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Paleozoic Geology of the New Madrid Area

Prepared by H. R. Schwalb

Illinois State Geological Survey

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

Thick sections of sedimentary rocks occupy two grabens, the Reelfoot Rift and the Rough Creek Graben. Early sediments of Middle Cambrian and sub-Mt. Simon (Lamotte) deposition are found in the grabens, but do not crop out in the area. Growth faulting continued to deepen the Rough Creek Graben and possibly the Reelfoot Rift during much of the Paleozoic interval. Renewed tectonic activity, probably occurring during the Mesozoic Era, uplifted the Pascola Arch near the center of the Reelfoot Rift and also renewed uplift of many structural features and fault zones, some of which were displaced in a direction opposite to earlier movements. Erosion then removed thousands of feet of sediment from the area, and beveled the Pascola Arch. Igneous plutons were injected into the Precambrian basement rocks and some penetrated into the sedimentary section and formed dikes and sills. Subsidence followed with the formation of the Mississippi Embayment where Cretaceous and Tertiary sediments collected and buried the Pascola Arch. The area remains seismically active to the present day.

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INTRODUCTION

The study of the Paleozoic geology of the New Madrid area encompasses portions of eight states within a two hundred mile radius around New Madrid, Missouri. Information for the geologic study is based on subsurface data collected from publications, private individuals, universities, and state geological surveys. The well data consist of records from 434 deep drill holes in and around the study area, thirty-eight (38) of these tests penetrate to the Precambrian basement rocks (fig. 1). Based on sample examination, wire line logs, and reported stratigraphic information, the geologic columns (fig. 2) were constructed for various areas which cross state boundaries and incorporate terminology not necessarily common to any one state.

Age and correlation of rocks were established on the basis of sequence, lithology, fossil identification, and radiometric dates. To better understand tectonic events leading to interruptions in the sedimentary record, the magnitude and extent of unconformities were appraised by detailed stratigraphic correlation, based partly on geophysical logs. Samples of igneous intrusives and crystalline basement rocks were collected for age dating by radiometric methods, in addition to age dates obtained from private and published reports.

I gratefully acknowledge the help and criticism from the following individuals: Kenneth Anderson, Missouri Division of Geology and Land Survey; Jerry Carpenter and Andrew Hreha, Indiana Geological Survey; William Caplan, Arkansas Geological Commission; Alvin Bicker, Jr., Mississippi Bureau of Geology; Dr. Robert Hershey and Dr. Edward Luther, Tennessee Division of Geology; Jack Kidd, Geological Survey of Alabama; Dr. Tom Buschbach, Saint Louis University; and all the members of the New Madrid Study Group. I assume sole responsibility for the interpretation of the data and the conclusions presented in this report.

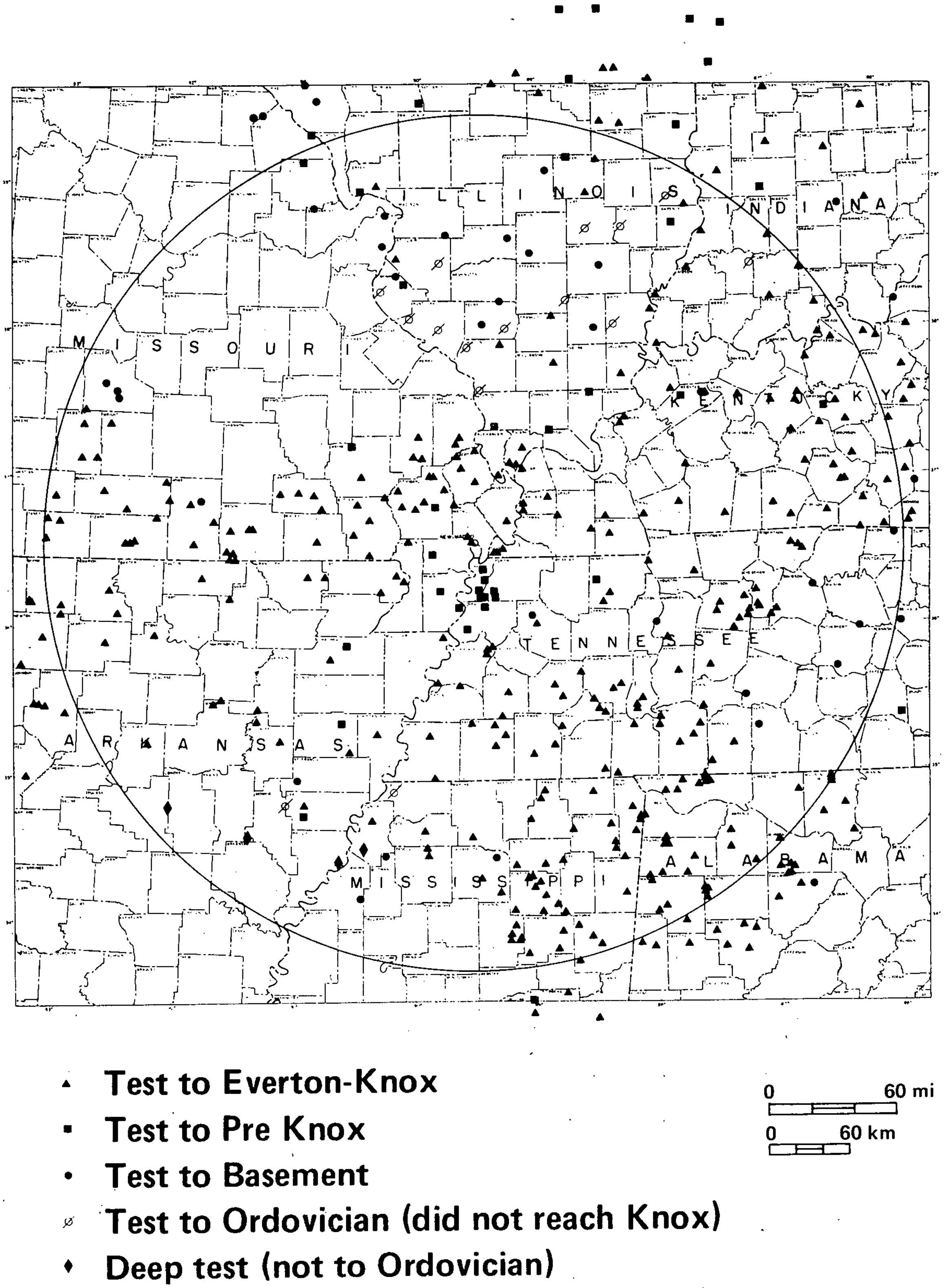


Figure 1. Datum points keyed to depth of penetration.

STRATIGRAPHY OF THE NEW MADRID AREA

PRECAMBRIAN

Precambrian age crystalline rocks in the Eastern Interior were subject to subaerial erosion, and a terrain with pronounced topographic relief was developed. As much as 1500 feet (450 meters) of relief existed in the area of the Ozark Uplift, and more than 500 feet (150 meters) of relief is documented for hills and ridges in the Illinois Basin area. The Sparta Shelf stood above the low area to the east by as much as 750 to 1000 feet (200 to 300 meters). Faulting probably controlled the alignment of many of the ridges and contributed to the formation of steep-sided uplifts. Stream gradients were steep and effectively contributed to the removal of erosional debris as no appreciable regolith or detritus zone has been noted at outcrops or in the subsurface. Debris transport was probably to the south (fig. 3) with a major river system in the approximate position of the present Mississippi River.

The major unconformity of the Precambrian surface is overlain by sedimentary rocks of varying age. In the Reelfoot and Rough Creek graben areas, the first sediments were probably of early Cambrian age. The eastern and southern edges of the ancestral Nashville Dome also have early Cambrian sediments deposited from a source that was probably different from that of the sediments in the New Madrid area.

Upper Cambrian sandstones (Mt. Simon) are the basal sediment in much of the area north of the Rough Creek Fault Zone, and the Ozark Uplift also has the equivalent Lamotte Sandstone partially infilling the deep valleys cut into the igneous terrain.

Sediments of Bonneterre, Eau Claire, and Franconia Formations cap the tops of the high ridges of Precambrian hills (see figs. 4 and 5). All of the crystalline Precambrian basement was probably covered by sedimentary rock by the end of the Cambrian time, although the thickness of cover varied from a few hundred to many thousands of feet.

LOWER CAMBRIAN

Sediments began to collect in the Appalachian Basin with a basal sandstone on the flanks of the Nashville Dome and lap onto the dome from the east and possibly from the south. Shale and sandy shale with some carbonate overlie

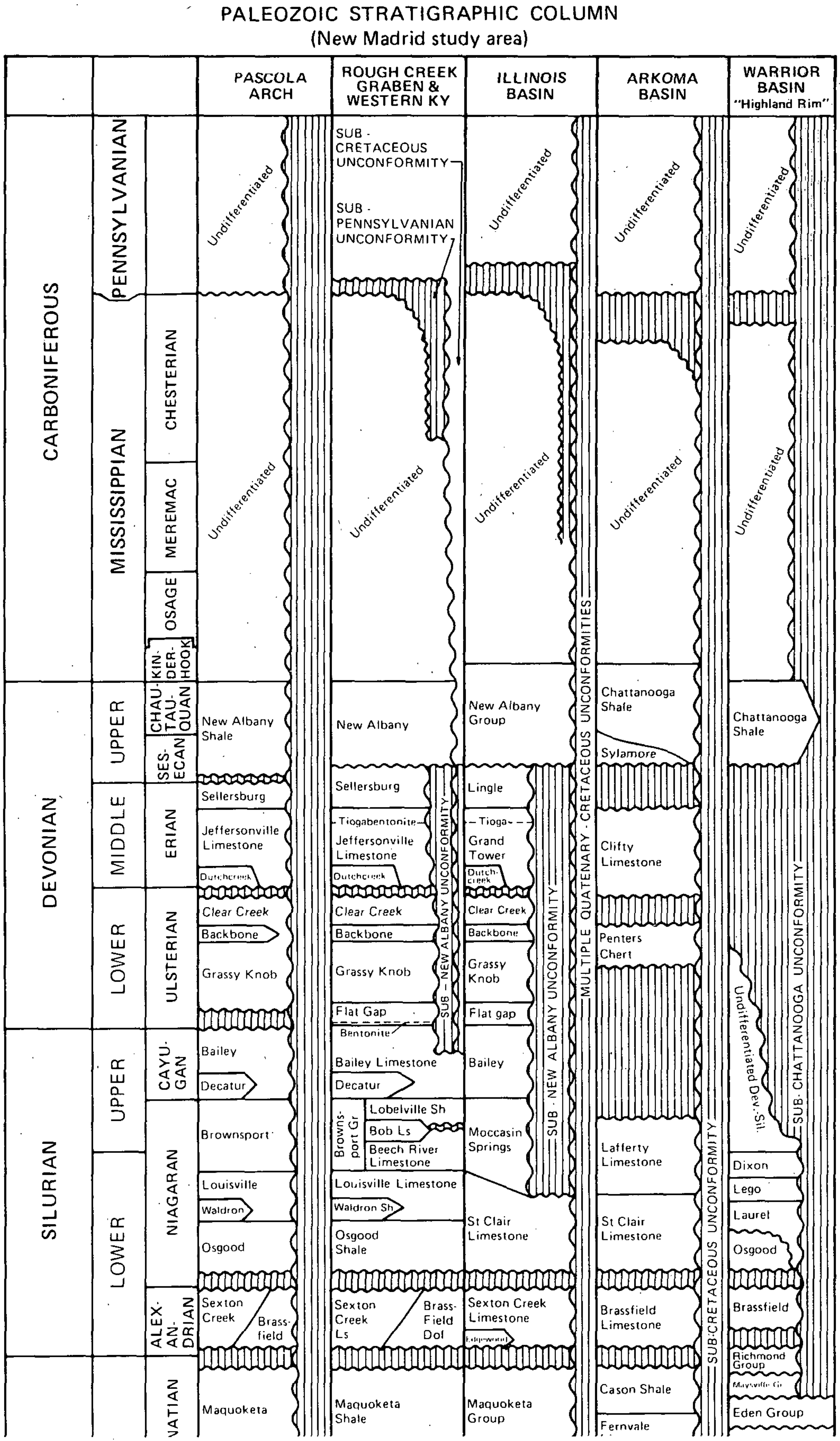


Figure 2. Geologic columns of study area.

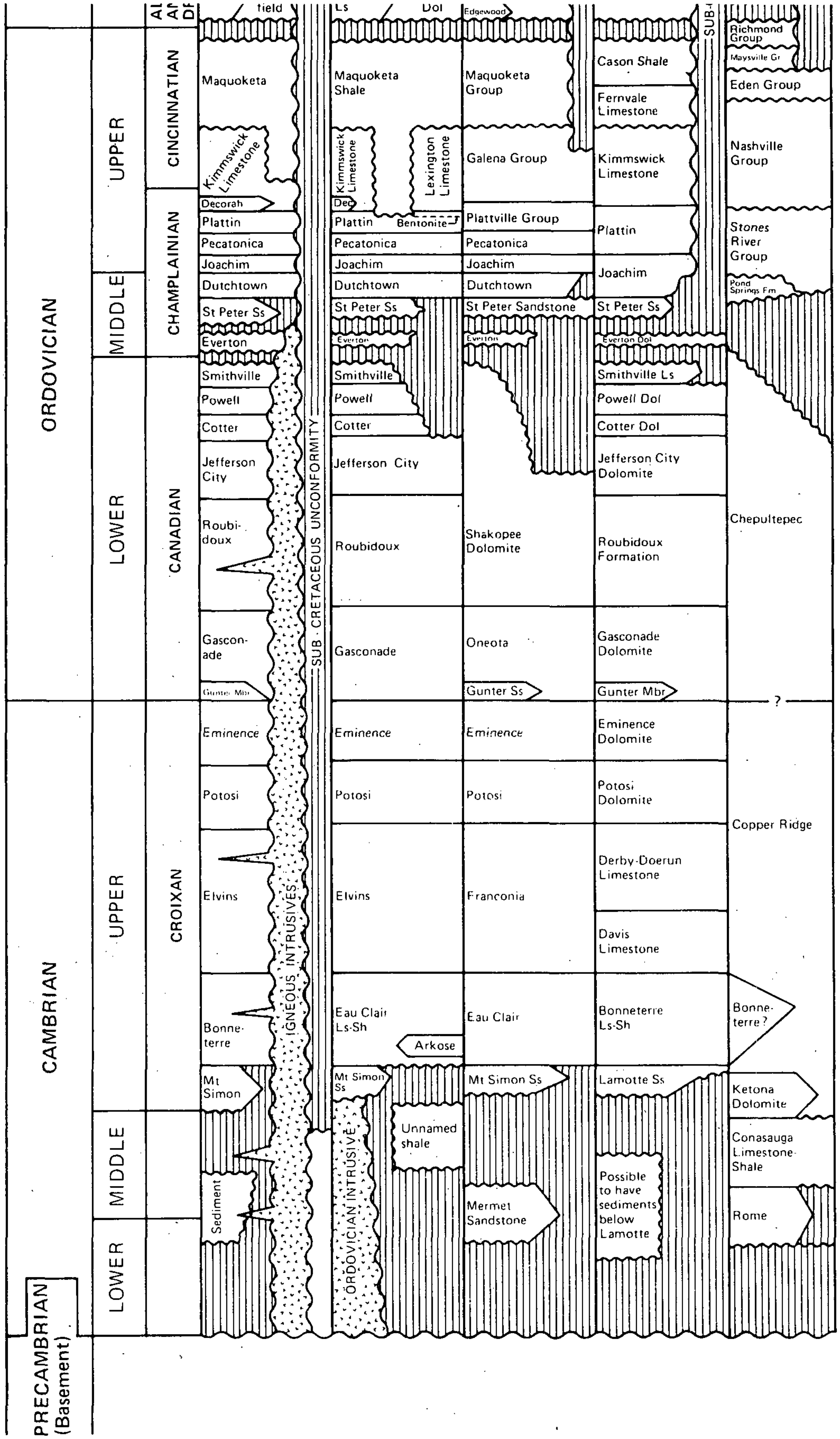


Figure 2, continued.

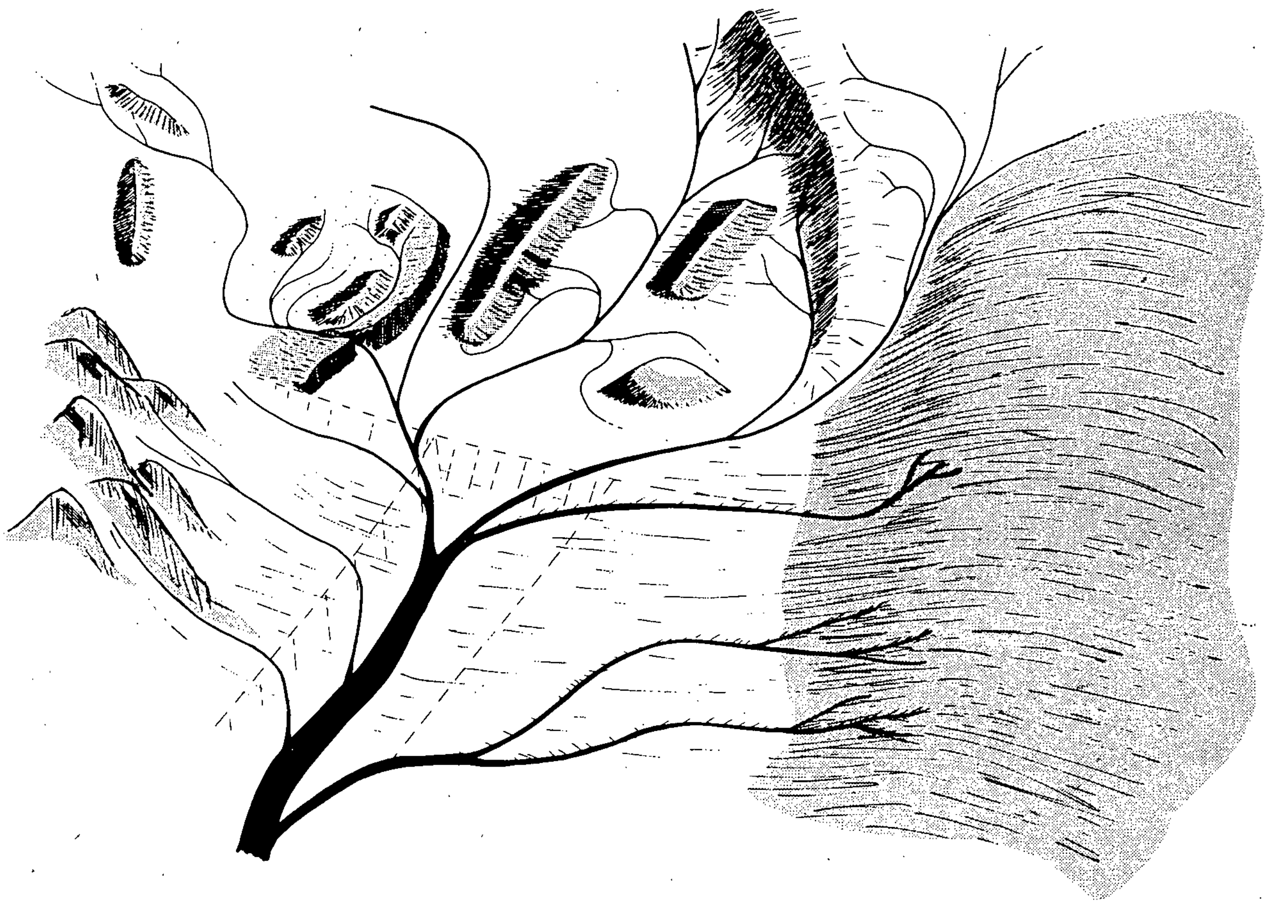


Figure 3. Cartoon showing topography on top of Precambrian rocks in the study area.

