Geol Survey

NEOGENE GRABENS IN SOUTHERNMOST ILLINOIS

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ABSTRACT

Test drilling and field studies were carried out at five sites in Massac and eastern Pulaski Counties of southernmost Illinois. These studies supplement mapping, drilling, trenching, and geophysical surveys conducted during previous years. All five sites contain grabens that strike north-south to northeast-southwest and are part of the Fluorspar Area Fault Complex. These faults and northeast-trending ones in the New Madrid Seismic Zone share common origin in a latest Proterozoic to early Cambrian rifting event. Faults at three of our five sites were active during middle Tertiary time, so latest Cretaceous, Paleocene, and Eocene sediments were dropped into grabens and protected from erosion. Major displacements at all five sites took place in Neogene through middle Pleistocene time, displacing the Mounds Gravel and the Metropolis Formation. In the deepest graben, Massac Creek, the Mounds Gravel is downthrown 150 m and 79 m of younger sediments were dropped down and preserved. Wisconsinan or Holocene deposits are not displaced at the sites studied this year; therefore, the faults are inferred to have been inactive for at least 75,000 years.

INTRODUCTION

This report updates our findings on Quaternary tectonic faulting in Massac and Pulaski Counties in southern Illinois (Fig. 1). Previous studies (Nelson et al., 1997, 1999) documented numerous fault zones that displace upper Tertiary and Quaternary strata in this area. Field mapping, drilling, trenching, and high-resolution seismic reflection surveys revealed numerous faults, most of which take the form of narrow, northeast-striking grabens. Activities during 1999 consisted mainly of drilling test holes into grabens to verify the age and thickness of deformed sediments.

Regional Setting

The report area is located near the northern end of the Mississippi Embayment, an extension of the Gulf Coastal Plain (Fig. 1). Weakly lithified Cretaceous, Tertiary, and Quaternary clastic sediments overlap Paleozoic bedrock in the Embayment. Many tectonic faults are mapped in the bedrock uplands that border the Embayment, but their extent into the Embayment itself was poorly known because of lack of exposure. As a consequence, some previous geologists (Kolata et al., 1981) concluded that all faulting was pre-Cretaceous. Younger faulting in the Embayment first became known in the early 1990s during a geologic quadrangle mapping program (scale 1:24,000) carried out by the Illinois State Geological Survey (ISGS).

The faults that are the focus of this report belong to the Fluorspar Area Fault Complex (FAFC). Steeply dipping faults that strike northeast and penetrate Precambrian basement are prevalent in the FAFC. These faults apparently originated as normal faults during an episode of crustal rifting of latest Proterozoic to early

Cambrian time (Kolata and Nelson, 1991; Potter et al., 1995). A northeast-trending, fault-bounded trough that developed at this time is known as the Reelfoot Rift (Figure 1). Also part of the Reelfoot Rift are faults that are seismically active today in the New Madrid Seismic Zone. Faults of the FAFC that displace Quaternary sediments in Massac and Pulaski Counties are directly in line with the New Madrid Seismic Zone.

Stratigraphy

Bedrock in the study area is of Mississippian age (Fig. 2). The Mammoth Cave Group, dominantly limestone with minor amounts of dolomite, shale, and sandstone, is Valmeyeran (middle Mississippian) and comprises the Fort Payne Formation (oldest) and the Ullin, Salem, St. Louis, and Ste. Genevieve Limestones. Chesterian (Upper Mississippian) rocks are found in northern Massac County and include numerous alternating units of limestone, sandstone, and shale.

Three Upper Cretaceous units are present in the study area. The Post Creek Formation (called Tuscaloosa in older reports) is a lenticular deposit of white to light gray chert gravel in a matrix of pyritic sand and clay. The Post Creek rests upon and grades into residual deposits of clay and angular chert fragments derived from deep weathering of Mississippian limestone. In places, Post Creek sediments fill deep crevices and solution cavities within the limestone. Overlying the Post Creek is the McNairy Formation, which is characterized by laminated and interbedded clay, silt, and fine sand containing large amounts of mica. The McNairy was deposited in marginal marine environments near the head of the Mississippi Embayment. The thin Owl Creek Formation, composed of mottled and burrowed sandy clay and clay-rich sand, conformably overlies the McNairy.

Paleocene and Eocene strata, along with the Owl Creek Formation, are found only in grabens in Massac and eastern Pulaski Counties. Elsewhere in the study area, these units were eroded and the McNairy is unconformably overlain by Mounds Gravel or younger units (Fig. 2). The Clayton, Porters Creek, and Wilcox are distinctive lithologies that are well known from adjacent areas south and southwest of the report area. The basal Paleocene Clayton Formation in a thin stratum of glauconite-rich, highly burrowed sandy clay that rests unconformably on Cretaceous sediments. The Porters Creek Clay is a stiff, massive, olive-gray clay that is mined for making kitty litter. The Clayton and Porters Creek contain a marine fauna and represent maximum advance of the Embayment. Eocene strata are assigned to the Wilcox, Claiborne, and Jackson Formations in western Kentucky (Olive 1980), but these formations can be difficult to distinguish from one another. The most characteristic Eocene lithology in Illinois is bright yellow to orange sand that contains small polished granules of white quartz and gray to black chert.

The Mounds Gravel, composed of red to brown chert gravel and sand, is believed to range in age from late Miocene to early Pleistocene (Olive, 1980). Chert pebbles in the Mounds bear a distinctive yellow-brown to bronze-colored glossy patina, which is not merely a surficial polish but a rim of iron oxides. The Mounds in this region represents alluvial-fan and braided-stream deposits of the ancestral Tennessee River (Potter, 1955; Olive, 1980; Nelson et al., 1999a). The youngest part of the Mounds occupies an incised valley close to the position of the modern Ohio River from Paducah, Kentucky to Cairo, Illinois. Overlying the Mounds within this valley are poorly sorted, deeply weathered and burrowed alluvial sediments known as the Metropolis Formation (Nelson et al., 1999a and 1999b). The Metropolis is composed of clay-rich silty sand and sandy silt, mottled in gray, yellow, and orange and containing bleached chert pebbles that were derived from the Mounds Gravel. This formation underlies a terrace bordering the Ohio River and also extends up some short tributaries of the Ohio. The Metropolis probably ranges in age from early through middle Pleistocene (Illinoian Stage and older), and contains the Sangamon Geosol at the top. The Metropolis is the youngest unit in the area that is extensively faulted.

Younger Pleistocene units in the report area include sand and gravel of the Henry Formation and silt and clay of the Equality Formation, both of Wisconsinan age. These units represent largely fluvial and lacustrine sediments, respectively, and are found in valleys of the Ohio River and its tributaries. Uplands are mantled in wind-blown silt, or loess, divisible into three units: Loveland Silt (Illinoian), Roxana Silt (middle Wisconsinan), and Peoria Silt (upper Wisconsinan). Holocene sediments of the study area are the Cahokia Formation (alluvium) in valleys, and colluvium on uplands.

STUDY SITES

Detailed studies were carried out at four sites during the past year. Locations of the Massac Creek, Choat, Maple Grove, and Post Creek sites are shown on a detailed map (Fig. 2). A fifth site, Unity School, was discovered this year and investigated with a single drill hole.

Massac Creek

Background. Ross (1963, p. 20) was the first to report faulted Mounds Gravel along a tributary of Massac Creek about 13 km north of Metropolis, Illinois (Fig. 3). Kolata et al. (1981) investigated the site, and were unable to determine whether tectonic faulting or non-tectonic processes had been at work. Nelson (1996) interpreted the mounds Gravel to be displaced within a NNE-striking graben, part of the Hobbs Creek Fault Zone in the FAFC.

A key piece of information for interpreting the structure is the log of a water well at the James Weaver residence, which lies along the axis of a narrow, NNE-trending linear valley. The Weaver well was drilled to a depth of 342 feet (105 m) without reaching Paleozoic bedrock, whereas nearby wells outside the valley reached bedrock at depths of 45 m or shallower. Such a situation strongly implied a graben along the valley. In 1995 the ISGS drilled a cored test hole (ISGS #R-1 Weaver) to a depth of 301 feet (91 m) close to the Weavers' water well. Samples from the #R-1 boring confirmed the presence of a graben in which Mounds Gravel is downthrown approximately 45 m relative to nearby exposures. Below the Mounds, #R-1 penetrated 58 m of unnamed sand, silt, and clay that yielded Miocene to lower Pleistocene pollen (Nelson et al., 1997). Drilling was halted due to lack of funds without reaching the base of this unnamed unit. Clearly, the Massac Creek structure had undergone substantial displacements during Neogene and Pleistocene time.

In year one of this project we ran high-resolution seismic profiles across the Massac Creek structure. One seismic line was run on the Weaver farms adjacent to the #R-1 boring; the other was run along Rosebud Road about 0.8 km south of the Weaver farm (Fig. 4). Both seismic lines (Nelson and McBride, 1998) depicted an intricate zone of high-angle normal and some reverse faults within Paleozoic bedrock along the Massac Creek structure. Although details are not clearly resolved, the seismic profiles depict faults in Cretaceous strata, and in younger units within the central graben.

In 1999 we drilled 15 shallow test holes along the lines where the seismic profiles were run. Ten holes were drilled on the Weaver farms and five along Rosebud Road (Fig. 4). These 15 holes were drilled using an AMS Power Probe, which provides continuous cores of unlithified materials to a maximum depth of 25 to 30 m. A special feature of the Power Probe is that because the drill string is driven and not rotated, oriented cores can be taken. Finally, a continuous cored test hole 173 m deep (ISGS #7 James Weaver, identified as J7 on Fig. 4) was drilled adjacent to the #R-1 boring using a wireline coring rig provided by the U.S. Geological Survey.

New Findings

Weaver Farms

A cross section of the Massac Creek structure on the Weaver Farms is shown in Figure 5. Interpretation is based on both drilling and seismic survey. These data indicate a complex graben, having a very deep, narrow central section and stair-step displacements along both margins. On the flanks of the graben, thin Pleistocene loess and alluvium overlie the McNairy Formation (Cretaceous), which rests of Mississippian bedrock. In these marginal cores, bedding in the McNairy was horizontal, or nearly so. Moving inward, the Metropolis Formation (Pleistocene) thickens markedly, and cores of the McNairy show bedding to be inclined.

In hole D3 on Figure 5, fine-grained yellow to pinkish-gray sand was encountered beneath the Metropolis Formation. This sand lacks mica, which typically is abundant in the McNairy Formation; but contains numerous small granules of white quartz and light to dark gray chert, which do not occur in the McNairy but are common in the Wilcox and other Eocene units of the northern Embayment. Laminations in the sand dipped at 20 to 30 degrees southeast. Eocene strata do not occur elsewhere in Massac County, where the Mounds Gravel (or younger units) unconformably overlie the McNairy. The presence of Eocene sand in hole D3 is evidence that the Massac Creek graben was active during, or after Eocene time and prior to deposition of the Mounds.

In the central area, boreholes D4, R-1 and J7 show thick Metropolis Formation beneath loess (Fig. 5). The Metropolis was 32.5 m thick in borehole J7, compared to a normal thickness of about 12 m along Massac Creek away from the fault zone. Ordinarily, the Metropolis underlies terraces that flank the modern flood plains of the larger creeks in southern Massac County. A thickness of 32.5 m virtually mandates active subsidence to accommodate continued alluvial deposition. Shear zones and steeply inclined bedding in cores of the Metropolis from R-1 and J7 confirm active faulting during deposition. Accurate dating of the Metropolis Formation in these cores was not possible, owing to absence of fossils or carbonaceous material. Based on stratigraphic relationships observed in the area, the upper part of the Metropolis is inferred to be of Illinoian age (which ended about 125,000 years ago).

