STATEMAP
Union County-BG

# Bedrock Geology of Union County, Illinois

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# Introduction

**Geographic Setting and History**
Union county is located in far southern Illinois. It is bounded on the west by the Mississippi river; north and east by Jackson County; and to the the south by Alexander and Pulaski Counties. The physiography of the county is more like southeastern Missouri than most of Illinois. The western half of the county is a part of the Salem Plateaus Section of the Ozark Plateaus Province, whereas the eastern half of the county is in the Shawnee Hills Section of the Interior Low Plateaus Province (Leighton et al. 1948, Horberg 1950). This change in physiography can be seen west and east of the Ste. Genevieve Fault Zone (fig. 1). The area is predominantly driftless except for the northeastern-most corner of the county (Willman and Frye 1980, Weibel and Nelson 1993, Nelson and Weibel 1995). The Ste. Genevieve Fault Zone divides Union County diagonally from the northwest to southeast and south. The physiography on the southwest side of the fault zone is composed of rugged hills of cherty Devonian limestone capped with Wisconsin Episode loess, whereas the area northeast of the fault zone is composed of rolling plateaus of carbonate rock and upper cyclic, siliciclastic, and carbonate rocks of the Carboniferous. The uppermost units are the siliciclastics of the Upper Carboniferous. The highest point in the county is Bald Knob at 1,020 feet above sea level. Bald Knob has the greatest local relief in the State of Illinois at 620 feet in about a mile. Total relief for the county is 680 feet from Bald Knob to the southern-most point on the Mississippi River.

Founded on January 2, 1818, Union County is located in the far southern portion of the state in an area that is known as "Little Egypt." European settlers entered Union County around 1803. The county seat is Jonesboro, but neighboring Anna (population 4,006) is the largest community. The total population as of the 2020 census was 17,244, which is 564 fewer than in 2010. Land area is 422 square miles. Union County is home to the Trail of Tears State Forest. The Indian Removal Act of 1830 led to the removal of all Native American tribes east of the Mississippi River. Andrew Jackson wrote, "…no state could achieve proper culture, civilization and progress, as long as Indians remain within its boundaries." Native Americans were pushed west along what is known as the "Trail of Tears." The trace or path of this road, which formed the major route of the Cherokee "Trail of Tears" through Union County, roughly corresponds to highway Rt. 146. In 1837-39, the Cherokee, Creek, Seminole, Choctaw and Chickasaw nations were forced by the U.S. Army to move from the southeastern U.S. to reservations in the Oklahoma Territory. One of the many routes taken by numerous Native American tribes was through Union County where the Trail of Tears State Forest lies. Campground Church in Union County, Illinois has been designated a certified Trail of Tears Site, where many Cherokee were buried. North of the Trail of Tears State Forest, in prehistoric times, chert was dug just north of Iron Mountain on Clear Creek. Well known to archeologists, the Cobden Chert was highly prized by Native Americans because of its waxy appearance, conchoidal fracture and highly knappable nature. Numerous

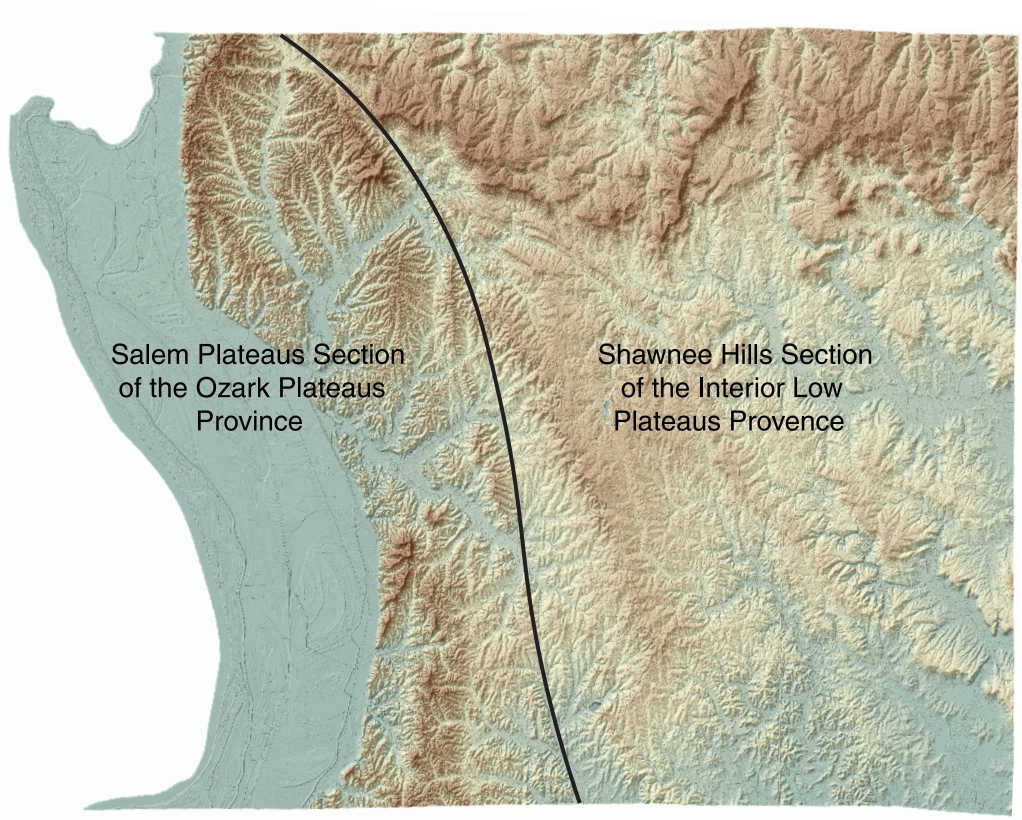



**Figure 1** Physiographic map of Union County

arrowheads made from this chert have been found in southern Illinois and beyond, as it was widely traded by Native Americans. The Cobden Chert is derived from nodules in the St. Louis Limestone. However, this high-quality chert is limited to the Iron Mountain area and does not possess these characteristics elsewhere in the St. Louis Limestone. The opalescent nature of this chert may be due to hydrothermal fluids that coursed through the faults and fissures of the Iron Mountain Fault Zone. Native Americans also made use of kaolinite found in the Iron Mountain area for firing pottery. Later, it was reported by A. H. Worthen (1868) that good potter's clay could be found at several localities in Union County. Anna was the home of the famous Kirkpatricks Pottery, which was quarried just southwest of Kaolin in the Iron Mountain area. Kaolin is now a ghost town, but water-filled pits of clay where kaolinite was extracted still can be seen. More information on the clay deposits is in the Economic Geology section of this report.

**Local Lore**

Several quaint landmarks in Union County add color to the area. One can be seen along State Highway 146 at the top of a ride just east of Interstate 57. This marker is made of local Ullin Limestone in the form of a headstone which has inscribed the name of King Neptune, the famous Navy mascot pig. King Neptune was rather portly at the time of his death–he weighed in at 700 pounds. He lived from 1941 to 1950 and was sold repeatedly to raise more than 19 million dollars in War Bonds from 1942 to 1946. Adjusting for inflation, the contemporary equivalent would be $319,000,000! King Neptune is supposedly buried at this site (photo 1). The epitaph reads, "To help make a free world." The old headstone weathered and crumbled, so a new brass one now stands at the site.

Another memorial landmark can be seen just north of the county line in Makanda, Illinois near the railroad tracks. It is a memorial to Boomer the dog (see photo 2 for the full explanation). Though this may be more of a legend, someone paid for a memorial and headstone for his faithful dog named Boomer.

**Previous Geologic Investigations**

The earliest geologic work in Union County was that of Worthen (1868), who described the geology and mineral deposits of the region. Worthen named the Clear Creek Chert (Lower Devonian), a name that is still in use today. T. E. Savage (1920, 1925) worked in Union County and named the Backbone Limestone and Grassy Knob Chert. Frank F. Krey mapped the Dongola 15-minute quadrangle in 1921; however, he did not publish the work on this map. The Dongola map became part of the preliminary geologic map by Stuart Weller and Frank F. Krey (1939). Bassett (1925) mapped the Alto Pass quadrangle. Another preliminary geologic map including parts of Union County is the Jonesboro 15-minute quadrangle, mapped by Savage in 1919, but not published until Weller and Ekblaw (1940) incorporated it into their map.


**Photo 1** Original headstone for King Neptune.

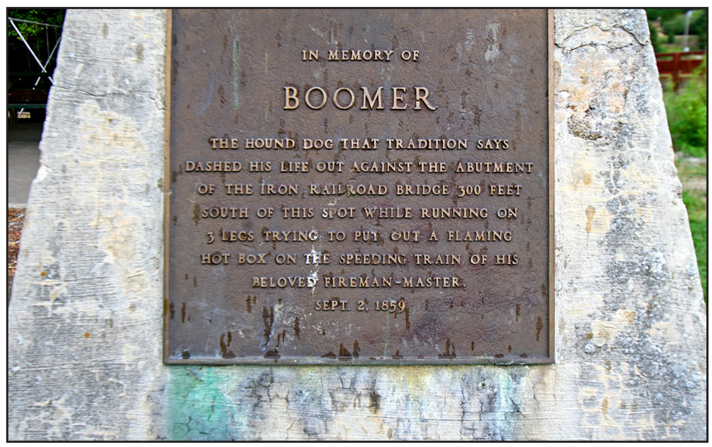



**Photo 2** Memorial to Boomer the Dog.

Renewed geologic mapping at 1:24,000 scale began in the 1980s under a cooperative agreement between the ISGS and USGS called the COGEOMAP Program. Fieldwork for this project started in 1985 and was completed in 1990, the maps being published several years later. Mapping in Union County started with the Wolf Lake 7.5' Quadrangle (Devera 1993) and the Makanda 7.5' Quadrangle (Jacobson and Weibel 1993). An interim project in the Tripoli District was funded by the USGS to map the Jonesboro/Ware (Nelson, and Devera 1994) and Mill Creek/McClure (Devera and Nelson 1994) 7.5' quadrangles. A new federal/state partnership called STATEMAP began in 1993 and continues to the present day. The remainder of Union County was completed under STATEMAP. These geologic maps that cover individual 7.5-minute quadrangles (scale 1:24,000) are the basis for the compilation map that accompanies this report. Some additional field work was carried out in 2020-2021 to resolve discrepancies that turned up among the earlier maps. Figure 2 is a complete listing of all of the 7.5' quadrangles and authors that produced them from 1993 to present.

# Stratigraphy

This section covers only the rocks that were exposed in Union County and the core and drilling data that pertains to these rocks.

**County and API Numbers**
The ISGS assigns a county number to every drillhole in its database. Originally, county numbers were serial, beginning with the number 1. Sometime in the early 1970s the ISGS switched to five-digit numbers beginning at 20,000 for the convenience of computer operators. The American Petroleum Institute (API) assigns a unique 12-digit number to each petroleum test hole drilled in the United States. The first two digits signify the state: 12 for Illinois. The next three digits designate the county: 181 for Union County. The next five digits are a serial number; in Illinois this is the county number. The final two zeroes are for a deepening (01) or an offset hole (02). Thus the Basler #1 test hole, Union County number 00012, translates to API number 12-181-00012-00. For the convenience of computer operators, the API number is usually rendered without commas or hyphens: 121810001200.

**Ordovician System**
A relatively small area of Ordovician rocks is exposed along the axis of the Harrison Creek Anticline in the southwestern corner of Union County on the Mill Creek and Jonesboro quadrangles (Devera et. al. 1994, Nelson and Devera 1994).

**Maquoketa Formation** (called Maquoketa Shale north of 40° North Latitude) in Union County comprises four members, in ascending order: Cape La Croix Shale, Thebes Sandstone, Orchard Creek Shale, and Girardeau Limestone. Only the latter three are exposed at the surface. The Maquoketa Shale is named for exposures on the Little Maquoketa River in Dubuque County, Iowa, and extends across a large portion of the upper Mississippi Valley (White 1870).

The oldest exposed rock is the **Thebes Sandstone Member** of the Maquoketa Formation. It is composed of greenish gray to light gray and tan, fine grained, well-sorted quartz arenite interbedded with siltstone. The Thebes is commonly laminated to thinly bedded, argillaceous, and calcareous in part. Ichnofossils include simple horizontal burrows, repichnia (crawling traces), and radial fodinichnia (feeding traces). Only the upper portion of the member is exposed and is conformable with the overlying unit. Savage (1909) described the small blind trilobite *Ampyxina bellatula* in the lower part of the Thebes Sandstone.

The **Orchard Creek Member** of the Maquoketa consists of interbedded shale and limestone, with limestone dominant in the upper part of the section. The shale is light to medium bluish green-gray, soft, fissile, and becomes more calcareous upward. Interbedded limestone contains chert nodules

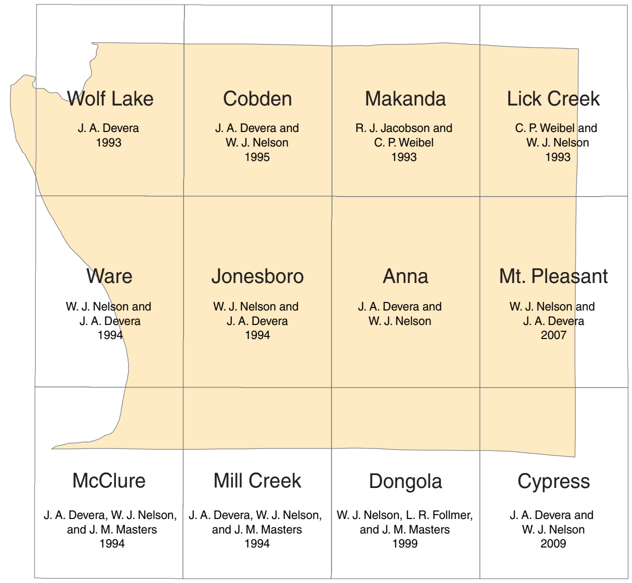



**Figure 2** Quadrangle index, author, and date list of all of the 7.5' maps produced in Union County, Illinois.

in the dark gray lime-mudstones. Fossils are rare; however, large, disarticulated anataphurid trilobites have been collected near Thebes, Illinois. Edrioasteroids found in the Orchard Creek suggest hardground formation in the nodular limestone. The upper contact is conformable and can be sharp or gradational.

The youngest Ordovician unit in Union County is the **Girardeau Limestone Member,** which is composed of very dark gray lime-mudstone that forms thin wavy beds and contains dark gray chert nodules. Thin argillaceous partings occur between the wavy limestone beds. Fossils are rare but include trilobites, articulated crinoids with calyxes, and sea stars (starfish). The upper contact is disconformable because the Leemon Formation, the youngest, is missing in the study area . The importance of this limestone is that it belongs to the Hirnantian Stage, which was deposited during the close of the Ordovician Period during an ice age. This was documented in the Schlamer #1 well where HICE carbon isotope excursion was recognized (McAdams et al 2018). The Schlamer #1 well is located on Sammons Creek three miles east of Thebes, Illinois. A large faunal list of articulated crinoid calyxes discussed by Brower (1973) was found in the Girardeau just south of the study area.

**Silurian System**
Poor exposures of Silurian rocks in Union County, along the Harrison Creek Anticline, preclude dividing these rocks into separate formations. Therefore, the Silurian was mapped as undifferentiated on the map. However, good exposures in Alexander County provide control for units depicted on the stratigraphic column and are largely the basis for the descriptions that follow. In ascending order, units of the Silurian are Sexton Creek Limestone and the Bainbridge Group, which includes the Seventy-Six Shale, St. Clair Limestone, and the

Moccasin Springs Formation. The lowermost 20 feet of the Bailey Limestone is also considered to be Silurian age. The Bailey is not part of the Bainbridge Group; it is part of the Tamms Group (irrespective of age).

The **Sexton Creek Limestone** takes its name from the exposures at the mouth of Sexton Creek in Alexander County (Savage 1909). It is a light to medium brownish gray lime-mudstone to wackestone that contains caramel-colored chert nodules and has shaly partings between beds. Near the top of the formation are small spheres of pyrite. Fossils include colonial *Favosites* corals that occur as prolate spheroids or biscuit-shaped colonies. Trilobites that occur in this unit include *Exallaspis* sp., *Ceratocephala* sp., *Platylichas* sp., an undescribed calymenid trilobite, and an encrinurid (Kloc 2017). The overlying contact is sharp.

Red and green shales, marls, and limestone comprise the **Bainbridge Group**. The **Seventy-Six Shale** at the base is a green to red mottled thin (2 ft.) shale. Conodonts found in the Seventy-Six include *Kockelella ranuiiformis, Pterospathodus amorphognathiodes amorphognathiodes, and Distomodus staurognathoides* (McAdams 2016). This unit provides a good resistive marker bed on electric logs. The contact with the overlying limestone is sharp (fig. 3).

The **St. Clair Limestone** is named for St. Clair Springs, 8 miles northeast of Batesville, Independence County, Arkansas (Penrose 1891). It is composed of hard, well-indurated, sublithographic lime mudstone to crinoid wackestone that weathers gray and blocky. Fresh exposures are mottled red and olive gray. The limestone is highly stylolitic and has distinctive tabular bedding. The lower part is thick to massively bedded and grades upward into a brick red, silty, calcareous, less resistant limestone that exhibits hour-glass weathering. At the top of the St. Clair is red and gray crinoidal, marly wackestone that is densely bedded and bioturbated. Disarticulated crinoid stems, commonly stained red, are ubiquitous, together with trilobite debris, brachiopods, ostracods, the tightly coiled foraminifer *Ammodiscus,* and the conodont genera *Ozarkodina* and *Kockelella*. Trilobites from the St. Clair include *Calymene celebra, Ommokris crone, Ommokris obex, Dalamanites platycaudatus, Eophacops* sp., and a cheirurid. The contact with the overlying unit is sharp but conformable.

The **Moccasin Springs Formation** is named for the village of Moccasin Springs, which is 9 miles north of Cape Girardeau, Missouri (Lowenstam 1949). The formation consists of brick-red marl to argillaceous limestone that is mottled and variegated with purple and green. It contains silt but is dominated by marly limestone at the base and grades into a calcareous shale in the upper part. Graptolites found in the shales include *Saetograptus incipiens*, *S.* sp. aff. *Leintuardinensis, S. fritschi, Colonograptus colonus, Pseudomonoclimacis* sp., and *Pristiopreptus* sp. (McAdams 2016). Trilobites from this unit include dalaminitids, cheirurids,

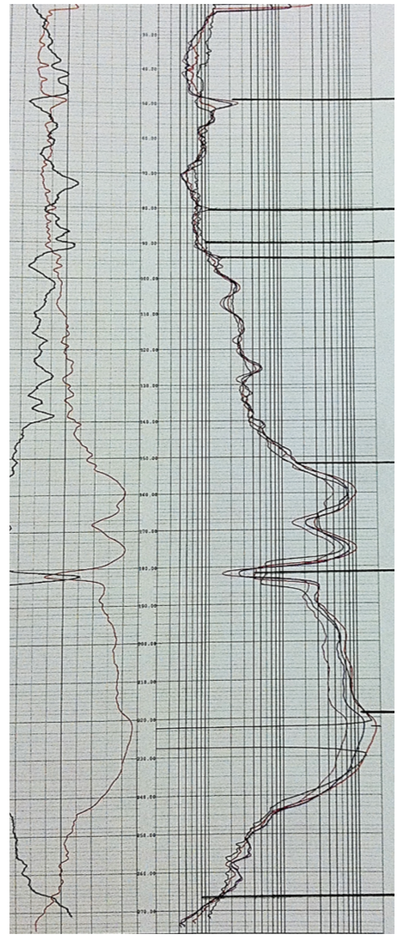



**Figure 3** E-Log of the Schlamer well showing the marker 76 Shale, SE 1/4 Section 2, T15S R3W.

*Ketteneraspis* sp., *Glyptambon* sp., and *Calymene celebra.* The epibole *Scyphocrinites* also occurs in the upper shaly part of the formation. This floating crinoid with a bulbous terminus has near-worldwide distribution near the Silurian/Devonian boundary (photo 3). The trace fossil *Zoophycos* is common in the upper greenish shale. The upper contact is gradational and interbedded with the overlying unit.

The Moccasin Springs contains four members: Greens Ferry (oldest), Sheppard Point, Lithium, and Randol Shale (McAdams et al. 2018). The **Greens Ferry Member** is red and gray-green marly fossil lime mudstone that has a “cloudy” mottled texture. The **Sheppard Point Member** is light greenish gray calcareous shale that contains black layers or bands containing the aforementioned graptolites, burrows, and *Zoophycos* in the upper part. The **Lithium Member** is purple and green mottled calcareous shale that also displays the “cloudy” mottled texture. The **Randol Shale** is olive green with abundant *Zoophycos* trace fossils. It is calcareous and contains lime mudstone beds. The Randol interfingers with the overlying Bailey Limestone which is a cherty lime-mudstone. Only the lower 20 feet of the Bailey is Silurian, as indicated by the Klonk carbon isotopic excursion found in the Mc Farland # 2 well just south of the study area (Grosch et al. 2021).


**Photo 3** Lobolith of Scyphocrinites elegans drilled in the McFarland core.

**Devonian System**

**Tamms Group** is the name introduced by Rogers (1972) to encompass cherty limestone of latest Silurian and Lower Devonian age in southern Illinois. The name also was used on the Mill Creek/McClure geologic map (Devera et al. 1994) and on the Paducah 1° X 2° Quadrangle (Nelson 1994). As defined, the Tamms Group comprises the Bailey Limestone (oldest), Grassy Knob Chert, Backbone Limestone, and Clear Creek Formation. This is a useful group classification because all four formations consist of light-colored, cherty or siliceous limestone. These formations can be difficult to differentiate in the outcrop belt and subsurface, but are readily distinguishable from the Bainbridge Group below and the Muscatatuck Group above. As noted above, approximately the basal 20 feet of the Bailey limestone is Silurian; the remainder of the Tamms Group is Early Devonian (Lochovian through Emsian) age.

The **Bailey Limestone** is named for the now-abandoned settlement of Baileys Landing that lay on the Mississippi River in Perry County, Missouri (Ulrich, in Buckley and Buehler 1904). The oldest Devonian unit in Union County is the Bailey Limestone, which occurs extensively on the western side of the county. Excellent exposures are in the La Rue-Pine Hills, where outcrops display 200 to 300 feet of relief. These exposures are a part of the southeastern edge of the Ozark Uplift, and the bluffs were carved when the Mississippi River carried Pleistocene glacial meltwater. Deposition of the Bailey was continuous between the Silurian and Devonian Periods. Lithologically, the Bailey is greenish gray lime-mudstone at the base, rapidly grading upward to light gray to yellow-gray cherty, argillaceous, thin, wavy bedded lime-mudstone that can be dolomitic in places. Bedding is thin and undulating, separated by thin clay-rich partings. The chert nodules are greenish-gray near the base, becoming dominantly medium to dark gray in the middle to upper parts of the formation. It is important to reiterate that the basal 20 feet of the Bailey is Silurian in age. An ecological epibole of *Scyphocrinites elegans* that straddles the Silurian-Devonian boundary was found in the Wolf Lake Quadrangle in a small anticline, and a lobolith of *S. elegans* was drilled into just south of the study area in the McFarland core #2, in the Thebes Quadrangle (photo 3).

