Illinois Preliminary Geologic Map
IPGM Ava-BG

Bedrock Geology of Ava Quadrangle

Jackson and Perry Counties, Illinois

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Introduction

The Ava Quadrangle is located in Jackson and Perry Counties in southwestern Illinois (fig. 1). The economy is agricultural, with row crops dominating the northern portions of the quadrangle and cattle ranching the southern portions. The topography of the northern portion is subdued and drainage is southerly and easterly into Gallum Creek. Gallum Creek flows easterly into Beaucuop Creek just east of the quadrangle. A drainage divide occurs along the southwest edge of the quadrangle near the community of Ava. South of Ava surface water flows southerly into Spring Creek and then into Little Kinkaid Creek, which flows southeasterly. North of the drainage divide, the water flows into Rattlesnake Creek, which drains easterly. Rocky Fork, which lies along the east limb of the Campbell Hill Anticline, is entrenched into the bedrock surface and flows northeasterly.

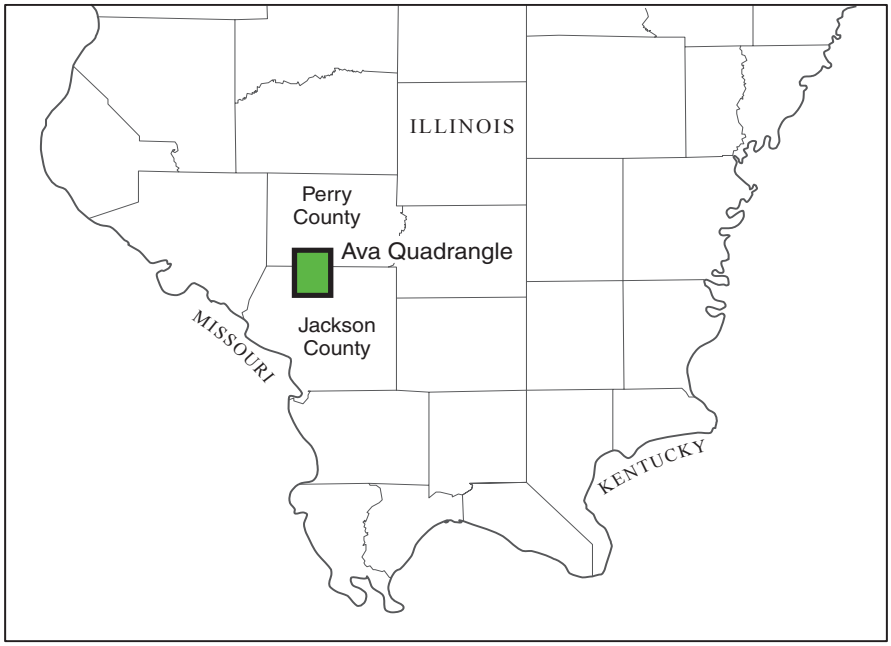

Figure 1 Location of the Ava 7.5 Minute quadrangle in southwestern Illinois.

The bedrock consists of Pennsylvanian units which outcrop in areas of moderate topographic relief along the southern half of the quadrangle. Pennsylvanian units are also present in northern portion but are blanketed and concealed by Pleistocene (Illinoian - Glasford Formation) glacial sediments and later by the Wisconsinan Equality Formation. Pleistocene tills occur at several places in the southern half of the quadrangle but do not blanket the region. These glacial units are present as isolated remnants in the valley along Rattlesnake Creek and thicken toward Beaucoup Creek. These surficial sediments are not present along the crest of the Campbell Hill Anticline, but glacial erratics were observed at elevations approaching 500 feet mean sea-level along the eastern edge of this structural and topographic high. The Pleistocene units appear to thicken eastward and water well records indicate that surficial sediments are over 80 feet thick along the floodplain of Beaucoup Creek. Windblown silt (loess) blankets the entire quadrangle and typically is less than 5 feet thick. These Pleistocene units have not been included on the accompanying bedrock geologic map.

Stratigraphy

Morrowan Series

Caseyville Formation The oldest rock exposed at the surface in the Ava quadrangle is the Caseyville Formation of the Morrowan Series. Subsurface data indicate that the Caseyville rests unconformably on Chesterian units throughout the Ava quadrangle. The Caseyville is composed of coarse-grained quartz sand with well-rounded quartz pebble (conglomerate) ledges separated by gray shale and siltstone. The sandstone conglomerates create resistant ledges which are 30 to 50 feet thick. The finer-grained sediments are usually less than 20 feet thick, and contain minor amounts of clay and mica (less than 2-3 percent). The sandstones beds are medium-to coarse-grained quartz arentites. The sandstones and conglomerate are white and weather tan-brown. The shales are light gray to tan-brown and thin bedded. Coal may be present but is thin and not laterally continuous.

The Caseyville was deposited on an erosional surface that in places has considerable relief (fig. 2). Paleovalleys with local relief up to 450 feet have been documented (Willman et al. 1975). This erosional surface marks the boundary between the Kaskaskia and Absaroka cratonic sequences (Sloss 1963). Caseyville sedimentation within the paleovalleys varies, but typically contains coarse pebble conglomerate at the base overlain by coarse-to medium-grained sandstone.

This package of quartz sand and pebbles is interpreted to be a fluvial-deltaic system that flowed southwesterly across a low-lying plain and rapidly subsiding marine shelf. The sediments were shed from the Canadian Shield or northern Appalachian front (Peppers and Popp 1979). The Formation fills paleovalleys with coarse-grained sediment and blankets most of southeastern Illinois. Sedimentation overflowed the paleovalleys and continued to deposit fairly clean quartz sand and gravel across the region. The quartz pebbles and clean quartz sandstone are diagnostic for this unit as the overlying finer-grained sandstones usually contain a larger percentage of clay and mica in the matrix. Younger stream channels eroded into the older sediment creating a complex fluvial system.

The top of the Caseyville is placed at the base of the Bell Coal (Greb et al. 1992) or at the top of the Reynoldsburg Coal. In the Ava area, neither the Bell Coal or the Reynoldsburg Coal have been positively identified; therefore the top of the Caseyville is placed at the top of the last coarse-to medium-grained quartz arenite or the top of the uppermost quartz pebble conglomerate. A bituminous coal, 2 inches thick, was observed along Rattlesnake Creek (Sec. 32 T.7S R.3W) that may be the stratigraphic equivalent of the Bell or Reynoldsburg Coal. This coal was not laterally continuous and a fine-grained sandstone of the Tradewater Formation was observed cutting out this coal along the creek bank. There is an unconformity between the Caseyville and the Tradewater in the Ava area.

Atokan and Desmoinesian Series

Tradewater Formation The lower part of the Tradewater Formation is transitional between the pure quartz sandstones (quartz arenite) of the Caseyville and the sublitharenites of the Upper Tradewater (Potter and Glass, 1958). The Tradewater is composed of silty gray shale, fine-grained sandstone, coal, and minor amounts of quartz pebble conglomerate.

