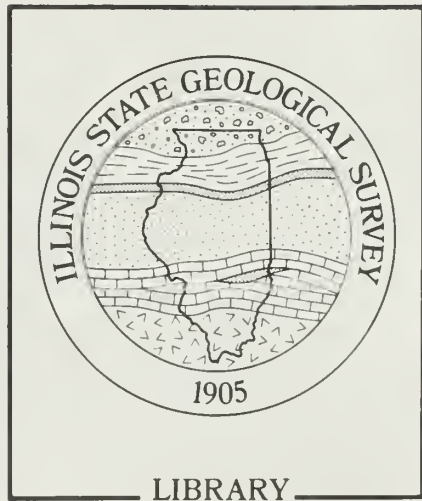


GEOLOGY OF THE JONESBORO 15-MINUTE QUADRANGLE, SOUTHWESTERN ILLINOIS

Jonesboro, Mill Creek, Ware, and McClure 7.5-Minute Quadrangles

W. John Nelson, Joseph A. Devera, and John M. Masters





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ABSTRACT

The Jonesboro 15-Minute Quadrangle in southernmost Illinois lies at the border of three major geologic provinces: the Ozark Dome, the Illinois Basin, and the Mississippi Embayment. Outcropping bedrock ranges from the Maquoketa Formation (Upper Ordovician) through the Pope Group (upper Mississippian). These rocks are mainly limestone, along with lesser amounts of shale, siltstone, sandstone, and bedded chert. Paleozoic rocks regionally dip east-northeast from the Ozark Dome toward the Illinois Basin. Weakly lithified Cretaceous and Eocene (?) sand, gravel, and clay occur as small downfaulted and erosional outliers on Paleozoic bedrock. Quaternary loess and colluvium mantle the uplands, while alluvial and lacustrine sediments underlie valley bottoms.

The area contains several systems of faults that reflect multiple episodes of deformation. Most faults are strike-slip and high-angle normal; prevalent trends area north-south to

north-northwest-south-southeast, northeast-southwest, and east-west. The tectonic history has not been worked out completely; many faults were active in the late Paleozoic and some underwent post-Eocene displacement.

Paleozoic rocks are thoroughly leached and silicified in most of the southern half of the study area. Altered rocks are riddled by innumerable intersecting joints and faults, most of which are too small to portray at the 1:24,000 scale. We interpret alteration as a product of hydrothermal activity. Hydrothermal fluids, heated by deep-seated igneous intrusions, percolated through joints and faults.

Microcrystalline silica, derived from leached and silicified Lower Devonian rocks, is the principal economic mineral product of the area. Substantial resources of Mississippian limestone suitable for various uses are available in the northeastern part of the quadrangle.



Faults apparently controlled selective silicification of rocks in the study area, as illustrated by this outcrop of highly silicified Clear Creek Formation (Lower Devonian) along a northeast-trending fault. (View is directed to the northeast.) Bedding strikes northeast and dips northwest. Originally a cherty limestone, the Clear Creek was totally converted to chert and tripoli in this area. Location is SW NW SW, Sec. 14, T14S, R2W, Mill Creek 7.5-Minute Quadrangle.



SUMMARY

The Jonesboro 15-Minute Quadrangle is situated in southernmost Illinois along the Mississippi River. It encompasses parts of three major geologic provinces: the Ozark Dome, the Illinois Basin, and the Mississippi Embayment. The Ozark Dome section on the west features rugged uplands underlain by Ordovician through Devonian bedrock. The Illinois Basin section, in the northeast corner of the quadrangle, is rolling upland having karst topography commonly developed in Mississippian limestone bedrock. The Mississippi Embayment section in the southeast corner is represented by nearly level Quaternary floodplain deposits in the Cache Valley. The broad floodplain of the Mississippi River crosses the east flank of the Ozark Dome along the west edge of the study area.

Cambrian and Ordovician rocks of the Jonesboro Quadrangle are known principally from borehole data. The oldest unit penetrated by drilling is the Upper Cambrian Mt. Simon (Lamotte) Sandstone. This is overlain by more than 6,500 feet of cherty, sandy dolomite of the Knox Group (Upper Cambrian and Lower Ordovician). Middle Ordovician rocks comprise the following: the Everton Formation at the base, 240 feet of sandy dolomite; the St. Peter Sandstone, about 45 feet of quartz arenite; the Dutchtown Formation, 200 to 360 feet of petroliferous limestone and dolomite; the Joachim Dolomite, about 230 feet thick; the "Pecatonica" and Plattin Formations, 525 to 700 feet of mostly dark, micritic limestone; the Decorah Formation, 40 to 60 feet of argillaceous limestone and shale; and the Kimmswick Limestone, 115 to 160 feet of white, coarsely crinoidal, high-calcium limestone. The Maquoketa Formation of Cincinnati (Late Ordovician) age is the oldest unit exposed in the Jonesboro Quadrangle. The Maquoketa comprises 140 to 200 feet of shale, siltstone, sand-

stone, and limestone. It represents two upward-shoaling cycles, with siliciclastics derived from both a distant eastern source and a nearby western source on the Ozark Dome.

Silurian strata include the Sexton Creek Limestone (30 to 40 feet of cherty limestone) and the Bainbridge Formation (120 to 180 feet of limestone, marlstone, and red to green calcareous shale). These rocks apparently were deposited in tectonically stable, quiet-water marine settings. The Silurian-Devonian boundary lies in the lower part of the Bailey Limestone, which overlies the Bainbridge.

Lower Devonian rocks include most of the Bailey Limestone, the Grassy Knob Chert, and the Clear Creek Formation. These three formations consist of light-colored, micritic to fine grained, cherty, siliceous limestone and bedded chert. They total 750 to 900 feet thick. Conditions of sedimentation are not well established, but the Bailey and Grassy Knob seem to record gradual deepening, and the Clear Creek gradual shoaling, of a sea where much biogenic silica was produced. The east flank of the Ozark Dome rose and periodically shed siliciclastics eastward during Middle and Late Devonian time. Middle and Upper Devonian rocks progressively thin and are truncated westward onto the flank of the dome. These strata include the Middle Devonian Grand Tower Limestone (skeletal limestone and quartz sandstone 10 to 125 feet thick) and St. Laurent Formation (cherty carbonates, shale, and siltstone 60 to 200 feet thick) and the Upper Devonian New Albany Shale (black shale, where present, up to 80 feet thick).

During Mississippian time the Ozark Dome was still a positive area, but it did not shed sediment to the study area. The Springville Shale (lower Valmeyeran) is an upward-coarsening prodeltaic wedge (distal Borden delta) probably derived from

a distant eastern source area. The Fort Payne Formation, fine grained siliceous limestone and bedded chert 10 to 140 feet thick, disconformably overlies the Springville. The overlying Ullin, Salem, St. Louis, and Ste. Genevieve Limestones are a laterally intergrading succession of shallow-water limestones about 1,000 to 1,250 feet thick. The youngest Paleozoic rocks in the quadrangle are intertonguing limestones, shales, and sandstones of the Pope Group (upper Valmeyeran to lower Chesterian Series).

Cretaceous and Eocene (?) sediments occur as scattered hilltop outliers and along a discontinuous north-trending belt in the eastern part of the quadrangle. The belt is interpreted as a fault-controlled paleo-valley. Deposits are tentatively assigned to the Upper Cretaceous Tuscaloosa Formation (light-colored chert gravel), the Upper Cretaceous McNairy Formation (brightly colored sand, silt and clay, with lenses of white quartz arenite and conglomerate), and the Eocene Wilcox Formation (?) (sand and gravel with gray to black, rounded chert pebbles). All of these appear to be fluvial and overbank sediments, except McNairy quartz arenite, which probably is a marine shoreface deposit.

Structure of the quadrangle is complex. The regional dip is ENE, into the Illinois Basin. The north-trending Harrison Creek Anticline probably overlies a basement fault. The Atwood and Delta Faults and several smaller faults that strike NNW are high-angle normal faults. Innumerable smaller faults occur in the southern Jonesboro 7.5-Minute Quadrangle and through most of the Mill Creek Quadrangle. The most common trends are north-south, north-northwest-south-southeast, east-west, and northeast-southwest. Many of these faults show features indicative of strike-slip, such as horizontal slickensides, "flower structures," and pull-apart grabens. The

amount and direction of displacement and the tectonic history are poorly understood. Some faults displace Cretaceous and Tertiary strata, but no examples of deformed Quaternary deposits are known.

Paleozoic bedrock is intensively altered, leached, and silicified in a large part of the study area. Limestones have been dissolved away or replaced by siliceous rocks known locally as chert, tripoli, novaculite, ganister, and calico rock. The silicified area is riddled with small-scale faults, which served as pathways for silicifying fluids. The rocks were probably altered by low-temperature hydrothermal activity, driven

by heat from deep-seated igneous intrusions (Berg and Masters 1994). The altered rocks originally had high silica content (detrital, biogenic, and diagenetic). This silica was remobilized and recrystallized.

Silica is the principal economic mineral deposit of the area. Tripoli is a white, pure form of microcrystalline silica, used widely as fillers, abrasives, and buffing and polishing agents. Commercial tripoli is derived from alteration of Lower Devonian siliceous formations—chiefly the Clear Creek Formation and to a lesser extent the Grassy Knob and Bailey. Less pure forms of silica are quarried for cement manufacture

and for road gravel. Other forms of silica, called ganister and calico rock, were mined or quarried in the past. Limestone was quarried in the past from several Mississippian formations and is being quarried today just east of the quadrangle. The Ullin and Ste. Genevieve Limestones, in particular, are suitable for a variety of purposes. The Kimmswick Limestone (Ordovician) is a potential source of high-purity limestone. Petroleum prospects of the area are speculative; about 17 dry test holes, mostly shallow, have been drilled in the quadrangle. Metalliferous cuttings from a deep borehole in the quadrangle indicate the potential for deep, metallic ore deposits.

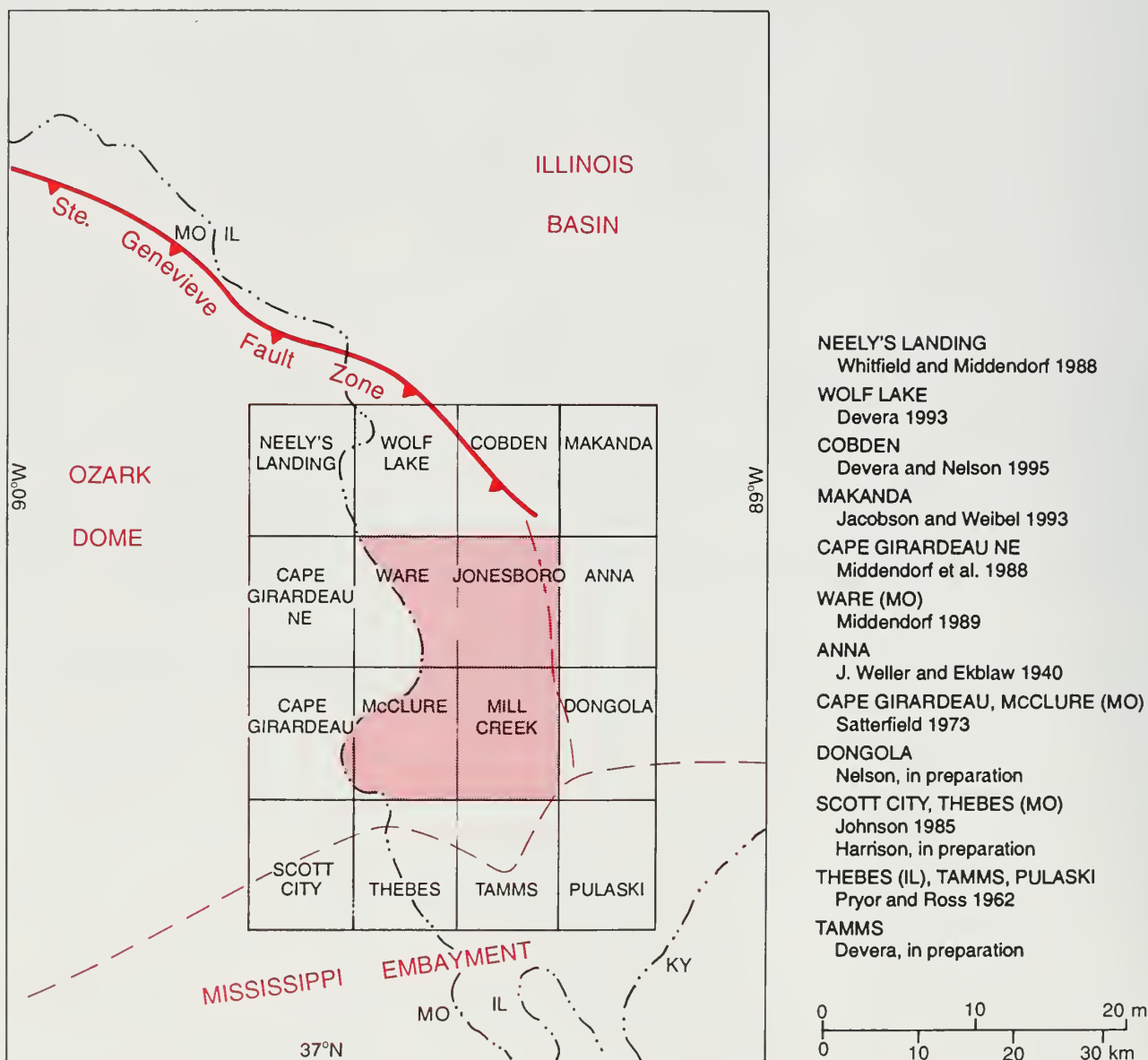


Figure 1 Location map, showing study area (shaded), adjacent quadrangles, and major structural features. Authors of the quadrangle maps are listed to the right.



INTRODUCTION

Purpose

This report accompanies geologic maps of the Jonesboro and Ware (Nelson and Devera, 1994) and Mill Creek and McClure (Devera et al. 1994) 7.5-Minute Quadrangles. These quadrangles were mapped under the Cooperative Geologic Mapping (COGEMAP) program, a joint effort of the U.S. Geological Survey (USGS) and the Illinois State Geological Survey (ISGS).

The Jonesboro 15-Minute Quadrangle lies in a key area geologically. Parts of three major geologic provinces—the Ozark Dome, the Illinois Basin, and the Mississippi Embayment—fall within the study area (fig. 1). Ordovician through Mississippian bedrock crops out in this quadrangle, as do Cretaceous and Tertiary strata. The quadrangle lies just north of the New Madrid Seismic Zone, the most active earthquake area in the central United States. Previous geologists, such as J. Weller and Ekblaw (1940), observed complex structure in this area but did not map it in any detail or interpret it. Faults that displace Tertiary and possibly Quaternary strata are reported in adjacent areas (McCracken 1971, Johnson 1985, Harrison and Schultz 1992). Immediately north of the study area, the Ste. Genevieve Fault Zone follows a major Precambrian crustal boundary (Heigold and Kolata 1993). Economically, the Jonesboro Quadrangle contains valuable limestone and silica resources. The origin and geologic controls of silica deposits in southern Illinois have long been a puzzle.

Location and Physiography

The Jonesboro 15-Minute Quadrangle contains the Jonesboro, Ware, McClure, and Mill Creek 7.5-Minute Quadrangles in Union and Alexander Counties, Illinois, and Cape Girardeau County, Missouri (fig. 1). Only the portion in Illinois was mapped for this report. The Missouri portions of the McClure and

Ware Quadrangles were mapped previously (Satterfield 1973, Midden-dorf 1989).

The study area contains parts of three physiographic provinces (Leighton et al. 1948). The north-eastern part (the area east of Illinois Rt. 127) is in the Shawnee Hills Section of the Interior Low Plateaus Province. This area of gently to moderately rolling topography is underlain by Mississippian limestone. Karst topography is locally present. The land is used mainly as pasture for cattle and some row-crop farming; steeper slopes are left as woodlots. Most of the area's population lives in the Shawnee Hills Section. Uplands of the western and most of the southern part of the study area are in the Salem Plateaus Section of the Ozark Plateaus Province (Leighton et al. 1948). Steep rugged hills and deep V-shaped ravines characterize this section. A mature dendritic or trellis drainage pattern has developed. The area is thinly populated and densely wooded; farming (mostly for raising cattle) is largely confined to bottomlands along the larger valleys. The southeast corner of the study area is within the Coastal Plains Province (Leighton et al. 1948). The broad Cache Valley, the floodplain of the ancestral Ohio River, follows the north erosional edge of the Coastal Plain. The Cache floodplain, along with the Mississippi River floodplain in the western part of the quadrangle, is the scene of extensive row-crop farming and livestock grazing.

Geologic Setting

The study area contains parts of three major structural provinces: the Ozark Dome, the Illinois Basin, and the Mississippi Embayment (fig. 1). These structural provinces coincide, respectively, with the Ozark Plateaus, Interior Low Plateaus, and Coastal Plains physiographic provinces previously described.

The Ozark Dome Province, which makes up the largest part of the study area, has been recurrently uplifted from Precambrian to Recent. Surface bedrock is of Ordovician through Devonian age. Strata dip gently in most places and are displaced by faults having a variety of trends.

The Illinois Basin is an intracratonic basin that attained its present form near the end of the Paleozoic Era. The basin contains Cambrian through Pennsylvanian sedimentary rocks and is structurally centered about 80 miles (130 km) northeast of the Jonesboro Quadrangle. In the study area, the edge of the basin may be regarded as the limit of Mississippian strata. These rocks dip eastward and northeastward at 2° to 12°; no large faults were mapped.

The Cache Valley at the southeast corner of the study area approximately follows the north erosional edge of the Mississippi Embayment, a northward extension of the Gulf Coastal Plain. Beyond the study area, Cretaceous and Tertiary sedimentary rocks crop out south and east of the Cache Valley. In the Jonesboro Quadrangle, Cretaceous and Tertiary strata occur as ridge-top outliers and in a south-trending paleo-valley that follows the boundary between the Ozark Dome and Illinois Basin.

Previous Studies

The only published geologic map for the Jonesboro 15-Minute Quadrangle is the "preliminary" map of J. Weller and Ekblaw (1940), compiled on a planimetric base of 1:62,500 scale and on the basis of field work conducted mainly during the 1920s. A descriptive report accompanies the map. Weller and Ekblaw thoroughly described Paleozoic rock units, but they purposely omitted small faults and treated Cretaceous and Tertiary deposits in a cursory fashion.

An unpublished manuscript and a hand-colored geologic map of the

Jonesboro 15-Minute Quadrangle were produced by Savage (1920b). The Missouri portion of the McClure Quadrangle was mapped by Satterfield (1973); the Missouri portion of the Ware Quadrangle was mapped by Middendorf (1989). Other geologic maps for the general area are indicated in figure. 1.

Methodology

We mapped the Jonesboro, Mill Creek, and Illinois portions of the Ware and McClure Quadrangles between October 1991 and May 1992, using USGS 7.5-minute topographic maps as base maps. A small area of the Mill Creek Quadrangle was mapped in 1989–1990 by Berg and Masters (1994) and spot-checked during the present study. Nelson used well records on public file at the ISGS to map the subsurface geology of the study area. These well records include drillers' logs, geologists' sample studies, and geophysical logs. Specifically for this study, Nelson examined cuttings from several wells .

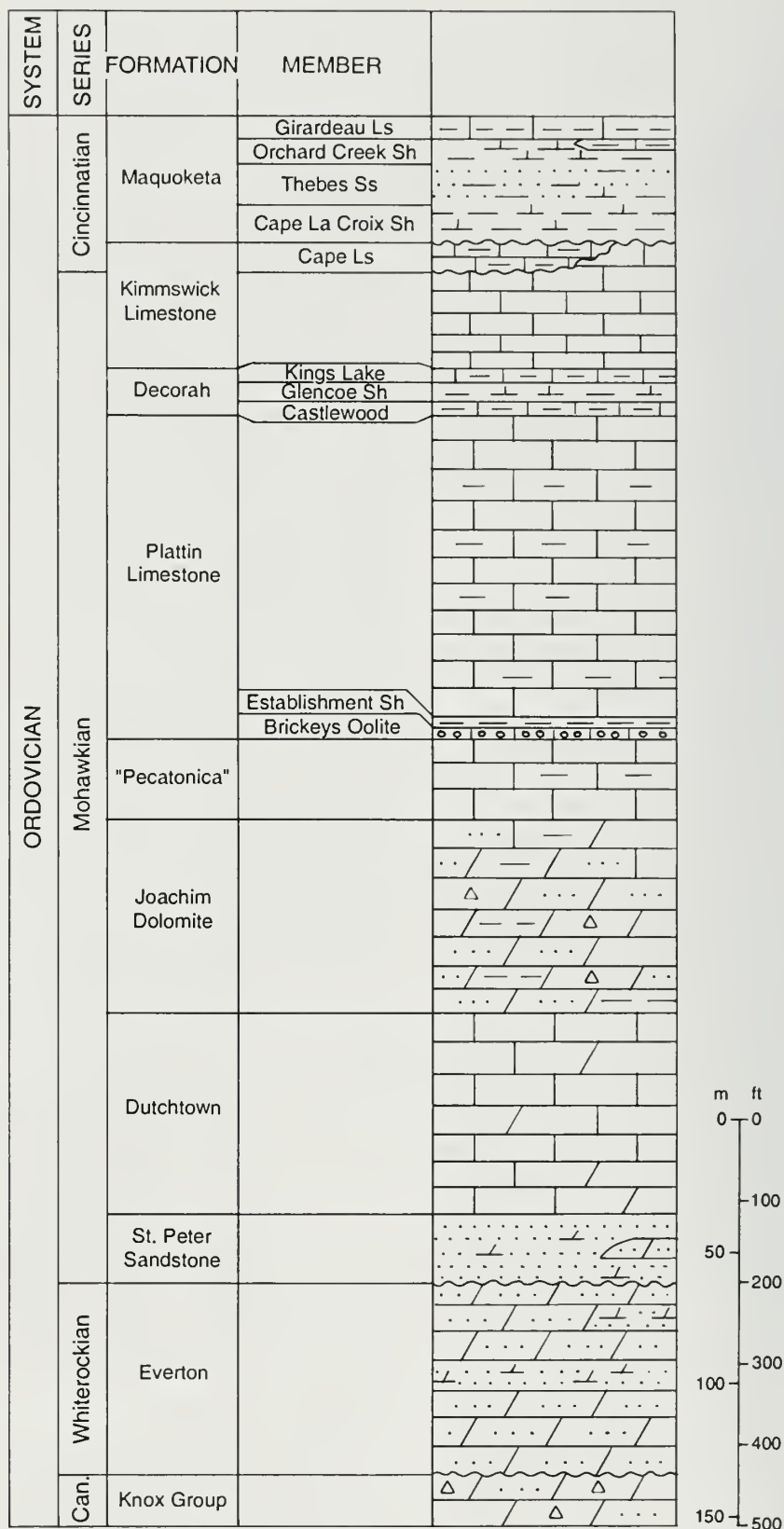


Figure 2 Stratigraphic column showing Middle and Upper Ordovician units (except Leemon Formation) in the study area.



STRATIGRAPHY

The Jonesboro Quadrangle contains Cambrian through Mississippian sedimentary rocks, weakly lithified Cretaceous and Tertiary sediments, and unlithified Quaternary sediments. The oldest rocks exposed in the study area are Late Ordovician (fig. 2). Cambrian through Middle Ordovician rocks are known from logs of deep boreholes and from exposures west of the study area in Missouri.

Mt. Simon (Lamotte) Sandstone

The oldest rock unit known in the Jonesboro Quadrangle is the Cambrian-age Mt. Simon (Lamotte) Sandstone, which was penetrated by the Humble Oil Company no. 1 Pickel borehole, in the NW SE NW, Sec. 21, T13S, R2W, in the Mill Creek Quadrangle. In this well, 122 feet of Mt. Simon was drilled, and the base of the formation was not reached. The sandstone is described on the sample log as white to pink, fine to medium grained quartz arenite with silica cement. This lithology is typical of the upper part of the Lamotte Sandstone on the Ozark Dome in Missouri (Hayes and Knight 1961) and the upper Mt. Simon Sandstone in the subsurface throughout Illinois (Buschbach 1975). The Lamotte and Mt. Simon are correlative units of the St. Croixan Series (Late Cambrian).

Knox Group

The name Knox Group is applied to the thick succession of Upper Cambrian and Canadian (Lower Ordovician) carbonate rocks overlying the Mt. Simon Sandstone in the southern part of the Illinois Basin. Equivalent formations that outcrop on the Ozark Dome in Missouri are difficult to trace into the subsurface because of lithologic similarity and down-dip facies changes.

A total of 6,624 feet of Knox strata was penetrated in the Humble no. 1 Pickel well. Subdivision of the Knox Group in the Pickel well (table 1) is

made on the basis of geophysical log interpretation and sample and insoluble-residue analysis by M.L. Sargent (written communication, 1992). Formation names are the same as those used for strata outcropping to the west of the study area, on the Ozark Dome in Missouri. For comparison, thicknesses of Cambrian units in Missouri (from Martin et al. 1961) and of Ordovician units (from Thompson 1991) are also listed in table 1. The table shows that the entire Knox Group and every constituent formation thickens eastward from Missouri to the Pickel well. This eastward thickening conforms with regional trends mapped by Sargent (1991, p. 82).

Everton Formation

The Everton Formation is a unit of Whiterockian age. It is composed of interbedded sandy dolomite and dolomitic sandstone, and it unconformably overlies the Knox Group (Kolata and Noger 1991, Thompson 1991). In the Humble no. 1 Pickel well, the Everton Formation comprises about 240 feet of sandy dolomite that is light to medium brown and micritic to coarsely crystalline. The Ohio Oil Company no. 1 Cross well, located in the NW NW NE, Sec. 21, T13S, R2W, in the Jonesboro 7.5-Minute Quadrangle, reached total depth about 15 feet into the Everton Formation. The Everton is 56 and 106 feet thick, according to the sample logs of two deep wells 8 to 10 miles southeast of the study area in Pulaski County. The Everton thickens southeastward, from about 70 feet in Perry County, Missouri, to more than 400 feet in the subsurface in southeastern Illinois (M.L. Sargent, personal communication, 1994). Variations in thickness of the Everton may reflect (1) differential subsidence during deposition, (2) deposition of the Everton on an irregular erosional surface, and (3) erosion of the Everton before deposition of the St. Peter Sandstone.

St. Peter Sandstone

The St. Peter Sandstone is one of the most widespread and easily recognized formations of the central United States. It is predominantly white to light gray, fine to coarse grained, well rounded and frosted quartz sand that is generally weakly cemented. Beds of sandy dolomite occur locally. The St. Peter is assigned to the lower Mohawkian Series (Middle Ordovician) and overlies the Everton Formation discontinuously in most places (Kolata and Noger 1991, Thompson 1991).

The St. Peter is 48 feet thick in the Humble no. 1 Pickel well and 40 feet thick in the Ohio Company no. 1 Cross well, both of which are on the Harrison Creek Anticline. At the nearest outcrops in Missouri, 8 to 10 miles west of the study area, the St. Peter averages about 100 feet thick (Thompson 1991, Nelson 1995). Two deep wells southeast of the study area, in Pulaski County, Illinois, penetrated 130 to 150 feet of St. Peter. Thinning of the St. Peter in the Pickel and Cross wells indicates that the Harrison Creek Anticline rose during early Mohawkian sedimentation. Alternatively, the thinning might simply reflect deposition of the St. Peter on an uneven erosional surface.

Dutchtown Formation

The Dutchtown is about 200 feet thick in the Cross well and 361 feet thick in the Pickel well. In both wells, the Dutchtown is composed of dark-colored, micritic to finely crystalline limestone, in addition to dolomite that is argillaceous and partly sandy. Identification of the Dutchtown is more definitive in the Pickel well, for which geophysical logs are available in addition to a sample log.

In its type area of southeastern Missouri, the Dutchtown is composed of dark brownish gray, micritic to very finely crystalline limestone and dolomite, containing

Table 1 Thicknesses and lithologies of formations in the Knox Group in the Humble no. 1 Pickel well (from M.L. Sargent, written communication, 1992). Thicknesses of the units at the nearest outcrops in southeast Missouri are given for comparison.

Unit (oldest first)	Thickness (ft)	Outcrop thickness (ft)	Lithology
Cambrian System			
Bonne Terre Fm	600	375–400	Dolomite, sandy, glauconitic, increasingly sandy near base
Davis Fm	136	170–225	Calcareous dolomite to dolomitic limestone, light to medium brown, oolitic
Derby/Doerun Fms	544	0–200	Dolomite, slightly sandy, very cherty
Potosi Dolomite	978	75–300	Dolomite, sandy, cherty, with quartz-filled vugs (drusy quartz)
Eminence Dolomite	758	200–350	Dolomite, slightly sandy, very cherty; some oolitic chert
Ordovician System, Canadian Series			
Gasconade Fm	584	400–500	Dolomite, light brownish gray, cherty; basal Gunter Sandstone Member about 30 feet thick
Roubidoux Fm	640	200–250	Dolomite, cherty, very sandy; sandstone, fine to medium, rounded, dolomitic
Jefferson City Fm	606	250	Dolomite, slightly sandy, very cherty with oolitic chert
Cotter Dolomite	871	350–500	Dolomite, sandy, with thin interbeds of sandstone
Powell Dolomite	389	100–150	Dolomite, slightly sandy, with dolomoldic chert
Smithville Dolomite	188	150	Dolomite, argillaceous to silty, with vitreous chert
Unnamed unit	330	?	Dolomite, mostly fine grained, argillaceous
Total Knox Group	6,624	2,270–3,275	

finely disseminated organic matter and bitumen-filled vugs (Martin et al. 1961, Thompson 1991). The Dutchtown thins northward; it is about 185 feet thick in southern Cape Girardeau County and pinches out in Perry County, Missouri (Nelson 1995).

Joachim Dolomite

The Joachim Dolomite is composed of light to medium gray and brown, very fine to fine grained sandy dolomite containing little chert. Lesser amounts of limestone occur in the upper part of the formation. Thin interbeds of gray dolomitic shale are present throughout the unit, and sandstone interbeds are common in the lower part (Thompson 1991). The Joachim in both the Ohio Company no. 1 Cross and Humble no. 1 Pickel wells is about 230 feet thick and is lithologically similar to Joachim in outcrops in Missouri. The Joachim was reported to be 190 to 275 feet thick in the Missouri part of the Cape Girardeau Quadrangle (Satterfield 1973).

"Pecatonica Formation"

The Pecatonica Formation was named by Hershey (1894) for its type locality in northern Illinois. It was extended into southeastern Missouri by Templeton and Willman

(1963). The Pecatonica was recently mapped in several quadrangles in southeastern Missouri. Comparison of maps and lithologic descriptions indicate, however, that the Pecatonica was not consistently differentiated from the overlying Plattin Limestone in these quadrangles (Nelson 1995). Thompson (1991, p. 109) regarded identification of the Pecatonica in Missouri to be "tentative and questionable" and placed "Pecatonica Formation" in quotation marks. Thompson stated that the "Pecatonica" is nearly identical in lithology to the Plattin.

The "Pecatonica" was tentatively identified in the Humble no. 1 Pickel well as a 93-foot-thick interval of dark, micritic limestone; it overlies sandy dolomite of the Joachim and underlies a thin oolitic limestone thought to be the basal Brickeys Member of the Plattin Limestone (M.L. Sargent, written communication, 1992). Other wells in and close to the study area lack logs that are sufficiently detailed to differentiate the "Pecatonica" from the Plattin.