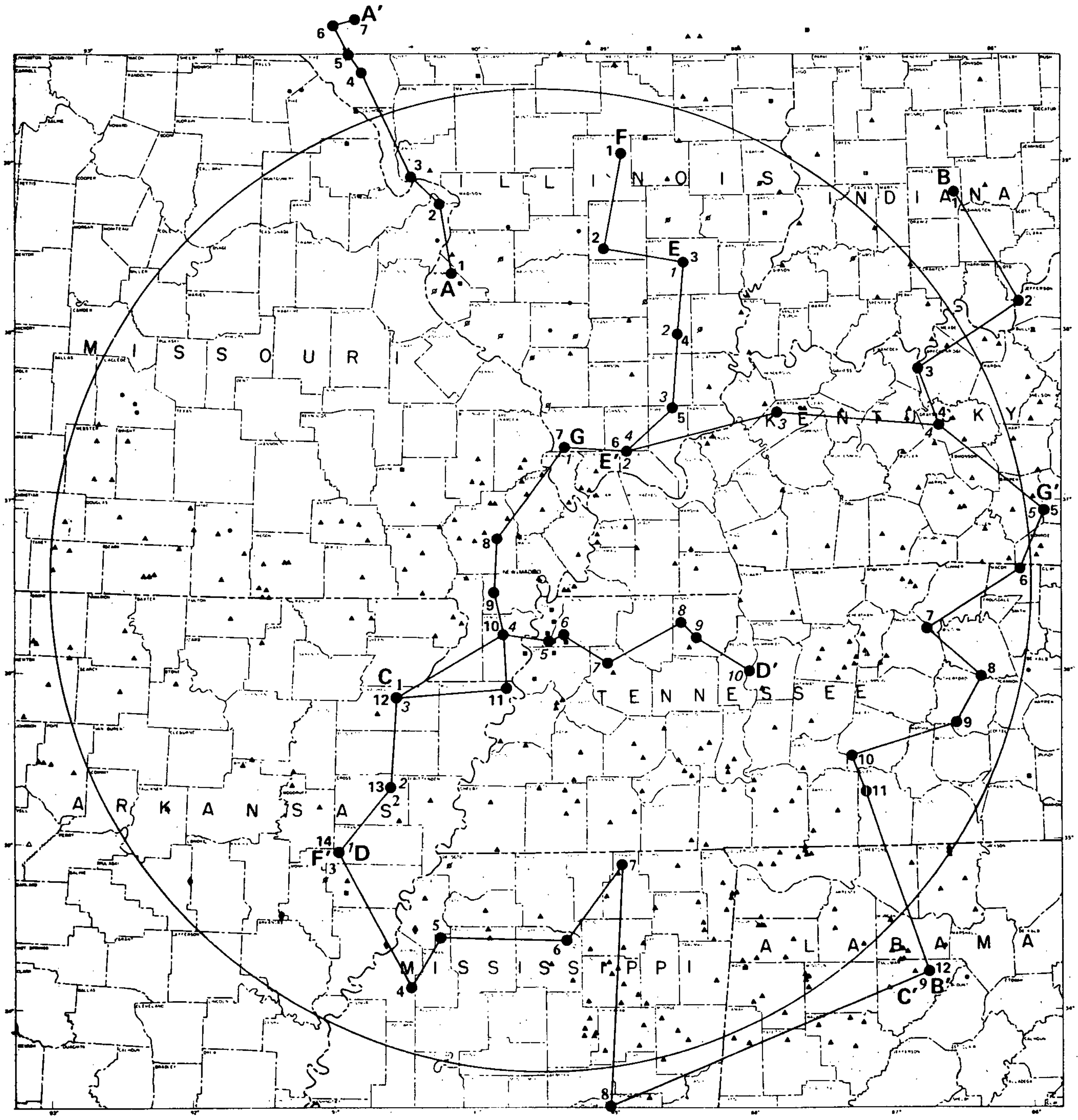


Figure 4. Lines of cross sections shown in Figures 5-8, 18, 20, and 21.

these sands; reddish coloration is typical of this section. These clastic rocks are believed to be equivalent to the Rome of Appalachian outcrop.

A large graben (Reelfoot Rift) formed in the Mississippi Embayment trending northeasterly into southern Illinois. A similar graben of smaller dimensions (Rough Creek Graben) formed trending easterly from southern Illinois into western Kentucky. Deep wells in southern Illinois and western Tennessee encounter early sediments of unknown age. The Mermet Sandstone of Johnson County, Illinois, which may be of only local extent, was deposited as fluvial deltaic or pediment fans southward of an east-west trending fault scarp (fig. 6). Dolomite and siltstone of pre-Lamotte age in Lake County, western Tennessee, may represent the first marine sediments in the Reelfoot Rift. Total thickness and exact age of early sediments is unknown, and they do not crop out.

MIDDLE CAMBRIAN

Limestones and shales of Conasauga age overlie "Rome" sediments in the Appalachian area thinning to zero on the northern rim of Nashville Dome. Thick shales accumulated in the Rough Creek Graben while crystalline basement rock remained partially exposed to the north and south (fig. 7). Dolomite deposition in northern Mississippi and eastern Arkansas may be of middle Cambrian age. This dolomite rests on a varied terrain of granite and metamorphic rocks which probably was exposed to erosion during earlier Cambrian time (fig. 8). The Reelfoot Rift and Rough Creek Graben nearly filled with sediment by the end of middle Cambrian time, and growth faulting probably deepened these troughs during most of the early to middle Paleozoic Era (fig. 9).

UPPER CAMBRIAN

Limestone deposition, since altered to dolomite in the Appalachian area, laps onto the Nashville Dome. Mt. Simon and Lamotte Sandstones accumulated in the Ozark and central Illinois regions where they rest on basement rock. Mt. Simon (Lamotte) sands extend southward and overlie Mermet Sandstone in southern Illinois. The Mt. Simon-Lamotte sandstones are present in northwestern Tennessee where they rest on older carbonate rock in the Reelfoot Rift, but they lap onto basement on either side of the graben. Basement apparently remained exposed along the eastern end of the Rough Creek Fault

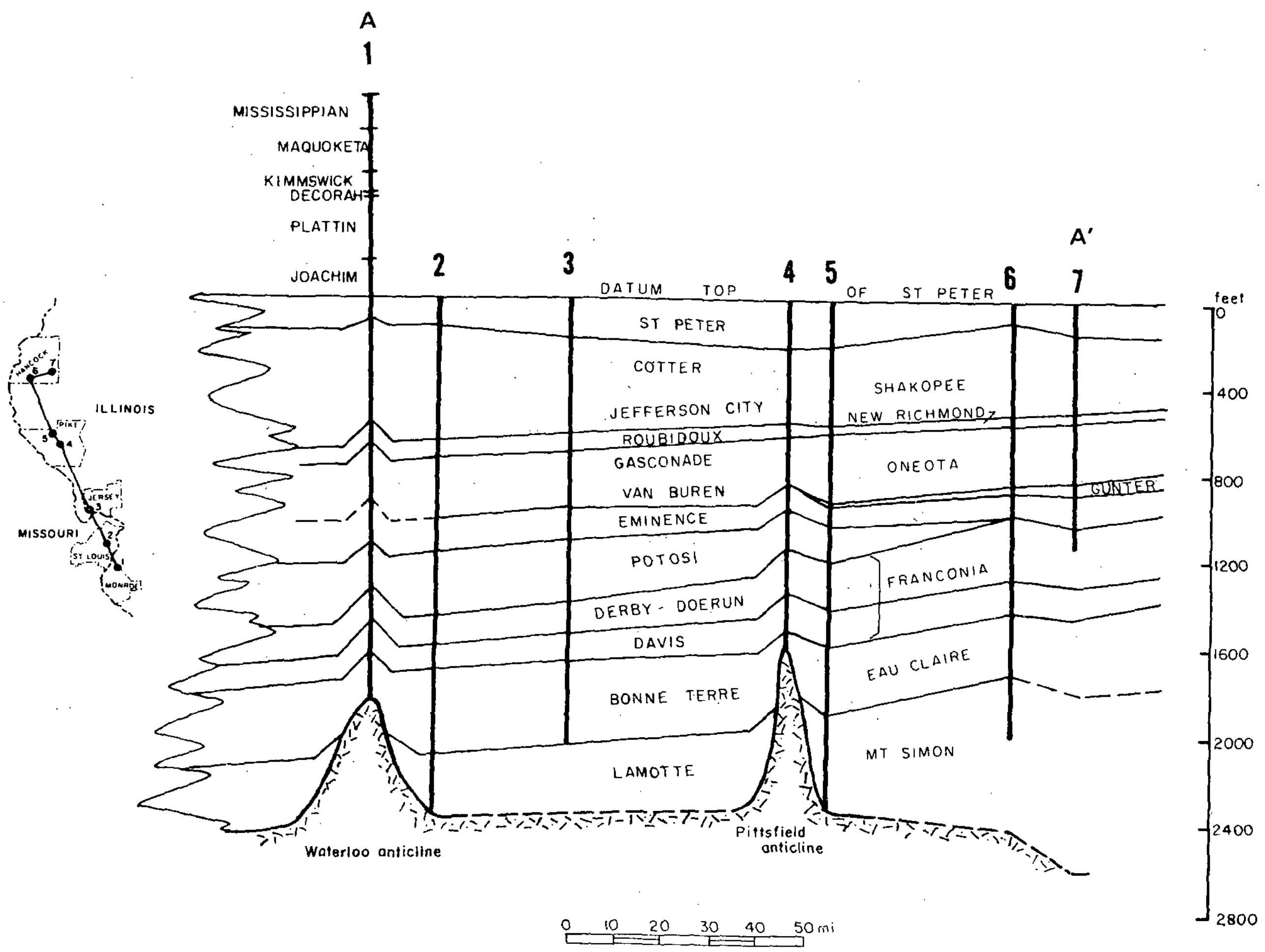
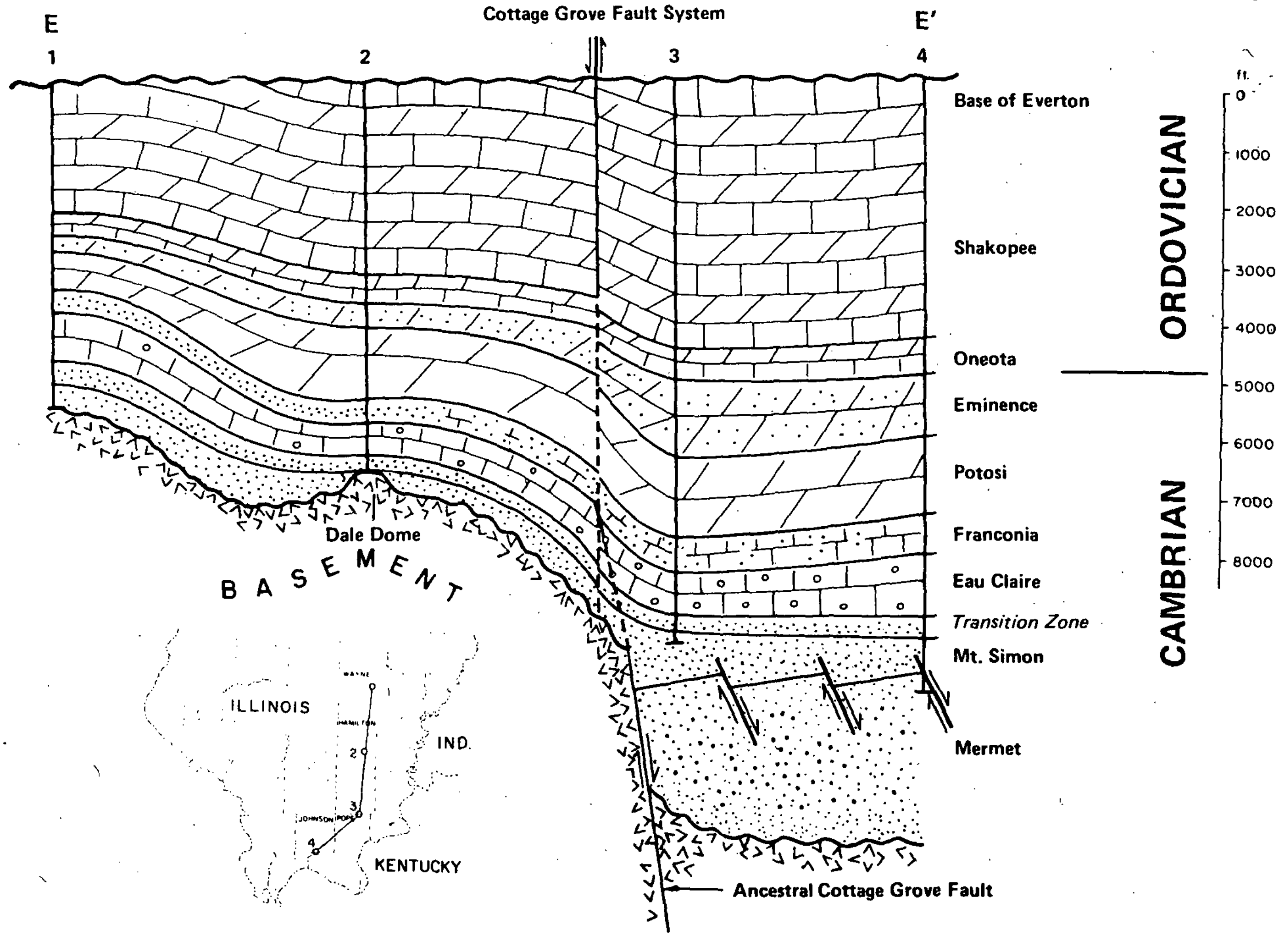


Figure 5. Cross section A-A', Hancock County to Monroe County, Illinois.



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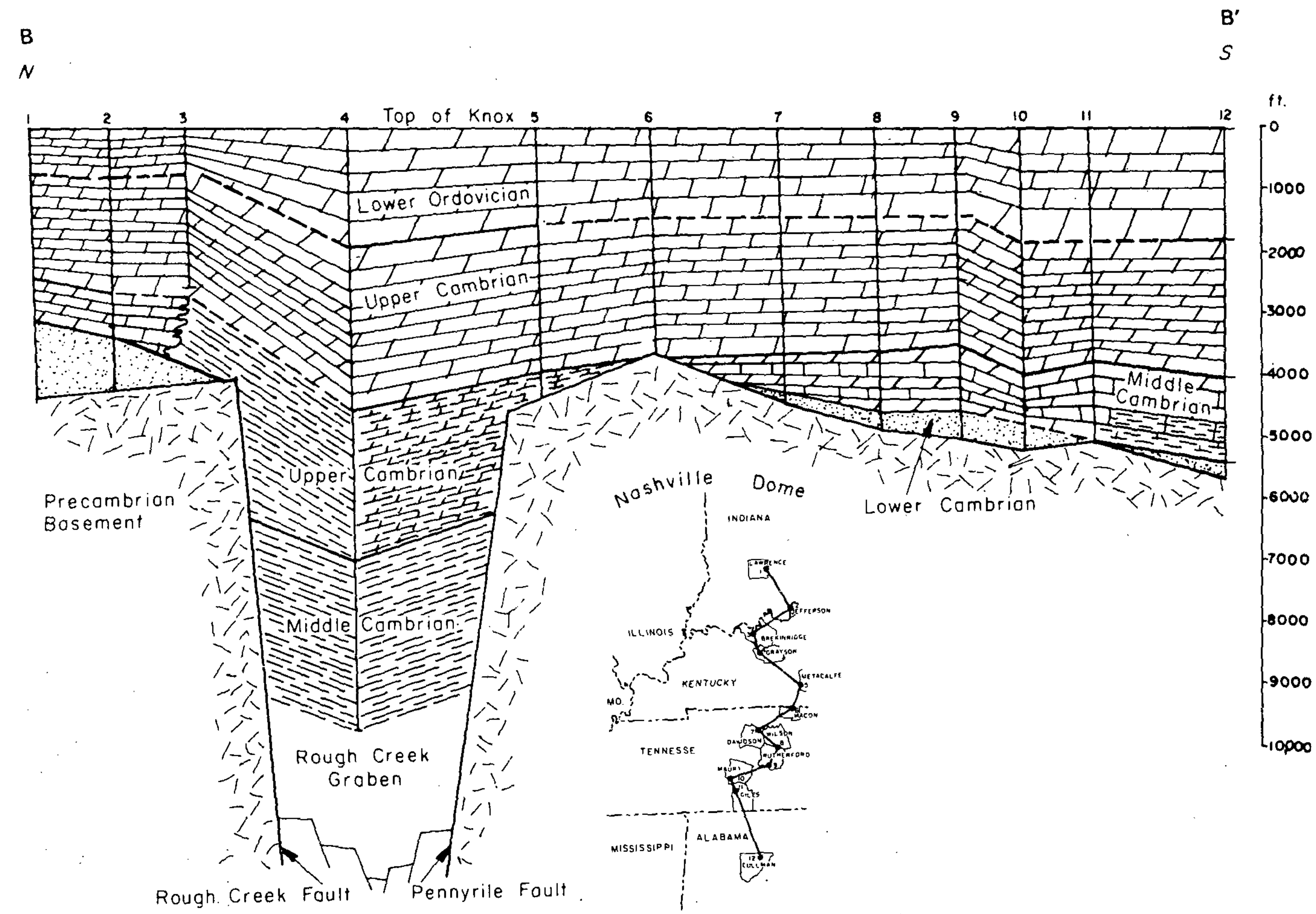


Figure 7. Cross section B-B', Lawrence County, Indiana, to Cullman County, Alabama.