Fossils are rare in the Bailey, but fossiliferous zones occur in the lower third of the formation, including the trilobites *Hutonia, Odontochile,* and *Paciphacops.* Large straight nautiloid cephalopods also occur in the lower or basal part of the Bailey. Also, the trace fossil *Zoophycos* occurs at various levels of the Bailey in the Pine Hills. Higher in the Bailey, a random conularid was found in the Pine Hills. Thin-sections reveal chitinozoans and abundant siliceous sponge spicules throughout the unit. Other siliceous microfossils include radiolarians. The contact with the overlying Grassy Knob Chert is transitional.

The **Grassy Knob Chert** was named by Savage (1925) for a hill in the northern part of the Pine Hills in the Wolf Lake Quadrangle (Sec. 34, T10S, R3W, Jackson County). The thickness of the Grassy Knob here is about 200 feet. However, because of the transitional nature of the contact, the thickness varies between 150 and 250 feet. The Grassy Knob in the outcrop belt may possibly be (at least in part) a weathered cap where carbonate has been leached out of the upper portion of the Bailey Limestone. As seen at the type locality and elsewhere, the Grassy Knob is predominantly white to yellowish to orange stained chert that is dense and displays tabular beds 1 to 3 feet thick. Thus, its bedding is thicker than that of the Bailey. Fossils are rare, aside from horizontal cylindrical burrows and a "popcorn" texture that is possibly related to the burrowing. Brecciated beds occur throughout the unit, but tend to be concentrated in the upper part. Besides porous tripolitic beds, some dense novaculitic beds occur in the formation. In the subsurface this unit generally is logged as siliceous limestone. There is typically a gradational contact with the overlying Backbone Limestone; however, the contact is sharp at some localities, such as along Hutchins Creek.

The **Backbone Limestone** in its type area of the "Devil's Backbone Ridge" at Grand Tower, southwestern Jackson County, is white crystalline limestone consisting of crinoidal grainstone, packstone, and wackestone. This unit was named by Savage (1920) in a fault-bounded ridge that displays only the upper 38 feet of the Backbone. The best exposures occur in Union County at the north end of the Pine Hills on the Big Muddy River and along Hutchins Creek in the Wolf Lake Quadrangle. Here the Backbone ranges up to about 100 feet thick. Spiriferid brachiopods are common and rugose corals are present. White chert nodules occur in the Backbone, together with silicified brachiopods. Although bedded chert is not typically common in the Backbone at Pine Hills, south in the area of Wolf Lake, Illinois, the Backbone becomes siliceous and is difficult to separate the Grassy Knob Chert below or from the Clear Creek Chert above.

The age of the Backbone is Pragian (middle Lower Devonian), based on conodont zonation (Collinson et al. 1967). The Backbone has a dominance of the spiriferid brachiopods *Acrospirifer murchisoni, Costispirifer arenosus,* and *Rensselaeria ovoidies* but also contains gastropods, bivalves, crinoids, and trilobites. The bryozoan *Lichenalia* is abundant in the upper part (Collinson et. al. 1967). Along Clear Creek, brachiopods and rare trilobites have been found in silicified limestone of the Backbone. However, contacts are difficult, if not impossible, to map due to the silicification. In the Pine Hills area, where the rocks are less thoroughly silicified, the contact with the overlying Clear Creek is gradational.

The **Clear Creek Chert** was named by Worthen (1866), and the name was restricted to its current use by Savage (1920). Worthen did not designate a type section, but the name comes from Clear Creek in the Cobden Quadrangle. The Clear Creek Chert is a white to light gray cherty lime mudstone that in the type area has been weathered and/or hydrothermally altered to silica. Such hydrothermal alteration can be seen at a roadcut on the State Forest Road near the center of Section 9, T12 S, R 2 W, in the Trail of Tears State Forest. Here beds of a fossiliferous chert with reddish stains and red clay occurs lateral to a cherty, gray unaltered lime mudstone similar to that seen in drill cores from southeastern Illinois. The beds are highly burrowed and contain brachiopods, corals, and trilobites along the forest road. Commonly, faults and burrowed zones in the Clear Creek are heavily silicified, as they were porous zones that acted as conduits for silica-rich fluids. Like other formations in the Tamms Group, the two main areas that show intense silicification of the Clear Creek are around Wolf Lake and Elco, Illinois. There are two main types of chert: a hard, milky white novaculitic chert and a soft powdery, tripolitic variety. Tripoli is snow-white when fresh, stained red to orange, soft and friable, porous microcrystalline silica. It is composed of microscopic, doubly terminated, euhedral quartz crystals (Berg and Masters 1994). South of Clear Creek in the Cobden Quadrangle, the upper part of the Clear Creek Formation is entirely silicified, whereas the lower part is only partially silicified. In the lower part of the unit, calcareous tripoli and siliceous limestone are intricately intergrown.

Thickness of the Clear Creek in Union County is difficult to ascertain because no wells penetrate both lower and upper contacts, and the aforementioned silicification may have altered the Backbone Limestone. Such alteration renders the Clear Creek, Backbone, and Grassy Knob formations nearly impossible to differentiate. At Bald Knob in the Cobden Quadrangle, the Clear Creek appears to be no less than 600 feet thick, but this apparent over-thickening may be a product of structural complications, such as imbricate thrust faults or flowage into the crest of a drag fold along the Ste. Genevieve Fault Zone. Poor exposures prevent resolution of the issue. The best defined thickness of the Clear Creek Chert is 419 feet in the Basler #1 oil test (API#121810001200) drilled 4 miles east of Cobden.

Fossils of the Clear Creek include the brachiopods *Amphigenia curta, Eodevonaria melonicus*, strophemenids, and spiriferids. *Amphigenia* and *Eodevonaria* are found in the upper part of the Clear Creek and in the overlying Dutch Creek Sandstone Member of the Grand Tower Limestone. These brachiopods straddle the Lower to Middle Devonian boundary. Other fossils include the trilobites, *Odontocephalus ageri, Odontochile (Dalmanites) pratteni, Acidaspis tuberculata*, *Coronuda* sp., and *Paciphacops* sp. Graptolites are rare but have been found in the upper part of the Clear Creek.

The Clear Creek Chert is distinguished from the older Grassy Knob Chert by its diverse shallow-water fauna, thinner bedding, and common vertical burrows rather than horizontal burrows. Near the top of the Clear Creek Chert, thin quartz arenite beds are interbedded with thin fossiliferous chert beds or siliceous lime mudstone beds. These rocks grade into the Dutch Creek Sandstone Member at the base of the overlying Grand Tower Limestone. Both the Clear Creek Chert and the Dutch Creek Sandstone Member are Emsian (uppermost lower Devonian) age.

**Muscatatuck Group** (Shaver 1974) includes relatively pure limestone of Middle Devonian age. Formations include the Grand Tower Limestone (Early Middle Devonian) and the overlying St. Laurent Formation (Late Middle Devonian) (which is called Lingle Limestone northward in the basin on the Sangamon Arch). In current nomenclature in southern Illinois, St. Laurent includes what was formerly called Lingle and Alto Formations. Both these Middle Devonian units overlie cherty carbonates of the Tamms Group and underlie the New Albany Shale (Upper Devonian) in Union County.

The **Grand Tower Limestone** takes its name from Grand Tower, Illinois, where the type section is located on the Devil's Bake Oven north of the town on the Mississippi River in Jackson County (Keyes 1894). Additional outcrops occur on the west side of Iron Mountain in a north-south narrow belt in the Cobden and Jonesboro Quadrangles and in a small area north and south of State Highway 146 along Dutch Creek.

The Grand Tower is dominated by limestone, but its basal member is sandstone composed of well-rounded pure quartz sand grains. This unit, the **Dutch Creek Sandstone Mem-**

**ber,** is thickest, about 15 feet, where it was named at the mouth of Dutch Creek (Savage 1920) but typically is 10 feet or less. The Grand Tower Limestone is about 160 feet thick at the type section but thins southward. Outcrops in the study area averages about 40 feet thick, but the Burr Lambert #1 Hagler borehole (Section 28, T10S, R2W Cobden Quadrangle) indicates the Grand Tower to be 122 feet thick (API#120770136700). Above the Dutch Creek Member it is a white crinoidal grainstone that contains "floating" sand grains in the carbonate matrix. The lower part of the formation displays prominent crossbedding. A flooding surface truncates the crossbedded limestone, above which is a darker brown lime mudstone and fossil wackestone with sparse boundstone patch reefs. Gray and dark gray chert nodules are present in the lime mudstone facies. Near the upper part of the formation, at least three chonetid packstone beds can be observed. These are the result of storm winnowing or tempestites. Chert is typically dark gray to light gray and occurs as nodules.

Characteristic fossils in the Dutch Creek Member are the brachiopods *Amphigenia curta*, *Eodevonaria arcuate,* and spiriferids and the strophominid *Protoleptostrophia perplana,* together with solitary rugose corals and the tabulate coral *Pleurodictyum problematicum.* The trilobites *Odontocephalus ageri* and *Paciphacops* sp. also occur in this member. The conodonts *Caudicriodus hankae, Latericriodus alces, Latericriodus robustus,* and *Latericriodus nevadensis* all indicate an Emsian Stage for the Dutch Creek which is uppermost Early Devonian.

Fossils in the carbonate portion of the Grand Tower include crinoids (nearly all fragmentary), the solitary rugose corals *Heliophyllum and Zaphrentis,* as well as the colonial rugose corals *Hexagonaria* sp., and *Aulopora,* phacopid trilobites, fenestrate, bifoliate and ramose bryozoans, chonetid brachiopods, *Brevispirifer gregarius*, *Atrypa* sp., and *Schizophoria* sp. Also common are *Tentaculites,* the bivalve *Paracyclas* sp. calcareous encrusting algae *Asphaltinoides grandtowerensis*, chitinozoa, *Alpenachitina eisenacki, Eisenachitina turgifunda,* scolecodonts, ostracodes, foraminifera, and the stromatoporoid calcareous sponges. Plates of placoderm fish and otoliths (fish ear stone) occur in this unit. Trace fossils found are *Zoophycos, Rhizocorallium,* and *Lockeia.* The conodont *Polygnathus partitus* defines the basal part of the Eifelian Stage called the partitus Zone. The conodont zones partitus and costatus (australis, kockelianus, and ensensis zones undifferentiated) define the Eifelian Stage. The upper contact of the Grand Tower with the overlying St. Laurent Formation is gradational.

**St. Laurent Formation (Lingle Limestone in central Illinois)** is a unit that is lithologically highly variable. It was named for St. Laurent Creek in Perry County, Missouri by Wilson (1922) and described in comprehensive fashion by S. Weller and St. Clair (1928). Savage (1920) gave the name Lingle Formation to the same interval of strata as exposed near Lingle Creek in Union County (SE¼ SW¼ SW¼, Sec. 26, T13S, R2W). Because the Lingle type section is poorly exposed and Savage's description is sketchy, geologists such as J.M. Weller and Ekblaw (1940) and J.M. Weller (1944) continued to use the name St. Laurent in southern Illinois. Nelson et al. (1995) formally proposed that the name Lingle be abandoned; however, geologists working in the Illinois Basin south of the Sangamon Arch continue to apply the name Lingle to carbonate strata overlying the Grand Tower Limestone. In the present report, we continue to call these strata the St. Laurent Formation.

In Union County, the St. Laurent occupies a narrow strip of outcrops extending southward from Bald Knob (map sheet **1** ). Along part of this belt, the St. Laurent is combined with other formations on the map because complex structure and silicification renders identification of individual formations difficult. Bedding strikes north to northwest and dips from 20° to 15° to the northeast. Good exposures are seen at Iron Mountain on the south side of Clear Creek in a north-trending ravine in the northeast quarter of Section 34, T11S, R2W, in the Cobden Quadrangle. Another good outcrop occurs in a roadcut south of State Highway 126 in the northwest quarter of Section 23, T12S, R2W, in the Jonesboro Quadrangle. At these locations the St. Laurent consists of dark-colored, very argillaceous limestone and dolostone. Rock colors range from medium to dark gray, brownish-gray, olive-gray and yellowish-tan. Most of the carbonate rock is lime mudstone and fossiliferous wackestone; packstone and grainstone facies are uncommon. Chert nodules are common; they are typically brown to gray brown and vitreous. Shale and siltstone are well indurated and laminated and can make up half or more of the formation thickness. The shale is calcareous and laterally grades into the Blocher Shale eastward in the deeper parts of the Illinois Basin.

Near the middle of the formation in the outcrop belt is a thin bed of oölite called the **Rendleman Oölite Bed**. It is a light tan, oölitic grainstone that can range between 1 to 5 feet thick. The colonial tabulate coral, *Favosites alpenensis,* is typically associated with the Rendleman Oölite Bed.

Fossils are common in the St. Laurent. The diagnostic "button" coral, *Microcyclus discus* epibole, occurs near the base of the formation. Other fossils of the lower St. Laurent are the brachiopods *Spirifer fornacula* and *Athyris spiriferoides* and the trilobite *Eldredgops rana*. In the middle part of the formation are patch-reefs dominated by stromatoporoids; brachiopods are *Tropidoleptus carinatus, Devonochonetes gibberus*. The bivalves, *Actinopteria muricata,* and *Phthonia* sp. and the trilobites *Bellacartwrightia* sp., and *Dipleura* sp., also occur in the middle of the formation. This is the first documented occurrence of *Dipleura* in Illinois, confirming correlation with the Hamilton Group of New York (photo 4). Phyllocarids occur in a silty laminated facies named the **Misenheimer Shale Member**. A diagnostic fossil in the upper part of the St. Laurent is *Spinocyrtia ravenswoodensis*.

The uppermost part of this unit contains the brachiopods *Mucrospirifer mucronatus, Leiorhynchus* sp., and *Devonochonetes* sp.

The St. Laurent grades vertically and laterally into the overlying New Albany Shale. In some areas the contact is disconformable, as indicated by an abrupt lithological change and the presence of a basal sandy zone that is probably equivalent to the Sylamore Sandstone of western and central Illinois.

**New Albany Shale** was named by Borden (1874) for New Albany in Floyd County, Indiana (opposite Louisville, Kentucky on the Ohio River). Regionally , the New Albany is an extensive dark to black shale of Middle to Late Devonian and Kinderhookian (early Mississippian) age. The New Albany is thin (0 to 80 feet) in Union County and confined to a narrow strip of outcrops that extends southward from Iron Mountain. On the geologic map, the New Albany is combined with two other thin formations, the Chouteau Limestone and Springville Shale.

One of the best exposures of the New Albany is along Cany Creek in the Jonesboro Quadrangle (Location fig. 4). Here it is dark brown to black, hard, brittle, fissile shale, typically containing pyrite nodules, and, in the upper part, phosphate nodules. It has a petroliferous odor and yields orange stains on exposed surfaces. In exposures along Cany Creek the New Albany is highly jointed (photo 5); joints are vertical and in two oblique sets. Invertebrate macrofossils are rare, but conodonts and the resinous, amber-colored spores of *Tasmanites* are common to abundant. The only known invertebrate from Union County is a rare lingulid brachiopod *Barroisella subspatulata.* Another exposure of New Albany is at the northern end of Iron Mountain in a north-trending tributary to Clear Creek in the Cobden Quadrangle. About 70 feet of shale is exposed in this area, again yielding phosphatic nodules near the top of the unit. This phosphatic interval is probably equivalent to the **Falling Run Nodule Bed** (Cluff et al. 1981). The basal New Albany contains a layer a few inches thick of well-rounded, medium grained quartz sand that is equivalent to the **Sylamore Sandstone Bed**. The contact with the overlying Chouteau Limestone is sharp as observed in the Cany Creek exposure (photo 6). It is probably disconformable with the overlying Mississippian limestone in the study area.

**Mississippian Subsystem of the Carboniferous System**
**Chouteau Limestone** was named by Swallow (1855) for Chouteau Springs, Cooper County, central Missouri. The Chouteau Limestone is a thin but highly persistent unit that extends over most of Illinois. In Union County it is only 1 to 2 feet thick and is composed of medium gray lime mudstone with olive green and dark gray mottling. The limestone contains phosphatic nodules with disarticulated crinoids and rare proetid trilobites (photo 7). The brachiopods, *Productella consentrica*, *Brachythyris semiplicata,* and *Ambocoelia unionensis* have been found in this unit. Angular to rounded

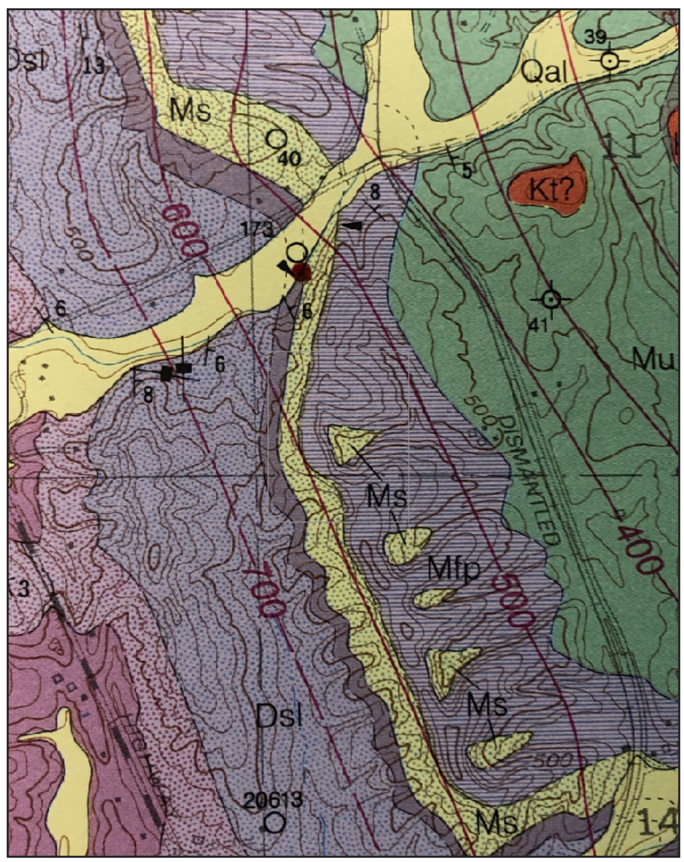



**Figure 4** Location of the contact with New Albany/Chouteau Limestone/Springville Shale in Cany Creek.


**Photo 4** Dipleura sp. cephlon found in the St Laurent at Iron Mountain.

**Photo 5** Jointed New Albany Shale in Cany Creek.

**Photo 6** Contacts of New Albany/Chouteau/Springville in Cany Creek.

green rip-up clasts, possibly reworked from the New Albany, are common in the lower Chouteau, whereas small white calcareous geodes are common in the upper part. Conodonts of the Chouteau indicate late Kinderhookian age (Collinson and Scott 1958). Exposures of the Chouteau accompany the New Albany along Cany and Clear Creeks and at the spillway of State Pond, 2 miles northwest of Jonesboro. The sharp contact with the overlying State Pond Member of the Springville Shale is interpreted as a disconformity (Collinson and Scott 1958).

**Springville Shale** takes its name from the abandoned village of Springville, which was situated along present State Rt. 127 about 5 miles west of Dongola in Union County (Savage 1920). The basal member, called **State Pond Member,** is only 1 foot to 1.5 feet thick and consist of greenish gray, soft glauconitic shale containing phosphorite nodules (photo 8). Outcrops are at State Pond, an artificial lake about 2 miles northwest of Jonesboro, Illinois; and also along Cany Creek. The Springville Shale above the State Pond Member is greenish gray, silty unit that is weakly fissile, poorly laminated, and contains siltstone beds. The formation is typically poorly exposed, but a good exposure can be seen on the south side of a roadcut on State Hwy 146 west of Jonesboro and along Old Cape Road one mile south of the turn-off from State Hwy 127.  The shale contains illite and chlorite clay, which produces the green color of the Springville. In outcrops the thickness of this unit ranges between 30 to 50 feet; however, a thickness of 76 feet was logged in the Burr Lambert #1 Hagler well (Sec. 28, T10S, R2W). No fossils have been found in this unit other than horizontal burrows and conodonts from the State Pond Member, which indicate early Valmeyeran (Osagean) age (Collinson and Scott 1958). The upper part of the Springville is silicified in places to a dense, slabby, variegated purple and white to red and green

**Photo 7** Proetid trilobite found in the Chouteau Limestone in Cany Creek.

**Photo 8** Phosphorite nodules from the State Pond Member of the Springville Shale.

mottled material informally called "Calico shale." The contact with the overlying Fort Payne Formation is disconformable.

**Mammoth Cave Group**

The Mammoth Cave Group comprises mid-Mississippian Subsystem formations that are dominantly limestone. In Union County the group contains, in ascending order: Fort Payne Formation, Ullin Limestone, Salem Limestone, St. Louis Limestone, and the Ste. Genevieve Limestone. As defined, the group comprises most of the Osagean and Meramecian Series and the lower part of the Chesterian Series.

**Fort Payne Formation** is named for Fort Payne, De Kalb County, Alabama (Smith 1890). The base of the Fort Payne in Union County is a resistant bed of chert called the Hartline Chert. Although the name Hartline previously referred to the entire Fort Payne in this area, we are restricting the Hartline to the bedded chert at the base of the Fort Payne as **Hartline Chert Bed.** The Hartline is a gray siliceous rock that has a very fine, silty texture with chalcedonic "burrow" fillings. It weathers brownish-orange and ranges between 1 and 3 feet thick. It is in sharp contact with the underlying Springville Shale. An easily accessible outcrop is in a roadcut south of State Road 146 in the northeast corner of Section 23, T12S, R2W, of the Jonesboro Quadrangle (photo 9). At the surface the Hartline Chert Bed displays numerous vertical fractures.

Above the basal Hartline Chert, the Fort Payne is dominantly gray cherty lime mudstone. However, outcrops in the Cobden Quadrangle show silicified limestone or bedded chert that is gray to orange-brown, dense, novaculitic, and thick bedded. In some exposures in the Iron Mountain area, the rock is brecciated by tectonic movement, solution collapse, or both. In the outcrop belt, the Fort Payne ranges from 10 to 60 feet thick. Eastward in the subsurface it reaches 110 feet at the eastern border of Union County and attains a maximum of 610 feet thick in the subsurface of Pope County, Illinois (Willman et al. 1975). The contact to the Ullin Limestone above is gradational.

**Ullin Limestone** is named for Ullin, Pulaski County (Lineback 1966). This limestone is white to light gray fossiliferous, commonly crossbedded packstone to grainstone that is dominated by fenestrate bryozoans and disarticulated crinoids. Outcrops display a distinctive speckled or granular texture made by brownish crinoid fragments composed of calcite crystals that are embedded in finer grained, lighter colored bryozoan matrix. The limestone is soft and weathers by exfoliation. It also weathers deeply by solution, producing many sinkholes. The outcrop belt has a north by northwest trend and widens to the southeast in Union County. This stone currently is being quarried by Shawnee Stone LLC north of Mill Creek. North of Bald Knob the Ullin is faulted out at the surface. The lower part of the formation is more siliceous, whereas the purer upper part is composed of up to 94% calcium carbonate. Bedding is thin to thick and displays cross bedding that implies lateral accretion of

**Photo 9** Hartline Chert in a road cut on State Highway 146 in the Jonesboro Quadrangle.

shoals. The Ullin can be as thick as 450 feet. The contact is well exposed in the northern Jonesboro Quadrangle and in a railroad cut in the southern part of the Cobden Quadrangle. This contact with the Salem Limestone is gradational and intertonguing.