The remainder of borehole J7 answers questions raised by borehole R-1, which had to be halted prematurely. A cross section at smaller scale (Fig. 6) depicts the Massac Creek structure in its larger context. The unnamed Neogene to early Pleistocene unit first identified in #R-1 is 79 m thick in J-7, and overlies 12 m of typical Mounds Gravel. The Mounds is downthrown 150 m relative to outcrops on hilltops that surround the Massac Creek graben. The age of the Mounds is bracketed as Upper Miocene to lower Pleistocene, which is the same age range as determined by fossil pollen from the overlying unnamed unit in #R-1. Thickness of the Mounds, about 12 m, is near normal for that unit and implies that the gravel was displaced after (not during) deposition. The unnamed unit has no lithologic or temporal equivalent anywhere in southern Illinois or, for that matter, anywhere in the Mississippi Embayment north of the state of Mississippi. Its presence here must reflect the active and ongoing subsidence of the Massac Creek structure during late Miocene, Pliocene, and early Pleistocene time. Most likely, the bulk of subsidence took place during the Pliocene.

Beneath the Mounds Gravel in borehole J-7 were found 10.4 m of the Porters Creek Clay (Paleocene), 1.2 m of the Clayton Formation (Paleocene), 4.8 m of the Owl Creek Formation (Maastrichtian or uppermost Cretaceous) and 33.2 m of the McNairy Formation (Maastrichtian or uppermost Cretaceous). The base of the latter unit was not reached. The Porters Creek, Clayton, and Owl Creek Formations do not occur in Massac County except in grabens. Elsewhere in the county, the Mounds Gravel unconformably overlies the McNairy. Presence of Porters Creek, Clayton, and Owl Creek necessitates that the graben was active between Paleocene and late Miocene time. A minimum displacement of 17 m is required to account for the formations that were eroded elsewhere in Massac County.

Rosebud Road

Turning to the cross section along Rosebud Road (Fig. 7), the graben seems to be wider but less complex than on the Weaver farms. Holes RK1 and RK5, near the ends of the cross section, penetrated loess overlying horizontal McNairy Formation. Hole RK4, on the west, drilled into a tilted fault block having Metropolis Formation overlying McNairy Formation that dips 30 to 40 degrees southeast, as shown by an oriented core. Holes RK2 and RK3, in the central graben area (as indicated by the seismic profile) encountered thick Metropolis Formation but we were unable to penetrate this unit. What underlies the Metropolis in this area is unknown.

Our drilling on the Weaver Farms and along Rosebud Road disclosed no thickness changes that might be attributed to faulting in the Wisconsinan loess or the Holocene alluvium. On the two detailed cross sections (Figs. 5 and 7), note that thicknesses of these units appear to be quite uniform. While mapping this area, we walked along the beds of Massac Creek and its tributaries, carefully examining the alluvium for any faults, systematic joints, liquefaction features, or other evidence of tectonic activity. No such evidence was observed.

Conclusions. The structure at Massac Creek is a complex graben that strikes north-northeast. This graben is part of the Hobbs Creek Fault Zone of the FAFC, and it has undergone multiple episodes of movement. One episode took place between the Eocene and the late Miocene, so that slices of latest Cretaceous, Paleocene, and Eocene strata were dropped down and preserved. Greater displacements took place between the late Miocene and the Illinoian Stage of the Pleistocene, displacing the Mounds Gravel 150 m downward and preserving a substantial thickness of Pliocene and Pleistocene sediments. We found no evidence for any displacement or deformation of Wisconsinan or Holocene sediments.

Choat

Background. The Choat site is located in western Massac County, about 8 km northwest of Metropolis and 4 km east of Joppa (Fig. 3). The ISGS became interested in the Choat area when we began mapping the Joppa Quadrangle in 1997. During this mapping we uncovered evidence of faults displacing geologically young formations in the Choat area. The evidence included abrupt changes in elevation and steeply tilted bedding of sand, gravel, and clay deposits observed in gravel pits and at the old Metropolis city landfill. Also, the log of a water well at the residence of Melferd Krueger, Jr. showed abnormally great depth to bedrock, suggesting that the well was drilled into a graben. Additional studies we carried out to investigate the faults at Choat included:

- Geologic mapping of the entire surrounding area.
- A seismic survey along Crim and Mount Mission Roads, intended to provide images of faults at depth.
- Ground-penetrating radar surveys in a pasture south of Crim Road. These surveys did not yield useful results.
- Drilling test holes at the Metropolis landfill and on the Krueger farm.

Findings. Geologic mapping indicates that the fault zone at Choat is roughly one mile wide and consists of numerous parallel fractures that trend north-northeast. These fractures are part of the Raum Fault Zone, which extends about 35 miles northeast from Choat to the northeastern corner of Pope County. The Raum Fault Zone in turn is part of the FAFC, and probably continues southwest into Kentucky, but there is no evidence there to map it.

A detailed geologic map of the Choat area (Fig. 8) shows faults and the distribution of formations in an area of about four square miles. Not shown on the map is loess, which blankets nearly all upland areas. The loess is of middle to late Pleistocene age (10,000 to 125,000 years old) and commonly is 1.5 to 4.5 m thick, as shown by drill holes and exposures in pits.

Krueger Farm

The seismic profile along Mt. Mission and Crim Roads showed numerous faults offsetting the Mississippian limestone bedrock. These faults dip steeply to nearly vertically, and outline grabens and horsts, as shown on the cross section (Fig. 9).

One graben is indicated on the seismic profile at the junction of Mt. Mission and Staton Ridge Roads, east of U.S. Rt. 45. A test hole here (ISGS #2 Krueger) penetrated 3.3 m of Cahokia Formation (gray to brown silt) and 12.8 m of Metropolis Formation (mottled gray, yellow, and orange sand and silt with gravel) without reaching the base of the Metropolis. Interpreting this borehole is difficult. Possibly, the Metropolis Formation fills a graben that formed during or after sedimentation; but deposition of Metropolis in an ancient stream channel is at least equally plausible.

Another graben passes through the Krueger residence on Crim Road west of Rt. 45. The Krueger water well is 122 m deep and did not reach bedrock. Because most other wells in the area reached bedrock at much shallower depths, we believe the Krueger well is in a graben where the bedrock is downthrown 60 to 75 m. Also, the log of the water well indicated gravel at a depth of 18 to 24 m. If this is the Mounds Gravel, the Mounds also is faulted down, and the faults were active at least into late Tertiary time.

The ISGS drilled two cored test holes near the Krueger residence. Their logs are shown as graphic columns (Fig. 10). The ISGS #1 Krueger penetrated 4.9 m of loess, 1.2 m of colluvium (a mixture of silt and gravel), and 8.2 m of fine to coarse, red to orange sand that probably is part of the Mounds Gravel. Some of the core samples showed layering in the sand dipping at 20 to 40 degrees. The drill rods became stuck at 14.3 m and we had to abandon the hole; but #1 Krueger did verify the presence of a fault zone at this site.

In July of 1999 we drilled another test hole, ISGS #3 Krueger, in a pasture northeast of the Krueger's house. This hole penetrated loess from 0 to 5.0 m (Fig. 10). From 5.0 to 9.0 m feet the samples were Mounds Gravel, fine reddish-gray sand at the top grading down to coarser pebbly sand, then gravel at the base. Below the mounds Gravel is about 1.5 m of Porters Creek Clay, below which is the McNairy Formation.

Layering in the McNairy dips about 30 degrees (the direction of dip could not be determined because the hole was drilled by rotary method). As at Massac Creek, the Porters Creek Clay is unexpected in Massac County; its presence strongly implies subsidence of the graben between Paleocene and Miocene time. Additional evidence for Tertiary movement is found in differential displacement of units of different age. The base of the McNairy Formation is downthrown 60 to 75 m into the Krueger graben, whereas the base of the Mounds Gravel is displaced approximately 45 m. No offset of the loess can be detected.

Metropolis Landfill

Borrow pits and bulldozed areas near the northwest corner of the city property reveal tilted and faulted McNairy Formation and Mounds Gravel overlain by undeformed loess. More information comes from the logs of water-monitoring wells on the property and from four cored test holes drilled by the ISGS. A cross section (Fig. 11) shows interpreted faults.

The evidence points to another graben, which probably lines up with one shown on the seismic profile near the junction of Rt. 45 and Mt. Mission Road. At the landfill, one of our test holes, LF-1, penetrated the graben. Mounds Gravel is at the surface and consists of gravel at the base, grading up to bright red and orange sand. Below the Mounds in LF-1 is an unexpected unit, the Clayton Formation (Paleocene), which consists of distinctive dark gray to black, sandy clay that contains a great deal of glauconite. Occurrence of the Clayton here is evidence that the faults were active during the Tertiary Period. Below the Clayton in LF-1 is the McNairy Formation.

Good exposures of Pleistocene loess and colluvium can be seen in a borrow pit near the northwest corner of the city property close to where we drilled. Units identified here include **(1)** Peoria Silt, of late Wisconsinan age, **(2)** Roxana Silt, of early Wisconsinan age, **(3)** Loveland Silt, of late Illinoian age, and **(4)** a thin layer of reworked mounds Gravel, interpreted as pre-Loveland colluvium. All four units are horizontal and contain no faults. An angular unconformity separates horizontal loess and colluvium, above, from sand of the Mounds dipping 30 to 40 degrees southeast. Evidence from the landfill therefore indicates that faults were active as early as Paleocene and no later than Illinoian time.

Faults southwest of landfill

Small faults were observed displacing the Metropolis Formation (Pleistocene) along a linear streambed about 0.9 km southwest of the Metropolis landfill (Fig. 8). In one exposure, two parallel faults about 40 cm apart trend N25E/80-85 NW, outlining a block of sandy silt juxtaposed with coarse gravel on either side. About 30 m northeast along the same stream are several clay-lined fractures and a fault that strike N35E and dip vertically. No slip indicators were observed, and the amount and direction of displacement could not be determined. Faults and fractures are truncated by horizontal, unfractured Holocene alluvium. The faults observed here are directly in line with those mapped at the landfill.

Water tower graben

The westernmost faults shown on the geologic map pass near the water tower on Crim Road (Fig. 8). Evidence for these faults is scanty, but suggests faults were active during the Pleistocene. Along a ravine northeast of the water tower are exposures of what appears to be the Metropolis Formation, and it contains numerous fractures. Southwest of the water tower, the log of a water well (Edwards) on Old Joppa Road indicates that Mounds Gravel and the top of bedrock are at least 15 m lower than their expected elevations.

Conclusions. Our studies in the Choat area indicate a zone of faults roughly one mile wide and trending north-northeast. These faults are part of the Raum Fault Zone in the FAFC. Most faults are nearly vertical, outlining narrow grabens and horsts. Formations that are displaced include Mississippian bedrock, Cretaceous McNairy Formation, early Tertiary Clayton Formation and Porters Creek Clay, late Tertiary to early Pleistocene Mounds Gravel, and early to middle Pleistocene Metropolis Formation. Formations that are not faulted (as far as we can tell) are late Pleistocene loess on the uplands, and late Pleistocene to Recent Equality and Cahokia Formations (alluvium) in bottomlands.

We conclude that faults in the Choat area were active during the Tertiary Period (before Mounds Gravel), because the Porters Creek Clay and Clayton Formation, unexpected in Massac County, were dropped down and preserved in grabens. The faults were active again during the early to middle part of the Pleistocene, displacing the Mounds Gravel and, at least locally, the Metropolis Formation. These faults have probably been inactive for at least 100,000 to 125,000 years.

Maple Grove

Background. The water well at the Maple Grove School, about two miles northwest of Joppa (Fig. 3) drew our attention to a possible fault here. The well was drilled in 1959 on the playground behind the school building. A driller's log and an incomplete set of soil samples (cuttings) are on file at the ISGS. These data indicate the depth to bedrock is at least 36 m greater at the school than in wells surrounding the school. Although several explanations are possible, the most likely is that the school well drilled into a graben.