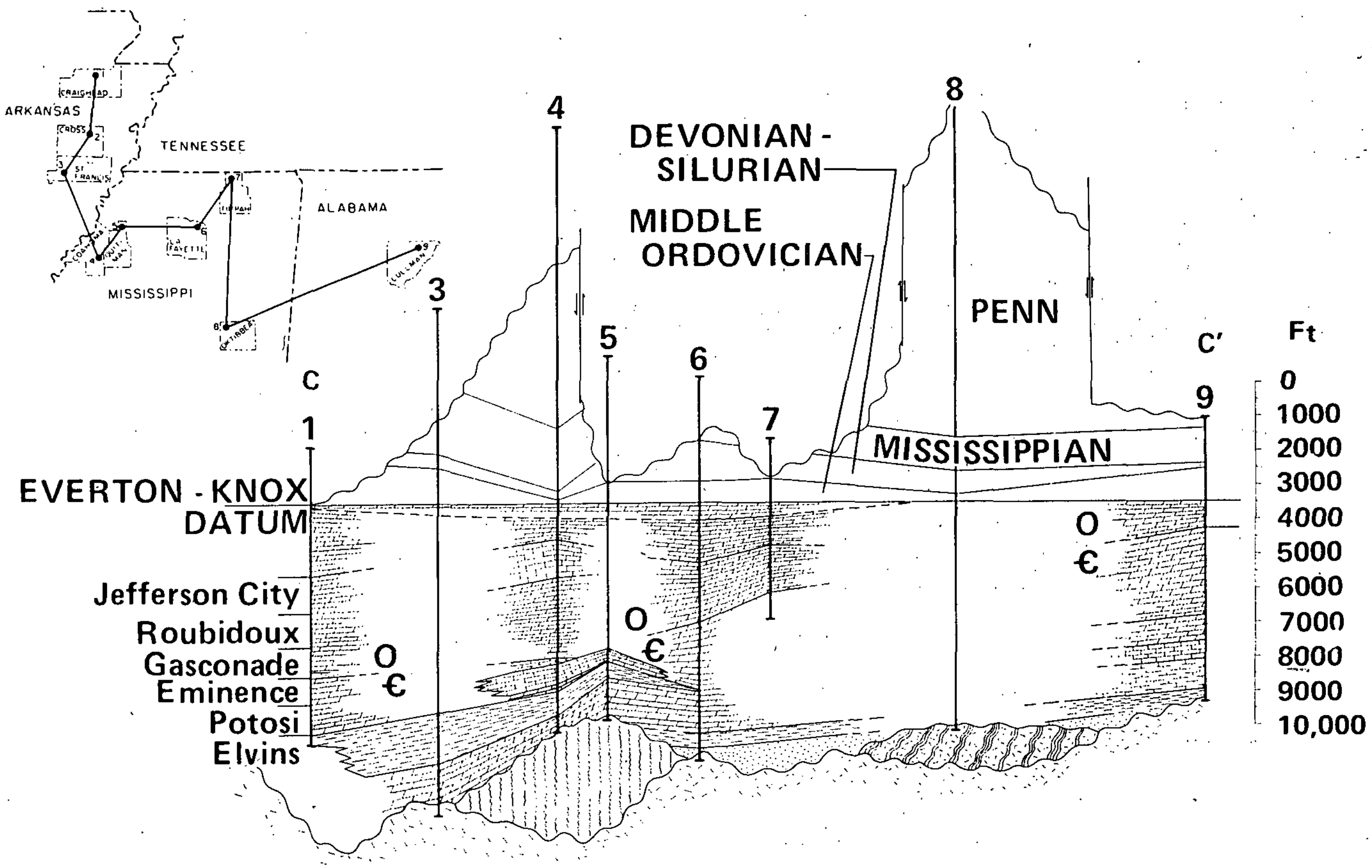


Figure 8. Cross section C-C', Craighead County, Arkansas, to Cullman County, Alabama.

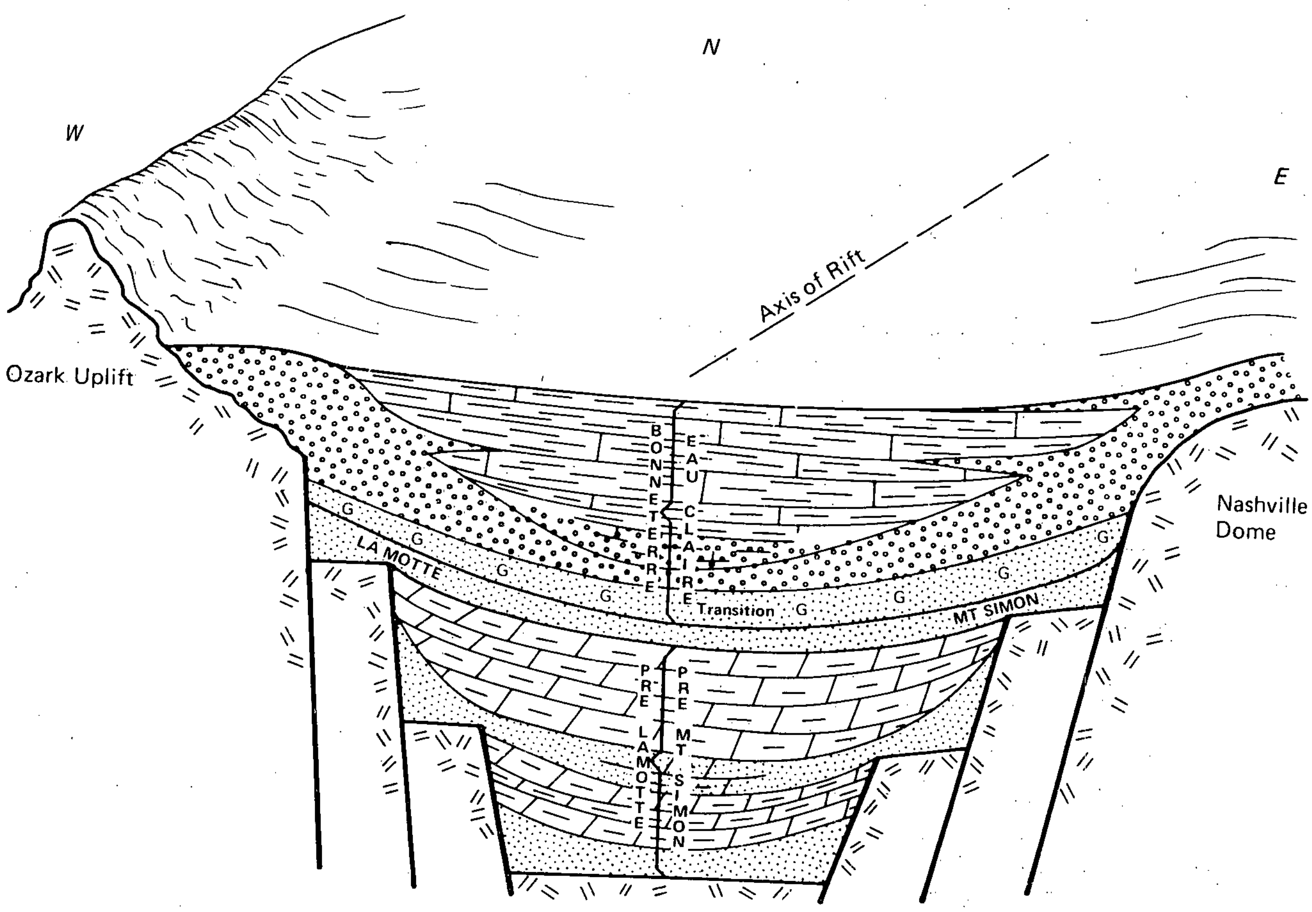


Figure 9. Schematic cross section showing interpreted growth faulting in the Rough Creek Graben.

Zone, and created a large shadow zone in which no Mt. Simon sands accumulated. The transition zone at top of Mt. Simon grades into the base of Eau Claire and Bonneterre limestone and dolomite which accumulated as thick carbonate banks of oolites with some sandstone incursions in the Ozark Region. The Eau Claire-Bonneterre oolitic carbonate was deposited north of the Rough Creek Graben in southern Illinois and in the Missouri Ozark region as a shallow water facies, while Bonneterre shale accumulated in the deep water of the Rough Creek Graben and Reelfoot Rift in western Tennessee, southeastern Missouri, and extended into eastern Arkansas and northwestern Mississippi (figs. 10-11). The bordering faults of the old grabens continued to be displaced as growth faults which deepened the grabens and allowed the accumulation of thickened marine sediments of shale and siltstone. Whether this clastic material was washed over the oolitic limestone banks flanking the graben areas or had a source from the south and southwest cannot be determined, but the northward coarsening of the Eau Claire formation to sands and siltstones would indicate a source from that direction.

The Franconia Formation of Illinois is a southward-thickening unit of silty, glauconitic and argillaceous sandstone with increasing amounts of dolomite toward the south. It is equivalent of the Elvins Group of Missouri and extends eastward into Kentucky where it is primarily dolomite with small amounts of black shale. In Kentucky it lacks the characteristic glauconite of areas to the north and west. The contact with the underlying Eau Claire is characterized on wire line logs by a positive or increased response to the more shaly Eau Claire formation.

This is one of the few zones of correlation in the lower Ordovician and Cambrian section that is readily identifiable on wire line logs. In southern Illinois and western Kentucky and Elvins and Franconia formations are included in the Knox Megagroup, and the thickness of the section in the Rough Creek Graben exceeds 1300 feet (390 meters). Oolitic cherts and relict oolite structures in the dolomite indicate that the lithology was originally predominantly an oolitic limestone of shallow water deposition.

CAMBRIAN-ORDOVICIAN KNOX MEGAGROUP

The Knox Megagroup, a lower Ordovician and upper Cambrian carbonate unit, underlies sedimentary cover between outcrops in the Appalachian areas of

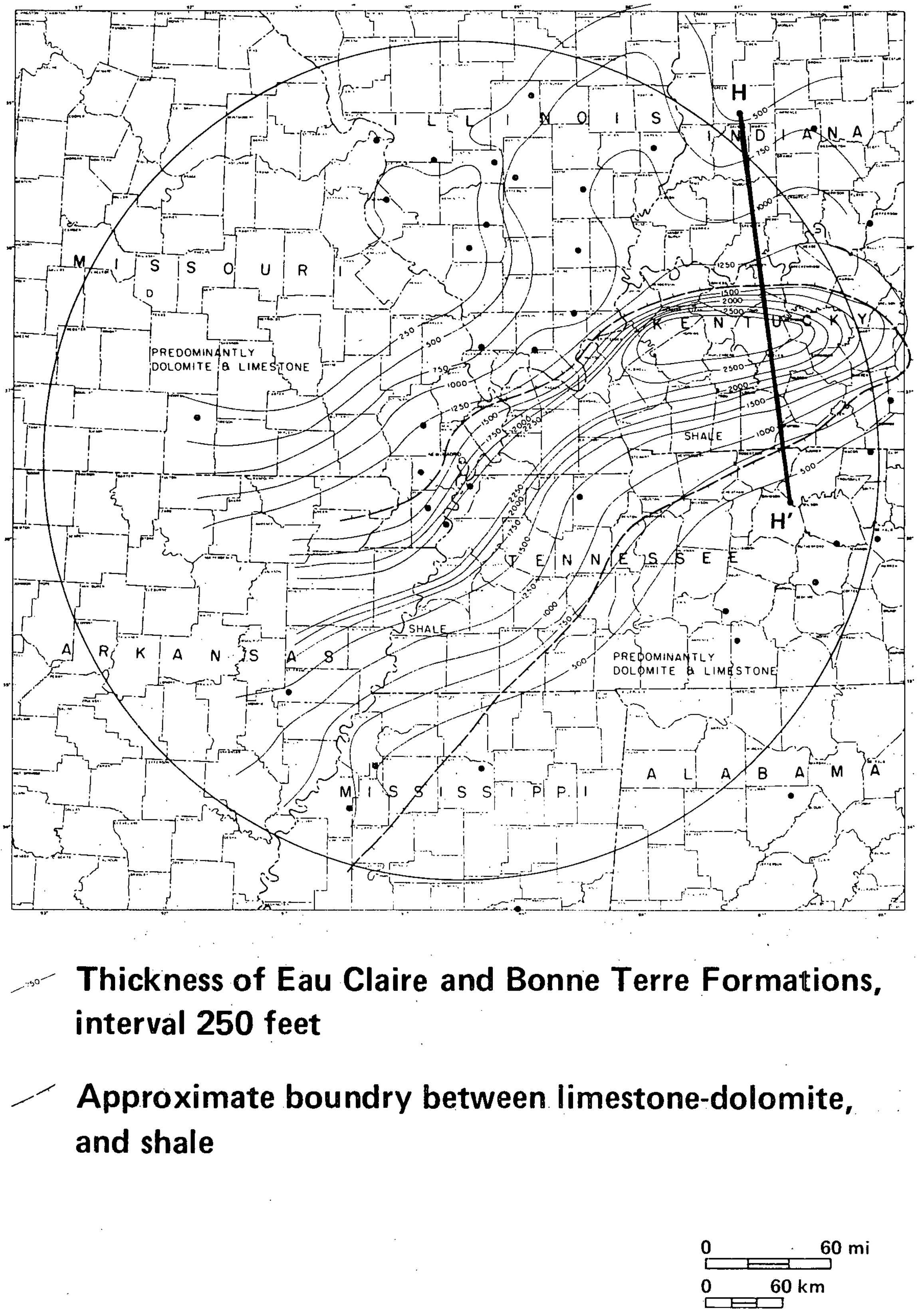


Figure 10. Thickness and lithology of the Eau Claire-Bonneterre Formations. H-H' is line of cross section for Figure 11.

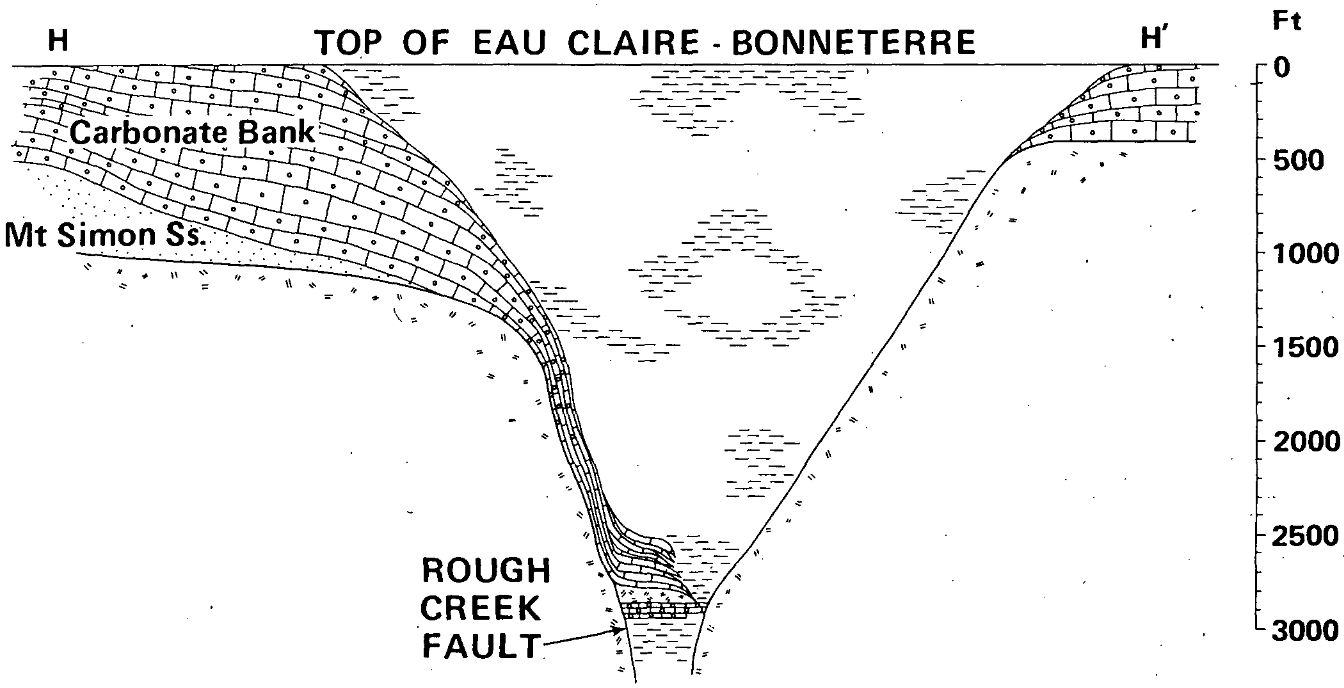


Figure 11. Schematic cross section showing lithology of the Eau Claire-Bonneterre Formations.

intense folding and faulting to outcrops in Missouri around the Ozark Uplift. From east to west this unit in the subsurface gradually increases from about 1000 to over 7000 feet (300 to over 2100 meters) in thickness (fig. 12). The maximum thickness occurs in the Reelfoot Basin of the upper Mississippi Embayment although the entire section of Knox has been beveled by erosion over the Pascola Arch. Here the truncated formations subcrop beneath Cretaceous sediments. West of the Mississippi River the thick Knox section extends into the Arkoma Basin and is called Arbuckle, which in general is correlated westward with the Ellenburger of Texas and Oklahoma.

In most areas the Knox has been subjected to subaerial erosion, and this surface represents one of the major unconformities within the Paleozoic sediments. The unconformity delineates the upper limit of the Sauk Sequence of the Paleozoic section. Above the unconformity are sandstones, such as the St. Peter, and shales, limestones, and dolomites of middle Ordovician (Champlainian) age. The Everton Dolomite partially covers the Knox unconformity in western Kentucky, Missouri, Arkansas, and southern Illinois. The Everton is included with the Knox on the structure (fig. 13) and isopach maps.

Within the Knox Megagroup are local unconformities around the basin margins, but there is very little evidence of unconformities within the Knox where thick sediments occur. The base of the Knox appears to be transitional, but it is marked by the occurrence of shales and sands, which dominate the lithologic sequence, and by minor carbonate units. The thickest pre-Knox sand and shale units are confined to earlier Cambrian depocenters, and to growth fault basins which were overridden by the carbonates of the Knox.

The original lithology of the Knox was relatively shallow water limestone with very minor amounts of sand, shale, and chert. Most of the limestones were oolitic and probably rather porous, but dolomitization and replacement chert destroyed much of the original texture and porosity. Much of the alteration appears to have occurred soon after deposition with several later periods of alteration occurring in local areas. The oolitic character of the formations is well preserved in the cherts, and where dolomitization is not complete the relict structure of oolites can be seen in sample cuttings. Much of the original fossil content of the formations has also been destroyed except where preserved in chert or unaltered limestone. In the Ozark region there are abundant nonsilicified algal deposits. Sandy zones are also numerous,

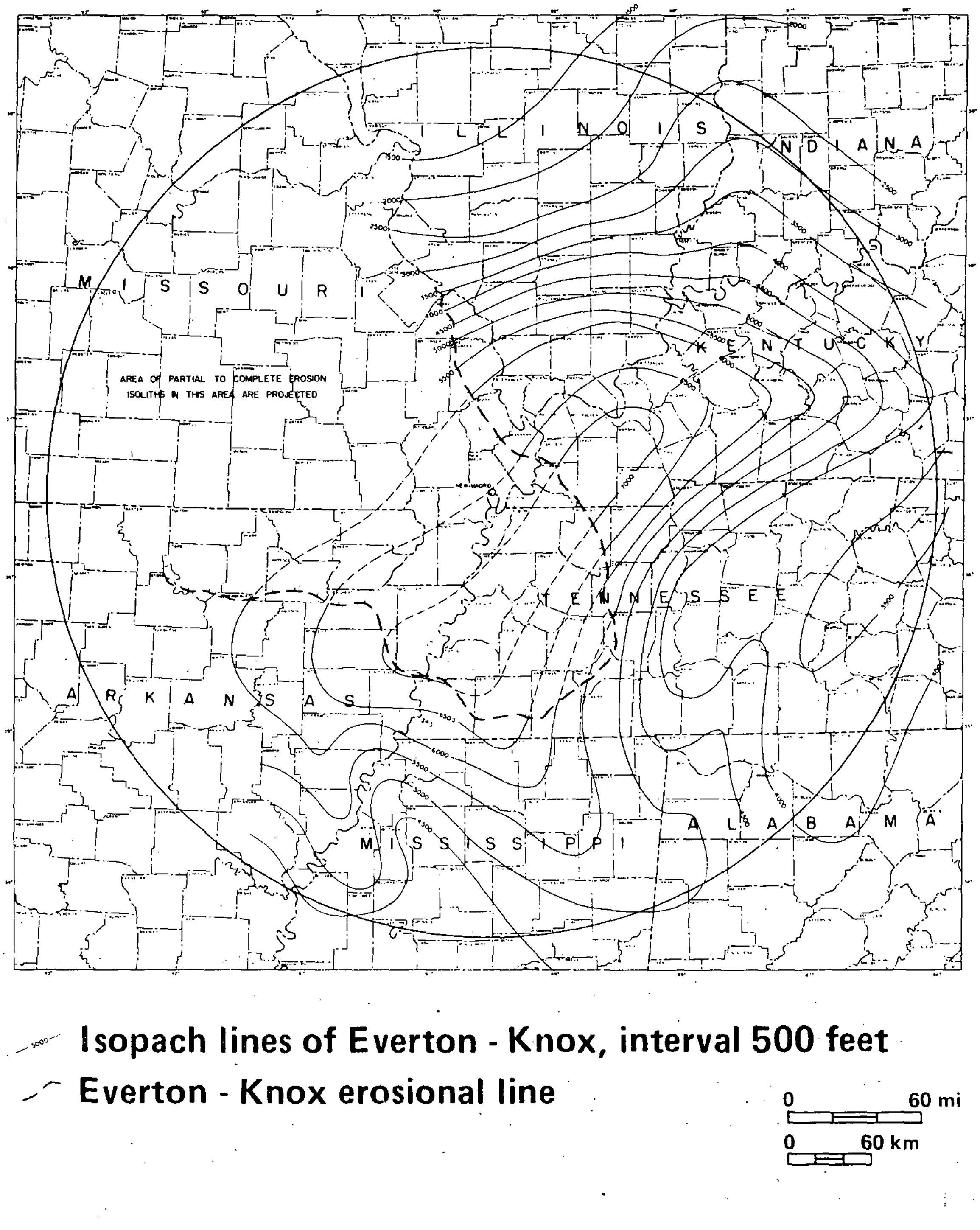


Figure 12. Thickness of the Everton-Knox.