**Salem Limestone** takes its name from Salem, Washington County, Indiana, where it is quarried as the famous “Indiana Limestone” (Cumings 1901). The outcrop belt of the Salem limestone parallels the Ullin outcrop belt. Good outcrops are sporadic in the Cobden, Jonesboro, and Mill Creek quadrangles. Some of the best exposures occur along Clear Creek in the Cobden Quadrangle and Kratzinger Hollow in the Jonesboro Quadrangle. The Salem Limestone in the study area is medium to dark gray fossiliferous wackestone, packstone to grainstone that contains round chert nodules. Some beds contain roiunded, coated fossil grains and small oolites. This formation is harder than the Ullin and lacks the speckled texture. Crossbedding occurs in the Salem but is far less prevalent than in the Ullin. The Salem is coarser-grained and less cherty than the overlying St. Louis Limestone.

The Salem is bryozoan rich and contains abundant endothyrid foraminifers. Other fossils include crinoid columnals of *Platycrinites*, *Melonechinus* echinoid plates and spines, blastoid plates, spiriferid brachiopods, and rugose corals. *Globoendothyra baileyi* is an index fossil of a foraminifer characteristic of the Salem. An important colonial rugose coral, *Acrocyathus proliferum* occurs in the transition zone between the basal St. Louis Limestone and the upper Salem. *Acrocyathus proliferum* is a regional epibole that extends from the Alton, Illinois area across southern Illinois into western Kentucky. The epibole has been documented in the upper Salem near Hicks Dome and in the basal St. Louis in the Cobden Quadrangle (Devera and Nelson 1995). These corals (photo 10) occur at or close to the Salem/St. Louis contact in Union County. This relationship is well exposed in Clear Creek, Section 35, T11S, R2W, of the Cobden Quadrangle. The Salem/St. Louis contact is transitional within a 20-foot interval, where the Salem Limestone is a crinoidal wackestone to a lime mudstone of the St. Louis above. The varying position of the epibole indicates overlap that straddles the boundary between Salem/St. Louis formations.

**St. Louis Limestone** was named by Engelmann (1847) for the St. Louis, Missouri, where it is extensively exposed. The St. Louis Limestone was mapped in a belt that trends N 30° to 40° W from the Dongola to Cobden Quadrangles (map sheet **1)**. Sinkholes are abundant along the outcrop belt. The limestone is largely dark gray to medium gray, micritic, and cherty. Much of it is lime mudstone that exhibits sublithographic texture with conchoidal fracture and stylolites. Some layers consist of fossiliferous wackestone and packstone. Beds of yellowish to brown dolostone also occur in this formation. Thin greenish shaly partings occur in some of the more fossiliferous beds. Some beds of limestone are brecciated due to solution collapse, most likely resulting from dissolution of anhydrite. Other beds are very finely crystalline limestone with faint laminations that may be tidallites.

**Photo 10** *Acrocyathus proliferum* from the Salem/St. Louis boundary.

Chert of the St. Louis is banded with shades of light to dark gray to black, forming smooth prolate spheroids in the limestone. At Iron Mountain the chert is waxy or vitreous, whereas elsewhere it loses its translucent character. Archaeologists call the chert from the St. Louis Limestone of the Iron Mountain region the Cobden Chert. This chert was highly prized material for Native Americans and still is sought by modern flint knappers; mainly because of its lustrous texture. The primary reason the chert is so glassy in this area is that the material was influenced by hydrothermal fluids that passed through faults along the Iron Mountain Fault Zone.

Fossils of the St. Louis include the echinoids *Archaeocidaris* and *Melonechinus multiporus*, the colonial rugose corals *Acrocyathus flouriformis* and *A. proliferum*, corals of genus *Syringopora,* the crinoids *Platycrinites penicillus, Holcocrinus, Dinotocrinus, Culmicrinus, Taxocrinus;* the bryozoans *Lyropora, Cystodictia,* and fenestrates, the brachiopods *Brachythyris altonensis, Spirifer littoni, Echinoconchus* sp., *Productus tenuicostus, Streptorhynchus ruginosum.* The upper St. Louis contain conodonts of the *Apatognathus* *scalenus – Cavusgnathus* Zone (Willman et al. 1975). Taken together, these fossils indicate late Meramecian age.

Thickness of the St. Louis is about 120 feet along Clear Creek, where both contacts are well exposed. Farther east and basinward the unit thickens to 350 feet in the Anna Quarry (fig. 5 on next page). The contact with the overlying Ste. Genevieve Limestone is gradational. This contact was mapped at the lowest occurrence of oölitic grainstone.

**Ste. Genevieve Limestone** Named for Ste. Genevieve, Missouri (Shumard 1860), the formation crops out along a narrow belt that extends northwest from the Cypress to the Cobden quadrangles. Due to deep dissolution, the Ste. Genevieve is poorly exposed. The best natural exposures occur in the Anna Quadrangle along Big Creek and in the Cypress Quadrangle along Adds Branch. Far more complete exposures are displayed in the Anna Quarries.

The Ste. Genevieve Limestone is composed of white to light gray to tan, oolitic grainstone, and fossiliferous grainstone and packstone facies. Most of the skeletal grains are composed of echinoderm fragments: crinoidal, blastoid, and echinoid. The rest of the fossil grains are of bryozoan, brachiopod, and coral debris. Intervals of darker gray wackestone and cherty dolomitic lime mudstone, lithologically similar to the underlying St. Louis, are interbedded with light gray limestone. These wackestone beds and lime mudstone beds are more common in the lower part of the unit. Lenses of calcareous quartz arenite and greenish gray shale and siltstone are more common in the upper part of the Ste. Genevieve, transitioning to cyclic Chesterian units above.

Fossils in the Ste. Genevieve are typically disarticulated. However, shaly beds contain articulated invertebrates, including solitary rugose corals, a diagnostic brachiopod, *Pugnoides ottumwa,* a large gastropod, *Bellerophon,* and the crinoid *Platycrinites penicillus*. Collinson et al. (1971) found that the Ste. Genevieve is in the lower part of the *Gnathodus bilineatus – Cavusgnathus charactus* conodont zone.

Thickness of the Ste. Genevieve Limestone is about 250 feet in the Anna Quarry, where the contact with the overlying Aux Vases Formation is gradational. A regional study suggests that Aux Vases clastics in southwestern Illinois intertongue with the Ste. Genevieve carbonate rocks in southeastern Illinois (Nelson and Cole 1992).

The relationship between the Aux Vases Sandstone and Ste. Genevieve Limestone is an intimate one. The first pulse of siliciclastic sediment into the Ste. Genevieve Sea produced the **Spar Mountain Member**, which is a quartz-rich sandstone with calcareous cement. This member laterally grades into the Aux Vases east and north of Union County. The **Karnak Limestone Member** occurs above the Spar Mountain; it is an oölitic grainstone typical of the Ste. Genevieve. The Karnak Limestone Member also laterally grades into the Aux Vases north of the study area. The uppermost part of the Ste. Genevieve, formerly called the **Joppa Member,** is a mixture of cross bedded, purple, skeletal/oölitic grainstones, red and green shales, and laminated siltstones with gray shale. Simple horizontal burrows and *in situ Conostichus* domicile burrows of sea anemones occur in the siltstone/shale facies. The siltstone is a mixture of quartz silt and fossil carbonate grains such as fragmented brachiopod shells, echinoderm, trilobite, coral and bryozoan debris, and is rhythmically laminated. Apparently, the upper Ste. Genevieve laterally grades into the Aux Vases Sandstone. An interpretive drawing (fig. 6) graphically shows the relationship of the upper Ste. Genevieve to the Aux Vases.

Nelson et al. (2002, ISGS Bulletin 107, p. 18) abandoned usage of the name Joppa Member.

**Pope Group**
Named for Pope County, Illinois (Nelson 1995), the Pope Group is an interval of rock composed of interbedded limestone, shale, and sandstone in the upper Mississippian Subsystem. The Pope Group contrasts with the limestone-dominated Mammoth Cave Group below and the sandstone-dominated Raccoon Creek Group in the lower part of the Pennsylvanian Subsystem, above. In Union County the Pope Group contains the following formations in ascending order: Aux Vases Formation, Paoli Formation, Bethel Sandstone, Ridenhower Formation, Cypress Sandstone, Golconda Formation, Hardinsburg Sandstone, Glen Dean Limestone, Tar Springs Sandstone, Vienna Limestone, Waltersburg Sandstone, Menard Limestone, Palestine Sandstone, Clore Formation, Degonia Sandstone, Kinkaid Limestone, and the Grove Church Shale.

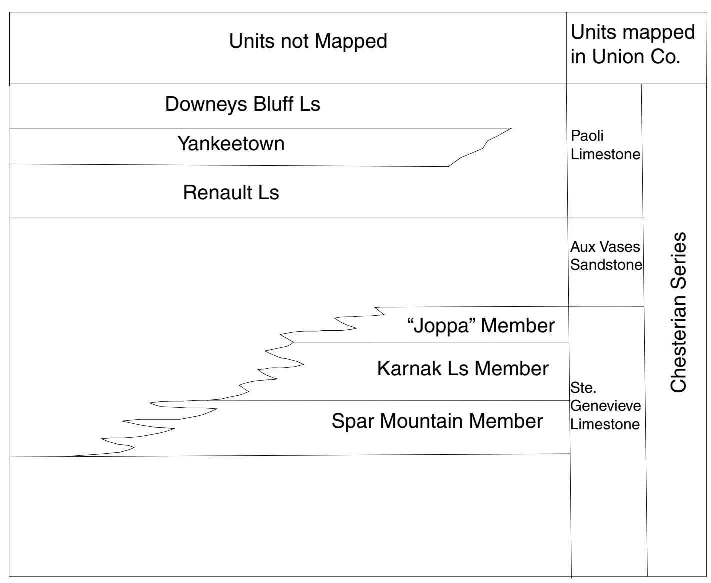



**Figure 6** Lateral relationship of Aux Vases to Ste. Genevieve.

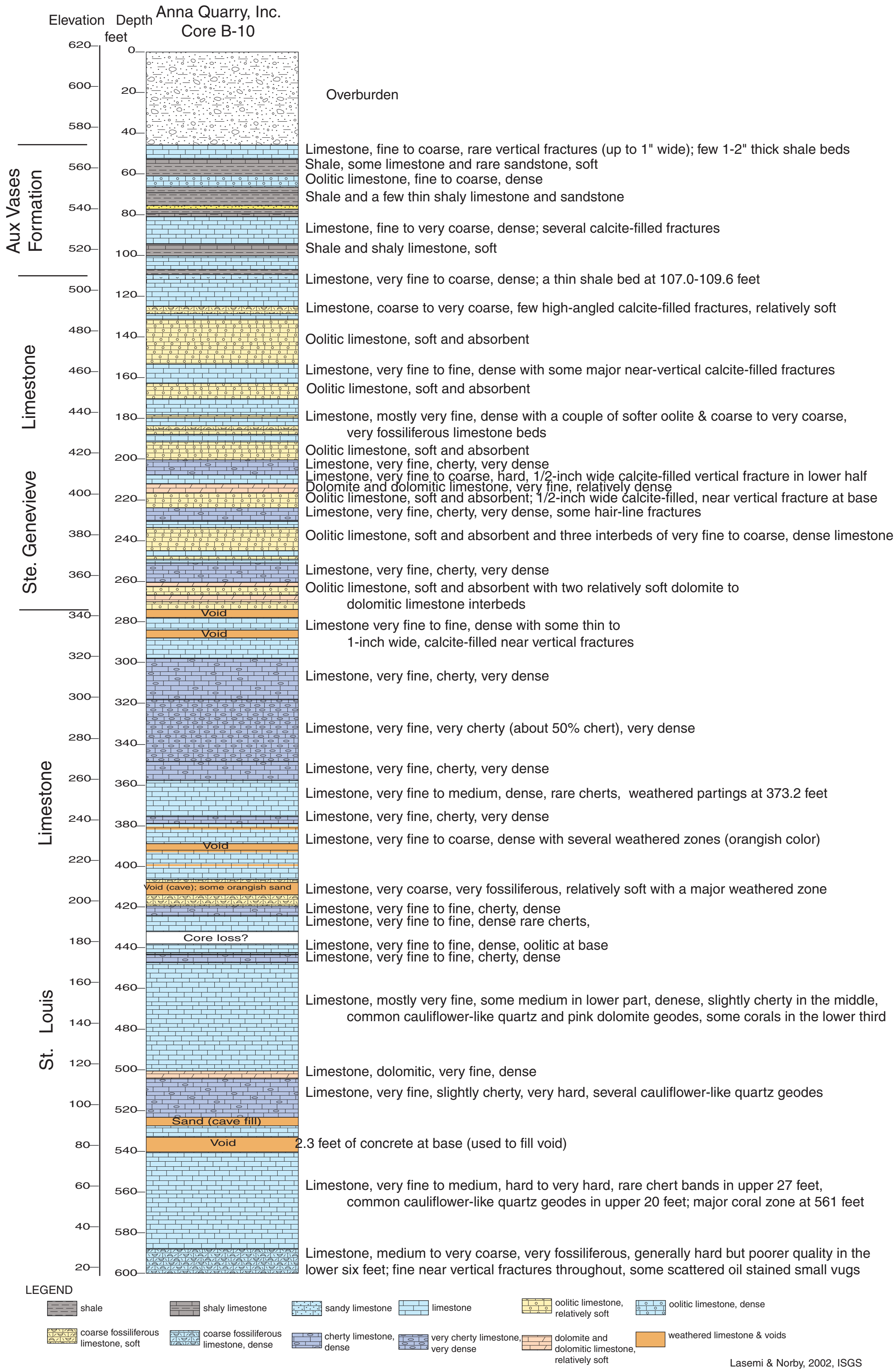



**Figure 5** Core drilled at the Anna Quarry

**Aux Vases Sandstone** is named for the Aux Vases River in Ste. Genevieve County, Missouri (Keyes 1892). This formation is intermittently exposed in a northwest-trending belt that extends from the Cypress to the Cobden quadrangles in Union County. It consists of tan to white, fine grained, well-sorted, quartz arenite, interbedded with siltstone and thin layers of greenish shale. Thickness in Union County varies from about 20 to 40 feet. Roadcuts along U.S. Highway 51 north of Anna reveal thin rhythmically laminated sandstone beds. Exposures at the White Hill Quarry just beyond the southeastern corner of Union County yield cross bedded, ripple marked, greenish and calcareous sandstone bodies and bar forms. These and other exposures in Union County suggest overall eastward deepening into the basin, from tidal flat to offshore bars and deltas.

The upper contact is sharp but conformable with the overlying limestone unit.

**Paoli Limestone** takes its name from Paoli, Orange County, Indiana and was originally described by Elrod (1899) and extended into Illinois by Nelson et al. (2002). The entire Paoli Limestone was cored in the Lyerla No. 1 stratigraphic test in the southeastern corner of Section 6, T11S, R2W of the Cobden quadrangle (fig. 7). Three continuous cores illustrate changes in lithology and nomenclature in the lower part of the Pope Group across southern Illinois, from the Chester type area through Union County to the Fluorspar District (fig. 8). On the east, the Paoli is mostly limestone and is divisible into four members: Levias Limestone (oldest), Shetlerville Limestone, Yankeetown Member, and Downeys Bluff Limestone. Toward Chester, shaly strata increase at the expense of limestone, and the nomenclature changes. The Renault Limestone is recognized as a thin formation correlative with the Levias and Shetlerville members in the fluorspar district. The Yankeetown also rises in rank from member to formation, while the Downeys Bluff and younger shale and limestone become members of the Paint Creek Formation. The diagram (fig. 8) also illustrates dramatic thickening of the Aux Vases Sandstone between Union County and Chester.

The basal part of the Paoli is gradational with the Aux Vases. It is a greenish silty limestone with burrowed siltstone stringers. Crinoidal grainstone grades upward into light gray with greenish mottling, oölitic grainstone facies that is cross bedded. In the middle part of the Paoli, the Yankeetown Member, red and green claystone and siltstone mixed with calcareous fossil debris encloses silty limestone 10 to 12 feet thick. The Downeys Bluff Member is dominated by oölitic and fossil grainstone that contains pink to red crinoid columnals. Interbeds of calcareous shale contain small lenses of packstone. Pink, red, and orange crinoid fragments are characteristic of the Downeys Bluff throughout southern Illinois. The contact with the overlying unit is gradational.

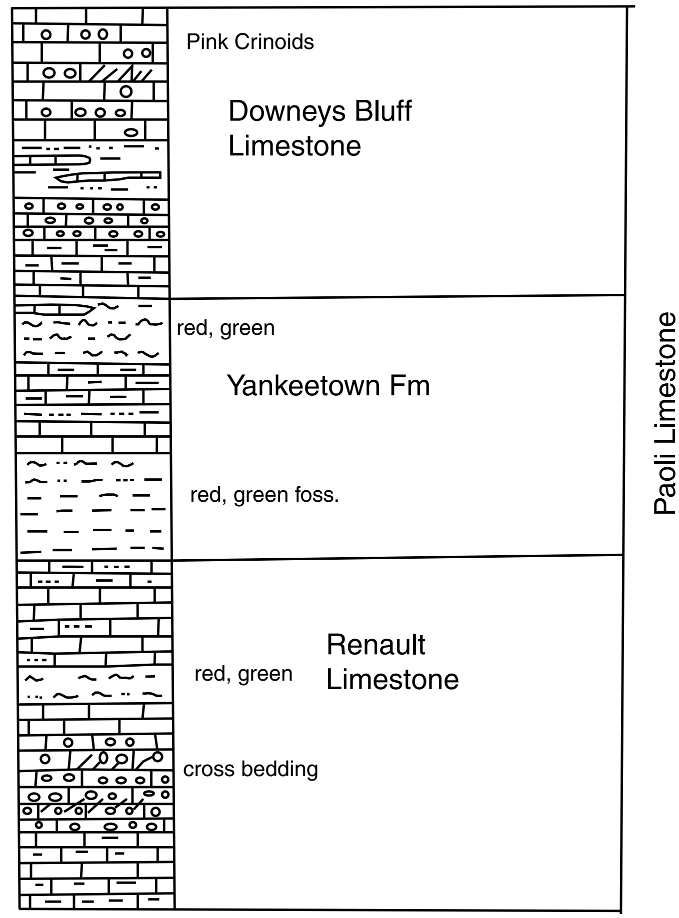



**Figure 7** Lyerla Well, SW 1/4, Sec.6, T115, R2W, Cobden Quad.

**West Baden Sandstone** is used on the Union County geologic map to encompass the Bethel, Ridenhower, and Cypress formations shown separately on the 7.5' quadrangle maps. The name West Baden is derived from West Baden in Orange County, Indiana (Cummings 1922). This unit is dominated by siliciclastics and trends in a northwest to southeast belt across most of Union County.

The **Bethel Sandstone** is thin in Union County and thickens northeastward. It does not occur in the Lyerla Well. An exposure of Bethel occurs in a linear ravine just east of State Highway 127 in the SW1/4, NE1/4, SE1/4, of Section 22, T11S, R2W. The sandstone here is light greenish gray, very fine grained, calcareous, and contains irregular laminae of green shale. Where it occurs in the subsurface in the northeastern corner of the county, the Bethel is white to light gray, well sorted, very fine to fine quartz arenite that has subrounded to angular grains. Calcite cement, oolites, and marine bioclasts commonly are present. Sedimentary features include planar, ripple, and cross lamination and trough and herringbone crossbedding. However, the lower contact is sharp. The sandstone appears to have a flat base and a convex-upward top.

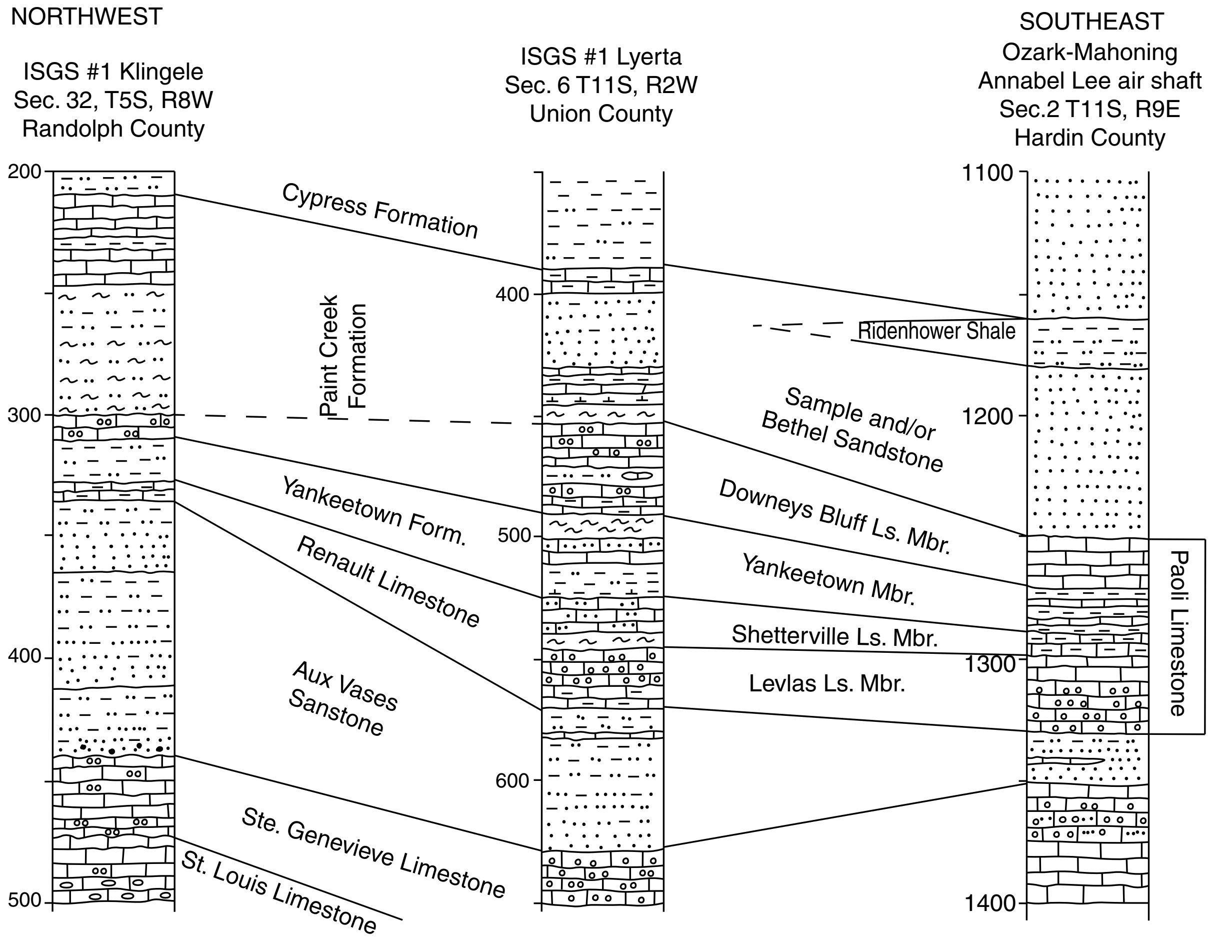



**Figure 8** Correlation of lower Chesterian Cores

The **Ridenhower Formation** only occurs in the northeastern part of Union County. This unit has mixed lithologies, dominated by shale but also containing beds of limestone, sandstone, and siltstone. The Ridenhower is poorly exposed and is mainly a slope forming unit. At its base, at least locally, is a shaly limestone called the **Beaver Bend Limestone Member,** which occurs in the Lyerla # 1 core. This limestone grades into a sandy to silty shale believed to represent the **Sample Sandstone Member,** which is about 30 feet thick in Union County. In turn, the Sample has a sharp contact with overlying argillaceous limestone identified as the **Reelsville Limestone Member**. An interesting feature of this limestone is that it has a regional epibole of a stemless, bullet-shaped crinoid called *Agassizocrinus*.