Further study at Maple Grove School included three steps: **(1)** Analysis of existing outcrops and well data. **(2)** Geophysical surveys, using ground-penetrating radar and seismic reflection methods. **(3)** Test drilling.

Existing data. Logs of water wells and engineering borings indicate that a fault zone displaces Mississippian bedrock beneath the Maple Grove School. The fracture zone runs north-northeast from the Ohio River through Maple Grove School to Mermet Lake and beyond (Fig 3). Near the school, Mississippian limestone formations (about 340 million years old) are displaced about 30 m downward on the southeast side of the fault. North of Mermet Lake, the Maple Grove fault lines up directly with the Lusk Creek Fault Zone, a major component of the FAFC (Figure 3).

Surface mapping was carried out but yielded few clues because of thick loess cover. The best nearby outcrops are along a small south-flowing creek 1.2 km west of Maple Grove School. This creek has eroded through the loess in many places, exposing the Metropolis Formation, which consists of compact clayey silt and sand containing small, scattered chert pebbles and pockets of gravel. Many vertical fractures cut the Metropolis, and they have two consistent trends. One set of fractures runs northeast to east-northeast, and the other set runs north-northwest. A few of the fractures are small faults, having displacements of less than one foot. None of the fractures affect the loess. These fractures suggest that small earth movements occurred here during the early to middle Pleistocene Period (more than 125,000 years ago).

Geophysical surveys. In the summer of 1998 we ran geophysical surveys near Maple Grove School in an effort to learn more about subsurface conditions. First, a ground-penetrating radar survey was run south of the school, crossing the projected fault line from east to west (Fig. 12). However, no useable data were collected. Apparently, the clay-rich silty soil (loess) was so dense that all of the radar energy was absorbed or reflected back within a few feet of the surface.

The seismic survey was run north of Maple Grove School following Garden Road and a private lane on Jimmy Rodgers' property (Figure 12). Results were quite good. A series of well-defined reflectors represent Paleozoic bedrock and overlying Cretaceous and younger sediments. We interpreted three small grabens, near vibration points 125, 200, and 300. Another fault, which appears to have the east side downthrown, is near vibration point 400. Several small faults are near the surface between points 300 and 400. From the seismic data we can say that several faults break the Cretaceous sediments, and may affect younger layers as well.

Drilling - Rodgers farm. The third and final stage of our investigation was test drilling to determine which rock and sediment layers are affected by the faults. First, seven shallow holes were drilled using the AMS Power Probe along the line of the seismic survey. A cross-section on the Rodgers farm (Fig. 13) is based on the seismic profile and the shallow drilling. Drilling shows that the surface material is loess that varies from 1.5 to 4.3 m thick. The next older unit is the Metropolis Formation, which was found only in hole JR3, where it is 2.7 m thick, and hole JR4, where it is 1.2 m thick. This unit is of Pleistocene age and is older than 125,000 years. Next older is the Mounds Gravel, red to brown chert gravel and coarse sand, found only at the top of the hill in hole JR1. All 7 holes reached the McNairy Formation (Cretaceous), where drilling was halted.

Drilling provided good evidence that the McNairy has been faulted. In several cores, layering of the McNairy is inclined at 20 to 40 degrees. The inclined layering was found in areas where the seismic profile indicates faults, and confirms that at least some faults are post-Cretaceous. Evidence on younger movements at the Rodgers farm is ambiguous. Mounds Gravel is present only on the hilltop and does not occur in the graben at holes JR3, JR4, and JR5 (Fig. 13). Had the faults been active after deposition of the Mounds, we would expect to find this unit downthrown into the graben. Its absence suggests that the graben is Miocene or older. The Metropolis Formation was found only in the graben, but it is thin, and Pleistocene faulting cannot be inferred thereby. Perhaps, the Metropolis merely filled a small valley. Loess deposits on the Rodgers farm appeared entirely normal for un-faulted areas of Massac County, and we are confident to say that faults here have not been active since the loess was deposited.

In conclusion, faults on the Rodgers farm were active after Cretaceous deposition but probably have been inactive since late Tertiary.

Drilling - Maple Grove School. We drilled two test holes near the old water well at Maple Grove School to try to get better samples from the fault zone here. The first hole was drilled in August, 1997 using the Geoprobe, a small drill rig similar to the AMS Power Probe. This hole was drilled a short distance northeast of the water well and reached a depth of 23.2 m, at which point further penetration was impossible. The following materials were encountered:

0 to1.8 m	Peoria Silt, mottled gray to yellow-brown loess.
1.8 to 3.5 m	Roxana Silt, yellowish to brown loess.
3.5 to 4.9 m	Loveland Silt, yellowish-gray to orange, strongly mottled, sandy loess.
4.9 to 6.8 m	Loveland(?) Silt, similar to above, with coarser sand and small granules.
6.8 to 11.6 m	Metropolis Formation, mottled gray, yellow, orange, and red silty and sandy clay mixed with chert pebbles.
11.6 to 23.2 m	Unidentified unit, silt and fine to medium sand of various colors, no pebbles, loose to compact.

In July, 1999 the U.S. Geological Survey drilled a deeper hole into limestone bedrock a few hundred feet southwest of the school water well. The following strata were encountered:

0 to1.8 m	Peoria and Roxana Silt.
1.8 to 3.0 m	No samples, the interval is probably mostly loess.
3.0 to 17.8 m	Metropolis Formation, mottled silt and sand with gravel at base
17.8 to 33.5 m	Unidentified sand, very fine to medium, colors vary, some silt

	layers.
33.5 to 38.7 m	Gravel, light gray chert pebbles with coarse white to gray sand.
38.7 to 99.4 m	McNairy Formation, mostly loose and water-bearing sand that is light gray to yellow and very fine to fine-grained, with mica.
99.4 to 109.0 m	Post Creek Formation, sandy clay mixed with gravel and chunks of chert.
109.0 to 110.0 m	Limestone, medium to dark gray. Probably the Salem Limestone.

The second hole answered some, but not all of our questions. It definitely indicates a graben that offsets the Cretaceous McNairy and Post Creek Formations, as well as the gravel and sand from 17.8 to 38.7 m. The latter unit does not resemble any formation found elsewhere in Massac County. The gravel definitely is not Mounds, because it lacks the distinctive red to brown color and patina of the Mounds. The sand is similar to the Wilcox Formation (Eocene), which occurs a short distance to the south in Kentucky and also is found near Olmsted in Pulaski County. Finally, both the shallow and the deep ISGS test holes encountered the Pleistocene-age Metropolis Formation above the sand and below the loess. Whether the Metropolis was dropped down into the graben by fault movements, or merely filled a small valley here, is not clear.

A cross section (Figure 14) shows what we believe the fault zone looks like. The cross section is about 5 km long and runs northwest, from the E.E.I. power plant through Maple Grove School. Two faults outline a narrow graben at the school. In this graben the Mississippian bedrock, the Cretaceous McNairy Formation, and the Eocene(?) sand and gravel dropped downward. The Pleistocene Metropolis Formation may also be faulted, but the amount of offset was less than on the older formations.

Conclusions. A fault zone underlies the Maple Grove School northwest of Joppa. The zone consists of several (perhaps many) parallel fractures that run north-northeast and are part of the Lusk Creek Fault Zone, which has been mapped northeast into Pope County where it connects with other faults. Drilling at the school indicates at least two faults that outline a graben. The seismic profile indicates three small grabens, along with several other faults, on Jimmy Rodgers' farm northeast of the school.

The seismic survey and drilling clearly indicate that faults were active after the Cretaceous Period. Sand and gravel of possible Eocene age at the school also is offset by faults. The Mounds Gravel does not appear to be faulted on the Rodgers farm. The Metropolis Formation, as young as 125,000 years, may be faulted at the school, as indicated by drilling. Small faults and parallel, well-aligned fractures seen along a stream west of the school also indicate earth movements within about 125,000 years of present. Loess is not broken by any faults or fractures. Most likely, the major activity on the fault zone at Maple Grove took place in middle Tertiary time (Eocene to Miocene), with minor adjustments during the early to middle part of the Pleistocene.

Post Creek

Background. Post Creek Cutoff is a ditch that was dug in the 1910s to drain the swampy Cache Valley to the Ohio River for agriculture (Fig. 15). Because digging the ditch lowered local base level, severe gullying has taken place along Post Creek Cutoff. One of these gullies exposed a graben-like structure in which the Mounds Gravel is 45 m below its normal elevation. Kolata et al. (1981) investigated this structure by drilling, and concluded that it was formed by solution-collapse of underlying limestone bedrock.

Observing that the Post Creek structure resembles nearby grabens that definitely have a tectonic origin, we carried out further studies at Post Creek. A seismic reflection profile run in 1998 indicated the bedrock is faulted. Test drilling in 1999 verified that one of the faults shown on the seismic profile displaces the McNairy Formation. Then, in February 2000, we found and described two additional graben-like structures along Post Creek Cutoff. The three structures are discussed separately below. The original structure that was studied by Kolata et al. (1981) is designated Post Creek South. The two new structures are Post Creek Central and Post Creek North (Fig. 15).

Post Creek South. The Post Creek South structure is exposed in a ravine east of Post Creek Cutoff and south of Ducks Lane (Figs 15, 16). A block of gravel and sand of the Mounds Formation about 135 m wide is folded into an open syncline, and downdropped into contact with the McNairy Formation on either side (Figure 17). The Mounds-McNairy contacts on the flanks of the feature dip steeply inward, but these appear to be depositional contacts rather than faults. The western contact strikes north-south and the eastern contact dips N 25 E.

Kolata et al. (1981) drilled three test holes to investigate Post Creek South. The cross section (Fig. 17) shows how these borings were used to interpret the structure. Miller #1, drilled near the eastern margin of the downdropped block, and Miller #3, drilled outside of the structure, both encountered the Ullin Limestone (Osagian; upper Lower Mississippian). A contact between light gray, coarse bryozoan-rich limestone (Harrodsburg Member, above) and dark gray, micritic limestone (Ramp Creek Member, below) was found at nearly the same elevation in Miller #1 and Miller #3. Based on this evidence, Kolata et al. (1981) concluded that the bedrock at Post Creek South is not faulted. Observing numerous karst features in limestone that crops out along Post Creek Cutoff west of the downdropped structure, Kolata et al. theorized that Post Creek South resulted from the collapse of a large mass of McNairy and Mounds Formations into a sinkhole in the Ullin Limestone.

Old findings re-evaluated

We revisited the ravine and nearby outcrops several times in search of new evidence on the origin of Post Creek South. One new discovery is a fault about 18 m east of the downdropped Mounds Gravel. This fault strikes N 20 W, dips about 70 degrees west and displaces McNairy Formation a minimum of 1.5 m. It is a normal fault and is accompanied by numerous small antithetic and synthetic normal faults.

Limestone is exposed along the bed of Post Creek Cutoff northwest of the ravine where the structure is seen (Fig. 16). Although Kolata et al. (1981) referred to the rock as Ullin Limestone, its lithology and fossils are characteristic of the younger Salem Limestone (Meramecian; lower Upper Mississippian). In fact, the limestone exposed in Post Creek Cutoff probably is upper Salem, younger than the Ullin Limestone encountered in the three Miller boreholes. Thus it is likely that the Miller boreholes penetrated a downthrown fault block and the outcrops in the ditch are on an upthrown block.

