	NE SE SW 23-5S-9W, Randolph	Renault (Weller, 1939)
Aux Vases	Sheet	NW SW NW 3-5S-9W, Monroe	Renault (Weller, 1939)
Aux Vases	Sheet	SW NW SW 6-13S-1E, Union	Dongola (Weller et. al., 1939)

The average composition of the late Mississippian sandstones, in outcrop and subsurface, is given in table 3 and shown diagrammatically in figure 5. Quartz is the principal component. Monocrystalline quartz, with or without strain shadows and inclusions, constitutes 96 to 98 percent of all the quartz in most samples. The remainder, polycrystalline quartz, includes a very few grains of composite quartz, aggregates of cemented quartz grains from unmetamorphosed sediments, but is chiefly metamorphic quartzite and mylonitized quartz. Quartz is also present as a precipitated cement and as overgrowths on some detrital quartz grains.

Because of leaching at outcrops, thin sections from the subsurface have, on the average, almost twice as much carbonate as do outcrop samples and thus more accurately reflect true composition. Most of the carbonate is present as a cement. In contrast to the Pennsylvanian sandstones, iron carbonate is rare as a cementing agent. Some of the carbonate is detrital and consists of fossil debris, oolites, and some other small limestone fragments.

In subsurface samples, matrix is about as abundant as carbonate cement. Feldspar, mica, chert, and rock fragments are present in only minor amount and individually form, on the average, one percent or less of the rock. The feldspars consist of orthoclase, plagioclase, and minor amounts of microcline. Authigenic overgrowths on feldspar occur but are not common. Muscovite is the most common mica in the sand fraction.

Individual thin sections may depart widely from the average values of table 3. The more fine-grained sandstones contain more matrix, some have as much as 25 percent. Some thin sections, even from the subsurface, contain no carbonate, whereas others may have as much as 24 percent. Rock fragments range from 0 to 5 percent. Mica ranges from 0 to 3.5 percent and is most abundant in the finer sandstones. Feldspar is almost always low in quantity but in one slide 3.5 percent was present.

The transparent nonmicaceous heavy minerals of the late Mississippian sandstones are chiefly zircon and tourmaline. Rutile and anatase are nearly always present, and garnet and apatite also occur but rarely do they form as much as several percent of the total. Other transparent, nonmicaceous heavy minerals, either rare or very rare, include brookite, epidote, topaz, zoisite, horneblende, and fluorite. Opaque minerals include ilmenite, leucoxene, pyrite, and magnetite. Weight percentage of heavy minerals is almost always less than 1 percent and commonly less than 0.5 percent.

Petrologically the average late Mississippian sandstone is a protoquartzite (Pettijohn, 1957, p. 291). Although most specimens belong to this category, a few, depending upon matrix content, are orthoquartzites and even subgraywackes (Pettijohn, 1957, p. 291).

The clay mineral composition of the less-than-two-micron material from the matrix of the sandstones consists of degraded illite and chlorite, kaolinite, and some montmorillonite (Smoot, 1960, table 4). Kaolinite exhibits excellent crystallinity. "Worms" or "books" of authigenic kaolinite can be observed in some thin sections. In comparison to their interbedded shales, clay mineral composition of the sandstones indicates alteration since deposition. The greater permeability of the sandstones and the attendant passage of mineralized fluids through them appears to be responsible for this contrast. Outcrop samples of sandstone show even more alteration.

Most late Mississippian sandstones are fine to very fine-grained and only rarely does one approach medium grain size (Wentworth scale).

Typically most of the elongate sandstone bodies have median grain sizes ranging from 0.11 mm. to 0.16 mm. The belt of sandstone in the Bethel Formation is an exception and has median sizes ranging from 0.24 to 0.30 mm. Figure 6 shows some examples of the size distributions in ribbon and belt sandstone bodies and the average distribution of all the late Mississippian sandstones sampled by Biggs and Lamar (1955, table 4). Many of the elongate sandstones tend to become finer grained from bottom to top.

The sheet sandstones of this sequence generally have median sizes ranging from 0.08 to 0.13 mm. Some typical size distribution curves are shown in figure 6. A larger silt and clay content is chiefly responsible for the small median sizes of the grains in sheet sandstones. This larger silt and clay content is also responsible for their poorer definition on electric logs and their greater induration in outcrop. Vertical variation in median size is not pronounced in most sheet sand bodies.

The sandstone of elongate sand bodies is very well sorted. Trask sorting coefficients generally range from 1.15 to 1.36. In the sheet sandstones, sorting coefficients generally range from 1.20 to 1.40. Good sorting is one of the significant textural features of late Mississippian sandstones in Illinois.

Because of secondary quartz overgrowths, average roundness (Krumbein, 1941, p. 68-70) of disaggregated sandstone samples is very low, commonly between 0.2 and 0.3. Biggs and Lamar (1955, pl. 1A) show an example from the Bethel Sandstone. Thin section study, however, shows that the average roundness of the original detrital grains is much greater, and average values appear to vary between 0.3 and 0.6 for most samples. In the majority of samples both angular and rounded grains can be found. There appears to be no major variation in roundness of the sand grains (for like size grades) between the different sandstones.

In summary, the typical late Mississippian sandstone is mineralogically mature and chiefly consists of moderately angular to moderately rounded quartz. Zircon and tourmaline are the dominant heavy minerals. Nearly all samples are fine to very fine-grained. Sorting is very good.

SEDIMENTARY STRUCTURES

The late Mississippian sandstones of Illinois contain every major and most of the minor types of sedimentary structures that are known to occur in sandstones, but only a few are common. Table 4 shows by X's their relative abundance in the sheet and elongate sand bodies.

The different late Mississippian sandstones all contain essentially the same types of sedimentary structures. Differences in abundance of the sedimentary structures in different formations are directly related to the relative proportions of sheet and elongate sand bodies.

TABLE 3 - AVERAGE PETROGRAPHIC COMPOSITION OF LATE MISSISSIPPIAN SANDSTONES
(In percent)

Type of sample	Quartz	Matrix	Carbon-ate	Feld-spar	Mica	Chert	Rock frag-ments	Misc.	No. of analy-ses
Outcrop	84.5	8.1	3.9	0.4	0.2	0.2	1.3	1.4	26
Well	82.6	7.0	7.2	0.7	0.2	0.2	1.4	0.7	31

TABLE 4 - TYPE AND ABUNDANCE OF SEDIMENTARY STRUCTURES
OF LATE MISSISSIPPIAN SANDSTONES

Sedimentary structure	Type of sand body	
	Sheet	Elongate
Cross-bedding	X	XXXXX
Ripple marks	XXXXXX	XX
Current lineation	XX	X
Sole marks	XXX	X
Cut-and-fill	X	XXX
Conglomerates	XX	XX
Contorted bedding	X	X
Sole marks	XXX	XX
Animal borings	XX	X

X = relative abundance

Cross-bedding.—Cross-bedding is the most prominent sedimentary structure of the elongate sand bodies. Cross-bedded units vary greatly in size. The smallest may be only a few inches wide and several feet long (microcross-bedding or rib-and-furrow). The largest units are more than 6 feet thick and perhaps more than 100 feet long and 50 feet wide. In the elongate sandstones cross-bedded units thicker than one foot are common.

Ripple Marks.—Asymmetrical (current), symmetrical (oscillation), and interference ripple marks occur. Asymmetrical and interference ripples are the most common. Ripples are best developed in the sheet sandstone in the finer grained and thinner beds. They are commonly well exposed in the bottom of creek beds.

Current Lineation.—Current lineation is most readily seen in the sheet sand bodies, but it also occurs in elongate sand bodies. If the sandstone is sufficiently indurated and has current lineation, it is a good source of flagstone.

Sole Marks.—Sole marks are of several types. One type results from debris having been dragged along the bottom. Both fine and coarse patterns of marking occur. Current flutings are another type of linear sole marks. Sole marks such as load casts are also present, and in part represent an intrusion of the underlying bed by overlying sand of higher bulk density prior to consolidation.

Cut-and-Fill.—Small erosional channels occur that range from a few inches deep and 1 or 2 feet wide to as deep as 5 feet and up to 20 feet wide, especially in elongate sand bodies. They result from local, linear erosion. Asymmetrical ripple marks are common on such channel surfaces.

Conglomerates.—Shale pebble conglomerates are best seen in loose slabs of sheet sandstones. Conglomerates of limestone and chert usually are restricted to the basal few feet of elongate sand bodies.

Contorted Bedding.—Plications and folds that involve two or more beds occur at places, especially in the finer grained sandstones and the siltstones. Such convoluted beds are not abundant. Plications and folds within a single sandstone bed occur in a few outcrops.

Animal Borings.—Disturbed bedding that probably resulted from animal borings is present in a few outcrops. It is not always possible to distinguish such structures from small-scale sliding and slumping. Worm borings occur at a few places but are not generally common.

The most useful structures to determine current direction are cross-bedding and current lineation, especially cross-bedding, because it occurs commonly in elongate sand bodies and because it can be measured easily and objectively.

Unlike ripple marks, direction of cross-bedding is generally oriented consistently in an outcrop. Such consistency may extend to large segments of individual elongate sand bodies. An example of the consistency of orientation of cross-bedding in a belt sand body is shown in figure 7, a map of a small portion of the Aux Vases Sandstone in Randolph County, Illinois. Here the Aux Vases is as much as 90 feet thick, has an unconformity at its base, and abundant cross-bedding that is striking in its consistent orientation. Such consistency appears to be typical of the majority of the elongate sand bodies.

Both regionally and locally, there appears to be good correspondence between direction of cross-bedding in outcrop and direction of elongation shown in the subsurface (Potter et al., 1958).

LOCAL PATTERNS OF SANDSTONE THICKNESS

Detailed studies were made of small areas, generally one or two townships or less, in which every available electric log was used to delineate the sand body. The local detailed studies, in addition to the insight they provided into shape of the sand body and to the problems of contouring local maps, also provided valuable knowledge for contouring the regional maps, which were, of necessity, made with much less control.

Electric logs were the source of information for both the local and regional maps. Sandstone was defined by establishing the shale base line and moving 10 millivolts to the left, a technique that yields footage of gross permeable sandstone. This measure of sandstone thickness accurately portrays the thickness of the elongate sand bodies and of many, but not all, of the sheets. Some thin-bedded, fine-grained, and either argillaceous or calcareous portions of the sheet sandstones may not be included. It should be kept in mind, when examining either the local or regional maps, that areas of zero sandstone thickness may in fact contain some relatively impermeable sandstone.