The unconformity between the Caseyville and Tradewater can be observed at Sec. 12 T.7S R.4W (3400'NL, 3500'EL). The Caseyville can be observed along the creek bottom and in the hillside to the west, while the Tradewater siltstone and sandstone onlap from the east (fig. 3). The outcrop shows the Tradewater Formation that is filling a low possibly along the flank of the Campbell Hill Anticline. A

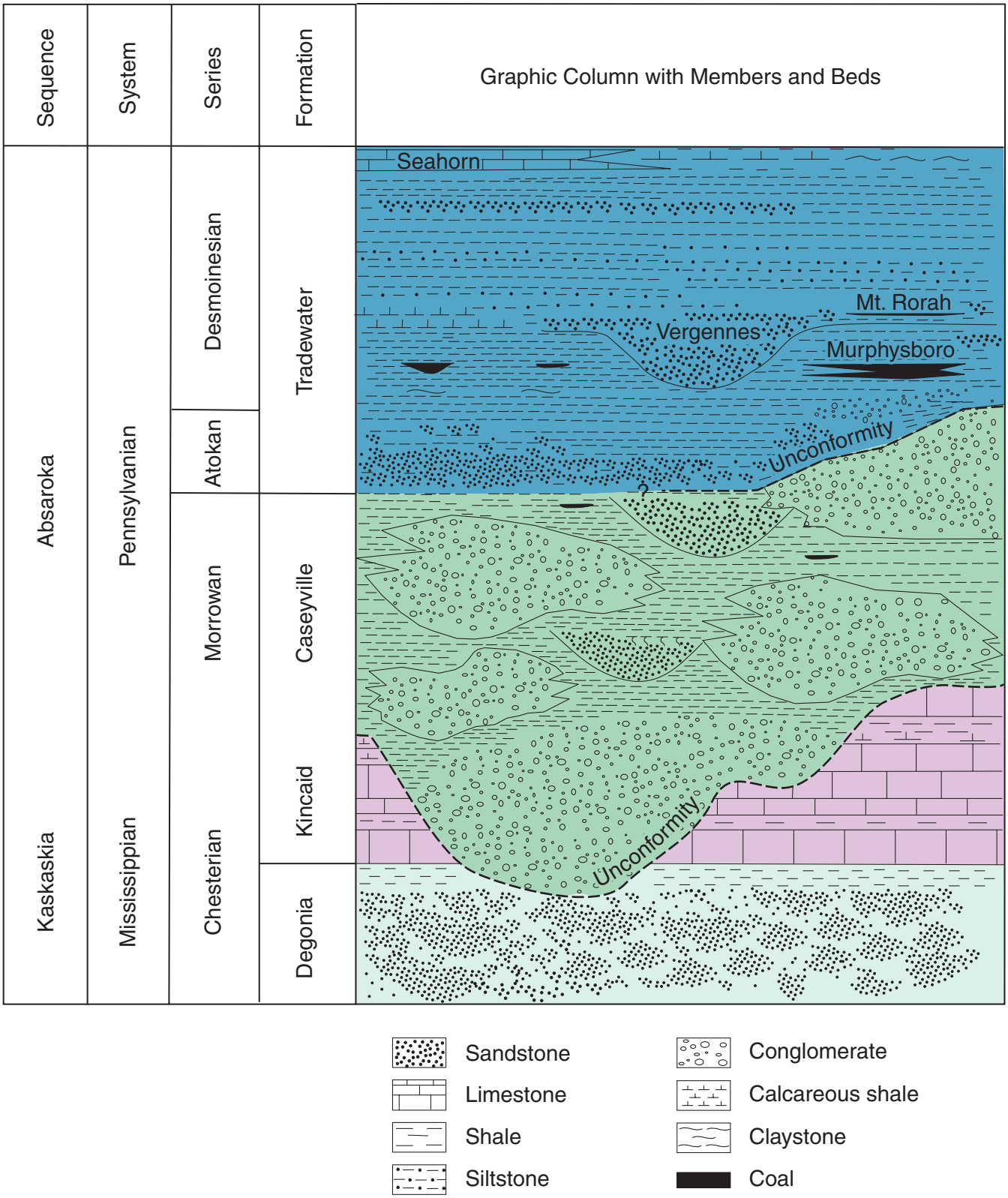

Figure 2 Relationship of the Lower Pennsylvanian-Mississippian unconformity and stratigraphic complexities of the lower Pennsylvanian.

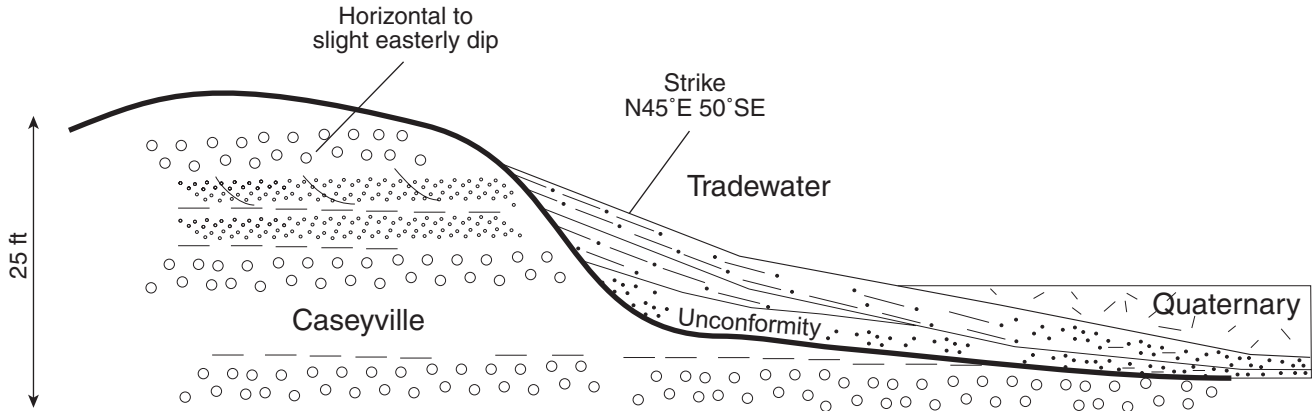

Figure 3 Relationship between the Caseyville and Tradewater along the east side of the Campbell Hill Anticline. Looking northeast.

reworked chert pebble conglomerate consisting of angular to sub-angular clasts of white, porous or punky quartz fragments in a sub-angular to sub-rounded quartz sand matrix was observed near the base of the Tradewater. This unit was observed at several locations (Secs. 20 and 18 T.7S R.3W). The unit weathers to a red-brown color and appears to be a reworked portion of the Caseyville quartz pebble conglomerate into the younger Tradewater Formation. This relationships may have implications concerning the timing of the Campbell Hill Anticline. The relationship between the Tradewater and the Caseyville suggest the Campbell Hill Anticline was a positive surface during deposition of the Tradewater. The lowest portion of the Tradewater near the Campbell Hill Anticline is variable and rests unconformably on the Caseyville Formation. Gray shales and fine-grained sandstone may be present and in places a carbonaceous claystone containing abundant *Neuropteris sp.* is present near the base of the formation. The coals are highly variable, from less than one inch to several feet thick. The Murphysboro Coal that has been by mined by surface and underground methods at numerous sites in the quadrangle is the oldest economic coal in this area. The Murphysboro is currently being mined at the creek Paum Mine.