Re-examining the Miller cores, we agreed with the stratigraphy interpreted by Kolata et al. (1981). However, some facts about Miller #1 are worthy of mention. From a depth of 39.9 to 63.4 m, the driller had problems with lost circulation and stuck drill rods, and no samples were recovered. In fact, at a depth of 62.7 m the driller abandoned the original hole, skidded the drill rig a short distance, and started a new hole. Core samples of limestone were taken in the second hole from 63.4 to 76.0 m (total depth).

These facts suggest that Miller #1 drilled through a fault (Figure 18). Faults frequently cause drilling problems such as stuck rods, lost circulation, and difficulty in sampling. Note that Miller #1 was drilled very close to the edge of the Post Creek structure. Unless the eastern boundary is nearly vertical, we would expect the drill hole to cross it. Actually, the eastern boundary, as exposed in the ravine, dips about 50 degrees. If Miller #1 crossed the fault, it encountered the Ullin Limestone in the footwall of the fault, explaining why there is no apparent offset in the Ullin between Miller #1 and Miller #3.

Seismic Survey

In June of 1998 we ran a seismic survey about ½ mile long along Tick Ridge Road. Our intent was **(1)** to try to detect either faults or karst features in the bedrock, and **(2)** to determine whether Post Creek South is linear, favoring a fault origin. If the seismic profile showed undisturbed bedrock, a karst origin for the structure would be implied.

The Post Creek seismic profile showed tilted and offset reflectors at the depth of Paleozoic bedrock. The largest fault, labeled Fault C on Figure 16, is near shot point 80, which is a short distance east of the intersection of Ducks Lane with Tick Ridge Road. Bedrock reflectors east of Fault C appear to be downthrown to the east. Fault C appears to line up with the western edge of the structure seen in the ravine. The eastern boundary of the structure in the ravine may line up with Fault E on the seismic profile, but this is not certain. No sinkholes are evident on the seismic profile, although small ones could be present. A sinkhole presumably would appear as a gap in near-surface reflectors, with no offset of deeper reflectors.

Drilling

As the final step in our investigation we drilled eight cored test holes, ranging from 7.5 to 17 m deep, with the AMS Power Probe. The holes were drilled north of Tick Ridge Road adjacent to the seismic line (Fig. 16).

Drilling showed the surface material to be loess that varies from 9 to 16 feet thick (Figure 19). The Peoria and Roxana Silts (Wisconsinan) were present in all eight holes, and the Loveland Silt (Illinoian) was identified in several. Beneath the loess is a layer of colluvium composed of weathered clay, sand, and gravel that varies from about 10 to 140 cm thick.

We did not find Mounds Gravel in any of the eight holes; however, hole MJ2 encountered 2.7 m of coarse orange sand that resembles the upper part of the Mounds exposed in the ravine. Otherwise, all holes entered the McNairy Formation below colluvium and loess (Figure 19). Evidence of a fault was found in samples from hole CJ1. The McNairy Formation in this hole consists of dark gray, stiff clay that contains thin layers of light gray silt and sand. The sandy layers dip about 50 degrees from vertical, and near the bottom of the hole, there is a sheared zone and a nearly vertical contact to fine sand below. The vertical contact looks like a fault. In hole CJ4, drilled only 27 m east of CJ1, there was no clay in the McNairy, only sand in which the layers dipped 5 to 10 degrees. Another 18 m east, and lower in elevation, hole MJ2 found 2.7 m of possible Mounds sand overlying finer-grained McNairy sand that has horizontal layers. If the coarser sand in MJ2 is Mounds, a fault having the east side downthrown is indicated. Referring to the seismic profile, the largest fault, Fault C, is indicated very close to the location of hole CJ1, CJ4, and MJ2. The drilling thus confirms the seismic data in showing that the McNairy Formation and possibly the Mounds Gravel, along with Mississippian limestone, have been tilted and faulted.

Topographic features align with the faults inferred from seismic and borehole data. North of Tick Ridge Road, a valley coincides with the area between faults C and E. Farther north, for a distance of more than a mile north of Tick Ridge Road, a linear ridge that trends N 15 E is in line with the inferred faults. Projecting this trend another 6 miles north, the Post Creek South structure aligns with the Little Cache Fault Zone, a zone of high-angle normal faults that displace Mississippian and Pennsylvanian bedrock (Fig. 3).

Conclusions

The available evidence strongly but not conclusively favors a tectonic origin for Post Creek South. The seismic data indicate large faults in the Mississippian limestone. The elevation difference between Salem Limestone outcrops and Ullin Limestone in the Miller boreholes also suggests a fault. The borders of the structure exposed in the ravine are in line with faults indicated on the seismic line and with a linear ridge and valley. Borehole CJ1 penetrated a fault surface in the McNairy Formation. Post Creek South closely resembles known tectonic grabens of southernmost Illinois, and it is in line with the Little Cache Fault Zone, which displaces Paleozoic bedrock north of the Cache Valley (Fig. 3).

The Post Creek South structure displaces the Mounds Gravel and does not displace Wisconsinan and Illinoian loess and colluvium. Accordingly, the time of movement is dated between the late Tertiary (probably Pliocene) and the Illinoian Stage of the Pleistocene.

Post Creek North. The Post Creek North structure was discovered by Martitia Tuttle (then at the University of Maryland) in April 1996. She described steeply dipping red sand and gravel in the bank of Post Creek Cutoff approximately 1.6 km north of Tick Ridge Road (verbal communication, April 1996). The feature Tuttle observed is visible only at low water, and it was first examined by ISGS personnel in February 2000. The structure is located on the east bank of Post Creek Cutoff. The legal location is approximately 2100 feet from north line, 1800 feet from east line, Sec. 35, T14S, R2E, Pulaski County, Karnak 7.5-minute quadrangle.

The Post Creek North structure is at least 60 m wide and trends northwest (Figure 20). It is a complex graben containing McNairy, Mounds, and Metropolis Formation juxtaposed with Mississippian limestone on north and south. Limestone to the immediate south is gray, cherty skeletal grainstone and packstone that contains scattered oolites and a diverse, open marine fauna, including the "finger coral", *Acrocyathus proliferus*. This fossil and lithology are diagnostic for the upper part of the Salem Limestone. Limestone in the bed of the ditch about 200 m north of the exposed structure is largely gray, dense lime mudstone that contains black chert nodules and specimens of the colonial coral *Acrocyathus floriformis.* This fossil and rock type are characteristic of the lower part of the St. Louis Limestone, within 9 to 12 m of the contact with the underlying Salem Limestone. Thus, the limestone south of the Post Creek North structure is slightly higher structurally (older rocks are at higher elevation on the south).

Directly overlying limestone south of the structure is at least 3 m of residuum composed of angular chunks of chert and silicified limestone in a matrix of red to yellowish-orange sand and clay (Figure 20). The residuum is directly overlain by clay and silt of the Equality Formation (Wisconsinan); no Mounds Gravel or McNairy Formation is in the southern area.

Steeply dipping McNairy Formation is overlain by Mounds Gravel near the southern margin of the structure. Bedding of both formations strikes N45E and dips 50 to 60 degrees northeast. The middle part of the structure (right side of Figure 20) contains pebbly sands and silts that are thoroughly burrowed and strongly mottled in shades of gray, yellow, orange, and red. The gravel portion is composed of rounded chert pebbles derived from the Mounds Gravel (brown patina partially bleached and worn). These sediments are typical of the Metropolis Formation, an alluvial deposit of early to middle Pleistocene age. Bedding of the Metropolis is horizontal toward the south; northward the dip increases to 25-30 degrees southeast, and several faults displace the Metropolis (Fig. 20, 21). A vertical fault separates Metropolis Formation from McNairy Formation and Mounds Gravel that dip steeply (nearly vertical in places) and contain numerous faults. Overall trend of faults and bedding is NW to WNW, and the larger faults generally are vertical, or nearly so.

Overlying all of the deformed strata are drab-colored soft silts and clays of the Equality Formation. Although the contact is mud-draped and we made no effort to dig it out, it appears that bedding of the Equality is horizontal and that this unit was not involved in the deformation that affects underlying strata.

Interpretation

Interpreting the Post Creek structure is complicated by incomplete, mud-draped exposures and modern slumping and landsliding. Nevertheless, there is no doubt that the McNairy Formation and Mounds Gravel are displaced. The Mounds-McNairy contact lies consistently at elevations of 120 to 135 m on hills that surround the Post Creek North site. At Post Creek North, the same contact is below water (and dipping vertically) at an elevation of about 93 m. Mounds and McNairy are juxtaposed with Mississippian limestone on both south and north.

Two hypotheses are proposed to explain the Post Creek North structure. One is collapse of caverns in the Mississippian limestone. Given that the Mounds Gravel is lowered at least 27 m below its normal elevation, at least that much limestone had to be dissolved away to lower the gravel by that amount. The Salem Limestone is prone to karst activity, and karst features definitely are present near Post Creek Cutoff. However, no features were observed at Post Creek North that directly address the question of whether solution collapse played a role in forming the structure.

Tectonic faulting is our preferred hypothesis to explain Post Creek North. The presence of several vertically dipping, northwest-striking fault planes in the bank exposure, juxtaposing slices of Mounds and McNairy, seems easier to explain by tectonic faulting than by solution collapse. The latter process might be expected to lower the sediments straight down in more or less jumbled fashion. We plan to conduct further studies of Post Creek North when conditions permit.

Post Creek Central

The Post Creek Central structure was discovered by the ISGS in February, 2000. It is exposed at low water in the west bank of Post Creek Cutoff about 250 m north of Tick Ridge Road (1100 feet from north line, 2000 feet from west line, Sec. 2, T15S, R2E, Pulaski County, Bandana 7.5-minute quadrangle).

The Salem Limestone crops out beneath the bridge carrying Tick Ridge Road across the cutoff. The limestone passes under water a short distance north of the bridge, but the overlying Post Creek Formation (Cretaceous) continues along both banks nearly 250 m north of the bridge. At this point (Figure 22, left side) the Post Creek dips sharply under the water, rises again in a little arch, then it dives under water again. A short distance north of the point where the Post Creek Formation disappears, McNairy Formation is in the west bank, and it dips very steeply northwest. The McNairy is overlain to the north by Mounds Gravel that is cemented by iron oxide and also dips steeply (bedding N 55 E/ 80 degrees NW. A short distance north of the steeply dipping Mounds Gravel is brightly colored silt, sand, and gravel of the Metropolis Formation. The bedding of the Metropolis is lenticular and displays cut-and-fill structures, but it is horizontal or nearly so, and no faults were observed. The bank north of the Metropolis exposure is covered with mud for a distance of several hundred feet to the north, and there are no outcrops on the east bank opposite the structure shown in Figure 16.

Interpretation

Although incompletely exposed, the Post Creek Central structure appears similar to Post Creek North and especially to Post Creek South. The Mounds Gravel again has been displaced downward at least 30 m, so that it lies below the level of limestone bedrock a short distance south. The Mounds and McNairy, dipping nearly vertical where observed, probably flatten out at depth and then rise up again in the covered area north of the horizontal Metropolis Formation. The Metropolis was not obviously deformed, but may have been deposited largely in the depression formed by foundering of the Mounds Gravel. The Loveland (Illinoian), Roxana, and Peoria (Wisconsinan) loesses on the bluff above the structure are horizontal and undisturbed.

Unity School

Background. The Unity School site is located about 16 km north-northeast of Metropolis in eastern Massac County (Fig. 3). As in several other cases, an anomalous well record suggested a graben. The key well is a bridge boring made by the Illinois Department of Transportation (IDOT) for the bridge that carries Unity School Road across Davis Bayou (0' from north line, 1500' from west line, Sec. 5, T16S, R6E, Paducah Northeast 7.5-minute quadrangle). This boring was drilled to a depth of 111 feet (33.8 m) without reaching bedrock, whereas less than 1 km northeast of the bridge, Mississippian sandstone is at the surface. Further suspicion was raised by the log of the IDOT boring. It indicates variable gray to brown silty clay and silty clay loam, with scattered gravel, to a depth of 30 m, and dense brown sand and gravel from 30 m to the bottom of the hole. The normal floodplain succession in the Unity School area finds less than 15 m of Cahokia, Equality, and Metropolis Formations (largely silt), overlying the McNairy Formation, which is well-laminated sand and clay that lacks gravel.