Plattin Limestone

Thompson (1991, p. 127) stated that the Plattin Limestone in southeastern Missouri can be classified as either a formation or a group, "according to the needs of the worker."

Although some geologists divide the Plattin into formations, quadrangle mappers in southeastern Missouri treated it as a single unit. The Plattin is difficult to subdivide in the subsurface, although the Brickeys and Establishment Members can be identified in some wells.

The Plattin is composed largely of brownish gray mottled and burrowed lime mudstone, similar to that of the "Pecatonica Formation." It is argillaceous and contains chert, but it lacks sand. Thin intervals of skeletal grainstone occur within the Plattin. The Brickeys Member, at the base, contains oolitic grainstone and is overlain by the thin but very widespread Establishment Shale Member. The oolitic limestone is distinctive in well cuttings, and the shale can be identified on many geophysical logs, particularly gamma-ray logs.

Three wells in the study area penetrated the entire Plattin. In the Humble no. 1 Pickel well, the Plattin (to the base of the Brickeys Member) is 432 feet thick, and the combined Plattin-"Pecatonica" thickness is 525 feet (M.L. Sargent, written communication, 1992). Undivided Plattin-"Pecatonica" is about 665 feet thick in the Ohio Oil Company no. 1 Cross well and 693 feet thick in the Mims no. 1 Potash-nick well (NW NW SE, Sec. 26, T13S,

R3W, McClure Quadrangle). Regionally, the Plattin-“Pecatonica” thickens southeastward; it is 500 to 525 feet thick in the Cape Girardeau Quadrangle (Satterfield 1973), 345 to 420 feet thick in wells north of the study area in Jackson County, and 715 to 780 feet thick in wells to the southeast in Pulaski County.

The contact of the Plattin with the overlying Decorah Formation is unconformable (Templeton and Willman 1963).

Decorah Formation

Geologists variously classify the Decorah as a formation (Decorah Shale), a subgroup (Templeton and Willman 1963), or a group (Thompson 1991). In and near the study area, the Decorah is only 40 to 60 feet thick and cannot be subdivided except in unusually good exposures (such as quarry faces and cores). Most mappers in southeastern Missouri either combined the Decorah and Plattin into one unit or did not distinguish the Decorah at all. The Decorah is treated as a formation in this report; the name Decorah Formation is used instead of Decorah Shale because limestone is a major constituent.

Cores from the northern Thebes Quadrangle, a few miles south of the study area, provide the best information on the Decorah. In these cores, the Decorah comprises 8 to 17 feet of fossiliferous, shaley limestone that has thin shale interbeds. The limestone is light to medium brownish gray lime mudstone and skeletal wackestone; the shale is light greenish gray to brownish gray, slightly fissile, and calcareous. Bedding is wavy, contorted, and nodular. Trepostome, bifoliate, and fistuliporid bryozoans; brachiopods, including *Rafinesquina* and *Hebertella*; gastropods; rugose corals; and echinoderm fragments are common. The contact with the Plattin Limestone is gradational in these cores, whereas the Decorah-Kimmswick contact is sharp and probably disconformable.

In wells lacking cores, the Decorah can be distinguished from the Plattin below and Kimmswick Limestone above by its greater clay content. The threefold division cited by Thompson (1991) can be recognized in wells for which good sample studies and geophysical logs are avail-

able. A lower argillaceous limestone (Castlewood) is overlain by a fossiliferous shale (Glencoe) and an upper argillaceous or silty limestone (Kings Lake). Only the Glencoe Shale can be identified on most of the geophysical logs. In and near the Jonesboro Quadrangle, the Decorah is about 40 to 60 feet thick, and the Glencoe is 15 to 20 feet thick. The Decorah Formation is disconformably overlain by the Kimmswick Limestone (Thompson 1991).

Kimmswick Limestone

The Kimmswick Limestone was named for exposures at Kimmswick, Missouri, about 20 miles south of St. Louis (Ulrich 1904). Although Templeton and Willman (1963) reclassified the Kimmswick as a subgroup of the Galena Group in Illinois, geologists in Missouri continue to rank the Kimmswick as a formation. Thompson (1991) points out that the Kimmswick in Missouri is substantially different in lithology from the type Galena of northwestern Illinois. The Kimmswick is a high-calcium limestone (coarse crinoidal grainstone), whereas the Galena is a fine to medium grained, argillaceous, and cherty dolomite. The Kimmswick in the Jonesboro area has the same lithology as occurs at the type locality and cannot be divided readily into smaller units. Therefore, we use the name Kimmswick Limestone rather than Kimmswick Subgroup of the Galena Group.

The Kimmswick crops out in the Missouri part of the McClure and Cape Girardeau Quadrangles (Satterfield 1973) and in the Thebes Quadrangle in Illinois immediately south of the study area (J. Weller and Ekblaw 1940, Pryor and Ross 1962). Excellent exposures of the Kimmswick are at the Grays Point Quarry in the Thebes Quadrangle. Several wells in the McClure and Mill Creek Quadrangles penetrate the Kimmswick. Also, cores of the Kimmswick from the northern Thebes Quadrangle were examined. In these outcrops and wells, the Kimmswick is white to light gray, mostly coarse grained crinoidal grainstone, which contains practically no terrigenous clastic material. Thin intervals of darker, finer grained wackestone and packstone occasionally occur in the upper part. Stylolites are com-

mon, as are vugs, some of which are lined with asphaltic residue. Black, semivitreous chert nodules are common 20 to 40 feet below the top of the formation. Fossils include the distinctive “sunflower coral” *Receptaculites*, in addition to gastropods, bryozoans, ostracods, illaenid trilobites, and the brachiopods *Hebertella* and *Platystrophia*. Light gray vuggy and crystalline dolomite is reported in the Kimmswick in sample logs from wells north of the Jonesboro 15-Minute Quadrangle. The Kimmswick ranges from about 115 to 160 feet thick in wells in and adjacent to the study area. The Kimmswick is assigned to the upper part of the Mohawkian Series (Thompson 1991).

Cape Limestone

The Cape Limestone was named for Cape Girardeau, Missouri, by Templeton and Willman (1963); the type section is on Main Street north of Broadway. This unit was previously called the Fernvale Limestone (Savage 1920b, J. Weller and Ekblaw 1940). The Cape was classified as a formation in the Maquoketa Group by Templeton and Willman (1963) and as a separate formation by Thompson (1991). The type section consists of 8 feet of medium to dark gray, very fossiliferous, crinoidal limestone that is distinctly darker, finer grained, and more argillaceous than the upper part of the Kimmswick (Thompson 1991). The Cape is middle Cincinnatian (Maysvillian to early Richmondian; Sweet et al. 1975) and is separated by disconformities from the Kimmswick below and the Maquoketa above (Templeton and Willman 1963, Thompson 1991).

We examined the Cape interval in several cores taken from the northern Thebes Quadrangle. Medium to dark gray, fine grained limestone as thick as 22 feet occurs at the top of the Kimmswick in some cores. This rock is largely skeletal packstone, but it contains layers of wackestone and lime mudstone. The contact with typical Kimmswick crinoidal grainstone is either gradational or sharp, but it is not noticeably disconformable. Whether the dark limestone in these cores is the Cape or a dark facies of the Kimmswick is not certain.

A dark, fine grained limestone that may be Cape was logged in several other boreholes in the area. In the Humble no. 1 Pickel well, the Cape (?) is about 18 feet of brown, very fine grained fossiliferous limestone. In the Mims no. 1 Potashnick well, the Cape (?) is 23 feet of light brownish gray, very fine grained shaley limestone. Two wells in Pulaski County encountered limestone that may also be the Cape; it is 5 feet thick in one well and 12 feet thick in the other.

The mappability of the Cape Limestone is not resolved. The Cape should perhaps be classified as a member of the Kimmswick instead of as a separate formation (fig. 2).

Maquoketa Formation

The oldest bedrock unit that crops out in the Jonesboro 15-Minute Quadrangle is the Maquoketa Formation. The Maquoketa Shale was named by White (1870) for outcrops near Maquoketa, Iowa, where the unit consists of shale with interbeds of limestone. Templeton and Willman (1963) elevated the Maquoketa to a group in Illinois. In southeastern Missouri and southern Illinois, some geologists classified the Maquoketa as a group (Middendorf 1989, Middendorf et al. 1988, Thompson 1991), whereas others called it a formation (Pryor and Ross 1962, Satterfield 1973, Johnson 1985). Among those who mapped the Maquoketa, most portrayed it either as a single unit or combined two or more members (formations) as a matter of convenience.

Subdivisions of the Maquoketa are thin (averaging 35 to 50 ft) in the study area, and their contacts intergrade vertically and laterally. Although distinct lithologically, these subdivisions cannot be mapped reliably and portrayed at scales of 1:24,000 and smaller. Moreover, these subdivisions can be recognized in only a small area of southeastern Missouri and southwestern-most Illinois. The subdivisions thus fail the test of mappability for valid formations (North American Stratigraphic Code 1983) and are properly classified as members. Accordingly, we classify the Maquoketa as a formation divided into four members: Cape La Croix Shale (oldest), Thebes Sandstone, Orchard Creek Shale, and Girardeau

Limestone. The name Maquoketa Formation is used instead of Maquoketa Shale because sandstone and limestone are important constituents.

In wells in the study area, the Maquoketa ranges from 140 to 200 feet thick. Similar thicknesses are reported by Pryor and Ross (1962) for the Thebes Quadrangle and by Satterfield (1973) for the Missouri portion of the McClure and Cape Girardeau Quadrangles. The Maquoketa thickens to 170 to 210 feet in wells southeast of the Jonesboro Quadrangle. A regional isopach map of the Maquoketa shows that the unit thickens eastward across the Illinois Basin and that a locally thick area (more than 300 ft) occurs in western Kentucky (Whitaker 1988).

The Maquoketa was assigned to the Richmondian Stage of the Cincinnati Series by Sweet et al. (1975) on the basis of conodont faunas.

Cape La Croix Shale Member The Cape La Croix Shale was named (as a formation) by Thompson (1991) for Cape La Croix Creek in the northern part of the Cape Girardeau Quadrangle. The type section consists of 17 feet of bluish gray, calcareous, platy shale containing occasional nodules and thin beds of limestone. This unit was described previously as an unnamed member or formation of the Maquoketa.

The Cape La Croix does not crop out in the Jonesboro Quadrangle, but well records indicate that it is present. Drill cores from the Thebes Quadrangle show the Cape La Croix to be 24 to 36 feet thick and composed of dark gray to olive gray clay shale or silty shale that commonly grades to siltstone near the top. The shale is slightly fissile, calcareous, and contains gastropods, nautiloid cephalopods, ostracods, trilobites, and brachiopods. Thin interbeds and lenses of fossiliferous lime mudstone occur in the shale. The basal portion of the Cape La Croix is a soft, gummy claystone that yields poor core recovery. The Cape La Croix grades upward to the Thebes Sandstone Member.

Well records in the Jonesboro Quadrangle indicate the Cape La Croix to be dark shale 35 to 60 feet thick. Southeast of the study area, well records show the member is 90 to 150 feet thick, apparently thickening at the expense of the Thebes.

Thebes Sandstone Member The Thebes Sandstone was named by Worthen (1866) for Thebes, Illinois. The Thebes is restricted to a small area of southeastern Missouri and southwestern Illinois.

The Thebes crops out at the crest of the Harrison Creek Anticline in the SW NE SW, Sec. 16, T13S, R2W, in the Jonesboro 7.5-Minute Quadrangle, and in the bluff at Gale, NE SW, Sec. 33, T14S, R3W, in the McClure Quadrangle. It is composed of siltstone and very fine sandstone in this area. These rocks are light to medium gray, greenish gray, and brownish gray, and laminated to thinly bedded. They are composed largely of subangular quartz sand having a clay matrix and calcite cement. Interlaminae of silty shale are present. The only fossils noted are horizontal burrows and trails. Well records indicate the Thebes is 25 to 60 feet thick in the Jonesboro Quadrangle.

Outcrops and cores from the northern Thebes Quadrangle show the Thebes to be as thick as 110 feet and composed of siltstone to very fine grained, argillaceous sandstone. Bedding or lamination is weakly developed and commonly obscured by bioturbation. Numerous burrowed intervals are present, particularly in the lower part of the member. A distinctive unit at the base of the Thebes is composed of dark gray mudstone containing small inarticulate brachiopods and other fossils, along with small, dark gray to black spherical pellets (phosphate?). Mudstone variegated in red, green, and ochre occurs at the top of the Thebes in some cores.

The Thebes thins eastward and northward in the subsurface, grading laterally to siltstone and silty shale and intertonguing with the Cape La Croix Shale. It is restricted to southern Jackson and part of Pulaski Counties as well as all of Union and Alexander Counties. The Cape La Croix and Orchard Creek Shales cannot be differentiated in areas where the Thebes is absent. The upper contact of the Thebes is sharp but apparently conformable.

Orchard Creek Shale Member The Orchard Creek Shale was named by Savage (1909) for a creek about 2 miles (3 km) south of Thebes, Illinois, which is south of the report area. The Orchard Creek

crops out in a small area near Gale in the McClure Quadrangle and south of Harrison Creek at the crest of the Harrison Creek Anticline. It is not well exposed. The upper part of the Orchard Creek and the gradational contact with the overlying Girardeau Limestone can be seen along Harrison Creek in the SW SW NE, Sec. 16, T13S, R2W. More details of the Orchard Creek are known from well records, particularly from cores from the Thebes Quadrangle.

Lithologically, the Orchard Creek is similar to the Cape La Croix Member. The shale is greenish gray to olive gray (less commonly dark gray to black), soft and fissile, and partly silty, becoming siltier upward. The upper part is strongly calcareous, the lower part less so. Nodules and thin interbeds of dense, argillaceous lime mudstone increase in number and thickness upward, as the Orchard Creek grades into the overlying Girardeau Limestone Member. Satterfield (1971) found that the Girardeau thickens westward at the expense of the Orchard Creek and suggested that the two members are facies equivalents.

Fossils from the Orchard Creek include rare *Flexicalymene* sp., *Ceraurus* sp., and disarticulated large vag-desid trilobites. More common are crinoid columnals and ramose bryozoans.

The Orchard Creek is about 25 feet thick in outcrops in the study area, as well as in cores from the Thebes Quadrangle. The unit is reported to be 60 to 70 feet thick in the Missouri part of the Ware Quadrangle (Middendorf 1989), 30 to 60 feet thick in the Cape Girardeau Quadrangle (Satterfield 1973), 22 to 30 feet thick in the Thebes Quadrangle (Pryor and Ross 1962), 50 to 80 feet thick in wells east of the outcrop in the Thebes Quadrangle, and as much as 100 feet thick in wells farther east in Pulaski County.

Girardeau Limestone Member

The Girardeau Limestone was named by Shumard (1855) for Cape Girardeau; the type locality is at Cape Rock, northeast of the city along the Mississippi shore. The type section was described in detail by Satterfield (1971, p. 266) and Thompson (1991). The Girardeau has heretofore been ranked as a formation and placed in the Maquoketa Group by Thompson (1991).

Early workers in the region, including Savage (1920b), J. Weller and Ekblaw (1940), and Pryor and Ross (1962), assigned the Girardeau to the Silurian System. Study of the conodont fauna by Satterfield (1971) indicated that the Girardeau is Richmondian (late Ordovician). Brower (1973) suggested, on the basis of a study of the crinoid fauna, that the Girardeau was Richmondian or slightly younger (Gamachian Stage). He also suggested that it may be earliest Silurian age.

The Girardeau Member is exposed along the Harrison Creek Anticline in the southwestern part of the Jonesboro 7.5-Minute Quadrangle, in a small area north of Valley Mission in the Mill Creek Quadrangle, and in the bluffs northeast of Gale in the McClure Quadrangle. The best exposure is a bluff south of Harrison Creek near the center of Sec. 16, T13S, R2W.

In the study area, as at the type locality, the Girardeau is composed of medium to dark gray and olive gray lime mudstone in thin wavy and lenticular beds. Dark gray chert nodules are common in the upper part. Interbeds of greenish gray calcareous shale occur throughout the unit and become thicker and more numerous toward the base. Fossils are scarce; they include well preserved crinoids, carpoids, edrioasteroids, tentaculids, and trilobites. The member is 20 to 30 feet thick in both outcrop and the subsurface. Identification of the Girardeau in well records is a bit tenuous because the unit is thin and similar to the overlying Sexton Creek Limestone.

The Girardeau is disconformably overlain by either the Leemon Formation or the Sexton Creek Limestone. The Sexton Creek overlies the Girardeau along the top of the bluff south of Harrison Creek; the contact is sharp and planar to slightly irregular. Where the Girardeau Member is eroded, the Sexton Creek directly overlies the Orchard Creek Member (Thompson 1991).

Leemon Formation

A unit previously called the Edgewood Formation was renamed the Leemon Formation by Thompson and Satterfield (1975). The type locality of the Leemon is in the Cape Girardeau Northeast Quadrangle. It is classified as a formation, despite

being discontinuous and less than 25 feet thick. Pending further study, that rank is left unchanged.

The Leemon does not crop out in the Jonesboro 15-Minute Quadrangle, but it does occur in the Thebes Quadrangle (Savage 1920b, Pryor and Ross 1962) and in nearby areas of Missouri. In those places, the Leemon is an oolitic and skeletal grainstone, commonly crossbedded and containing thin interbeds of shale. Phosphatic pebbles and clasts eroded from the underlying Girardeau Limestone are common near the base (Thompson and Satterfield 1975, Thompson 1991).

The Leemon probably is present in several wells in and near the report area. It is logged as oolitic limestone and is less than 20 feet thick. An isopach map by Rogers (1972) shows the "Edgewood" (Leemon) largely absent east of the outcrop belt in far southern Illinois, but it thickens northeast of the study area to more than 66 feet.

The Leemon ("Edgewood") originally was assigned to the Silurian System, but a study of the conodont fauna by Thompson and Satterfield (1975) established late Richmondian (latest Ordovician) age. Later, Amsden and Barrick (1986) placed the Leemon of southwestern Illinois within the Hirnantian Stage. The contact of the Leemon to the Sexton Creek Limestone is disconformable. Where the Leemon is missing, the Sexton Creek Limestone rests on the Maquoketa Formation (Pryor and Ross 1962, Thompson 1991).

Sexton Creek Limestone

The type section of the Sexton Creek Limestone is in the Mississippi River bluff in the SW, Sec. 27, T14S, R3W, McClure Quadrangle (Savage 1909). This unit crops out northward along the bluffs and also near the mouth of Dongola Hollow in the McClure Quadrangle. It is also exposed along the crest of the Harrison Creek Anticline in the northwestern Mill Creek and southwestern Jonesboro 7.5-Minute Quadrangles. A fine exposure is just north of the mouth of Dongola Hollow in the SE NW, Sec. 12, T14S, R3W, McClure Quadrangle (fig. 3). The lower part (including the basal contact) crops out on the south side of Harrison Creek in the center of Sec. 16, T13S, R2W, Jonesboro Quadrangle.



Figure 3 Sexton Creek Limestone and St. Clair Limestone Member of Bainbridge Formation, north of the mouth of Dongola Hollow, NW SE NW, Sec. 12, T14S, R3W, McClure Quadrangle. The Sexton Creek is the lower unit that contains numerous thin dark chert layers; the St. Clair is the overlying thick bedded limestone. The height of the exposure is about 40 feet.

The lithology is distinctive: medium brownish gray, slightly argillaceous lime mudstone and skeletal wackestone, containing regular layers of caramel-colored to greenish gray chert (figs. 3, 4). Calymenid trilobite fragments and large biscuit-shaped colonies of *Favosites* sp. are common in the upper part. The Sexton Creek somewhat resembles the Girardeau Limestone, but the Sexton Creek contains less shale and more chert (20–30% of the unit), and it has more regular layers. The Sexton Creek is described in sample logs as white to light and medium brownish gray micritic limestone, which is argillaceous and contains shale laminae and abundant chert.

The contact of the Sexton Creek with the overlying Bainbridge Formation is sharp, but it appears to be conformable. The Sexton Creek is about 40 feet thick in outcrops in the study area. It is 30 feet thick in the

Schneider Drilling Company Pearce water well (Sec. 6, T14S, R2W). Reported thicknesses are 30 to 35 feet in the Missouri part of the McClure and Cape Girardeau Quadrangles (Satterfield 1973), 30 to 40 feet in the Missouri part of the Ware Quadrangle (Middendorf 1989), and 15 to 40 feet thick in the Thebes Quadrangle (Pryor and Ross 1962). The Sexton Creek is 45 to 92 feet thick in wells located southeast of the Jonesboro Quadrangle. North of the report area, in Jackson and southern Union Counties, the unit is 30 to 95 feet thick. An isopach map of the Alexandrian Series (Sexton Creek plus Leemon) (Willman and Atherton 1975) shows that the limestone thickens to the north and east of the study area to a maximum of more than 125 feet in Franklin County, Illinois.

Most workers since Savage (1920b) consider the Sexton Creek to be of

Alexandrian age, equivalent to the Brassfield Formation in Kentucky. Thompson (1987) suggested that the Sexton Creek ranges from the Alexandrian into the lower part of the Clintonian Stage, Niagaran Series.

Bainbridge Formation

The Bainbridge Formation was named by Ulrich (1904, p. 110), and its type section was described in detail by Ball (1939). The type section is in the Mississippi River bluff in the SE SE NW, Sec. 24, T32N, R14E, Ware Quadrangle (Missouri). It consists of 120 feet of interbedded variegated red and green silty limestone and calcareous shale, grading upward into the Bailey Formation. Basal beds of the Bainbridge are covered at the type section.

The Bainbridge is ranked as a formation by some stratigraphers and as a group by others. The lower subdivision, the St. Clair Limestone, is too thin and poorly exposed to be mapped as a formation in the study area. Accordingly, we treat the Bainbridge as a formation, containing the Seventy-Six, St. Clair, and Moccasin Springs Members (fig. 5).

Seventy-Six Shale Member

Satterfield and Thompson (1975) named the Seventy-Six Shale Member of the Bainbridge Formation for a village in the Altenburg Quadrangle, Perry County, Missouri. They described the member as variegated brick-red and green, partly fissile, calcareous, glauconitic shale that contains hematitic "buttons" and ranges from a few inches to 4 feet thick. We did not observe the Seventy-Six Shale during this study, but Satterfield and Thompson (1975) reported that they dug it out of the bluff north of Dongola Hollow in the "NW¼ NE¼ NW¼", Sec. 12, T14S, R3W, McClure Quadrangle. The cited location is on the Mississippi floodplain and probably is a misprint. The correct location probably is NW NW NE, Sec. 12.

St. Clair Limestone Member

The St. Clair Limestone was defined in Independence County, Arkansas, by Penrose (1891) and extended into southern Illinois by Lowenstam (1949). It has been classified as a formation but in this report it is considered a member of the Bainbridge Formation. The "McClure Limestone" shown on the stratigraphic



Figure 4 Sexton Creek Limestone with numerous closely fractured chert layers. Location is the same as in fig. 3. The staff is 5 feet long.

column of Satterfield's (1973) geologic map of the Cape Girardeau Quadrangle and Missouri portion of the McClure Quadrangle actually is the St. Clair. The name St. Clair clearly has priority over McClure and is accepted in this report.

The St. Clair Member crops out along the Mississippi River bluffs in the McClure Quadrangle southwest of the mouth of Sexton Creek and near the mouth of Dongola Hollow. Small exposures occur along Harrison Creek Anticline in the southwestern part of the Jonesboro 7.5-Minute Quadrangle and northwestern Mill Creek Quadrangle. Exposures north of the mouth of Dongola Hollow are readily accessible and fairly complete.

The St. Clair is composed of light gray limestone that is mottled in pale red and greenish gray. It is argillaceous lime mudstone to skeletal in large, scattered pink to red echinoderm stem fragments. The bedding is thick and tabular, and it is separated by stylolitic partings. The upper part of the unit is argillaceous. In the subsurface, the St. Clair is identified as white to gray limestone with pink, orange, and red fossil fragments or "spots." Ostracods

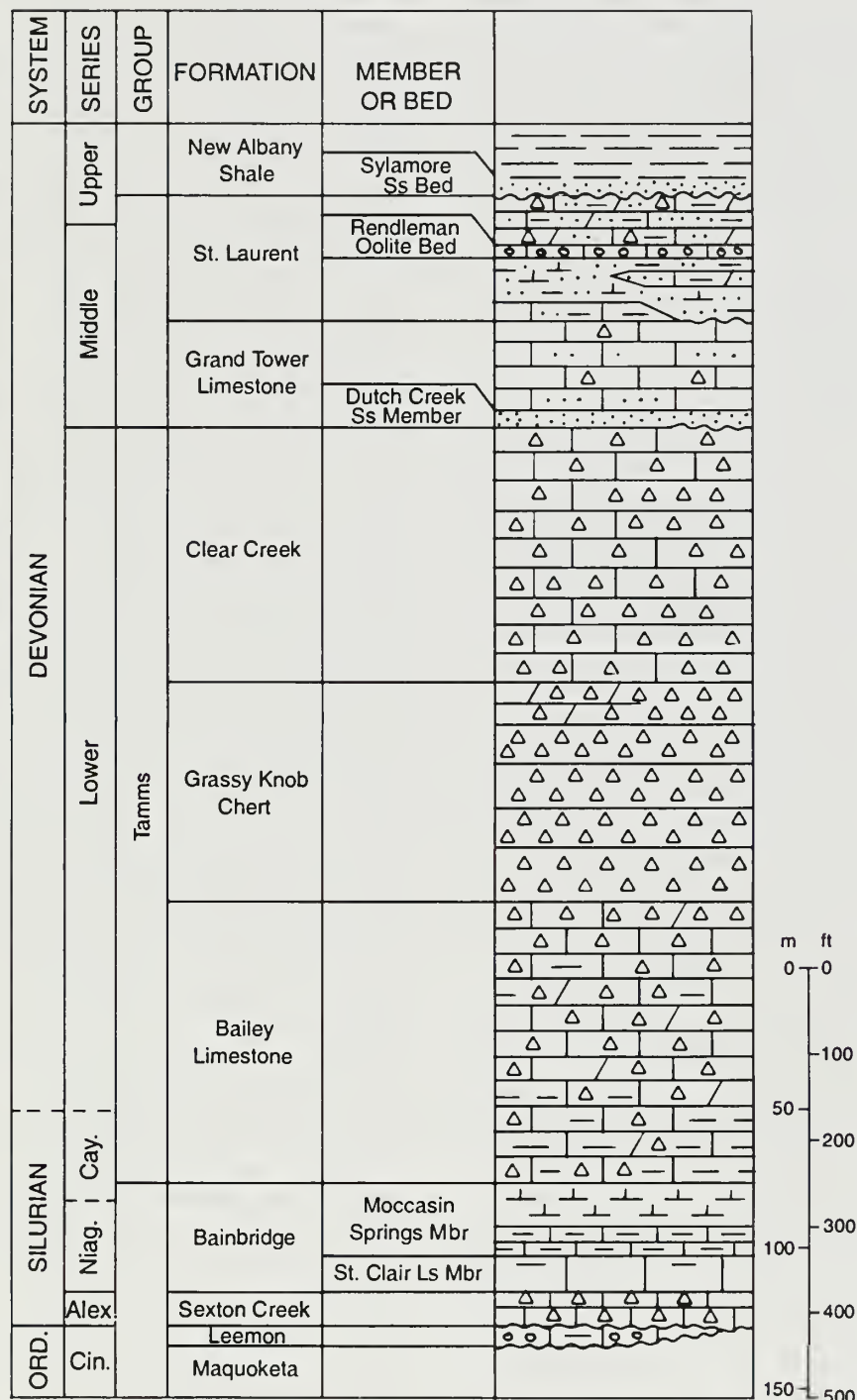


Figure 5 Stratigraphic column, showing Silurian and Devonian units in the study area.

and small coiled foraminifera (*Ammodiscus*) have been reported in well cuttings. The contact between the St. Clair and the Moccasin Springs Member is sharp, but probably conformable.

Thickness of the St. Clair is about 25 feet in outcrops and wells in the study area. Southeast of the study

area, the member is 8 to 24 feet thick. Satterfield (1973) reported 25 to 30 feet of "McClure Limestone" in the Cape Girardeau and McClure Quadrangles (Missouri portion), and Pryor and Ross estimated the St. Clair to be 10 to 20 feet thick in the Thebes Quadrangle. Well records indicate the unit to be 30 to 50 feet

thick north of the study area. These findings are consistent with Lowenstam's (1949) statement that the St. Clair thickens progressively north-east and east from the outcrop area in southernmost Illinois.

The St. Clair was assigned to the Clintonian Stage of the Niagaran Series by Thompson (1987).

Moccasin Springs Member The thick upper member of the Bainbridge Formation is the Moccasin Springs Member, named (as a formation) by Lowenstam (1949). The type section of the Moccasin Springs is the same as that of the Bainbridge.

The Moccasin Springs is a slope-forming unit exposed only in ravines and, in some places, on steep bluffs. It underlies broad valleys along the crest of the Harrison Creek Anticline and crops out in the Mississippi River bluffs near Dongola Hollow and south of Sexton Creek in the McClure Quadrangle. Most exposures are fragmentary. The most complete sections are in gullies on the west flank of the Harrison Creek Anticline in the E½ SE SW, Sec. 9, and west of the center of the SW, Sec. 16, T13S, R2W, Jonesboro 7.5-Minute Quadrangle.

The Moccasin Springs is composed of interbedded chert-free, very silty, and argillaceous limestone (lime mudstone) and calcareous mudstone, shale, and siltstone. Both rock types are mottled and variegated in brick-red, brownish red, purple, greenish gray, and olive gray. Limestone is the predominant lithology, but shale interbeds increase in number and thickness upward. The only common fossils are large nautiloid cephalopods in limestone near the base of the member. In the study area, the Moccasin Springs and St. Clair are the only Paleozoic units containing much red. These units are readily recognized in outcrops and well samples by their distinctive color, and they are thus noted on most drillers' logs.

An interval of shale about 30 feet thick commonly occurs at the top of the Moccasin Springs Member. This shale was called the Randol shale in a thesis by Rogers (1972), but this term has remained informal.

The contact of the Moccasin Springs Member with the overlying Bailey Limestone is gradational in the study area, as is the case at the

type section (Ball 1939) and at outcrops in the Thebes Quadrangle (Pryor and Ross 1962). A gradual color change from predominantly brick-red in the Moccasin Springs to predominantly greenish gray in the Bailey marks the transition zone. The lower part of the Bailey consists of gray to green cherty limestone. The limestone has numerous greenish gray shale interbeds that decrease in number and thickness upward. The base of the Bailey was mapped at the lowest occurrence of gray, cherty limestone.

The Moccasin Springs is about 90 feet thick along the Harrison Creek Anticline and about 145 feet thick in the Pearce water well in Sec. 6, T14S, R2W, Mill Creek Quadrangle. It is reported to be 100 to 120 feet thick in the Cape Girardeau and McClure Quadrangles (Satterfield 1973) and 100 to 130 feet thick in the Thebes Quadrangle (Pryor and Ross 1962). Well records show that the Moccasin Springs thickens east of the study area to as much as 270 feet in Pulaski County, Illinois. North of the study area, in northern Union and Jackson Counties, the member is 180 to 215 feet thick. A regional isopach map by Whitaker (1988) shows the entire Silurian succession thickening both northward from the study area, through Jackson County, and eastward through Alexander, Pulaski, and western Massac Counties.