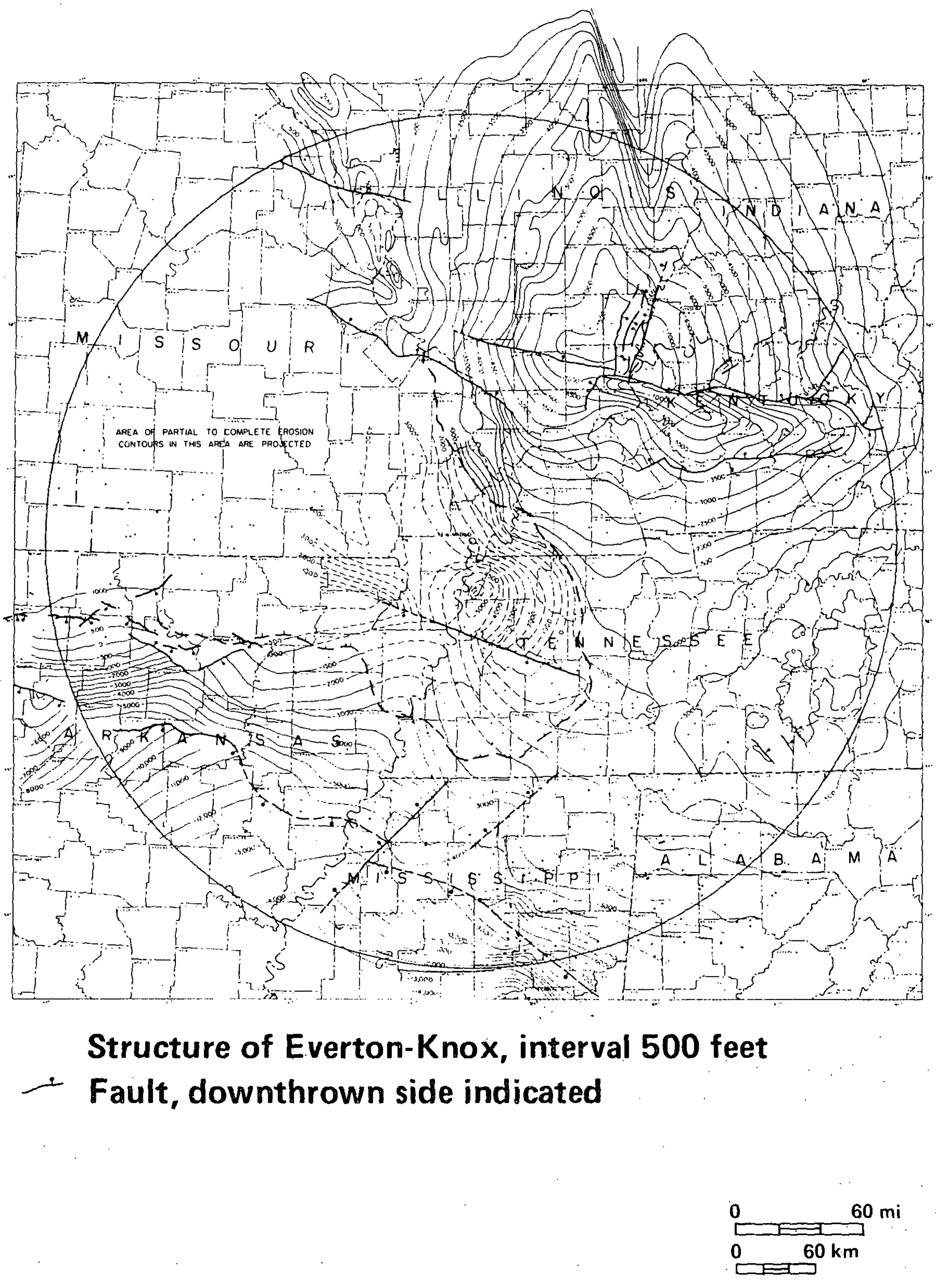


Figure 13. Structure on top of the Everton-Knox.

usually noted as "floating" grains and very thin sand streaks. The sand is of the Ste. Peter type of rounded and frosted grains mixed with finer grains, thus giving a bimodal distribution.

Some of the other minor constitutents noted during microscopic examination of samples are chert, glauconite, anhydrite, druzy quartz, and hollow silicified ooliths. Chert is the most abundant and is found in many varieties scattered throughout the Knox. The most characteristic form is oolitic chert in which the oolites are beautifully preserved in detail. Coloration of oolites varies with both light and dark centered varieties and some with alternating bands of light and dark rinds. Clear grains of "floating" sand also may be seen in the chert, sometimes in association with oolites, and occasionally as the centers of oolites. Dolomoldic chert is also common and especially noticeable in insoluble residue. Occasionally very large dolomite rhombs are embedded in a very soft, chalky chert matrix. Most of the cherts are vitreous, but devitrified or chalky chert may be found separately or in association with the vitreous chert.

Residue studies have been very successful in identifying correlative units on outcrops in the Appalachians and in the shelf areas of Missouri. Correlations have been made to a limited extent in Arkansas where drilling is relatively shallow and more closely spaced. As deep tests become more numerous, residue studies offer the best means of zonation of the Knox section.

Knox deposition in the Appalachian area

The Appalachian or eastern section of the Knox is subdivided into several formational units, most of which are assigned to the Beekmantown Group. The top of the Beekmantown is consistent with the top of the Knox, but the base of these two groups vary widely and have been moved up and down so often they are no longer in agreement. The Beekmantown is now limited to rocks of Ordovician age with Cambrian units excluded from the group. The Ordovician-Cambrian boundary is generally placed at the top of the Copper Ridge Formation, and the base of the Copper Ridge is generally an acceptable base for the Knox.

In eastern Tennessee and Kentucky the Copper Ridge is the youngest upper Cambrian formation and overlies the Conasauga Group of upper and middle Cambrian age. The base of the Ordovician section is sometimes marked by the presence of the Rose Run Sandstone, an important marker bed with a westward equivalent, the Gunter Sandstone Member of the Gasconade Formation. The upper Knox of Ordovician age in this area is subdivided into four formations. From youngest to oldest they are: the Mascot, Kingsport, Longview, and Chepultepec. The Chepultepec is sandy at its base, and the Rose Run Sandstone probably equates with this zone.

Knox deposition in the Reelfoot Basin

The Reelfoot Basin of the upper Mississippi Embayment area has preserved a much thicker section of Knox sediments than is preserved in the Appalachian Basin. The increase in formational units named in the area reflect this thickening westward.

The stratigraphic equivalents in the Appalachian Basin and the Reelfoot Basin are shown in Table 1.

Table 1. Stratigraphic equivalents of Cambrian and Ordovician rocks in the Appalachian Basin and the Reelfoot Basin

Reelfoot Basin	Appalachian Basin
ORDOVICIAN	
Smithville-Black Rock	
Powell	
Cotter	Mascot
Jefferson City	Kingsport
Roubidoux	Longview
Gasconade	Chepultepec
(Gunter SS at base)	(Rose Run Sandstone)
CAMBRIAN	
Eminence	Copper Ridge
Potosi	
Elvins (Derby-Doe Run-Davis)	

On the basis of paleontolgical evidence (Oder, 1934), the Mascot, Kingsport, and Longview are equivalent to the Cotter, Jefferson City, and Roubidoux. More than 2,000 feet (600 meters) of Knox is found above the Cotter-Mascot boundary in the Reelfoot Basin. These younger Knox formations of the Powell-Smithville-Black Rock age underlie the Everton and St. Peter of Whiterockian and Chazyan (early Champlainian) age. The Cambrian section also thickens into the Reelfoot Basin where the Eminence-Potosi-Elvins section may exceed 4,000 feet (1200 meters) in thickness. Whether this increase in section represents thickening of the Copper Ridge equivalents or addition of older units such as the Bibb and Ketona at the base is unknown at this time.

Some characteristics of the Knox in wells drilled in certain areas of upper Mississippi Embayment area as used to define formational units are as follows:

1. The Cambrian formations are the Eminence-Potosi-Elvins Group which may combine for an overall thickness in excess of 4,000 feet (1200 meters). These formations are dolomites with less chert than the overlying formations and a decrease in sand and chert downward. The lower part of the section is non-sandy and is almost lacking in chert. The typical glauconitic zones of the Elvins disappear basinward, and no clear distinction has been made between the formations where they are unusually thick.

2. The Gasconade is very cherty, but there is a decrease in the sandiness from the overlying formation. The basal member of the Gasconade is the Gunter Sandstone which also is used to define the base of the Ordovician system. Maximum thickness of the formation is 700 feet (200 meters).

3. The Roubidoux is a very sandy and very cherty dolomite and dolomitic limestone with an abundance of both oolitic and sandy chert. Sandiness is noted at the top and bottom of the formation, which may reach 500 feet (160 meters) in thickness.

4. The Jefferson City contains oolitic limestones, and the formation has usually been only moderately dolomitized; it reaches about 500 feet (150 meters) in maximum thickness.

5. The Smithville-Black Rock-Powell-Cotter, where this section has not been removed by erosion, may attain 2000 feet (600 meters) in thickness. It is represented by dolomites and dolomitic limestones with occasional sandy zones and with very little chert present. Limestones are present through much of this section in Arkansas.

Knox deposition in the Rough Creek Graben

Between the Rough Creek and Pennyrile fault systems is a graben-like depression with an unusually thick Cambrian-Ordovician section. Here the Knox ranges in thickness from about 4,000 to 6,000 feet (1200 to 1800 meters). Although growth faulting can be demonstrated during Devonian and Silurian time in the Rough Creek Graben, there is no evidence from the sparse deep drilling to prove or disprove movement along the bounding fault zones during the deposition of the Knox.

Summary of the Depositional History of the Knox

The vast amount of carbonate that was deposited during upper Cambrian and lower Ordovician time represented by the Knox Megagroup is characterized by shallow water lithologies and fossils. This carbonate was probably derived from lowlying continental masses, and the source rocks were most likely deeply weathered, contributing to a high concentration of minerals in solution, and very little suspended material in the waters discharging from the land areas. Oolitic limestone was the predominant rock type formed with occasional floods of sand being swept into the seas. The source areas must have been composed of sedimentary carbonates and sands because very little clastic material was available, and the sands were already mature when deposited in the Knox. The beginning of Ordovician time was marked by additional sources of sand being exposed to erosion, and the lower Ordovician rocks received continually renewed supplies of sand. This culminated during the early middle Ordovician (Whiterockian and Chazyan) time when the very sandy Everton and the St. Peter were deposited.

Of particular interest are the anhydrite beds found scattered through the Knox. Restricted circulation of the marine waters with lagoonal conditions and high rates of evaporation must have provided the conditions for the formation of the anhydrite. The question posed is why these beds occur most frequently west of the Cincinnati Arch in the area where open seas connected through the Arkoma Basin to the west and the marine waters were least likely to be restricted. Perhaps the area of evaporite deposition extended into the Appalachian region and was even more widespread. Evidence for this theory would be the breccia zones found in the Knox of the Appalachians, the breccias possibly resulting from collapse of the overlying dolomite after solution and removal of evaporites.

The source of carbonates was probably banks of oolites moving from the north and west with some locally derived sediment, especially sands from the Ozark Uplift. Although the oolites probably all originated in shallow water shelf areas, they were swept into deeper waters in areas of thick accumulations. As the basinal areas filled, they also gradually subsided. Although some of the upper Knox was removed by erosion in the northern and eastern areas, the younger upper Knox formations of the Reelfoot Basin probably never extended much beyond their present limits. Because the oolite banks were moving from shallow into deeper waters, time lines would cross formational units diagonally.

MIDDLE ORDOVICIAN

Although included with the Knox in some areas, the Everton Dolomite overlies the major unconformity at the top of the Knox in much of the study area. The Everton is a sandy dolomite generally lacking chert, and it is not known to be oolitic; therefore, the oolitic cherts of the Knox do not occur in the Everton. The Everton was deposited in a restricted sea that lapped onto Knox carbonates to the east and north, and subaerial erosion continued to bevel the Knox in exposed areas while the Everton was being deposited. The Everton is unconformably overlain by the St. Peter Sandstone which is a more widespread formation that laps onto the Knox unconformity to the north. However, the St. Peter is thin or absent to the east in Indiana and Kentucky where emergence continued to expose the Knox.

More widespread marine invasion occurred following St. Peter deposition, and the Blackriver sediments were deposited over a very extensive area. The lower formations, the Dutchtown and Joachim, are dolomitic. The Dutchtown is also very sandy and gradational with the upper St. Peter. Anhydrite occurs locally in the Joachim, but other than that there is very little lithologic distinction between the Joachim and overlying Pecatonica. Despite the lack of lithologic difference, the Pecatonica-Joachim contact has a pronounced characteristic on wire line logs which is a helpful correlation marker. Above the Pecatonica near the base of the Plattin section is another marker bed, the Brickey's oolite, a very persistent zone that can be recognized in sample studies. All of the upper Midwest was submerged by marine waters, and the Plattin limestone with a vaughanitic texture accumulated during a long period of stability with little clastic influx. Toward the end of middle Ordovician time, volcanic activity, believed to be located to the east, produced numerous ash falls which have been preserved as metabentonites.

UPPER ORDOVICIAN

An unusual geologic event of the late Ordovician was the formation of a submarine current-swept valley, the Sebree Valley, of very large proportions extending from Ohio southwestward across southern Indiana and western Kentucky toward Tennessee (fig. 14). In many places the base of this valley rests on a thinned Plattin Limestone, and most or all of the Trenton Limestone is absent within the valley confines. Commercial accumulation of phosphates in Tennessee and Kentucky has been attributed to currents that flowed within this valley (Cressman, 1973, p. 57) and upwelled on the east side to bring phosphate-rich water from below the euphotoc zone to the surface (see fig. 15). The Cincinnatian (upper Ordovician) Maquoketa Shale Group filled the valley after carbonate deposition gave way to clastic sedimentation at the end of middle Ordovician time. Ordovician sedimentation ended with a shallowing and partial withdrawal of the seas, creating an unconformity of low relief.

SILURIAN-DEVONIAN

Virtually quartz sand-free Silurian carbonates were deposited throughout the region during a widespread marine advance which apparently had submerged clastic source areas. Thick carbonate banks surrounded the Illinois Basin except to the south, and bioherms developed in front of and on these banks.

Starved basin conditions existing during Silurian time in Illinois resulted in thin deposits in the areas of deep water, and some marked facies changes occurred between contemporaneous deposits. Gradual subsidence seems to have been the only tectonic activity during the Silurian.

Cayugan (upper Silurian) and lower Devonian sediments which filled the starved basin are mostly sand-free limestone and dolomite. Some of these beds were extensively altered to chert in the northern part of the Mississippi Embayment, but the source of the silica is not known.

The end of lower Devonian time was marked by pronounced uplift and the reactivation of many local features. Erosion then removed large quantities of weathered rock from the Sparta Shelf, Sangamon Arch, and the eastern ends of the north side of the Rough Creek and south side of the Pennyrile Fault System, respectively. Sources of quartz sand were exposed and the beginning of middle Devonian time is noted for the first widespread occurrence of mature sandstones and sandy limestones since the middle Ordovician. The

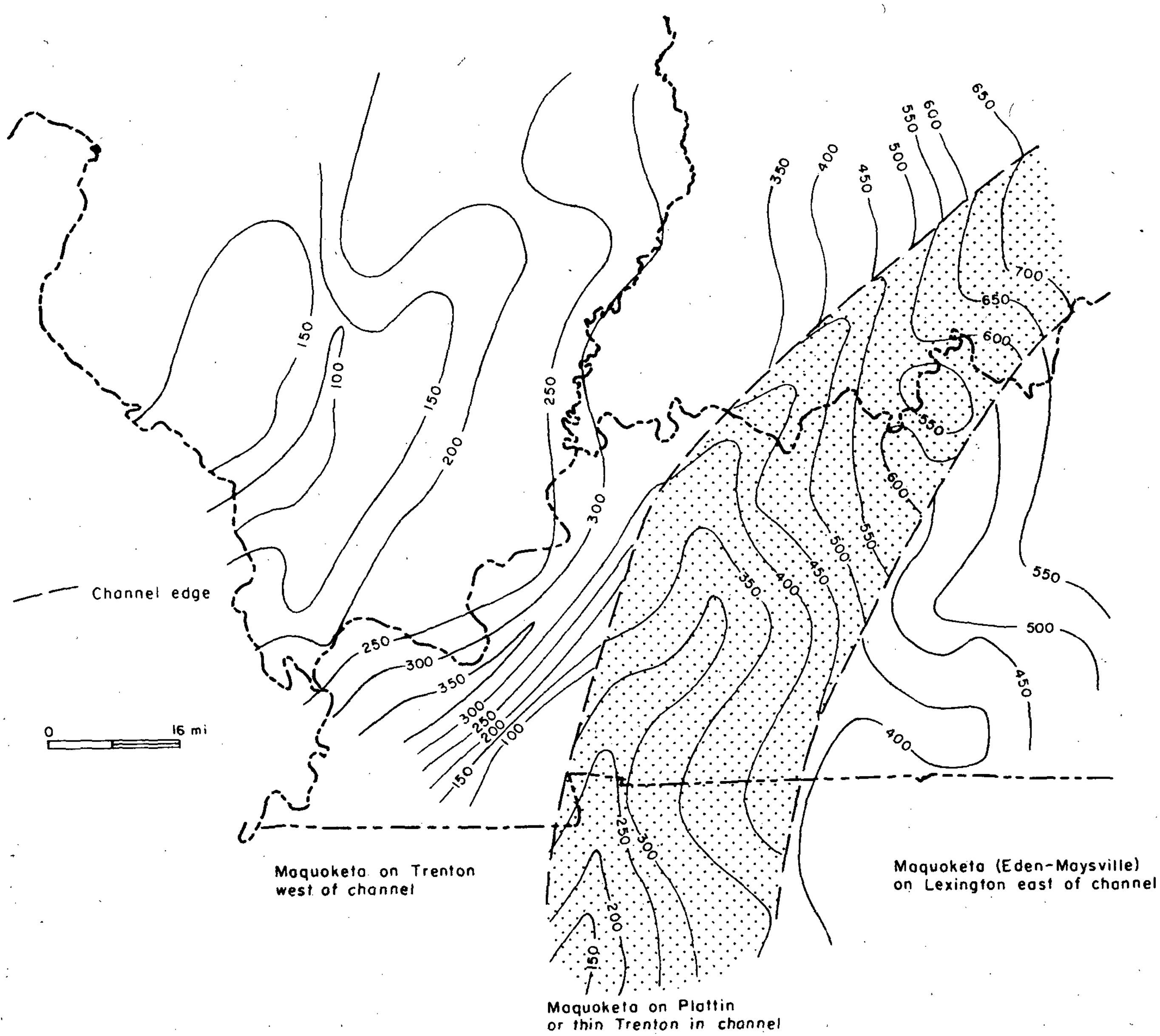


Figure 14. Thickness of Maquoketa Shale and the location of Sebree Valley.