Detailed maps of sand bodies in the Waltersburg (figs. 8, 9), and Degonia (fig. 11), and Cypress (fig. 10) Formations illustrate elongate sand bodies that are typical of the late Mississippian Sandstone.

Waltersburg Sandstone

Figures 8 and 9 show an elongate sand body of the Waltersburg Sandstone in the Eldorado Consolidated pool in Saline County, Illinois. The same data have been contoured in two ways.

Figure 8 emphasizes the continuity of the sand body by connecting as many points as possible. The result is a linear sand body, never more than one mile wide, with weakly meandering channel-like extremities at the northeast and southwest corners of the map. Maximum thickness is 75 feet.

Figure 9 presents an alternative interpretation which emphasizes the discontinuous nature of the sand bodies. Although the main sand body remains much the same, its extremities are contoured as a series of parallel, en echelon disconnected sand bodies. Such map patterns have commonly been considered as representing deposition on a shallow marine shelf.

Choice between these alternatives is a recurring problem in mapping based on subsurface data. The following measurable criteria can be of help in trying to decide which environmental interpretation is better in a given instance:

1) Proximity to other sand bodies
2) Orientation with respect to other sand bodies
3) Orientation with respect to depositional strike*

*By depositional strike is meant the orientation of a line parallel to the strike of the average regional strand line. Orientation of average regional strand line closely corresponds, in the Illinois Basin, to the orientation of the regional isopach of dominantly marine units such as the shales and carbonates of the Menard Formation, etc.

4) Cross section
5) Lithologic contrasts in the shales on either side of the sand body
6) Textural or mineralogical properties of the sand body itself
7) Reservoir history
8) Response to injected tracers

Applying these criteria to the choice between the two methods of contouring shown in figures 8 and 9 brings out the following facts.

The regional map of sandstone in the Waltersburg Formation (pl. 3) shows that other large sand bodies are nearby, and that all the sand bodies of Saline, Gallatin, and White Counties have a pronounced southwestward trend. Many geologists would use this fact, in conjunction with the proximity of other Waltersburg sand bodies, to connect the sand bodies, unless clearly precluded by either dense control or evidence based on performance of an oil reservoir.

Statistically, the regional depositional strike in Saline County, as inferred from an isopach map of total limestone in the Menard Formation was approximately N 70° W. Available evidence indicates no reason to believe that depositional strike was different during deposition of the Waltersburg Sandstone in Saline County. Thus the elongate sand body is almost perpendicular to depositional strike. This favors either a fluvial channel origin or down-dip migration of a marine sand rather than transport parallel to the strand line.

The cross sections of figure 8 and 9, drawn with the base of the underlying Vienna Limestone as the level line, clearly illustrate the lenticular character of the sand body. These cross sections are consistent with a channel origin.

Although detailed knowledge is not available because of lack of diamond-drill core samples, well cuttings suggest little, if any, difference in lithology in the Waltersburg sediments northwest or southeast of the ribbon sandstone. Lack of lithologic contrast on opposite sides of the sand body is characteristic of a sandstone deposited in either a fluvial channel or an isolated marine sand body. In contrast, the shales should differ on the seaward and landward sides of a sand body of the strand line.

Insofar as sample studies permit judgment, the textural properties of this sand body differ little from other Waltersburg or from other late Mississippian sandstones.

History of an oil reservoir can be one of the most useful means of deciding if two or more adjacent sand bodies are connected. If connected, there should be no discontinuity in pressure, but if not connected, reservoir pressures could differ, especially after oil production, because of differing histories of reservoir performance. Oil-water contacts in incompletely oil-saturated sandstones can also be used. Both techniques are the same as those used to determine whether or not faulted reservoirs are interconnected. Another petroleum engineering technique is the injection of a tracer into the reservoir. Squires (1948, p. 5 and fig. 6) early suggested the use of injected tracers to determine if injection and production wells are connected by a common sand body.

Evidence favoring at least some continuity of the permeable sandstone shown in figures 8 and 9 is the proximity to nearby sand bodies, similar orientation of the neighboring sandstone ribbons, and orientation approximately perpendicular to strand line. The cross sections in the thickest portions of the sand body are also channel-like, suggesting continuity. In contrast, evidence favoring separation is the apparent lack of a meandering pattern of the trend (pl. 3) and thickness of more than 60 feet in sections 11 and 15. If this elongate sandstone body were of ordinary fluvial origin, a six-fold variation in thickness could, of course, occur but would seem less likely. The available evidence of reservoir performance suggests separation. The apparent separation of the northeasternmost ribbon in T. 5 S., R. 10 E., in White County, from the main area of sandstone to the north also suggests that separation of the ribbons within this trend may be the rule rather than the exception. There is little evidence to indicate that the elongate sand bodies of the Eldorado pool were originally beach sands.

The Waltersburg Sandstone of the Eldorado pool clearly indicates the difficulties of distinguishing between alternative methods of contouring and their different possible genetic implications. Although origin as a beach deposit seems remote, it is difficult to distinguish definitely between either a fluvial or an off-shore marine bar origin. An important factor is the inability to bring sufficient criteria to bear in the subsurface, in order to establish with reasonable certainty the environment of deposition. In the typical subsurface mapping problem, electric logs and sample studies of rotary drill cuttings are usually the only practical sources of data. Under these circumstances, knowledge of the relations between the local sand body and the regional map are essential. In most cases, final judgment on contouring proceeds on the assumption that the sand body in question is similar in cross section and map pattern to others in areas of dense control. Reservoir performance can also contribute to this decision.

Cypress Sandstone

Figure 10 is a detailed map showing thickness of sandstone in the Cypress Formation in Jasper County, Illinois. The sandstone forms a broad belt, generally more than 160 feet thick, and exhibits a clear south-southeast trend. The cross section shows the unconformity at the base of the Cypress Sandstone, because the limestones of the Ridenhower ("Paint Creek Formation") and the underlying Bethel Sandstone had been eroded before the Cypress was deposited. Local relief at the base of the sandstone is 40 to 50 feet. The map provides a good example of a belt sand body that has an erosional, unconformable base, with appreciable relief.

Degonia Sandstone

Figure 11 is a map, based on 1223 wells, that shows the thickness of two dendroid sand bodies of the Degonia Formation in Wayne County, Illinois. The larger is approximately 2 miles wide, the narrower slightly less than one mile wide. As in the Waltersburg sand body (figs. 8 and 9), the thickness decreases abruptly as the margin of the sand body is approached. Transitions from less than 20 feet of sandstone in the sheet phase to more than 80 feet of sandstone in the ribbon phase occur in less than a quarter of a mile. Both sand bodies display weakly meandering borders, and the narrower also shows some possible tributaries or distributaries.

The electric log cross section shown in figure 12 demonstrates that three thin limestone beds and several thin sandstone beds of the Clore Formation are progressively truncated by the Degonia Sandstone. The other narrower elongate body displays similar relationships. Thus cross section and, to a lesser extent map pattern, provide a strong basis for interpreting these sand bodies as of fluvial origin.

A complicating factor is the superposition of the Degonia Sandstone on the sandstones of the Clore Formation. In the Robinson Puckett No. 1 Hiley well, question marks indicate the probable contact of the Degonia Sandstone on the thickest of the sandstones of the Clore Formation. Thick sand bodies that result from the superposition of one sand body on another are called multi-story.

When one sandstone is superimposed on another, they can scarcely be differentiated on the basis of an individual electric log, but as the cross section of figure 12 illustrates, a series of logs can be very helpful. The possibility of a multistory origin should be considered when unusually thick sandstone sections are encountered.

The three detailed sandstone thickness maps and cross sections illustrate some important features of the late Mississippian sandstones. These are:

1) Thickness of sandstone changes abruptly along the margins of many elongate sand bodies. Transitions from sheet to elongate phases can occur in less than 660 feet.
2) Neighboring elongate sand bodies tend to parallel each other.
3) Pronounced compactional structural highs occur on marker beds above lenticular sand bodies.

REGIONAL PATTERNS OF SANDSTONE THICKNESS

In mapping thickness of sandstone within the Degonia, Palestine, and Hardinsburg Formations in Illinois, 2 to 3 wells per section were used south of T. 3 N. and one well per section northward. Somewhat less dense control was used for the Waltersburg. Each unit was mapped from T. 10 S., northward to the subcrop.

Degonia Sandstone

Thickness of sandstone in the Degonia Formation in Illinois is shown on Plate 1. Belt, dendroid, ribbon, pod, and sheet sand bodies are present. Belts are best developed in Jackson County and portions of Williamson, Franklin, Jefferson, and Marion Counties. Thicknesses approaching 100 feet are locally present, although thickness of 40 to 80 feet are more typical. Although subsequently transected by pre-Pennsylvanian valleys 2 to 5 miles wide, this sand belt appears to have been originally continuous. In northern Marion County in T. 3 N., R. 2 W., and T. 4 N., R. 2 W., the western boundary of the belt is just inside the western subcrop.

Extending to the northeast of the belt are three well defined, continuous, narrow, elongate sand bodies. The southernmost extends from McLeansboro in Hamilton County eastward through Carmi in White County to the subcrop in Indiana.

Another clearly defined elongate body is present from the subcrop west of Fairfield, Wayne County, to T. 3 S., R. 5 W., of the same county. This sand body is commonly 2 miles wide and has a general southwestward trend. An isolated outlier of thick sandstone in T. 1 N., R. 10 W., Edwards County, is probably part of this sand body.

A third well defined elongate sand body, in part connected with those described above, extends from northeastern Wayne County southwestward into Jefferson County and joins the principle belt east of Mt. Vernon in T. 2 S., R. 4 W.

An apparent distributary to the principle belt occurs in northwestern Williamson County and western Saline County. Another sand body that may be connected to it extends southward from Harrisburg in Saline County.

The southerly trend of the principal belt sand body and the small elongate bodies that join it from the northeast with acute angle suggest a dominantly fluvial origin. Although pre-Pennsylvanian erosion precludes more than speculation, it is possible that west of the present subcrop there were tributaries comparable in number and trend to those east of the principal belt.