Above the Murphysboro Coal, an unnamed gray, silty-shale commonly showing tidal rhythmites has been observed. Joe Devera (personal communication) observed a *Conosticus* sp. (sea anemone trace fossil) in the northeast corner of the Raddle Quadrangle (Sec. 36 T.7S R.4W) above a two-foot carbonaceous zone that may correlate with the Murphysboro Coal. Above the silty gray shale, a thin coal is present in places that correlates with the Mt. Rorah Coal Member. This coal is typically only a few inches to a few feet thick and is overlain by a fine-grained sandstone or silty shale. The Vergennes Sandstone of Shaw and Savage (1912), composed of fine to medium micaeous sandstone, is present northwest of the Creek Paum Cemetery.

Utilizing primarily electrical logs, Jacobson (1983) mapped a fluvial sandstone in the region. Jacobson placed this sandstone at the same stratigraphic level as the Murphysboro Coal and attached the name Oraville Channel (fig. 4) to this feature. This sandstone is present along eastern edge of the Ava Quadrangle as a gentle topographic high west of Beaucoup Creek. Jacobson (1983) considered the Oraville Channel to be adjacent to the Murphysboro Coal in a fluvial-dominated environment. The thicker coals aligned parallel to the sandstone channel and the coal splits are a result of crevasse splays along the margins of the channel.

The Allard core, drilled by the ISGS during the spring of 2005, encountered at least 50 feet of sandstone "Oraville Channel" and no Murphysboro Coal. Sandstone was detected in the Engelhardt core near

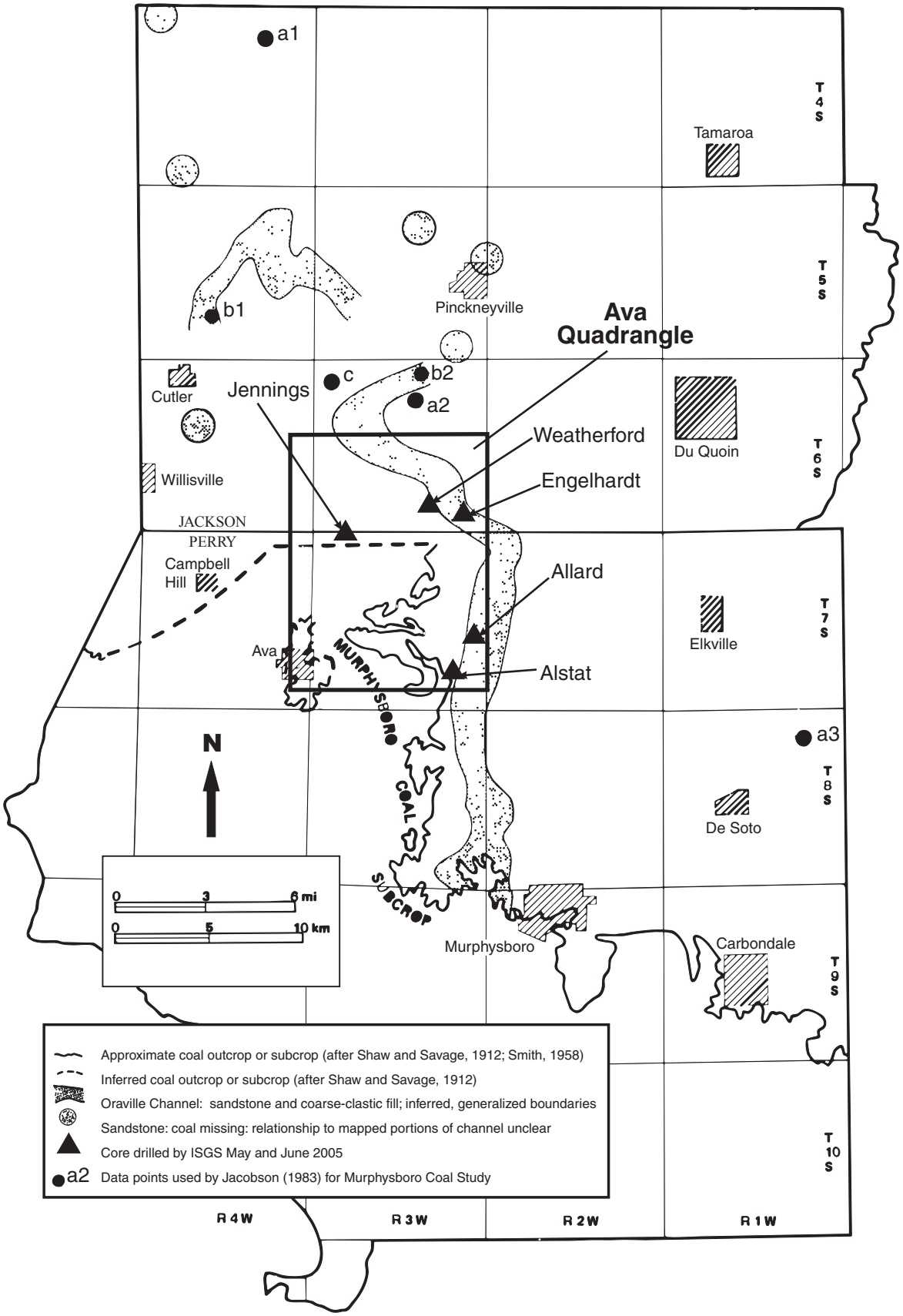

Figure 4 Map showing the suspected location of the "Oraville Channel" in relation to the Ava Quadrangle (adapted from Jacobson 1983).

the stratigraphic position of the Mt. Rorah and Murphysboro Coal. The sandstone in the Engelhardt was less than 15 feet thick and was underlain by a 2 to 3 inch coal. More than 40 feet of claystone was observed below the thin (Mt. Rorah ?) Coal in the Engelhardt boring. No sandstone was observed at this stratigraphic position in the Weatherford boring where 2.5 feet of Murphysboro Coal was observed. In the Weatherford boring, 6 feet of interbedded coal and claystone was observed above the 2.5 feet of Murphysboro Coal. The claystones are 3 to 4 inches thick and the coals are 1 to 2 inches thick. The stratigraphic relationship of the sandstone observed in these borings suggests that the sandstone unit is younger than the Murphysboro Coal. This sandstone is probably equivalent in time to the Mt. Rorah Coal, which is normally 30 to 50 feet above the Murphysboro Coal. The fine-grained sediments present at the Murphysboro horizon in the Engelhardt core appear to be part of an eustarine system and not fluvially-dominated. The splits within the upper portion of the Murphysboro indicate that sea level was fluctuating or the area was slowly subsiding. There are limestone and green and red shale beds several feet above the Murphysboro Coal in the Jennings boring which fits well with the proposed eustarine model.