The Moccasin Springs is generally considered to be of Niagaran age, but the upper beds may be Cayugan. Lowenstam (1949, p. 18) reported that "the uppermost bed (of the Moccasin Springs type section) includes a *Lissatrypa* and other fossils that suggest a late Silurian rather than Niagaran age." Graptolites from the upper Moccasin Springs in southern Illinois indicate correlation with the lower Ludlovian Stage of Europe (Ross 1962). Conodonts from the Bainbridge of northern Perry County, Missouri, indicate late middle to early late Ludlovian age (Rexroad and Craig 1971). On the COSUNA chart for Illinois (Shaver 1985), the Niagaran-Cayugan Series boundary is shown to be questionably correlative with the middle Ludlovian. According to Shaver, the Moccasin Springs is largely Niagaran, and the overlying Bailey is Cayugan to Lower Devonian.

Bailey Limestone

The Bailey Limestone was named by Ulrich (1904) for the no-longer-extant community of Bailey's Landing on the Mississippi River in northern Perry County, Missouri. The Bailey is a unit of drab-colored, thin bedded, and cherty micritic limestone containing shale interbeds in the lower part (J. Weller and Ekblaw 1940, Croneis 1944).

The Bailey crops out extensively in the Jonesboro 7.5-Minute Quadrangle on both flanks of the Harrison Creek Anticline and along the Mississippi River bluff south of Atwood Ridge (Nelson and Devera 1994). It extends southward through the western part of the Mill Creek Quadrangle and underlies large areas of the McClure Quadrangle (Devera et al. 1994). Unfortunately, the few wells that penetrate the Bailey lack accurate and detailed logs.

The Bailey is composed of light brown to yellowish gray, argillaceous to finely silty, dolomitic lime mudstone. Throughout the Bailey, the bedding is thin and wavy, and abundant chert occurs as nodules, lenses, and discontinuous layers. Most of the chert in the upper part of the Bailey is off-white to yellow or orange, and it is somewhat porous. Nodular chert having a distinctive convoluted texture is common near the top. In the lower part of the Bailey, both limestone and chert are greenish and contain thin interbeds of greenish gray shale, which is transitional from the underlying Bainbridge Formation. Chert of the lower Bailey generally is dense and occurs in thin, wavy beds rather than in nodules.

The fauna of the Bailey is sparse. Sponge spicules, chitinozoans and conodonts, and sparse trilobite and echinoderm fragments are present. Most macrofossils are in the upper third of the formation. They include crinoid fragments and the trilobites *Huntonia palacea*, *Phacops* sp., and *Dalmanites* sp. The trace fossil *Zoophycos* is common in the upper part of the Bailey.

The contact with the overlying Grassy Knob Formation is gradational. An interval of chert nodules in a matrix of residual silt and clay marks the contact in the Jonesboro 7.5-Minute Quadrangle.

The Bailey is about 350 feet thick along the west flank of the Harrison

Creek Anticline, where exposures are best. South of the mouth of Harrison Creek, a 300-foot bluff is Bailey from top to bottom. The Bailey may be considerably thinner north of Harrison Creek on the west flank of the anticline in Sec. 9, T13S, R2W.

The Devonian–Silurian systemic boundary probably lies in the lower part of the Bailey. Uppermost Bainbridge strata contain Late Silurian fossils, whereas conodont studies (Collinson et al. 1967) indicate the upper Bailey is Lower Devonian. To date, the lower and middle Bailey have not yielded fossils useful for biostratigraphic zonation.

Grassy Knob Chert

The Grassy Knob Chert was named by Savage (1925) for a locality about 10 miles north of the study area in Jackson County, Illinois. At the type section, the Grassy Knob overlies the Bailey Formation and is overlain by the Backbone Limestone. The Backbone pinches out south of the Grassy Knob type section and does not occur in the Jonesboro Quadrangle (Devera 1994).

The Grassy Knob crops out on both limbs of the Harrison Creek Anticline and in large areas of the western Mill Creek and eastern McClure Quadrangles. The upper part of the Grassy Knob is exposed in the southeastern part of the Mill Creek Quadrangle. This unit erodes to a very rugged topography and caps high hills such as Atwood Ridge in the Jonesboro Quadrangle and Pine Knob in the Mill Creek Quadrangle. Massive chert beds of the Grassy Knob form discontinuous cliffs and ledges in many places.

Bedded chert and microcrystalline silica make up the Grassy Knob in outcrop. The chert is typically off-white to light gray, stained yellow or orange. Most chert is dense and novaculitic, medium to thick bedded, and very sparingly fossiliferous. Chert at the top of the Grassy Knob is persistently brecciated, and it overlies an interval of highly porous, “popcorn”-textured chert riddled with horizontal burrows. Lenses of brecciated chert occur lower in the formation. In the northern part of the area, nearly massive, ledge-forming chert occurs close to the middle of the Grassy Knob. The lower part of the Grassy Knob is predominantly dense, thick

bedded chert. In some places, this chert has been altered to white or very light gray, relatively soft and friable microcrystalline silica or tripoli, which resembles that of the younger Clear Creek Formation.

In the subsurface, the Grassy Knob is predominantly chert similar to that observed on the outcrop. Light gray, micritic to fine grained cherty limestone and dolomite occur near the top in a few wells.

The Clear Creek Formation overlies the Grassy Knob with a conformable, probably gradational contact throughout the study area. Lithologies of the Grassy Knob and Clear Creek are similar, and differentiating the two can be difficult. Abundance of fossils is perhaps the best criterion for differentiation. Only a few poorly preserved spiriferid (?) brachiopods have been found in the Grassy Knob, whereas the Clear Creek contains common, well preserved brachiopods and trilobites. Both Grassy Knob and Clear Creek are burrowed, but burrows typically are horizontal in the Grassy Knob and vertical in the Clear Creek. The Grassy Knob contains fewer clay partings and more stylolites than does the Clear Creek. Dense, thick bedded, brecciated and “popcorn” chert are more typical of Grassy Knob than Clear Creek, as are yellow to off-white colors. The Grassy Knob contains less microcrystalline silica than does the Clear Creek.

The Grassy Knob and Clear Creek were not differentiated in two parts of the quadrangle. The larger area is in the central and south-central part of the Mill Creek Quadrangle; the smaller area is in the Ware Quadrangle. The rocks are highly silicified in both areas, blurring lithologic differences; lack of outcrops and structural complexity further hamper interpretation.

The Grassy Knob is about 200 to 250 feet thick in the Jonesboro 15-Minute Quadrangle. No thickness trends are evident.

Clear Creek Formation

The Clear Creek Chert was named by Worthen (1866) for Clear Creek in the Cobden Quadrangle, north of the Jonesboro Quadrangle. Worthen did not specify a type section, and his description of the limits of the Clear Creek is vague. Savage (1920a) restricted the Clear Creek to strata

between the Backbone Limestone (or Grassy Knob Chert where the Backbone is absent) and the Grand Tower Limestone. Savage’s definition is used here. The unit is called Clear Creek Formation rather than Clear Creek Chert because the unit is composed of limestone in some areas.

The Clear Creek Formation has the largest outcrop area of any bedrock formation in the study area. It crops out through most of the western and southeastern parts of the Mill Creek Quadrangle, much of the western Jonesboro 7.5-Minute Quadrangle, and portions of the Ware and McClure Quadrangles. Many wells have been drilled into the Clear Creek but, unfortunately, most lack detailed logs and none completely penetrate the formation.

The Clear Creek erodes to a very steep and rugged topography that is characterized by deep V-shaped ravines and sharp-crested ridges. The drainage pattern is largely dendritic, but a trellis pattern, indicative of structural control, is developed in parts of the Mill Creek Quadrangle. Despite the steep topography, outcrops of the Clear Creek are small and fragmentary. Most information on the Clear Creek comes from man-made exposures in silica mines and quarries.

The Clear Creek Formation is 300 to 400 feet thick in the Jonesboro 7.5-Minute Quadrangle and 200 to 300 feet thick in the Mill Creek and McClure Quadrangles. Uncertainties arise from poor exposure, complicated structure, and the locally problematic lower contact. The Clear Creek and Grassy Knob cannot be differentiated in any well logs in the study area. In a well in Sec. 9, T15S, R1E, Pulaski County, the Clear Creek apparently is 550 feet thick and overlies Backbone Limestone. Northeast of the study area, in a well in Sec. 35, T11S, R1W, the Clear Creek overlies Backbone and is 419 feet thick. Thus, available data indicate that the Clear Creek thickens from the Ozark Dome to the Illinois Basin.

Two distinct lithologies of the Clear Creek are present in the study area. The “normal” or unaltered lithology, found mainly in the northern Jonesboro 7.5-Minute Quadrangle, is limestone that contains chert lenses and layers. The “altered” lithology, found in most of the Mill



Figure 6 Manmade exposure of the Clear Creek Formation near the NW corner, Sec. 11, T14S, R2W, Mill Creek Quadrangle. The photo shows thin alternating layers of tripoli (white) and hard bedded chert (dark). Note the gently undulating layers and minor faults.

Creek and southern Jonesboro Quadrangles, is bedded chert and microcrystalline silica (tripoli).

Unaltered lithology The unaltered lithology of the Clear Creek Formation is limestone containing subordinate bands and nodules of chert. Typical exposures occur along tributaries of Cany Creek in the western part of Sec. 10 and the northernmost part of Sec. 15, T12S, R2W. In these areas and elsewhere, the limestone is uniformly light gray and light brownish gray, faintly mottled, very siliceous lime mudstone. The texture is generally aphanitic, but some limestone appears very finely granular. Scattered bioclasts are present; they are largely echinoderm and trilobite fragments, as well as whole shells of strophomenid and spiriferid brachiopods. Brachiopods are common in the upper part of the Clear Creek and uncommon in the middle and lower parts. Bedding is thin and wavy to nodular; most beds are 1 to 4 inches

thick, but occasional layers reach 1 foot in thickness. Some limestone near the top of the Clear Creek is silty to finely sandy, as reported by Allen (1985) and also as can be found in sample logs from some wells in the study area.

Chert in unaltered Clear Creek is dull white to light gray, slightly mottled, and resembles unglazed porcelain. In the upper Clear Creek, chert occurs in distinct lenticular beds and layers of nodules, 1 to 4 inches thick. Downward, chert generally blends into the enclosing limestone. Chert of the middle and lower Clear Creek is mostly tripolitic and calcareous, grading to highly siliceous limestone. Contacts between tripolitic chert and limestone are intricately intergrown; in places, the rock is chert with "nodules" of limestone. This type of rock exfoliates on weathered surfaces of stream banks. Digging into unweathered rock yields siliceous limestone and lesser amounts of chert, similar to that found near the top of the Clear Creek.

The Clear Creek is fossiliferous, particularly in the upper part. Forms identified include *Dalmanites prat-teni*, *Phacops cristata*, *Odontochile* sp., *Leonaspsis* sp., *Cordania* sp., *Eodevonia arcuata*, *Strophostylus cancellatus*, and *Amphigenia curta*. Strophomenid and spiriferid brachiopods and echinoderm fragments are particularly common. Trace fossils include vertical burrows, borings in brachiopod shells, and large domichnia cavities.

Altered lithology Where it is altered, the Clear Creek Formation is composed of chert and microcrystalline silica. Limestone was leached out and/or replaced by silica. Altered Clear Creek is found in much of the study area (see the red dashed lines on the geologic maps of Nelson and Devera 1994, and Devera et al. 1994). Well records show that the Clear Creek is altered to at least 400 feet below the surface in some places.

Bedded chert of the altered Clear Creek is mottled white to light gray,



Figure 7 Abandoned underground silica mine in white tripoli of Clear Creek Formation, overlain by hard, fractured, brownish orange bedded chert. The tunnel was driven through the crest of a ridge; it served room-and-pillar workings within the ridge and also provided a haulage road to mines on the other side of the ridge. The location is in the SE NE, Sec. 23, T14S, R2W, Mill Creek Quadrangle.

commonly stained red, yellow, and orange. The chert is dull to slightly vitreous. Some of it is vuggy, containing irregularly shaped cavities and vertical cylindrical tubes (burrows?) less than 0.5 inch in diameter. Bedding is thin, lenticular, and undulating. Occasional beds, as much as 2 feet thick, of vuggy to partly brecciated chert are interspersed with thinly bedded chert. All this rock is closely fractured and faulted; it is folded into small open synclines, anticlines, and monoclines. Dips steeper than 20° are uncommon, except along large faults.

Unlithified clay, silt, and fine sand occur along bedding planes and fractures in altered Clear Creek. Unweathered clay commonly is light gray to greenish gray and grades, in part, to silt and fine sand composed of chert and tripoli fragments. Weathered clay is commonly reddish or orange brown. Most clay layers are less than 2 inches thick. Lamar (1953) attributed clay layers to dissolution of argillaceous lime-

stone. Some clay, silt, and sand is distinctly laminated, however, indicating deposition from water in open fissures and cavities. Good exposures of fissures filled with laminated sediment occur along Jackson Creek in the NW NW, Sec. 24, T14S, R2W, Mill Creek Quadrangle. Other clay layers and veins are not laminated and pinch and swell in irregular fashion, indicating that clay was injected into fissures in the rock.

Altered Clear Creek contains the same fossils as unaltered limestone. Fossils are generally well preserved and are most abundant near the top of the formation.

Soft microcrystalline silica (tripoli) is interlayered with bedded chert in the altered Clear Creek Formation (figs. 6, 7). Most tripoli layers are 3 to 10 feet thick, but they rarely reach 50 feet or more. In some exposures, chert and tripoli are thinly interbedded (fig. 6). Layers are somewhat lenticular, although little information is available on their lateral extent. The purest form of tripoli is

nearly white, soft enough to be dug with hand tools, and indistinctly bedded. Most tripoli, however, is partly stained orange and red, and contains thin layers and lenses of friable to hard, fractured, bedded chert.

Large clean exposures of interbedded tripoli and chert are in the active Lone Star Industries open-pit mine (NE NW, Sec. 15, T14S, R2W) and the abandoned Jason no. 2 open-pit mine (near the center of the SE, Sec. 22, T13S, R2W, Mill Creek Quadrangle). Tripoli also is visible at the portals of many abandoned underground silica mines (fig. 7).

Chert of the altered Clear Creek Formation forms ledges and small cliffs along steep hillsides and ravines in parts of the Mill Creek Quadrangle. Ledges as high as 50 feet occur just north of the center of the west line of Sec. 27, T14S, R2W. Other extensive exposures are in the southeastern and west-central parts of Sec. 14, T14S, R2W. Ledge-forming chert is indicated with a stippled pattern on the Mill Creek geologic

map (Devera et al. 1994). This chert is white to light gray and grayish orange; weathered surfaces are commonly dark gray and very rough and jagged. It is dull to slightly vitreous, very hard, and more or less vuggy due to selective weathering of burrows and trackways produced by organisms prior to lithification of the lime mud. From a distance, the chert appears thickly bedded to massive; but, on close examination, thin, crinkly, and undulating bedding is evident on many layers. Much of the ledge-forming chert is recemented intraformational breccia of angular chert fragments and shows residual layering (fig. 8). Ledge-forming chert grades laterally within short distances to poorly exposed thin bedded chert and tripoli.

Contrary to the interpretation of Berg and Masters (1994), this ledge-forming chert is not confined to any particular stratigraphic levels in the Clear Creek. In some areas, particularly in Sec. 14, T14S, R2W, ledge-forming chert follows northeast-trending faults or fracture zones. In the western Mill Creek Quadrangle, massive or brecciated chert commonly crops out at the tops of steep slopes, forming a "caprock" beneath Quaternary surficial materials. Such chert apparently is a product of surficial weathering.

The only good exposure of the Clear Creek–Grand Tower contact is in the bank of Sexton Creek behind Pleasant Valley Church in the NW NW, Sec. 21, T14S, R2W, Mill Creek Quadrangle. Here the Dutch Creek Sandstone lies with sharp, uneven contact on a breccia of chert fragments, angular sandstone clasts, and contorted sandstone laminae in a matrix of soft clay (fig. 9). This breccia may be insoluble residue of a sandy, argillaceous limestone. Although the sharp contact at the base of the sandstone bed indicates a disconformity, the presence of sandstone in the breccia suggests a gradational, conformable contact.

Elsewhere in the study area the contact is covered or is obscure because of leaching, silicification, in situ brecciation, and faulting. The Clear Creek Formation lacks marker beds that might aid detection of a disconformity (if present). Thickness variations of the Clear Creek are too poorly known to assess possible pre-Grand Tower erosion.



Figure 8 Ledge-forming chert of Clear Creek Formation in the S½ SW SE, Sec. 14, T14S, R2W, Mill Creek Quadrangle. Although the chert is brecciated, the bedding is partially intact.

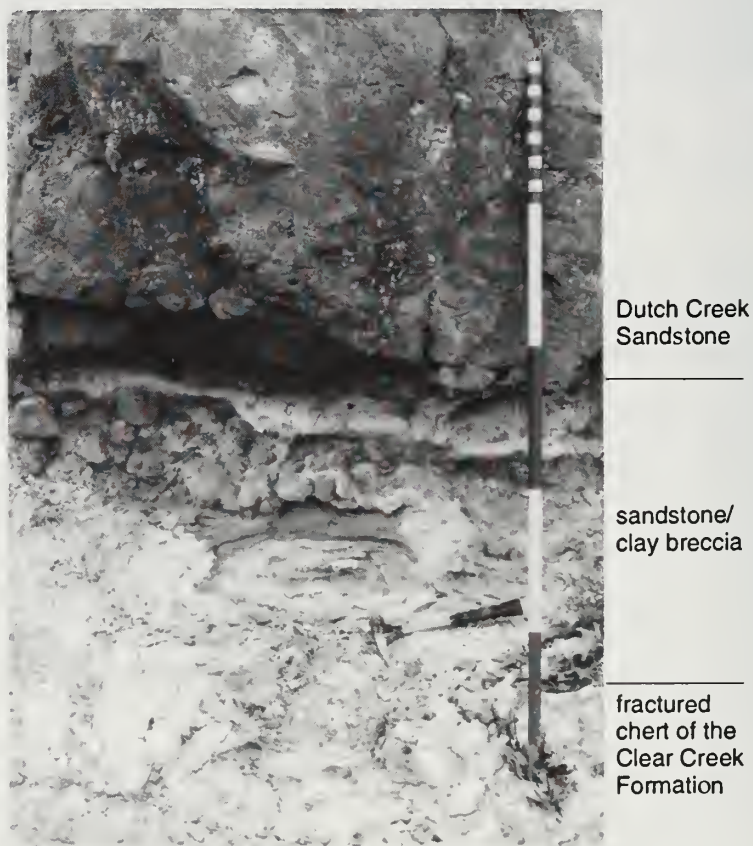


Figure 9 Contact of Dutch Creek Sandstone (above) to Clear Creek Formation. The sandstone contains numerous well preserved molds of fossils. Underlying the sandstone (middle of photo) is an interval of angular sandstone clasts in a matrix of sandy clay. Fractured chert is below that; clay is injected into the fractures. The staff is 5 feet long.



Figure 10 Brecciated Dutch Creek Sandstone, consisting of angular sandstone clasts cemented by silica and iron oxide. Location is the SE NW NW, Sec. 23, T13S, R2W, Mill Creek Quadrangle.

Grand Tower Limestone

The Grand Tower Limestone was named for Grand Tower (Jackson County, Illinois), which is about 10 miles northwest of the study area (Keyes 1894). At the type locality, the Grand Tower is predominantly light-colored, slightly sandy, and cherty limestone. The Dutch Creek Sandstone Member is at the base.

The outcrop of the Grand Tower extends due south from the center of the north line of the Jonesboro 7.5-Minute Quadrangle to the center of the north line of the Mill Creek Quadrangle, and thence south-southeast to the Cache Valley south of Elco. Downfaulted inliers occur west of the main outcrop belt. There is no limestone in the Grand Tower in much of the study area; only the Dutch Creek Sandstone is present. Where limestone is present (northern part of Jonesboro 7.5-Minute Quadrangle), the Grand Tower was mapped as a separate unit. Where limestone is absent, the thin Dutch Creek and the overlying St. Laurent Formation were combined as a single map unit.

The Grand Tower thins southward in the study area. Four well logs in the northeast quarter of the Jonesboro 7.5-Minute Quadrangle indicate thicknesses of 58 to 125 feet. In the Mill Creek Quadrangle, where only the Dutch Creek Sandstone is present, the Grand Tower is only 10

to 25 feet thick. Records of four wells in the Dongola Quadrangle, just east of the Mill Creek Quadrangle, indicate that the Grand Tower is less than 10 to about 40 feet thick in this area. Only two of these wells encountered limestone in the upper Grand Tower.

The Grand Tower Limestone in southwestern Illinois is assigned to the Eifelian Stage, or lower part of the Middle Devonian Series. The equivalent unit in western Kentucky and southwestern Indiana is the Jeffersonville Limestone (Shaver 1985).

Dutch Creek Sandstone Member Savage (1920a) named the Dutch Creek Sandstone for Dutch Creek in the Jonesboro 7.5-Minute Quadrangle. No type section was designated, but the unit is well exposed on the west-facing bluff near the mouth of Dutch Creek in the NE, Sec. 19, T12S, R2W. The Dutch Creek originally was a separate formation, but was revised to a member of the Grand Tower by Meents and Swann (1965).

The Dutch Creek is white to very light gray, very fine to medium grained quartz arenite, composed of subrounded to well rounded and frosted quartz grains. The sandstone crops out as broken ledges, but it is more commonly found as large blocks displaced downslope by soil creep. Bedding is slightly irregular and indistinct, and generally 0.5 to 3 feet thick. Molds of fossils are pres-

ent in most exposures, particularly spiriferid brachiopods, bivalves, rugose corals, conularids, the problematic fossil *Pleurodictyum*, crinoid stems, and poorly defined burrows. Well samples indicate that the sandstone commonly has calcite cement.

The Dutch Creek commonly is brecciated in the area of altered rocks in the southern Jonesboro and Mill Creek Quadrangles. The breccia consists of sandstone clasts as large as 2 feet across, as well as lesser amounts of light-colored chert clasts, which are cemented by silica and iron oxide (fig. 10). Clasts commonly have rounded corners and fit adjacent clasts in jigsaw-puzzle style, showing that little fragment displacement occurred after the rock was shattered. In many outcrops, only certain layers are brecciated and adjacent layers are undisturbed. Joints, where present, penetrate both clasts and matrix. Evidently, jointing took place after the sandstone was brecciated and recemented.

The Dutch Creek contains a basal conglomerate on the south face of Burner Hill, about 1,800 feet from the south line and 2,000 feet from the east line, Sec. 24, T14S, R2W. The conglomerate consists of scattered angular light gray chert granules and silicified crinoid, bryozoan, and horn-coral fragments in a matrix of sand cemented by iron oxide. The conglomerate indicates a disconformity at the base of the Dutch Creek. The Dutch Creek typically is 10 to 15 feet thick, but it reaches 25 feet. The upper contact is gradational.

Unnamed limestone member

The unnamed, upper limestone member of the Grand Tower crops out in the northern half of the Jonesboro 7.5-Minute Quadrangle and is present in wells east of the outcrop belt in and near the study area. The lower part of the limestone member is typically white to light gray, fine to coarse grained skeletal grainstone that contains little, if any, silt and clay. The upper part is largely darker colored skeletal packstone and wackestone. The limestone member is medium to thick bedded throughout, commonly crossbedded, and slightly cherty. Some limestone in well cuttings contains well rounded, frosted quartz sand, similar to that of the Dutch Creek. Fossils include echinoderm fragments and abundant whole and broken brachiopods,

corals, and trilobites. Large crinoid stems and chonetid brachio-pods are abundant in the upper Grand Tower.

Good exposures of the limestone member were found in three places in T12S, R2W: in the bank of Green Creek just south of Illinois route 146, NW NE NW, Sec. 23; in a tributary of Cany Creek just east of route 127 north of the center of Sec. 10; and on the west-facing bluff in the W½ SE SE, Sec. 19.

The limestone member of the Grand Tower is absent in the south half of the Jonesboro 7.5-Minute Quadrangle and in the Mill Creek Quadrangle. In some areas, plastic clay and silt containing nodules, lenticular beds, and fragments of light-colored, dense, dull to slightly vitreous chert were found at the position of the limestone. A good exposure can be found in the south bank of the creek in You-Be-Damned Hollow in the SE SW NW, Sec. 35, T13S, R2W. The material is thought to be insoluble residue from dissolution of the limestone.

The contact with the overlying St. Laurent Formation is generally sharp. Regionally, this contact is reported to be disconformable on the margins of the Illinois Basin, and becomes conformable toward the center of the basin (Meents and Swann 1965, Shaver 1985).

St. Laurent Formation

Dake (1918, p. 175) and S. Weller and St. Clair (1928) defined and mapped the St. Laurent Formation in Ste. Genevieve County, Missouri. The type section comprises steeply dipping strata, 275 feet thick, along St. Laurent Creek. Strata equivalent to the St. Laurent in southern Illinois were named the Alto and Lingle Formations and the Misenheimer Shale by Savage (1920a). Savage did not map these units, and his descriptions of them are sketchy. Geologists who later mapped in southern Illinois combined the Misenheimer, Lingle, and Alto as a single unit, and they recommended the name St. Laurent be adopted (J. Weller and Ekblaw 1940, J. Weller 1944). Nevertheless, the names Alto and Lingle persisted in Illinois literature (fig. 11). The Misenheimer Shale eventually was reduced to a member of the Lingle (North 1969).

We are formally extending the St. Laurent Formation into Illinois and rejecting the Alto and Lingle Formations. The Lingle and Alto Formations cannot be distinguished reliably either in outcrop or in subsurface. Even at the type localities, the Lingle and Alto are not lithologically distinct. Comparison of sections (fig. 12) shows that the St. Laurent contains siliciclastic and carbonate rocks that intertongue in

complex fashion. It is not a layer-cake succession, as visualized by North (1969) and other workers. The only subdivision of the St. Laurent we could identify was the Rendleman Oolite Bed (fig. 11), and we are not certain that this is a single bed.

A conodont study by Orr (1964) indicated that the St. Laurent ranges from Givetian (late Middle Devonian) to early Frasnian (early Late Devonian). Shaver (1985) assigned the St. Laurent Formation to the Givetian Stage. The St. Laurent is equivalent to the Sellersburg Limestone in western Kentucky and the North Vernon Limestone in Indiana (Shaver 1985).

Unaltered lithology The St. Laurent Formation is an interval of limestone, dolomite, shale, and siltstone, all of which intertongue in complex fashion (fig. 12). The carbonate rocks are mostly dark, micritic, cherty, and very argillaceous to silty. Medium to dark gray, olive gray, and brownish gray are the usual colors. A dark punky rind develops on weathered surfaces. Much of the rock is dolomitic lime mudstone, lithographic to very finely granular, containing scattered bioclasts. Bedding is thin, typically 1 to 6 inches. Chert commonly composes 20% to 30% of the rock and occurs as small ovoid or irregular

Savage 1920a	Cooper et al. 1942	Orr 1964 and Norton 1966	North 1969	This report	
Mountain Glen Shale	Mountain Glen Shale	Grassy Creek Shale	Grassy Creek Sh in New Albany Group	New Albany Shale	
Alto Formation	Alto Formation	Alto Formation	Alto Formation		
Lingle Formation	Lingle Formation	 Lingle Limestone Misenheimer Shale (facies)	Lingle Formation Walnut Grove Ls Member Misenheimer Sh Member Tripp Ls Mbr Howardton Ls Member	 Rendleman Oolite Bed	
Misenheimer Shale	St. Laurent Fm			St. Laurent Fm	
Grand Tower Limestone	Grand Tower Limestone			Grand Tower Limestone	Grand Tower Ls
Dutch Creek Sandstone	Dutch Creek Sandstone			Dutch Creek Sandstone	Dutch Crk Ss Mbr

Figure 11 Chart showing development of lithostratigraphic classification of Middle and Upper Devonian strata in southwestern Illinois.

nodules and as discontinuous layers. It is dark gray to black, somewhat vitreous, and dense.

A bed or lens of light gray coarse crinoidal and oolitic grainstone 1 to 4 feet thick was observed at several outcrops and in cuttings of several wells (fig. 12). This is probably the Rendleman Oolite Bed of North (1969). Oolitic limestone generally occurs near the middle of the St. Laurent, near the base of a limestone interval and overlying an interval of shale and siltstone. The best outcrop is in the bank of Darty Creek, 900 feet from the south line and 700 feet from the east line of Sec. 10, T12S, R2W, Jonesboro 7.5-Minute Quadrangle. (The name "Darty Creek" does not appear on the topographic map; the creek shown at this location bears no name. The name was used by J. Weller and Ekblaw [1940] and in several subsequent publications, and there is no doubt regarding the location of the outcrop.) Available data are insufficient to show whether the oolitic limestone represents a single bed or a series of lenses.

The St. Laurent contains echinoderm stems and plates, spiriferid and chonetid brachiopods, fenestrate bryozoans, trilobites, and rugose corals. Silicified corals are abundant in the lower part. A diagnostic fossil of the basal St. Laurent is the "button coral" *Microcyclus discus*.

Shale and siltstone constitute less than 20% to more than 80% of the St. Laurent in the study area. These rocks vary from light gray, olive gray, brownish gray, and dark gray to nearly black; they are generally calcareous or dolomitic, grading to argillaceous and silty carbonate rock. Shale and siltstone are fissile and have well developed planar to slightly wavy or lenticular laminations. Trace fossils (vertical and horizontal burrows and escape structures) are common, but body fossils are rare. Some siltstone grades to very fine grained, thinly bedded sandstone. Dark brown to dark gray vitreous chert nodules and bands occur in shale and siltstone at some outcrops.

The succession of beds in the St. Laurent is highly variable (fig. 12). In general, there is more carbonate rock in the upper portion and more shale and siltstone in the lower portion. The siliciclastic content is much

higher in the study area than elsewhere in southern Illinois. Outside of the Jonesboro Quadrangle, the St. Laurent generally consists of argillaceous and silty carbonate rocks with only thin shale interbeds.

Thickness of the St. Laurent in the study area ranges from 80 to 200 feet, thinning southward. Regionally, the St. Laurent is thickest in Union County, Illinois, and Perry and Ste. Genevieve Counties, Missouri (North 1969).

The St. Laurent is overlain discontinuously by the New Albany Shale or by the Springville Shale where the New Albany is absent. The St. Laurent–New Albany contact is exposed (digging may be necessary) along Darty Creek, in the SW NW SW, Sec. 11, T12S, R2W. Springville directly overlies St. Laurent in a streambank near the center of the south line of Sec. 1, T13S, R2W, and at the south border of the Jonesboro 7.5-Minute Quadrangle in the east bank of the large stream in the NW, Sec. 23, T13S, R2W. At the latter outcrop, the upper surface of the St. Laurent is thickly encrusted with a botryoidal black mineral thought to be manganese oxide.

Altered lithology Carbonate rocks have been dissolved and siltstones and shales bleached in the area of altered rocks, as indicated on the geologic maps of Nelson and Devera (1994) and Devera et al. (1994). Shales typically are dull white to light yellowish gray, locally mottled, and banded with pale green, pink, and violet. Lamination and fissility are preserved. Most altered rock is very porous and low in density. Such rock probably was originally limestone or dolomite with a high silt/clay content. Dark brownish gray vitreous chert layers and nodules are common in altered St. Laurent. The St. Laurent is difficult to distinguish from the Springville Shale in areas where it has been strongly altered.