Additional features of plate 1 are the small, apparently isolated, ribbons and pods of sandstone that are most common in Hamilton, Saline, White, and Gallatin Counties. The origin of these bodies is not clear. They may represent isolated marine sand bodies.

Sheet sand, 1 to 20 feet thick, is present in most of the eastern half of the map. In much of Saline and Gallatin Counties no permeable sandstone is present.

Palestine Sandstone

Plate 2 shows the thickness of sandstone in the Palestine Formation in Illinois. Elongate and sheet bodies are present. The predominant feature is the pattern in Edwards, Gallatin, Hamilton, Saline, White, and Williamson Counties that suggests a southwestward trending system of distributaries. Crossbedding dips south and southwestward in southern Illinois (Potter et al., 1958, table 2, fig. 13). Where the sandstone is thickest, the top of the upper massive limestone of the Menard Formation has been eroded. One distributary occurs southeast of Carmi in T. 7 S., R. 8 and 9 E., one in southwestern Hamilton County, another in northeastern Gallatin County, and the available data indicate an additional one in southern Williamson County.

Locally, as in most of White County, this distributary system consists of belt sand bodies more than 6 miles wide, but generally, sand body width is 2 to 3 miles. In most areas of dense control, margins are strikingly abrupt. What may be minor distributaries occur at a few places along the margins. Although pre-Pennsylvanian erosion precludes definitive judgment, another possible small tributary dendroid sand body may be present in eastern Wayne County joining the main distributary system northeast of Carmi in White County.

Northwest of the principal distributary system, thickness of the sandstone generally decreases irregularly until near the western subcrop there are large areas with no permeable sandstone. An exception is the area with more than 20 feet of sandstone north of Chester in Randolph County. Another is the area of sheet sandstone in Wayne, Clay, and Effingham Counties. The small, apparently isolated, elongate sand bodies northwest of the principal distributary system tend to have a southwestward orientation.

North of T. 4 N., differentiation of the sheet phase of the Palestine from overlying Pennsylvanian sediments is difficult on many electric logs. As would be expected, pre-Pennsylvanian valleys are not as prominent on this map as on that of the Degonia, except near the northern margin.

Waltersburg Sandstone

Thickness of sandstone in the Waltersburg Formation in Illinois is shown in plate 3, a modification and extension of the map by Swann (1951, fig. 13).

Most of the Waltersburg Formation in Illinois is shale with some siltstone and a few thin, relatively impermeable beds of sheet sandstone. These sand bodies occur as isolated, irregularly oriented, minor patches of sheet sandstone. Elongate sand bodies are present but are principally restricted to the eastern third of the area mapped in Illinois. Ribbons are more abundant than belts.

A prominent trend of largely isolated ribbon sand bodies extends from Marion in Williamson County northeastward to Carmi in White County. Another group of ribbons that can be traced northeastward into Indiana occurs in Gallatin County and probably in southeastern Saline County and northeastern Pope County as well. Other good examples of isolated ribbon sand bodies occur in T. 5 S., R. 13 W. and T. 4 S., R. 10 E.

In Richland, Edwards, Lawrence, and Wabash Counties there are three clearly defined, southwestward trending, elongate ribbon sand bodies that have a narrow, sinuous, pattern on plate 3. The two elongate in Richland and Edwards and southwestern Lawrence County extend from the subcrop to the principal sand belt.

In Edwards, Wayne, Richland, and portions of Clay County is a complex of elongate sand bodies. One extends southwestward from near Fairfield in Wayne County almost to McLeansboro in Hamilton County. A well defined belt sand body occurs in southeastern Edwards County. A belt also extends from west of Olney in Richland County northwestward beyond Effingham in Effingham County. This sand body thins to the northwest. A small Waltersburg sand body more than 20 feet thick occurs in south-central Cumberland County.

Most of the sand in Edwards, Wayne, and Richland Counties seems to have been supplied along the path indicated by the two elongate sand bodies that extend northward to the subcrop.

The only known exposure in Illinois of a thick elongate Waltersburg sand body occurs in southeastern Johnson County, east of Vienna. The cross-bedding of this body dips to the southwest (Potter et al., 1958, fig. 12).

Hardinsburg Sandstone

Plate 4 shows thickness of sandstone in the Hardinsburg Formation in Illinois. Belts, ribbons, pods, and sheets are present. A combination of them defines the southwestward trending sand complex that extends from the Indiana border in Lawrence County to the southern outcrop. Several tributaries in Lawrence County combine to form a belt more than 8 miles wide in Edwards County and more than 15 miles wide in Hamilton and White Counties. Thickness of sandstone in much of the belt exceeds 60 feet, and in Hamilton County local thicknesses greater than 160 feet are known. "Islands" of little or no permeable sandstone are a common feature of the belt. Southward in Jackson, Williamson, Franklin, and Saline Counties are a series of four distributaries. A belt sand body in southeastern Gallatin County and in parts of Hardin and Pope Counties connects with a system in Indiana and Kentucky. A small elongate sand body that is part of this system extends southwestward from southeastern White County to T. 8 S., R. 10 E., Gallatin County, where it joins the main belt of Gallatin, Hardin, and Pope Counties.

The map pattern of the sandstone suggests a complex braided stream pattern that widens to the southwest with the development of distributaries or bifurcations near the present outcrop. Cross sections show that erosional channels that cut into and through the underlying Haney Limestone are common under thick sand bodies of the Hardinsburg. Cross-bedding in the Hardinsburg dips southwestward in southern Illinois (Potter et al., 1958, table 2).

Northwest of the principal southwest-trending sandstone complex is an area, generally 15 to 25 miles wide, that contains a number of apparently isolated, small, elongate sand bodies. The map pattern is complex but suggests, at least in part, origin as a series of small distributaries that extended to the northwest, perpendicular to the main belt.

Very little permeable sandstone occurs in southwestern Illinois, along all the western border. The lack of sand in the area north of Vandalia, Effingham, and Newton is especially notable.

REGIONAL INTERPRETATION

Comparison of plates 1 through 4 suggests that they have a close relationship. The patterns are probably representative of all the late Mississippian sandstones in Illinois. Figure 13 shows the fundamental distribution pattern of these sandstones in the basin.

The Degonia, Palestine, and Hardinsburg Formations have regional dendritic and distributary patterns as well as meandering belts.

The Degonia map shows a large belt with several clearly defined tributaries. The Hardinsburg pattern suggests a complex of braided stream channels that has several tributaries at its northeastern end, and at least four major distributaries at its southern end. Small distributaries occur along the northwest side of the principal Hardinsburg belt. The Palestine pattern, with three prominent delta distributaries, appears to represent an even further down-slope, seaward phase of sand deposition.

The Waltersburg Sandstone differs from the other three in several ways. The Waltersburg does not have prominent fluvial or deltaic map patterns. Although its southwestward trend differs little from the other three, the lower half contains a series of relatively straight to gently curved, discontinuous ribbon and pod sand bodies, probably of marine origin. In general, these sand bodies tend to be nearly perpendicular rather than parallel to depositional strike, and appear to have very similar shales on both sides. Although available evidence does not permit a definitive interpretation, such sand bodies are probably of marine off-shore origin and appear to be dominantly oriented down the paleoslope. They are not beach deposits.

It seems plausible that the Degonia, Palestine, and Hardinsburg may have had sand patterns south of the present outcrop that were similar to that of the Waltersburg Formation in southern Illinois. The Big Clifty (Jackson) Sandstone of Indiana and Kentucky appears to have had a pattern of sand distribution similar to that of the Waltersburg in southern Illinois. The sand bodies of the Spar Mountain were deposited still farther down-slope and in a marine environment. These bodies tend to be isolated, and some are entirely or partly surrounded by limestone rather than by shale. The trend is generally south to southwesterly. Although some have thicknesses of nearly 80 feet, the majority are only 10 to 30 feet thick. Thus the Waltersburg and Big Clifty Sandstones in much of southern part of the basin are probably typical of the down-slope marine phase of Pope deposition, and the Spar Mountain sand bodies are even farther down-slope. This phase is logically seaward of deltaic distributaries such as those noted in the Palestine.

Another feature of the regional maps is the shifting location of the principal wet sand bodies. In the Degonia Formation the principal belt is located along the western part of the basin, whereas in the Palestine and Hardinsburg they are better developed in the center of the basin along the Wabash Valley. The Cypress Sandstone is best developed in an area trending northeast-southwest through the center of the basin. Some sandstones, such as the Sample and Big Clifty, are best developed in Indiana and Kentucky. Still others, such as the Tar Springs, are prominent throughout much of the basin. Figure 14 shows diagrammatically the locations and trends of the late Mississippian sandstones in the Illinois Basin. Names in capitals indicate principal sandstones in each region.

The petrographic homogeneity of these sandstones suggests a common source. Direction of cross-bedding also supports this view (Potter et al., 1958, p. 1037-1040). Figure 13 shows an interpretation of the origin of the late Mississippian sandstones that emphasizes the role of a large river system as the principal distributor of sand to and across the basin. Stuart Weller (1927, p. 26) early suggested such an ancestral river system. This river system was principally localized along a northeast striking, weakly negative axis along the present Wabash Valley. At times, however, sand input was chiefly along the west side of the basin and at others along the east side. This river system may be a later westward extension of the Ontario River described by Pepper, et al., (1954, p. 95-107), or it may have paralleled that river.

Sand was chiefly deposited in the basin by a series of streams whose shifting channels produced sand belts with tributaries on their up-slope portions and distributaries on their down-slope portions. These dendroid and belt sand bodies extend down the paleoslope. Where present, cross-bedding commonly dips to the southwest and generally parallels the elongation of the sand bodies. Sand bodies of the strand line, such as beaches, appear to be virtually absent. Marine sandstones are present. Most commonly the marine sandstones are either the sheets or the isolated ribbons and pods, the latter being oriented approximately parallel to the paleoslope. Depending on the magnitude of sand input into the basin in late Mississippian time, a sandstone will display a predominantly up-slope pattern of anastomosing belt sand bodies with dendritic-like tributaries, an anastomosing belt pattern in which distributaries predominate, a delta distributary system, or the down-slope pattern of isolated marine sand bodies. Figure 13 shows such an interpretation.