Above the Mt. Rorah, a thin coal may be present that is correlated with the Wise Ridge Coal. This coal is overlain by a claystone with abundant plant debris which grades into a calcareous shale and in places a thin limestone. The limestone unit is the Seahorn. The Mt. Rorah, Seahorn, and Wise Ridge are not laterally continuous. Above the Seahorn is the Davis Coal which represents the base of the Carbondale Formation.

Carbondale Formation

The Davis Coal averages about 3 to 4 feet thick throughout much of southern Illinois (Willman et al. 1975). The Davis Coal was intersected in the Weatherford boring (Appendix 1) where it was measured to be 4 feet thick. This coal appeared to be relatively free of pyrite and probably is a high quality bituminous coal.

Directly above the Davis lies a 3-foot shale parting with 0.8 feet of Coal resting on the parting. This upper coal bed may be the Dekoven Coal Member or may be a split within the Davis Coal. The Dekoven Coal is located above the Davis Coal but is thin and discontinuous. Where present the Dekoven is 20 to 30 feet above the Davis. Above the Dekoven, a coarsening upward sequence is normally present with a sandstone at the top. The Colchester Coal lies atop the sandstone between 60 and 75 feet above the Davis Coal. There usually is a thin sandy underclay at the base. The Colchester in this region is less than 1.0 feet thick and overlain by a black shale and limestone. The limestone is several feet thick and is named the Oak Grove Limestone.

The Houchin Creek Coal is present approximately 40 to 50 feet above the Oak Grove Limestone. The Houchin Creek is less than 0.5 feet thick and overlain by thin black shale and then by a brown micaeous sandstone.

The Springfield Coal lies 70 to 80 feet above the Houchin Creek. The Springfield has been mined extensively throughout southern Illinois. This coal was mined along with the overlying Herrin Coal in the northwestern portion of the quadrangle. The Coal is 3 to 5 feet thick and the interval between the Springfield and Herrin Coal is 20 to 40 feet composed of sandstone, limestone, and shale. The Herrin Coal is 4 to 6 feet thick and is overlain by shale and limestone. The limestone unit is called the Brereton, the black shale is named the Anna Shale, while the silty-gray shale is called the Energy Shale.

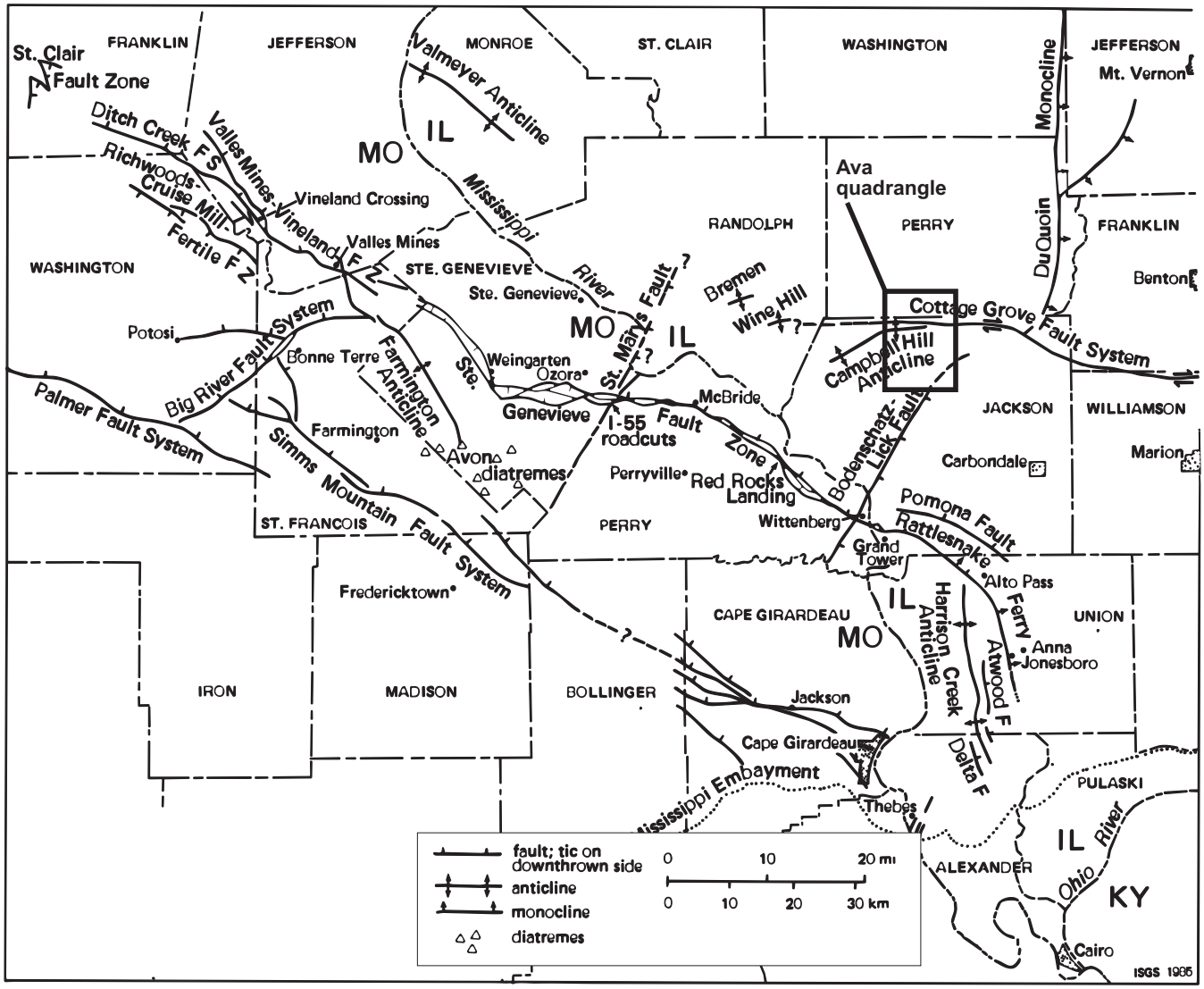

Figure 5 Regional structural geology of the southwestern Illinois and southeastern Missouri (adapted from Nelson 1985).

Structure

Several tectonic features have effected the Ava Quadrangle 1) Cottage Grove Fault Zone, 2) Campbell Hill Anticline, 3) Ste. Genevieve Fault Zone, and 4) Bodenschatz-Lick Fault Zone (fig. 5). The timing of each feature has implications for the economic geology of the region. Stratigraphic information implies at least a portion of the faulting occurred after the deposition of the Caseyville but prior to the deposition of the Tradewater, producing an unconformity on the Caseyville surface.