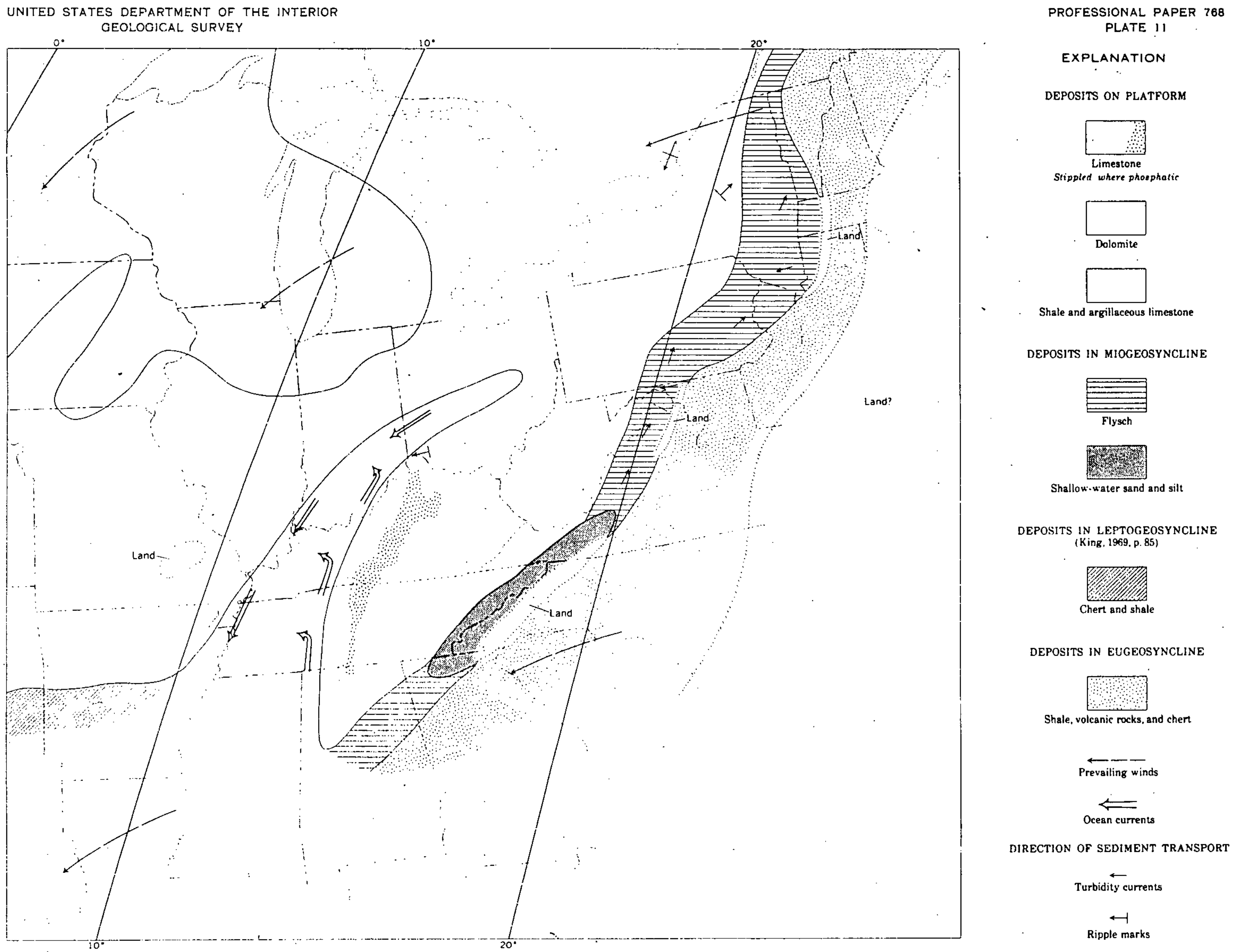


Figure 15. Map showing paleogeography and lithofacies in the eastern United States during Lexington (middle to late Ordovician) time. After Cressman, 1973.

sand filled fissures in the Silurian reefs and penetrated to great depths below the old land surface. Whether these sands accumulated under marine or eolian conditions is unknown. Dolomite and limestone are the principal rock types formed during the balance of middle Devonian time.

Before deposition of the New Albany Shale Group (upper Devonian and Kinderhookian) another erosion surface developed on exposed rocks around the margins of the basin. The seas then advanced in the most widespread inundation since Ordovician time. The various Devonian unconformities merge beneath the New Albany Shale toward the basin edges and other uplifted features, bringing the New Albany Shale in contact with strata as old as Champlainian (middle Ordovician).

MISSISSIPPIAN

Subsidence continued during Mississippian time with shale and siltstone deposition predominant in the lower part, and limestone deposition dominant toward the middle of the period. Cyclic deposition of alternating beds of sandstone, shale, and limestone is typical of Chesterian (late Mississippian) time. From a northeastern source, clastic sediments were carried by a southwestward flowing river system across the Illinois Basin (Swann, 1964). Total thickness of the Mississippian in southern Illinois is about 3,200 feet. Some Mississippian-age faulting has been identified in the Illinois Basin, and a minor amount of structural movement is indicated for some of the flexures in the region.

PENNSYLVANIAN-PERMIAN

Southwestward-flowing streams incised a vast drainage pattern (fig. 16) on Mississippian and older strata (Howard, 1979), which was subsequently buried by Pennsylvanian clastics. Coal, the chief economic mineral of the Illinois Basin, was formed in vast amounts, although coal beds represent less than 1 percent of the Pennsylvanian sedimentary column. Sandstone and shale are the main lithic types of Pennsylvanian strata while limestones constitute only minor portions. Some thin marine limestone and coal beds can be traced over large portions of the Illinois Basin. The thickest Pennsylvanian succession preserved north of the Pascola Arch is located just south of the Rough Creek Fault Zone in western Kentucky and in fault blocks within the fault zone.

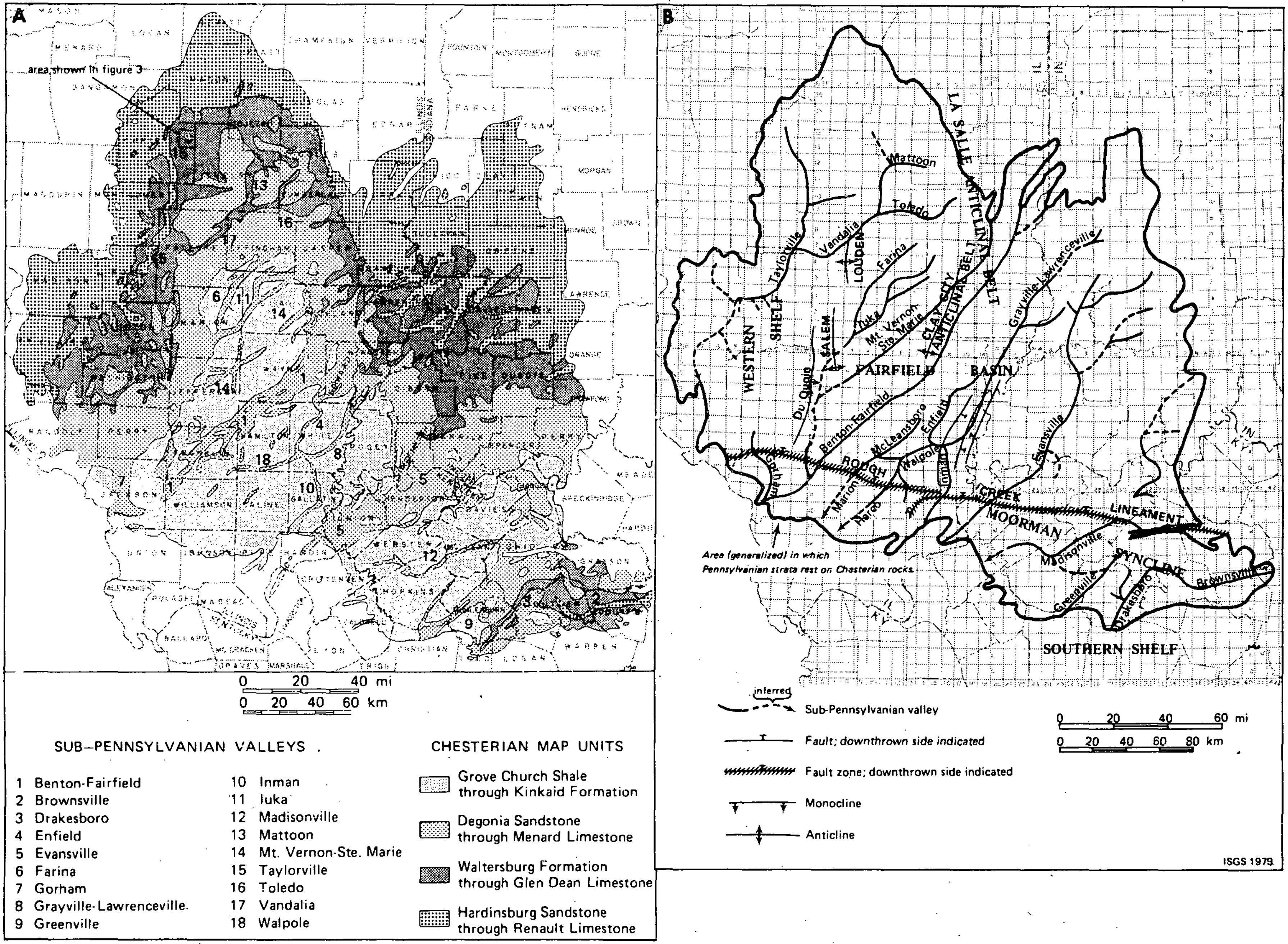


Figure 16. (A) Paleogeographic map of the sub-Pennsylvanian Chesterian surface in the Illinois Basin.
(B) Relationship of sub-Pennsylvanian valleys to tectonic features of the Illinois Basin.
(A) and (B) from Howard, 1979.

Slightly more than 3,200 feet (900 meters) of Pennsylvanian strata occur in Union County, Kentucky (Smith and Smith, 1967), and include an almost continuous section of the very youngest Pennsylvanian.

In a down-dropped fault block within the Rough Creek Fault Zone beds of lower Permian age have been identified (Douglas, 1979), based on the study of fusulinids. All Paleozoic deposits younger than lower Permian are believed to have been entirely removed by erosion from the region.

The Illinois Basin remained open to the south during Pennsylvanian time and was subject to repeated marine flooding. The Sparta Shelf was uplifted during Pennsylvanian time with marked thinning of the Pennsylvanian strata on the shelf; also thinning occurs over some anticlinal structures, but slow subsidence seems to have been the only other tectonic activity. Permian sediments were presumably deposited over at least a portion of southern Illinois and western Kentucky, but their thickness can only be surmised from the rank of the Pennsylvanian coal beds which indicate a previous depth of burial by 4,000 feet (1300 meters) of sedimentary cover (Damberger, 1971). A deep source of heat such as an igneous body could have achieved the same rank in the coals, but most of the plutons recognized in the area north of the Pascola Arch are not of sufficient areal extent to have uniformly changed the coalification for the entire region.

POST-PALEOZOIC

There was a long hiatus between the last Paleozoic sedimentation in the study area and the first Mesozoic deposits of Cretaceous age. During this time interval a great amount of tectonic activity changed the structural configuration of the region. From early Permian to late Cretaceous the sedimentary history of the New Madrid area is unknown. This interval is probably represented by uplift and erosion, and any sediments deposited have been completely removed. Drilling in the area indicates that a karst topography developed on the land surface with sink holes later filled with upper Cretaceous and younger sediments. Pleistocene mammal remains have been found in sink holes developed in Ordovician rocks in the Nashville area, and dinosaur remains have been reported from a sink hole in Missouri.

STRUCTURAL AND TECTONIC HISTORY OF THE NEW MADRID AREA

OZARK UPLIFT

The igneous rocks exposed in the St. Francois Mountains of Missouri have been extensively studied; they represent a portion of the Central Province terrain which is bounded to the northwest by the Churchill Province (fig. 17). A volcanic pile thousands of feet thick was built up in the St. Francois Mountains of the Ozark Uplift, and broken into blocks by Precambrian and younger faulting. Subaerial erosion developed a rugged topography on the Ozark Uplift before sedimentation began, and subsequent uplift believed to have occurred in stages has raised the St. Francois Mountains to their current elevation.

Major tectonic movements of the Ozark Uplift are believed to have taken place during early middle Ordovician, late middle Devonian, and in early Pennsylvanian (Tikrity, p. 177, 1968); also post-Pennsylvanian, Tertiary, and Recent uplifts are proposed. Movement probably continued into present time.

While the crest of present igneous exposures on the uplift is more than 1,700 feet (520 meters) above sea level, the Illinois Basin has subsided to about 14,000 feet (4300 meters) below sea level with even deeper basement subsidence in the Reelfoot Rift and Rough Creek Graben.

REELFOOT RIFT

Extending northeastward from northeastern Arkansas into southern Illinois is a down-faulted portion of the craton produced by tensional forces. Formed late in the Precambrian or possibly early in Cambrian time, the Reelfoot Rift (Ervin and McGinnis, 1975) affected the region between the Ozark Uplift and the Nashville Dome, and the area of subsidence is believed to be step-faulted toward the center producing a deep trough in which sediments accumulated. The thickness of these sediments is conjectural, but 3,500 feet (1000 meters) of sub-Lamotte marine sediments were penetrated in Lake County, Tennessee (fig. 18, well #5) without reaching crystalline basement. These sediments consist of dolomite and siltstone and are of unknown age, but probably middle Cambian would best fit the stratigraphic position. Whether lower Cambrian sediments underlie these rocks would depend on the age of formation of the Reelfoot Rift.

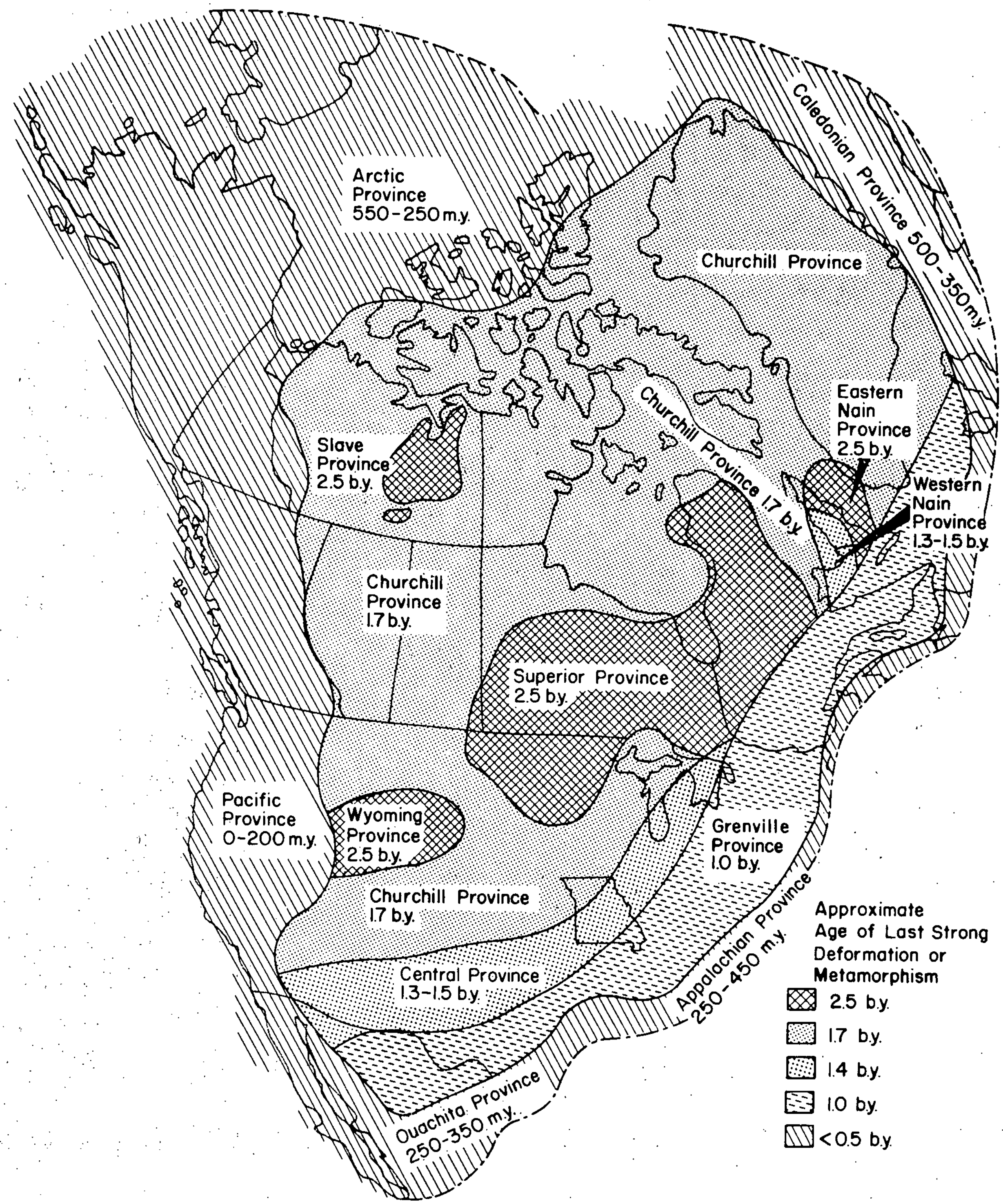


Figure 17. Tectonic provinces of Ancestral North America (from Seyfert and Sirkin, 1973; modified slightly by G. Kisvarsanyi, 1976).