The widespread marine transgressions in late Mississippian time complicate the above picture because what is commonly thought of as one cycle of sand deposition (for example, the Tar Springs or Cypress Sandstones) generally appears to represent several cycles or subcycles. This complication exists because marine sediments immediately overlie fluvial deltaic sediments. Sand bodies that are of mixed environmental origins, dominantly fluvial or deltaic in some portions and marine in other portions, result. Separation of these environments is commonly difficult. Thus through superposition, both are included in a total sand thickness map, tending to complicate interpretation. Another complicating factor results from differential subsidence in the basin. Where subsidence is most rapid, minor clastic cycles occur.

Two other complicating factors exist. First, neither field nor subsurface observation has been able to demonstrate convincingly the relative ages of a sheet sand body where it is lateral to either a pod, ribbon, dendroid or belt. Although the sheet on the top of either a ribbon or belt sand body is, of course, younger, the age of the sheet sandstone laterally has never been demonstrated.

A second and related problem is the tendency to interpret the sand patterns on plates 1 to 4, as chiefly the result of one dominant, synchronous mechanism of sand dispersal. This tendency nearly always results in an erroneous simplification of geologic reality in ancient sediments. Just as difficulties would arise in devising a simple erosional mechanism to explain the geomorphic features of a multicycle landscape, similar difficulties exist when a single synchronous sand dispersal mechanism is invoked to account for all the features of a sand isopach map. This difficulty obviously includes the relative ages of the sheet versus elongate sand bodies. It also applies to the migration of sand deposition either down-slope or up-slope, that is, if sand prograded seaward or retrograded sourceward.

SUMMARY

Maps showing thickness of formations, thickness of limestone, orientation of sand bodies, and direction of cross-bedding show that the paleoslope in the Illinois Basin during late Mississippian time was southwestward. Slope components trend towards the weakly negative axis of the basin. Despite a series of major regressions and transgressions, the direction of the slope remained essentially constant throughout late Mississippian time. The predominant longitudinal clastic filling of the basin resulted from sand input at the northeast margin of the basin.

Pre-existing sediments were the chief source of the late Mississippian clastics. The sands and muds were transported to and across much of the basin by an ancestral river system that flowed to the south-southwest across a low-lying coastal plain toward a shallow marine shelf. Different sandstones display the different features of this ancient dispersal system. Some are chiefly fluvial, some are chiefly deltaic, and some are predominantly of shallow marine shelf origin.

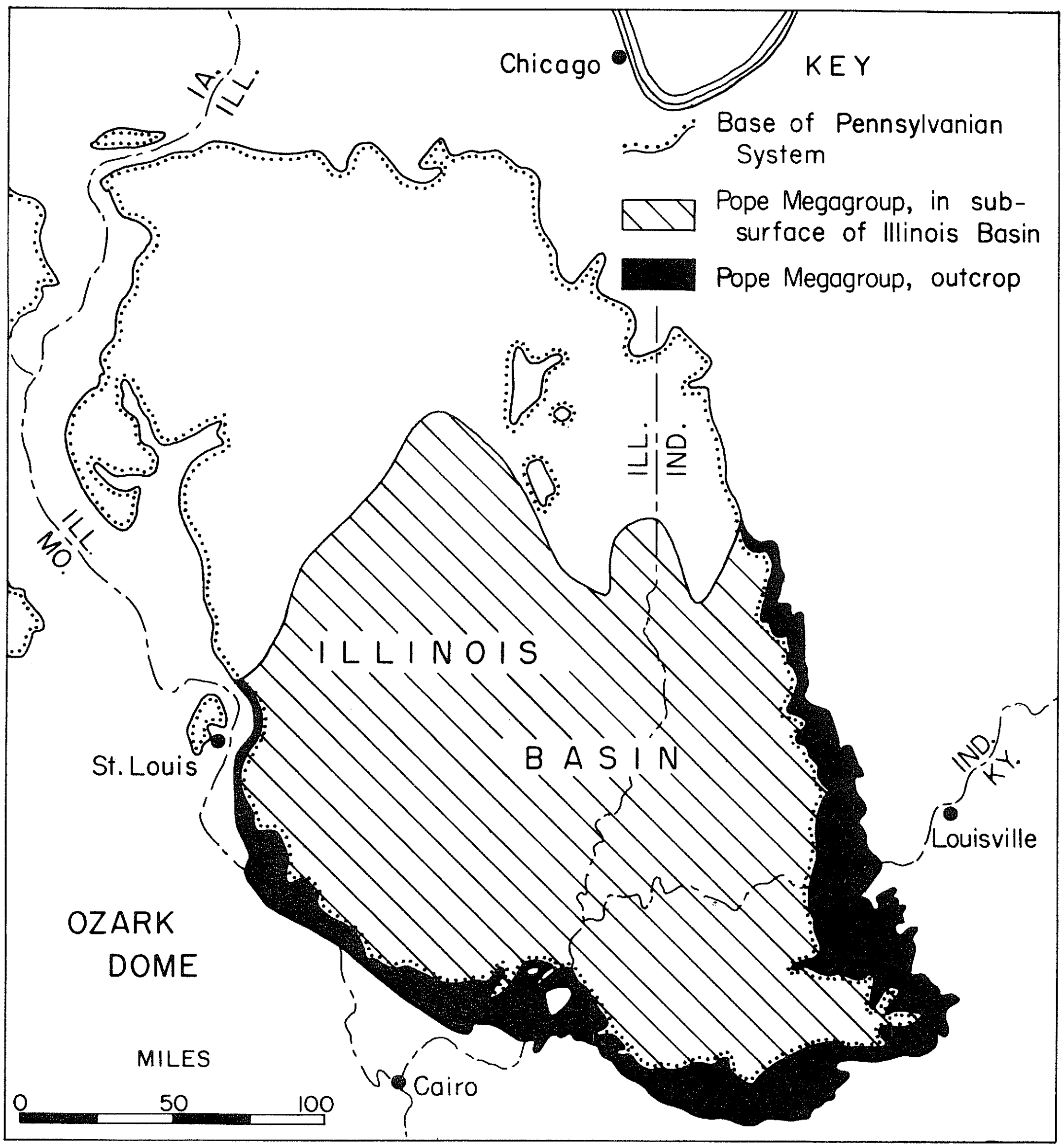

Fig. 1 - The Pope Megagroup (sandstone-bearing Chesterian and Valmeyeran rocks) in the Illinois Basin.

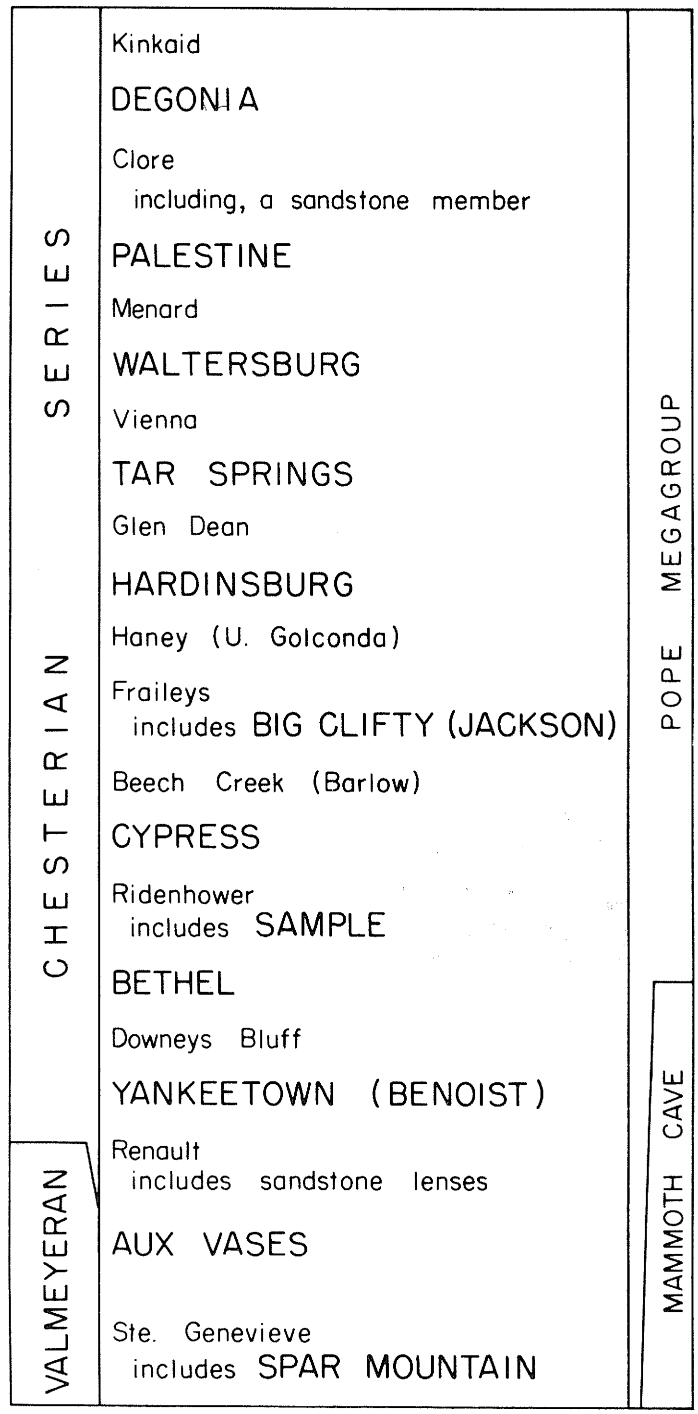

Fig. 2 - Stratigraphic classification of units used in this report. Sandstones in capitals.