New Albany Shale

The Upper Devonian/Kinderhookian black shale in southern Illinois has been alternatively called Chattanooga, Mountain Glen, Grassy Creek, and New Albany Shale by various geologists. The name New Albany Shale (Borden 1874) has priority and is accepted by most recent authors. Although some

geologists (e.g., Collinson et al. 1967, Cluff et al. 1981) classify the New Albany as a group in Illinois, it is ranked as a formation in this report because it cannot be subdivided.

The New Albany is very dark gray to black, brittle, highly fissile, siliceous or finely silty shale. It weathers to dark olive gray or brownish gray and splits into paper-thin layers. The uppermost 1 foot of the shale is less fissile and is mottled in dark greenish gray and olive gray. The only common fossil is *Tasmanites*, an algal test that is called "spores" or "Sporangites" in many sample logs and older reports.

A very thin sandstone or sandy zone occurs locally at the base of the New Albany. Several authors called this zone the Sylamore Sandstone at formation rank (Collinson and Scott 1958, Collinson and Atherton 1975, Cluff et al. 1981). Clearly, a unit that is only a few inches thick should not be classified as a formation. The Sylamore Sandstone in southern Illinois is herein revised to the Sylamore Sandstone Bed in the New Albany Shale. Exposures of the Sylamore Bed are reported in the bank of Darty Creek, in the SE SE, Sec. 10, T12S, R2W, Jonesboro 7.5-Minute Quadrangle (Collinson and Scott 1958), and the bank of Clear Creek in the N½ NE NE, Sec. 34, T11S, R2W, Cobden Quadrangle (Orr 1964, p. 3). Digging is required to reveal these occurrences.

The New Albany is absent in most of the area of altered rocks. The only New Albany we observed in the altered area was float in a stream bank near the center of the east line of Sec. 2, T14S, R2W, and shale that had been cast out from a manmade pit about 0.5 mile south of the stream. The shale at those places did not differ noticeably from normal New Albany.

The New Albany is 55 feet or thinner in most of the study area, but it may reach 80 feet in Sec. 29, T12S, R2W (fig. 13). The New Albany is absent as a result of pre-Springville erosion in the southeastern Jonesboro 7.5-Minute Quadrangle and in most of the Mill Creek Quadrangle. Eastward, in the Dongola Quadrangle, the New Albany thickens to 50 to 110 feet. About 60 miles east of the study area, the New Albany reaches a maximum of more than 450 feet (Cluff et al. 1981).

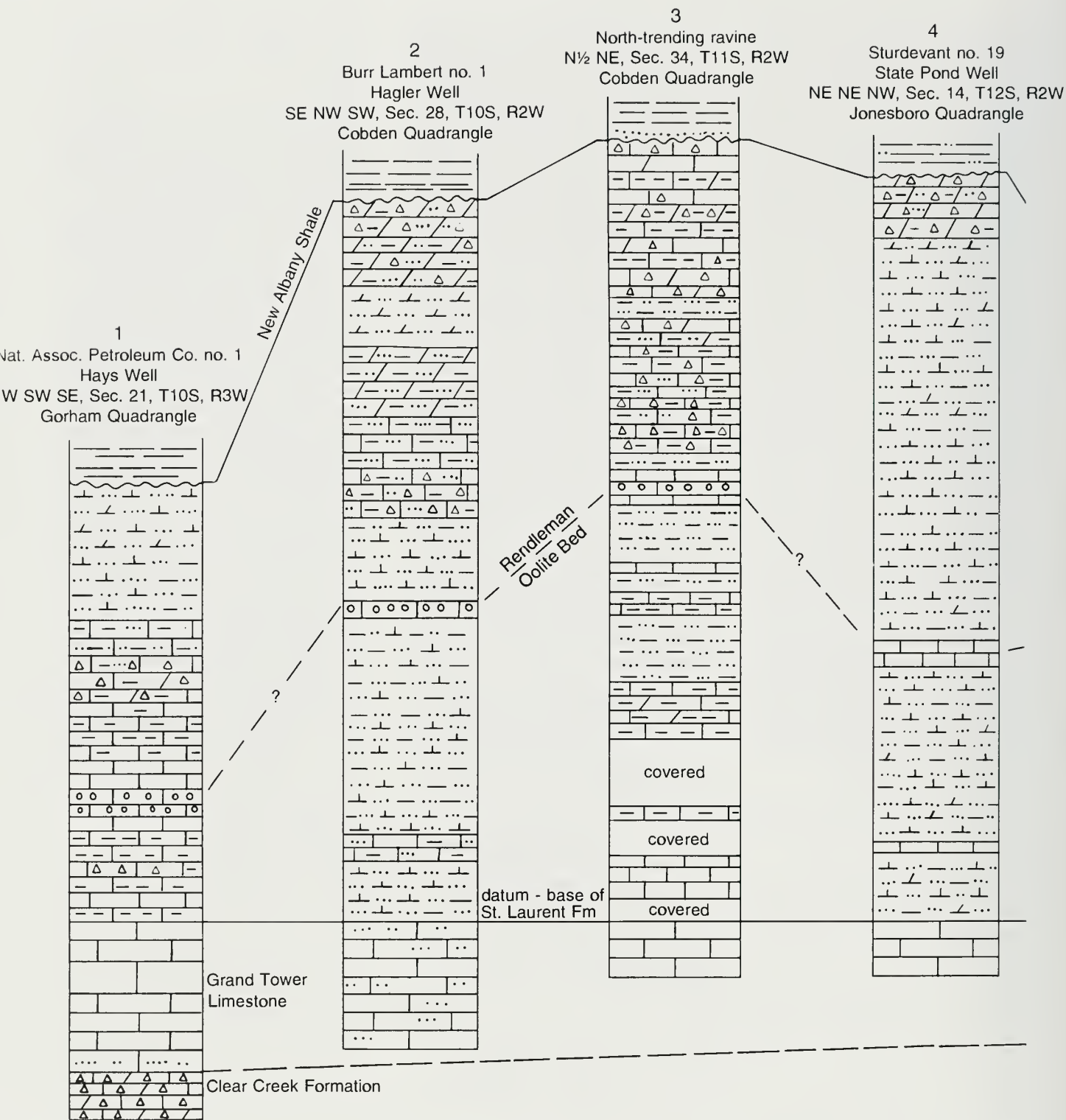
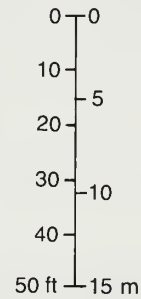
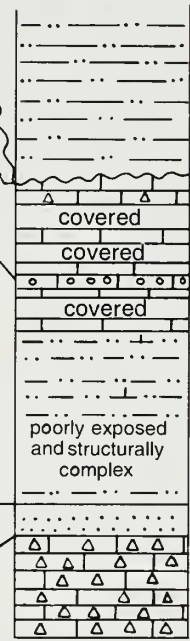
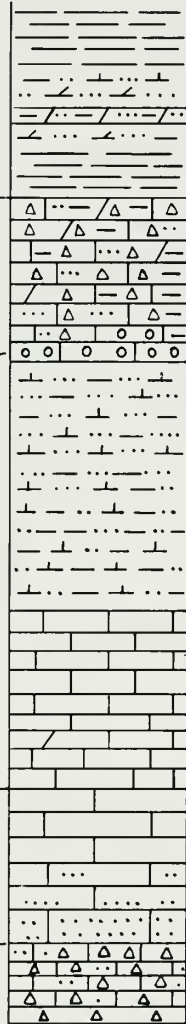
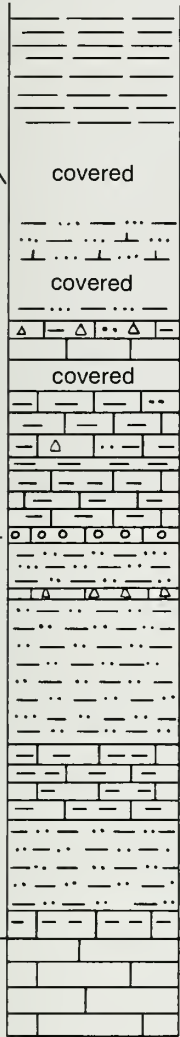
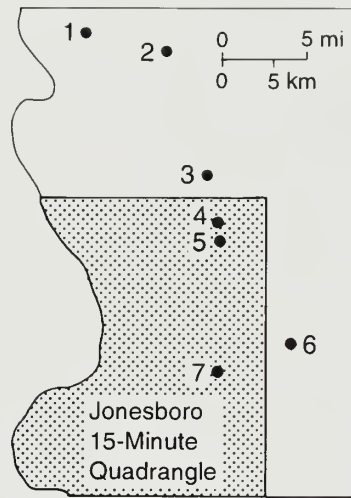


Figure 12 Graphic columns illustrating the lithologic variability of the St. Laurent Formation in and near the study area. (1) National Associated Petroleum Company no. 1 Hays well: the column was made on the basis of electric log and sample study by Elwood Atherton. (2) Burr Lambert no. 1 Hagler well: the column was made on the basis of electric log and sample study by Howard Schwalb. (3) North-trending ravine: the column is a measured section by Orr (1964) and Norton (1966). This is

5
Roadcut ravine on south side
of Route 146
NE NE NW, Sec. 23, T12S, R2W
Jonesboro Quadrangle

6
Rigney no. 1
Hileman Well
NW SE SW, Sec. 21, T13S, R1W
Dongola Quadrangle

7
Streambed and adjacent
hillside, Lingle Creek
E½ SW SW, Sec. 26, T13S, R2W
Mill Creek Quadrangle



the type section of the Alto Formation (Savage 1920a). (4) Sturdevant no. 19 State Pond well: the column was made on the basis of sample study by George Ekblaw. (5) Roadcut and ravine: the measured section is by Norton (1966) and W.J. Nelson. (6) Rigney no. 1 Hileman well: the column was made on the basis of sample study by Elwood Atherton. (7) Streambed and adjacent hillside: the measured section is by Norton (1966). This is the type section of the Lingle Formation (Savage 1920a).

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NEW ALBANY SHALE

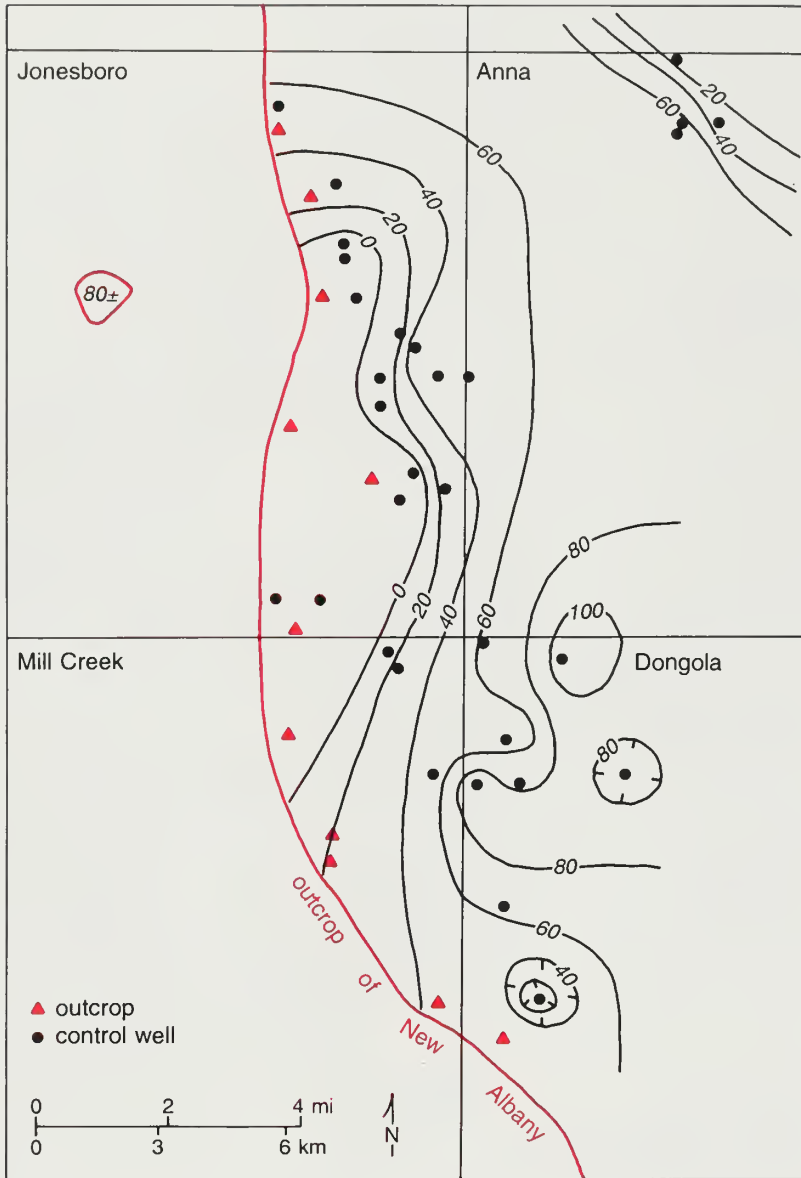


Figure 13 Isopach map of New Albany Shale. Contour interval is 20 feet.

The New Albany is disconformably overlain by the Springville Shale throughout the study area. The contact is well exposed at the spillway of State Pond in Sec. 14, T12S, R2W, Jonesboro 7.5-Minute Quadrangle, and in the south bank of Darty Creek, in the SW NW SW, Sec. 11 of the same township.

The age of the New Albany in Illinois ranges from late Givetian through Kinderhookian (Early Mississippian) (Shaver 1985). Considering that the New Albany in the report area is thin, and bounded above and below by disconformities,

the shale here is probably entirely Late Devonian.

Chouteau Limestone

Savage (1920a) observed thin calcareous lenses at the base of the type Springville Shale in the Mill Creek Quadrangle; J. Weller (1948) proposed the name Darty Limestone for these lenses. Later, Workman and Gillette (1956) and Collinson and Scott (1958) correlated the unit with the Chouteau Limestone (of Swallow 1855) and suppressed the name Darty. The name Chouteau is now generally accepted. Because it is less than 10 feet thick in southern Illinois

(Workman and Gillette 1956), the Chouteau does not meet the standard of mappability required for a formation (North American Stratigraphic Code, Article 24d). The unit probably should be reclassified as a member in southern Illinois, yet the Chouteau is not allied lithologically to either the New Albany Shale below or the Springville Shale above. The matter of rank of the Chouteau is thus deferred, pending further study.

The Chouteau is exposed at the spillway of State Pond in Sec. 14, T12S, R2W, and along Darty Creek, in the SW NW SW, Sec. 11, T12S, R2W, Jonesboro 7.5-Minute Quadrangle. Large float blocks of the limestone occur at several other sites north of Illinois route 146. The Chouteau also was identified in the logs of several wells near the east edge of the study area. It is about 1 foot thick at all of these places and was combined with the Springville Shale in mapping (Nelson and Devera 1994). The Chouteau is absent south of route 146.

The Chouteau is medium brownish gray lime mudstone that is mottled with greenish blue and contains scattered coarse fossil fragments, mainly echinoderm stems. The limestone is argillaceous, particularly near the base. Angular fragments of green clay, which were probably eroded from the subjacent New Albany Shale, are common. The upper contact is sharp, slightly irregular, and possibly disconformable. Collinson and Scott (1958) discussed a weathering profile in the Chouteau and overlying shale at the State Pond section but considered the disconformity local.

The Chouteau is assigned to the Kinderhookian Series on the basis of the conodont fauna (Collinson and Scott 1958).

Springville Shale

The Springville Shale was named by Savage (1920a) for the village of Springville, which is near the southeast corner of the Jonesboro 7.5-Minute Quadrangle. No specific type section was designated, but Savage listed several places near Springville where the shale is well exposed. The Springville is a unit of siliceous shale and siltstone, typically greenish gray where unaltered. Its thickness ranges from 8 to 88 feet (fig. 14).

State Pond Member The State Pond Member of the Springville Shale is a thin unit of soft greenish shale that directly overlies the Chouteau Limestone at the spillway of State Pond, in the SW NW SW, Sec. 14, T12S, R2W, Jonesboro 7.5-Minute Quadrangle (Collinson and Scott 1958). The member occurs elsewhere in the study area but is poorly exposed. It is composed of clay shale that is bright green to dark greenish or olive gray, mottled, soft, and slightly calcareous. Black, phosphatic (?) pebbles occur in the State Pond Member at the type locality. A few inches of quartz sandstone are at the base of the State Pond where it disconformably overlies the St. Laurent Formation southwest of Kornthal Church, in the SE SE SW, Sec. 1, T13S, R2W, Jonesboro 7.5-Minute Quadrangle. The State Pond Member is 1 to 5 feet thick and grades into overlying silty shale of the upper member of the Springville.

Collinson and Scott (1958) reported that the State Pond Member contains conodonts indicating earliest Valmeyeran age.

Upper member The upper (unnamed) member of the Springville Shale makes up 90% or more of the thickness of the formation. In areas where it is not altered, the upper member is composed of medium greenish gray to bluish gray silty or siliceous shale and siltstone. This rock is slightly fissile to blocky and occurs in irregular or lenticular layers 1 to 2 inches thick. The rock coarsens upward, and layering becomes thicker toward the top. Most of the shale and siltstone is only slightly calcareous, but the upper part approaches a silty limestone in some areas (e.g., along Darty Creek). Trace fossils, consisting of small burrows and trails, are uncommon; no body fossils were found. In places, the lower part contains discontinuous layers of clay shale that weathers chocolate brown to purplish brown. Small quartz-filled vugs occasionally can be found in the upper part of the Springville.

Good exposures of the upper member can be seen at the Darty Creek and State Pond localities, as well as in a roadcut and adjacent abandoned shale pit in the NE, Sec. 23, T12S, R2W. Outcrops also are common along the creek south-

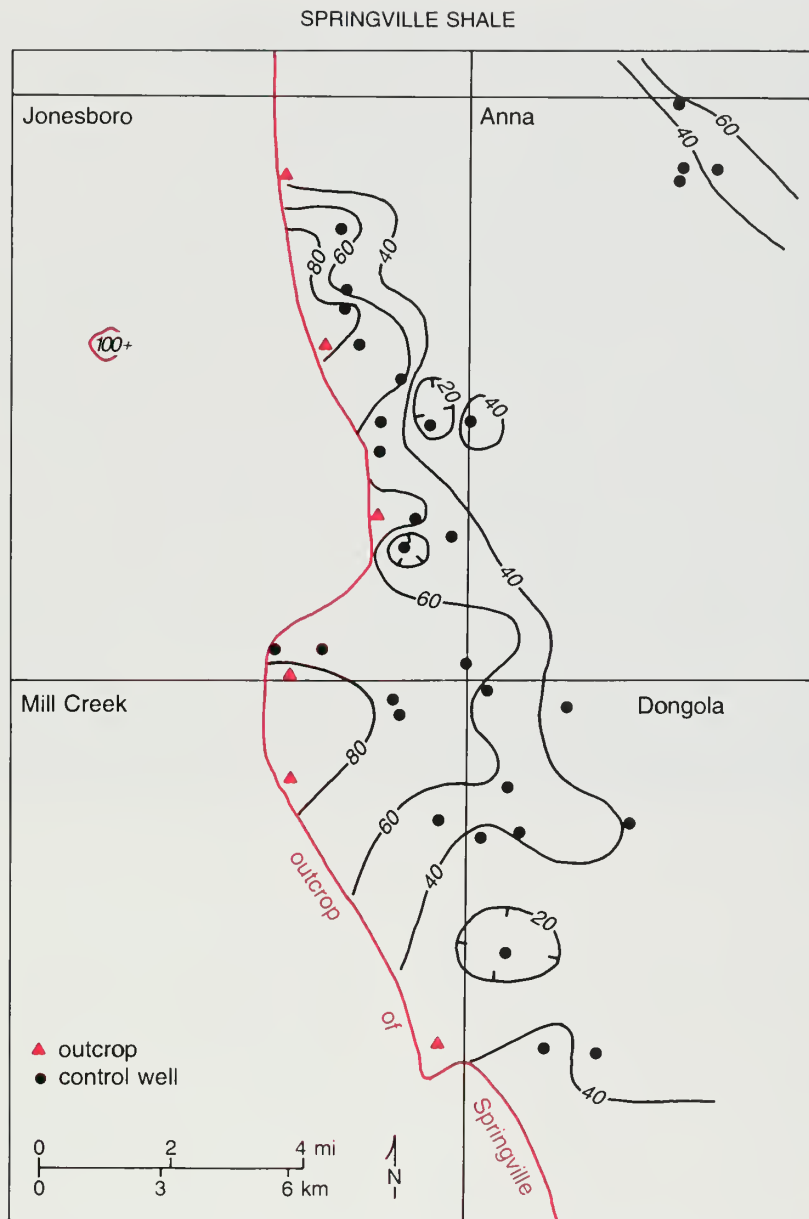


Figure 14 Isopach map of Springville Shale. Contour interval is 20 feet.

west of Kornthal Church in Sec. 1, T13S, R2W. The upper contact is exposed just south of the church, and the lower contact just east of the road junction near the south line of Sec. 1.

The contact with the overlying Fort Payne Formation is well exposed in many places, and it is invariably sharp and planar or slightly uneven. As Collinson and Scott (1958) reported, this contact probably is disconformable. The top of the Springville was used as structural datum on the Jonesboro geologic map (Nelson and Devera 1994).

The Springville is 35 to 75 feet thick at most places in the study area; however, it ranges from 8 to 88 feet thick in the area. A comparison of the Springville (fig. 14) and New Albany isopachs (fig. 13) shows that the Springville commonly is thin in areas where the New Albany is thick and vice versa. This pattern indicates that the Springville filled depressions eroded into the New Albany.

The upper member of the Springville Shale is assigned to the lower part of the Valmeyeran Series (Collinson and Scott 1958, Shaver 1985).



Figure 15 Basal Fort Payne Formation and upper Springville Shale in the altered area. The closely jointed, tabular-bedded rock is "calico rock" of Springville. The dark crumbly material above is ganister of the Fort Payne. Locality is in You-Be-Damned Hollow, NE SE NE, Sec. 35, T13S, R2W, Mill Creek Quadrangle.

Altered lithology In the Mill Creek Quadrangle and part of the southern Jonesboro 7.5-Minute Quadrangle, the Springville Shale is altered to "calico rock" (Lamar 1953), a dull white to light gray siliceous rock that is banded and blotched with pink, magenta, and orange brown. Most "calico rock" has thin, flaggy bedding but, near the top of the Springville, blocky layers reach 12 to 18 inches thick (fig. 15). In some outcrops, "calico rock" occurs in tabular layers 4 to 8 inches (10–20 cm) thick, each layer separated by thinner intervals of ripple-laminated siliceous rock. "Calico rock" rings when it is struck with a hammer.

In some areas, the upper Springville is altered to dark brown or orange semivitreous chert that resembles the overlying Fort Payne Formation. In general, the lower part of the Springville is less strongly altered than is the upper part. Some of the lower Springville retains its green color, albeit slightly bleached.

In areas of intense alteration, the Springville and St. Laurent are diffi-

cult to distinguish. Both formations yield "calico" colors, although colors of the St. Laurent generally are paler than those of the Springville. Also, most of the altered St. Laurent contains nodules and thin bands of dark gray to brown vitreous chert, a feature that is absent in the Springville.

Fort Payne Formation

The Fort Payne is a formation of bedded chert and siliceous limestone, named for Fort Payne, Alabama (Smith 1890). The name Fort Payne was first used formally in Illinois by Lineback (1966). Previous authors used such names as Osage limestone, Burlington–Keokuk limestone, and Hartline chert.

Although Lineback (1966) stated that the Fort Payne does not crop out in the Jonesboro Quadrangle, we mapped it through the eastern Mill Creek and Jonesboro 7.5-Minute Quadrangles and northward into the Cobden Quadrangle. Fort Payne in this area is similar to typical Fort Payne in Alabama (Thomas 1972). Some rocks that Lineback assigned to the overlying Ullin Limestone are

actually Fort Payne. An interval of 49.5 feet of bedded chert, which Lineback (1966, p. 37) erroneously included in the Ullin type section, is actually Fort Payne.

Unaltered lithology Unaltered Fort Payne is dark-colored, highly siliceous and cherty, fine grained or micritic dolomite and dolomitic limestone. Typical colors are medium-dark to dark gray, olive gray, and brownish gray. Weathered surfaces are dark and commonly bear a porous rind of silica. Texture is micritic to very finely granular. Bioclasts, consisting of echinoderm fragments and small brachiopods, are uncommon. Bedding is uneven to wavy and relatively thin; most beds are 2 to 12 inches thick. The Fort Payne is commonly glauconitic; glauconite occurs as dark green to black grains, which are the size of fine sand. Small quartz geodes are common. Chert, which commonly makes up 20% to 30% of the rock, occurs as irregular bands and nodules that are dark gray to brown and dull. Weathered chert from the Fort



Figure 16 Siliceous limestone of the Fort Payne Formation cropping out north of Lingle Creek near the center of the SW, Sec. 30, T13S, R1W. This is a typical exposure of unaltered Fort Payne in the Mill Creek Quadrangle.

Payne is light to medium brownish gray and has coarse, wavy banding that resembles wood grain. In the northern Mill Creek Quadrangle, the Fort Payne commonly forms ledges, and weathered surfaces are rough and jagged. Weathering accentuates the layering, which is faint in fresh exposures (fig. 16). At unweathered exposures (such as the abandoned quarry near Illinois route 127 in the NE SW SW, Sec. 19, T13S, R1W), the Fort Payne is thick bedded limestone that has shaley partings spaced 1 to 3 feet apart.

Other good exposures of Fort Payne can be found in several areas: the bank of Darty Creek in the NW SW, Sec. 11, T12S, R2W; the roadcut along Illinois route 146 in the NE NE, Sec. 23, T12S, R2W; the streambed just south of Kornthal Church near the center of the E½, Sec. 1, T13S, R2W; and the south bank of the east-flowing stream in the SW SE, Sec. 13, T13S, R2W.

Contrary to the findings of Lineback (1966), the contact with the overlying Ullin Limestone is transitional throughout the study area. Dark, very siliceous lime mudstone

of the Fort Payne gradually changes upward to medium gray, very fine to fine grained skeletal limestone that contains less chert and disseminated silica. Intertonguing Fort Payne and Ullin can be seen in outcrops near the boundary of the Jonesboro and Mill Creek 7.5-Minute Quadrangles. In this area, the Fort Payne thickens southward from less than 20 feet to more than 100 feet within a distance of 0.5 mile.

The Fort Payne is thinnest, 15 feet or less, in the southeastern Jonesboro 7.5-Minute Quadrangle (fig. 17). In the northeastern Jonesboro Quadrangle, it thickens to 50 to 110 feet. The Fort Payne is 100 to 140 feet thick in the northeastern Mill Creek Quadrangle; a few miles farther east, well records show it to be 300 or more feet thick.

Altered lithology The altered Fort Payne Formation is composed of dense, hard, bedded chert and a granular form of microcrystalline silica, commonly called ganister.

The bedded chert is mottled or banded in brownish gray to orange gray. Banding is ropey or resembles

coarse wood grain. Chert is dull to slightly vitreous, dense to slightly vesicular, and commonly contains small quartz geodes. Beds are generally tabular and range from 1 to 24 inches thick, but most are 6 to 18 inches thick. The basal part is most strongly silicified.

Ganister (Lamar 1953) is granular, pelletal, and very porous. It is reddish orange, dark red, or burnt orange in most exposures, but it is white to light gray in some areas. It is more difficult to dig ganister from this formation than it is to dig tripoli from the Clear Creek Formation. The thin layering of the Fort Payne is preserved in ganister. Occasional layers of sticky orange to brown clay are present. Ganister grades laterally to unaltered siliceous limestone and bedded chert. Ganister grades to limestone along the bluff south of Lingle Creek in the SW SW, Sec. 30, T13S, R1W, Mill Creek Quadrangle. Ganister grades to bedded chert in roadcuts along Illinois route 127 just north of Elco, and also near abandoned ganister mines in the hills east of Elco.

FORT PAYNE FORMATION

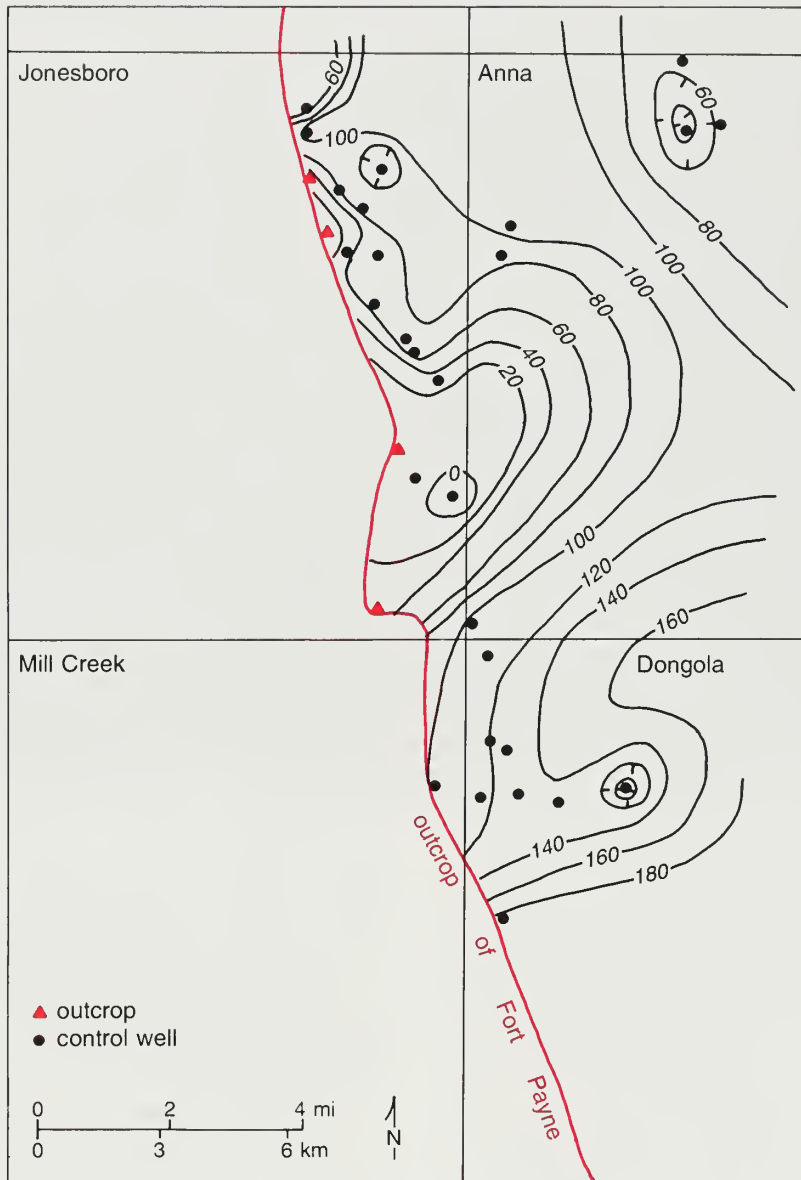


Figure 17 Isopach map of Fort Payne Formation. Contour interval is 20 feet.