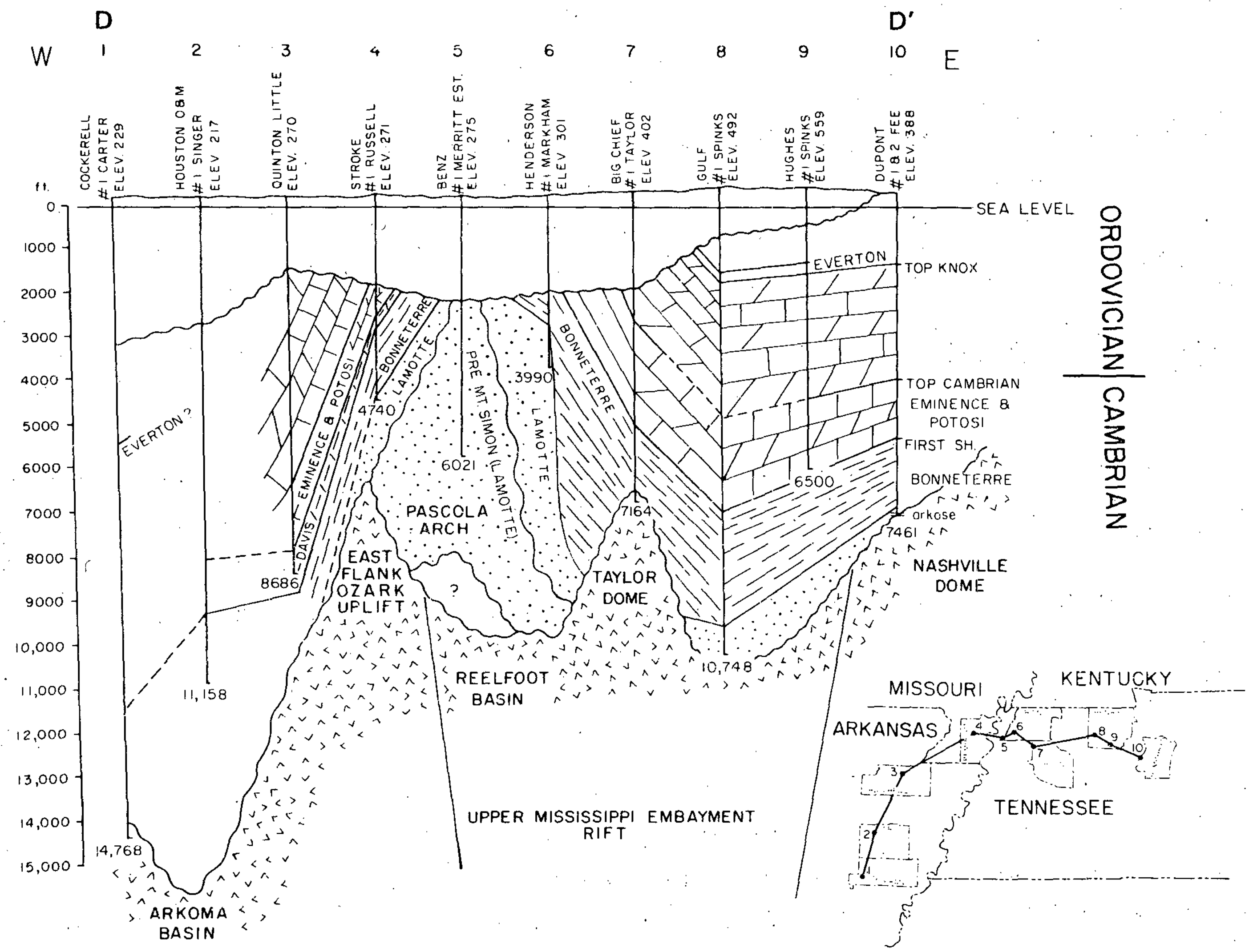


Figure 18. Cross section D-D', St. Francis County, Arkansas, to Humphreys County, Tennessee.

By upper Cambrian time the Lamotte and its equivalent Mt. Simon Sandstone invaded the rift area from the north, and in Johnson County, Illinois, the Mt. Simon rests on sub-Mt. Simon sandstones probably with a fault contact. The Lamotte Sandstone is the basal sediment in the region of the Ozark Uplift, but the Mt. Simon was not deposited on the Nashville Dome. The basal sandstone on the south and east side of the Nashville Dome is lower Cambrian and its equivalent in the Reelfoot Rift may be the Mermet Sandstone (fig. 6), (Schwalb and Cluff, in preparation) found in Johnson County, Illinois. By the end of Bonneterre-Eau Claire sedimentation, the Reelfoot Rift was probably filled, and the thickness of the sedimentary column may have exceeded 6,000 feet (1,800 meters) in the deepest part. Continued deepening of the rift zone, probably by growth faulting, is evident during the deposition of Knox sediments which thicken to 7,000 feet (2,100 meters) in the Reelfoot Basin overlying the rift zone. Post-Knox sediments have been mostly removed by erosion during and after the uplift of the Pascola Arch. However, sedimentation was probably continuous in the area during post-Knox Ordovician, Silurian, Devonian, and Mississippian time because the rubble eroded from the Pascola Arch, which was deposited as the Cretaceous Tuscaloosa Formation, contains cobbles of rock derived from the previously-mentioned Paleozoic formations. Pennsylvanian rock fragments have also been tentatively identified in the Tuscaloosa Formation, but their derivation from the Pascola Arch is only speculative. Pennsylvanian sediments are present near the top of the Ozark Uplift, and if they were deposited over this feature they were probably also deposited over the Pascola Arch. This suggests a connection at that time from the Illinois Basin through the Reelfoot Basin to the Arkoma and Warrior Basins. Permian sediments were deposited in the Moorman Syncline (Rough Creek Graben), but equivalent strata may not have been deposited in the area of the Reelfoot Rift.

Total thickness of the post-Knox sediments in the Reelfoot Basin can only be estimated from the thickness of these rocks in nearby areas where they have been preserved. Excluding the Pennsylvanian and Permian, the post-Knox sediments are about 7,000 feet (2,100 meters) thick in southern Illinois, and the units thicken in a southward direction. In western Tennessee the equivalent section is about 3,000 feet (900 meters) thick, but at no locality is the entire section preserved; in northwestern Mississippi about an equal amount of section is present.

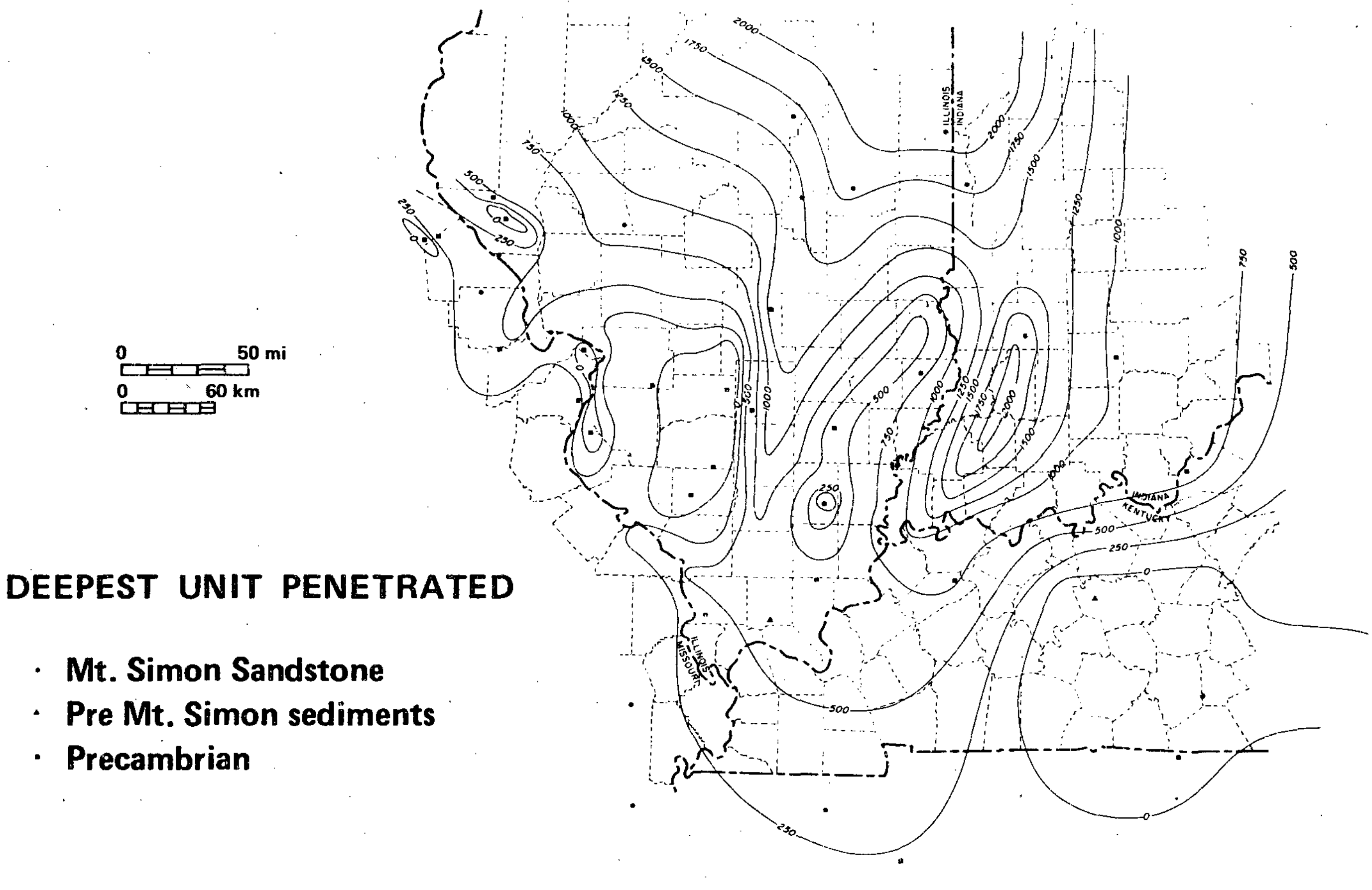


Figure 19. Thickness of Mt. Simon Sandstone.

Assuming that the Reelfoot Basin was not subsiding as rapidly as the Illinois Basin during post-Knox sedimentation as depocenters moved northward, I estimate that 6,000 feet (1,800 meters) of sediments ranging in age from middle Ordovician through Mississippian accumulated before Pennsylvanian deposition began in the Reelfoot Basin. The Pennsylvanian section thickens from western Kentucky to northeastern Mississippi from 3,200 feet (975 meters) to about 7,000 feet (2,100 meters), and continued to thicken southward into the Warrior Basin and Southwestward into the Arkoma Basin. Therefore, the Reelfoot Basin probably received Pennsylvanian sediments at least equal to those 3,200 feet (975 meters) in the Moorman Syncline (Rough Creek Graben) of western Kentucky. The total section of Paleozoic sediments originally present in the deepest part of the Reelfoot Basin was of the order of 23,000 feet or about 7,000 meters.

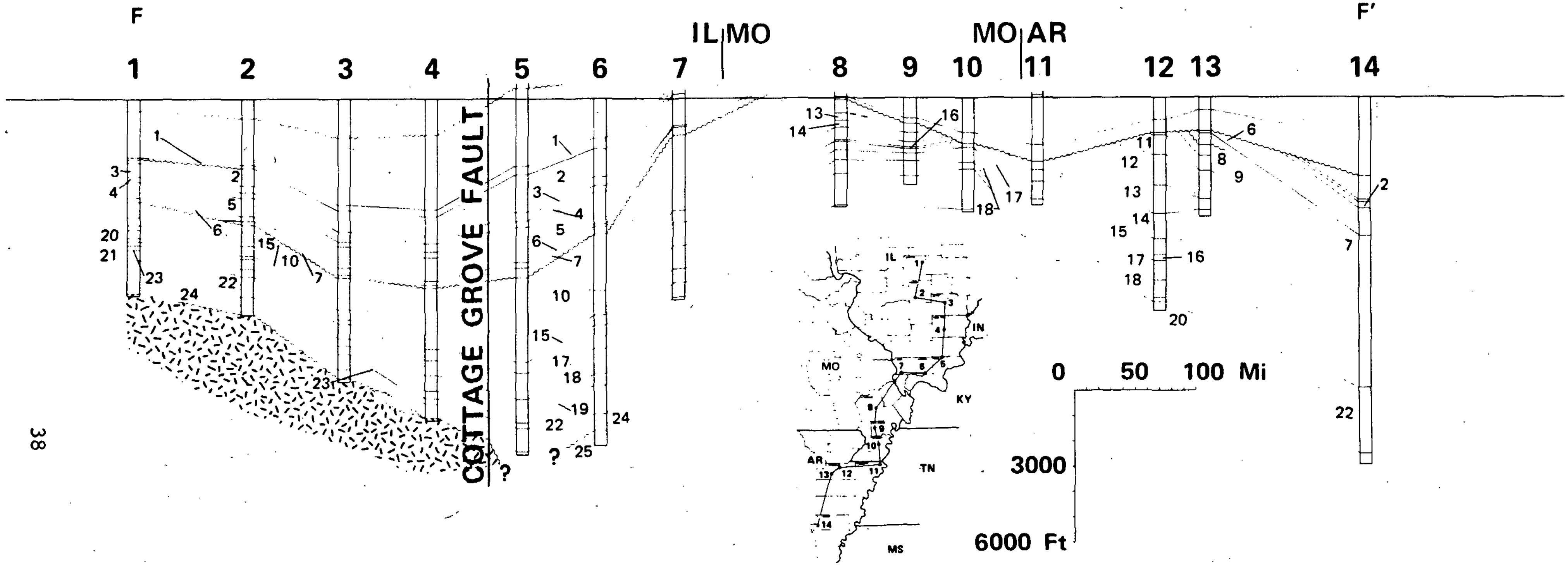
ILLINOIS BASIN

The Illinois Basin did not start to receive sediments until upper Cambrian time when the Mt. Simon Sandstone from a depocenter in northern Illinois spread southward encroaching on but not covering Precambrian topographic highs (fig. 19). Sediments continued to accumulate with depocenters located beyond the basin to the south until the end of lower Ordovician time. Uplift to the north and east of the Illinois Basin occurred at the end of Knox sedimentation causing the seas to withdraw and exposing the land to widespread subaerial erosion. A karst topography developed in northern Illinois, (Buschbach, 1961) and an arid climate topography of buttes and mesas is believed to have been produced in northern Indiana (Patton and Dawson, 1969). Erosional remnants of the upper Knox section are also found in south-central Kentucky. The middle Ordovician Everton Dolomite (limited to the south) and St. Peter Sandstone then covered Illinois, southeastern Indiana, and portions of western Kentucky. This was followed by extensive carbonate deposition (middle Ordovician) throughout the basin and then followed by deposition of shale and limestone (upper Ordovician) which continued to the end of the Ordovician. The next major event to expose much of the basin to erosion occurred in Devonian time, and the sub-Kaskaskia unconformity caused the New Albnay Shale to rest on successively older formations descending to the lower Silurian.

Extensive post-Pennsylvanian uplift accentuated many of the structures of earlier origin in the Illinois Basin, and reactivated many of the fault systems, some of which were displaced in an opposite direction to earlier movement. The uplift of the Pascola Arch, which may have occurred some time in the Mesozoic before upper Cretaceous time, provided the southern closure on the Illinois Basin (fig. 20) with rocks as old as middle Ordovician being exposed in southwestern Illinois.

ROUGH CREEK GRABEN

Bounded on the north by the Rough Creek Fault Zone and on the south by the Pennyrile Fault Zone, the Rough Creek Graben extends westward from Grayson County, Kentucky, into southern Illinois where it meets the Reelfoot Rift. The Rough Creek Graben is genetically related to the Reelfoot Rift, and both probably formed contemporaneously. If the segment of basement rock which incorporates the Nashville Dome to the east of the Reelfoot Rift rotated toward the southwest, then a westward widening graben would be formed as the tensional forces allowed basement rocks to subside. The Rough Creek Graben fits the position of such a crustal breakup as described above, and provides the locus for the thick section of sedimentary rock found between the Rough Creek and Pennyrile Fault Zones (fig. 21). The original downward displacement in the Rough Creek Graben is estimated to have exceeded 3,000 feet (900 meters) with the depression being filled with sub-Mt. Simon sediments of middle and possibly lower Cambrian age. Intermittent growth faulting from upper Cambrain to Devonian accentuated the graben and an additional 3,200 feet (975 meters) of downward fault displacement is indicated by the thickening of stratigraphic units into the graben. Post-early Permian reactivation of the Rough Creek and Pennyrile Fault Zones took place with the north side of the Rough Creek Fault Zone displaced downward, a reversal of earlier movement. South of the Rough Creek Fault Zone in Union and Webster Counties, Kentucky, the strata were steepened, and some reverse movement is found in the fault zone. The severe steepening of dip to the south would indicate another fault in the basement rocks must have occurred to provide room for the 1,000 feet (300 meters) or more wedge of sediments, plunging toward the axis of the Moorman Syncline.



- 1 New Albany Shale
- 2 DEVONIAN
- 3 SILURIAN
- 4 ORDOVICIAN
- 5 Trenton Limestone
- 6 St. Peter Sandstone
- 7 Everton Dolomite
- 8 Blackrock Formation
- 9 Smithville Formation
- 10 Knox-Shakopee Dolomite
- 11 Powell Formation
- 12 Cotter Formation
- 13 Jefferson City Dolomite
- 14 Roubidoux Formation
- 15 Oneota Dolomite
- 16 Gunter Sandstone
- 17 Eminence Formation
- 18 Potosi Dolomite
- 19 Franconia Formation (IL), Elvins Group (MO)
- 20 Derby-Doerun Member
- 21 Davis Member
- 22 Eau Claire Formation (IL), Bonneterre Formation (MO, AR)
- 23 Top of red shales
- 24 Mt. Simon Sandstone (IL), Lamotte Sandstone (MO)
- 25 Mermet Sandstone
- Granite Basement

Figure 20. Cross section F-F', Fayette County, Illinois, to St. Francis County, Arkansas.

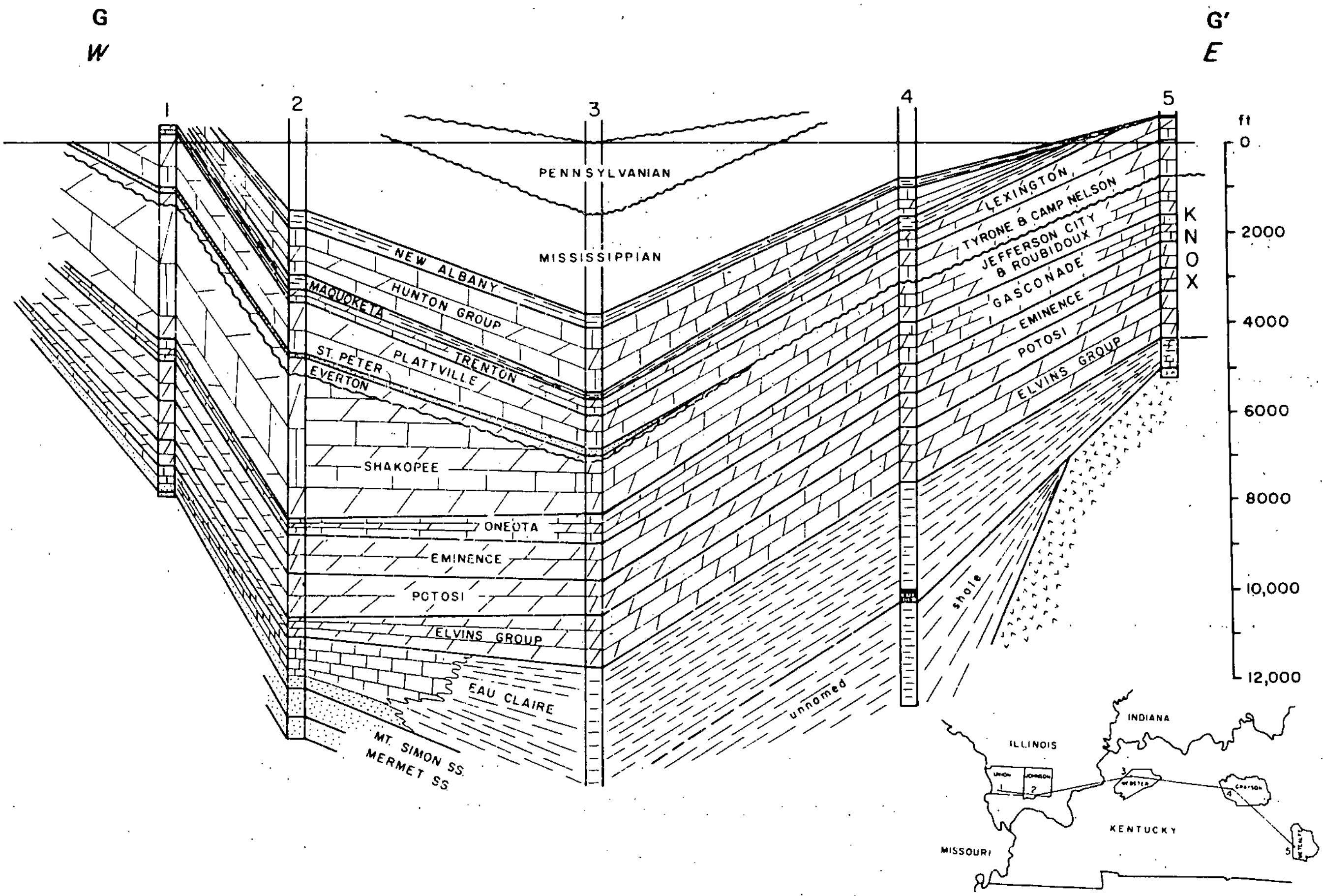


Figure 21. Cross section G–G'. Union County, Illinois, to Metcalf County, Kentucky.