Ste. Genevieve Fault Zone

The Ste. Genevieve Fault Zone, located approximately 10 miles southwest of the Ava Quadrangle, trends northwest. Structural offset on the Ste. Genevieve in this region exceeds 3000 feet (Nelson 1995). The Ste. Genevieve was active during Ordovician, Devonian, and late Mississippian-Pennsylvanian, with the latest period being reverse movement with the southwest block being uplifted. Several workers have proposed strike-slip movement along this structure (Heyl 1972; Clendenin et al. 1989; Schultz 1992). The Bodenschatz-Lick Fault crosses the Ste. Genevieve at 90 degrees and the relationship between these two faults is not well documented.

Bodenschatz-Lick Fault

The Bodenschatz-Lick Fault (BLF) crosses the Ava Quadrangle at the extreme southeastern portion of the map. The steeply dipping eastern limb of this fault can be observed at the surface to the south in the Oraville quadrangle where a prominent topographic ridge is present. This topographic high was recognized by Root (1928) who related this feature to a structure which he named the Levan Anticline (fig. 6). Shaw (1912) depicts this structure plunging 150 feet per mile down to the east and diminishing northward. Nelson (1995) suggested the Levan Anticline was actually a monocline related to the Bodenschatz-Lick Fault and therefore discarded the term Levan. Nelson and Lumm (1985) traced the BLF using subsurface data and determined the fault extends northeast from south of the Ste. Genevieve Fault Zone in Missouri and merges with the Cottage Grove Fault Zone in Jackson County, Illinois. Nelson and Lumm suggested that there was an increase in vertical offset on units lower in the section and the Pennsylvanian was folded into a monocline at the surface. Bristol (1968) mapped several hundred feet of vertical offset on the base of the Barlow Limestone (Mississippian Beech Creek Limestone) along this feature (fig. 7).

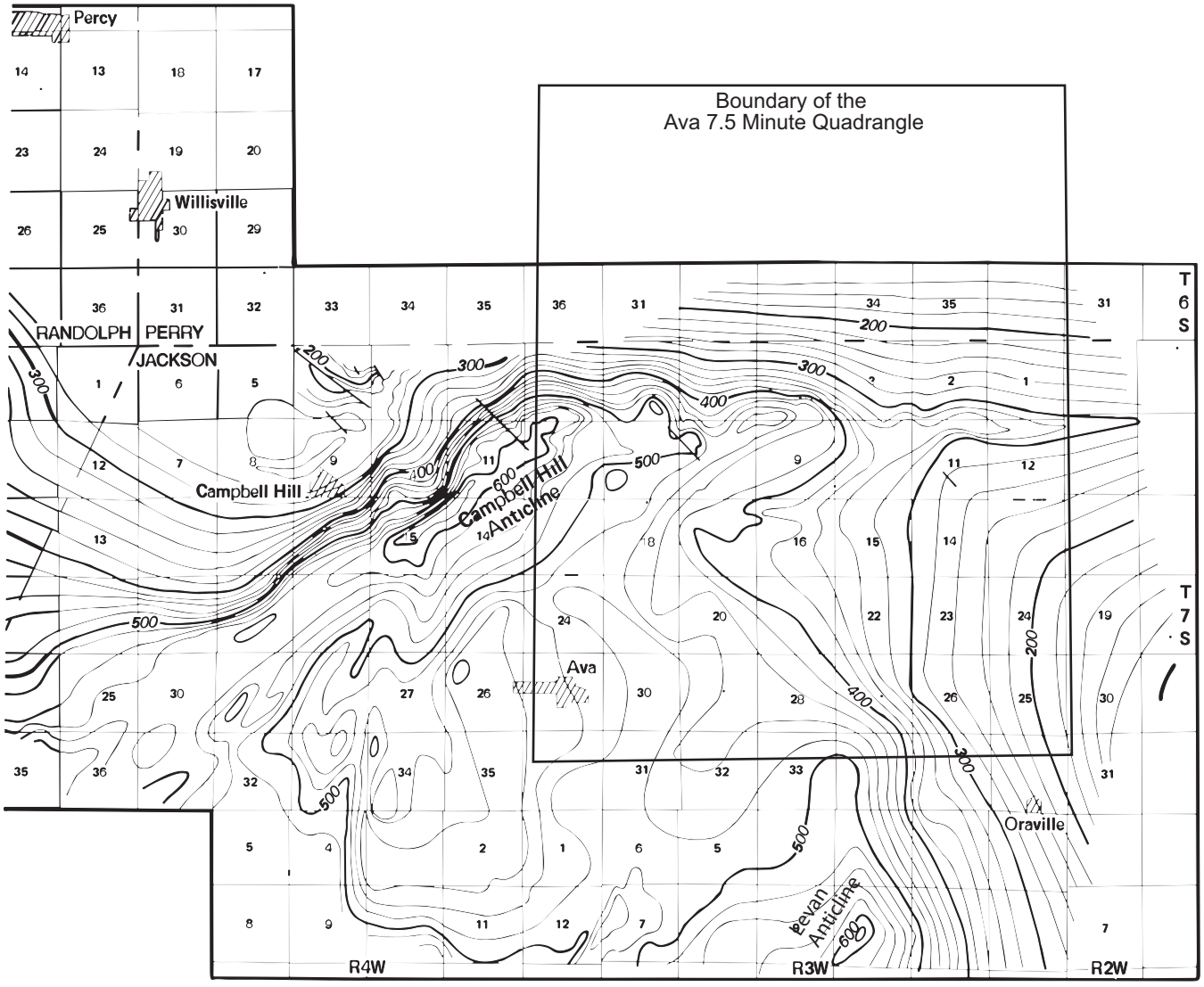

Figure 6 Structure map of the Campbell Hill Anticline based on the Ava Shale (Root 1928).