Near Hartline Creek in Sec. 18 and 19, T14S, R1W, bedded chert of the lower Fort Payne forms dark scraggly ledges. This is the "Hartline chert" of J. Weller and Ekblaw (1940). "Hartline" chert is transitional between bedded chert and ganister. Light bluish gray vitreous chert and reddish orange porous ganister are intricately intergrown.

Ullin Limestone

The Ullin Limestone was named by Lineback (1966) for the town of Ullin, which is just east of the study area. Lineback described a composite type section consisting of two

natural exposures and a quarry face near Ullin. The limestone that Lineback named Ullin was previously called by such names as Osage, Warsaw, Warsaw-Salem, Burlington-Keokuk, and Harrodsburg.

Lineback's definition of the Ullin is confusing because he assigned some rocks that are typical Fort Payne to the Ullin Formation. For example, Locality 1 of the Ullin type section (Lineback 1966, p. 37) includes bedded chert 49.5 feet thick. We restrict the name Ullin to limestone that is composed predominantly of echinoderm fragments in a matrix of bryozoan fragments.

Most of the Ullin is light gray, but medium-dark gray and brownish gray limestone occurs in the lower part. Echinoderm fragments are darker than the matrix and impart a speckled appearance (fig. 18). Ullin limestone is laminated throughout, and parts are distinctly crossbedded. Crossbedding commonly stands out sharply in relief on weathered surfaces (fig. 19). Most crossbed sets are 1 to 4 feet thick. Fossils other than echinoderms and bryozoans are uncommon; a few brachiopods were noted. The Ullin contains scattered chert nodules; they are light gray, concentrically banded, dull textured, and commonly 6 to 10 inches long and 3 to 4 inches thick. This chert is distinctive in float.

In general, the Ullin becomes lighter colored and coarser grained upward. Medium gray or brownish gray, fine grained, faintly speckled limestone transitional to the Fort Payne occurs at the base. This limestone is glauconitic and slightly siliceous. The limestone becomes medium to coarse-grained upward and contains brownish gray echinoderm clasts in a dull white to very light gray matrix. The middle Ullin lacks glauconite and contains only scattered chert lenses. Near the top the Ullin is very coarse and strongly speckled, and fossil grains are poorly sorted.

The Ullin Limestone is readily identified in well cuttings as speckled, crinoid-bryozoan limestone. On drillers' logs, the Ullin is frequently reported as white or light gray, soft limestone; this is in contrast with the dark gray, hard, and cherty limestones of the underlying Fort Payne and overlying Salem Limestone. The Ullin has uniformly high spontaneous potential and uniformly low natural gamma readings on geophysical logs.

Lineback (1966) divided the Ullin into two members: the Ramp Creek Member below and the Harrodsburg Member above. He described the Ramp Creek as a darker, finer grained limestone and the Harrodsburg as a lighter, coarser variety. Lamar (1959) previously described and illustrated the same two types of limestone in the Jonesboro area (under the heading "Warsaw-Salem limestone"). Lamar's "Mill Creek type" corresponds to Lineback's Harrodsburg Member, whereas

Lamar's "Kornthal type" matches Lineback's Ramp Creek. As Lamar observed, the two types of limestone intertongue with one another. The best place to see intertonguing of Harrodsburg and Ramp Creek is at the Ullin Quarry of the Columbia Quarry Company. This quarry contains part of the Ullin type section. Furthermore, the Ramp Creek lithology is transitional between the Fort Payne and the Harrodsburg, and intertongues with both. The Harrodsburg and Ramp Creek are better classified as facies than as members.

The outcrop belt of the Ullin lies mostly east of the area of altered rocks. A few inliers of Ullin were found near the east margin of the altered area. (They are mapped as Mississippian-Devonian undivided.) Altered Ullin consists of blocks of light gray, banded chert and limestone in a matrix of plastic clay. Evidently, most of the limestone was dissolved in the altered area.

Thickness of the Ullin, as indicated by borehole data, ranges from 225 to 490 feet. The Ullin averages 345 feet thick in the wells that have the most reliable logs.

The Ullin-Salem contact appears sharp in some exposures, but beds of Ullin lithology occur in the lower Salem, indicating intertonguing. Such interbedding was observed in gullies southeast of Darty Creek, in the center SW NE, Sec. 11, T12S, R2W, and a streambed and roadcut in the SE NE, Sec. 6, T13S, R1W. Sample logs of wells in the Anna Quadrangle also indicate intertonguing. The top of the Ullin was mapped at the base of the lowest dark limestone of Salem lithology.

Salem Limestone

The Salem Limestone was named by Cumings (1901) for Salem, Indiana, where the limestone is quarried for building stone. In its type area, the Salem is largely light gray oolitic grainstone that exhibits large-scale crossbedding. In other areas, a wide variety of limestone lithologies are assigned to the Salem. For example, dark gray to black, argillaceous, and dolomitic lime mudstone was mapped as Salem in the Fluorspar District (Baxter and Desborough 1965, Baxter et al. 1967). The Salem Limestone seems to be a catch-all for strata between the Ullin (or equivalent) and St. Louis Limestones,

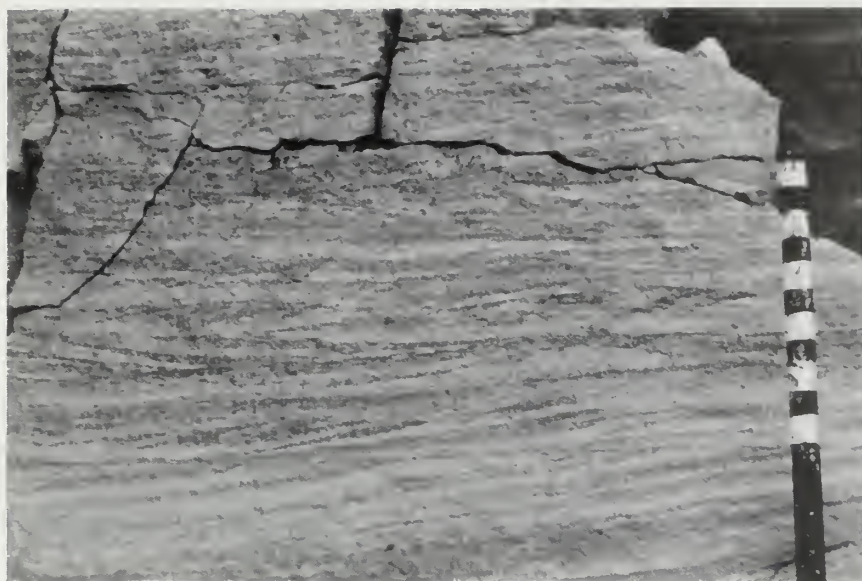


Figure 18 Crosslaminated Ullin Limestone (Jonesboro Quarry), showing the typical "speckled" appearance of the limestone, which is caused by darker crinoid fragments in a lighter matrix. Staff is graduated in feet and inches.

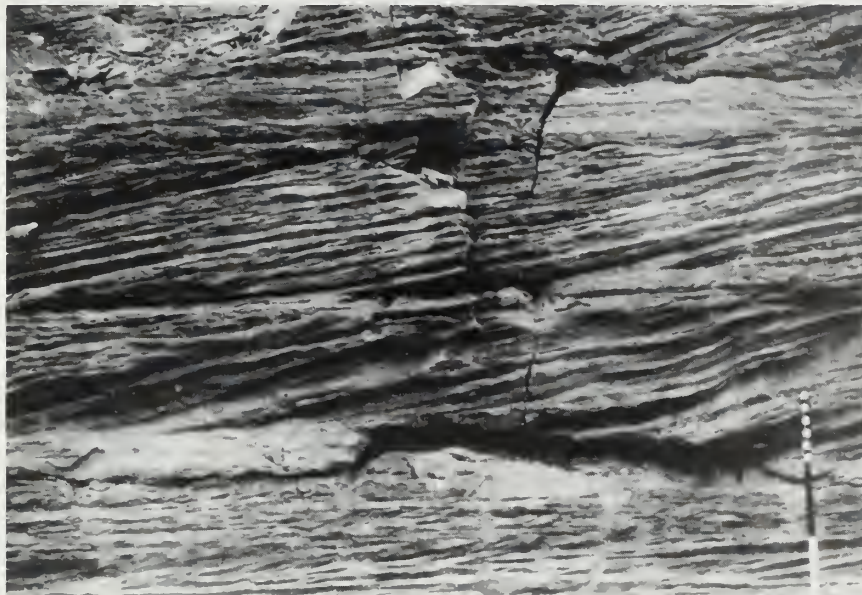


Figure 19 Large-scale planar crossbedding in upper Ullin Limestone at the Columbia Quarry Company's Jonesboro Quarry, just east of the study area in the SE NE, Sec. 17, T13S, R1W, Anna Quadrangle. Staff is graduated in feet and inches.

whose lithologic characters are more narrowly constrained.

In this study area, the Salem is a unit of medium to dark-colored limestone that ranges from lime mudstone to grainstone but most commonly is packstone. Darker color, finer texture, presence of oolites, and lack of crossbedding distinguish the Salem from the Ullin. The overlying St. Louis Limestone differs from the Salem in that it is predominantly

lime mudstone and fine grained skeletal limestone having few or no oolites and much chert.

Two informal units make up the Salem in the Jonesboro Quadrangle. The lower unit, which makes up one-quarter to one-third of the formation, is interbedded dark micritic limestone and light skeletal limestone. The dark limestones are argillaceous to silty, partly dolomitic lime mudstones and wackestones. They are

very thin or thinly bedded and contain numerous nodules and discontinuous layers of light grayish brown chert. The light-colored limestones are fine to coarse grained skeletal packstones and grainstones, which are generally poorly sorted and sparingly oolitic. Fossil fragments include echinoderms, brachiopods, and bryozoans. In contrast to the Ullin, where darker crinoid fragments stand out against a white matrix, fossil grains in the lower Salem are generally lighter than the matrix. Light-colored lower Salem limestones are relatively pure carbonate containing little chert, and bedding ranges from thin to thick.

The upper unit of the Salem Limestone is predominantly medium to dark gray and brownish gray, fine to coarse grained skeletal packstone and wackestone. Fossil fragments are poorly sorted, partly rounded, and oolitically coated. Bedding is generally 1 to 3 feet thick. The upper Salem is at most slightly argillaceous and contains only a few chert nodules. Whole fossils are rare except near the top, where silicified rugose corals are common. The diagnostic fossil for the uppermost Salem and basal St. Louis is the "finger coral," *Acrocyathus proliferus*, which was called *Lithostrotionella proliferus* in many older reports; its present classification was established by Sando (1983).

The Salem–St. Louis contact is gradational and intertonguing. Beds of skeletal packstone, typical of the Salem, alternate with beds of typical St. Louis cherty lime mudstone in the contact zone. Exposures of the contact are east of State Pond in the SE SE, Sec. 12, T12S, R2W, and in ravines south of Anna in the E½ NE, Sec. 30, T12S, R1W. Intertonguing and lateral gradation of the Salem and St. Louis Limestones previously were documented by Lineback (1972). In the field, we mapped the Salem–St. Louis contact at the lowest occurrence of lime mudstone.

Thickness of the Salem Limestone, as determined by well records in the Jonesboro and western Anna 7.5-Minute Quadrangles, ranges from 285 to 435 feet.

St. Louis Limestone

Englemann (1847) named the St. Louis Limestone for St. Louis, Missouri. Concise definitions of the St. Louis Limestone are difficult to find.

In general, the St. Louis is an interval of micritic to fine grained, cherty limestone and dolomite. Rocks fitting this description in the study area are mapped as St. Louis.

The most distinctive rock type in the St. Louis is thick bedded, cherty, dolomitic, micritic lime mudstone that breaks with conchoidal fracture. This rock type is commonly called "sublithographic." It is typically medium gray or brownish gray on fresh surfaces and weathers to lighter shades of gray and olive gray. Some chert is light gray, but most of it is dark bluish gray to nearly black and vitreous; it occurs as large lenses and discontinuous bands. Also common are small vugs and geodes filled with white sparry calcite and drusy quartz.

Alternating with lime mudstone are beds of medium to dark gray, very finely to finely granular limestone. Some of these beds are skeletal wackestones and packstones similar to those of the upper Salem, whereas other beds are recrystallized mudstones that contain few or no fossil fragments. Oolites are rare. Fossils include brachiopods, blastoids, crinoids, and rugose corals. *Acrocyathus proliferus* is abundant in the basal St. Louis.

Light gray, fine grained skeletal limestones dominate in the upper part of the St. Louis. Occasional silicified colonies of *Acrocyathus floriformis* (found mainly as float) are present.

Good outcrops of the St. Louis can be found along the road and stream in Kratzinger Hollow in small roadcuts and in two small, abandoned limestone quarries north of the road in the hollow. Outcrops also can be found near the heads of several ravines north of Kratzinger Hollow. The basal St. Louis is well exposed in several small ravines just south of Anna.

The contact with the overlying Ste. Genevieve Limestone is transitional and arbitrary. Other geologists mapped this contact at (1) the lowest occurrence of light-colored oolitic limestone, (2) the highest occurrence of chert, (3) the highest occurrence of "lithostrotionellid" corals, or (4) a combination of the above (Atherton et al. 1975, Sable and Dever 1990). In the Jonesboro area, cherty limestone occurs throughout the Ste. Genevieve, so the contact cannot be

based on chert. The most practical place for the contact in this area is the lowest occurrence of oolitic limestone. Because the St. Louis/Ste. Genevieve transition is poorly exposed in the study area, the two formations were combined as a single unit in the Jonesboro 7.5-Minute Quadrangle (Nelson and Devera 1994). The only place where the contact can be located closely is near the head of Kratzinger Hollow in the NW SE, Sec. 18, T12S, R1W.

The St. Louis is approximately 100 feet thick in Kratzinger Hollow, the only place where both contacts can be located accurately. Sample logs from five water wells in the city of Anna indicate the St. Louis to be from 70 to 140 feet thick. The formation thickens eastward to 250 feet in wells in the eastern part of the Anna 7.5-Minute Quadrangle. A regional isopach map of the St. Louis in southern Illinois shows that the St. Louis thickens eastward to more than 500 feet in southeastern Illinois (Atherton et al. 1975, p. 141).

Ste. Genevieve Limestone

The Ste. Genevieve Limestone was named for Ste. Genevieve, Missouri, by Shumard (1859). This formation generally is recognized as an interval that is dominated by light-colored oolitic and skeletal limestones. It contains lesser amounts of micritic limestone, shale, and sandstone.

The outcrop belt of the Ste. Genevieve crosses the northeast corner of the Jonesboro 7.5-Minute Quadrangle. This is an area of gently rolling topography and numerous sinkholes. Outcrops are few and small in the Jonesboro Quadrangle, but a nearly complete section can be seen at the active Anna Quarry just east of the study area. Information given here is derived mainly from these quarry exposures and is supplemented by data from nearby outcrops, core descriptions, and sample logs of water wells.

The Ste. Genevieve contains several types of limestone that are interbedded. (1) Roughly half the formation is white to light gray oolitic and skeletal grainstone that is typically crossbedded. This rock occurs in intervals 4 to 20 feet thick and is relatively soft and lacks chert. (2) About a quarter of the formation is light to medium gray and brownish gray, fine grained skeletal grainstone,

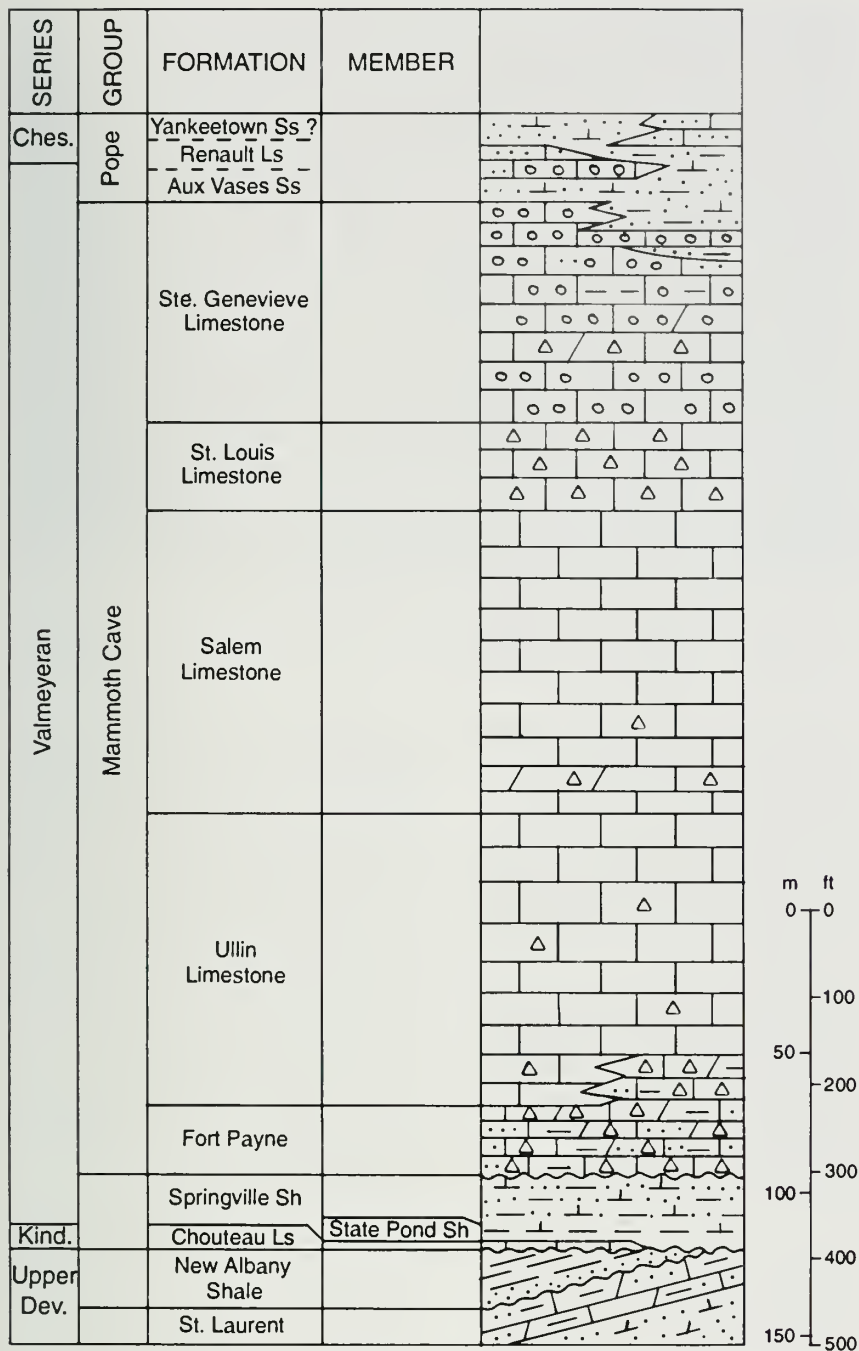


Figure 20 Stratigraphic column showing Mississippian units of the study area.

packstone, and wackestone. This rock is harder than the oolitic limestone and typically not crossbedded. Intervals are generally 2 to 10 feet thick. (3) Another quarter of the formation is medium to dark brownish gray, slightly dolomitic lime mudstone that contains as much as 30% bluish gray vitreous chert in bands and nodules as thick as 6 inches. This rock closely resembles St. Louis Limestone. Intervals of lime mudstone are generally 1 to 10 feet thick.

(4) A minor rock type, observed in the lower part of the Ste. Genevieve in the Anna Quarry, is mounded algal boundstone that contains abundant stromatoporoids and bryozoans.

The four types of limestone occur in the Anna Quarry in layers that pinch and swell. Contacts are gradual in some cases, sharp and undulating in others. The upper contacts of oolitic units generally are sharp.

The Ste. Genevieve is fossiliferous, although whole fossils are uncommon. Bryozoans, blastoids (*Pentremites* sp.), crinoids (including *Platycrinites penicillus*), brachiopods (including *Derbyia* sp.), syringoporous corals, and *Chaetetes* sp. all were found in the upper Ste. Genevieve at the Anna Quarry.

Lenses of shale and sandstone less than 5 feet (1.5 m) thick occur in the upper part of the Ste. Genevieve. Shale is medium greenish gray to nearly black, calcareous, fissile, partly silty, and fossiliferous. Sandstone is light gray and greenish gray, very fine grained, quartzose, and calcareous. Similar shales and sandstones occur in the lower part of the overlying Pope Group.

The Ste. Genevieve intertongues with the overlying Aux Vases Sandstone (Swann 1963, Nelson and Cole 1992). We mapped the contact at the base of the lowest sandstone unit. Because of the thick loess, we could only approximately locate the contact.

The Ste. Genevieve is about 250 feet thick in the study area. About 245 feet of Ste. Genevieve is exposed at the Anna Quarry, and the base is concealed. Well records indicate the limestone to be about 220 to 300 feet thick in the northern part of the Anna Quadrangle.

Pope Group

The Pope Megagroup was named for Pope County in southern Illinois by Swann and Willman (1961). Revised to the Pope Group (Nelson 1995), the Pope is a lithostratigraphic unit equivalent to what was formerly called the Chester Group or Series. The name Chester is reserved for chronostratigraphic usage as Chesterian Series (fig. 20). The Pope Group is largely Chesterian but includes late Valmeyeran rocks at the base (Swann 1963). The group contains alternating carbonate and siliciclastic rocks. The term Pope Group was first used in Weibel et al. (1993).

Rocks of the lower Pope Group underlie the northeast corner of the study area. They do not crop out, but they are known from borehole records and from nearby outcrops in the Anna and Cobden Quadrangles. Not enough detail is available to map individual formations in the Jonesboro Quadrangle.

At the base of the group is sandstone presumed to be the Aux Vases. It is light brownish gray to light greenish gray, very fine grained, quartzose, calcareous, and glauconitic. The thin, tabular beds display ripple marks, horizontal burrows, and dessication (?) cracks. In well samples, the sandstone commonly contains oolites the size of sand and fossil fragments, and grades to sandy limestone. Interbeds of green to gray and red variegated shale and claystone are present.

Overlying the sandstone is an interval of limestone containing lesser amounts of shale and sandstone. The limestone ranges from light gray oolitic grainstone to dark gray, argillaceous, and dolomitic lime mudstone. Outcrops of coarse dark purplish gray grainstone and packstone, containing hematitic oolites and pink, purple, and green echinoderm fragments, occur along the creek in the NW SE NW, Sec. 8, T12S, R1W (Anna Quadrangle). Shale and sandstone are similar to those in the basal Pope Group. Siliciclastic rocks apparently intertongue and intergrade laterally with limestone.

The portion of the Pope Group within the Jonesboro Quadrangle is less than 100 feet thick and is overlain by Quaternary loess, alluvium, and colluvium.

Cretaceous System

Unlithified clay, sand, and gravel, as well as lithified sandstone and conglomerate, crop out in the Jonesboro Quadrangle. These deposits are partly Cretaceous and partly Tertiary age. The strata are poorly exposed and differ somewhat from well known Cretaceous and Tertiary strata that occur southward in the Mississippi Embayment. Thus, formational assignments are tentative, and Cretaceous and Tertiary deposits are shown as a single unit on the geologic maps.

Tuscaloosa Formation (?)

Named for Tuscaloosa, Alabama, this formation is the oldest Cretaceous unit known to occur in the Mississippi Embayment of southern Illinois and adjacent states. Some gravel in the Jonesboro Quadrangle is similar to the Tuscaloosa and is tentatively assigned to that unit. The best exposures of Tuscaloosa-type gravel are near Elco in the Mill Creek Quadrangle. The gravel is



Figure 21 Steeply dipping Cretaceous-Tertiary sand and gravel, SW SW SE, Sec. 11, T13S, R2W, Jonesboro Quadrangle. Bedding strikes N20°E and dips 40°SE. The staff is 5 feet long.

composed mostly of white to light gray, angular to subrounded chert fragments that are as much as 12 inches in maximum dimension. These clasts are mostly dull, porous, pitted, and more or less tripolitic, resembling unglazed porcelain. Many of them are derived locally from the Clear Creek, Fort Payne, Ullin, and other cherty limestone units. Intermixed with locally derived chert are smaller amounts of darker, rounded chert pebbles. The matrix is mostly fine grained tripolitic chert and some quartz sand. Roadcuts along Illinois route 127 and an abandoned gravel pit in the south-central part of Sec. 7, T14S, R1W, are the best places to see Tuscaloosa-type gravel. Field notes made when the Elco gravel pit was in operation reveal that the gravel was interbedded with reddish brown sand, well rounded chert gravel, and clay containing scattered pebbles (unpublished ISGS field notes by J.E. Lamar 1927 and J.C. Frye, H.B. Willman, and A. Jacobs 1967).

General lithologic similarity is the only basis for calling the Elco gravel Tuscaloosa. Relationships to other Cretaceous and Tertiary units in the area are not known. The gravel at Elco is at least 50 feet thick.

McNairy Formation The McNairy Formation (Upper Cretaceous) almost certainly is present in

the Jonesboro Quadrangle. Deposits thought to be McNairy include clay, silt, sand, gravel, sandstone, conglomerate, and silcrete. Sand is the most common component.

The main outcrop area of the McNairy is a discontinuous belt trending south-southeast from the south-central part of the Jonesboro 7.5-Minute Quadrangle into the northeastern Mill Creek Quadrangle. The belt, which varies from ¼ to 1 mile wide, enters the Dongola Quadrangle east of Elco and disappears farther south beneath Quaternary alluvium in the Cache Valley. Sediment in this belt is largely unlithified sand, intermixed with minor amounts of clay, silt, and gravel. Scattered outliers of McNairy occur mostly west of the main belt in the Mill Creek and southern Jonesboro 7.5-Minute Quadrangles. Outliers are composed largely of gravel, conglomerate, and lithified sandstone.

McNairy sand is brightly colored and variegated in red, orange, ochre, purple, and brown. It is mostly fine grained, subrounded to subangular quartz sand, containing minor or trace amounts of lithic fragments, muscovite, and dark minerals in a matrix of silt and clay. Coarse grained sand is uncommon. Subangular to well rounded chert pebbles are scattered through the sand and occur as lenses, layers, and stringers (fig. 21). Some sand grades to sandy

silt and clay. Irregularly shaped pockets, veins, and dikes of light to medium gray clay are common in sand and, in some areas, make up the bulk of the deposit. Much of the sand has no visible bedding or lamination. In areas where layering is visible, it commonly is steeply inclined, contorted, and offset by small faults (fig. 21).

Some exposures of McNairy sand are along small east-flowing streams in the NE SE and SW SE, Sec. 11, and the SW NE, Sec. 24, T13S, R2W, Jonesboro 7.5-Minute Quadrangle, and along the small stream that flows through the center of Sec. 24, T13S, R2W, Mill Creek Quadrangle.

Silt and clay of the McNairy are various shades of gray. The clay is typically plastic; silt grades to very fine sand. Most silt and clay lack bedding or lamination. They occur as irregular lenses, blebs, and vein-like intrusions in sand.

Well indurated quartz arenite occurs in many places in the study area. This sandstone occurs only as float blocks, the largest of which are 15 feet in maximum dimension. The sandstone is white to light gray and weathers to a smooth, dark gray case-hardened surface; it is composed almost entirely of very fine to fine (rarely medium), well sorted quartz sand. Grains are sub- to well rounded (mostly well rounded) and frosted. Planar crossbedding in sets 6 to 12 inches thick can be seen in large blocks of this sandstone. Bidirectional or crossbedding was observed in sandstone boulders on hillsides near the Old Cape Road in the NW SE NE, Sec. 11, T13S, R2W, Jonesboro 7.5-Minute Quadrangle. Other occurrences include the hilltop in the SE SE, Sec. 11, T13S, R2W, and hilltops and gullies northwest of Berryville (Jonesboro 7.5-Minute Quadrangle).

McNairy quartz arenite can be mistaken for the Dutch Creek Sandstone (Devonian), except that the McNairy lacks molds and casts of marine fossils common in the Dutch Creek. Also, some McNairy quartz arenite contains chert pebbles and grades to chert-pebble conglomerate.

Quartz arenite in the study area is nearly identical to sandstone called "Commerce quartzite" after Commerce, Missouri (Thebes Quadrangle). Commerce quartz arenite is both overlain and underlain by typi-

cal McNairy strata, and therefore is assigned to the McNairy (Johnson 1985; Richard Harrison, USGS, personal communication, 1992).

McNairy gravel occurs mainly as scattered chert pebbles intermixed with sand. Laminae and beds of gravel, interlayered with sand, are less common. The gravel is composed mainly of off-white to medium gray and brown, rounded to subangular chert pebbles less than 4 inches in diameter. Most of the pebbles are dull, more or less tripolitic, and not polished. Float and small outcrops of such gravel are common 1 to 2 miles west of Mill Creek village, particularly in the SW, Sec. 25, and NW, Sec. 36, T13S, R2W. Coarse gravel well cemented by iron oxide was observed in the NE SE, Sec. 35.

A final rock type assigned to the McNairy is a siliceous rock that meets the definition of a silcrete (Summerfield 1983). It crops out near the top of a hill in the SW SW, Sec. 25, and in thickly vegetated gullies trending southward from that hilltop into the NW NW, Sec. 36, T13S, R2W. The rock is dull white to light gray, banded, and mottled with light red and yellowish brown. It is well indurated and resembles "calico rock" from the Springville Shale except for the lack of layering. Floating grains of well rounded quartz sand and occasional small rounded chert pebbles are embedded in silcrete. Casts and carbonized impressions of plant material, including roots and rootlets, indicate that this rock is a silicified paleosol. Silcrete is both overlain and underlain by sand and gravel.

Silcrete similar to that found during this study occurs in undoubted McNairy strata in the Thebes Quadrangle to the south. Two samples of petrified wood from McNairy sand and gravel in the Jonesboro Quadrangle were identified as similar to *Paraphyllanthoxylon illinoisense* (Elisabeth Wheeler, North Carolina State University, Raleigh, written communication, 1992). This tree is common in the McNairy Formation in the Thebes Quadrangle near silcrete exposures (Wheeler et al. 1987). However, *Paraphyllanthoxylon* is known from early Tertiary deposits as well as Cretaceous (Wheeler, written communication, 1992).

Identification of the McNairy Formation in the Jonesboro Quadrangle

rests mainly on lithologic evidence. The strata here are similar to undoubted McNairy strata farther south in Illinois and western Kentucky (Olive 1980, Kolata et al. 1981, Trace and Amos 1984). The sand in the Jonesboro Quadrangle contains less mica and more gravel than that typical for McNairy. These differences might relate to the source area. The highly micaceous, gravel-poor McNairy south of the study area was derived largely from metamorphic terranes in the Appalachian Mountains (Pryor 1960). In the Jonesboro area, however, much of the McNairy sediment might have come from the north, where the bedrock contains much chert and little mica.

Tertiary System

Wilcox Formation (?) Chert gravel, sand, and conglomerate that occurs mainly as hilltop outliers is tentatively assigned to the Wilcox Formation (Eocene). Gravel, the most common lithology, consists of subangular to well rounded chert granules and pebbles that are as much as 6 inches in diameter. The pebbles range from light gray to medium and dark bluish gray to nearly black. They are dull to vitreous and have smooth but not highly polished surfaces. Well rounded white quartz granules and pebbles as much as about ½ inch in diameter also are present. Some gravel is intermixed with poorly sorted, fine to coarse sand of quartz and chert grains. Most gravel occurs only as float along gullies and streams or as a component of colluvium, intermixed with loess near the tops of steep ridges. One of the few places where more or less uncontaminated gravel can be seen is near the top of a steep east-facing slope near the center of the SW, Sec. 1, T14S, R2W, Mill Creek Quadrangle.