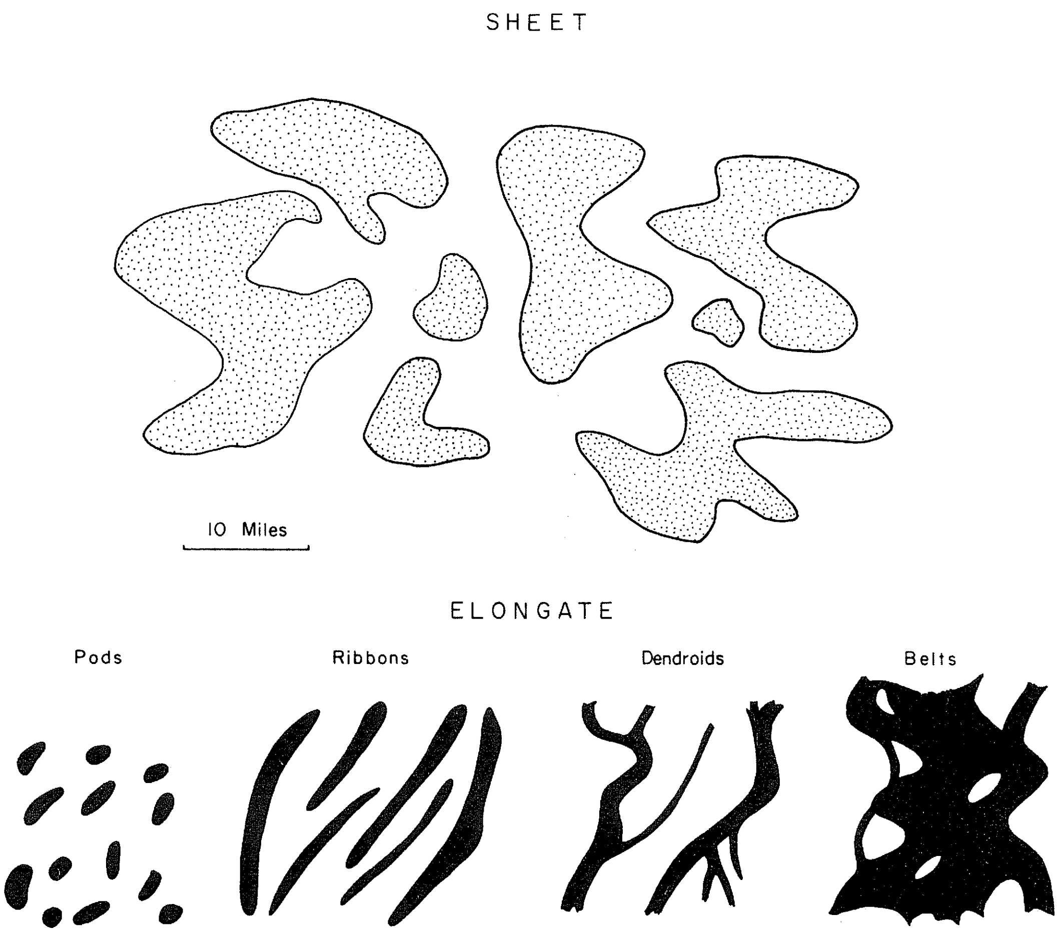

Fig. 3 - Idealized map patterns of sheet and elongate sand bodies.

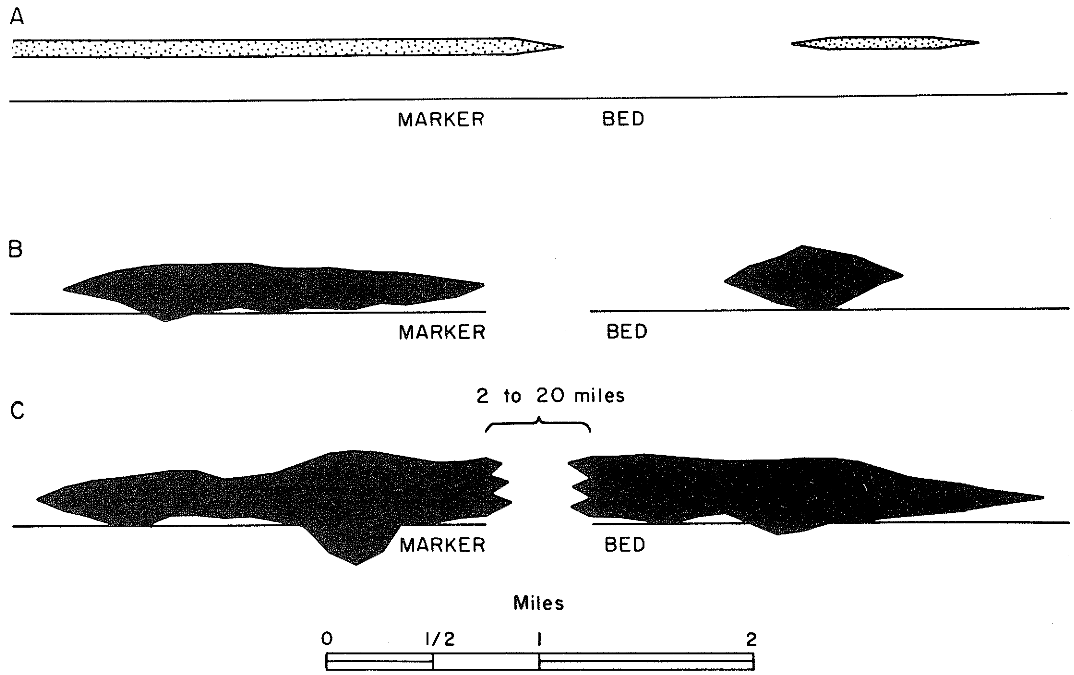

Fig. 4 - Idealized cross sections of (A) sheet, (B) ribbon and dendroid, and (C) belt sand bodies.

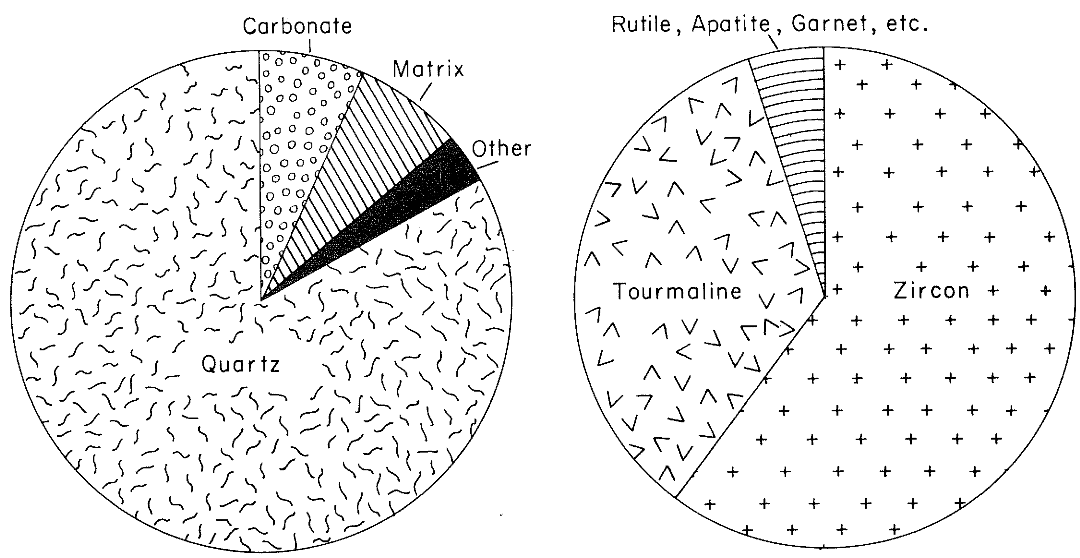

Fig. 5 - Average thin section and non opaque heavy mineral composition of late Mississippian sandstones.

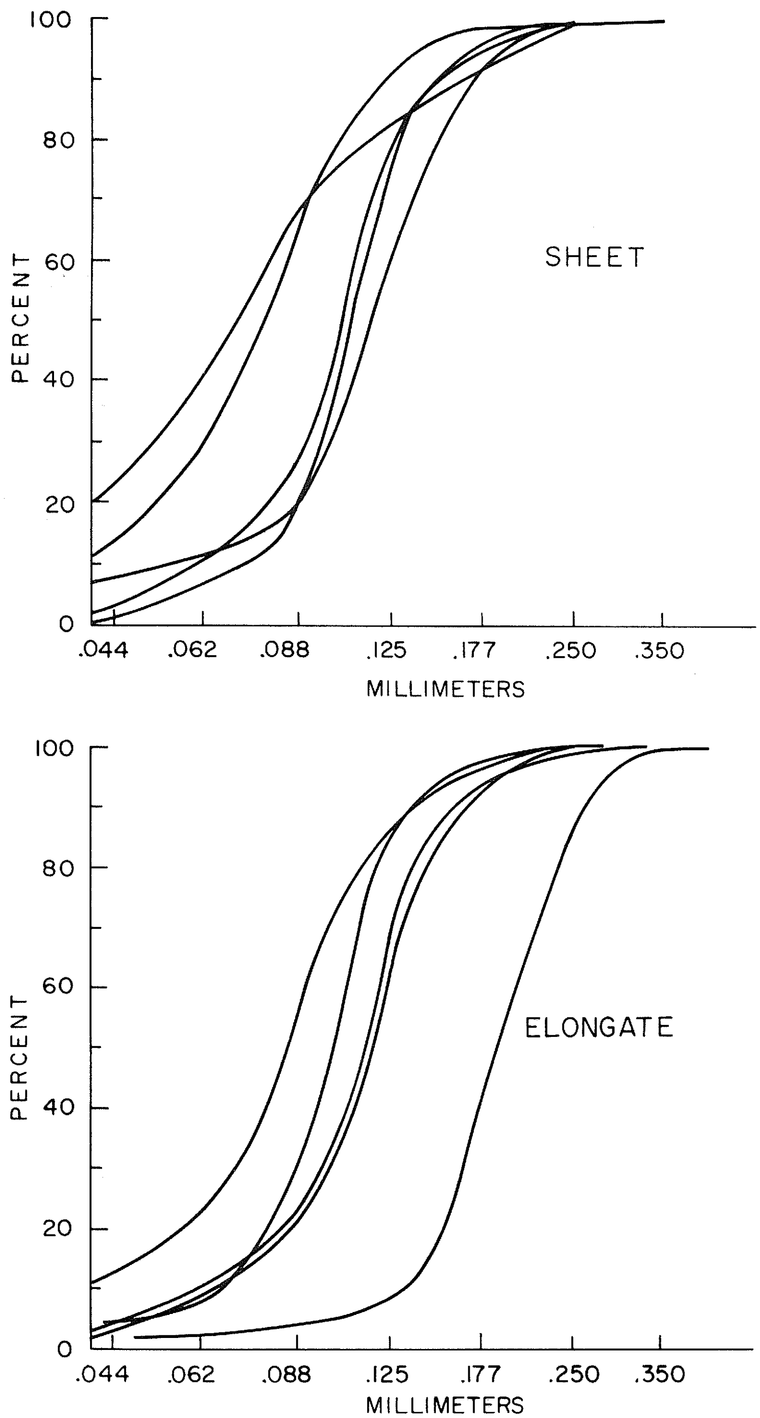

Fig. 6 - Typical cumulative curves showing grain size of sand from sheet and elongate sand bodies.