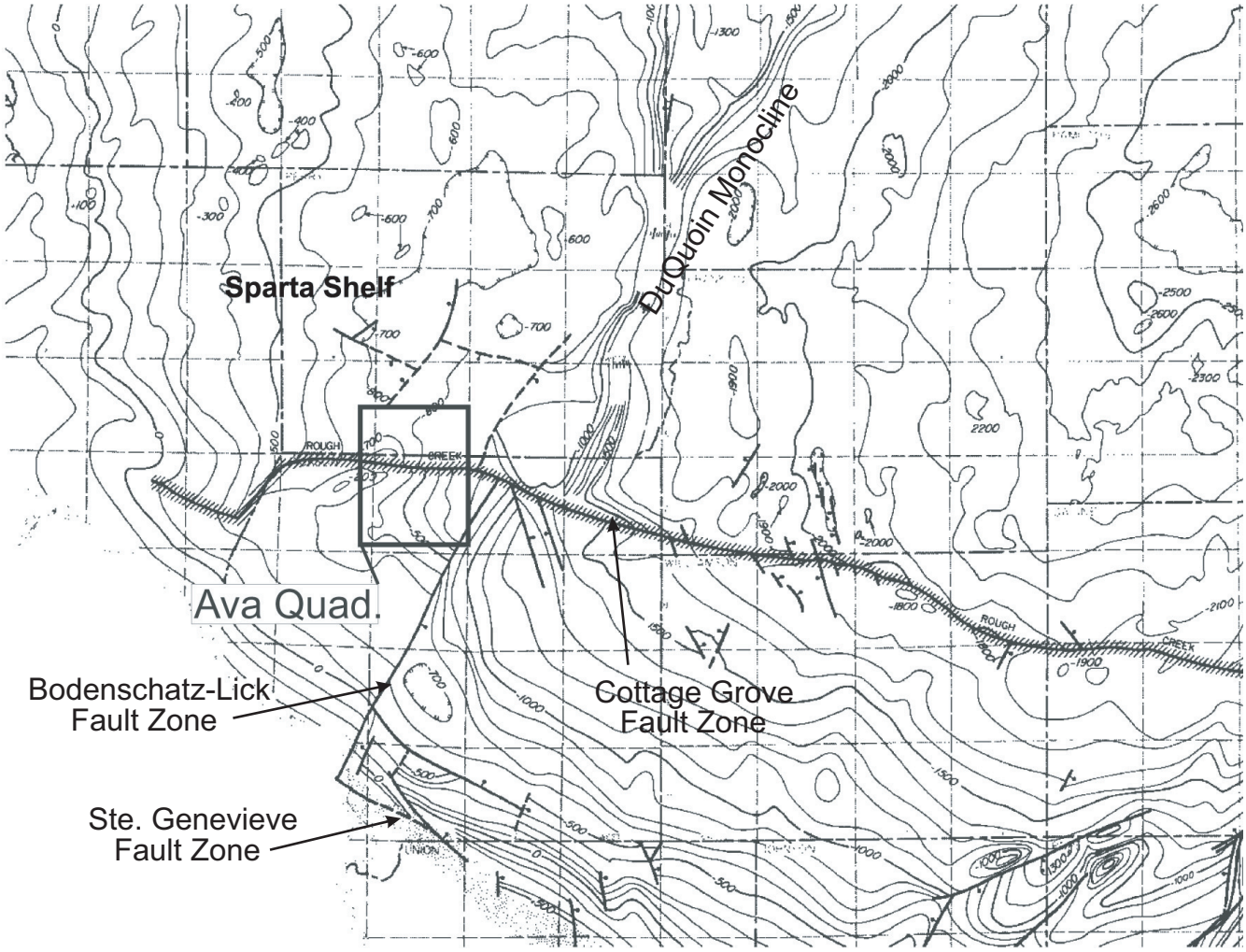

Figure 7 Structure contour on the base of the Barlow Limestone (Mississippian, Colgonda Formation). Note that the Cottage Grove Fault has been labeled the Rough Creek Fault Zone (modified from Bristol 1968).

Cottage Grove Fault Zone

The Cottage Grove Fault Zone crosses this quadrangle from east to west just south of the Jackson-Perry County line. While there is significant topographic relief along this feature, there are surprisingly few exposures. This fault zone is undoubtably more complex than the single master fault depicted on the geologic map, but there is not enough data to accurately project additional fault segments.

The faulting along the east-west trending Cottage Grove Fault Zone is described as a right-lateral strike-slip fault (Nelson and Krausse 1981). This fault extends from Gallatin County westerly into Perry and Jackson Counties. Northwest trending subsidiary faults are theorized to be related to this wrenching movement. Igneous rock has intruded some of these northwesterly trending faults at the eastern end of this fault zone in Gallatin and Saline Counties. An igneous dike in Saline County has been dated as Early Permian (269.61+/-0.39 Ma) using radiometric (40Ar/39Ar) isotopic dating techniques (Denny 2005). These igneous intrusions are theorized to be emplaced at or very soon after the strike-slip deformation along this fault zone, thereby yielding an early Permian age of tectonic activity. The structure is also theorized to be located over a Precambrian crustal boundary (Heigold and Kolata 1993).

Seismic Data Recent seismic interpretation by Duchek et al (2004) describes the Cottage Grove Fault Zone. The authors describe an area east of Ava as the West Bend section of the Cottage Grove Fault

Zone. Several reflection profiles were reprocessed and the tectonics of the Cottage Grove Fault Zone was discussed. The precise location of the two seismic lines along the West Bend was not determined but should be within a few miles of the Ava Quadrangle. The authors stated that they couldn't definitively demonstrate dextral displacement along the Cottage Grove due to lack of data. They also concluded that there is no evidence for two or more episodes of movement under different stress orientations.

Campbell Hill Anticline

The Campbell Hill Anticline is exposed along the western edge of the Ava Quadrangle south of the Perry County line. Only the gentle-sloping eastern limb is apparent in the Ava quadrangle. This feature was first described by Root (1928) who utilized a thick shale bed (Ava Shale) within the Caseyville Formation to map the structure (fig. 6). This anticline is responsible for the southeasterly dips south of the Cottage Grove Fault along the southwest portion of the map.

Field Observations

Vertical slickensides were observed along one fault in the study area in the Cottage Grove Fault Zone. The exposure (Sec. 1 T.7S R.4W; 1500 ft. SL, 2500 ft. EL) was only a few feet of fractured Caseyville sandstone with nearly vertical striations on remobilized white quartz. The strike of the fault is $N70^0E$ steeply dipping (nearly vertical) to the south. The amount of displacement was not observable but the rocks being moderately fractured indicate moderate displacement. High-angle reverse movement is implied due to the steep southerly dip, vertical striations on the fractured rock, and the apparent rise of the unit northerly into the master fault along the Cottage Grove. A few hundred feet to the north of this outcrop the Caseyville Formation was observed striking due east-west and dipping 6 degrees north which projects into the master fault along the Cottage Grove. The amount of vertical displacement along the master fault is between 100 and 200 feet down to the north. No horizontal displacement can be documented along this segment of the fault zone. The structural trend of this segment of the fault zone appears to be anticlinal or monoclinal, with an east-westerly axial trend parallel to the Cottage Grove Fault. The topographic expression of this feature dies out and the fault zone can not be traced eastward near the eastern edge of the quadrangle.

Three faults were observed approximately one mile south of the master fault along Cottage Grove at the Creek Paum Coal Mine (Secs. 12 and 14, T.7S R.3W). These faults trended N 40^0W to N55^0W with dips of approximately 70^0 NE. Striations on the Murphysboro Coal and the underclay just below the coal were both horizontal and vertical indicating a horizontal strike-slip movement to produce the horizontal striations followed by a dip-slip component to produce the vertical striations. Vertical offset was less than 3 feet on each fault. These observations were along the pit of an active coal mine and the coal has been subsequently mined. These faults imply a transpressional component of strike-slip movement. The northern fault was observed by Heinze Damberger (ISGS Coal Section field notes) who reported this fault was high angle reverse with the northeast side being up thrown 15 feet. This indicates the fault scissors along its length (see geologic map).

Two other northwesterly trending faults were observed both within one mile of the master fault of the Cottage Grove. These faults were very poorly exposed. Fractures in the rock trend northwesterly but displacements of strata were not obtainable to determine the direction or amount of throw. These faults appear to have been subjected to the same forces that created the small northwesterly trending faults observed in the Creek Paum Mine.