Wilcox (?) conglomerate is composed of chert gravel (similar to that described previously) cemented by silica (gray) or by iron oxide (dark red, brown, and nearly black). The matrix is sand that ranges from predominantly quartz to a mixture of quartz and chert grains. All gradations exist—from clast-supported conglomerate having little matrix, through matrix-supported conglomerate, to sandstone containing scattered chert pebbles. Conglomerate varies from massive to crudely

stratified or, rarely, crossbedded. Most conglomerate occurs as cobbles and boulders in float but, in a few places, it forms ledges. Outcrops of conglomerate occur along the south side of the hilltop in the S½ NE NE, Sec. 11, T14S, R2W.

Most Wilcox (?) outcrops and float in the study area are high on the hillsides west of the south-trending belt of McNairy sediments. Wilcox (?) gravel and conglomerate were also found near the northeast corner of the study area in Sec. 1, 2, 11, and 12, T12S, R2W. Gravel of the Wilcox type probably occurs within the McNairy belt as well, where it is commonly found intermixed with McNairy lithologies in float and in slumped, overgrown stream banks. Auger borings by the ISGS in the southern part of Sec. 25, T13S, R2W, recovered Wilcox (?) gravel overlying red McNairy sand along the west edge of the McNairy belt. This limited evidence indicates Wilcox (?) gravels are younger than the McNairy.

The Wilcox Formation (Eocene) in the northern Mississippi Embayment is composed mainly of sand intercalated with lesser amounts of silt, clay, and gravel. Pebbles in the Wilcox in the Embayment are predominantly smaller than 1 inch in diameter. Gravel composed of white to clear quartz pebbles and dark olive gray to grayish black chert pebbles as large as 2 inches can be found in the Thebes Quadrangle (Missouri and Illinois). This gravel is assigned to the Wilcox (Johnson 1985; Richard Harrison, personal communication, 1992). The northern, upland setting of the Jonesboro Quadrangle might explain the presence of larger pebbles in the Wilcox here.

Palynological evidence further supports the presence of the Wilcox Formation in the Jonesboro Quadrangle. Palynomorphs from lignite collected in the Cobden Quadrangle, north of the study area, are Eocene in age (Aureal T. Cross, Michigan State University, East Lansing, personal communication, 1984; D.J.

Nichols, USGS, written communication, 1993). The Eocene lignite came from clay pits (now abandoned) near the village of Kaolin. Clay at Kaolin reportedly overlay deposits of white to yellow, orange, and red micaceous sand (McNairy ?) and was interbedded with lignite, gravel, and limonite-cemented conglomerate of subangular to rounded chert pebbles as large as 3 inches in diameter (St. Clair 1917, Parmalee and Schroyer 1921, Lamar 1948, Nelson and Lumm 1985). Gravel that crops out along ridge tops west of the Kaolin clay pits is identical to Wilcox (?) gravel in the Jonesboro Quadrangle (Nelson and Devera 1994).

Quaternary System

Upland silt and colluvium All upland surfaces in the Jonesboro Quadrangle are mantled with wind-blown silt (loess) and colluvium composed of rock fragments intermixed with silt. Silt is typically at least 10 feet thick on level and gently sloping ridge crests, and it exceeds 40 feet in bluffs near the Mississippi River. Five cores drilled in upland areas during this study showed the total thickness of loess to be 15 to 20 feet. The silt is substantially thinner on steep hillsides and absent or intermixed with weathered rock debris (colluvium) in some areas. At least three distinct loesses are present in the study area (Leon Follmer, personal communication, 1993). These include the following: (1) the Loveland Silt, a reddish orange to reddish gray, well leached clayey silt of Illinoian age; (2) the Roxana Silt, a brown clayey silt of early Wisconsinan age; and (3) the Peoria Silt, a yellowish gray to brownish gray, slightly clayey silt of late Wisconsinan age.

In some streambank exposures, large polygonal cracks, lined with reddish brown clay, occur in the Loveland Silt. These may represent the C (basal) horizon of the Sangamon Soil (Follmer, personal communication, 1992). Exceptionally thick deposits of Peoria Silt formerly

were quarried for fill material in the NE, Sec. 29, T12S, R2W, Jonesboro 7.5-Minute Quadrangle. Some of the silt in these pits grades to fine grained sand that was windblown from the adjacent Mississippi floodplain.

Alluvial and lacustrine deposits

Undifferentiated alluvial and lacustrine sediments fill all of the major valleys in the study area. These sediments are most extensive in the Mississippi and Cache Valley floodplains, where borehole records indicate thicknesses in excess of 100 feet. Deposits along smaller streams in the study area may be quite thick also, judging by the V-shaped profiles of most bedrock valleys.

The deposits are composed of poorly sorted and poorly stratified clay, silt, sand, and gravel. Cutbanks along Cany Creek, Dutch Creek, and other large streams show thicknesses as great as 40 feet above the present stream level. These deposits are remnants of terraces. In some areas, small streams that enter wide valleys are "perched" on terrace remnants above present-day base level. Some cut banks reveal three or more distinct layers of gravelly alluvium or silt, separated by mottled and rooted paleosols. These deposits attest to several stages of alluviation and downcutting in drainages near the Mississippi.

Fraser (1980) studied the Pleistocene history of Hutchins Creek in the adjacent Wolf Lake Quadrangle. Fraser determined that the bottom of the bedrock channel of the Mississippi River is as deep as 200 feet below present river level. This valley is pre-Illinoian. An early episode of aggradation, followed by downcutting, took place during the Illinoian Age. Slackwater lakes then formed in tributaries of the Mississippi in early Woodfordian and again in late Woodfordian time. Each episode of lake formation was succeeded by downcutting, as the streams reentered their old valleys and reworked the lacustrine deposits.



STRUCTURAL GEOLOGY

The Jonesboro 15-Minute Quadrangle lies in one of the most structurally complex areas in the Mid-continent. Previous geologists recognized the complexity but had difficulty portraying it. For example, the map of J. Weller and Ekblaw (1940) shows only the Harrison Creek anticline and three faults in the quadrangle. These authors observed (p. 6), however, that "complicated structure involving folds of considerable magnitude and a great number of faults of different types and ages and variable intensity...are exceedingly difficult to locate and trace because of the general lack of readily recognizable stratigraphic horizons and the inadequacy of outcrops."

Likewise, our maps cannot do justice to the structural complexity of the area. Poor exposures, lack of marker beds, and altered strata prevent the tracing of most structures in the study area. Enough is exposed, however, to provide an overview of the deformation.

Structural features of the study area are grouped as follows (fig. 22).

- Eastern homoclinal area
- Western homoclinal area
- Harrison Creek Anticline
- Major faults
- "Thumb area"
- Altered area
- Post-Cretaceous faulting

Eastern Homoclinal Area

Gentle, uniform east to northeast dips prevail in the eastern homoclinal area (fig. 22). The west border of the area parallels Illinois route 127 and extends from the north edge of the study area south to Elco. This area contains outcrops of Middle Devonian through Chesterian rocks. On the north, bedding strikes north-northwest and dips northeast at 12° or less. Southward the strike gradually changes to nearly north-south and dips diminish to less than 5°.

Eastward homoclinal dips of 2° to 5° also occur in the northwest corner of the Jonesboro 7.5-Minute Quad-

rangle, where the Clear Creek Formation crops out. Details are scanty due to poor exposure and absence of marker beds.

No faults were mapped in this homoclinal area, but jointing is prominent in limestone. Primary joints strike north-south to north-northwest-south-southeast, parallel to the strike of the bedding; secondary joints are perpendicular or nearly so. Primary joints contain fillings of sparry calcite as much as 1 inch wide. Some primary joints in the Anna Quarry contain sphalerite and fluorite, as well as calcite. Secondary joints generally are unmineralized.

Western Homoclinal Area

The western homoclinal area is in the McClure and western Mill Creek Quadrangles, west of the Delta Fault (fig. 22). Silurian and Lower Devonian rocks crop out here. The average dip in this area is 1° to 2° eastward. Minor structures include a subtle dome or anticline that brings Silurian strata to the surface near the mouth of Dongola Hollow in the McClure Quadrangle. A syncline that trends east-northeast was mapped in Sec. 13 and 14, T14S, R3W. A few poorly exposed faults of small displacement are present.

Harrison Creek Anticline

The largest fold in the study area is the Harrison Creek Anticline. First mapped by Savage (1920b), the anticline was named by J. Weller and Ekblaw (1940) for Harrison Creek, which cuts across the highest part of the fold. J. Weller and Ekblaw (p. 25) stated that the anticline extends north to Bald Knob in the Cobden Quadrangle (about 3 miles north of our study area), but our mapping indicates that it ends near Dutch Creek in the Jonesboro 7.5-Minute Quadrangle (fig. 22).

The Harrison Creek Anticline has a slightly sinuous axis that strikes a little east of north and is about 7 miles long. The fold crest is broad

and nearly symmetrical. Maximum dips are about 20° on the west limb and 15° on the east limb. The apex of the fold is in the S½, Sec. 16, and the N½, Sec. 21, T13S, R2W, where the Maquoketa Formation comes to the surface. The anticline has at least 350 feet of closure and more than 550 feet of total relief. The lower part of the west flank is concealed by alluvium, and no borehole data are available for that area. The nearest outcrops west of the anticline are in Missouri and at the same or slightly higher structural elevation as the west flank of the anticline in Illinois (Middendorf 1989).

At its southern end, the anticline gradually plunges and dies out into a gentle east-facing homocline. On the north, the east flank is truncated by the Atwood Fault. The anticline and fault pass under the alluvium of Dutch Creek and Green Creek and then die out.

Like most other large anticlines of the Ozark Dome, the Harrison Creek is an isolated structure, without parallel synclines. It is parallel to several large nearby faults and is faulted along its east limb. A pronounced gravity high coincides with the anticline, implying that basement rocks are uplifted (Segar 1965, Nelson and Lumm 1985, p. 68-70). These data indicate that the Harrison Creek Anticline is a drape fold overlying a horst in crystalline basement.

Major Faults

Three large faults—the Atwood, Delta, and Cape Road Faults—were mapped in the Jonesboro Quadrangle. All strike north-south to slightly west of north and have overall displacement down to the east (fig. 22).

Atwood Fault The Atwood Fault was mapped by Savage (1920b) and J. Weller and Ekblaw (1940). The latter named the fault for Atwood Ridge. Our mapping of the Atwood Fault differs little from previous mapping.

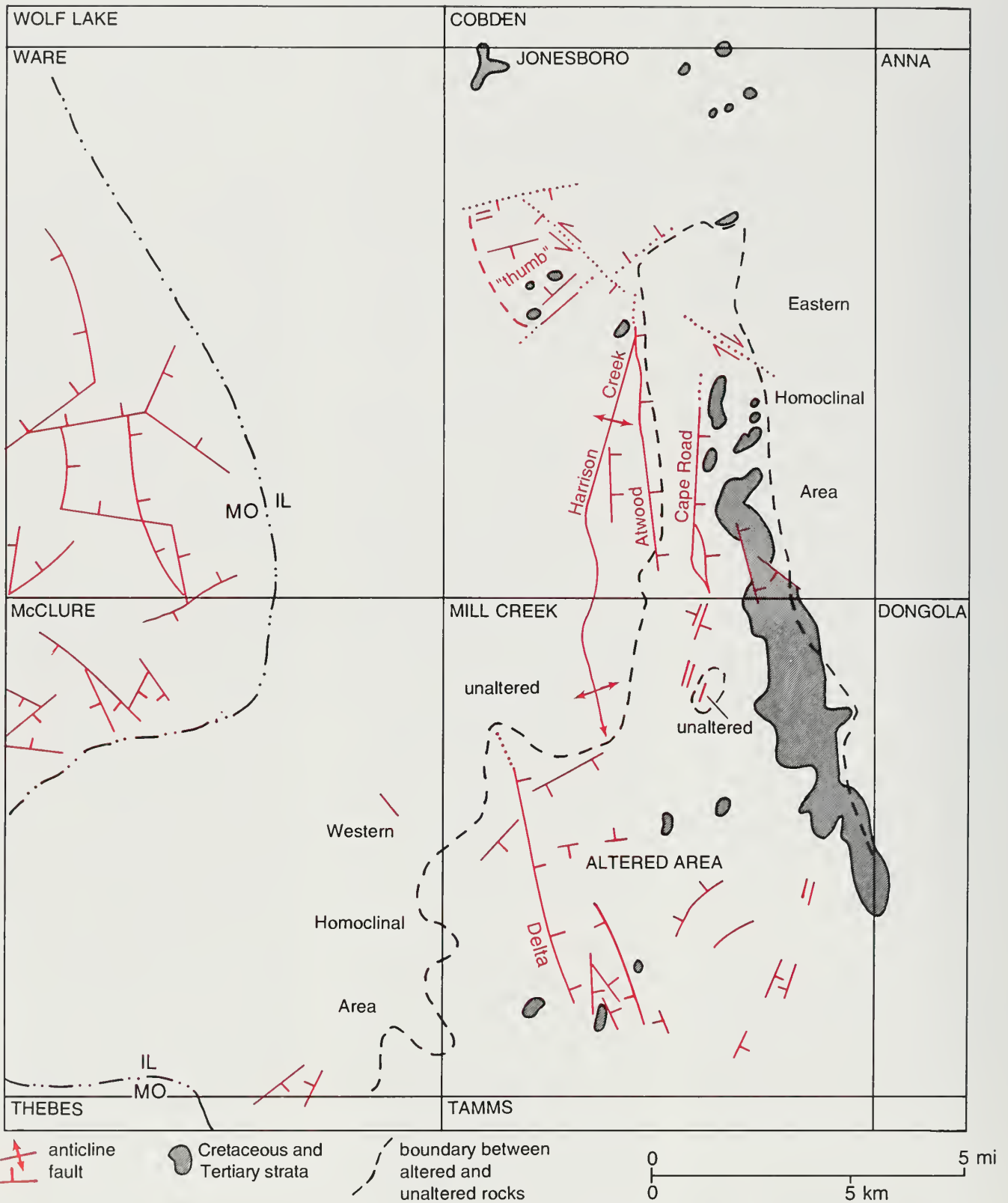


Figure 22 Map showing structural features of the study area and distribution of Cretaceous-Tertiary strata. Location of faults in Missouri are taken from Satterfield (1973) and Middendorf (1989).

The fault is about 3.5 miles long, and the north end is concealed by alluvium. Near its north end, the fault strikes north-south; to the south, it curves to N15°W. The fault surface was not observed, but it dips steeply. The east side is downthrown along the entire length of the fault. Displacement probably is greatest in Sec. 33, T12S, R2W, where upper Bailey Formation on the west is faulted against Clear Creek Formation on the east. Throw here is at least 300 feet, and it may be as great as 500 feet.

The Atwood Fault is a single plane or narrow fracture zone with little brecciation or drag. Minor faults and joints adjacent to the Atwood Fault strike parallel with the fault. These observations indicate that the Atwood Fault is a normal fault.

A smaller parallel fault is about 0.4 mile west of the Atwood Fault in Sec. 9, T13S, R2W. The smaller fault also parallels the axis of the Harrison Creek Anticline a short distance to the west. Maximum displacement of the smaller fault is roughly 300 feet, where upper Bailey Formation on the east is downthrown against Bainbridge Formation on the west.

Delta Fault The Delta Fault was first mapped by J. Weller and Ekblaw (1940) and named for the village of Delta (of which Pleasant Valley Church is the only extant structure). Our map of the fault is similar to that of Weller and Ekblaw, except that we do not extend the fault quite as far south.

The Delta Fault is about 4 miles long and nearly linear, striking N15°W. Along most of the fault, the Clear Creek Formation on the west is faulted against Clear Creek, Grand Tower, and St. Laurent strata on the east. Near the north end of the fault, the Grassy Knob Chert on the west is juxtaposed with the Clear Creek on the east. Throw is probably 100 to 200 feet along the middle part of the fault; lack of marker beds prevents accurate measurement.

Breccia zones are as wide as 12 feet along the Delta Fault. Breccia is composed of angular chert fragments cemented by silica and iron oxide. The fault surface, observed in several places, dips 60° to 80° east and bears nearly vertical mullion and slickensides. Smaller faults and joints adjacent to the main fault

strike subparallel. In some places, the Delta Fault splits into several closely spaced parallel fractures having stepwise displacement down to the east. Steep eastward dips (drag folds) occur within a few feet of the fault surface and in narrow slices within the fault zone. These observations indicate that the Delta Fault is a high-angle normal fault.

Southeast of the Delta Fault in Sec. 21 and 22, T13S, R2W, are several smaller faults that strike N25–40°W. These faults outline a graben in which Grand Tower and St. Laurent Formations are down-dropped against Clear Creek Formation. One of these faults is exposed in a silica mine; it is a nearly planar normal fault that dips 80° to 85° northeast and has a thin zone of breccia. Drag folding adjacent to the fault surface is consistent with normal displacement.

Cape Road Fault We give the name Cape Road Fault to the fault that extends south from the west part of Sec. 2 to the west edge of Sec. 23, T13S, R2W. It is named for Old Cape Road (labelled "Plank Hill Road" on the USGS topographic map; Old Cape Road is the current name). Savage (1920b) mapped this fault much as we do, except that he showed it extending farther south. The Cape Road Fault does not appear on the map of J. Weller and Ekblaw (1940).

The fault is about 4.5 miles long, and its net displacement is down to the east. Along most of its length, the Clear Creek and Grand Tower Formations on the west are juxtaposed with undifferentiated Mississippian-Devonian strata on the east. The throw is estimated to be 100 to 200 feet in most places.

The Cape Road Fault differs from the Atwood and Delta Faults because it has much more extensive brecciation. A zone of megabreccia as wide as $\frac{3}{8}$ mile is on the east side of the fault for most of its length. The best exposures of megabreccia are along the stream that flows east through the center of Sec. 11, T13S, R2W, Jonesboro 7.5-Minute Quadrangle. In this and other areas, large and small clasts are chaotically jumbled in a matrix of multicolored, soft plastic clay (fig. 23). Clasts consist of silicified and leached Springville and St. Laurent shale and siltstone, Fort Payne chert and ganister, a few

pieces of Dutch Creek Sandstone, and chert nodules and fragments of unknown origin. These clasts range from pebbles to boulders more than 10 feet in maximum dimension. Most clasts are sharply angular, although some have rounded corners. Breccia is largely matrix-supported, but parts are clast-supported. The megabreccia is faulted against Grand Tower and Clear Creek Formations on the west and grades eastward into less strongly deformed Mississippian-Devonian strata.

The Cape Road Fault splits into three branches that outline a lozenge-shaped block in the SW, Sec. 14, T13S, R2W. Farther south, two faults extend south-southwest. The fault zone is well exposed along a streambed in the NE NW SW, Sec. 23, T13S, R2W, near the north edge of the Mill Creek Quadrangle. The main fault is marked by a 10-foot-wide zone of iron-cemented breccia and gouge. The breccia zone strikes N20°E and dips vertically, separating shattered chert of the Clear Creek Formation on the west from strongly folded and faulted shales of the St. Laurent Formation on the east. Exposures of deformed and altered multicolored shale occur along the streambed as far as 1,000 feet east of the main fault.

Near its southern end, the Cape Road Fault splits into three en echelon faults that strike N20°E. These dip vertically or nearly so, and some have wide zones of breccia (fig. 24). Faults outline upthrown and downthrown slices of folded or steeply tilted rocks. In places the sense of drag and the indicated stratigraphic displacement are in opposite directions (fig. 24). Good exposures of these faults occur along the east-trending ravines in the NE SE, Sec. 27, and along the south branch of Lingle Creek near the farmhouse in the SW SW, Sec. 26, T13S, R2W. A graben about 50 feet wide is at the latter site; contorted and jumbled shale of the St. Laurent Formation is down-dropped into Dutch Creek Sandstone.

A northeast-facing monocline continues farther south in line with the Cape Road Fault, from the NW, Sec. 35, T13S, R2W, to the west part of Sec. 19, T14S, R1W. Dips along the flank are typically 15° to 25° and locally are steeper. Small faults are present, but poor exposures obscure

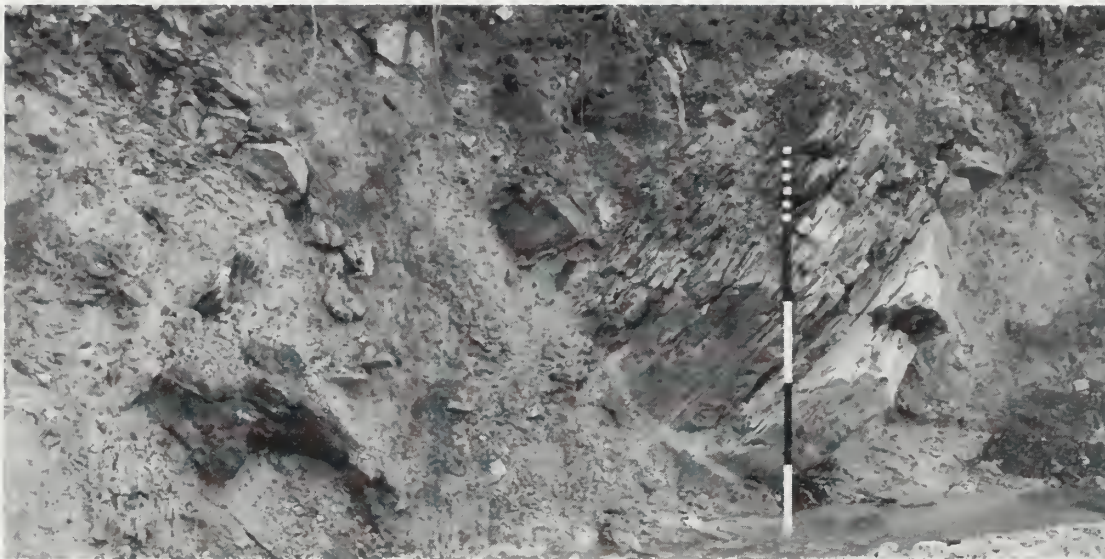


Figure 23 Megabreccia, composed of blocks of altered Springville Shale and St. Laurent Formation in a soft claylike matrix. This breccia occupies a zone as wide as $\frac{3}{8}$ mile on the east side of the Cape Road Fault. Overlying Quaternary alluvium is undeformed. Locality is an east-flowing stream, NW NE SW, Sec. 11, T13S, R2W, Jonesboro Quadrangle. The staff is 5 feet long.

them. The monocline coincides with the southern part of the Cape Road Fault as mapped by Savage (1920b).

At its north end, the Cape Road Fault passes under alluvium in the NW, Sec. 2, T13S, R2W, Jonesboro 7.5-Minute Quadrangle. A possible continuation is exposed in the bank of Dutch Creek near the center of the NW, Sec. 35, T12S, R2W. Several faults in this area offset chert of altered Clear Creek Formation. The largest fault has a breccia zone more than 5 feet wide, which is filled with large, angular blocks of silicified Springville Shale, St. Laurent Formation, and probable Fort Payne. Clasts are as large as several feet across and float in a matrix of brown plastic clay containing laminae of well rounded quartz sand. The clasts are downropped a minimum of 200 feet. Smaller faults in the bank also dip vertically or nearly so, and they contain breccias composed of chert from the Clear Creek.

The brecciation along the Cape Road Fault is out of proportion with the modest vertical displacements. Breccias are composed of younger rocks that dropped several hundred feet downward but underwent little grinding or crushing, implying that they collapsed into wide open fissures. Such fissures can develop under divergent wrench faulting (Wilcox et al. 1973, Woodcock and Fischer 1986). The en echelon pat-

tern of faults near the ends of the Cape Road Fault is consistent with right-lateral wrench faulting. Megabreccias similar to those along the Cape Road Fault occur in the Thebes Quadrangle and are interpreted as pull-apart grabens along northeast-trending, right-lateral faults (Harrison and Schultz 1992).

“Thumb Area”

The name “thumb area” refers to an upland area, shaped like a thumb in map view. The “thumb area” is along the Mississippi River bluffs in Sec. 20 and 29, T12S, R2W (fig. 22) and has unusual stratigraphy and structure.

Paleozoic rocks in the thumb range from upper Clear Creek Formation through Springville Shale. Outliers of Wilcox (?) gravel cap hills near the “base” (south end) of the thumb. Several units are thicker here than in adjacent areas. The Springville Shale may exceed 100 feet in the thumb—the thickest Springville found in the study area. The New Albany Shale appears to be about 80 feet thick, whereas it is absent in outcrops east of the thumb. The limestone member of the Grand Tower Limestone is well developed in the thumb but thin or absent in exposures to the south and east.

Structurally, the thumb is downropped. At the base of the thumb, Paleozoic strata dip 10° to 15° north-

west, away from the Harrison Creek Anticline. Farther north, several faults that strike east-northeast outline grabens and horsts. Either a fault or a sharp flexure underlies the northwest-trending valley of Dutch Creek northeast of the thumb. The nearly linear, northeast-trending valley of Green Creek (east of the base of the thumb) may also contain a fault. Faults under Green Creek may be offset continuations of faults that cross the base of the thumb.

Evidently, the thumb area was deformed repeatedly. Thick Grand Tower, New Albany, and Springville rocks imply Devonian to early Mississippian downwarping. Subsequently, these strata were folded and faulted. The Harrison Creek Anticline rose, tilting the base of the thumb northwest prior to Eocene (?) time. Wilcox (?) gravel was then deposited across the beveled edges of dipping Paleozoic rocks. Additional, later downdrop is indicated by the fact that Wilcox (?) gravel is absent on nearby higher hills.

Altered Area

The altered area is a region where all Paleozoic rocks are leached of carbonate and silicified. It contains important commercial silica deposits. The altered area is structurally distinct from surrounding areas, and tectonics evidently played a role in altering the rocks.

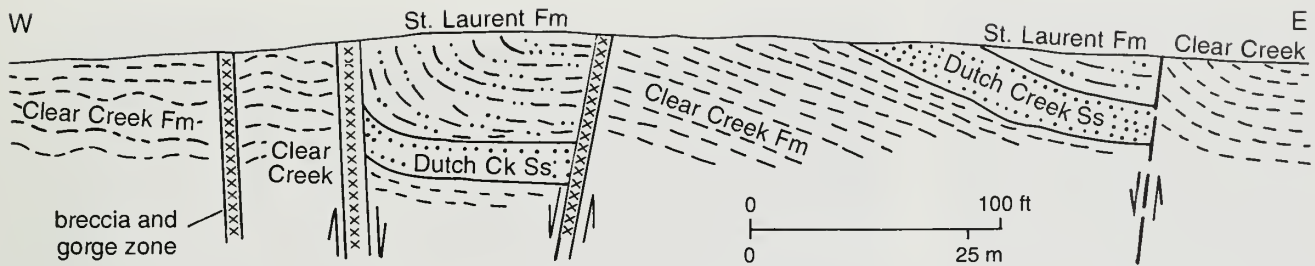


Figure 24 Profile of fault zone along an east-trending ravine in the SE NE SE, Sec. 27, T13S, R2W. Faults strike about N20°E and outline a graben. On the easternmost fault, the "drag" is opposite to the stratigraphic offset, indicating that this fault either underwent a reversal of the direction of throw, or has a component of strike-slip.

Extent The altered area covers most of the Mill Creek Quadrangle, the southern part of the Jonesboro 7.5-Minute Quadrangle, and part of the McClure Quadrangle. A small inlier of unaltered rocks occurs near Lingle Creek in the SW, Sec. 26, T13S, R2W. The border of the altered area is marked on the geologic maps (Devera et al. 1994, Nelson and Devera 1994).

Lateral boundaries of the altered area are well defined in some places, diffuse in others. The east boundary is fairly sharp; for example, on the south side of Lingle Creek (Sec. 30, T13S, R1W), unaltered Fort Payne limestone changes to ganister in less than 100 feet. The west boundary in the Mill Creek Quadrangle is highly irregular. Certain layers (presumably more permeable strata) in the Grassy Knob Formation seem to have been altered selectively while overlying and underlying beds were unaffected.

The extent of alteration at depth is little known. The deepest test holes are about 400 feet deep, and most lack accurate and detailed logs. Available records indicate alteration extends at least 400 feet downward in most of the altered area. Silica miners confirm that underground tripoli deposits extend several hundred feet below the surface.

Nature of alteration Detailed descriptions of the lithologies of altered units are in the Stratigraphy section. Briefly, all carbonate minerals were removed, and silica was concentrated. Altered rocks are either bleached or blotched and banded in a variety of bright colors (calico rock). The Bailey, Grassy Knob, and Clear Creek Formations, which originally were cherty and siliceous limestones, are altered to bedded chert and tripoli. The Grand

Tower Limestone, a relatively pure limestone, was largely dissolved; whereas, the Dutch Creek Sandstone Member was brecciated. Argillaceous limestones and calcareous shales of the St. Laurent Formation were altered to calico-colored, slabby, siliceous rock and brown, punky rock interbedded with chert. The Springville Shale was silicified and stained in calico colors. The Fort Payne was changed to bedded chert and ganister, and the Ullin Limestone was largely dissolved, leaving residual chert nodules and reddish brown clay.

Faults The altered area has a much greater density of faults than does the surrounding region. Hundreds of faults, mostly too small to map, were observed. Given the density of faults seen in good exposures such as silica mines, thousands more probably are concealed by loess, alluvium, soil, and vegetation. Few exposures longer than 50 feet lack faults.

In the Jonesboro 7.5-Minute Quadrangle and in northern parts of the Mill Creek Quadrangle, most faults strike north-south or nearly so; they are subparallel to the Atwood, Delta, and Cape Road Faults. In the southern part of the Mill Creek Quadrangle, the principal fault trend is N30-40°E; north-south faults are uncommon. Linear north-east-trending topographic features such as Sexton Creek, Sandy Creek, Jim Branch, and the Cache Valley bluff at Tatumville may be fault-controlled. East of the Delta Fault, several smaller faults strike north-northwest. Faults that strike east-west to about N60°W occur throughout the altered area but are less common than other trends.

Nearly all faults in the altered area dip steeper than 60°, and many are

vertical. Most fault surfaces are planar to slightly sinuous in dip direction. A few surfaces are strongly curved, typically steepening downward. A few subhorizontal faults (parallel to bedding) were observed. Some of them offset steeply dipping faults.

Displacements are difficult to determine due to the small size of exposures and the scarcity of marker beds. In most places where throw could be measured, displacement was less than 10 feet. Larger faults having 10 to 100 feet of throw occur mostly in the Mill Creek Quadrangle. Most of these are mappable only because Dutch Creek Sandstone or St. Laurent strata serve as marker beds. A fault having more than 100 feet of displacement could easily go undetected in the uniform chert of the Clear Creek Formation.

Most faults in the altered area lack slickensides. Where present, slickensides and mullion are commonly horizontal or nearly so. In a few places, the direction of horizontal (strike-slip) displacement may be deduced. Two faults northwest of Dago Hill in the SW, Sec. 3, T14S, R2W, Mill Creek Quadrangle, strike west-northwest and have horizontal slickensides. The "smoothness test" on the slickensides, combined with the orientation of pinnate fractures along the faults, indicate left-lateral displacement. A fault in the NW SE NE, Sec. 4, T14S, R2W, strikes N40°W, dips 84° NE, and has striations that plunge 70° SE, indicating left-lateral oblique slip.