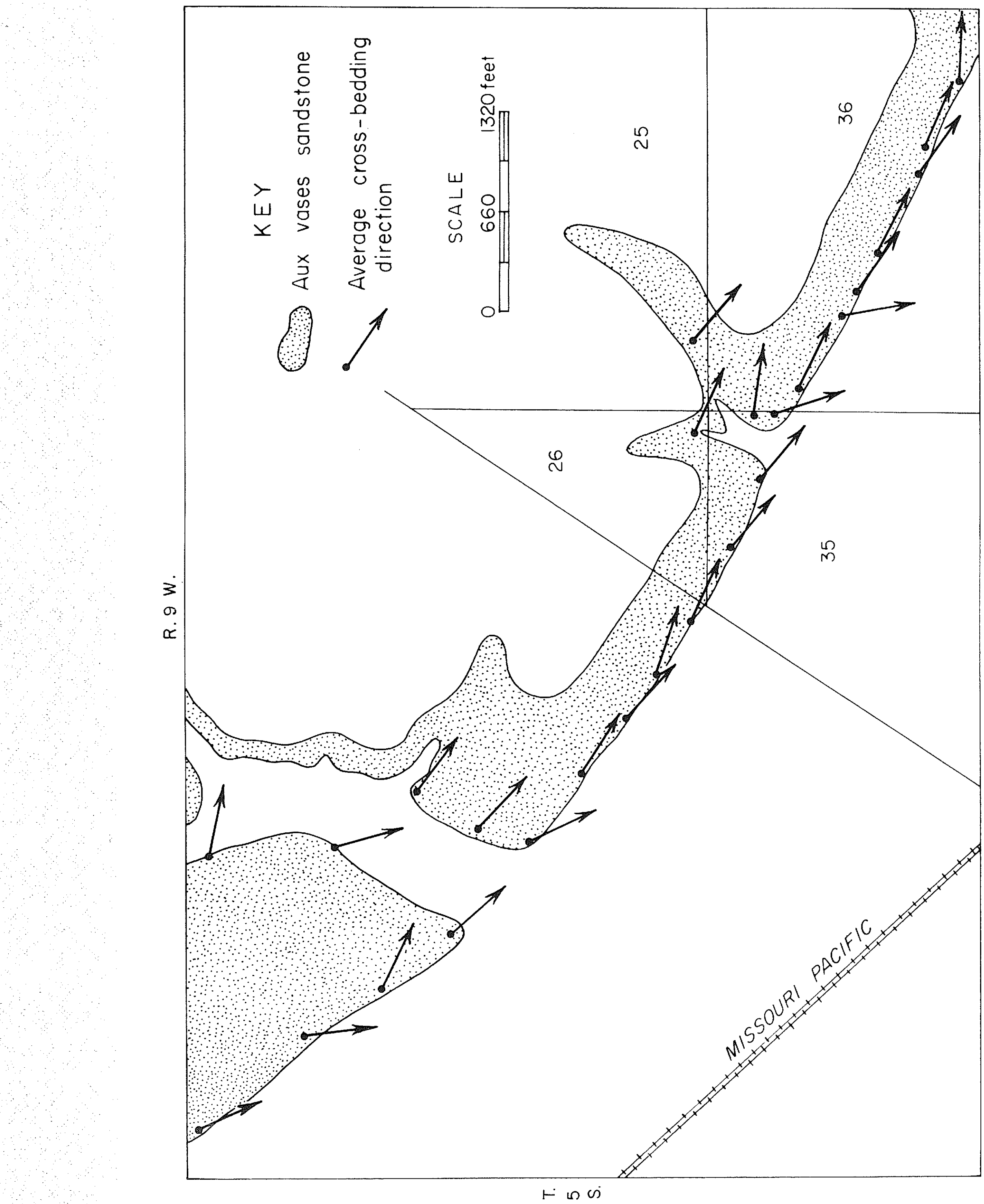

Fig. 7 - Cross-bedding in Aux Vases Sandstone in Randolph County, Illinois.

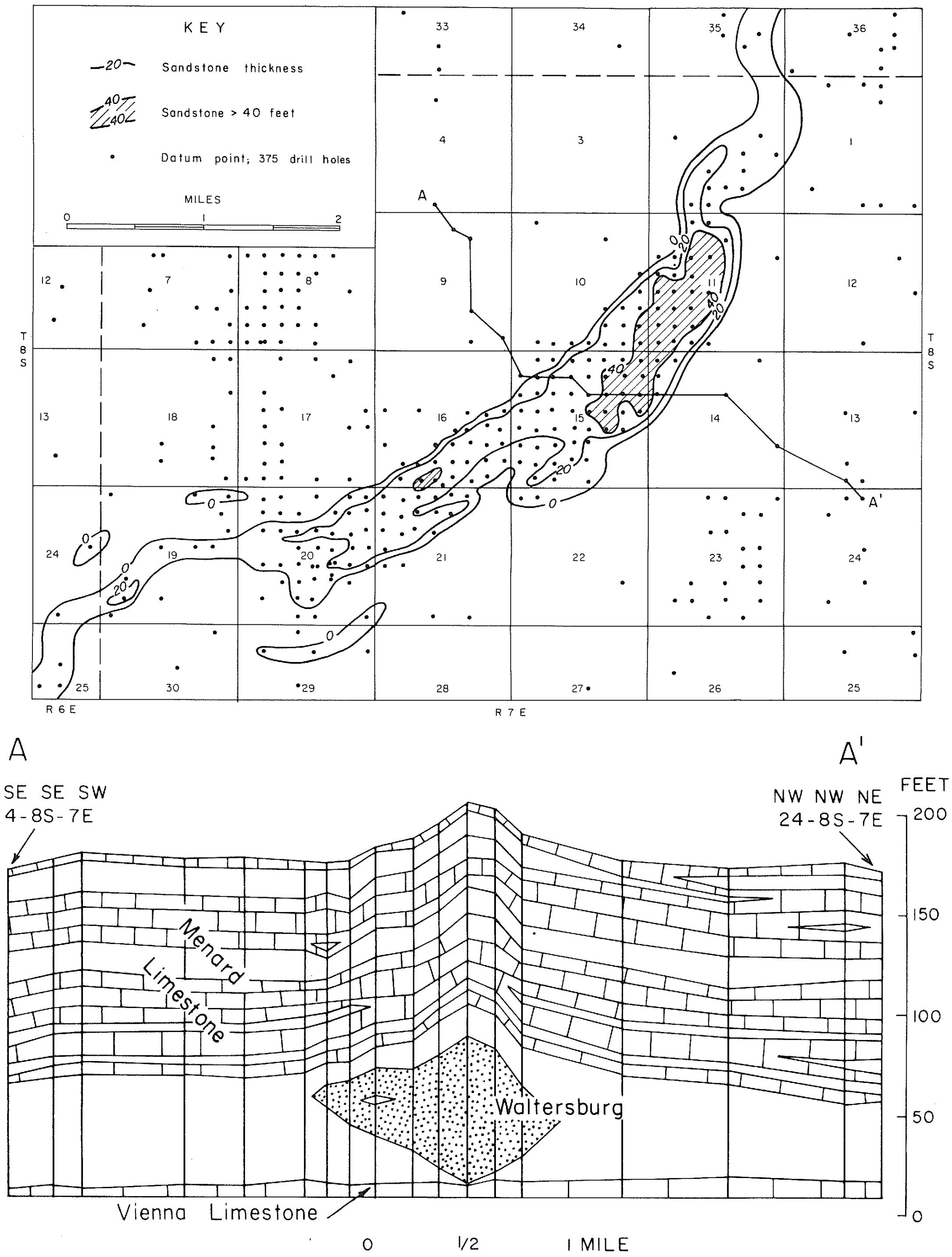

Fig. 8 - Thickness of sandstone and cross section of Waltersburg Formation in Saline County, Illinois. Sand bodies contoured to emphasize a channel-like origin. Compare with figure 9.