An inferred fault drawn south of the Cottage Grove Fault Zone trends southwest-northeast. Caseyville

sandstone was observed striking N75^{0}E and dipping 12 degrees to the southeast (NW 1/4, Sec. 10 T.7S R.3W). The trend is in-line with the disappearance of sandstone ledges mapped in the northwest quarter of Sec. 16, T.7S R.3W. These ledges can be observed west of the creek, but where the creek turns east they can not be detected. This fault is parallel with both the Bodenschatz-Lick fault and the strike of the Campbell Hill Anticline.

A fault is depicted on an oil and gas structure map of the base of the Mississippian Beech Creek Limestone (Barlow Lime) which would project into the northwestern portion of the Ava quadrangle (fig. 7). This inferred fault is normal down-thrown to the northwest. This inferred fault is parallel to the crop-line of the Herrin and Springfield Coals.

Summary

At least three and probably four periods of movement are needed to explain the tectonic activity within this area. The seismic lines published by (Duchek et al, 2004) depicts these movements. The first period of movement is extensional and rifted the Precambrian Basement which was then filled with Knox Group sedimentation. The second period of movement is probably related to the regional uplift of the Sparta Shelf northeast of the Ste. Genevieve Fault Zone during the Devonian. The Sparta Shelf is defined as the southern portion of the Western Shelf that defines the western flank of the Illinois Basin (Nelson 1995). This Western Shelf exhibits a slower rate of subsidence than the area to the east of the Du Quoin Monocline, which marks its' eastern boundary. The unconformity near the top of the Knox Group probably relates to this regional uplift.

The third period of movement effectively raised the southern portion of the region along the Cottage Grove Fault. It is also likely that movement on the Bodenschatz-Lick Fault occurred simultaneously with this Early Pennsylvanian (Atokan) event. The unconformity along the flanks of the Campbell Hill Anticline between the Caseyville Sandstone and the Tradewater Formation supports this tectonic event. The stratigraphic correlation of the early Desmoinesian Murphysboro strata indicate that along the down-thrown side of the Bodenschatz-Lick Fault marine limestones are present while on the up-thrown side fine-grained intertidal and eustarine deposits were being deposited. This also indicates that movement may have been active during early Desmoinesian. During middle to late Desmoinesian the region was apparently fairly stable and widespread coal formation prolific.

The fourth period of movement (post-Desmoinesian) occurs as reverse movement along a south side of the Cottage Grove Fault Zone. Anticlines along the Cottage Grove Fault Zone have been described by Nelson and Lumm (1987). With the exception of the Cottage Anticline in Saline County, which is related to a Permian igneous intrusion (Denny, 2005), they are confined to the southern portion of the Cottage Grove Fault Zone. This leads to the speculation that reverse movement along the western end of the Cottage Grove Fault Zone is related to deep-seated northerly directed post-Desmoinesian compressional force. This movement may be related to continental compression from the Ouachita region. Alternatively, the final period of movement may be a result of east-west transpression along a Precambrian crustal boundary during Permian (Nelson and Krausse 1981; Duchek et al 2004). The horizontal striations along small northwesterly trending faults observed in the Creek Paum Mine tend to support the transpressional theory.

Economic Geology

Oil and Gas

Gas and some oil was produced from the Campbell Hill Anticline along the western portion of the quadrangle. Several petroleum borings have been drilled in this quadrangle but most were dry or contained only shows of oil and gas. The primary production form the Campbell Hill Anticline occurs to the west in the Willisville Quad (see Nelson 2005). A more detailed investigation of the Levan Anticline (Root, 1928), southeast of Ava, is warranted to determine if this structure is an anticline or monocline related to the Bodenschatz-Lick Fault Zone (fig. 6).

Coal

Coal has been mined extensively within the Ava Quadrangle. A single mine is currently active which extracts the Murphysboro Coal near the center of the quadrangle. The earliest coal mining in this quadrangle also occurred within the Murphysboro Coal near the former community of Sato. Dozens of abandoned underground mines are present and several surface operations have been active south of the Cottage Grove Fault Zone. The earliest coal mining occurred around 1886 at the Campbell Mine (Sec. 2 T.7S-3W, SE 1/4). Intermittent mining from 1900 to the 1940s near Sato ceased along a linear southeast-northwest boundary. A fault was observed near this boundary (Sec. 15 T.7S R.3W, SW 1/4). Thin beds of silty gray sandstone and interbedded siltstone were observed to strike $N25^0$ W with dips 25^0 NE. This inferred fault would be normal down to the northeast side. This fault probably offset the coal near Sato and explains the abrupt end of the early mining in this area. The strata overlying the Murphysboro is thin and typically composed of thin beds of siltstone that are poor as roofs for underground mines. It is likely that roof stability near faults would be more unstable.

The Murphysboro Coal is a high quality, low sulfur bituminous coal (Jacobson, 1983). Murphysboro Coal should be present near the surface along the Perry-Jackson County line along the western portion of the Ava quad. This area may contain Murphysboro Coal within 75 feet of the surface. The Jennings boring (Sec. 36 T.7S R.3W) encountered nearly 4 feet of Murphysboro Coal at 94 feet below the surface. The area south of this boring should be drilled to determine the quality and thickness of the Murphysboro in this region - north of the Cottage Grove Fault Zone. The Cottage Grove Fault will certainly effect the mineability of the coal in this area.

The Davis Coal was observed in the Weatherford and Engelhardt borings. It was observed to be bright banded with few partings and little pyrite, and about 4 feet thick in the Weatherford boring and 2.8 feet thick in the Engelhardt boring. Above the Davis a coal up to 1.3 feet thick was present which may be the Dekoven Coal. The upper coal appeared to be shaley and probably would be of marginal quality.

The Herrin and Springfield Coals have been mined along the northen portion of the Ava quadrangle and are mostly mined-out. There may be a small area southeast of the community of Denmark where the Herrin and Springfield may be present. Core drilling in this area would be necessary to verify this assumption (see geologic map). The Houchin Creek and Colchester Coals have been identified in this area but are less than 2 feet thick in most borings.