Overall, the Ridenhower consists of layers of light-colored oölitic and skeletal packstone and grainstone alternating with shaly, silty, and sandy lithologies. Shale and claystone beds are variegated red, green, gray, and purple. Thickness of the Ridenhower varies between 17 to 116 feet. Fossils include the brachiopods *Girtyella intermedia, Dielasma illinoisensis, Productus parvus,* and *Diaphragmus elegans,* the bryozoans *Lyropora*, *Rhombopora, Cystodictya, Archimedes,* fistuliporates, and fenestrates, the blastoid *Pentremites*, echinoid plates and spines of archaeocidarids, the crinoids *Zeacrinites, Pterotocrinus,* and *Agassizocrinus,* rugose corals, and proetid trilobites.

The Ridenhower has a sharp unconformable contact with the overlying Cypress Sandstone in many places but interfingers with the Cypress locally.

The **Cypress Formation** (Englemann 1863) takes its name from Cypress Creek in southeastern Union County, where sandstone in the lower part of the formation forms extensive bluffs. There is no specific type section, but continuous core from the ISGS Tripp #1 stratigraphic test provides an excellent principal reference section (fig. 9). This hole was drilled in Sec. 29, T12S, R1E of Union County and carries county number 21909.

In southern Illinois, the Cypress Formation typically comprises an upper unit of thinly layers, fine-grained clastic rocks, and a lower unit of thick-bedded to massive sandstone. The upper unit is known mainly from drilling records; outcrops are sparse. Shale, siltstone, and thin-bedded sandstone dominate, although lenses of thick-bedded sandstone are present. The upper unit contains carbonaceous

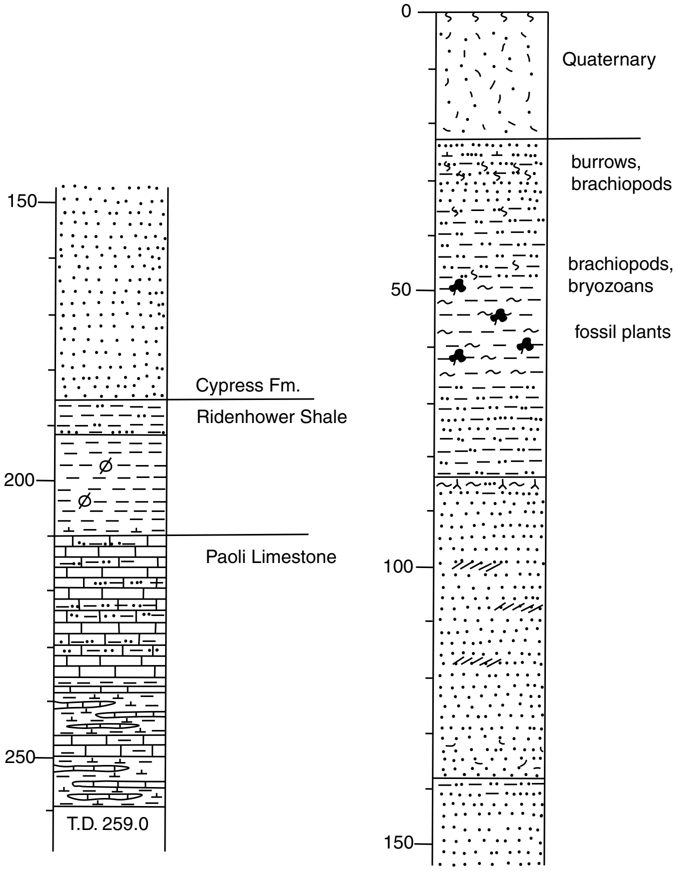



**Figure 9** ISGS #1 Tripp Stratigraphic test hole, continuously cored in Sec. 29, T125, R1E, Union county. This is the principal reference section of the Cypress Formation.

shale, thin coal layers, and claystones having paleosol features. Both fossil plants and marine invertebrates, including crinoids, brachiopods, and bryozoans (found mainly as casts or molds in sandstone) are present. The lower Cypress sandstone is resistant to erosion, forming bluffs and ledges. Crossbedding and massive bedding are prevalent. The lower Cypress sandstone fills valleys incised into the Ridenhower Shale and Paint Creek Formation (Cole and Nelson 1995, Nelson et al. 2002).

In Union County, the Cypress Formation ranges from less than 50 to about 190 feet thick, thinning toward the northwest. The lower bluff-forming sandstone reaches 100 feet thick along Cypress Creek and its tributaries in the Mt. Pleasant quadrangle. The sandstone is white to light gray quartz arenite, very fine to fine-grained with local medium sand. The rock tends to be friable, case-hardened on outcrops, and exhibits honeycomb weathering and Liesegang banding. Lower-angle wedge and planar tabular crossbedding is prevalent, showing paleocurrents primarily to the west and northwest, less commonly south and southwest. In the Mt. Pleasant quadrangle, the upper 5 to 30 feet of the lower sandstone exhibits pervasive slumped and contorted laminations, together with “healed” joints that strike N 5-20°W – features that suggest seismic activity prior to lithification (Nelson and Devera 2007). Other sedimentary structures in the lower sandstone include planar lamination and ripple marks. The only fossils are casts of *Lepidodendron* logs. The lower contact is erosive, with Cypress sandstone filling valleys eroded into the Ridenhower Shale and Paint Creek Formation.

The upper Cypress is composed of interlayered shale, siltstone, and sandstone that is mostly very fine-grained and laminated to thinly bedded. Planar lamination, interference ripples, and ladderback ripples are common; bidirectional cross-lamination has been observed. Some beds are intensively bioturbated, containing ichnofossils such as *Eiona, Nerites (formerly Sclaratuba) missouriensis,* and *Psammichnites (*formerly *Olivelites) plumeri.* Both fossil land plants and marine invertebrates occur in the upper Cypress. The latter include casts and molds of spiriferid and productid brachiopods, bryozoans, and echinoderm fragments. Paleosols and rooted zones also are present in the upper unit. Red and green variegated claystone has been logged in well samples from northwestern Union County.

The contact to the Beech Creek Limestone Member of the Golconda Formation may be sharp or gradational.

**Golconda Formation** Formerly designated as a group (Swann 1963), the Golconda Formation in Union County comprises three members: the Beech Creek Limestone at the base, the Fraileys Shale, and the Haney Limestone.

**Beech Creek Limestone Member (“Barlow lime”of petroleum geologists)** was named by Malott (1919) for Beech Creek in Greene County, Indiana. This limestone is persistent through most of the Illinois Basin and is an important structural datum in petroleum exploration. In Union County the Beech Creek is thin and poorly exposed. In the Lyerla No. 1 stratigraphic test core, the member is 3.4 feet thick and composed of crinoid/bryozoan packstone to grainstone facies. Near the base are laminae of calcareous shale and shale rip-up clasts probably derived from underlying Cypress. In outcrops, the Beech Creek is typically dark gray or brownish gray, slightly cherty and very fossiliferous, pelletal packstone. Characteristic fossils are the brachiopods *Martinia contracta* and *Productus inflatus* and the bivalve *Euphemia randolphensis*. The Beech Creek grades into shale of the overlying Fraileys Member.

**Fraileys Shale Member** was named for Fraileys Landing, Hardin County, Illinois (McFarlan et al. 1955). This unit is dominated by shale and claystone, with thin fossil packstone layers. The lower Fraileys is dark gray, thinly fissile shale that is fossiliferous, pyritic, and partly silty to sandy. Common in the upper Fraileys are lenses of argillaceous packstone containing fenestrate and rhomboporoid bryozoans, small rugose corals and common crinoid and blastoid fragments. The index fossil *Pterotocrinus capitalis* is commonly found as “wing plates” on the fossiliferous layers (plate 1).

It is a unique bulbous plate that is known only from the Fraileys. In the Lyerla #1 core, variegated, non-fissile claystone occurs near the top of the Fraileys. The red-brown slickensided claystone in the Lyerla core contains numerous small limestone nodules and apparently represents a paleosol. The Fraileys is gradational with the overlying Haney Member.

**Haney Limestone Member** takes its name from Haney Creek, Hardin County, Illinois (McFarland et al. 1955). This member is dominantly limestone with interbeds of gray, fossiliferous shale. The limestone is light to medium gray, weathering tan, fossil packstone composed of bryozoans (fenestrates and rhomboporoids) and pelmatozoans (crinoid and blastoid) grains with some oölitic grains. In the lower part of the Haney is shale interbedded with wackestone, packstone, and grainstone facies. The upper part shows lateral accretion of fossil grains.

An excellent, highly fossiliferous exposure of the Haney is in a roadcut on State Highway 146 just east of Interstate 57. Found at this exposure are small rugose corals and the bryozoans *Archimedes,* twig-like *Rhombopora*, and encrusting fistuliproids. Brachiopods include *Cleiothyridina sublamellosa, Composita, Eumetria acuticosta, Reticularia setigera, Spirifer leidyi, Spiriferina spinose, Girtyella brevilobata, Dielasma shumardanum,* and *Diaphragmus elegans.* Numerous complete crinoid calyxes have been found at the 146 State Highway cut in the shaly upper portion of the Haney. They include very common *Phanocrinus formosus, Phanocrinus cylindricus, Phanocrinus bellulus, Zeacrinites wortheni, Taxocrinus,* and *Onychocrinus*. Rarer types are *Ramulocrinus, Fifeocrinus,* and *Pterotocrinus;* some of these are shown on plate 2. Blastoids are commonly found in the shale as well, mainly *Pentremites godoni* and *Pentremites pyriformus* with brachioles intact. Mollusks include planispiral gastropods and small involute goniatites. Proetid trilobites are rare but found as disarticulated pygidia and cephalons. The Haney is about 30 to 40 feet thick.  The upper contact may be either gradational to shale of the Hardinsburg or erosive to Hardinsburg sandstone that fills incised valleys.

**Hardinsburg Formation** was named for Hardinsburg in Breckenridge County, western Kentucky (Brokaw 1916). The Hardinsburg thins from a maximum of 90 feet in southeastern Union County to less than 10 feet on the northwest, as shown in the Lyerla No. 1 stratigraphic test. Where the Hardinsburg is too thin to be mapped separately, it is combined with the Golconda and Glen Dean Limestones as "Okaw Formation" on the geologic map. On the southeast where it is thicker, the Hardinsburg exhibits architecture similar to the older Cypress Formation. The lower Hardinsburg is ledge-forming sandstone that is white to light gray, weathers brown and reddish, well sorted, fine-to medium-grained, thick-bedded to massive quartz arenite. The upper Hardinsburg is composed of laminated to thinly bedded sandstone that shows ripples, tool marks, and small load casts. Trace fossils are common, including *Lockeia, Aulichnites, Curvolithus, Cruziana, Ucherites, Nerites (Sclaratuba) missouriensis,* and *Psammichnites (Olivelites).* The only other fossils are fragmentary plant remains. Well records indicate that the upper Hardinsburg contains shale that is gray to dark greenish gray. North of the study area, red shale occurs in the upper part in the Chester, Illinois area; thin coal beds are present in Johnson and Pope Counties. The upper contact with the Glen Dean Limestone is gradational.

**Glen Dean Limestone** named by Butts (1917) for Glen Dean, Breckenridge County, Kentucky. In Union County, the Glen Dean was mapped as a separate unit 65 to 120 feet thick on the southeast, and as part of the Okaw Formation on the northwest. Poor exposures and structural complications precluded splitting out the components of the Okaw Formation here. Where the Glen Dean is clearly recognized in Union County, it generally comprises an upper limestone 15 to 45 feet thick and a lower unit that is mostly shale with thin limestone interbeds. The lower shale varies from medium to dark gray, greenish gray, and olive-gray and is platy or fissile, slightly calcareous, and clayey to slightly silty. Limestone beds in the lower Glen Dean are mostly coarse crinoid-brachiopod packstone and grainstone. A bed of very sandy limestone to calcareous sandstone 2 to 3 feet thick occurs at the base in the Mt. Pleasant quadrangle. The upper Glen Dean is mostly brown to gray, medium to coarse-grained, crinoid-bryozoan packstone and grainstone. Light gray, crossbedded oolitic grainstone occurs near the top. Less common are layers of silty to argillaceous, dolomitic lime mudstone and wackestone.

Fossils of the Glen Dean are mostly disarticulated, but whole specimens include the blastoid *Pentremites spicatus,* which is characteristic of the formation, and several species of the crinoid *Pterotocrinus*, which are all long ranging. An epibole of the bryozoan *Prismopora serrulata* is also indicative of the unit. Other bryozoans are fenestrates and rhomboporoids; spiriferid and productid brachiopods are common in the shales. The uppermost part of the Glen Dean is a dark gray shale that is transitional to the overlying sandstone.

**Tar Springs Formation** is named for Tar Springs in Breckenridge County, western Kentucky (Owen 1856, Butts 1917). Thickness in Union County varies from about 70 to 120 feet, with no obvious regional trend. Sandstone is largely confined to the upper Tar Springs in the Mt. Pleasant quadrangle, but sandstone as thick as 60 feet occurs in the lower part of the formation in the Makanda quadrangle.

The Tar Springs is primarily made up of sandstone, siltstone and shale, with minor amounts of coal and claystone. Sandstone is well exposed as cliffs striking northwest and forming a northeast-facing dip slope. This rock is white to light gray to brownish-gray, very fine to fine-grained, well sorted, quartz arenite. Crossbedding and ripple marks are prevalent, together with load casts and ball-and-pillow structures. Shale and siltstone of the Tar Springs are mostly medium to dark gray with a greenish to olive cast. Small limonite nodules are common. Some of the shaly, laminated strata are rich in trace fossils, including *Planolites, Lockeia,* and *Conostichus.* Plant remains are common, but largely fragmentary. Invertebrate fossils are rare. Bryozoans were observed in shale near the top of the Tar Springs in well cuttings., and a thin lens of gray limestone containing a tabulate coral occurs in the upper part of the Tar Springs in the Lyerla core.

A world-class exposure of tidal rhythmites occurs in the Cobden Quadrangle in the southern part of Section 15, T11S, R2W in a southwest flowing ravine about 1 mile due south of Alto Pass. Here, the bedding is seen as troughs and cross beds with thicker and thinner couplets that are rhythmic, yielding beautiful semi-diurnal tidal cycles (photo 11). The sandstone below the tidal rhythmites is a massive bedded sand-wave deposit, signifying a shallowing upward trend.

The Lyerla #1 well was spudded into the Tar Springs and cored 97 feet of the formation. The lower 40 feet is mainly gray shale with sandstone laminae. The upper 57 feet is dominantly a fine grained, quartz arenite that displays rhythmic laminations and cross laminations similar to those in the above-mentioned outcrop. Near the top of the core, a thin coal overlies a shale bed with rootlets. This unit locally grades upward into the overlying limestone but can have a sharp contact in some wells.

**Vienna Limestone** Named for Vienna in Johnson County, Illinois (S. Weller 1920), the Vienna Limestone is a thin but distinctive unit that is widespread across the Illinois Basin. Thickness in Union County varies from about 5 to 30 feet and appears to decrease toward the northwest. The lower part of the Vienna is medium to dark brownish-gray lime mudstone to wackestone that contain pelmatozoan (crinoid and blastoid) bioclasts as the primary component. Light gray, crinoidal packstone and grainstone and crossbedded oolitic grainstone occurs in the lower Vienna in southeastern Union County. Bedding can be hummocky and is thin to medium. Fossils common to the Vienna include *Pentremites, Archimedes, Polypora, Rhombopora*, productid brachiopods, and small rugose corals. The limestone is highly siliceous and contains abundant chert as nodules and layers. The Vienna is more siliceous than any of the other of the Chesterian limestones. The chert is gray to chocolate brown with an orange porous rind and fossiliferous with pelmatozoan grains throughout, generally as molds. Residuum of this brown chert marks the outcrop belt of the Vienna.

The upper part of the Vienna consists of alternating dark gray to black fissile shales and siliceous mudstones. Along a stream bed beside an abandoned railroad in the NE1/4, NW1/4, of Section 25, T11S, R2W, of the Cobden Quadrangle is a good exposure of the upper part of the Vienna. The contact is not clearly exposed in the study area, but an increasing amount of shale in the upper Vienna suggests a gradational boundary with the Waltersburg Formation.

**Waltersburg Formation** was named by Stuart Weller (1920) for the hamlet of Waltersburg in Pope County, Illinois. Largely shale in Union County, this formation underlies slopes and outcrops are sparse. Thickness approaches 90 feet in the Mt. Pleasant quadrangle, decreasing toward the northwest to the Wolf Lake quadrangle, where the thickness is probably less than 30 feet. Because of lack of control, the Waltersburg has been combined with the Vienna and Tar Springs for mapping purposes and is labeled "Mwvts."

At most localities in the study area, the Waltersburg is predominantly shale, that grades upward to thin sandstone near the top. The shale is mostly dark gray to greenish or olive gray, fissile, soft, and slightly calcareous. The sandstone portion is white to light gray, weathers brown and orange, and is a very fine-grained, well sorted, quartz arenite. Simple horizontal burrows and trails and molds of well-preserved *Anthracospirifer increbescens* and other invertebrates in sandstone comprise the fossils. The upper contact is gradational with overlying calcareous shales of the Menard Limestone.

**Menard Limestone** was named for Menard Correctional Center at Chester in Randolph County and the type section is at the prison quarry (S. Weller 1913). Six members, three

**Photo 11** Tar Springs outcrop south of Alto Pass showing tidal bedding.

of them formally named (Swann 1963), are widely recognizable in the southern part of the Illinois Basin. In ascending order, these are the Walche Limestone Member, the lower shale, the Scottsburg Limestone Member, the middle shale, the Allard Limestone Member, and the upper shale member. Total thickness of the Menard in most of Union County ranges from 80 to 140 feet, but may diminish to less than 70 feet near the northwest corner of the county. The Menard is nonresistant, eroding to gently rolling hills and valleys that are pock- marked with sinkholes. Outcrops are confined to ravines and to south- and west-facing slopes where ledges of limestone can be observed.

Outcrops of the basal Menard reveal soft, calcareous, dark gray shale that contain thin lenses of light gray to yellowish-brown, argillaceous, fossil wackestone. This grades upward into packstone containing echinoderm fragments, whole and fragmented brachiopods, and fenestrate bryozoan debris. This part of the Menard is the basal **Walche Member**. Above the basal limestone, the lower unnamed shale contains a long-ranging species of *Pterotocrinus spatulatus* and *P. subspatulatus* but also contains the index *P. menardensis* and *P. clorensis* (see plate 1). The blastoid *Pentremites fohsi* occurs in the lower shale as well.

Abruptly overlying the lower unnamed shale is the **Scottsburg Limestone Member** (Middle Menard in oil terminology). The Scottsburg contains numerous lithofacies. Near the base is dense, dark gray lime mudstone or sublithographic limestone that weathers light gray and contains well preserved whole specimens of *Anthracospirifer increbescens, Composita subquadrata, Diaphragmus cestriensis, D. nivosus, Rhipidomella carbonaria, Schuchertella* sp., *Eumetria costata, Punctospirifer transverses,* and *Orthotetes kaskaskiensis* brachiopod fauna. Above this are wackestone to packstone in which whole fossils are rare. Yellow dolostone beds and laminated, non-fossiliferous limestone with alternating dark gray and light gray laminae occur within the Scottsburg. In the upper part of this member are dark gray chert nodules and many of the beds are knobby or hummocky. The most common fossils here are echinoderm fragments from archeocidarid spines and plates to crinoid and blastoid debris. Besides a plethora of brachiopods, the Scottsburg contains gastropods, rugose corals, and the ever-present *Archimedes* "screws."

An important oölitic grainstone facies occurs in the upper part of the Scottsburg, as found in core holes and outcrops. Outcrops yield as much as 15 feet of oölite north of Hutchins Creek, in Sections 5 and 6, T11S, R2W. In a COGEOMAP borehole CB #1 there is 21 feet of oölitic limestone. Oölites are not known east of this area, where the sediments apparently were deposited in deeper water, perhaps due to the effects of the Ozark high. The core shows that the oölites are cross bedded. Oölitic limestones also has been reported north and west of the study area in the Gorham and Altenburg Quadrangles (Seid et al. 2009).

The middle unnamed shale member overlies the Scottsburg Limestone. The shale is gray to greenish-gray, occasionally bright green (unusual in the Pope Group), and partly calcareous with slabby coquina-like layers that are highly fossiliferous. Fossils from this interval include the echinoderms *Pentremites, Pterotocrinus menardensis* wing plates, which as the name suggests are an index of this formation. Brachiopods in this interval are *Cleiothyridina sublamellosa, Anthracospirifer increbescens, Composita subquadrata, Punctospirifer transversa, Diaphragmus cestriensis, D. nivosus,* and *Orthotetes kaskaskiensis*. These brachiopods are well represented in the Elviran Stage, carbonate rocks and are seen as a recurring theme in many, if not all of the shales and limestones of this stage. Typical bryozoans in the middle shale are *Archimedes, Rhombopora,* and *Polypora.*

The Allard Limestone Member is composed mainly of gray lime mudstone and wackestone separated by thin layers of gray shale. One of the most common bivalves observed in the Allard is *Sulcatopinna missouriensis*, which can occur in clusters, especially in lime mudstone facies and typically seen in life position. Another smaller, clam-like bivalve, *Ectogrammysia* sp., occurs with the "bullet-shaped" stemless crinoid *Agassizocrinus.* Laminated lime mudstone facies also occur in the upper limestone. North of the study area, a number of large coiled nautiloid cephalopods were collected from the very top of the Allard Member, in transition to fossiliferous shale grading upward to silty shale and sandstone of the Palestine Formation. The cephalopod is *Endolobus spectabilis*; the largest phragmacone found thus far is 2.5 feet in diameter.

No good outcrops of the unnamed upper shale member of the Menard occur in Union County. Well records and outcrops in adjoining counties reveal gray, greenish gray, and olive-gray shale that is fissile, calcareous, and contains lenses and thin interbeds of limestone. Both shale and limestone are fossiliferous.

The contact between the Menard Limestone and the Palestine Formation is locally erosional but typically transitional in Union County.

**Palestine Formation** is named for Palestine Township, Randolph County (S. Weller 1913). The Palestine is about 30 to 80 feet thick in Union County, overall thinning toward the northwest. This unit is weakly resistant, containing thinly layered sandstone, siltstone, and shale. Outcrops mainly occur in stream cut-banks and ravines. In the northwestern part of the outcrop area in Cobden and Wolf Lake the Palestine underwent tectonic deformation. In one area on the east half of Section 36, T10S, R3W the Palestine is overturned. This is a part of the tectonic deformation that occurs above the Menard, which is unaffected in this area but does affect the Palestine, Clore, Degonia, and Kinkaid formations.