The estimated thickness of sediments that accumulated in the Rough Creek Graben is between 19,000 and 20,000 feet (5,800 - 6,100 meters) in the deepest part. This estimate does not include any Permian or younger rocks that have been removed by erosion, and is 4,000 - 5,000 feet (1,200 - 1,500 meters) greater than in the Fairfield Basin of Illinois.

PASCOLA ARCH

A vast, nearly circular uplift occurs between the Ozark Uplift and the Nashville Dome. It is separated from these two features on the east by the Clifton Saddle in Tennessee and on the west by a sag with about 1,000 feet (300 meters) of relief, centered near the town of Gibson in Dunklin County, Missouri. The uplift of the Pascola Arch affects rocks as young as Pennsylvanian in southern Illinois where the beveled outcrop of the base of these sediments has been elevated to about 500 feet (150 meters) above present sea level. This surface dips northward into the Fairfield basin to 2,700 feet (820 meters) below sea level. The dome of the Pascola Arch rises to a crest in southern Lake County, Tennessee where sub-Mt. Simon (Lamotte) sediments underlie the Cretaceous unconformity (fig. 22). The uplift of the Pascola Arch affects an area of more than 15,000 square miles, but the tectonic forces responsible for the creation of this feature are unknown. The Pascola Arch is nearly comparable in size to the Black Hills and Llano Uplifts although it is not as deeply eroded. Plutons believed to be of Mesozoic age are identified by gravity and magnetic characteristics in the Reelfoot Rift, although none is identified beneath the crest of the Pascola Arch (fig. 23). If the Pascola Arch was uplifted by magmatic intrusion there is no evidence of this intrusive other than some thin igneous sills in drilled wells. The Precambrian basement rocks which may have been uplifted are still buried at depths greater than any drilling has penetrated.

Faulting accompanied the uplift of the Pascola Arch, but faults are difficult to identify in an area so sparsely drilled. Dark gray to black shaly limestones penetrated by two wells in Dyer County, Tennessee are believed to be part of the Cambrian Bonneterre section, and to the south in Lauderdale County, Tennessee, and in Mississippi County, Arkansas, the first Paleozoic rock encountered is the Ordovician Jefferson City Dolomite. A fault is placed between these wells trending slightly south of east (fig. 13) with displacement

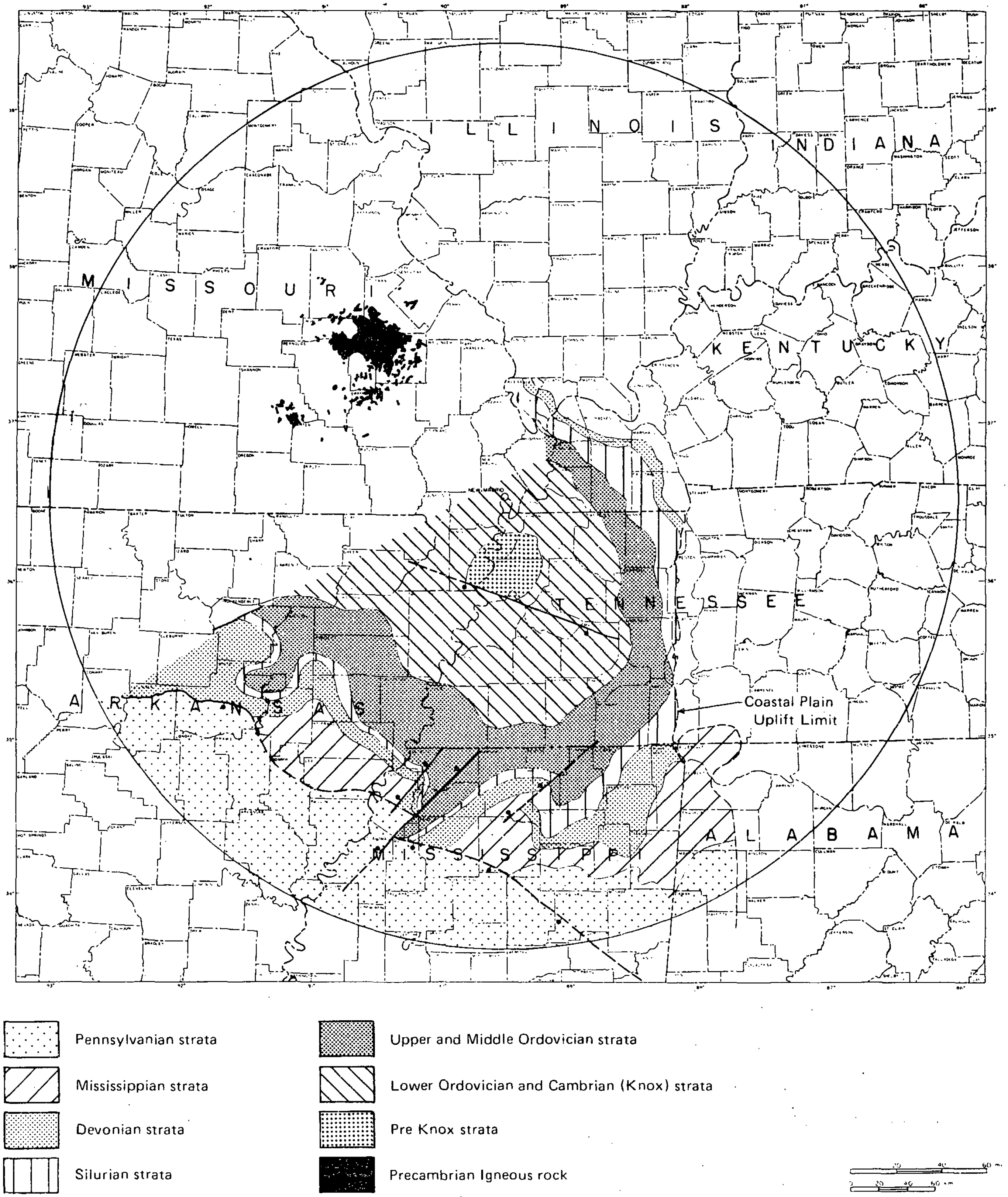


Figure 22. Subcrop pattern of Paleozoic rocks beneath Cretaceous cover.

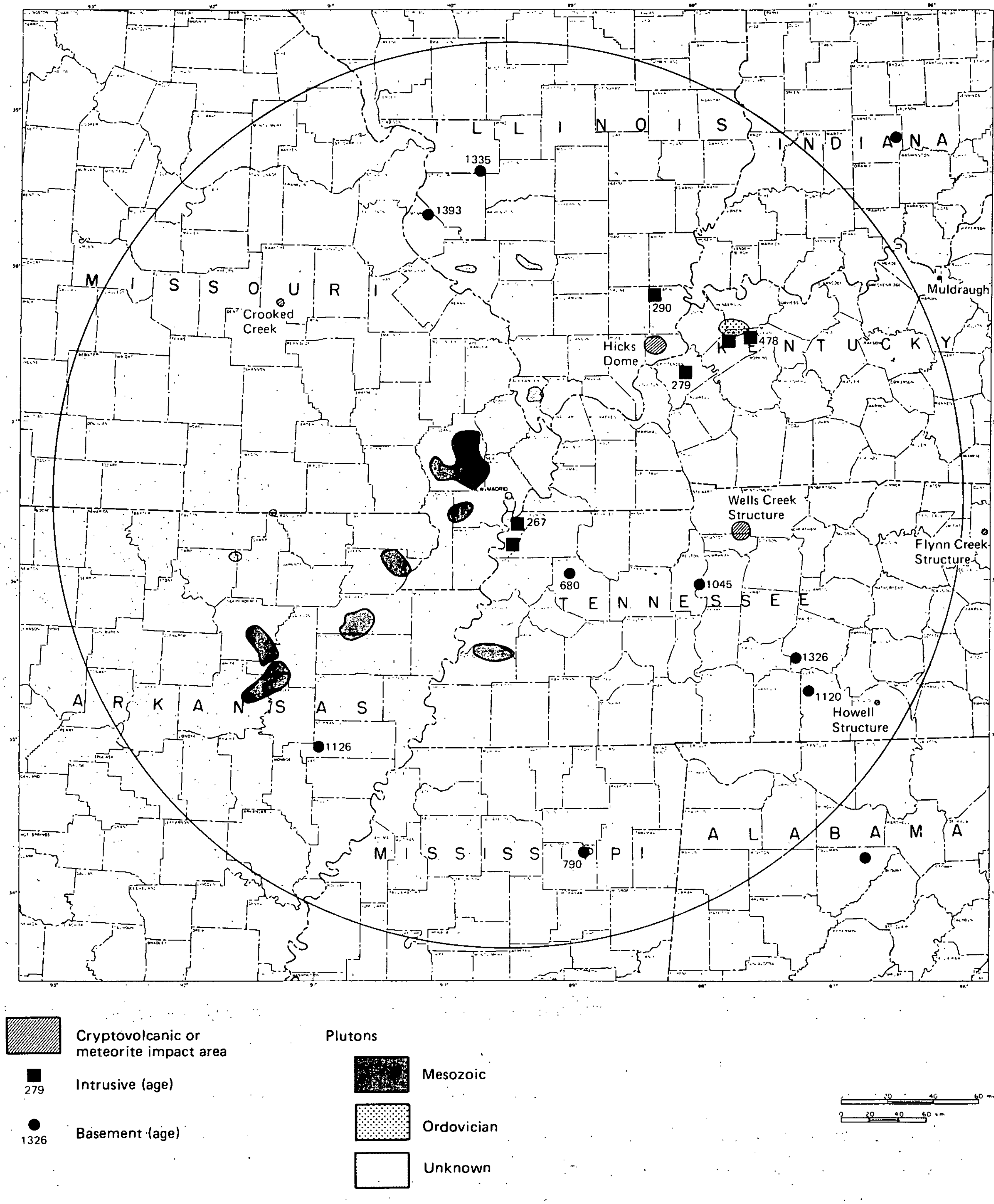


Figure 23. Locations of sampled intrusive rocks, interpreted plutons, and explosion structures. Radiometric dating shown where available.

estimated to be greater than 3,000 feet (900 meters) down to the south.

The post-Pennsylvanian faults of the Fluorspar District in southeastern Illinois and western Kentucky are also believed to be genetically related to the Pascola Arch. These faults trend from almost due east in western Kentucky to northeasterly in southeastern Illinois to almost due north near Vienna in Johnson County, Illinois (Stonehouse and Wilson, 1955). An exact age is not known for any of these faults other than post-Pennsylvanian, and only a few appear to extend southward beneath the Cretaceous into the area of the Pascola Arch.

STE. GENEVIEVE FAULT ZONE

The Ste. Genevieve Fault Zone has been mapped at the surface for a distance of about 140 miles in Missouri (Tikrity, 1968) and extends an additional 10 miles into Illinois where surface exposures become obscured by debris and steeply dipping beds (fig. 24). Although the faults are complex and incorporate grabens and cross faults, the overall displacement across the system is down to the north. On the south side of the system in Missouri near the Mississippi River rocks of Devonian-Silurian age are at the surface and exposures descend through the Ordovician and Cambrian, westward toward the Ozark Uplift. Rocks of Devonian age are exposed in Illinois south of the fault zone (sometimes called Rattlesnake Ferry Fault) while on the north side Mississippian and Pennsylvanian age rocks are at the surface. Comparably Mississippian, Ordovician, and Cambrian age rocks bound the north side of the fault in Missouri with increasing age to the west. Devonian age rocks occur in the fault zone in unusual thickness and far to the west of their normal distribution. This fault-controlled trough of deposition has been named the Wittenberg Trough (Meents and Swann, 1965), and is evidence for Devonian age movement. Post-Mississippian movement of the fault zone is described (Desborough, 1961) based on analysis of the transport direction of basal Pennsylvanian sands which were deflected to the southeast on the north side of the fault in Illinois. The upthrown south side of the fault acted as a barrier to sediment transport. Post-Pennsylvanian faulting is also recognized in the area north of the Ste. Genevieve faults, but there are no Pennsylvanian rocks on the south side of the fault zone; therefore, there is no direct evidence of post-Pennsylvanian movement on the Ste. Genevieve faults.

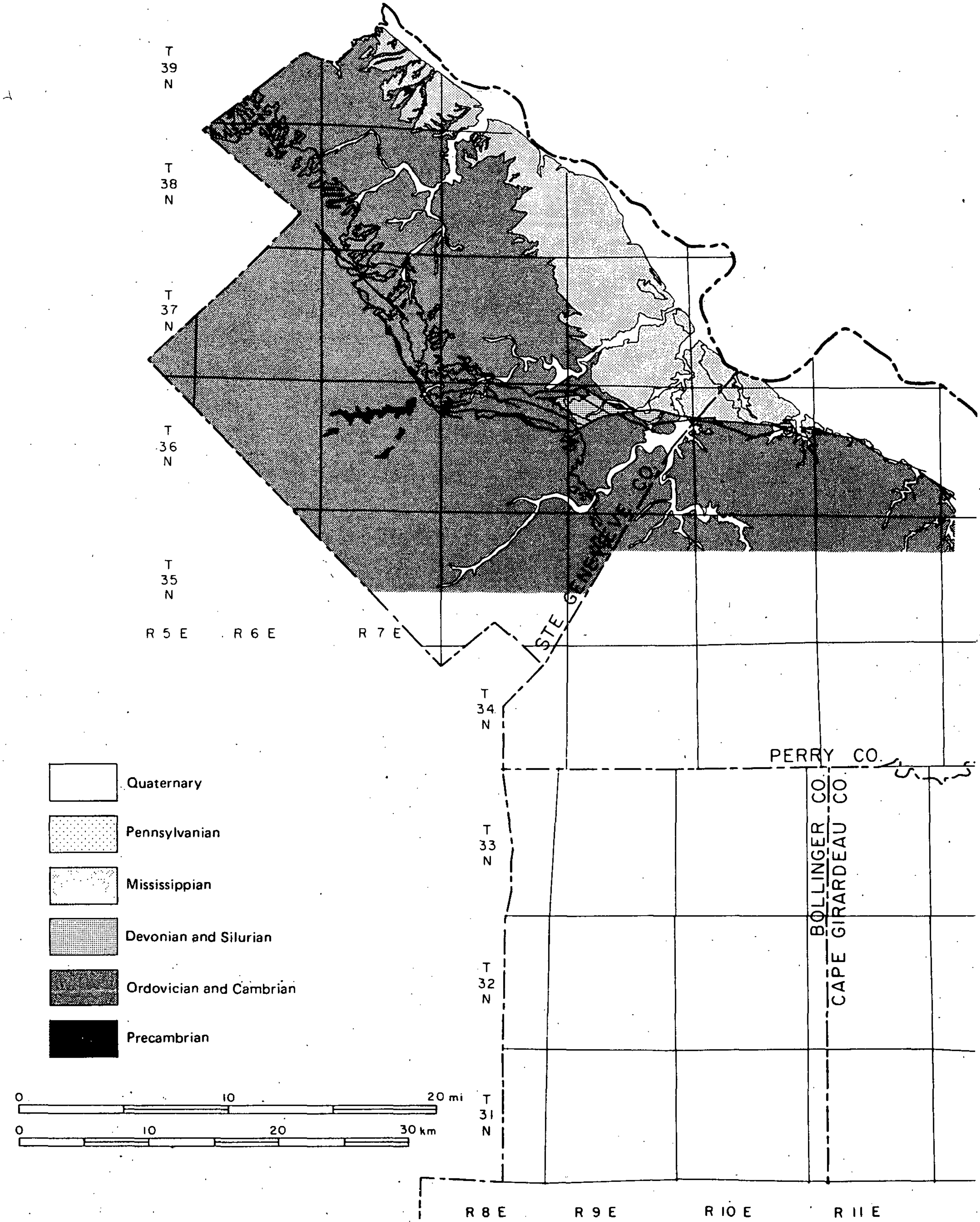


Figure 24. Geology along the Ste. Genevieve Fault Zone.

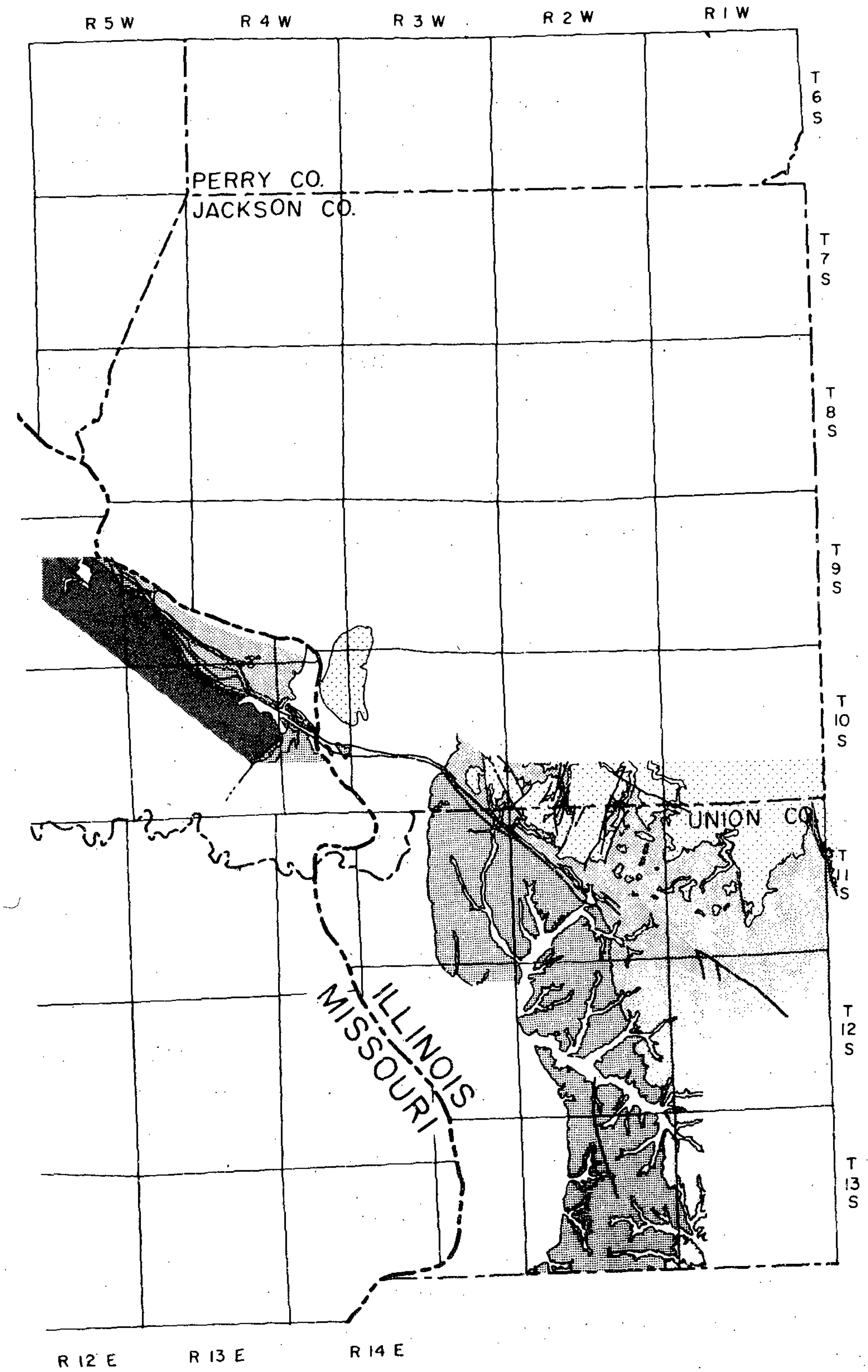


Figure 24, continued.