To obtain more information we drilled a cored test hole near the Davis Bayou bridge. The following strata were penetrated:

0 to 2.5 m	Cahokia Formation: mottled, laminated to massive silt and sand.
2.5 to 8.3 m	Equality Formation: clay and silt, olive-gray to dark gray, organic matter common, laminae of sand.
8.3 to 21.0 m	Metropolis Formation: pebbly sand and silt, mottled yellow, orange, gray, and brown; reworked Mounds gravel.
21.0 to 25.9 m	Mounds Gravel: sand and gravel, chert pebbles having typical bronze patina. Refusal at 25.9 m.

Our log verified the IDOT log, showing good agreement in description of materials. However, the top of the Mounds was encountered at a depth of 21 m in our boring, compared to 30 m in the IDOT boring, less than 30 m northwest from our drill site. An elevation difference of 9 m in a lateral distance of 30 m is equivalent to a minimum dip of 16 degrees (if the IDOT boring is not directly down dip from the ISGS boring, the actual dip is greater than 16 degrees). Such a dip strengthens the interpretation that tectonic faulting is involved here.

The Unity School site is in line with mapped segments of the Rock Creek Graben, several km to the northeast (F. Brett Denny and John M. Masters, unpublished data), and about 4 km south of the Mallard Creek site, where faults associated with the Rock Creek Graben displace sediments as young as Wisconsinan (Nelson et al., 1999a).

Although the evidence is not conclusive, presence of a Quaternary tectonic graben at the Unity School site is strongly suggested.

SUMMARY

Test drilling and field studies during 1999 and early 2000 provide new insights on neotectonic faulting in southernmost Illinois. The five structures that we studied this season are complex grabens that strike north-south to northeast-southwest and are part of the Fluorspar Area Fault Complex. These steeply dipping, basement-seated faults date back at least to the latest Proterozoic to early Cambrian extensional event that created the Reelfoot Rift. Faults that are currently active in the New Madrid Seismic Zone formed during the same rifting event, and some are directly in line with faults in southern Illinois. All of these faults have undergone multiple episodes of movement under different stress regimes, dating from Cambrian through Quaternary.

The Choat, Maple Grove, and Massac Creek structures in our study area were active between Eocene and Miocene time. As a consequence, the Owl Creek Formation (latest Cretaceous), Clayton and Porters Creek Formations (Paleocene), and Eocene strata were dropped downward into grabens and preserved. Outside of grabens, those units were eroded prior to Pliocene time. All five structures described in this report were active during Neogene and early to middle Pleistocene time, displacing the Mounds Gravel and the Metropolis Formation. The greatest displacements took place in the Massac Creek structure, where the Mounds Gravel is downthrown 150 m and a younger, unnamed Neogene to Quaternary interval 79 m thick accumulated in the subsiding graben. The youngest formation displaced at any of the five sites is the Metropolis, which bears the Sangamon Geosol at the top and therefore is Illinoian and older (125,000 years or more). No deformation of Wisconsinan or Holocene sediments has been detected at these sites. Therefore, we conclude that the last active movements on these five structures took place more than 75,000 years ago.

These findings are in concert with those from other neotectonic sites in southernmost Illinois, on which we reported previously (Nelson et al., 1997 and 1999a). At these other sites, upper Tertiary and lower to middle Pleistocene sediments exhibit large offsets, a few small faults displace Wisconsinan sediments, and none affect Holocene deposits.

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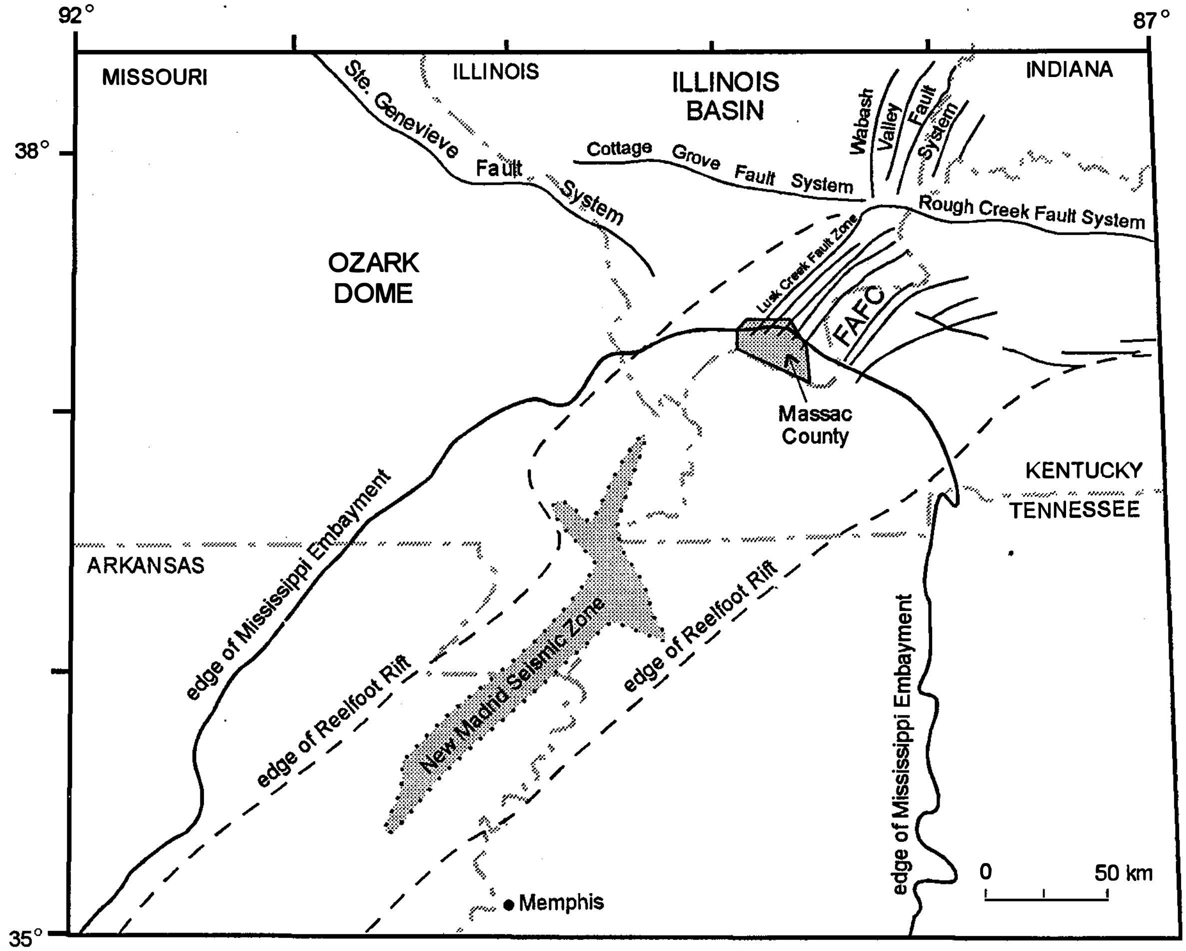
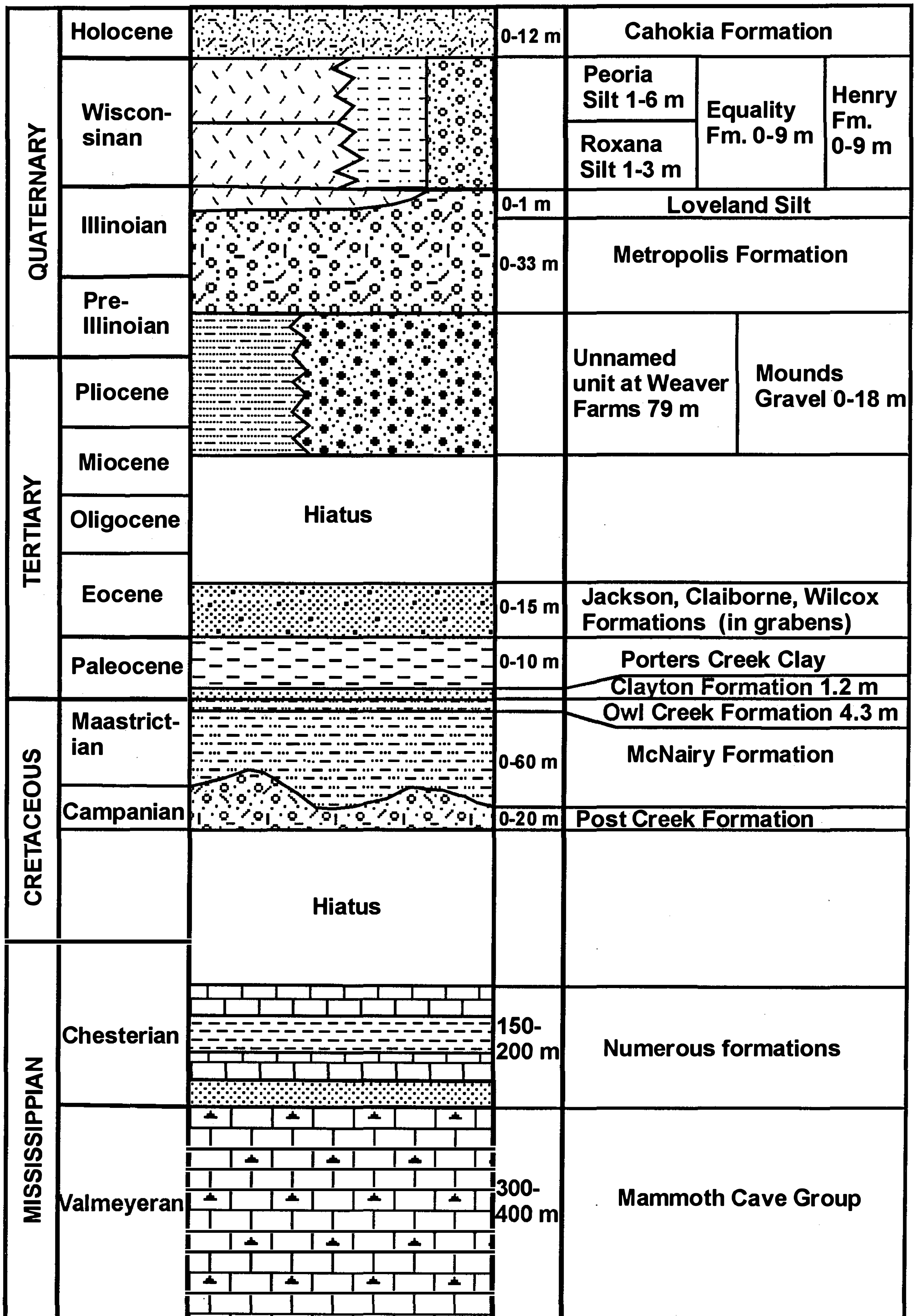


Figure 1. Map of central Mississippi Valley, showing study area in Massac County, Illinois, the New Madrid Seismic Zone, and selected geologic features. FAFC= Fluorspar Area Fault Complex.

Figure 2. Stratigraphic column for study area. Not to scale.