Typically, the Palestine coarsens upward from shale and siltstone in the lower part to sandstone in the upper part. Two upward-coarsening sequences of roughly equal thickness occur in the Mt. Pleasant quadrangle. In each sequence, dark gray fissile clay shale at the base grades upward to a silty shale and siltstone that is laminated or ripple laminated. The siltstone in turn coarsens to very fine or fine-grained, rarely medium-grained, thin bedded sandstone. The sandstone weathers brown and contains mica and carbonaceous debris in places. The middle part of the formation shows cross bedding and tabular bedding. Fossils include lycopods and other plant remains, mostly poorly preserved; and trace fossils such as *Lockeia, Cochlichnus, Conostichus,* and *Psammichnites (Olivelites).* Thin coal overlies rooted sandstone or shale near the top of the Palestine and in places, near the middle of the formation. The upper contact is either transitional or sharp with the overlying shales of the Clore Formation.

**Clore Formation** is named for Clore School, Randolph County (S. Weller 1913). The Clore is dominated by shale and thus is mainly nonresistant and forms a rolling topography. Outcrops are only seen in steep ravines and cut-banks. Thickness of the Clore decreases from more than 100 feet in eastern Union County to perhaps as little as 40 feet near the northwest corner. Three members can be recognized in parts of the county.

The lower **Cora Member** of the Clore is mainly dark gray to greenish gray shale with thin lenticular fossil packstone layers. The shale is blocky to fissile, non-silty, and calcareous in places. The thin limestone beds are either lime mudstone or a brachiopod coquinoid pavement that commonly is stained red or has a silvery appearance. Brachiopods include *Anthracospirifer, Composita,* and *Diaphagmus*. In the lime mudstone layers, *Archimedes* and other fenestrate bryozoans are common, along with an occasional large derbyid brachiopod. The ramose bryozoan, *Batostomella nitidula,* forms an ecological epibole (Acme zone) on some of the thin lenticular limestones that cover the surface with the twig-like organisms (S. Weller 1926). The faunal make-up of the Cora Member is similar to that of the Menard Limestone.

The middle part of the Clore is comprised of the **Tygett Sandstone Member**. The sandstone is thicker and more developed east of the study area and may be absent on the northwest. In Union County the Tygett is represented as a shaly siltstone that grades upward into a fine grained, well sorted, tan to gray quartz arenite. Near the top of the sandstone, stigmarian roots and *Lepidodendron* impressions can be observed in the thin sandstones and local thin coals are present. The contact with the overlying member is sharp.

The **Ford Station Member** of the upper Clore varies from 10 to 40 feet thick and consists of interbedded limestone and dark shale. At the base of this member is dolomitic limestone that has distinctive orange weathering and has been traced from Pope County. This bed varies from 3 to 10 feet thick and either contains thin shale partings or can be massive. The orange bed is composed of gray wackestone to packstone that contains crinoidal debris and bellerophontid gastropods. Oölitic grainstone overlies the orange bed near the northwestern corner of the county in the Wolf Lake Quadrangle. This oölitic bed has not been observed in the Clore elsewhere in Illinois. Its local presence likely relates to westward shallowing of the Illinois Basin toward the Ozark high. Similar oölitic limestone occurs in the Menard in northwestern Union County. Fossils are common in the Ford Station, especially the brachiopods *Cleiothyridina sublamellosa, Anthracospirifer increbescens, Composita subquadrata, Punctospirifer transversa,* and *Derbyia*, along with ramose bryozoans *Batostomella nitidula, Rhombopora,* and fenestrates. The crinoid that Sutton (1934) named *Pterotocrinus clorensis* occurs in the Clore; however, its morphology is so similar to that of *P. menardensis* that we do not accept *P. clorensis* as a distinct species. It is also important to note *P. clorensis* was found in the Menard as well (Tobinski 2011). (See the Section on Paleontology in this report.)

The upper part of the Ford Station Member is mostly dark gray shale. In some places this shale grades into the overlying Degonia Formation, but in other places the contact is erosive.

**Degonia Formation** is named for Degonia Township in Jackson County, Illinois (S. Weller 1920). Composed of sandstone, siltstone, shale, and non-fissile mudstone, the Degonia undergoes a rapid thickness and facies change in eastern Union County. In the eastern area, the Degonia is about 40 feet thick and is composed of fine-grained clastic rocks that are weakly resistant to erosion. Shale is mostly gray to brown, fissile, and noncalcareous. Siltstone is gray to greenish gray, noncalcareous, and moderately indurated. Sandstone occurs in various colors and is very fine to fine-grained and argillaceous, showing planar and ripple lamination and indistinct burrows and root traces. Red and green variegated, non-fissile claystone 10 to 15 feet thick is at the top of the Degonia (Nelson and Weibel 1996).

Near the western edge of the Lick Creek quadrangle, the Degonia doubles in thickness through the introduction of a thick body of bluff-forming sandstone. Thickness further increases to about 120 feet in the Makanda quadrangle. The lower part of the sandstone is thick bedded and contains large-scale cross bedding. It is white to light gray, fine grained, well sorted, quartz arenite that grades upward into thinner beds, laminated and rippled bedding. Overlying the sandstone is dark gray shale that locally contains thin coal and casts of *Lepidodendron*. The lower Degonia sandstone is well exposed as numerous hogbacks and slump blocks along Hutchins Creek near the northwest corner of the county, and it also forms a small escarpment near Cobden. A roadcut along U.S. Highway 51 east of Cobden provides the most easily accessed exposure.

Sedimentary sequences in the Degonia are variable. In some places sandstone fines upward from an erosional base, but in other areas basal shales or siltstones coarsen upward to thick bedded sandstone. In the northwestern part of Union County, ripple-laminated shaly sandstone grades upward to cross bedded sandstone. This in turn grades into sandstone that yields dewatering features or soft-sediment slump structures near the top.

Where the lower Degonia sandstone is best developed, its lower contact is erosive, locally incised through the Ford Station Member of the Clore Formation and into the Tygett Member (Jacobson and Weibel 1993).
The upper part of the Degonia is complex laterally, because some areas yield marine fossils within a sandstone in the highly faulted area in northwestern Cobden and northeastern Wolf Lake Quadrangles (polygons marked Mpu on the map). This fossiliferous facies continues north in Jackson County (Seid et al. 2009, Larson 2012). The fauna is found as molds and casts in the sandstone, including arthropods, brachiopods, bryozoans, and mollusks. The arthropod is a burrowing barnacle called *Acrothoracica* sp. The brachiopods are typical Elviran species that include *Diaphragmus nivosus, Composita subquadrata, Anthracospirifer,* and *Orthotetes kaskaskiensis.* Fenestrate and trepostome bryozoans were also found, as well as a diverse mollusk fauna including the bivalves, *Wilkingia walkeri, Edmondia, Aviculopecten winchelli, Promytilus illinoisensis, Myalina, Septimyalina, Sphenotus monroensis,* and *Myalinella meeki.* Also collected from the marine zone of the Degonia were the cephalopods *Endolobus, Liroceras, Metacoceras, Domatoceras,* and *Reticycloceras.* This list of marine fossils strongly supports other sedimentological reports of tidal influence and herringbone cross bedding in the upper parts of the Degonia.

Throughout Union County, variegated red and green claystone occurs at the top of the Degonia. This paleosol extends through much of the Illinois Basin. Laterally in areas where the marine zone is not present the paleosol tends to be thicker. The claystone is non-calcareous, green, olive, red, and purple. Also, laterally thin coal beds are associated with the claystone interval.

The contact to the overlying Kinkaid Limestone is sharp but apparently conformable.

**Kinkaid Limestone** is named for Kinkaid Creek in Jackson County, Illinois (S. Weller 1920). The Kinkaid is mainly composed of limestone, with lesser amounts of shale and claystone. Three members were named by Swann (1963); from bottom to top they are the Negli Creek, Cave Hill, and Goreville Members. Exposures of the Kinkaid occur in drainages along a west by northwest belt just below the Pennsylvanian escarpment. The Kinkaid also occurs in areas mapped as Mpu (upper Pope Group undivided) in the northwestern corner of Union County map. The formations that are affected by structural deformation in the northwestern part of the county include Palestine through Grove Church Formations.

The basal **Negli Creek Member** is consistently between 25 to 30 feet thick, where it is not truncated by sub-Pennsylvanian erosion. The limestone is brownish gray to dark bluish gray on fresh surfaces, weathering with dull yellow or orange mottling. Argillaceous lime mudstone prevails, with fossil wackestone and to a lesser extent fossil packstone subordinate. The upper part of the Negli Creek is lighter gray, and coarser grained limestone. It can be a coarse crinoidal grainstone or locally an oölitic grainstone at the top of the member.

An ecological epibole occurs in the Negli Creek. The diagnostic fossils are *Girvanella* oncoids (filamentous algae), large bellerophontid gastropods, and the demosponge *Chaetetella* sp. These three are found together across the basin in Kentucky, Indiana, and Illinois. This is overlain by a dark gray shale that contains large numbers of *Pterotocrinus tridecibrachiatus.*

As shown by core drilling and quarry exposures in nearby Johnson County, the **Cave Hill Member** is further divisible into three sub-units. The lower part is greenish to bluish gray shale that is soft, fissile, calcareous, and fossiliferous. Fenestrate bryozoans, brachiopods, pelcypods, gastropods, and pelmatozoan fragments are abundant. Most notably, the diagnostic crinoid "wing" plate *Pterotocrinus tridecibrachiatus,* which is consistently found across the basin in this shale (that occurs above the Negli Creek Limestone Member, see plate 1**).** A large number of *Pterotocrinus tridecibrachiatus* have been collected from the roadcut on State Highway 51 near the Sub-Absaroka unconformity, 15 miles south of Carbondale in the Makanda Quadrangle.

The middle part of the Cave Hill is dominantly siliceous, argillaceous, lime mudstone. The rock is medium to dark gray when fresh but weathers olive-gray mottled with dull orange staining. Higher in the Cave Hill are thin beds with dark gray chert nodules and sublithographic lime mudstones that display hour-glass weathering. The chert can be black, vitreous, and occurs in layers. Light gray laminated, rhythmic limestone beds also occur in the middle Cave Hill. Separating beds of limestone are parting, laminae, and thin beds of dark gray shale.

The upper part of the Cave Hill is variegated shale or claystone with green, gray, and red colors. Vertebrate remains have been found in the red claystone in Johnson County (Lombard and Bolt 1999). The contact with the overlying Goreville Limestone Member is sharp.

The **Goreville Limestone Member** is only known in Union County from core and cuttings from subsurface water well and oil and gas tests, mainly in the northeastern part of the county. Excellent exposures occur in the Illinois Stone Quarry at nearby Buncombe in Johnson County. The Goreville consists of tan to gray coarse crinoidal grainstone that can be oölitic in places. Where not truncated by pre-Pennsylvanian erosion, this unit is typically 45 to 50 feet thick. Where it occurs at the surface in Johnson County, the Goreville contains an epibole of exceptionally large *Archimedes* that is observed across the basin. Conditions at this time favored filter feeders, resulting in another population burst and brief proliferation. This proliferation event took place near the top of the Goreville Limestone.

The contact with the overlying Grove Church Shale is disconformable and sharp. A hiatus is indicated by a missing conodont zone between the Goreville Limestone Member and the overlying Grove Church Shale (Weibel and Norby 1992).

**Grove Church Shale** takes its name from Cedar Grove Church in Johnson County, Illinois (Swann 1963). This unit is poorly exposed, non-resistant, and is confined to the interfluves between Pennsylvanian paleo-valleys. Maximum known thickness is Union County is about 18 feet in core CB-1, Section 5, T11S, R2W, in the Cobden Quadrangle. As seen here and elsewhere, the Grove Church is largely greenish gray shale in the lower part and becomes dark red in the upper part. Limestone occurs in thin interbeds as fossil wackestones and packstones. Some of the limestones are medium gray and nodular. The “wing” plate *Pterotocrinus pegasus* has only been found in the Grove Church Shale (Devera and Tobinski 2016). The contact is a major sequence boundary, the sub-Absaroka unconformity.

**Upper Pope Group undivided**

The Palestine, Clore, Degonia, Kinkaid, and Grove Church formations were mapped as a single unit labeled Mpu in a large area of northwestern Union County, north and northwest of Alto Pass. These strata are tilted and faulted here so that individual formations cannot be resolved even at 1:24,000 scale. These upper Pope Group units are sandwiched between unfaulted and horizontal Menard Limestone below and nearly horizontal Caseyville Formation above. Causes of this unusual deformation will be covered in more detail in the Structural Geology Section of this text.

**Mississippian – Pennsylvanian boundary**

A major unconformity and sequence boundary occurs between Mississippian and Pennsylvanian Subsystems of the Carboniferous System. The so-called sub-Absaroka unconformity is present throughout the Illinois Basin and on surrounding domes and arches. A good exposure can be examined on U.S. Highway 51 about 15 miles south of Carbondale, where a roadcut exposes the Cave Hill Member of the Kinkaid Limestone overlain directly by the Pennsylvanian Caseyville Formation as a passive fill over a paleo-topographic high. Thus, the Grove Church Shale, Goreville Limestone Member, and the upper part of the Cave Hill Member of the Kinkaid were eroded here before the Caseyville was deposited.

Across an area about 2 miles wide just west of Alto Pass, the contact between the Caseyville Formation and the Pope Group is an angular unconformity. The Caseyville truncates the Kinkaid, Degonia, Clore, and Palestine formations to rest directly on the Menard Limestone (Devera and Nelson 1995). Uplift along the closely adjacent Ste. Genevieve Fault Zone probably created the angular discordance. Angular contacts occur at many other localities in the northwestern Cobden and Wolf Lake quadrangles (Devera 1993), where horizontal Caseyville truncates tilted and faulted blocks of the upper Pope Group. These structures will be discussed more thoroughly in a later chapter under the heading of Wolf Lake Fault Zone.

**Pennsylvanian Subsystem of the Carboniferous System**

**Caseyville Formation** is named for Caseyville, Union County, Kentucky (Owen 1856). The Caseyville Formation is composed of quartz-rich sandstone, gray shale and siltstone, lenses of conglomerate, thin beds of coal, non-fissile claystone, and rare limestone. It is distinguished from the Pope Group by coarser grain size (up to small pebbles in sandstone) and the rarity of limestone and marine invertebrate fossils. The Caseyville differs from the Tradewater and younger Pennsylvanian formations in that Caseyville sandstone is dominantly quartz arenite, in contrast with sublitharenite and lithic arenite found in younger units (Nelson 1989).

Thickness of the Caseyville varies substantially across southern Illinois. The formation ranges from 200 to 500 feet thick in Hardin County 200 to 450 feet in Pope County 150 to 400 feet in Johnson County, and 150 to 300 feet in Union County. Much of the thickness variation relates to the highly irregular sub-Pennsylvanian erosion surface. The Caseyville thickens into paleovalleys and thins across interfluves. Also, tectonic activity during Caseyville sedimentation may have caused thickness changes in Johnson County (Nelson and Devera, in press).

In Hardin, Pope, and Johnson Counties, the Caseyville Formation contains two thick sandstone members that form widely continuous escarpments. These are the Battery Rock Sandstone Member (older) and the Pounds Sandstone Member at the top of the Caseyville. The succession of shale, siltstone, and largely thin-bedded sandstone beneath the Battery Rock Sandstone is named the Wayside Member. Entering Union County on the east, the three members are prominently exposed in highway cuts along Interstate 57 between the Goreville and Lick Creek interchanges (fig. 10) . The Caseyville is about 305 feet thick in these roadcuts and thickens further to about 400 feet in the Johnson County portion of the Lick Creek quadrangle (Weibel and Nelson 1993). Continuing west of the highway, the Pounds and Battery Rock Members both pinch out, and the Caseyville becomes mostly thin-bedded strata except for a basal sandstone informally named the Keller sandstone lentil. A few miles farther west in the Makanda quadrangle, the Caseyville thins to less than 200 feet and the Keller sandstone is discontinu-

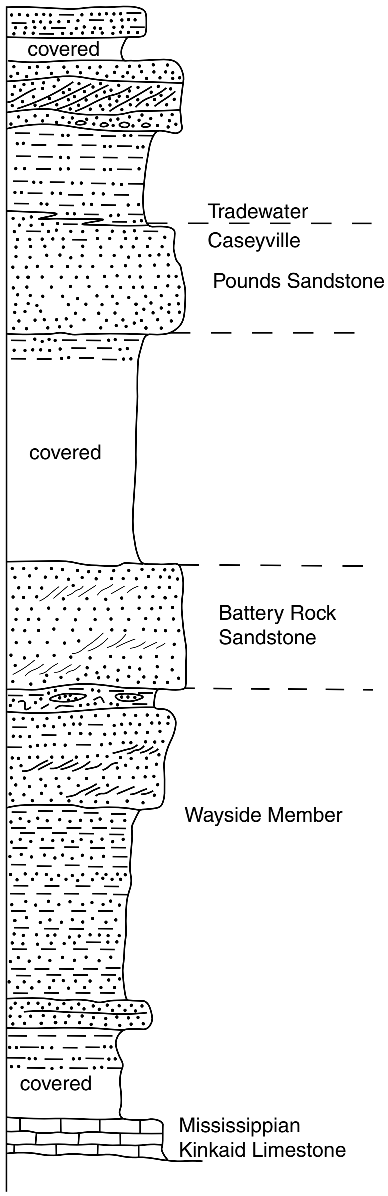



**Figure 10** Stratigraphic column of the Caseyville Fm at I-57.

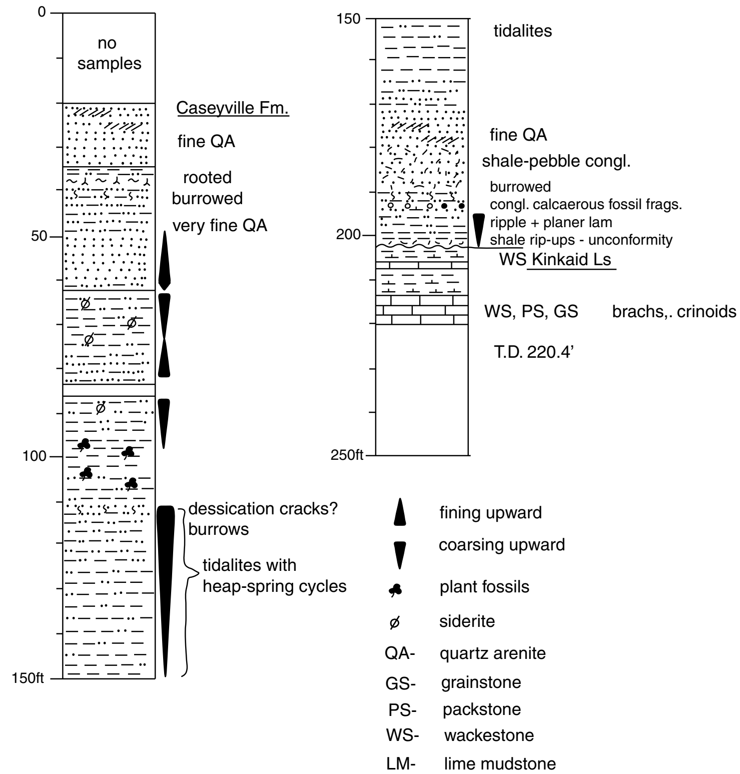



**Figure 11** Caseyville Core M-1; section 7, T. 115., R. 1W, Union County, Makanda Quadrangle; graphic log by John Nelson.

ously present (Jacobson and Weibel 1993). A core from the Makanda quadrangle (fig. 11) illustrates the character of the Caseyville in this area.

Absence of the Pounds Sandstone or a correlative marker unit in the western Lick Creek and eastern Makanda quadrangles created a problem in delineating the Caseyville-Tradewater contact. The map authors elected to leave the two formations undifferentiated and drew "scratch boundaries" to separate undivided Raccoon Creek Group from areas where Caseyville and Tradewater were mapped separately. During the winter of 2020-2021 we remapped the problem area, paying special attention to character of the sandstones. In so doing, we were able to distinguish quartz arenites of typical Caseyville aspect underlying micaceous sublitharenite characteristic of the Tradewater Formation. The contact is not abrupt, but generally can be placed within 20 to 30 feet vertically, more than adequate for our published map scale of 1:48,000.

Continuing westward into the Cobden quadrangle, the Caseyville becomes thicker and sandstone again becomes more prominent, although neither Pounds nor Battery Rock Sandstones were mapped. Cliffs east of Alto Pass display the sandstone very well (photo 12). Maximum thickness of about 300 feet occurs in an area where the Caseyville fills a paleovalley incised through the entire Kinkaid Limestone into the Degonia Formation. As mentioned above, near Alto Pass the Caseyville rests with an angular unconformity on strata as old as the Menard Limestone.

The members of the Caseyville Formation mapped farther east in southern Illinois were identified in only a small area of eastern Union County. Elsewhere in Union County, the Caseyville is comprised of one to three crossbedded bluff-forming sandstones that are between 10 to 80 feet thick, separated by intervals of thinly bedded, fine-grained clastic rocks. The different lithofacies that make-up the unit will be discussed below.

Locally at the base of the Caseyville is a significant **chert-pebble conglomerate**. It is an intermittent lithology that

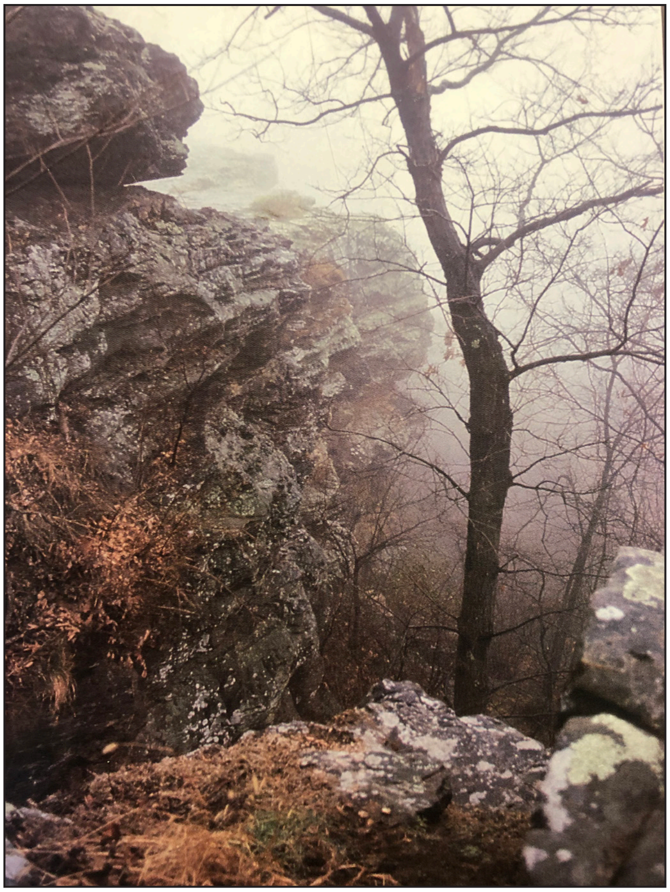


**Photo 12** Caseyville outcrop at Alto Pass showing the escarpment.

occurs in the study area and has been documented elsewhere in the Altenberg, Gorham, and Pomona quardangles to the north, as well as the Glendale Quadrangle in Johnson County to the east. The chert clasts are subangular to rounded and range up to about 3 inches in diameter. Chert is white to light gray and can weather from vitreous to dull and show brown, yellow, and red staining. Some chert clasts contain fossils, including crinoid stems, bryozoan and solitary rugose corals reworked from older formations. In the study area, fossils observed within the chert clasts were found to be Chesterian. However, in other areas such as the Pomona quadrangle, Desborough (1961b) described conglomerate with clasts as old as Silurian. R.S. Poor (1925) also described fossils in the chert clasts being Mississippian through Silurian, indicating derivation from the Ozark Dome southwest of the Ste. Genevieve Fault Zone. Other clasts are ironstone concretions, shale, siltstone, and coal in a fine sandstone matrix that is weakly cemented with brown iron oxide cement. Milky white, well rounded, quartz pebbles are also common to this conglomerate. Thickness is typically a few feet to 15 feet; the unit is highly lenticular. A good exposure occurs in a north- to west-trending ravine, just east of the center of Section 6, T11S, R1W, in the Cobden Quadrangle. Here, the conglomerate rests with an angular unconformity on the upper Pope Group undivided (Mpu on the map).