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The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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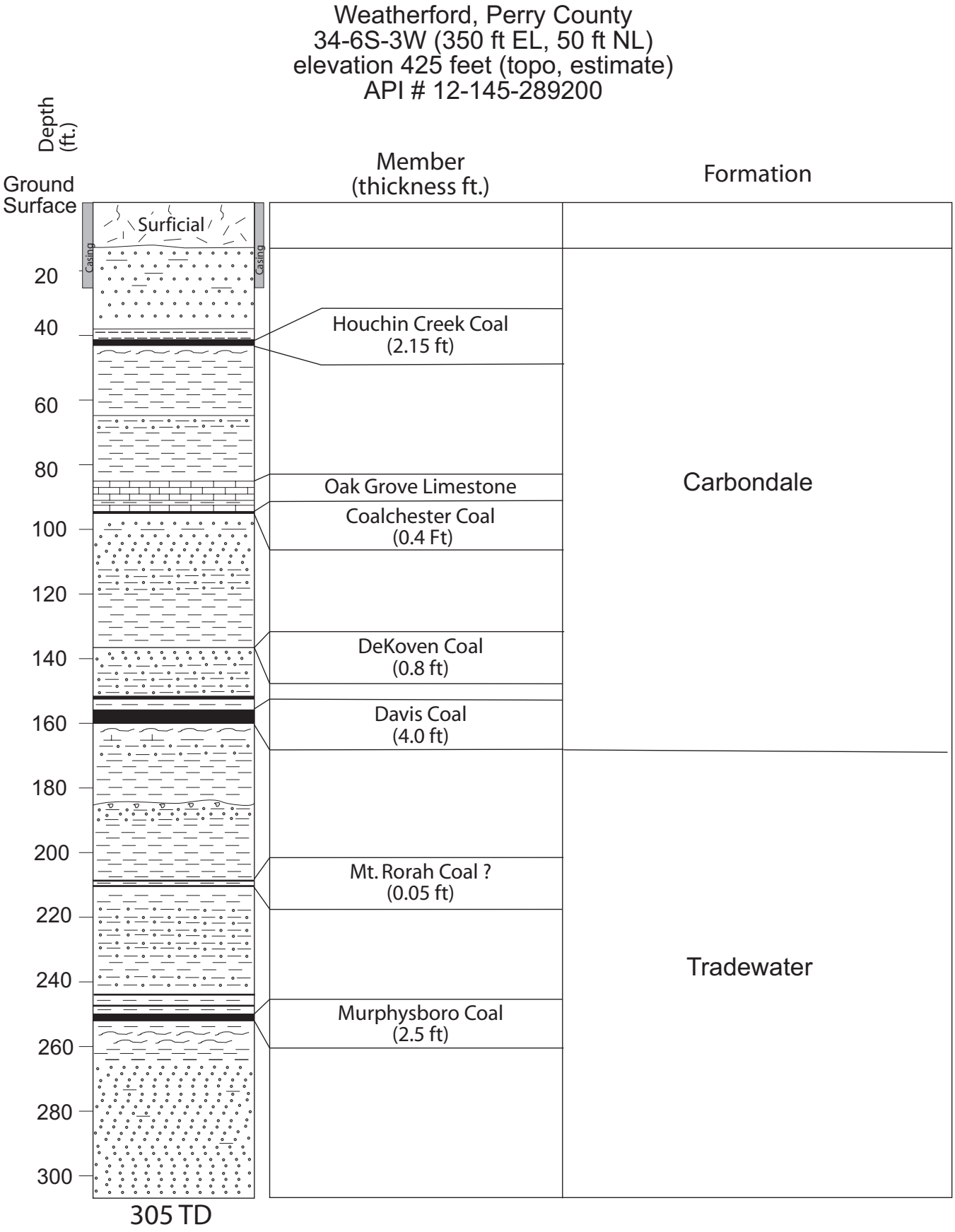
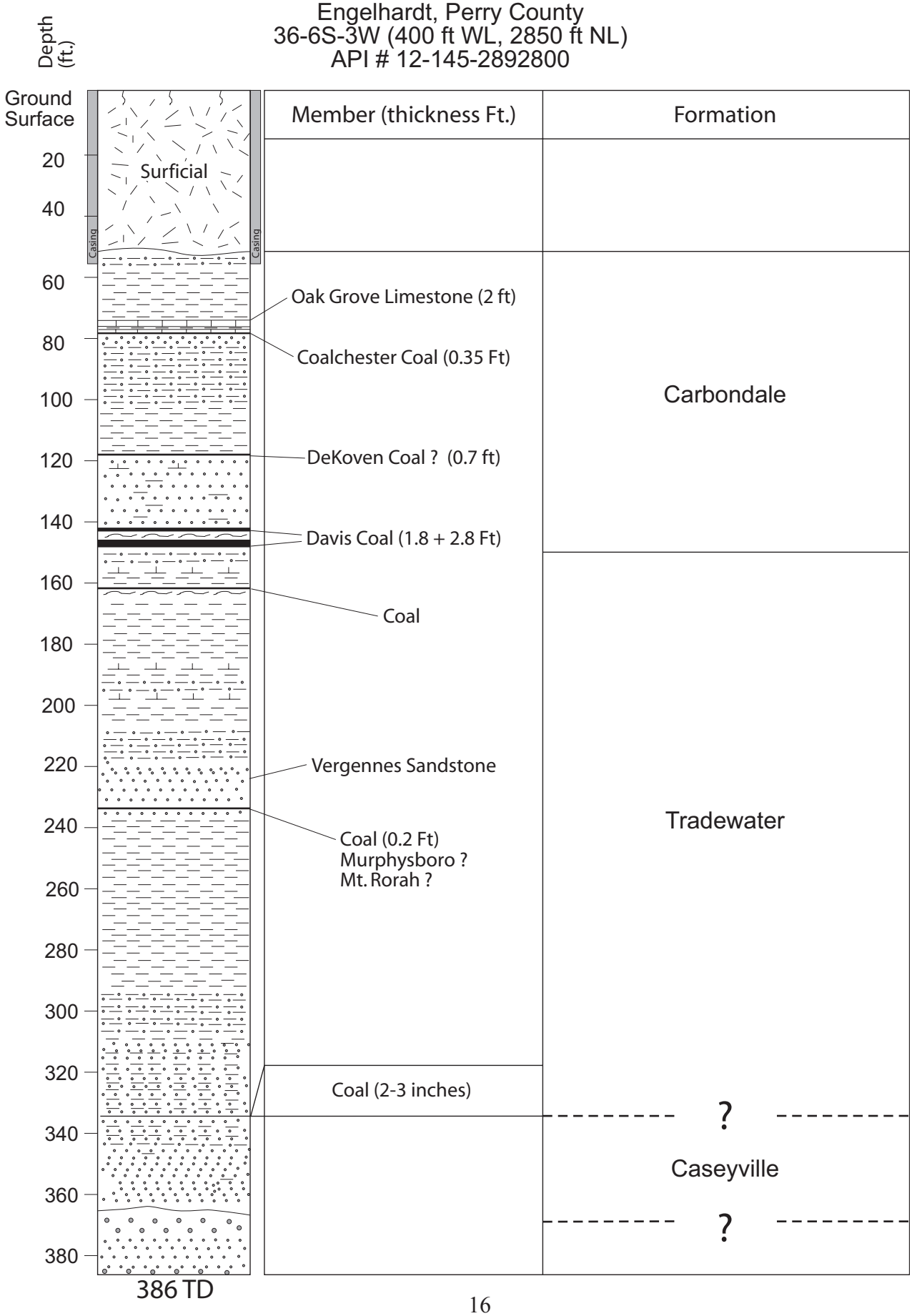
Appendix 1 Graphic Log of the Weatherford Core (34-T6S-R3W).



Appendix 2 Graphic Log of the Engelhardt Core (36-T6S-R3W)



Appendix 3 Graphic Log of the Jennings Core (6-T7S-R3W).