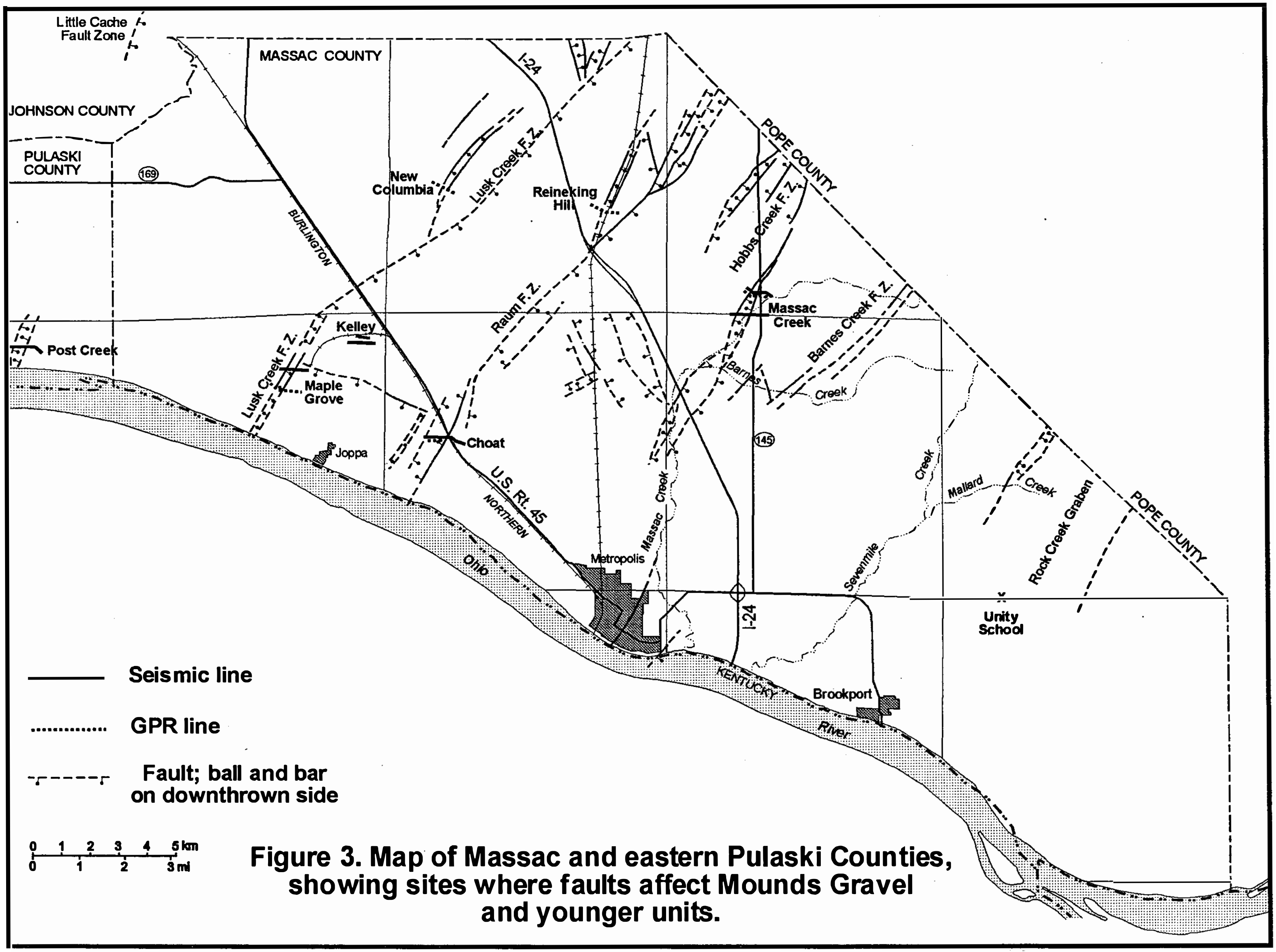


Figure 3. Map of Massac and eastern Pulaski Counties, showing sites where faults affect Mounds Gravel and younger units.

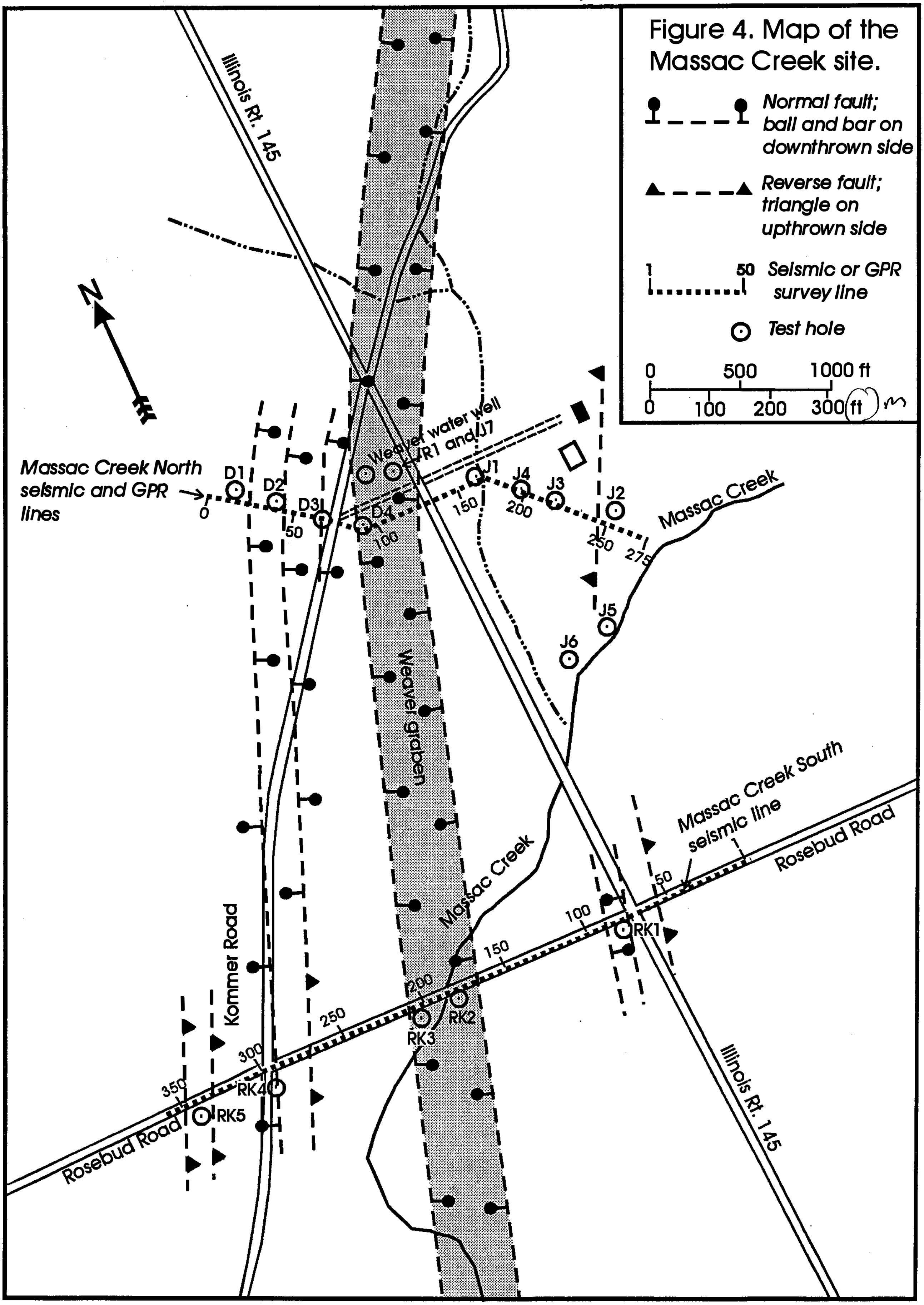


Figure 4. Map of the Massac Creek site.
Normal fault; ball and bar on downthrown side
Reverse fault; triangle on upthrown side
1 50 Seismic or GPR survey line
Test hole
0 500 1000 ft
0 100 200 300 ft
N
Illinois Rt. 145
Weaver water well JR1 and J7
Massac Creek North seismic and GPR lines
D1
D2
D3
D4
J1
J4
J3
J2
J5
J6
0
50
100
150
200
250
275
Massac Creek
Weaver graben
Massac Creek South seismic line
Rosebud Road
Kommer Road
RK1
RK2
RK3
RK4
RK5
1
50
100
150
200
250
300
350

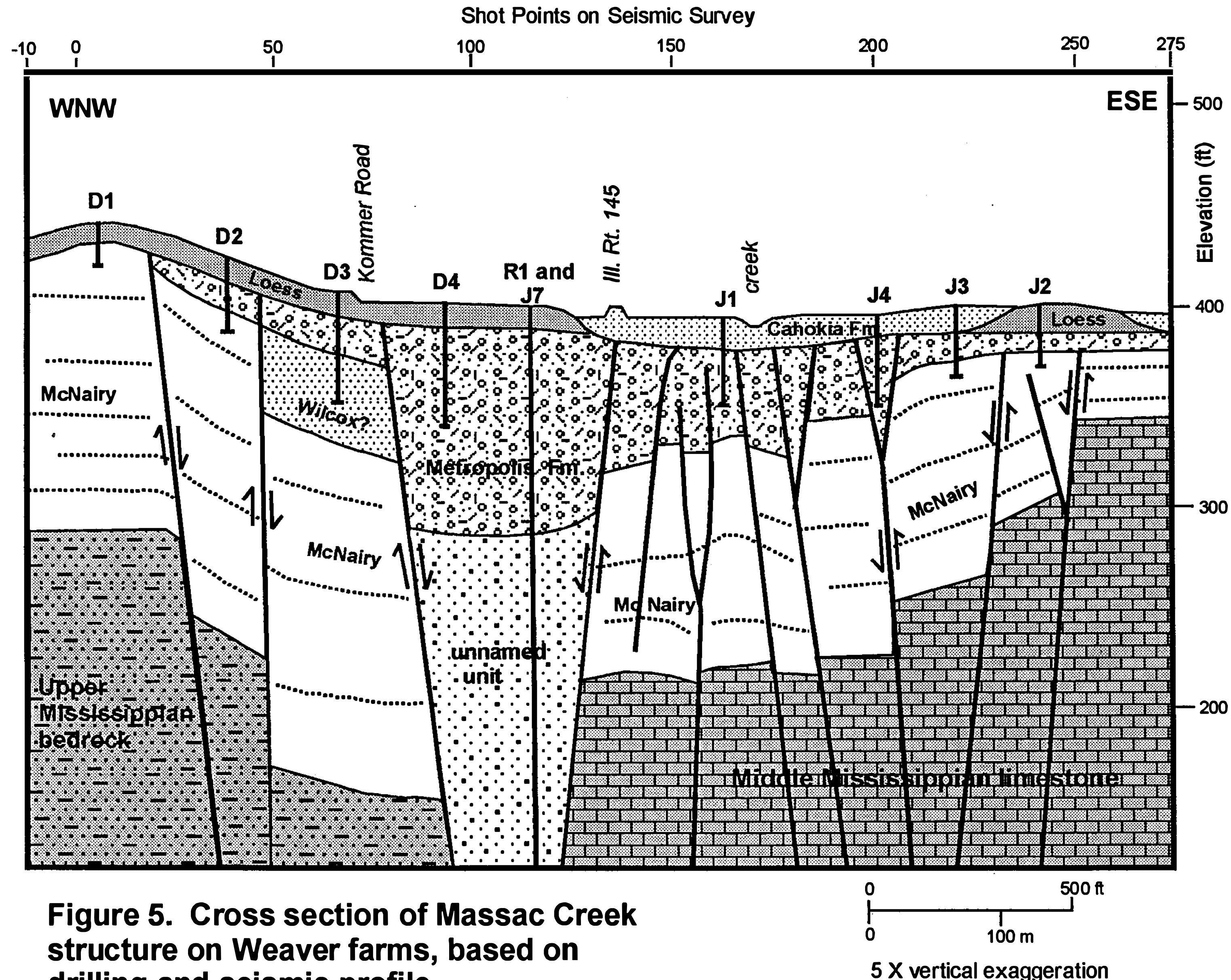


Figure 5. Cross section of Massac Creek structure on Weaver farms, based on drilling and seismic profile.