Above the basal conglomerate is a cliff-forming, **crossbedded sandstone** that can be traced laterally for thousands of feet to several miles. One such informally named sandstone unit is the Keller sandstone lentil of Jacobson and Weibel (1993). These sandstone lithologies are all similar: white to light gray, fine to coarse-grained, poorly to well-sorted quartz arenites. A common component is milky white, well rounded, translucent quartz pebbles. The sandstone contains very little or no clay matrix and varies from friable to well-cemented with silica cement and liesagang (iron oxide) bands. Most of the crossbeds range between a few inches to 4 feet thick and dip toward the southwest. Also, tabular planar crossbeds occur as top set or bottom set beds. Other primary sedimentary structures include current ripple marks, interference ripples, linguloid ripples, and soft-sediment deformation, probably due to de-watering before lithification.

Some of the crossbedded sandstones show fault control near the northwestern corner of Union County. The best example is the sandstone body that runs northward from the NE 1/4 of Section 8, T11S, R2W to the north edge of the Cobden Quadrangle. Along its eastern margin, the sandstone body thins from 70 feet to zero within a horizontal distance of 250 feet. On the west the sandstone thins and grades into shale and siltstone. At Milligan Hill in the northwestern Cobden Quadrangle, the Degonia Formation forms a hogback, striking northwest and dipping 35° to 50° northeast. Basal Caseyville strata truncate the Degonia with an angular unconformity high on the hill. A short distance northeast of this point, thick crossbedded Caseyville sandstone cuts down to a lower elevation, filling a pre-Caseyville valley eroded into the Kinkaid Limestone.

**Shales and thin-bedded sandstone** facies make-up the largest volume of the Caseyville Formation, although good exposures are not common. Good exposures occur in ravines in the Cave Creek drainage, along streams west and south of Cedar Lake, and along Drury Creek in Giant City State Park. Interbedded siltstone or fine-grained sandstone and shale contain current ripples and interference ripples with tool marks and load casts. Fossil plants are common, including *Lepidodendron* and *Calamites* impressions as well as carbonaceous plant debris and stigmarian root casts. Dark gray shales have carbonaceous fossils of *Lepidodendron cf. aculeatum, L. mannabachense, Neuropteris* sp., *Pinnularia* rootlets, and *Lepidocarpon,* lycopod leaves. Ichnofossils are also common in the fine-grained sandstones and siltstones. They include *Cochlichnus, Lockeia,* and generalized tubular burrows. In a small ravine in Giant City State Park (NE ¼, Section 3, T11S, R1W), *Nereites (Scalarituba) missouiensis* was found in the upper part of the Caseyville above the Keller sandstone lentil. This trace fossil is known to occur in the *Zoophycos* ichnofacies, which has definite marine connotations. Influxes of marine influences have been seen in other areas of southeastern Illinois where *Conostichus,* a domicile of burrowing sea anemones, also occur in the upper parts of the Caseyville.

The upper part of the Caseyville Formation is composed of interbedded shales, siltstones, and thin- to thick-bedded sandstones. Coal seams as thick as 14 inches crop out in several places in Sections 30 and 31, T10S, R1W. Some coals are bright banded, whereas others are dull and shaly. The coal beds overlie claystone and/or sandstone that contains stigmarian roots. Three coal beds that lie 8 to 40 feet below the top of the Caseyville in the Cobden Quadrangle are equivalent to or slightly younger than the Gentry Coal Bed of southeastern Illinois, based on palynological work of Russel A. Peppers (written communication 1989).

As remarked above, the contact between the Caseyville and Tradewater Formations has been mapped where clean quartz arenite of the Caseyville gives way upward to micaceous lithic arenite or sublitharenite of the Tradewater. Although this contact may be locally erosive, in most places it is gradational though an interval of about 20 to 30 feet.

**Tradewater Formation** was named for the Tradewater River in western Kentucky (Lee 1916). The Tradewater crops out in the northeastern corner of Union County in the Cobden, Makanda, and Lick Creek Quadrangles. Lithologies of the Tradewater are sandstone, siltstone, shale, minor mudstone, and thin coal beds. Sandstone characteristically contains noticeable mica flakes and becomes more micaceous upward. Lithic sand grains also are noticeable, together with clay matrix and rare feldspar grains that have not weathered to clay. Sublitharenites to litharenites of the Tradewater contrast with quartz arenites of the Caseyville. Both formations contain much secondary iron oxide staining and liesagang banding that can obscure primary sedimentary structures. Although small quartz pebbles and granules are present in the Tradewater, they are less abundant than in the Caseyville.

Tradewater outcrops consist predominantly of sandstone that is tan to medium brownish-gray on freshly exposed surfaces and weathers dark gray to brown. The sandstone is mostly fine- to medium- grained but can contain scattered coarse sand quartz grains. Quartz granules are locally present. Shale and siltstone separates ledge-forming sandstone bodies. Bedding in the Tradewater is lenticular and irregular; bed thickness ranges from under an inch to 3 or 4 feet. Tabular planar and wedge planar cross bedding is common.

The most prominent sandstone in the lower Tradewater is the unit that forms the scenic bluffs in Giant City State Park (mostly in Jackson County) and Panther Den Wilderness (SE ¼ of Sec. 3, T11S, R1E, Lick Creek quadrangle). Ranging up to 90 feet thick, the sandstone is dominantly well sorted and fine- to medium-grained, although small quartz granules are widely scattered. Composition approaches quartz arenite, with mica, lithic grains, and interstitial clay sparse. Wedge- and tabular-planar crossbedding is conspicuous, the foreset beds indicating transport toward the south and southwest. Palynology of bracketing coal beds by Russel A. Peppers supports assignment of this sandstone to the Tradewater rather than the Caseyville. Lithology and stratigraphic position suggest correlation with the Grindstaff Sandstone member of the Tradewater in southeastern Illinois (Nelson 2013). At both Giant City and Panther Den the sandstone contains widely spaced vertical joints that extend the entire height of the sandstone cliffs. In many places large blocks of sandstone, outlined by joint faces, have crept down slope, producing the "streets" that gave Giant City its name.

Only the lower part of the Tradewater is present in Union County. Thickness in the subsurface near the northeastern corner of the county approaches 300 feet.

**Cretaceous and Tertiary Systems**

Weakly lithified Cretaceous and Tertiary (T/K) sediments are found in southernmost Illinois (Alexander, Pulaski, and Massac Counties) within the Mississippi Embayment, a northward extension of the Gulf Coastal Plain. The Embayment does not extend into Union County; however, T/K deposits have been mapped on uplands in the county, overlying various units of Paleozoic bedrock. The largest area of T/K lies in the Cypress and Jonesboro Quadrangles and has a northwest trend overlying Lower Mississippian rocks. The same is true for the Iron Mountain area in the Cobden Quadrangle, where the T/K units are confined to a graben. Another area farther west in the Jonesboro and Mill Creek Quadrangles contains the McNairy Formation (Upper Cretaceous) and small outcrops of the Wilcox Formation (Eocene). Smaller outcrop outliers occur in the Jonesboro, Cobden and Wolf Lake Quadrangles. The stratigraphy is poorly known, so, we mapped the Cretaceous and Tertiary as a single undifferentiated unit designated TKu.

Sediments mapped as TKu are largely sand and gravel. The sand is red, orange, and brown, the lower part being micaceous, fine grained, unconsolidated, and laminated in places. Higher in the outlier, the sand is coarse-grained and contains small rounded quartz and chert pebbles. Gravel is angular to well-rounded pebbles and small cobbles that are leached white or gray to black and are partly vitreous. Bedding is indistinct to contorted.

Another Cretaceous outlier, labeled Kmp on the geologic map, trends north in Sections 36, 25, 24, T13S, R2W in the Mill Creek Quadrangle and extends to the Jonesboro Quadrangle in Sections 24, 13, 14, and 11 of the same township and range. Sediments here have been identified as the **Post Creek Formation** overlain by the **McNairy Formation**, both Late Cretaceous age. The Post Creek (formerly called Tuscaloosa) Formation is composed of gravel and conglomerate. The gravel is composed of chalky white, well rounded pebbles and cobbles up to 6 inches in diameter. Chert clasts are commonly tripolitic, suggesting local derivation from Lower Devonian bedrock. The conglomerate is cemented with iron oxide or silica; clasts are similar to above, but include medium gray to black pebbles and cobbles.

The McNairy Formation consists of sand, gravel, silt, clay, sandstone, and conglomerate. The *sand* is multicolored: white, gray, yellow, red, orange, and brown. It is mostly fine grained, but can become medium to coarse grained. The quartz sand is commonly mica-rich and contains lithic fragments and dark minerals such as zircon, magnetite, and rutile in a clay matrix. Some of the fine-grained sand is rhythmically laminated and contains occasional large rounded pebbles, which may be dropstones. The sand is typically unconsolidated, but locally is indurated. Most of the sand can be massive to poorly stratified. The *gravel* is mostly light to medium gray, sub-angular to well-rounded in a sand matrix; occurs in lenses. *Silt* and *clay* of the McNairy are light gray to dark gray and typically occur as irregular pockets and stringers in sand. Also found in the McNairy is a silicified zone, which is believed to be a silcrete or paleosol, because it contains root casts and impressions of plants and petrified wood. Similar silcrete, informally named the Diswood silcrete, is well exposed just to the south in the Tamms Quadrangle in Alexander County (J.A. Devera, unpublished mapping). The *sandstone* of the McNairy also is tightly indurated or silicified, behaving like quartzite and informally called the Commerce quartzite. This rock is white, very fine to medium grained quartz arenite with rounded and frosted grains. The sandstone is cross bedded to massive and contains no fossils. Except for the lack of fossils, the Commerce quartzite resembles the Devonian Dutch Creek Sandstone or the Ordovician St. Peter Sandstone. The Commerce sandstone occurs as large float boulders up to 20 feet in diameter, found as isolated blocks in the Wolf Lake, Jonesboro, and Cobden Quadrangles. A good exposure is along the south side of Old Cape Road in Section 11, T13S, R2W, south of Jonesboro. The *conglomerate* of the McNairy is composed of chert gravel with a quartz matrix and cemented with silica or iron oxide. The upper contact is unconformable with the Wilcox Formation, where present.

In the Cobden Quadrangle deposits of clay, sand, gravel, conglomerate and lignite occur along and within the Iron Mountain Fault Zone. This zone extends from Section 22, T11S, R2W, to the southern edge of the quadrangle. A small mass of conglomerate was mapped north of Bald Knob in the same township. Our descriptions are based on scattered small outcrops and float in the Iron Mountain area, publications by St. Clair (1917a), Parmalee and Schroyer (1922), Lamar (1948), and Nelson and Lumm (1985), and unpublished descriptions made by past ISGS geologists in the clay pits that were active in the early 20th century. All of the clay pits are currently caved or flooded and inaccessible.

As described by the above-named authors, the oldest stratum in the pit was a bluish-white clay that contains some lignite. This was underlain and laterally flanked by sand and lignite (fig. 12). Above the bluish to white clay was a layer of pure white clay. Next upward was pink clay or mottled pink and white plastic clay. Capping the clay pit was red and white sand with clay pockets (Grim 1934). The clays were predominantly composed of kaolinite (Lamar 1948). Lignite at the bottom of the pit occurred as small isolated lenses in various orientations. It probably represented transported plant debris rather than in situ peat deposits (St. Clair 1917a). Spores collected from the lignite for palynological analyses were found to be of Eocene age (Aureal T. Cross 1984 oral communication to J. Nelson; D. J. Nichols, letter to Nelson March 23 1993). The clay also contained scattered nodules or concretions of iron oxide. Overlying some of the pits was a layer of white, pink to purplish-red, fine grained argillaceous sand. A gravel composed of rounded to subangular chert pebbles occurred above all of the pits (fig. 12).

Also as described by contemporary geologists, the clay deposits lay in small, steep-walled depressions in Mississippian limestone. Walls of these depressions were vertical, or nearly so. Lamar (1948) believed many of the depressions were sinkholes. St. Clair (1917a) described an east-west fault, having as much as 15 feet of throw down to the south, in the north wall of the Illinois Kaolin Co. pit in the SW1/4, Section 35, T11S, R2W. The fault displaced clay and sand and was lined with iron oxide. Parmalee and Schroyer (1922) described and illustrated a "sand dome", more than 30 feet wide at the base, on the north wall of the same pit. The borders of the "sand dome" were slickensided and impregnated with iron oxide.

The latest gravel deposited on top of the clay pits consisted of well-rounded to subrounded chert pebbles in a sand matrix. Most pebbles were light gray to dark bluish-gray with a few ochre to dark red; the chert was mostly dense and rarely vesicular. Most of the pebbles were less than 3 inches in diameter, but cobbles as large as 12 inches were present. Small, white rounded quartz pebbles, similar to those of the Caseyville Formation, also were mentioned.

Along the westernmost large fault in the Iron Mountain Fault Zone, we observed gravel heavily cemented with iron oxide. Outcrops of iron-cemented chert breccia and silicified Paleozoic sedimentary rocks also mark the fault trace. Chert breccia along the fault locally grades eastward into conglomerate

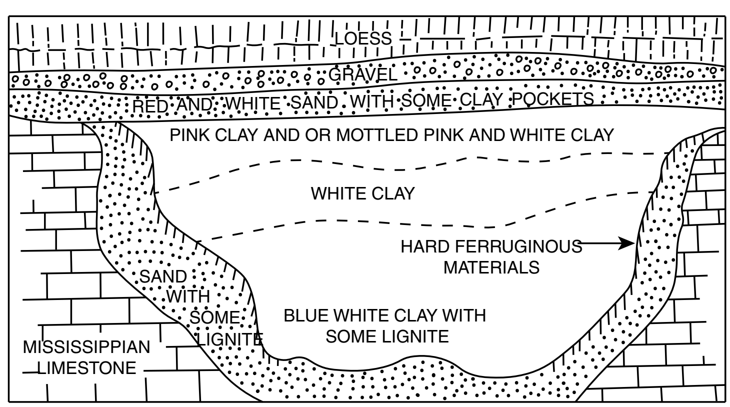



**Figure 12** Generalized sketch of a kaolin clay pit from Grim, 1934

in which angular, fractured chert fragments are intermixed with well-rounded chert pebbles. These exposures of iron-cemented conglomerate probably inspired the name, Iron Mountain.

To summarize, our own observations and those of earlier geologists indicate that clay, gravel, and associated sediments near Iron Mountain lay in sinkholes and/or in grabens along the Iron Mountain Fault Zone. Fossil pollen indicates Eocene age. Apparently, Eocene sediments accumulated in depressions that were formed by dissolution of Mississippian limestone and by contemporaneous movement along faults.

## Structural Geology

The study area straddles the boundary between the Ozark Dome (Ozark Plateaus Province) and the Illinois Basin (Interior Low Plateaus Province) (fig. 1). Regional dips in Union County are typically 1º to 4° northeast into the Illinois Basin. Separating dome and basin is one of the major fault zones of the Midcontinent–the Ste. Genevieve Fault Zone. From its northwest terminus near Sullivan, Missouri, the fault zone extends more than 120 miles into southern Illinois, terminating in Union County (Nelson and Lumm 1985). This zone of faults represents several styles and multi-phase movements or periods of deformation. All of the faults in the study area are considered to be related to the Ste. Genevieve Fault Zone. The Ste. Genevieve Fault Zone consists of numerous faults that will be described under separate headings: (1) master fault zone, (2) Iron Mountain Fault Zone, (3) Clear Creek lineament, (4) Pomona Fault, (5) faults southwest of the master fault, and 6 the Wolf Creek Fault Zone.

**Ste. Genevieve Master Fault Zone**

The master fault zone of the Ste. Genevieve Fault Zone strikes N45°W in the Cobden and Wolf Lake quadrangles. In the Wolf Lake Quadrangle, this master fault zone was called the Rattlesnake Ferry Fault or Fault Zone by earlier workers. This name refers to a long-ago ferry across the Big Muddy River at the northern edge of the Wolf Lake quadrangle (Sec. 27, T10S, R3W, Jackson County). The rattlesnakes that inspired the name for the ferry are still abundant in the area, especially during spring and fall, emerging from their dens along the bluffs.

From Missouri, the master fault enters Illinois just north of Grand Tower, separating Devonian rocks at Grand Tower from Pennsylvanian on Fountain Bluff to the northeast. After following an eastward course beneath Mississippi River alluvium, the fault enters the rock bluffs at Rattlesnake Ferry and assumes a southeastward course. Nelson and Lumm (1985) observed vertical to steeply overturned bedding on Chesterian strata adjacent to the fault zone, which is expressed as a zone of mineralized breccia. The presence of overturned bedding and a broad northeast-facing monocline or fault-propagation fold is indicative of high-angle reverse faulting. Nelson and Lumm estimated 1,200 to 1,400 feet of fault displacement and 1,500 to 1,700 feet of relief attributed to folding. Lower Devonian strata southwest of the fault zone are juxtaposed with Upper Mississippian rocks on the downthrown northeastern side. In Missouri are several clean exposures of the Ste. Genevieve master fault showing it to be a high-angle reverse fault (Flint 1925 and 1926, Gibbons 1974, Nelson and Lumm 1985).

Between Rattlesnake Ferry and Bald Knob, the master fault follows a nearly linear course, but is entirely concealed by surficial sediments. Bedding dips do not exceed 25º southwest of the fault or 45º on the northeast side. The Lower Devonian Clear Creek Formation is faulted against lower Chesterian rocks along this segment, indicating a minimum throw of 2,000 feet. We infer that a single high-angle reverse fault or narrow zone of faults exists beneath Quaternary cover.

Close to Bald Knob, the master fault abruptly loses displacement and splits into multiple branches (fig. 13). There is no indication of reverse faulting south of Clear Creek. The structure changes to a fractured monocline that rapidly widens toward the south and southeast, with rapid decrease of maximum dip. Although they do not reflect later detailed surface mapping under STATEMAP, three cross sections by Nelson and Lumm (1985) illustrate the likely subsurface configuration of the Ste. Genevieve Fault Zone near its southeastern terminus in Union County (fig. 14 on next page). At section B-B', through Bald Knob, a single reverse fault cuts along the hinge line of an earlier fault-propagation fold. Just south of Clear Creek in section C-C', the reverse fault continues at depth but does not reach the surface. Farther south at Iron Mountain, section D-D', the deep-seated reverse fault is dying out. We now consider unlikely the fault steepening with depth, as shown.

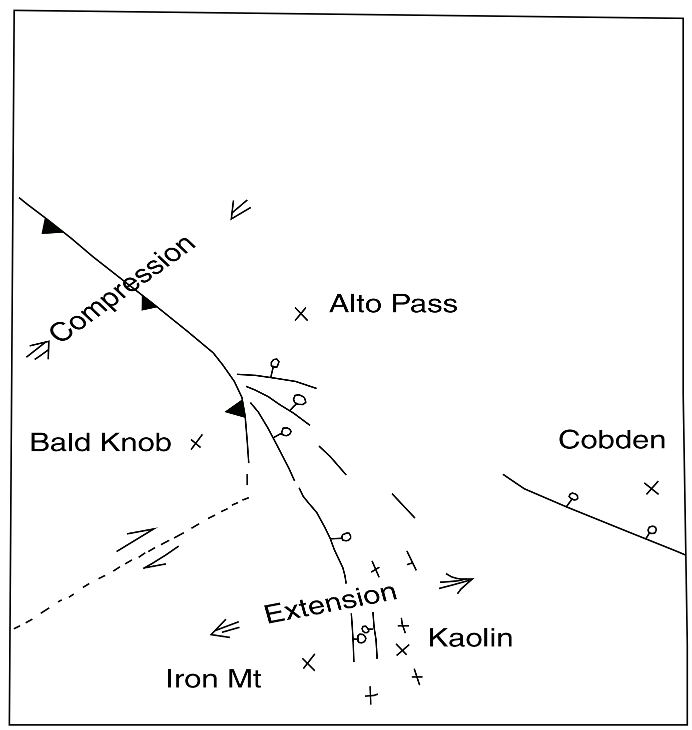
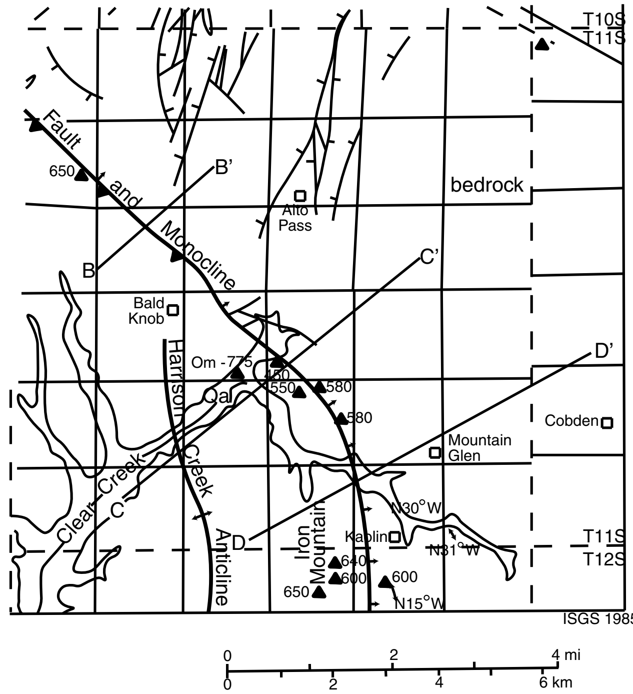
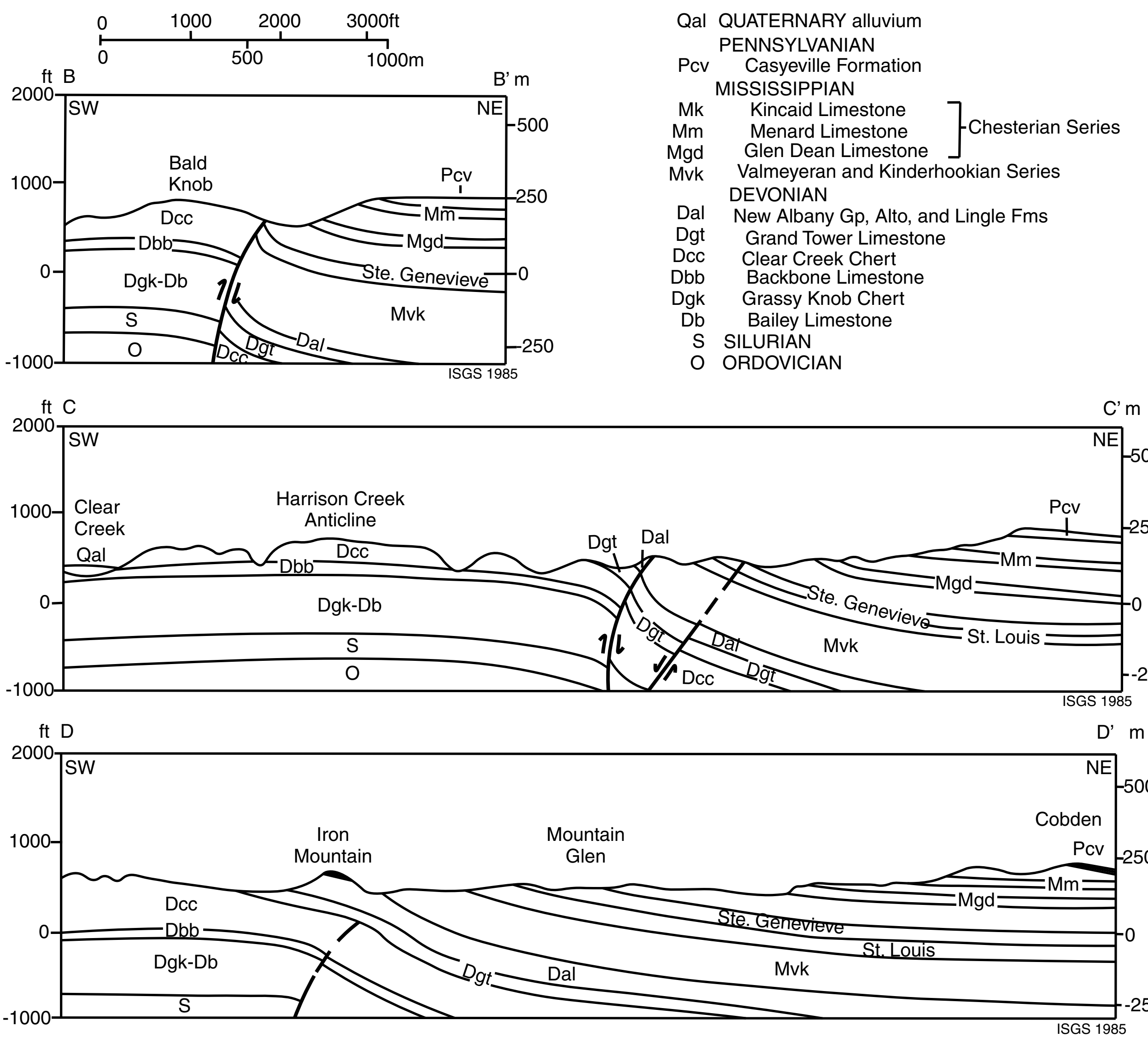