Several upthrust faults or positive flower structures (Harding 1985) were observed. A good example of a positive flower structure was exposed on the highwall of the Lone Star Cement Company's silica quarry (NW, Sec. 15, T14S, R2W).

Several curving high-angle reverse faults steepen downward and converge to a single vertical fault (fig. 25). Another flower structure was observed in the bank of Lingle Creek (NW NE, Sec. 26, T13S, R2W). A small reverse fault and a small, tight reverse kink fold both strike N80–85°E and dip steeply north (fig. 26). Other compressional structures include a monoclinial kink fold near the portal of an abandoned silica mine (SE NW NW, Sec. 14, T14S, R2W). The axial plane of the kink fold trends N70°W/70°SW. Nearly all of the reverse faults in the altered area dip at least 60°.

What may be a large positive flower structure was mapped in the NE, Sec. 33, and an adjacent part of Sec. 34, T13S, R2W. A narrow block of Bailey Limestone and Bainbridge Formation is faulted against Bailey and Grassy Knob on both sides. Bounding faults strike west-northwest, parallel to nearby faults that have horizontal slickensides.

Pull-apart structures, or negative flower structures, may be more common than positive flower structures. Many fault zones in the altered area are filled with coarse breccia of angular chert fragments and, less commonly, Cretaceous–Tertiary gravel (fig. 27). Some faults that have only a few inches or feet of vertical separation contain breccia zones several feet wide. For example, a northeast-trending fault at the head of Sexton Creek (near the SE corner, Sec. 4, T14S, R2W, Mill Creek Quadrangle) has a breccia zone 30 feet wide but no detectable vertical offset. Breccia zones occurring along vertical faults typically are funnel-shaped, narrowing downward. Breccias also occur at the crests of small chevron anticlines (fig. 28). J. Weller (1940, unpublished field notes, ISGS open files) reported vertical fractures filled with gravel (Tuscaloosa?) in the roof of a ganister mine (now abandoned) northeast of Elco in the NE NE NW, Sec. 18, T14S, R1W.

A large pull-apart structure is present in You-Be-Damned Hollow in the SW NW, Sec. 35, T13S, R2W. The fault zone, which appears to strike north-south, contains a megabreccia zone nearly 100 feet wide. Blocks and fragments of limestone, siltstone, and shale from the Devonian St. Laurent Formation and Mississippian Springville Shale are down-

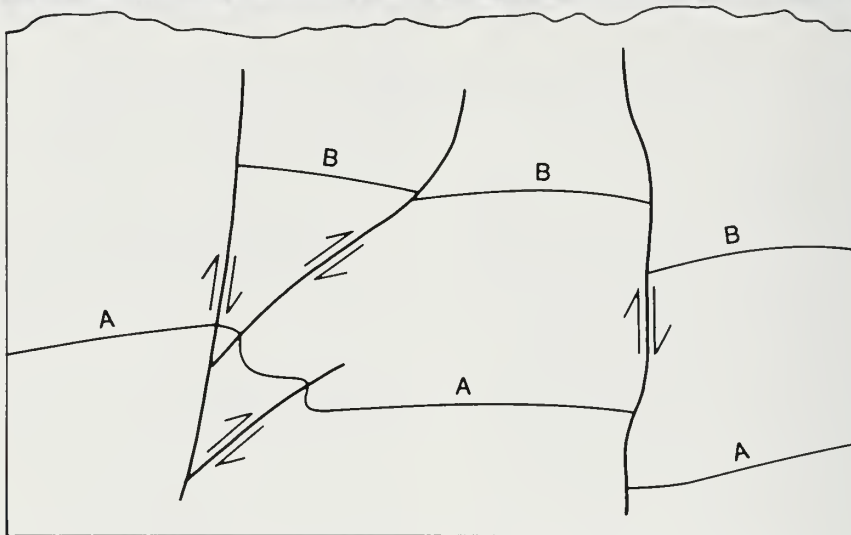


Figure 25 Faults on the north-facing wall of Lone Star Cement Company's open-pit silica mine in the NE NW, Sec. 15, T14S, R2W, Mill Creek Quadrangle. On the east (left) is a positive flower structure composed of several upthrust faults that steepen downward and combine into a single vertical fault. Note that the beds do not match on opposite sides of this structure. The hard brown chert layer "A" traces across with little vertical offset, but chert layer "B" is not present east of the fault. This is further evidence for strike-slip displacement. The nearly vertical fault west of the flower structure has a sinuous fault surface, indicative of strike-slip. The rock is altered Clear Creek Formation (interbedded chert and tripoli). The strike trend of faults could not be determined. The staff is 5 feet long.

dropped against Dutch Creek Sandstone. Clasts are as much as several feet across, and some are internally deformed (fig. 29). Bedding of Dutch Creek Sandstone west of the fault zone and St. Laurent Formation east of the zone both dip gently east. Springville clasts in the breccia are downdropped at least 100 feet relative to adjacent strata. This breccia is similar to that found along the Cape Road Fault.

Normal and reverse faults commonly occur parallel and side-by-

side. For example, in the Lone Star Cement Company's silica mine, two normal faults and one reverse fault all strike N40–45°E. Normal and reverse faults strike both north-south and east-west at the Jason no. 2 open-pit silica mine in the SE, Sec. 22, T13S, R2W. Moreover, drag along many faults indicates movement opposite to the observed stratigraphic (vertical) displacement. Bedding on both sides of a fault may be folded in the same direction (upward or downward), or bedding may be

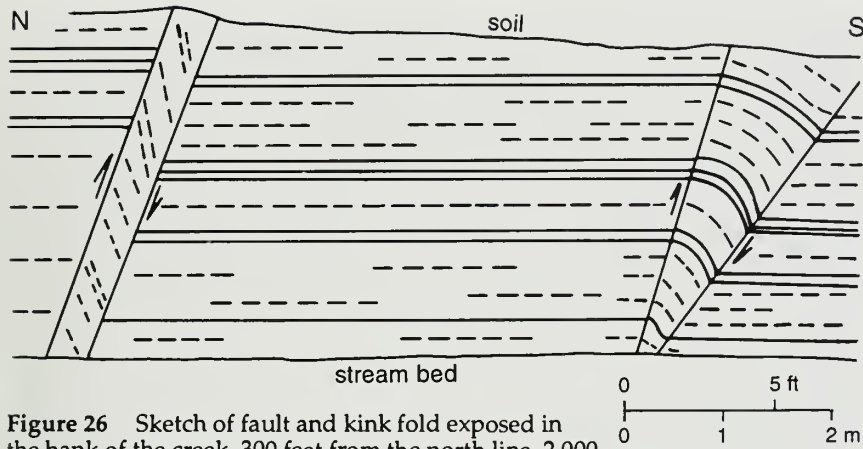


Figure 26 Sketch of fault and kink fold exposed in the bank of the creek, 300 feet from the north line, 2,000 feet from the east line, Sec. 26, T13S, R2W. Both the reverse fault and the axial plane of the kink fold strike N80–85°W and dip steeply north. These structures are more likely products of strike-slip faulting than of horizontal compression.

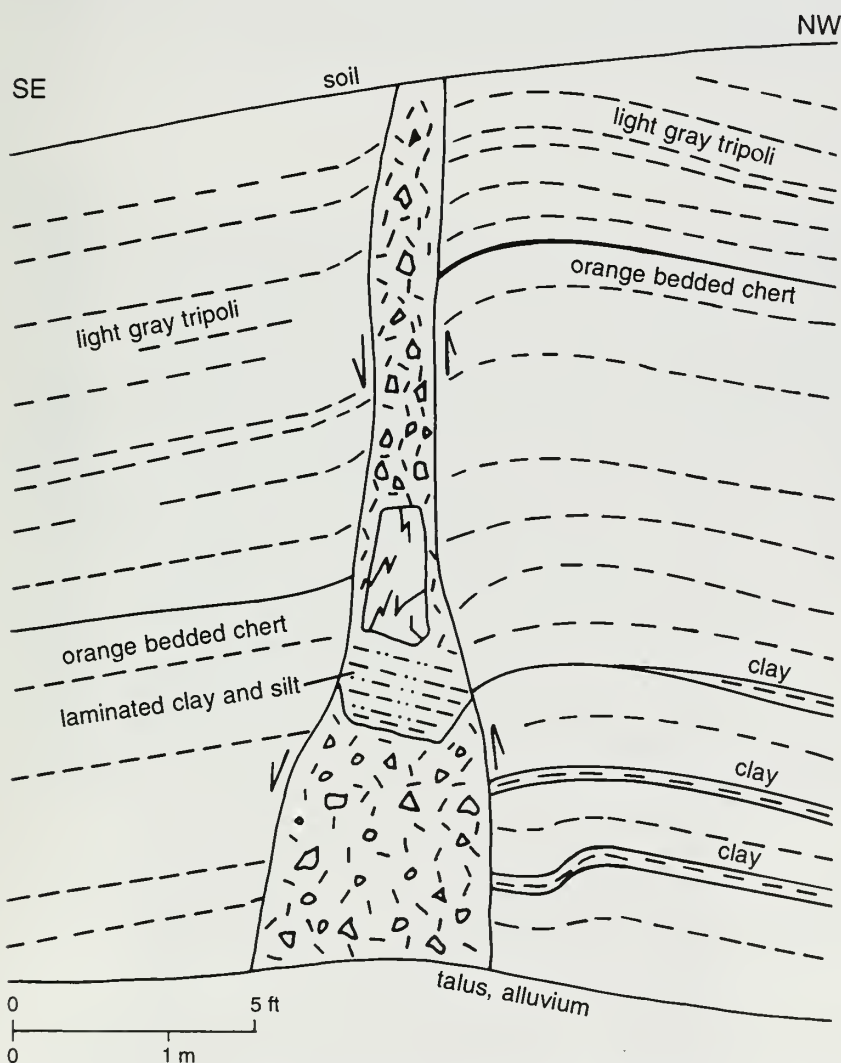


Figure 27 Sketch of a fault in the southwest bank of Johnson Creek, just east of the NW corner, Sec. 24, T14S, R2W. Fault strikes north-northeast and dips vertically; chert and tripoli of Clear Creek Formation apparently are downthrown to the southeast. The fault zone is filled with a loose breccia of angular chert fragments intermixed with silt and clay, some of which is laminated, indicating deposition by water in large open crevices. The sinuous fault surface, wide breccia zone, and inconsistent “drag” folds indicate a component of strike-slip.

nearly horizontal on one side of a fault and steeply tilted on the other (fig. 30).

Folds Folds in the altered area are predominantly brittle. Most folds are chevron or hinge-shaped (fig. 28). Flanking dips greater than 30° are uncommon except adjacent to faults. Small monoclines, anticlines, and synclines have vertical or steeply dipping axial planes, along which rocks are intensively fractured. Such folds pass laterally or vertically into faults of small displacement. Distinguishing sharp hinge-like folds from faults can be difficult when there are no marker beds (as is usually the case).

Small arcuate folds and kink folds are associated with flower structures. Most such folds trend east-west to east-southeast-west-northwest. These folds are closely associated with faults. They may be fault-propagation folds.

Bedding of the Clear Creek Formation in the altered area gently undulates in seemingly random manner (fig. 6). Undulations may be partly tectonic structures and partly products of uneven settling during alteration.

Joints and clastic dikes Jointing is pervasive in all hard rocks of the altered area. Only soft tripoli and claylike shales do not display joints. Most large outcrops display two to four sets of joints. North-south joints are abundant and closely spaced throughout the altered area. Joints that trend north-northeast are abundant in some areas and uncommon in others. East-west joints occur throughout the altered area but rarely are closer than 1 foot apart. Joints that trend west-northwest are common, but they are widely spaced also. Thus, the trends and abundances of joints are closely similar to those of faults in the altered area.

Narrow veins and dikes filled with clay, silt, sand, gravel, and chert fragments are widespread in the altered area. Trends vary, but many strike east-west to west-northwest-east-southeast and are vertical or nearly so. Most clastic dikes are slightly sinuous in strike and dip. Clay-filled veins and dikes are most common in the Clear Creek Formation but occur in other units, including Cretaceous-Tertiary sands and

gravels. Most dikes are only a few inches wide, but a few are as wide as 2 feet (fig. 31). Near the Delta Fault, dikes are numerous and strike west-southwest and north-northwest, normal and parallel to the fault.

Altered Clear Creek Formation contains both vertical dikes and horizontal or inclined veins filled with sediment. The filling is light gray to light greenish gray plastic clay, mottled in pale pink and violet. Some veins also contain light gray silt and chert sand, as well as occasional large angular fragments of chert. Some vein-filling sediment is laminated (fig. 27), indicating deposition by water in open cavities. Some sediment-filled veins and fissures are associated with faults (fig. 27), but most are not.

Causes of alteration Several previous authors published theories on the causes of alteration. J. Weller (1944) suggested deep weathering and leaching beneath a Tertiary peneplain. Lamar (1953) concurred with Weller that the rocks were altered by groundwater close to the surface. Both Weller and Lamar thought that much of the complex structure in the altered area resulted from dissolution and collapse. Berg and Masters (1994) propose that the silica deposits are of hydrothermal origin. Their conclusion is based partly on similarity of southern Illinois silica to other deposits of known hydrothermal origin. Berg and Masters also note that large gravity and magnetic highs coincide with altered areas, implying the presence of mafic plutons that served as heat sources.

The deep-weathering hypothesis of Weller and Lamar fails to account for the fact that altered rocks extend at least 400 feet below the surface in some areas, whereas unaltered rocks crop out nearby. Deep weathering also does not explain silicification of noncalcareous rocks, such as the Springville Shale. Weathering may have played a role in altering some rocks. Outcrops of Clear Creek limestone commonly have tripolitic rinds, and Fort Payne outcrops have rinds of ganister. These surficial rinds are generally a few inches thick at most. Limestone undergoes extensive dissolution in the subsurface throughout southern Illinois,



Figure 28 Anticline in the Springville Shale, SE NE NE, Sec. 11, T13S, R2W, Jonesboro Quadrangle. The axial plane strikes about N30°E and dips steeply. At the crest of the fold, just left of the staff, fissures and angular rotated blocks of silicified shale indicate pull apart. The staff is 5 feet long.



Figure 29 Tight chevron fold in shale and siltstone of the St. Laurent Formation in You-Be-Damned Hollow, SE SW NW, Sec. 35, T13S, R2W, Mill Creek Quadrangle. Siltstone just east (right) of fold is horizontal. This exposure is part of a megabreccia that contains clasts of St. Laurent and Springville Shale. The staff is 5 feet long.

but the usual products are terra rosa and karst topography.

We favor hydrothermal alteration, as proposed by Berg and Masters (1994). Hydrothermal activity would affect all lithologies and extend to depth, as is observed. Deep-seated plutons, indicated by magnetic/

gravity anomalies, provided heat and perhaps acidic fluids that dissolved carbonate and precipitated silica. Certain layers, more permeable or chemically susceptible, were selectively affected.

Mineralization in and near the altered area lends additional support



Figure 30 Fault in the Springville Shale, SW SE SE, Sec. 11, T13S, R2W, Jonesboro Quadrangle, strikes N20°E and the west (left) side is downthrown. Note the steep dip of the downthrown block contrasting with near-horizontal shale in the upthrown block.



Figure 31 Fissure (2 ft wide) in Clear Creek Formation is filled with breccia of angular chert clasts and strikes N38°E. It is located just west of the Delta Fault.

to the hydrothermal theory. Limonite, goethite, and botryoidal manganese oxides are common in the altered area, particularly along faults. The characteristic rose and magenta shades of calico rock are probably due to manganese. Iron and manganese oxides are common in low-temperature hydrothermal deposits, although they also occur in non-hydrothermal settings. Fluorite occurs in veins and cavities in the Ste. Genevieve Limestone at the Anna Quarry, a short distance north of the altered area. Cuttings from the Humble Oil Company no. 1 Pickel well, drilled just west of the altered area, contained unusually high concentrations of silver, arsenic, lead, molybdenum, and copper. Total metallic content of samples from the Pickel well was the highest among 29 wells sampled around the western and southern margins of Illinois (Erickson et al. 1987).

Our mapping reveals that bedrock is intensively faulted and fractured throughout the altered area. Faults and joints trend in several directions, forming an intersecting gridwork. The density of faults in the altered area contrasts with the virtual absence of faults in the bordering eastern and western homoclinal areas. Faults and fractures provide pathways for hydrothermal fluids. In particular, open fissures and pull-apart structures, common throughout the altered area, are highly permeable. Some of the most intensive silicification (e.g., near Elco and in the central Mill Creek Quadrangle) occurs along mapped faults. Clastic dikes may be extensional or transtensional fissures that were filled with sediment carried by circulating fluid.

In conclusion, low-temperature hydrothermal action was the primary cause of altered rock in the study area. Deep-seated plutons supplied the heat. The fluids may have come from the plutons or from groundwater, circulated by convection. Intersecting sets of closely spaced, extensional and transtensional faults and fractures provided pathways for the hot water. An ample supply of fine grained biogenic and detrital silica lay in the Bailey, Grassy Knob, Clear Creek, Fort Payne, and other formations. Acidic hydrothermal fluids removed carbonate minerals and replaced them

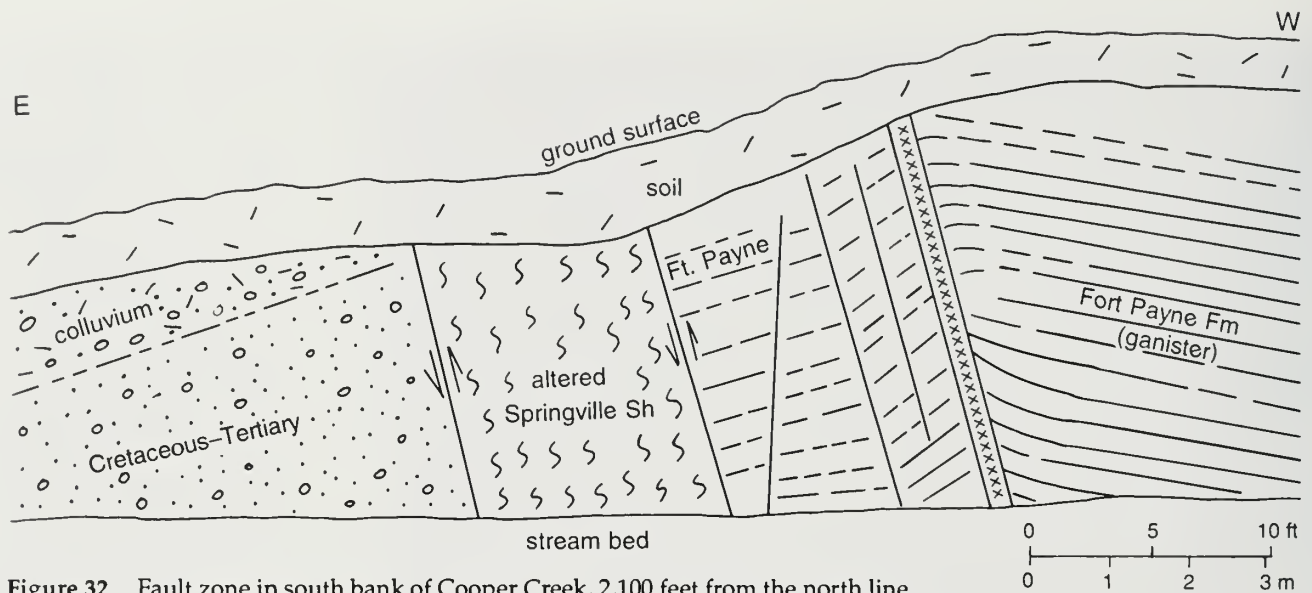


Figure 32 Fault zone in south bank of Cooper Creek, 2,100 feet from the north line, 2,400 feet from the east line, Sec. 1, T14S, R2W, Mill Creek Quadrangle. High-angle reverse and normal faults strike approximately N20°W and displace Mississippian rocks against Cretaceous-Tertiary sand and gravel. The wide deformed zone and inconsistent direction of “drag” indicate a large component of strike-slip movement.

with silica. Units like the Clear Creek, originally very siliceous, may have undergone little loss in volume (although data on this subject are lacking). Relatively pure carbonate units, such as the Grand Tower Limestone, were largely dissolved away, allowing overlying rocks to collapse and fracture further.

Post-Cretaceous Faulting

Tectonic faults that displace Cretaceous and Eocene sediments were observed during this study. The extent and nature of post-Cretaceous faulting is difficult to assess because of the poor exposures and lack of stratigraphic control. Exposures of faulted Cretaceous strata are small, and most required digging to reveal details. Evidence indicates, however, that post-Cretaceous tectonic activity was widespread and significant. The main belt of Cretaceous and Eocene (?) outcrops parallels major faults and may be tectonically controlled.

The best fault exposure is in the south bank of Cooper Creek 2,100 feet from the north line and 2,400 feet from the east line, Sec. 1, T14S, R2W, Mill Creek Quadrangle. The fault zone strikes about N20°W, dips steeply west, and juxtaposes Cretaceous or Eocene (?) sand and gravel on the east against Fort Payne chert and Springville Shale on the west (fig. 32). Drag folding is not consistent with the observed stratigraphic

displacement, which indicates a component of strike-slip displacement.

Another fault that offsets Cretaceous or Eocene strata against Paleozoic rock is exposed along the east-flowing stream about 700 feet from the south line and 300 feet from the west line of Sec. 13, T13S, R2W, Jonesboro 7.5-Minute Quadrangle. The fault surface is obscure, but Cretaceous (or Eocene) sand and gravel dip steeply west and butt against Springville Shale. The shale is highly fractured and bears a drag fold that indicates displacement down to the west, a finding that would be consistent with stratigraphic offset. This fault forms the east side of a narrow graben that trends north-south or slightly west of north. The west side of the graben is covered by slumped material. A cross fault strikes N65°W and displaces Springville and Fort Payne strata a short distance east of the graben. Abrupt elevation changes of the McNairy on opposite sides of the cross fault indicate that it also is displaced.

Tuscaloosa (?) gravel is faulted against Paleozoic rocks near Elco. At the portal of an abandoned underground ganister mine, 800 feet from the north line and 3,300 feet from the west line, Sec. 18, T14S, R1E, two faults displace light gray chert gravel against ganister of the Fort Payne Formation. One fault strikes N5°W and dips 75°W, with the east

side downthrown. This is geometrically a reverse fault. The other fault strikes N75°W and dips 75°N, with the north side downthrown (a normal fault). The normal fault appears to terminate against the reverse fault. Both faults have dip-slip displacements of at least 10 feet. No drag, mineralization, or slickensides are present; only a thin layer of clay and sand gouge occurs along the steeply dipping fault surfaces (fig. 33).

Field notes made by J. Weller (1940, ISGS files) while the ganister mine was active describe vertical fissures or veins filled with gravel in the interior of the mine. Weller did not mention the orientation of the fissures.

Tuscaloosa (?) gravel probably was faulted in the Elco gravel pit (now mostly backfilled) near the center of the north line of Sec. 18, T14S, R1E. Light gray chert gravel is still exposed in the pit and nearby roadcuts along Rt. 127. Notes and a sketch from the pit by J.E. Lamar (1927, ISGS files) show gravel in a deep rectangular depression, bounded by nearly vertical walls of Paleozoic bedded chert. The walls of the pit ran north-south and east-west. Lamar also depicted a north-south fissure, filled with clay containing angular chert fragments and intruded into sand and gravel on the pit floor. Although Lamar did not call these features faults, his description implies they are faults.

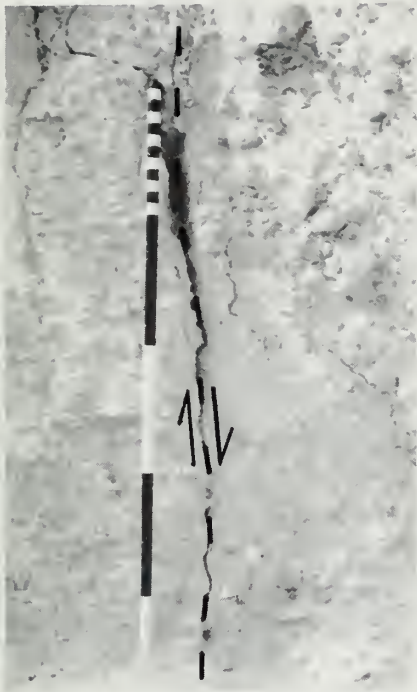


Figure 33 Fault at the portal of an abandoned ganister mine near Elco, 800 feet from the north line, 3,300 feet from the west line, Sec. 18, T14S, R1W, Mill Creek Quadrangle. Cretaceous–Tertiary gravel on the north (right) is in fault contact with bleached ganister derived from the Mississippian Fort Payne Formation. The fault trends N75°W, dips 75°N and is normal. A fissure (perhaps caused by subsidence of the mine opening) has developed along the clay-lined fault surface. The staff is 5 feet long.

Moreover, they are nearly parallel to the faults at the abandoned ganister mine described above.

Steeply dipping and faulted Cretaceous or Eocene sand and gravel crop out along a small stream in the SW SW SE, Sec. 11, T13S, R2W, Jonesboro Quadrangle. These sediments are folded into a monocline that strikes N20°E and dips as steeply as 40°SE (fig. 21). Nearby, a small fault displaces the gravel; it strikes north–south, and the west side is downthrown (fig. 34). The fault and monocline trend parallel to nearby faults in Paleozoic bedrock.

Deformed outcrops of McNairy and Wilcox (?) sand, clay, and gravel occur along an east-trending ravine in the NE SE, Sec. 11, T13S, R2W. The McNairy is brightly colored sand containing stringers and layers of chert gravel and lenses of gray silty clay. Elisabeth Wheeler (North Carolina State University, Raleigh, written communication, 1992) identified a piece of petrified wood from this exposure as typical of McNairy species. Light to dark gray, well rounded chert gravel in the ravine is tentatively identified as Wilcox. Steeply dipping and contorted layering, as well as small normal faults were observed in McNairy and Wilcox (?) sediments along this drainage.

A small inlier of McNairy sand and gravel, probably in a down-

faulted block, is exposed along a small south-flowing stream north of You-Be-Damned Hollow in the NE of Sec. 35, T13S, R2W, Mill Creek Quadrangle. The inlier is surrounded by tilted and faulted Mississippian rocks. Bedding of the sand and gravel strikes approximately east–west and dips 25°S. Exposures of Springville Shale and Fort Payne Formation occur immediately north of the dipping sand and gravel. They are offset by a fault that trends N80°E and dips 70°S. A short distance south of the gravel inlier, Springville Shale dips 15°N. Southward, along the bed of the main stream in You-Be-Damned Hollow, Springville Shale is strongly jointed. Primary joints strike N5°W, secondary joints east–west; bedding dips variably, as steeply as 20°E or 20°W.

Cretaceous and/or Tertiary sand and gravel occur in pull-apart breccia zones along faults in the altered area. An example visible from a county road is in a high cut bank of Lingle Creek in the NW NE, Sec. 26, T13S, R2W, Mill Creek Quadrangle.

Structural control of the south-trending belt of Cretaceous–Tertiary strata in the eastern part of the study area is indicated by the fact that the belt parallels the Atwood, Delta, and Cape Road Faults and the Harrison Creek Anticline (fig. 22). Most faults that displace Cretaceous–Tertiary materials in this belt run north–south. Just north of the study area (in the Cobden Quadrangle), the west edge of the belt is a fault that juxtaposes Cretaceous and Eocene sediments with Paleozoic bedrock (Devera and Nelson 1995).

No tectonic deformation of Quaternary sediments was detected. Several post-Cretaceous faults described previously are overlain by undeformed Quaternary loess and alluvium. Undisturbed Pleistocene sediments also overlie many exposures of faults that displace Paleozoic rocks. An especially instructive exposure is in a high cutbank of the east-flowing creek 2,300 feet from the south line and 1,700 feet from the west line of Sec. 17, T11S, R2W, Jonesboro 7.5-Minute Quadrangle. At this site, about 30 feet of subhorizontal, unfaulted Pleistocene sediments overlie Paleozoic megabreccia near the Cape Road Fault. The Pleistocene strata include Peoria, Roxana, and Loveland Silts overlying

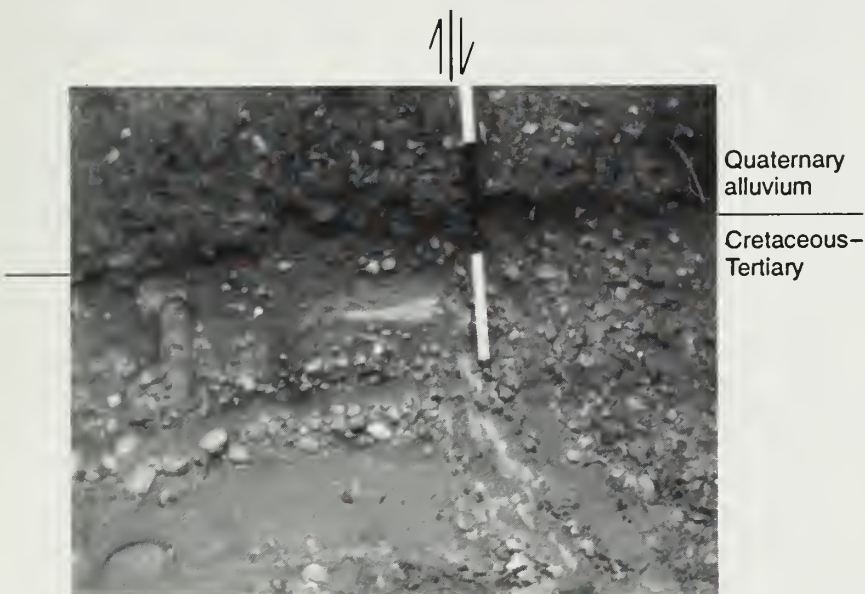


Figure 34 Small fault displacing Cretaceous–Tertiary sand and gravel, SW SW SE, Sec. 11, T13S, R2W, Jonesboro Quadrangle. The fault strikes north–south and the west (right) side is downthrown. The amount of displacement is unknown but probably small. Overlying Quaternary alluvium is not displaced.

two distinct layers of pre-Loveland alluvium (Leon R. Follmer, personal communication, 1993).

To summarize, faults that displace Cretaceous–Tertiary sediments in the Mill Creek and Jonesboro Quadrangles strike approximately north–south and east–west, and they dip steeply, nearly vertical in most cases. Vertical displacements probably range from a few tens of feet to 100 feet or more. Some faults, particularly the north–south ones, probably have large components of strike-slip displacement. No evidence of Quaternary tectonic activity was discovered.

Summary

The Jonesboro Quadrangle clearly has a complex tectonic history, and the order of events and their role in regional geology remain unclear. Mapping in adjacent areas may further clarify the relationships.

Gentle eastward dips in the eastern and western homoclinal areas reflect subsidence of the Illinois Basin relative to the Ozark Dome. This subsidence took place during and after the Paleozoic Era.

The Harrison Creek Anticline is similar in trend and geometry to the Du Quoin Monocline and the Salem and Loudon Anticlines farther north in Illinois. Like them, it probably overlies faults in crystalline basement (Nelson 1991). The Du Quoin, Salem, and Loudon structures devel-

oped principally in the late Mississippian and Pennsylvanian Periods, with additional post-Pennsylvanian uplift (Kolata and Nelson 1991).

The Atwood and Delta Faults are post-Devonian, high-angle normal faults. Northeast of the study area, similar normal faults strike north-northwest in the Makanda (Jacobson and Weibel 1993) and Bloomfield (Nelson 1993) Quadrangles. These faults displace rocks as young as Morrowan (Lower Pennsylvanian) and presumably are products of horizontal extension.