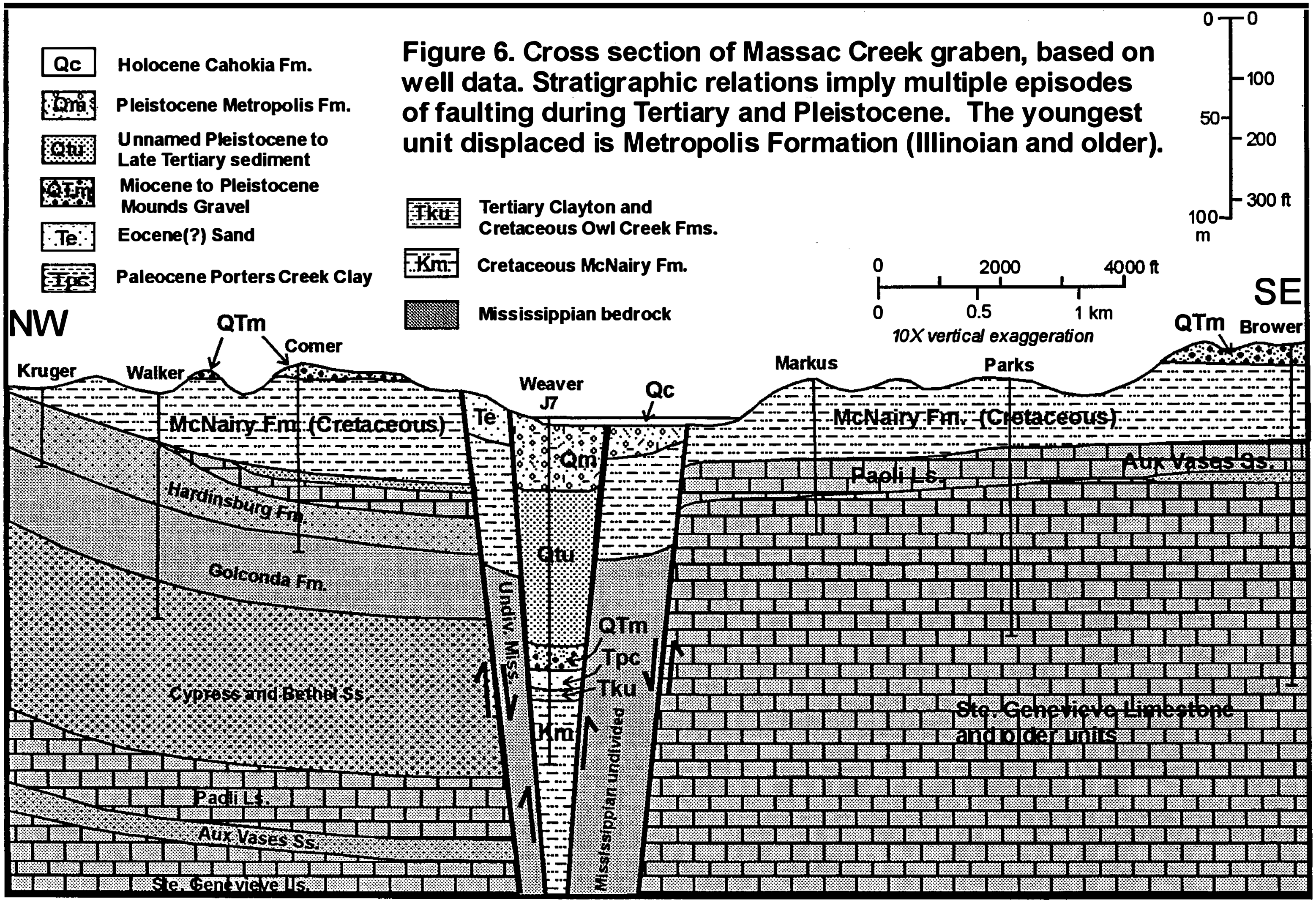


Figure 6. Cross section of Massac Creek graben, based on well data. Stratigraphic relations imply multiple episodes of faulting during Tertiary and Pleistocene. The youngest unit displaced is Metropolis Formation (Illinoian and older).

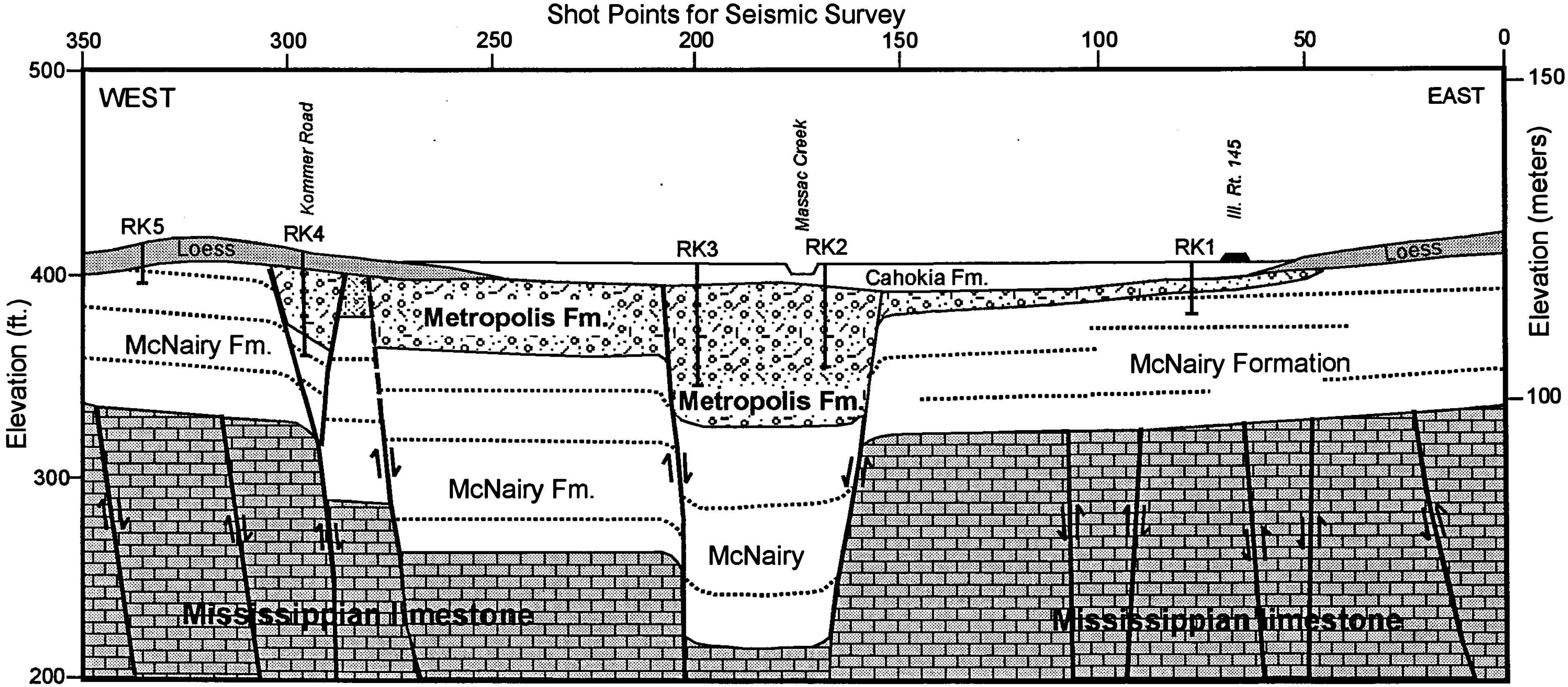


Figure 7. Cross section of Massac Creek structure along Rosebud Road, based on drilling and seismic profile.

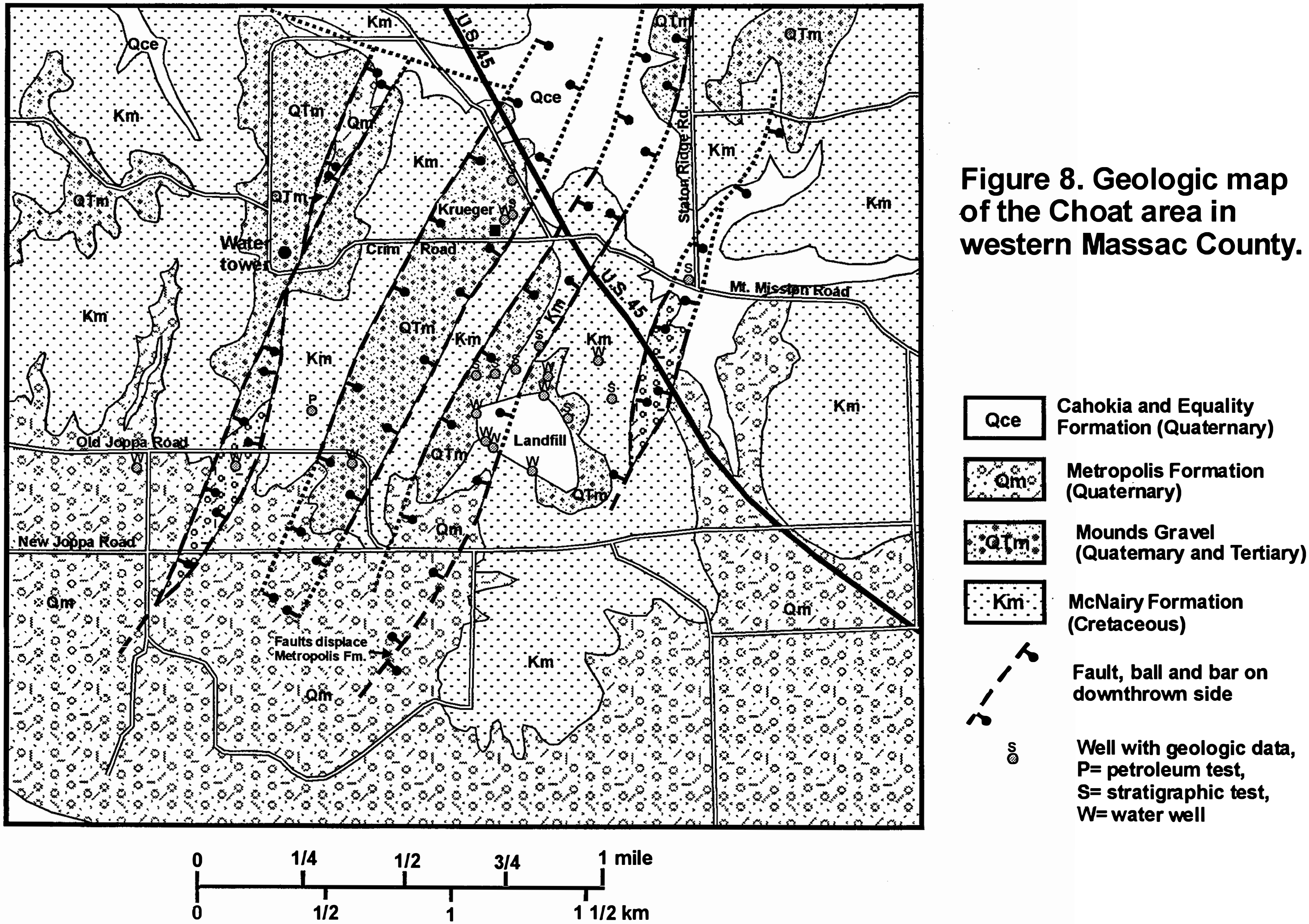


Figure 8. Geologic map of the Choat area in western Massac County.