**Figure 13** A possible explanation of "bottleneck." A right-lateral fault in inferred in the linear valley of Clear Creek. The Bald Knob block moved NE, overriding the Alto Pass block along the St. Genevieve reverse fault. At the same time, the Iron Mt. Block moved SW and the southern area underwent extension, creating vertival faults and open joints.

**Figure 14** Three cross sections from Nelson and Lamm (1985) depict likely deep structure of Ste. Genevieve Fault Zone at its southeastern terminus in Union County.




| | |
|---|---|
| Qal | QUATERNARY alluvium |
| | PENNSYLVANIAN |
| Pcv | Casyeville Formation |
| | MISSISSIPPIAN |
| Mk | Kincaid Limestone (Chesterian Series) |
| Mm | Menard Limestone (Chesterian Series) |
| Mgd | Glen Dean Limestone (Chesterian Series) |
| Mvk | Valmeyeran and Kinderhookian Series |
| | DEVONIAN |
| Dal | New Albany Gp, Alto, and Lingle Fms |
| Dgt | Grand Tower Limestone |
| Dcc | Clear Creek Chert |
| Dbb | Backbone Limestone |
| Dgk | Grassy Knob Chert |
| Db | Bailey Limestone |
| S | SILURIAN |
| O | ORDOVICIAN |

The master fault zone is a product of late Paleozoic compression with the principal stress axis oriented NE-SW. Chesterian rocks are strongly deformed, while Pennsylvanian and younger rocks are not known to be involved. Several lines of evidence indicate major deformation took place in the Morrowan (Early Pennsylvanian) prior to the deposition of the Caseyville Formation. Evidence includes: basal Pennsylvanian conglomerates contain chert clasts derived from the Ozark Dome (Poor 1925), paleocurrent trends in the Caseyville Formation change near the Ste. Genevieve Fault Zone (Desborough 1961a), angular unconformity between the Pope Group and Caseyville Formation (Nelson and Lumm 1985, Devera and Nelson 1995), and angular unconformities within the Caseyville Formation in the Pomona Quadrangle (Desborough 1961b). The southern extension of the master fault zone becomes the Iron Mountain Fault Zone, discussed below.

**Iron Mountain Fault Zone**

Devera and Nelson (1995) mapped and named the Iron Mountain Fault Zone, which was unknown to earlier authors. It is composed of a series of nearly vertical faults that outline grabens in which Cretaceous and Tertiary sediments are dropped downward against Paleozoic strata. Devera and Nelson (1995) observed abundant calcite-filled vertical joints in Mississippian and Devonian limestone subparallel to the Iron Mountain Fault Zone.  The grabens of the Iron Mountain Fault Zone may reflect a pull-apart structure produced by right-lateral or left-lateral stresses (Clendenin et al. 1989, Schultz et al. 1992, Devera and Nelson 1995).

As an aside, two archaeologically significant cherts were mined by Native Americans prior to white settlement along the Iron Mountain Fault Zone and distributed throughout the Midwest. The Cobden Chert (St. Louis Limestone) and the Kaolin Chert (Ft. Payne Limestone) were altered due to the combination of tectonic activity and later hydrothermal activity, producing a denser, waxy, better-flaking, and more superior chert than found at other locations where these formations outcrop.

The largest fault is the one at the west edge of the Iron Mountain Fault Zone. Outcrops of limonitic breccia, which contain water-worn Eocene (?) chert pebbles in addition to angular, shattered chert fragments, mark the fault trace. Devonian bedrock near the fault is leached and silicified in the SW ¼ of Section 22, T11S, R2W. The large western fault places formations from St. Laurent (Middle Devonian) through the Fort Payne (Mississippian) on the west, in contact with Cretaceous and Eocene gravel, sand, and clay on the east. The fault plane is not cleanly exposed, but on the bluff southwest of Clear Creek it appears to dip vertically or nearly so, and Eocene (?) conglomerate east of the fault dips 50-60° northeast. Figure 15 shows a more detailed cross section of the Iron Mountain Fault Zone. Other faults in the Iron Mountain Fault Zone strike parallel with the large western fault. They are not exposed but are inferred along linear contacts between the Ullin and Salem Limestones (Mississippian) on the east and Cretaceous and Eocene deposits on the west. Some of these faults formerly were exposed in clay pits near the village of Kaolin (St. Clair 1917a, Parmelee and Schroyer 1922, Lamar 1948) and were described as being vertical or nearly so. St. Clair also described a cross fault that ran east-west and had a throw of 15 feet down to the south in the large pit just northwest of the deserted community of Kaolin.

The graben structure and presence of wide, mineralized fractures indicates that the Iron Mountain Fault Zone formed under extensional stress oriented ENE-WSW. The time of faulting was post-Eocene.

**Clear Creek lineament**

The wide, linear valley of Clear Creek south of Bald Knob is a striking topographic feature. This valley is perpendicular to the Ste. Genevieve Fault Zone and it terminates at the fault zone. Structure of the fault zone abruptly changes across the valley. Northwest of Clear Creek, a monocline less than 1/2 mile wide accompanies a large high-angle reverse fault (fig. 13). Southeast of Clear Creek, the monocline widens to more than 2 miles and the style of faulting switches from reverse (compressional) to extensional or pull-apart, as shown by the Iron Mountain Fault Zone. Moreover, the Clear Creek Formation northwest of the Clear Creek lineament is completely silicified. In contrast, considerable limestone remains southeast of the lineament. Ridges northwest of the lineament run mostly north-south, while those southeast of the lineament trend NE-SW (parallel to the lineament). Anomalous samples were recovered from a well drilled along the lineament. Pure crystalline quartz was found at the expected position of the Kimmswick Limestone (Middle Ordovician) in the Smith #1 Hines well (SW SE, Section 21, T11S, R2W). All of these features and conditions imply that the Clear Creek lineament represents a tectonic fault or fracture zone concealed by Quaternary alluvium. In light of findings by Berg and Masters (1994), silicified bedrock in southernmost Illinois is of hydrothermal origin, suggested by crystalline quartz in the Hines well. Faults commonly serve as conduits for hydrothermal solutions. If the lineament is a fault zone, the net displacement is small; no offsets of formations across the lineament can be documented.

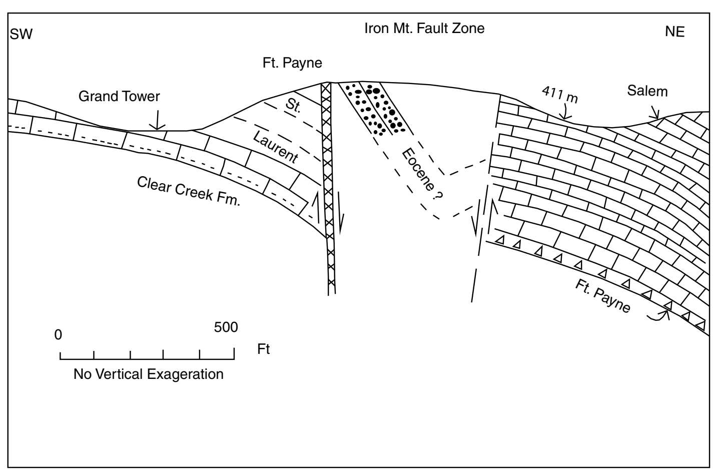



**Figure 15** Cross Section of the Iron Mountain Fault Zone

## Pomona Fault

The Pomona Fault crosses the northeastern part of the Cobden Quadrangle on a heading of N55°W, continuing across southern Jackson County. This structure was first mapped and named by Desborough (1961b) in the adjacent Pomona Quadrangle to the north and confirmed through subsequent investigations by Nelson and Lumm (1985) and Seid et al. (2007, 2009). This fault barely enters northern Union County, dying out in Section 6, T11S, R1W. Southeastern termination of the Pomona Fault coincides with the break-up and splaying of the Ste. Genevieve Fault Zone about 4 miles due southwest. Both the Pomona and the Ste. Genevieve played key roles in the formation of the Wolf Creek Fault Zone, discussed later in this text.

The Pomona Fault offsets Mississippian strata, but Pennsylvanian rocks are merely folded. Faulting is evident in the NE ¼ of Section 35, T10S, R2W, where the Degonia Formation on the southwest is juxtaposed with the Kinkaid Limestone on the northeast. The fault surface is not exposed; however, silicified, fractured, and slickensided sandstone indicate its presence. In this same area, the Caseyville Formation is not faulted, dipping uniformly northeast at 8° to 12°. Similar relationships were observed in the Pomona Quadrangle by Nelson and Lumm (1985) and Seid et al. (2007). Our findings contradict those of Desborough (1961b), who showed the fault displacing both Mississippian and Pennsylvanian units.

Jointing is strongly developed in both Mississippian and Pennsylvanian rocks along the Pomona Fault. One set of joints trends ENE and the other trends NNW. Johnson (1970) observed the same joint pattern as we did and interpreted it as a conjugate system produced by compressive stress oriented N40°E. Such a stress orientation implies that the Pomona Fault is a reverse fault.

We propose that displacement along the Pomona Fault was largely post-Kinkaid and pre-Caseyville–that is, latest Chesterian to early Morrowan. Additional Morrowan or post-Morrowan deformation folded and fractured but did not offset the Caseyville Formation. An alternative explanation would be that all the movement was post-Morrowan and that a reverse fault in Mississippian rocks dies upward into a fault-propagation monocline in Pennsylvanian rocks. However, it seems unlikely that the thick sandstones of the Caseyville would undergo ductile deformation unless they were still incompletely lithified.

Borehole data suggest an earlier period of activity on the Pomona Fault. Northeast of the fault (and north of the study area), deep wells show the New Albany Shale (Upper Devonian) directly overlying the Clear Creek Formation or older Lower Devonian units (fig. 16). Southwest of the fault, a complete Middle and Upper Devonian succession is shown by logs of the Lambert # 1 Hagler hole (Section 28, T10S, R2W). Uplift of the block northeast of the Pomona Fault during Middle to Late Devonian time is signified. The Pomona Fault is in line with a fault in Missouri, along which the northeastern block rose in late Middle to Late Devonian time (S. Weller and St. Clair 1928, Nelson and Lumm 1985, Nelson 1995).

In summary, the Pomona Fault probably was active in Middle to Late Devonian time as a normal fault with the southwest side downthrown. It was reactivated as a reverse fault, southwest block upthrown, after deposition of the Kinkaid Limestone (late Chesterian) but prior to Caseyville (Morrowan) sedimentation. Additional post-Caseyville uplift of the southwest block warped and fractured but did not offset the Caseyville Formation.

## Faults southwest of the master fault zone

A number of parallel to subparallel normal faults occur in the Wolf Lake Quadrangle in T11S, R3W, west and southwest of the master fault zone, in the northern Hutchins Creek area (Devera 1993). Offsets on these faults range from a few tens of feet to about 100 feet. The larger offsets are closer to the master fault, where the smaller faults strike parallel to the master fault. These faults juxtapose Grassy Knob Chert to the west with Clear Creek Chert on the east, which removes the Backbone Limestone from the surface section. The throw on the fault that places Grassy Knob Chert next to Clear Creek is approximately 100 feet. An antithetic fault was observed in SW¼, Section 1, T11S, R3W, juxtaposing the upper Backbone on the east side with Clear Creek on the west. The throw is minor, only 10 to 20 feet. Many of the southwest-flowing streams in the Wolf Lake Quadrangle are wide linear streams where faults are suspected, and stratigraphic offsets are observed where the Backbone is present as a limestone. However, where the Backbone Limestone is silicified, in the southern portion of the Wolf Lake Quadrangle, it is not possible to use the Backbone as a marker. The silicification may be related to hydrothermal activity from

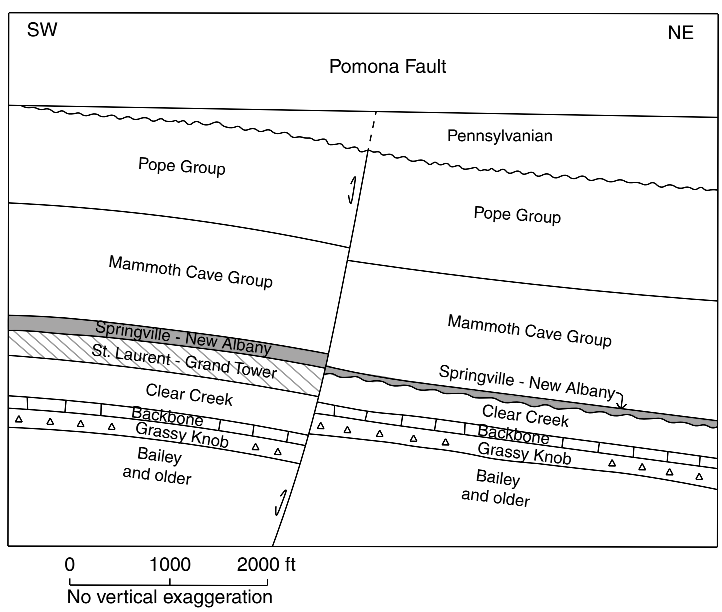



**Figure 16** Cross Section of the Pomona Fault

a deep igneous intrusion imaged by the Wolf Lake gravity anomaly, discussed by Berg and Masters (1994).

**Wolf Creek Fault Zone**
An important series of small faults lies between the Ste. Genevieve Fault Zone and the Pomona Fault in the northwestern corner of Union County and southern Jackson County, as seen on the geologic map. St. Clair (1917b) was the first to observe these faults and determined that they are largely of post-Kinkaid, pre-Caseyville age. Subsequent geologic mapping (Desborough 1961b, Nelson and Lumm 1985, Devera and Nelson 1995, Seid et al. 2007 and 2009) added many details and invoked several models of fault origins.

Where the polygons are labeled, Mpu for upper Pope Group (Palestine – Grove Church) is an area that was tectonically active at the end of the Mississippian Period or Early Pennsylvanian Period, during the period of erosion and formation of the sub-Absaroka Unconformity. Faulting in this area is called the Wolf Creek Fault Zone (Seid 2013). Strata above the Menard Limestone and below the Caseyville Formation are structurally tilted; both the Menard and Caseyville are horizontal. Nearly all of the observed faults are normal faults, and there are indications that they are listric, flattening with depth and merging with bedding in soft, ductile upper shale member of the Menard Limestone. Small thrust faults have been observed just above this surface. Tilted Chesterian rocks lie on the downthrown sides of faults and dip toward the faults, a geometry consistent with rotational slumping. Healed fractures in sandstone suggest that faulting took place before the sediments were fully lithified.

This fault zone is complex, dominantly an *en échelon* array of NNW to NNE trending normal faults that occurs between the Ste. Genevieve and Pomona fault systems. Lacking a clearly developed model of origin, Nelson and Lumm (1985, p. 55) wrote, “At least some of the structures described above may have originated by slumping of unconsolidated sediments, but we propose that such slumping may have been triggered by tectonic movements.” Nelson and Devera (1995) invoked “rotational slumping or landsliding that took place in response to tectonic and seismic activity along the Ste. Genevieve Fault Zone.” More explicitly, Seid (2013) concluded that the Wolf Creek Fault Zone is a consequence of “transpression at a restraining bend followed by transextension at a releasing bend, when the sense of slip of the strike-slip component on the Ste. Genevieve Fault Zone changed left-lateral to right-lateral.”

**Harrison Creek Anticline**
The Harrison Creek Anticline is in the Jonesboro and Mill Creek Quadrangles and was named by Weller and Ekblaw (1940). The anticline has a slightly sinuous axis about 7 miles long and striking slightly east of north. Maximum bedding dips are about 20º on the west limb and 15º on the east limb. At its structural apex, the Maquoketa Formation (Upper Ordovician) is at the surface. Closure is at least 350 feet and total relief may reach 550 feet. Toward the northern extent of the Harrison Creek Anticline, the eastern flank is truncated by the parallel Atwood Fault, a high-angle normal fault. Subparallel to the Atwood Fault to the east is the Cape Road Fault, also a high angle normal fault. An unusually wide zone of brecciation is associated with the Cape Road Fault along much of its length, until it passes into a zone of *en échelon* faults south of Union County (Devera et al. 1994). A continuation of the Harrison Creek Anticline is seen on the west limb in Sections 29 and 20, T12S, R2W, where the normal stratigraphic succession was mapped from the Clear Creek Formation to the Springville Shale. In Section 20 of the same township, a northeast-trending high-angle fault juxtaposes the Grand Tower Limestone (Middle Devonian) with the Springville Shale (Mississippian). The east limb in the northern part of the Harrison Creek Anticline is truncated by an unnamed N 30° W trending fault that displaces Middle Devonian and Mississippian rocks on the south with Lower Devonian rocks to the north.

Similar to the Saratoga Anticline, the Harrison Creek fold is one of several isolated, gentle north-trending upwarps in southwestern Illinois. Relation to other regional structures is unclear. This early symmetrical fold has been interpreted to have formed as a surficial expression of a horst in the underlying Precambrian basement (Nelson and Devera 1994). Gravity surveys conducted by Segar (1965) confirm that a basement high exists.

**Saratoga Anticline**
The Saratoga Anticline in northern Union County is a broad, nearly symmetric, northeastward-plunging anticline having an axial plane that strikes north-northeast and dips to the northwest (Jacobson and Weibel 1993). Both limbs of the anticline have dips of a few degrees, with dips becoming steeper near the nose along the Bradshaw Creek Fault that cuts the eastern limb. The Bradshaw Creek Fault offsets upper Chesterian units together with the Caseyville Formation; its throw is approximately 50 to 60 feet. Salt licks occur along the Bradshaw Creek Fault, which is in line with the Saratoga Springs (named for the more famous resort in New York) to the south. The Shiloh Church fault to the west of the Saratoga Anticline also offsets upper Chesterian units, with throw estimated to be 70 to 80 feet.

As with the Harrison Creek structure, relationship of the subtle Saratoga Anticline to regional tectonics is unclear. Plausible theories include draping across a basement high and response to regional compression that induced reverse faulting along the Ste. Genevieve zone.

**Tectonic Summary**
The Ste. Genevieve Fault Zone is the dominant tectonic feature of Union County. Extending more than 120 miles across southern Illinois and southeastern Missouri, this Zone has undergone at least three episodes of deformation under different stress regimes. The first took place during the Middle Devonian, as evidenced by stratigraphic relations along the Pomona Fault in Illinois and the Ste. Genevieve Fault Zone proper in Ste. Genevieve County, Missouri (S. Weller and St. Clair 1928). This episode involved displacement along high-angle faults, probably normal faults, with throw down to the south and southwest. The second and largest episode took place during middle Carboniferous time (perhaps continuing later), with uplift of the southwestern block along high-angle reverse faults and associated monoclinal fault-propagation folds. Timing and

structural style of this event coincided with the Ancestral Rocky Mountains orogeny. The third tectonic episode took place during early Cenozoic time, producing north- and northwest-trending normal faults such as the Iron Mountain Fault Zone.

Other structures in Union County have uncertain tectonic affinities because they lack definite constraints on kinematics and timing of displacement. North-trending high-angle faults, such as the Cape Road and Atwood Faults, are plausibly related to early Cenozoic extension. The Harrison Creek and Saratoga Anticlines might reflect basement faulting related to Cenozoic extension or an earlier episode of compression.

## Altered and Silicified Rocks

Paleozoic rocks have been extensively altered and silicified in parts of Union County and Alexander County to the south. Carbonate minerals have been dissolved and replaced by various forms of microcrystalline silica, some of which is commercially valuable. Most visibly affected are Devonian and Lower Mississippian rocks in two distinct areas (fig. 17). One area is in northern Union County, bounded by the Ste. Genevieve Fault Zone on the northeast, the Clear Creek lineament on the southeast, and an indefinite border on the west. This area has been named the Wolf Lake district (Berg and Masters 1994). The Lower Devonian Grassy Knob and Clear Creek Formations are entirely silicified in the Wolf Lake area. A larger area of alteration, dubbed the Elco district, extends southward from Jonesboro into Alexander County (fig. 17). The border of the Elco district is marked on the Jonesboro (Nelson and Devera 1994) and Mill Creek (Devera et al. 1994) geologic quadrangle maps. Formations affected here range from the Grassy Knob through the Osagean Ullin Limestone. The western boundary of the Elco district is stratiform in the lower part of the Grassy Knob Formation. The Bailey Limestone is unaffected, as are Cretaceous and Tertiary sediments that overlie altered Paleozoic rocks. Depth of alteration in the Wolf Lake district extends at least locally into Ordovician rocks, as shown by crystalline quartz at the position of the Kimmswick Limestone along the Clear Creek lineament.