As the fault system crosses the Mississippi River from Missouri into Illinois the exposures are covered by recent alluvium. An outlier of Pennsylvanian sediments known as Fountain Bluff lies to the north of the fault zone in Jackson County, Illinois, and subsurface studies of well logs in the area indicate that this Pennsylvanian remnant lies in a down thrown block faulted on the west side. The subsurface trace of the Fountain bluff fault aligns in a southerly direction with a similar trending fault in Missouri which drops Devonian rocks against Ordovician rocks, and is also down thrown to the east. It is in this area of the Illinois segment of the Ste. Genevieve Fault Zone that the southern upthrown portion of the fault scarp is interpreted as having acted as a barrier to basal Pennsylvanian sediments. If an additional northward trending fault is buried in the alluvium on the east side of Fountain Bluff the Pennsylvanian sediments in the outlier could have been deposited in a post-Mississippian graben. Many of the numerous northward trending faults to the east along the Union and Jackson County boundary are post-Pennsylvanian in age, and a similar age for the Fountain Bluff fault seems to be more appropriate.

The last surface trace of the Ste. Genevieve fault is located near the center of the north line of Section 27, T. 11 S., R. 2 W. in Union County, Illinois. Beds of lower Mississippian age rocks dip steeply eastward at the last surface fault trace, and these steeply dipping beds can be traced several miles to the south in Iron Mountain, an erosional ridge of highly silicified lower Mississippian rocks. West of Iron Mountain where Devonian age rocks are exposed, they are more gently dipping, and the structure is anticlinal with the axis oriented in a north-south direction extending about 15 miles to the south. This structure named the Harrison Creek anticline (Weller, 1940) is faulted on the east side for a distance of about 4½ miles by the Atwood fault which starts near the center of the west line of Section 27, T. 12 S., R. 2 W. and extends slightly past the center of the south line of Section 15, T 13 S., R. 2 W.

Because the Harrison Creek anticline is aligned nearly north-south and the steeply dipping monoclinal beds of Mississippian rocks trend in the same direction at the last exposure of the Ste. Genevieve Fault Zone, there is a strong possibility that the fault may also follow this southerly trend in the subsurface. Previous workers have extended the Ste. Genevieve fault to the southeast, and one published map (Heyl and others, 1965, p. 4) shows the Ste.

Genevieve fault extending southeastward across southern Illinois through western Kentucky and into Tennessee. Several faults are located to the southeast of the eastern exposure of the Ste. Genevieve fault in T. 12 S., R. 1 W. of Union County. These faults break Mississippian age rocks and have displacements of less than 100 feet. Numerous maps show these faults to be connected to the Ste. Genevieve fault although there is no surface indication of connection over the three and one half mile interval separating them. The minor displacement of these faults and their short range of about four miles leaves some doubt as to their being associated with the Ste. Genevieve fault zone which extends into the crystalline basement rocks.

The Shawneetown Fault Zone trends westward in Gallatin County, Illinois, and swings to the south in Saline County, and continues in a southerly direction into northern Pope County where it joins the faults of the Dixon Springs graben. This faulting delimits the western end of the Rough Creek graben and is post-Pennsylvanian in age, although the fault trends probably follow lines of earlier weakness and displacement extends downward into the basement complex. If the Ste. Genevieve Fault Zone also swings to the south along the east flank of the Harrison Creek anticline, the deep graben between these two fault zones (Ste. Genevieve and Shawneetown) could be considered the northern end of the Reelfoot Rift. Such an interpretation would imply early movement of the Ste. Genevieve Fault Zone with activation at the same time as the formation of the Reelfoot Rift in early Cambrian or late Precambrian time.

Based on the assumption that the Ste. Genevieve Fault Zone trends in a southerly direction and might be observable in the subsurface with reflection seismograph, several lines of seismic shot points were laid out in Union County, Illinois to test this hypothesis.

A seismic reflection Survey consisting of three lines of profiles was conducted in Union County (T12, 13S, R1, 2W) in an attempt to determine the structure of the rocks there. The first line, located in Kratzinger Hollow and along State Highway 146, extended from a point south of the center of Section 18, T. 12 S., R. 1 W. to a point southeast of the center of Section 21, T. 12 S., R. 2 W. The second line, located along the Dongola Road, extend from a point west of the center of Section 18, T. 13 S., R. 1 W. to a point west of the center of Section 16, T. 13 S., R. 1 W. The third line, located along the Plaza Hill Road, extended from a point south of the center of

Section 1, T. 13 S., R. 2 W. to a point west of the center of Section 16, T. 13 S., R. 2 W.

The seismograph employed in this study was a 12 channel Nimbus, on loan to the Illinois State Geological Survey from Northern Illinois University. The seismic profiles were usually 600 feet long (50 feet between take outs). Multiple geophone arrays were connected to each take out in an effort to reduce the effects of ground roll and other extraneous noise, while at the same time allowing discernible first arrival data for weathering corrections in the reduction of the data phase of this study. Where culture permitted the seismic profiles were laid out in a continuous manner and shot on both ends.

The seismic sources consisted usually of 3 pound dynamite charges. The size of the charge was less in the event of culture or shallow bedrock. These charges were located at the bases of holes drilled through the unconsolidated surficial material and just into bedrock or at a depth of 20 feet, whichever came first.

The length of the seismic records was usually 1.000 seconds with most discernible events occurring in the first .500 second. Prior to each shot filter settings were adjusted (based on experience in the area) in an effort to obtain and enhance the recording of possible reflections.

Despite the absence of good down-hole velocity data in the immediate study area, data reduction is proceeding with the aid of a digital computer.

SUMMARY OF EVENTS

Precambrian - Crystalline rocks exposed to subareal erosion, fault controlled ridges and hills with sufficient stream gradient to remove erosional debris and prevent formation of significant regolith. Rugged topographic relief over most of area (500' - 1500').

Early Cambrian - Probable time of opening of northward trending Reelfoot Rift, also formation of Rough Creek Graben, first marine invasion of cratonic lands in region. No outcrops of these rocks which lie deeply buried.

Middle Cambrian - Marine sediments accumulate in down-faulted graben areas, subaerial erosion of exposed basement rocks in areas around rifted zones. Deepwater shale deposition in trough areas.

Upper Cambrian - Submergence of entire region with marine sediments eventually covering old topographic highs, carbonate banks built on areas surrounding rift zone with deepening of the rift troughs and dark shale deposited in the deep water zones. Eventually carbonate buildup of lower Knox covers all of region—composed mostly of shallow water oolites. Erosion exposes sources of sand which frequently swept into area but seldom reached into Reelfoot Basin.

Lower Ordovician - First major influx of sand with widespread deposition of Gunter Sandstone, continued subsidence of rift areas receiving greater thickness of sediments (Reelfoot Basin-Rough Creek Graben). Lower Ordovician ends with widespread withdrawal of marine waters and subaerial erosion becoming dominant element.

Middle Ordovician - Seas readvance with deposition of Everton Dolomite, continued erosion along Cincinnati Arch and northern Illinois. St. Peter Sand covers much of previously exposed area except for Cincinnati Arch, followed by widespread submergence and carbonate deposition producing uniform blanket of marine limestone. Volcanic activity leaves numerous thin sheets of bentonite over much of region.

Upper Ordovician - Shale replaces carbonate as predominant sediment. Northeast-trending submarine valley which was probably established in middle Ordovician is infilled with shale. Phosphate deposits accumulate along eastern bank of valley. Brief hiatus before start of Silurian deposition.

Lower Silurian - Limited formation of hematitic iron, and widespread marine conditions producing dolomite to east (Brassfield) and limestone to west (Sexton Creek).

Middle Silurian - Limestones and silty dolomites accumulate with much red coloration of sediment. Reefs grow around flanks of basin restricting influx of sediment producing starved basin conditions. Sediments noted for lack of sand. Increase in shaliness of upper Middle Silurian rocks.

Upper Silurian - Very little break in sedimentary conditions noted. Lower Bailey formation confined to deeper basin and lapping around reef structures which continued growth.

Lower Devonian - Reefs die out, but carbonate continued to be deposited—continued lack of sand in sediments. Major withdrawal of marine waters, uplift and tilting of older rocks north and south of Rough Creek Graben and Sparta Shelf with widespread subareal erosion.

Middle Devonian - First widespread occurrence of sand deposition since Middle Ordovician time. Carbonate deposition with much incorporated sand noted. Tioga bentonite provides extensive time marker horizon. Renewed uplift and tilting with additional erosion of older rocks around verge of basin.

Upper Devonian - Marked change in sedimentation to black shale which overlaps angular unconformity covering rocks as old as Ordovician.

Lower Mississippian - Waters deepen with little change in sedimentary conditions, except for color of shale which is no longer typically black. Carbonate banks eventually engulf region and appear to infill what may have been a starved basin.

Middle Mississippian - Carbonate deposition predominant, very little shale or sand being carried into area. Oolite shoals and banks form McClosky oolite zones.

Upper Mississippian - Change in regime to cyclic sedimentation with alernating sandstone, shale, limestone deposits. Minor elevation of some older structural features. Michigan River system brings sediment from northeast direction. Period closes with widespread withdrawal of marine waters, and major unconformity produced by southwestward trending river systems eroding valleys into Mississippian rocks.

Lower Pennsylvanian - Sands infill old valley system and cyclic sedimentation continues with alternating marine and nonmarine deposits.

Middle and Upper Pennsylvanian - Extensive coals deposited. Continued growth of some of the old major structures. Frequent widespread shallow marine invasions, with shale and sand deposits, also continental deposits intervening.

Permian - Lower Permian marine limestones and shales probably extensive in southern Illinois and western Kentucky. Only preserved in graben within Rough Creek Fault Zone. End of Paleozoic sedimentary record. Assumed continued deposition buried coal zones and raised rank of coal.

Mesozoic - Triassic and Jurassic either not deposited or all removed by erosion. Widespread tectonic activity possibly beginning in Cretaceous. Injection of plutons and uplift of Pascola Arch. Renewed dislocation of basement rocks reactivates old fault zones and causes pronounced structural uplift of features throughout area. Erosion of Pascola Arch produces Tuscaloosa gravels which are upper Cretaceous in age.

Tertiary - Subsidence of Mississippi Embayment allows accumulation of continental and marine sediments to accumulate in trough deepening to the south. Erosion dominant condition throughout remainder of area. Slow uplift of region manages to outpace down cutting.

Quaternary - Glaciation produces erosional and depositional features which mask much of the region. Extensive lake deposits in valley areas and loess on uplands.

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APPENDIX A

List of Wells in Cross Sections

Cross Section A-A', Figure 5

1.	Mississippi River Fuel Corporation #A-15 Theobald	Sec. 35-1S-10W Monroe County, Illinois
2.	St. Louis City Sanitarium #1 Fee	Sec. 31-45N-7E St. Louis County, Missouri
3.	T. R. Kerwin #1 Legate	Sec. 2-6N-13W Jersey County, Illinois
4.	Panhandle-Eastern #1 Mumford	Sec. 21-5S-4W Pike County, Illinois
5.	Herndon Drilling Company #1 Campbell	Sec. 15-4S-5W Pike County, Illinois
6.	Herndon Drilling Company #1 Laffy	Sec. 17-3N-7W Hancock County, Illinois
7.	Sam Tate et al #1 Rice	Sec. 28-4N-5W Hancock County, Illinois

Cross Section B-B', Figure 7

1.	Texas #2614 Brown (Indiana Farm Bureau)	Sec. 20-5N-2E Lawrence County, Indiana
2.	E. I. DuPont #1 Wad Fee	Sec. 10-U-44 Jefferson County, Kentucky
3.	Lanford Oil and Gas #1 Knight Bros.	Sec. 6-P-35 Breckinridge County, Kentucky
4.	Texas Gas Exploration #1 H. Shain	Sec. 10-L-36 Grayson County, Kentucky
5.	Benz Oil Co. #1 Nunnally	Sec. 16-F-46 Metcalfe County, Kentucky
6.	Houghland and Hardy #2 S. Goad	Sec. 12-A-43 Macon County, Tennessee
7.	E. I. DuPont, #1 Fee	Sec. 16-3S-35E Davidson County, Tennessee
8.	Texaco #1 B. Haynes	Sec. 10-7S-39E Wilson County, Tennessee

Cross Section B-B', Figure 7 continued

9.	Gordon Street #1 R. Holden	Sec. 13-10S-37E Rutherford County, Tennessee
10.	Staufer Chemical Company #1 Fee	Sec. 16-12S-28E Maury County, Tennessee
11.	California Co. #1 E. W. Beeler	Sec. 4-15S-29E Giles County, Tennessee
12.	Shenandoah Oil Corp. #1 F. W. Smith and Occidental Pet.	Sec. 26-9S-2W Cullman County, Alabama

Cross Section C-C', Figure 8

1.	Quintin Little #1 Little	Sec. 30-15N-5E Craighead County, Arkansas
2.	Houston Oil and Minerals #1 Singer (Held confidential—well does not appear on illustration)	Sec. 36-9N-4E Cross County, Arkansas
3.	Cockrell Corporation #1 Carter	Sec. 4-4N-1E St. Francis County, Arkansas
4.	Texaco-Exxon #1 Ivy	Sec. 36-27N-3W Coahoma County, Mississippi
5.	Tipperary Oil and Gas Corporation #1-X Harpole	Sec. 8-7S-10W Quitman County, Mississippi
6.	Pruet and Hughes #1 Dunlap	Sec. 18-7S-1W Lafayette County, Mississippi
7.	Memphis Equip. Co. #1 W. E. Melton	Sec. 12-2S-3E Tippah County, Mississippi
8.	Exxon #1 Fulgham	Sec. 33-19N-12E Oktibbeha County, Mississippi
9.	Shenandoah & Occidental #1 Smith	Sec. 26-9S-2W Cullman County, Alabama

Cross Section D-D', Figure 18

1.	Cockrell #1 Carter (log interpretation)	Sec. 4-4N-1E St. Francis County, Arkansas
2.	Houston Oil and Minerals #1 Singer (log interpretation)	Sec. 36-9E-4E Cross County, Arkansas
3.	Quintin Little #1 Little	Sec. 30-15N-5E Craighead County, Arkansas

Cross Section D-D', Figure 18 continued

4. Strake Petroleum #1 Russell	Sec. 24-19N-11E Pemiscot County, Missouri
5. Benz Oil Corporation #1 Merritt Est.	Sec. 3-4S-1E Lake County Tennessee
6. Henderson Oil Company #1 Markham	Sec. 21-2S-1E Lake County, Tennessee
7. Big Chief Drilling Company #1 Taylor	Sec. 19-5S-6E Gibson County, Tennessee
8. Gulf Oil Corporation #1 Spinks Clay Co.	Sec. 25-2S-13E Henry County, Tennessee
9. Hughes Petroleum Corp. #1 Spinks Clay Co.	Sec. 4-4S-14E Henry County, Tennessee
10. E. E. DuPont de Nemours Inc. #2 Fee	Sec. 14-6S-19E Humphreys County, Tennessee

Cross Section E-E', Figure 6

1. Union Oil Company #1 Cisne Comm	Sec. 3-1S-7E Wayne County, Illinois
2. Texaco Oil Company #1 Cuppy	Sec. 6-6S-7E Hamilton County, Illinois
3. Texas Pacific Oil Company #1 Streich	Sec. 2-11S-6E Pope County, Illinois
4. Texas Pacific Oil Company #1 Farley	Sec. 34-13S-3E Johnson County, Illinois

Cross Section F-F', Figure 20

1. Humble Oil and Refining Company #1 Weaber-Horn Unit	Sec. 28-8N-3E Fayette County, Illinois
2. Texaco Oil Company #1 Johnson	Sec. 6-1N-2E Marion County, Illinois
3. Union Oil Company #1 Cisne Community	Sec. 3-1S-7E Wayne County, Illinois
4. Texaco Oil Company #1 Cuppy	Sec. 6-6S-7E Hamilton County, Illinois
5. Texas Pacific Oil Co. #1 Streich	Sec. 2-11S-6E Pope County, Illinois

Cross Section F-F', Figure 20 continued

6.	Texas Pacific Oil Company #1 Johnson	Sec. 34-13S-3E Johnson County, Illinois
7.	Humble Oil and Refining Company #1 Pickell	Sec. 21-13S-2W Union County, Illinois
8.	M. H. Marr #1 Barnett	Sec. 3-25N-11E Stoddard County, Missouri
9.	U.S. Bureau of Mines #1 Oliver	Sec. 29-22N-11E New Madrid County, Missouri
10.	Strake Petroleum #1 Russell	Sec. 24-19N-11E Pemiscot County, Missouri
11.	Benedum-Trees Oil Company #1 Mack	Sec. 3-15N-12E Mississippi County, Arkansas
12.	Quintin Little #1 Little	Sec. 30-15N-5E Craighead County, Arkansas
13.	Tennark #1 Martin	Sec. 35-14N-3E Craighead County, Arkansas
14.	Cockrell Corporation #1 Carter	Sec. 4-4N-1E St. Francis County, Arkansas

Cross Section G-G', Figure 21

1.	Humble Oil Company #1 Pickell	Sec. 21-13S-2W Union County, Illinois
2.	Texas Pacific Oil Company #1 Farley	Sec. 34-13S-3E Johnson County, Illinois
3.	Exxon #1 Duncan	Sec. 5-M-22 Webster County, Kentucky
4.	Texas Gas Trans. #1 Shain	Sec. 10-L-36 Grayson County, Kentucky
5.	Benz Oil #1 Nunnally	Sec. 16-F-46 Metcalfe County, Kentucky

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16. ABSTRACT (200 words or less)

This is the final report on the geologic and geophysical study of the New Madrid area by the Illinois State Geological Survey. The area of investigation for this study encompassed portions of eight states within a two hundred mile radius around New Madrid, Missouri. The objectives of the study were to provide a better understanding of the regional structure and tectonics of the New Madrid zone through geologic time by understanding the Paleozoic geology.

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