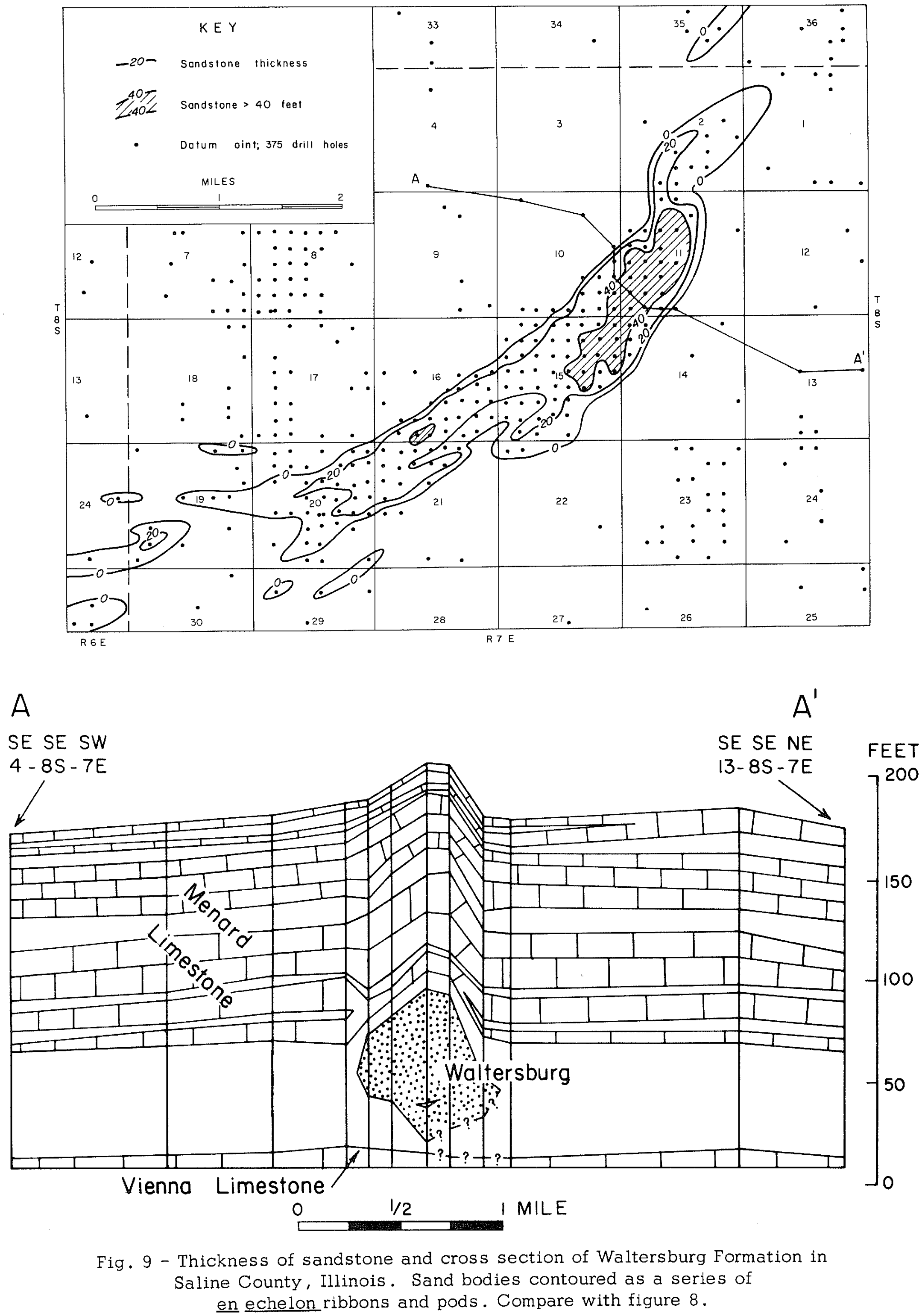

Fig. 9 - Thickness of sandstone and cross section of Waltersburg Formation in Saline County, Illinois. Sand bodies contoured as a series of en echelon ribbons and pods. Compare with figure 8.

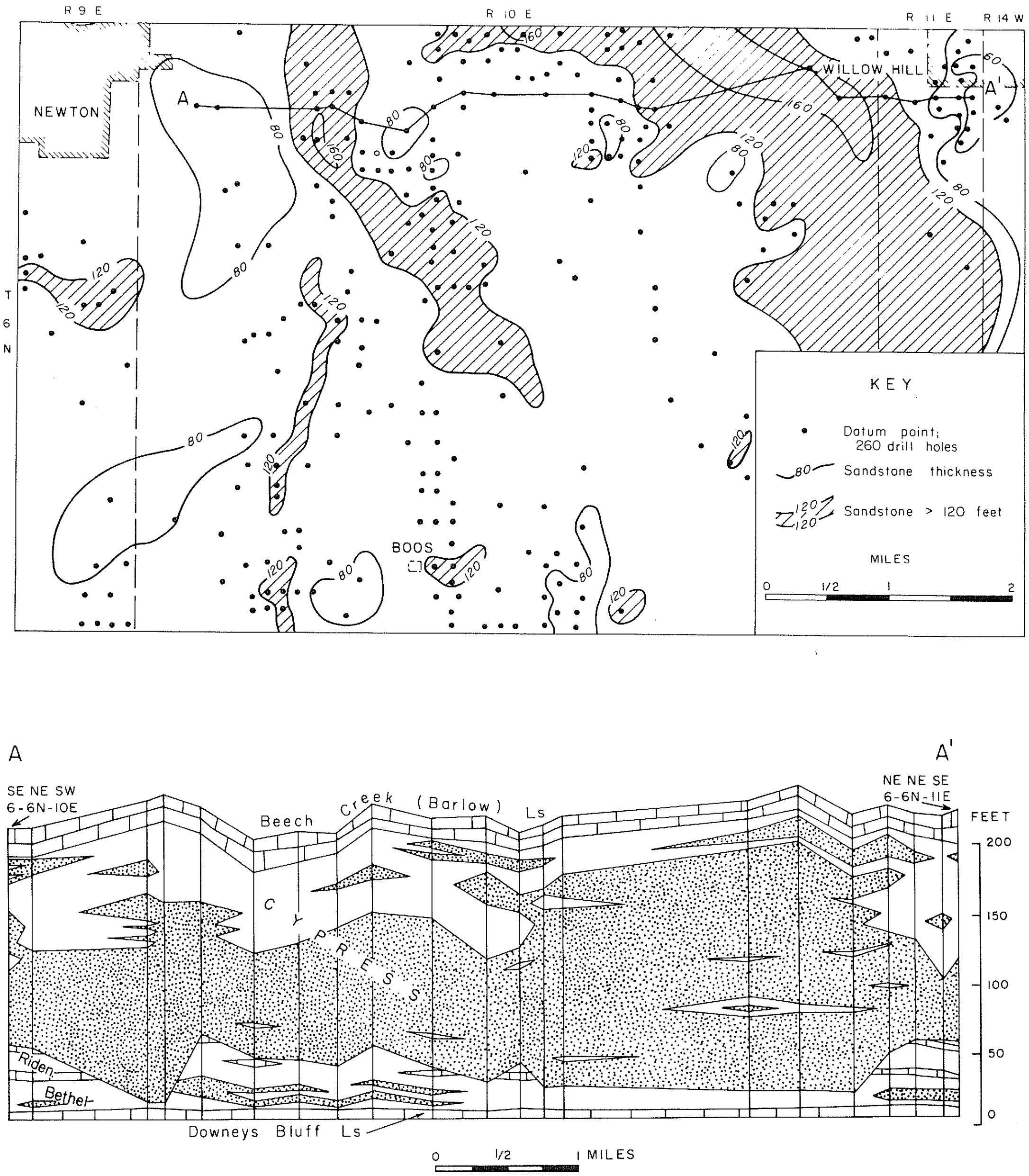

Fig. 10 - Thickness of sandstone and cross section of the Cypress Formation in part of Jasper County, Illinois.

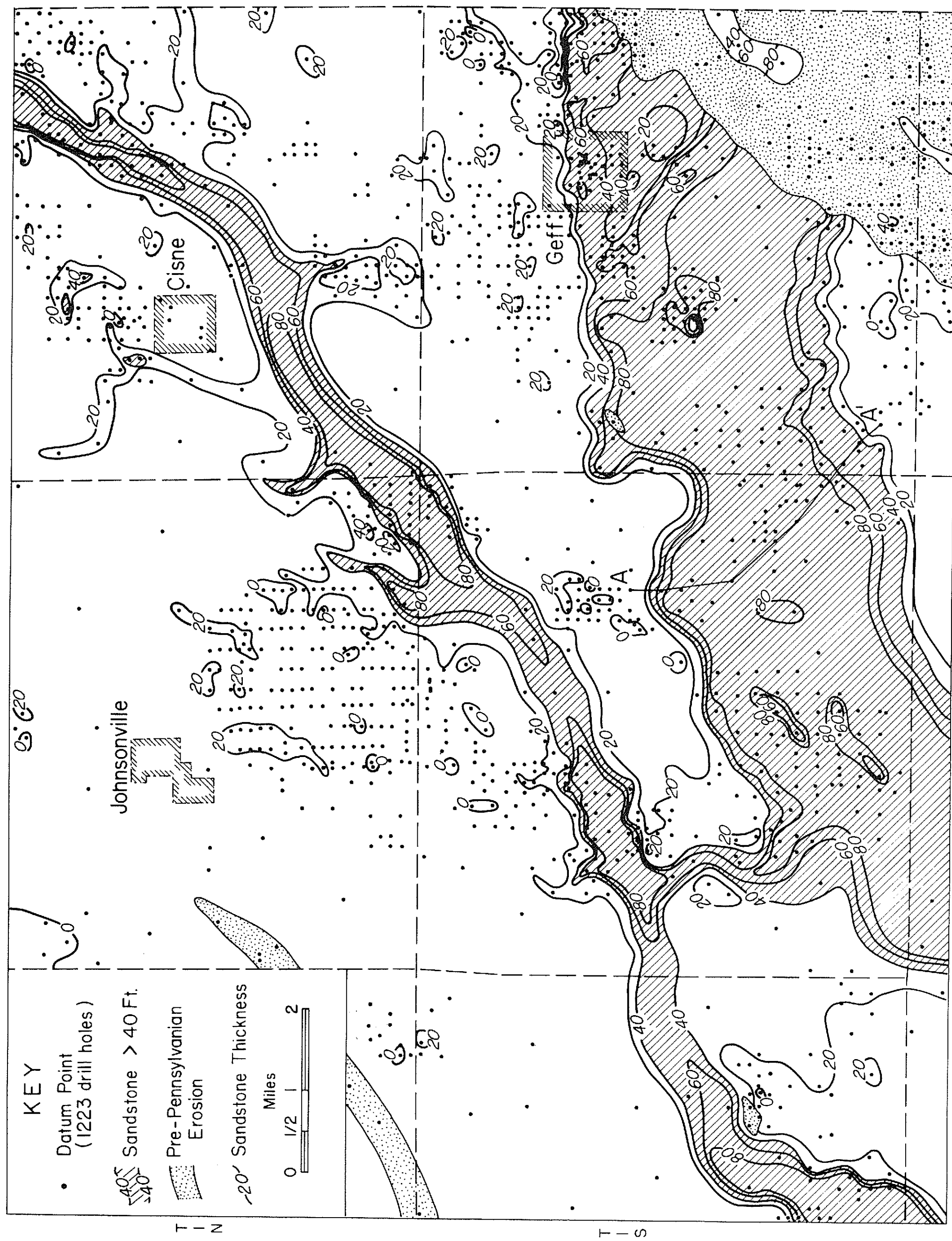

Fig. 11 - Thickness of sandstone in the Degonia Formation in part of Wayne County, Illinois