The Cape Road Fault parallels the Atwood and Delta Faults but exhibits extensive brecciation and fracture patterns that indicate dextral strike-slip. No other large fault in the area has similar features. Small, parallel faults east of the Cape Road displace Cretaceous and Eocene (?) strata. Possibly, the Cape Road Fault originated as a normal fault, along with the Atwood and Delta Faults, and later was reactivated under a different stress field as a strike-slip fault.

Altered (leached and silicified) rocks in the study area are shattered by three or four intersecting sets of faults and joints. This fracture system provided pathways for hydrothermal fluids that were heated by deep-seated plutons. The nearest outcropping igneous rocks, in the Fluorspar District to the east, are Early Permian (Zartman et al. 1967). More likely, the Jonesboro hydrother-

mal event is related to Late Cretaceous–early Tertiary igneous activity in the Mississippi Embayment. The inferred pluton in the Jonesboro Quadrangle is in line with a series of known and inferred mafic plutons along the west edge of the Embayment in Arkansas and Missouri. All of these plutons exhibit high gravity and magnetic values (Hildenbrand 1984). The Little Rock (Arkansas) pluton crops out and is composed of nepheline syenite of Late Cretaceous age (Moody 1949). Northeast of the Little Rock pluton is the Newport pluton, interpreted to be Upper Cretaceous or Paleocene. Associated with the Newport pluton are manganese deposits and silicified Paleocene limestone (Glick 1982).

Many faults in the altered area probably are strike-slip. Some are compressional, but transtensional faults that produced pull-apart structures are more common. The dominant trends are north–south, east–west, and northeast–southwest. In the adjacent Thebes Quadrangle many northeast-striking faults exhibit right-lateral strike-slip and outline pull-apart structures. Units as young as the Mounds Gravel (Pliocene ?) are displaced in the Thebes Quadrangle (Harrison and Schultz 1992, Nelson and Harrison 1993). Major northwest-trending faults on the Ozark Dome were interpreted as left-lateral transfer faults by Clendenin et al. (1989).



GEOLOGIC HISTORY

In this section, we interpret depositional and tectonic events in the study area. A comprehensive treatment is not attempted; emphasis is given to new findings on Devonian, Mississippian, and Cretaceous–Tertiary sedimentation and tectonic activity.

Ordovician

Pre-Maquoketa strata will not be discussed here because information is limited. For a regional review, see Kolata and Noger (1991).

A rapid marine transgression began the deposition of the Maquoketa; the Cape La Croix Member was deposited in relatively deep water. Gradual shoaling is reflected in the upward increasing silt content, gradational to the Thebes Sandstone Member. Part of the Ozark Dome in southeast Missouri was exposed subaerially and supplied sediment to the Thebes Member. During deposition of the Thebes, the sea gradually became shallower; finally, the sea floor was exposed in the tidal flats represented by the red and green mudstone at the top of the Thebes.

The Orchard Creek–Girardeau represents another sequence of rapid transgression (dark clay shales) followed by gradual shoaling (increasing limestone content upward). These strata closely resemble the Fayetteville Shale (Mississippian) of Arkansas, which likewise represents an upward-shoaling sequence (Handford 1986). Limestones of the Orchard Creek–Girardeau are confined to the flanks of the Ozark Dome and do not extend into the more rapidly subsiding Illinois Basin to the east.

After regression and erosion came deposition of shallow, subtidal sediments of the Leemon Formation, which were then largely removed by another cycle of erosion, bringing Ordovician history to a close.

Silurian

Silurian depositional conditions in southwestern Illinois are poorly defined and have received little attention in the literature. According to Whitaker (1988), the study area lay on a shallow, east-sloping ramp between land on the Ozark Dome and deeper water in the southern part of the Illinois Basin. The region seems to have been stable tectonically, and sedimentation proceeded under low energy conditions. There is little evidence relevant to estimating water depth.

Beginning in mid-Niagaran (Moccasin Springs) time, increasing amounts of fine terrigenous clastics were deposited in the study area. Although the source of these clastics is not known, they are widespread in southeastern Missouri and southern Illinois. Sedimentation apparently continued without a break into the Bailey Limestone and across the Silurian–Devonian boundary.

Devonian

Terrigenous clastic input waned as Bailey deposition proceeded, but sponges and other organisms produced large amounts of silica. The fine grain size and thin, even layering of the Bailey imply low energy but not necessary deep water sedimentation. Banaee (1981), however, interpreted the Bailey as comprising carbonate turbidites laid down in a relatively deep basin.

The heavily silicified, unfossiliferous Grassy Knob Chert is an enigmatic unit. Although the unit is partly carbonate rock outside of the altered area, bedded chert persists into the deep subsurface. This indicates that part of the Grassy Knob is primary silica. The lithologically similar and partly coeval Arkansas Novaculite and Caballos Novaculite continue to engender controversy after more than 100 years of study. These novaculites have been assigned to settings that range from intertidal to abyssal (McBride and

Folk 1977). We tentatively favor relatively deep water (below wave base, and deeper than either Bailey or Clear Creek) for the Grassy Knob. Evidence includes the sparse fauna and presence of horizontal burrows rather than vertical (escape) burrows.

The Clear Creek Formation was deposited as primary carbonate mud with a large dose of biogenic silica from sponges and radiolaria (Allen 1985). Common fossils and vertical (escape) burrows indicate fairly rapid sedimentation albeit under low energy conditions. Water depth probably diminished toward the end of Clear Creek time. Upward, brachiopods become more numerous, and terrigenous silt and fine sand came in possibly from the Ozark Dome. A major drop in sea level near the end of Early Devonian time resulted in widespread unconformity on the flanks of the dome.

The eastern Ozark Dome was uplifted recurrently from Middle Devonian on into Mississippian time; this strongly influenced thickness and facies patterns in the study area. Although direct evidence is lacking, basement faults may have been reactivated during this time period. The “thumb area” in the western Jonesboro 7.5-Minute Quadrangle remained persistently low while adjacent parts of the Ozark Dome rose.

During the Eifelian transgression, quartz sand from the St. Peter and older sandstones exposed on the Ozark Dome was reworked into the shoreline deposits that later became the Dutch Creek Sandstone Member. This was followed by deposition of clean skeletal carbonate (upper member of the Grand Tower) in shallow subtidal settings. Tectonic action ushered in the Givetian Age; the crustal block north of the Ste. Genevieve Fault Zone rose (S. Weller and St. Clair 1928, Nelson and Lumm 1985), along with parts of the eastern Ozark Dome. Fine terrigenous clastics from these sources intertongued

with shallow water carbonates of the St. Laurent Formation.

Another drop of sea level in late Givetian or early Frasnian time occurred, and the St. Laurent strata were eroded. Transgression first brought basal sand (Sylamore Bed) and then the main body of the New Albany Shale. The latter was laid down in still water under anoxic, reducing conditions (Cluff et al. 1981). The Ozark Dome, except for the "thumb area," continued to rise during New Albany sedimentation. Near the end of the Devonian Period, sea level dropped and the top of the New Albany was beveled in the study area.

Mississippian

The feather-edge of the Chouteau Limestone reached the northern part of the study area during the Kinderhookian Age. This transgressive limestone contains rip-up clasts from the New Albany. The Chouteau was succeeded disconformably (?) by the Springville Shale (lower Valmeyeran), which was a distal, prograding clastic wedge of the Borden delta (Lineback 1966). In the tectonically positive southwestern part of the study area, the Springville overstepped the New Albany onto the underlying St. Laurent Formation.

After another relative fall and rise of sea level, siliceous carbonates (Fort Payne) accumulated on the eroded surface of the Springville. Fine grain size, sparse fauna, thin even layering, and lack of high energy sedimentary structures indicate relatively deep water (below wave base) for the Fort Payne. The source of silica in the Fort Payne has not been addressed. Possible terrigenous sources include the Borden delta (contrary to Lineback 1966, the Borden and Fort Payne may be coeval) and the Ouachita trough. Biogenic silica may also be involved. The gradual, intertonguing change from dark, fine grained, siliceous sediments of the Fort Payne to light, coarse, crossbedded sediments of the Ullin Limestone reflects shoaling into high energy settings above normal wave base. The prevalent crossbedding of the Ullin is not in accord with Lineback's (1966) hypothesis that the Ullin is a deep water deposit filling in a "starved basin."

The Salem, St. Louis, and Ste. Genevieve Limestones represent a

variety of predominantly shallow subtidal, carbonate-shelf depositional settings. Crossbedded oolitic and crinoidal grainstones alternate and intertongue with cherty lime mudstones and wackestones. These represent offshore bars, and lagoons protected by bars, respectively (Cluff and Lineback 1981). In the study area, Paleozoic sedimentary history drew to a close with the influx of terrigenous clastics (Pope Group) from a source area northwest of the region.

Late Mississippian through Early Cretaceous

No sedimentary record remains in the study area of early Chesterian through Late Cretaceous time although many structural features probably developed during this long episode. Widespread folding and faulting in adjacent areas reflect the compressional Alleghenian and Ouachita orogenies and later continental rifting (Kolata and Nelson 1991).

The Harrison Creek Anticline is probably a late Paleozoic structure. Devonian rocks are folded, but Cretaceous-Tertiary strata on the northwest flank, near the base of the "thumb," rest unconformably on various Paleozoic units at nearly the same elevation. Hence, the anticline probably is pre-Cretaceous. The Harrison Creek is similar in trend and structural style to anticlines in the central part of the Illinois Basin, which underwent uplift from late Mississippian through Pennsylvanian time. A similar age for the Harrison Creek Anticline is indicated.

The Atwood and Delta Faults and smaller, parallel faults are high-angle normal faults nearly parallel with the Harrison Creek Anticline. It is unlikely that these extensional faults formed at the same time as the anticline. The faults displace Devonian rocks and are not known to affect younger units. High-angle normal faults having similar trends displace Pennsylvanian rocks in the Makanda (Jacobson and Weibel 1993) and Bloomfield Quadrangles (Nelson 1993). This evidence indicates that the Atwood and Delta Faults are post-Pennsylvanian and younger than the Harrison Creek Anticline.

Cretaceous and Tertiary

The Tuscaloosa (?) and McNairy Formations (late Cretaceous) are largely of fluvial origin, but some parts probably are shallow marine. The most obvious nonmarine units are rooted silcretes. Poorly sorted, clayey, and lithic sands and gravels are interpreted as fluvial deposits. They are found mainly along a paleo-valley or paleochannel trending north-south in the eastern part of the study area. The well sorted "Commerce" quartz arenite, with its bidirectional crossbedding, probably is a shallow subtidal marine deposit. Some of the well sorted, well rounded chert gravels that intergrade with quartz arenite may be marine also.

Fossil flora indicate that both Late Cretaceous (McNairy) and Eocene (Wilcox (?)) strata occur in the area. The possibility of deposits of other ages cannot be eliminated. The stratigraphic succession is still poorly known.

The McNairy and Wilcox (?) resemble the same formations in the Mississippi Embayment, but they are coarser and contain less mica in the study area. An upland source of sediment north of the Jonesboro Quadrangle is indicated. Rocks north of the study area contain little mica, but they do contain abundant chert and quartz sand. Farther south in the Embayment, mica in the McNairy Formation probably was derived from other sources in metamorphic rocks of the Appalachian Mountains (Pryor 1960, Potter and Pryor 1961). Small, well rounded quartz pebbles are common in Cretaceous-Tertiary deposits; the Caseyville Formation (Pennsylvanian), which crops out extensively just north of the study area, is the probable source.

Faults that strike north-south and east-west displace Cretaceous-Tertiary sediments. Both sets of faults bear the earmarks of strike-slip displacement. North-south faults, notably the Cape Road Fault, probably underwent right-lateral slip having a large extensional or pull-apart component. East-west faults near Dago Hill seem to be left-lateral. Northeast-trending faults, in the southern part of the study area, probably are strike-slip faults also. In the Thebes Quadrangle, northeast-trending faults exhibit right-lateral

displacement and deform units as young as the Mounds Gravel (Pliocene to early Pleistocene). The implied stress field of these faults is identical to the current stress regime in southern Illinois and the New Madrid Seismic Zone (Harrison and Schultz 1992, Nelson and Harrison 1993).

Paleozoic rocks were leached of carbonate and silicified in a large part of the study area. This alteration is interpreted to be the product of hydrothermal activity. Deep-seated intrusions provided the heat, and intersecting, closely spaced fault zones provided the pathways. The intrusions may have supplied hydro-

thermal fluids or merely recirculated groundwater through the fracture systems via convection. The most likely time of alteration was Late Cretaceous to early Tertiary, when a series of syenitic or mafic plutons were intruded along the west edge of the Mississippi Embayment (Hildenbrand 1984, Glick 1982).



ECONOMIC GEOLOGY

Silica

The Jonesboro Quadrangle contains some of the largest known microcrystalline silica deposits in the United States. Several types of silica have been mined here; they are called tripoli, bedded chert or "novaculite," chert gravel, ganister, and calico rock. The first three are being mined at present, whereas ganister and calico rock are chiefly of historic interest. All of these forms of silica are products of the alteration of sedimentary rocks, mostly siliceous and cherty limestones. Causes of alteration were covered previously in the Structural Geology section.

Tripoli in Illinois is a white, soft variety of microcrystalline silica. It is used widely as a filler, abrasive, and buffing and polishing compound. Tripoli has been mined in the Jonesboro Quadrangle since at least the early part of this century (Berg and Masters 1994). Early mines were small room-and-pillar operations accessed via slopes and drifts driven into hillsides. Most old mines lacked timbering and relied on natural air currents for ventilation. Silica was drilled, shot with explosives, and loaded into wagons or trucks for shipment to local mills or shipping terminals. We mapped more than 200 abandoned mine adits; doubtless, many more are concealed by soil, slope wash, and vegetation.

Unimin Specialty Minerals of Elco, Illinois, currently operates one underground tripoli mine, one open-cast mine, and one tripoli processing plant in the study area. The underground mine is in the SW SE, Sec. 27, T14S, R2W, Mill Creek Quadrangle; the open-cast mine is in the NE NE, Sec. 28, T14S, R2W. The mill is located at Elco and served by a railroad spur. Another Unimin processing plant is located at Tamms, Illinois, immediately south of the study area. The Jason no. 2 Mine (SE, Sec. 22, T13S, R2W, Mill Creek Quadrangle) was operated until about 1988 by the Illinois Minerals

Company, a predecessor of Unimin. The Jason pit is partially backfilled. Remains of an abandoned silica mill, operator unknown, are in the SE, Sec. 33, T14S, R2W. Foundations of settling tanks and several large grinding wheels made of limestone are at the site (fig. 35).

Most active and abandoned tripoli mines in southern Illinois are in the Clear Creek Formation or in undifferentiated Clear Creek and Grassy Knob (Lower Devonian). Recently active mines are in the upper Clear Creek. A few mines may have operated in the Bailey Limestone (Silurian–Devonian). Deposits are more or less stratiform, but their lateral continuity is poorly documented.

Bedded chert in the study area often is called "novaculite," because it somewhat resembles Arkansas novaculite. Large chert quarries are in the bluffs west of Tatumville, near the southeast corner of the Mill Creek Quadrangle. The largest pit, in the E½ NW, Sec. 36, T14S, R2W, has been operated intermittently by

the Markgraf Materials Company in recent years. Chert from Tatumville was used for making refractory brick and for sodium silicate, as well as for road surfacing and construction materials (Lamar 1953). The Lone Star Cement Company of Cape Girardeau (Missouri) operates an open-pit silica mine in the E½ NW, Sec. 15, T14S, R2W, Mill Creek Quadrangle. Interbedded chert and tripoli from this pit are used in manufacturing Portland cement. Impurities of clay and iron oxide, which are unwanted in a tripoli operation, are desirable in cement making.

Many small operators in the area have dredged chert gravel from creek beds and used it for surfacing roads. Weathered chert from roadside outcrops is quarried for the same purpose. A small plant near Alto Pass, north of the study area, screens and sorts streambed gravel for road metal and other uses.

Water-worn chert gravel of Cretaceous (?) age formerly was quarried



Figure 35 Twin "chaser" grinding mills of an abandoned silica plant in the SE, Sec. 33, T14S, R2W, Mill Creek Quadrangle. The limestone grinding wheels rolled around circular tracks to crush the silica.

from a pit near Elco in the NE NE NW, Sec. 18, T14S, R1W (Lamar 1953).

Ganister is a coarsely granular form of silica derived from the alteration of siliceous limestone of the Fort Payne Formation (Mississippian). Ganister formerly was quarried and mined underground at several sites in the Mill Creek Quadrangle. Several abandoned underground mines are south of Cooper Creek in Sec. 1 and 2, T14S, R2W; more are in the hills east of Elco in Sec. 18, T14S, R1W. The ganister mines were also single-entry room-and-pillar drift mines. The mined ganister was white to light gray, rather than the usual orange or reddish brown. It was used in making fire bricks and linings for ovens and kilns (Lamar 1953). Other materials are currently used for these applications, and mining of ganister in southern Illinois has ceased.

Calico rock is a compact, blocky fractured siliceous rock derived from the alteration of the upper part of the Springville Shale (Mississippian). It received its name from its attractive multicolored mottled and banded surfaces. This material formerly was quarried on a small scale in the study area and used for masonry in foundations, walls, well linings, and similar applications.

Limestone

The Jonesboro Quadrangle contains abundant limestone resources, and several quarries are active just east of the quadrangle. The Ste. Genevieve Limestone is quarried at the Anna Quarry in the Anna Quadrangle, and the Ullin Limestone is extracted from the Jonesboro and Ullin Quarries of the Columbia Quarry Company in the Dongola Quadrangle.

The Ste. Genevieve is composed of interbedded light gray, soft, oolitic limestone and lesser amounts of hard, somewhat cherty, dolomitic limestone. Oolitic stone is well suited for agricultural limestone, whereas the harder dolomitic limestone is used as aggregate and road-surfacing material. The two types of stone occur in distinct layers and can be quarried in benches. The Ste. Genevieve is about 250 feet thick in the study area.

The Ullin Limestone is used for agricultural lime and road metal, as well as in power plant scrubbers.

Ullin Limestone is similar to the oolitic variety of the Ste. Genevieve in that it is too soft to use as aggregate. Some Ullin Limestone takes a good polish and makes a handsome building stone (Lamar and Willman 1955). Ullin Limestone was formerly quarried for that purpose near Kornthal Church in Sec. 1, T13S, R2W, and also near the center of the S½, Sec. 24, T12S, R2W (Jerome Lutz, local resident, personal communication). High-calcium limestone is available from the upper part of the Ullin Limestone in the study area. Analyses by Lamar (1957) indicate that this rock is composed of more than 95% calcium carbonate. The Ullin is as much as 450 feet thick.

The Salem Limestone potentially has economic uses. This dark, hard stone is nearly chert-free and 300 to more than 400 feet thick. The Fort Payne Formation is an extremely tough, siliceous stone that weathers to rough, pitted surfaces. This rock may be usable for aggregate in asphalt highways. The Fort Payne is quarried for that purpose at the Reed Quarry east of Paducah, Kentucky. A small quarry in the Fort Payne was formerly operated south of Springville in the SW, Sec. 19, T13S, R2W, Mill Creek Quadrangle. The stone may have been used for railroad ballast.

Small amounts of high-calcium limestone might be obtainable from the Grand Tower Limestone (Devonian) northwest of Jonesboro.

Clay and Shale

The Springville Shale (Mississippian) was mined for use as roofing granules from a pit south of Illinois route 127 west of Jonesboro, NW NE, Sec. 23, T12S, R2W. The operation consisted of an open pit and several drifts (J.E. Lamar, unpublished IGS field notes, 1927). According to Lamar (1948), the shale mine was abandoned prior to 1925 because the shale was found to be unsuitable for its intended use.

Kaolinitic clay was mined during the early 1900s near the now-abandoned village of Kaolin, just north of the study area. The clay was a sedimentary deposit of Eocene age, and it filled structural depressions (sink-holes or grabens?) in Mississippian limestone. Workings consisted of open pits and shafts as deep as 100 feet. Details of the geology, mining

history, and properties of the clay are in St. Clair (1917), Parmalee and Schroyer (1921), and Lamar (1948). Similar deposits of clay may be present in the Jonesboro Quadrangle, but drilling would be needed to locate any such deposits.

Oil and Gas

About 11 oil and gas test holes were drilled (records are ambiguous) in the Jonesboro Quadrangle (table 2). No commercial production or shows of oil or gas are reported for any of these wells. The deepest test was the Humble Oil Company no. 1 Pickel well (Sec. 21, T13S, R2W, Mill Creek Quadrangle), which reached a total depth of 8,492 feet in the Cambrian Lamotte/Mt. Simon Sandstone. The Pickel well was sited near the structural apex of the Harrison Creek Anticline. Another test hole on the Harrison Creek structure was the Ohio Oil Company no. 1 Cross, also in Sec. 21. This well was abandoned at a total depth of 1,500 feet in the Ordovician Everton Formation. The only other relatively deep oil test hole in the study area was the Mims no. 1 Potashnick well, which was drilled to a depth of 1,525 feet. Other test holes listed in table 2 were shallow, most less than 500 feet deep. These are listed as oil and gas exploration wells in the files of the IGS, but other wells in the same area, drilled at about the same time to similar depths by the same operators, are listed as water wells.

The closest petroleum production is near Marion, Illinois, more than 20 miles northeast of the Jonesboro Quadrangle.

The chief producing formations of the Illinois Basin are the Ste. Genevieve Limestone and younger rocks, which are eroded or at cropline in the Jonesboro Quadrangle. The Salem and Ullin Limestones have yielded oil in the deep Illinois Basin and contain permeable beds, but these limestones yield only water in the study area. The St. Laurent Formation, Dutch Creek Sandstone, and Clear Creek Formation (all Devonian) as well as the Kimmswick Limestone (Ordovician) support oil production elsewhere in the basin. Stratigraphic traps may occur in these units in the study area. Negative factors include the following: (1) facies changes in the St. Laurent and Dutch Creek seem to be in the

Table 2 Significant boreholes in the study area.

Operator, farm	Location	Deepest unit	Total depth (ft)
Anna City Well no. 1 (W)*	NE NW SE, 18-12S-1W	Ullin Ls	787
Anna City Well no. 2 (W)	NW SE SE, 19-12S-1W	Ullin Ls	428
Jonesboro City Well (W)	SW NW, 30-12S-1W	Ullin Ls	302
Beanland no. 1 Dillow (W)	NE NE SE, 31-12S-1W	St. Laurent	660
Beanland no. 1 Ury (W)	NE NW NW, 31-12N-1W	Grand Tower Ls ?	577
McRauer no. 4 Jonesboro (W) (well was drilled to 1,300 ft but log only goes to 300 ft)	SE NE SE, 25-12S-2W	St. Laurent	1,300
Sturdevant no. 13 Turner (W?)	SE NE NW, 25-12S-2W	Springville Sh	110
Sturdevant no. 1 Ury (W)	NW NW NW, 7-13S-1W	St. Laurent	340
Sturdevant no. 2 Ury (W)	SW NW NE, 7-13S-1W	St. Laurent	489
Sturdevant no. 1 Barnhardt (W)	SE NE NE, 19-13S-1W	Springville Sh	329
Andrew Davis (W)	SW SW NE, 31-13S-1W	Clear Creek	678
Carl Howell (W)	NE SW SE, 24-13S-2W	Clear Creek	580
Schneider no. 1 Pearce (W)	NW NE SW, 6-14S-2W	Maquoketa Fm	390
Al Froemsdork (W)	SW SW NE, 12-14S-3W	Plattin Ls	558
J. Meyers (W)	SW NE NW, 12-14S-3W	Kimmswick Ls	430
Richard Mosby (W)	NW NW NE, 12-14S-3W	Kimmswick Ls	395
C.C.C. Camp Delta (W)	NE SW, 20-14S-2W	Clear Creek	405
Landers no. 1 Dillow (O)	NE NE SW, 31-12S-1W	Clear Creek ?	700
Sturdevant no. 17 Andrews (O?)	750 ft N of C, 11-12S-2W	Springville Sh	355
Sturdevant no. 18 Spurlock (O?)	SW NW NE, 13-12S-2W	Springville Sh	545
Sturdevant no. 19 State Pond (O?)	NE NE SE, 14-12S-2W	Grand Tower Ls	425
Sturdevant no. 14 Greer (O?)	200 ft N of C, 24-12S-2W	Springville Sh	240
Sherman no. 1 Dossett (O)	NE NW SE, 9-13S-2W	no logs	1,078
Ohio Oil Company no. 1 Cross (O)	NW NW NE, 21-13S-2W	Everton Fm	1,500
Humble no. 1 Pickel (O)	SE SE NW, 21-13S-2W	Mt. Simon Ss	8,492
Staicup no. 1 Newell (O)	SE SW SW, 19-14S-1W	unknown (bad log)	390
Staicup no. 2 Newell (O)	SW NE NW, 30-14S-1W	unknown (bad log)	1,200
Mims no. 1 Potashnick (O)	NW NW SE, 26-13S-3W	Dutchtown Fm	1,525
ISGS no. J-1 Rhodes (S)	NE SE SE, 2-12S-2W	McNairy Fm	51
ISGS no. J-2 Hunter (S)	NW SE SE, 11-13S-2W	McNairy Fm	74
ISGS no. MC-1 Dillow (S)	SE NW SE, 24-13S-2W	McNairy Fm ?	58
ISGS no. MC-2 Rosson (S)	SE SE SW, 25-13S-2W	McNairy Fm	71
ISGS no. MC-3 Moreland (S)	NW SW SE, 25-13S-2W	Fort Payne Fm	72

* W: water well; O: oil test; S: stratigraphic test

wrong direction—clastic content and porosity increase westward, in the up-dip direction; and (2) widespread jointing may have allowed volatile hydrocarbons to escape. The altered area in the central part of the study area is a very poor petroleum prospect because the rocks are thoroughly shattered, leached, and silicified. Any hydrocarbons originally present probably were expelled during alteration.

Fluorite and Metallic Ores

No mining of fluorspar or metallic ore is recorded for the study area, but fluorite, manganese oxide, and metallic minerals occur in the area.

Fluorite occurs in the Ste. Genevieve Limestone at the Anna Quarry just east of the study area. The mineral occurs along with calcite in vertical joints that strike north-south to N20°W and, to a lesser extent, along fractures within chert nodules. Fluorite

was observed in cores from the Ste. Genevieve near the quarry. In the Illinois-Kentucky fluorspar district east of the study area, fluorspar occurs as vein deposits along faults and as bedded-replacement deposits. The Ste. Genevieve Limestone and the lower part of the Pope Group are the principal host rocks for fluorite there.

Manganese oxide was observed or reported at several sites in the

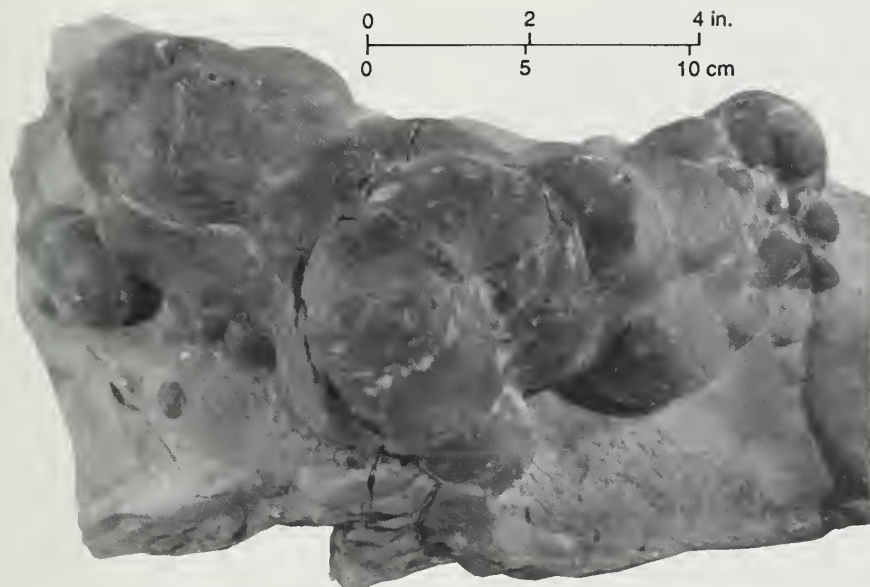


Figure 36 A sample of mammillary manganese dioxide from the St. Laurent Formation near the Delta Fault, NE SE SE, Sec. 17, T14S, R2W, Mill Creek Quadrangle.

study area. All manganese findings are in the St. Laurent Formation (Devonian) along faults near the margins of the altered area. One site is in the east bank of a stream near the Cape Road Fault at the south edge of the Jonesboro 7.5-Minute Quadrangle (NW SE NW, Sec. 23, T13S, R2W). Spheroidal and botryoidal pellets of black manganese oxide encrust altered siliceous limestone at the top of the St. Laurent Formation about 20 feet above creek level. A second site is in a small graben east of the Delta Fault in a gully in the NE SE SE, Sec. 17, T14S, R2W, Mill Creek Quadrangle. Here, large mammillary nodules of manganese oxide (fig. 36) occur in altered siltstone of the St. Laurent Formation. Float of similar material was found on a hillside southwest of Sexton

Creek in the SW, Sec. 16, T14S, R2W. Manganese oxide also lines joints that strike N20°W in chert of the Clear Creek Formation along the bed of Sexton Creek near the center of the E½, Sec. 9, T14S, R2W. A manganese prospect pit near Berryville, Jonesboro Quadrangle, was reported by J.E. Lamar (unpublished ISGS field notes, 1940). Local residents told Lamar that the pit was worked secretly around 1905, then concealed by blasting. Lamar in 1940 observed a vein in a gully near the reported site of the prospect pit. The vein was as much as 12 inches wide and consisted of several parallel stringers of manganese oxide. It followed the bedding of "rotted ochreous chert," which dipped 10° to 15° east. Lamar also saw manganese ore along joints

in the chert, and found small pellets of manganese oxide in a manmade pit about ¼ mile north of the gully. Iron-cemented chert breccia indicated a fault (confirmed by our mapping) to Lamar. The site reported by Lamar is now densely overgrown with brush and brambles, and we did not observe any manganese minerals near Berryville.

Unusually high concentrations of metals were reported by Erickson et al. (1987) in cuttings from the Humble no. 1 Pickel oil-test hole in the Mill Creek Quadrangle. Erickson et al. (1987) analyzed the cuttings from 29 deep wells around the western and southern borders of Illinois. Among these wells were one near Galena, Illinois, in the Upper Mississippi Valley zinc-lead district, and several in the Illinois-Kentucky fluorspar district. The Pickel well had the highest concentrations of silver, arsenic, and lead, the second highest concentration of molybdenum, and the third highest concentration of copper. The silver content of samples from the Pickel well was six times greater than that of any other well. Nickel and zinc concentrations in the Pickel well were not particularly high, but visible sphalerite crystals were noted in the Bonnetterre Formation, which is the principal host rock for ore in the southeast Missouri lead district.

The discovery of high metal content in the Pickel well raises the possibility of ore in the study area. The Pickel well is near the west edge of the altered area, which we think was formed by hydrothermal activity. The most likely area for ore at shallow depth is along the margins of the altered area, especially where limestones abut against major faults.



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Siliceous limestone of the Fort Payne Formation cropping out north of Lingle Creek.