A third area of alteration, possibly an extension of the Elco district, is known from core and well cuttings in the vicinity of Olmsted in southern Alexander County. Silicified units extend from the Mississippian Fort Payne Formation, at the bedrock surface, to the Middle Ordovician Plattin Limestone, more than 2,000 feet below the surface in the deepest well in the area (Nelson et al. 2009).

Within areas of alteration, all carbonate minerals have been removed and silica has been concentrated. Strata of cherty carbonate rocks (such as the Grassy Knob, Clear Creek, and Fort Payne Formation) have been converted to bedded and brecciated chert together with softer varieties of microcrystalline silica commonly known as tripoli and gannister. Relatively pure limestone like that of the Grand Tower (Devonian) and Ullin (Mississippian) is almost entirely dissolved, leaving only residual chert and clay. The basal Mississippian Springville Shale has been converted to "calico rock", a hard and dense siliceous rock that is white to light gray banded and blotched with pink, magenta, and orange. Only the black shale of the Upper Devonian New Albany is relatively unaffected.
Structurally, the altered rocks exhibit a wide array of fractures and small faults too small to depict on maps of 1:24,000 and smaller scale. Locally, zones of megabreccia have developed. Larger faults, including the Ste. Genevieve, Clear Creek, and Atwood, outline areas of alteration. Whether the smaller faults and breccia zones are entirely of tectonic origin or partly caused by solution collapse is unclear.

Early geologists, including J.M. Weller (1944) and Lamar (1953), attributed alteration and silicification to deep weathering. Such a mechanism cannot account for the locally sharp lateral boundaries between altered and unaltered rocks or for alteration extending more than 2,000 feet below the ground surface. The alternative hypothesis, which we support, is hydrothermal activity derived from deep igneous intrusions. The silica is not merely insoluble residue of carbonate rocks but rather microcrystalline (and occasionally macrocrystalline) quartz. Most importantly, fluid inclusion studies indicate that silica was precipitated from low salinity

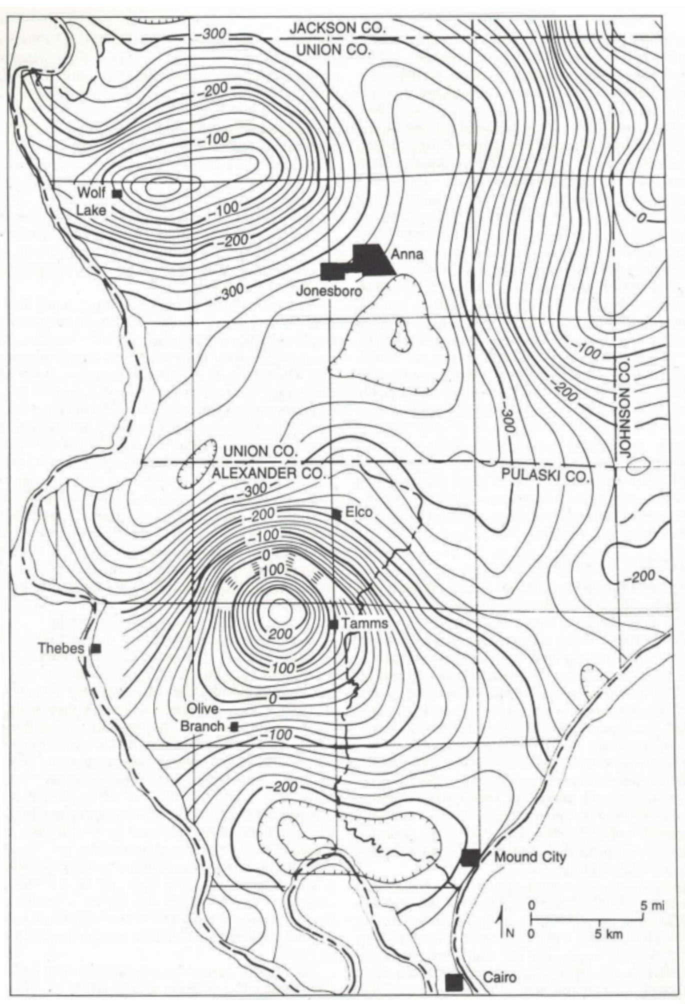



**Figure 17** Gravity map of Wolf Lake and Elco. Residual total magnetic intensity map with contour interal of 20 gammas for southernmost Illinois (modified from plate 1 in Heigold 1976).

fluids at temperatures of about 200º C. Prominent positive magnetic anomalies that likely represent mafic intrusions into Precambrian basement, underlie both the Wolf Lake and Elco silica districts (Berg and Masters 1994).

# Epiboles

Occasionally mentioned in the Stratigraphy section of this text is the term epibole. This concept has been revived and redefined by Brett and Baird (1997) which is equivalent to an abundance zone or deposits accumulated during a *hemera,* a unit of geologic time corresponding to the acme of one or more species (Buckman 1893). Trueman (1923) defined epibole as a time-stratigraphic term to encompass the expression of the hemera in a section or to imply an acme or maximum abundance of a particular species in strata. Event-bed chronostratigraphy has greater resolution of time between biostratigraphic ranges (Brett and Baird 1997). Additionally, they redefine the term epibole to classify different types of epiboles as taphonomic, ecologic, and incursion types (Brett and Baird 1997). Thus, epiboles represent thin intervals from a bedding plane to a few meters and are stratigraphic signature of local to regional biological events.

# Paleontology

Significant fossils found during the years of mapping the quadrangles in Union County include the Middle Devonian trilobite *Dipleura* sp., previously unknown from the St. Laurent (Lingle) Formation of Illinois (photo 4). This finding further reiterates the connection to the Late Middle Devonian Hamilton strata of New York and the Givetian strata of Illinois. The trilobite was found in a north trending ravine in the NE1/4, of Section 34, T11S, R2W of the Cobden Quadrangle.

An important ecological, biostrome epibole of *Acrocyathus proliferum,* the rugosid "finger" coral, is quite helpful in locally and regionally defining the map boundary between the Salem and St. Louis. This colonial coral straddles the boundary between these units. This was particularly helpful in the Jonesboro and Cobden Quadrangles (Devera and Nelson 1994, 1995).

Certain species of *Pterotocrinus* that were found in Union County are important biostratigraphic indicators (fig. 18). Not all pterotocrinids are useful biostratigraphically, though some have been found to be restricted to one or two formations. The most useful types are *P. capitalis* for the Fraileys Shale Member of the Golcanda Formation. Above this *P. menardensis* is known to occur in the shale above the Walche Limestone Member of the Menard Limestone (Tobenski 2011). A morphologically similar species *P. clorensis* is known from the Clore Formation. However, the similarities between *P. menardensis* and *P. clorensis* are too close to distinguish because the Clore type is slightly smaller. Also, Tobinski (2011) reported *P. clorensis* from the Menard Limestone. The authors used both species to define the range from Menard to the Ford Station Limestone Member of the Clore (fig. 18). *P. tridecibrachiatus* occurs in the shale above the Negli Creek Limestone Member of the Kinkaid Formation. Where there is Grove Church Shale, *P. pegasus* occurs below the Dutchman Limestone Member of the Grove Church.

An abundant, diverse, and well-preserved crinoid fauna occurs north and south of a road cut on State Highway 146, in the Golconda Formation about ¼ mile east of Interstate 57 in the Anna Quadrangle. The shaly limestone contains complete calyxes of *Phanocrinus formosus, P. cylindricus, P. bellulus, Zeacrinites wortheni, Taxocrinus, Onychocrinus*, *Dasciocrinus, Ramulocrinus, Rhopocrinus, Aphelecrinus, Fifeocrinus,* and *Pterotocrinus.* The blastoid *Pentremites godoni* was found with pinnules and column articulated. These well-preserved specimens are the result of a taphonomic epibole (obrutionary, i.e., rapid burial) preserved by mud laden tempestites. Delicate pinnules and arms are preserved on some of the specimens in some layers that are mainly composed of shale. These were buried rapidly from distal tempestites. Other layers show thin limestone with disarticulated crinoid debris; these were from proximal tempestites.

# Economic Geology

**Clay**

Clay classified as kaolinite was formerly mined as both open-pit and underground workings west of Cobden in the Mountain Glen and Iron Mountain areas. The mines have been inactive for more than 70 years and are totally inaccessible. The original workings were crude pits made by Native Americans. By 1859 the Kirkpatricks established the Anna Pottery Company and began mining clay near Anna. Their product was a brown clay that was used for making stoneware. A short time later, the Kilpatricks opened a larger quarry east of Iron Mountain, and the village of Kaolin grew up around it. Here the clay is white and composed of kaolinite. Worthen in his 1868 Union County Report located several clay pits in Section 2 of T12S, R2W, straddling the Jonesboro and Cobden Quadrangles. Worthen stated, "A very fine white pipe clay is found, which is used at the pottery in Anna, for the manufacture of common stone-ware, by mixing with a common clay found near the town." Anna Pottery remained in the Kirkpatrick family until 1900. Some of the Kirkpatrick products were plates, crocks, jugs, buckets, roof tiles, stems of tobacco pipes, and pipe bowls. The Kirkpatricks were also known for their unique one-offs, e.g., folk art, including snake jugs, piggy banks, commemorative jugs of the Anna 1884 fair, frog-on-a-shell paper weights, and Modoc Indian face pipes.

Clay mining in Union County peaked during World War I, when imports from Germany were cut off. More detailed information on the clay mines can be found in publications from St. Clair (1917a), Parmelee and Schroyer (1922), and Lamar (1948). These authors suggest that the deposits lay in sinkholes or erosional depressions on the land surface. However, mapping in the Cobden Quadrangle indicates that some of the clay occurs in grabens bounded by faults and may be related to hydrothermal alteration along the faults (Devera and Nelson 1995). The kaolinite occurs as sedimentary de-

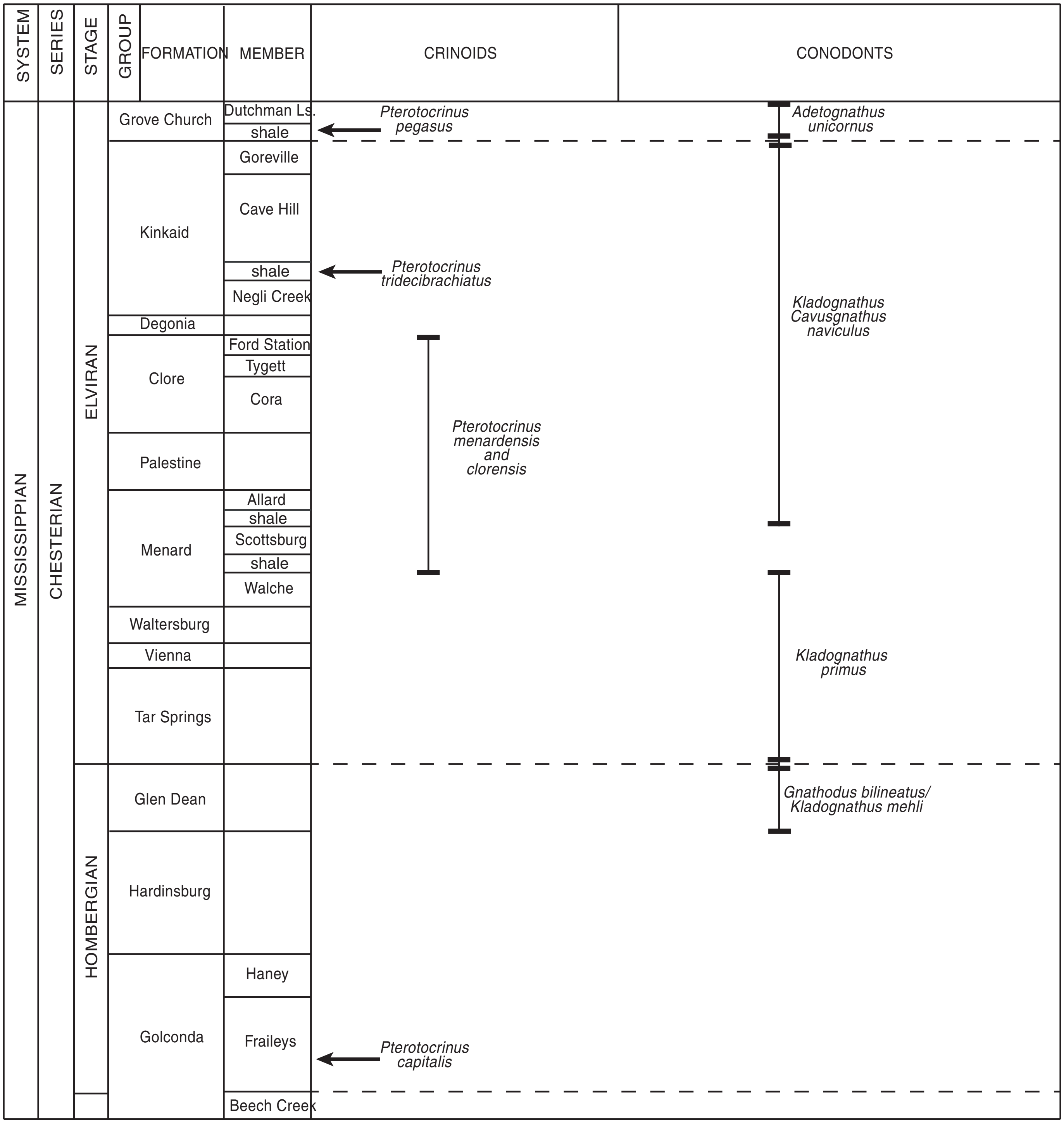



**Figure 18** Pterotocrinus Biostratigraphy in Union County.

posits interlayered with silt, sand, chert gravel and lignite. The lignite was analyzed for fossil pollen and yielded an Eocene age (personal communication Aureal Cross 1984). Most of these clay deposits occupied steep or vertical-walled depressions in the Paleozoic rocks. The thickest clay deposit recorded was 87 feet. On a personal note, the daughter of one of the clay miners said that her father was paid 25 cents an hour in 1927-28 (personal communication from Martha Angell Schwegman).

Additional clay may still exist in the area, as one landowner found more kaolinite on his property as recently as the early 2000s. He was excavating clay with a backhoe north of Mountain Glen Road. Evaluation of reserves will require a thorough core-drilling program, given that the clay occurs in narrow steep fault-bounded or fault-controlled, vertical-walled depressions. A negative factor is that much of the area south of Clear Creek, where the old pits occur, is on Shawnee National Forest property.

**Silica and Chert**

As described in the chapter on altered and silicified rocks, Lower Devonian strata are extensively silicified in parts of the Wolf Lake, Cobden, Jonesboro, and Mill Creek Quadrangles as well as farther south in Alexander County. Silica and chert have been mined, quarried, and extracted from creeks on a small scale in Union County. More extensive mining occurs south of the study area near Elco, Illinois (Berg and Masters 1994).

At least 3 tripoli (microcrystalline silica) mines operated in southeastern Wolf Lake Quadrangle in the early 20th century. Tripoli is derived mainly from the Clear Creek Chert with lesser amounts from the Grassy Knob and Bailey Formations. The largest Tripoli mine in the county was the Wolf Lake Silica Mine, located in the W1/2, NW1/4, NE1/4, Section 2, T12S, R3W, and was active circa 1917-1920. This was a room-and- pillar mine; the silica was used for refractory brick (Berg and Masters 1994). Two adits of the Wolf Lake Silica Mine are still visible. Chert for road gravel and fill is currently being quarried from the upper Bailey to Grassy Knob, east of the village of Wolf Lake, Illinois, in Section 3, T12S, R3W.

A long abandoned open pit silica mine occurs north of the summit of Bald Knob in the Cobden Quadrangle. It contains interbedded chert and tripoli from the upper Clear Creek Chert. Chert gravel was also extracted from stream beds and used for road metal. A gravel screening operation that screened chert gravel from the streams was located south of Alto Pass, on the east side of State Highway 127, and is no longer in operation.

**Limestone**

There are two active limestone quarries in Union County, the Anna and Jonesboro Quarries. The limestone currently mined at Anna Quarry is mainly the St. Louis Limestone. See attached lithologic column (fig. 5) drilled in the Anna Quarry. Although Ste. Genevieve Limestone and younger units are exposed in the quarry, they are not currently mined. These units are mostly relatively soft oolitic limestone and not the best quality for most construction uses. They are, however, a good source of high-calcium limestone and mainly used as aglime when mined. The St. Louis Limestone and the cherty/siliceous unit of the Ste. Genevieve Limestone find their best uses in road construction and maintenance. These units are mainly of "A" grade (highest quality) for concrete aggregate and other construction purposes. Because the cherts are very dense and solid, they do not tend to cause any deterioration issues when used in asphalt and concrete. This contrasts with chert in the Ramp Creek Member of the Ullin Limestone, which is soft and porous, making it a deleterious component and reducing its suitability for most construction purposes. However, the stone still is used for secondary roads, road base and surface materials, and other commercial construction.

The Ullin Limestone, among the best high-calcium limestones in the state, is quarried at the Jonesboro Quarry. Its calcium carbonate content reaches up to 98% or or higher, making the rock highly suitable as agricultural limestone. It has also been used in power plants for desulfurization. The high absorption of the limestone due to the abundance of fenestrate bryozoans increases the reactivity of this limestone for capturing sulfur oxide. Quarry supplies this limestone for flue gas desulfurization to SIPC (Southern Illinois Power Cooperative) at the Lake of Egypt. They recently also supplied the limestone to PSEC (Prairie State Generating Company) at Lively Grove, Illinois. However, their main product is aglime; they supply a lot of aglime for soil amendments of various types. The Ullin is soft and therefore not suitable for most construction purposes. However, they supply some material for commercial construction uses, which includes course bituminous aggregate, base and surface materials, and riprap. They are currently mining the floor of the quarry that includes the Ramp Creek Member, which is a better-quality construction aggregate.

A core drilled near the top of the quarry (362 feet long) by the company at a surface elevation of 545 feet suggests that most of the Ullin here is high-calcium Harrodsburg Limestone down to 330 feet. The surface elevation of the core was at 545 feet. Ramp Creek lithology ranges from 330 feet to 359.3 feet. There is a sharp break at 359.3 feet where the rock is dark gray, cherty, and very siliceous; this is probably the Fort Payne Limestone. Only about 3 feet of the Fort Payne was penetrated.

Besides the lower Mississippian limestones, various upper Mississippian units contain limestone thick enough to quarry, notably the Kinkaid Limestone and the Menard Limestone. However, only the Kinkaid has been quarried north of the study area in Jackson County and east of Union County in Johnson County.

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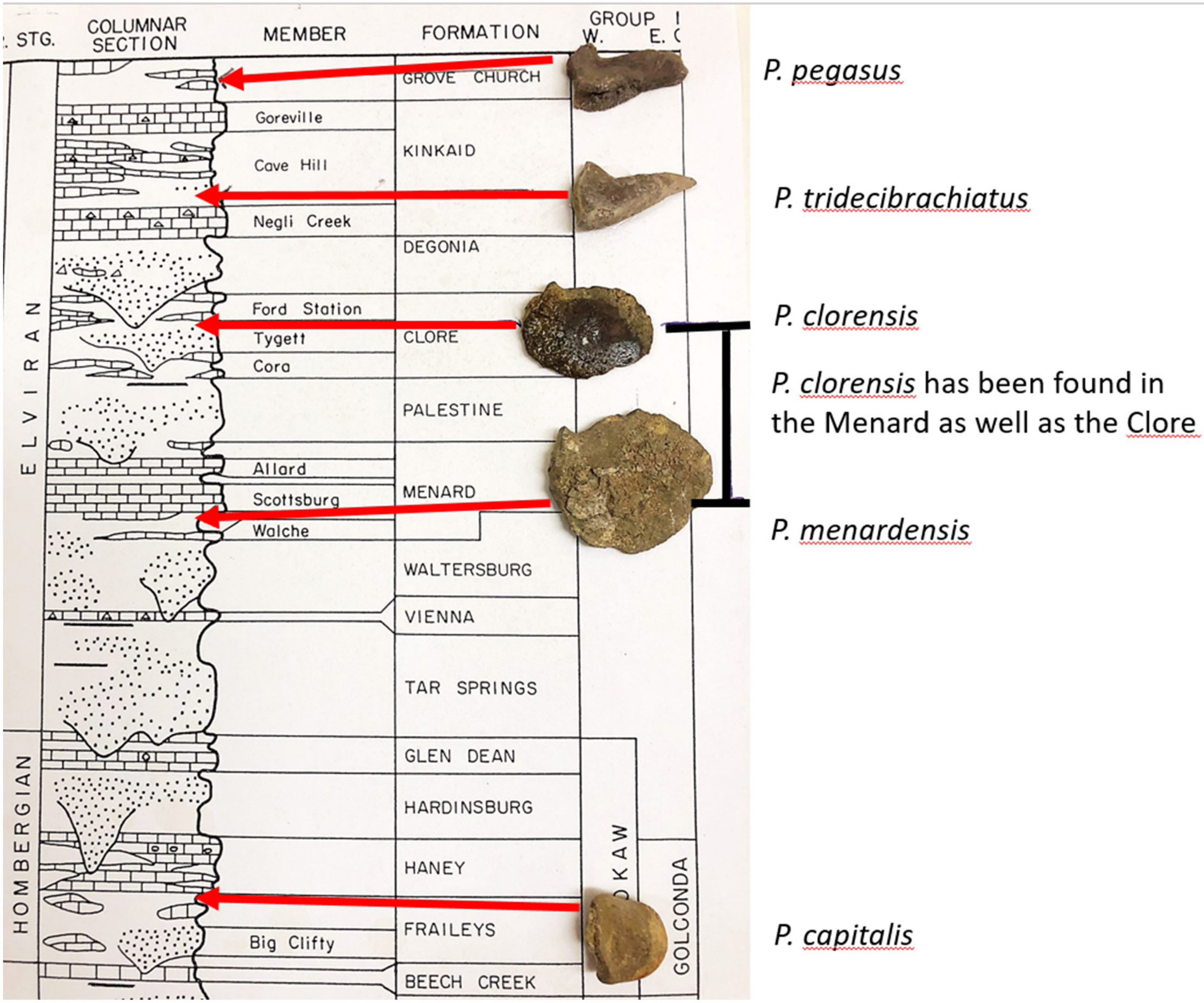


**Plate 1** Biostratigraphic distribution of Pterotocrinus in the Chesterian Series. Pterotocrinus "wing" plates found to be stratigraphically restricted to narrow zones within the Hombergian and Elviran Stages.

*Zeacrinites wortheni* 1x

*Phanocrinus formosus* 1.5x

*Onychocrinites* sp. 2x

*Onychocrinites* sp. 1.5x

**Plate 2** Crinoids from the Haney Member of the Golcanda Formation.