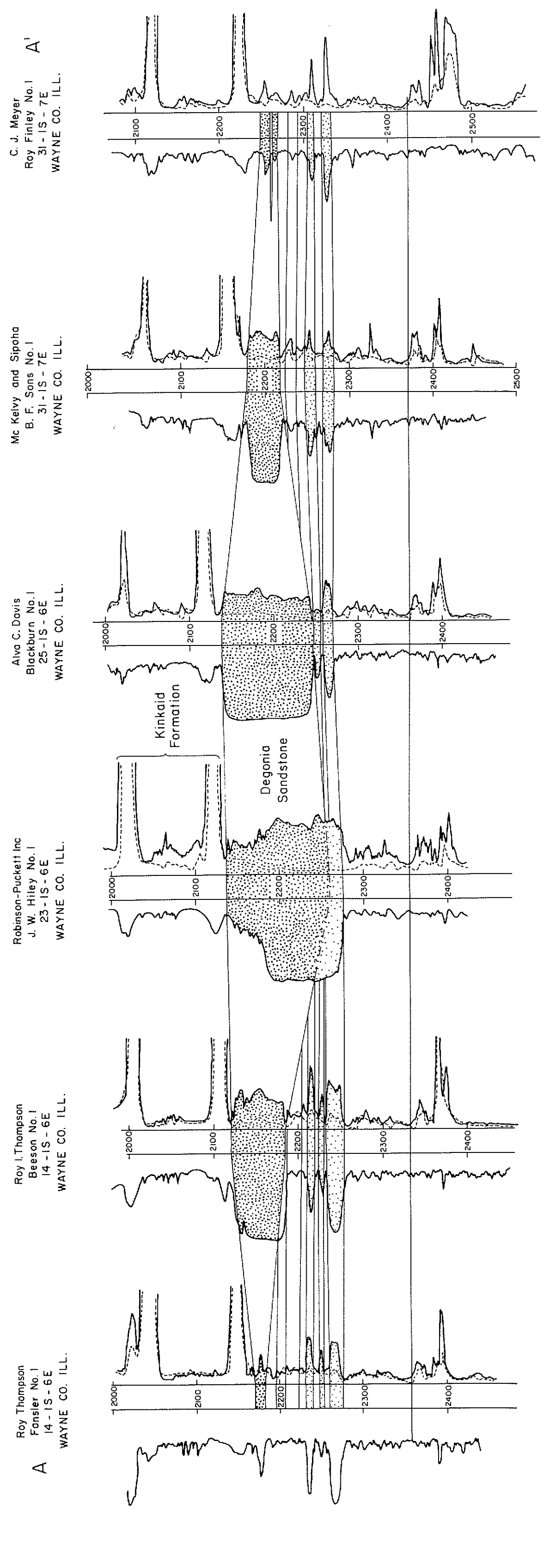

Fig. 12 - Electric log cross section of Degonia Formation along line shown on figure 11.

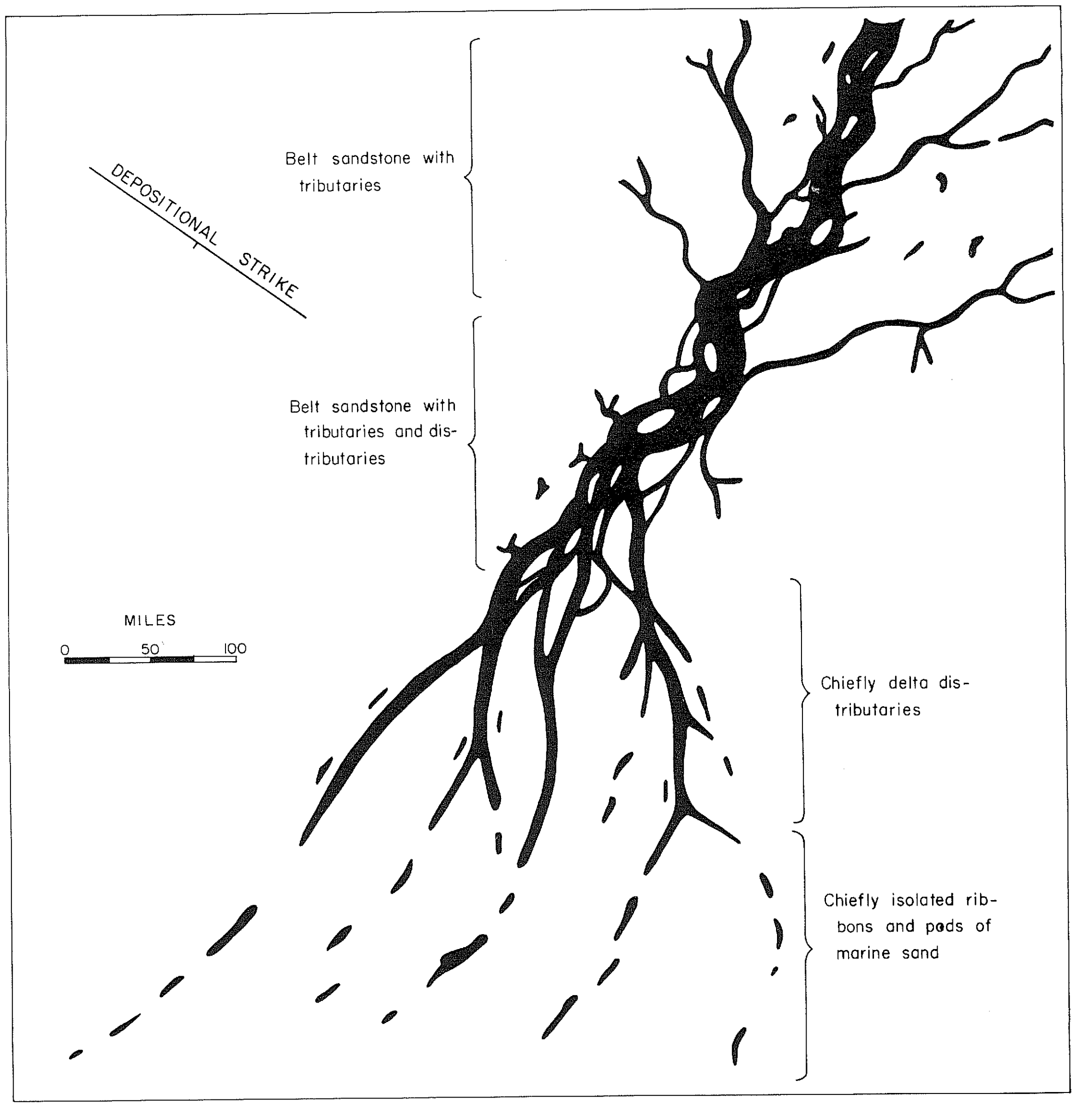

Fig. 13 - Idealized distribution pattern of elongate sandstone bodies in the late Mississippian.

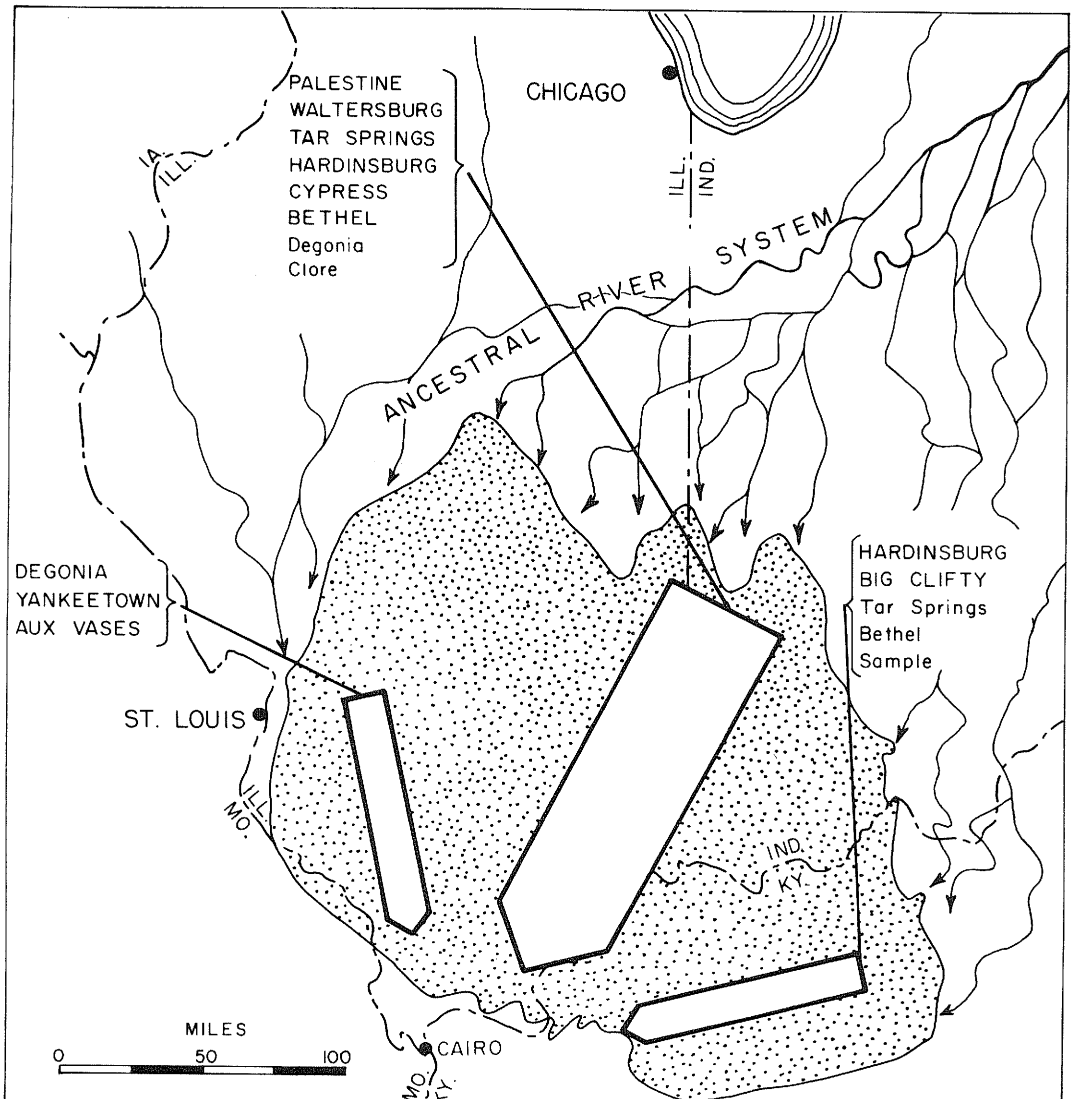

Fig. 14 - Diagrammatic location and trends of late Mississippian sandstones in Illinois Basin. Names in capitals represent principal sandstones in each region. Inferred location and trend of ancestral river system also indicated. Size of arrows is indicative of relative sand input into basin (modified from Potter et al., 1958, fig. 17). Late Mississippian sediments extended well to the north of present subcrop.

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