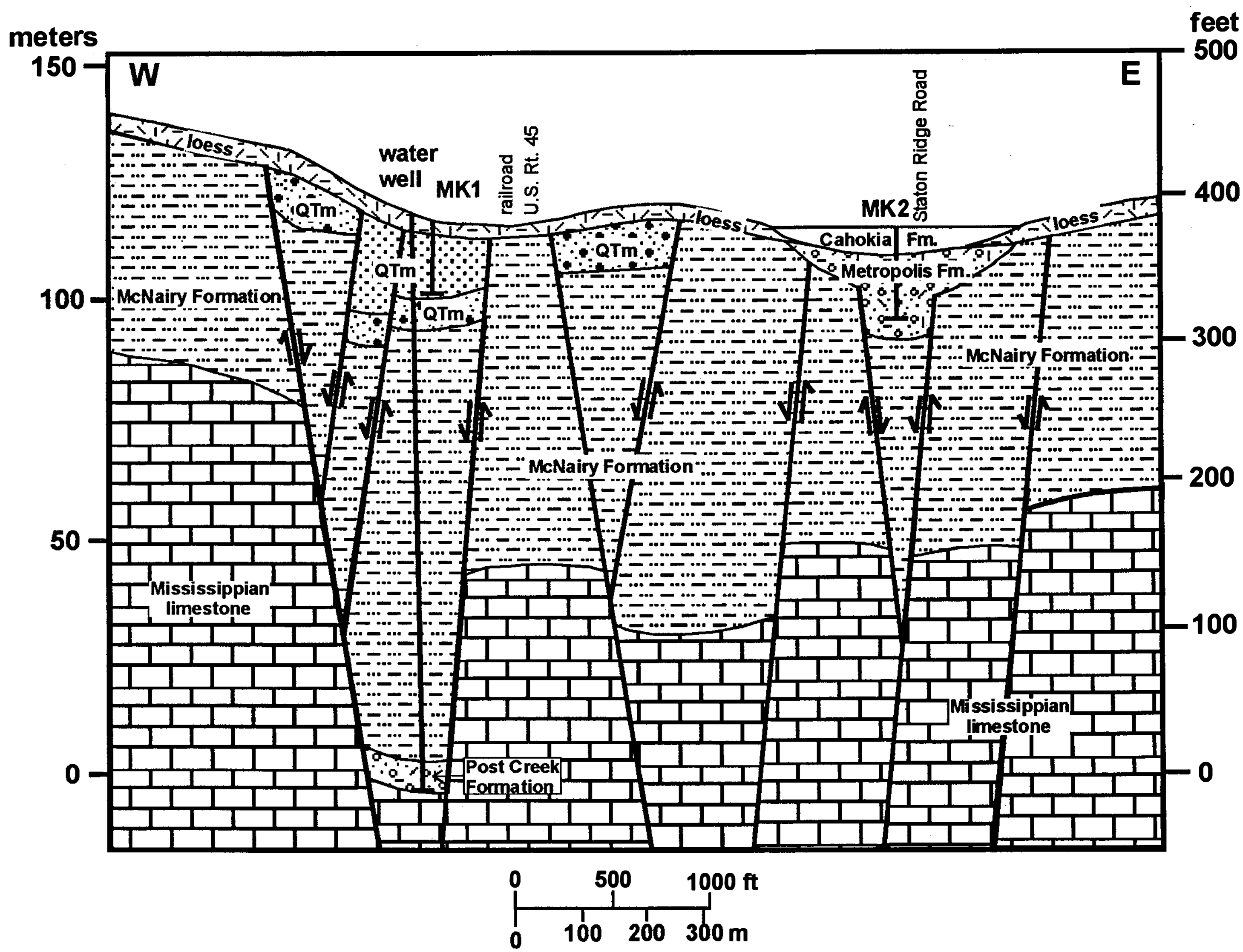


Figure 9. Cross section of Choat structure more or less parallel with seismic profile along Crim and Mt. Mission Roads. QTm = Mounds Gravel, which consists of lower gravel and upper sand. Note that the vertical scale is 10 times the horizontal scale.

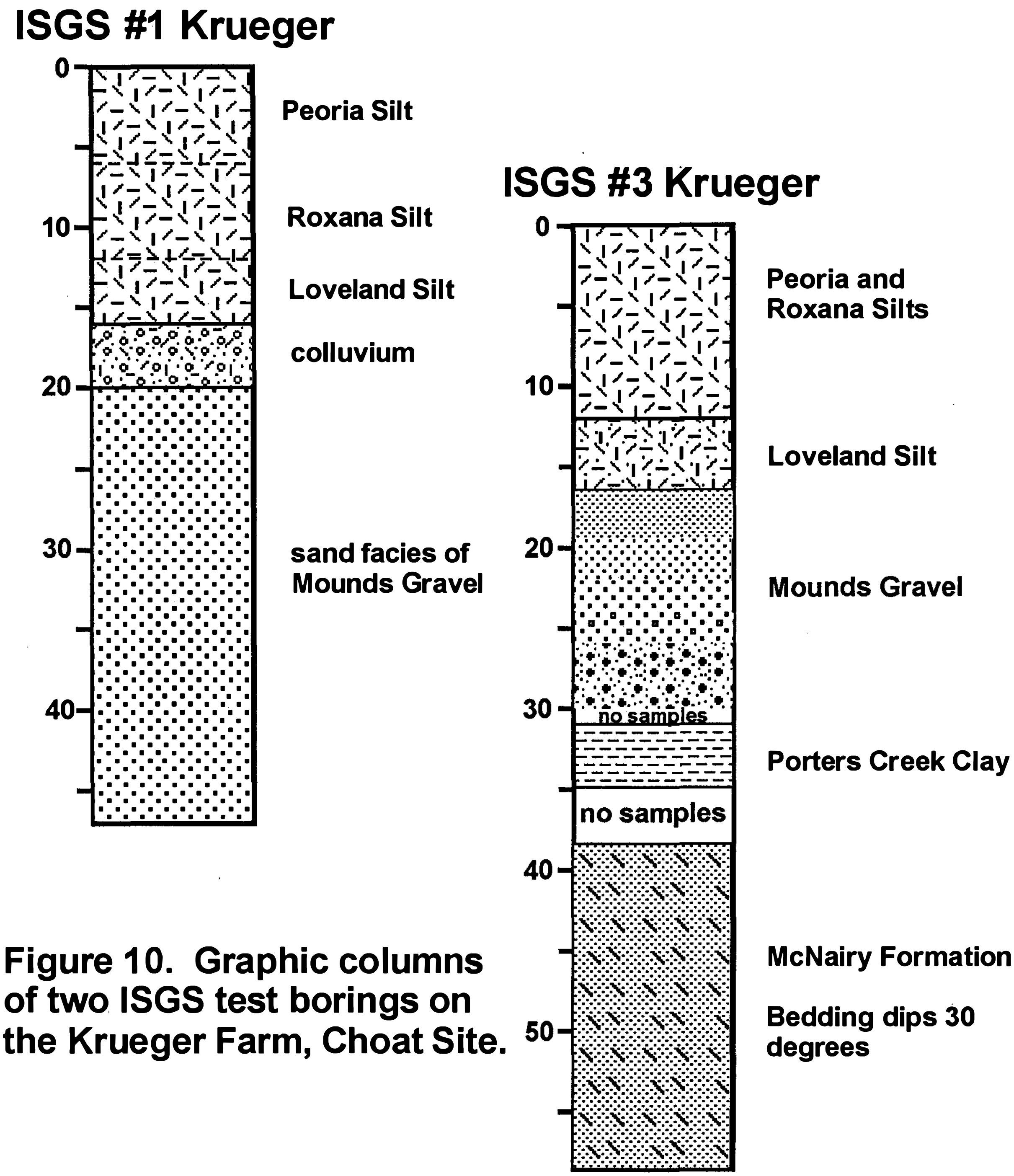


Figure 10. Graphic columns of two ISGS test borings on the Krueger Farm, Choat Site.

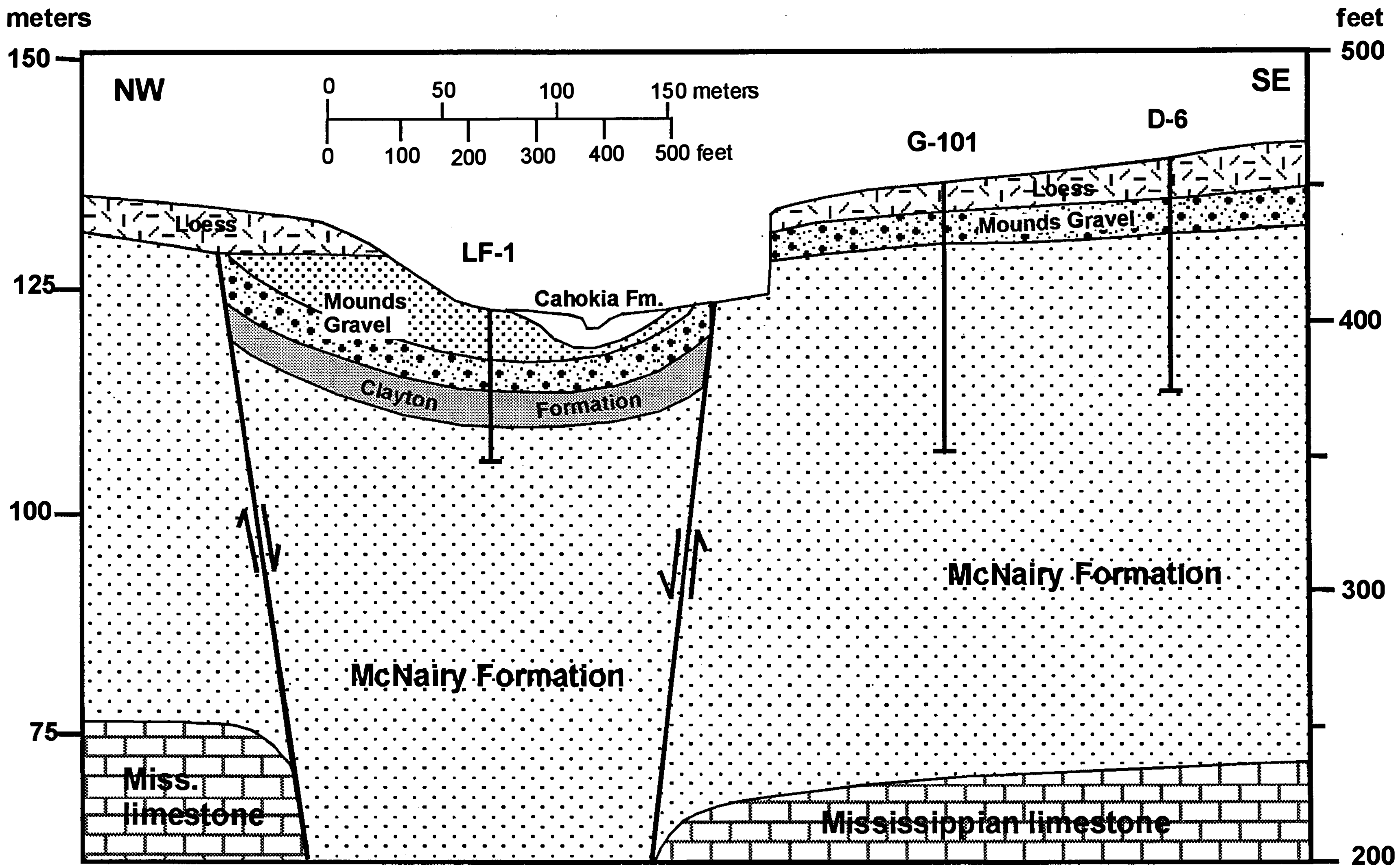
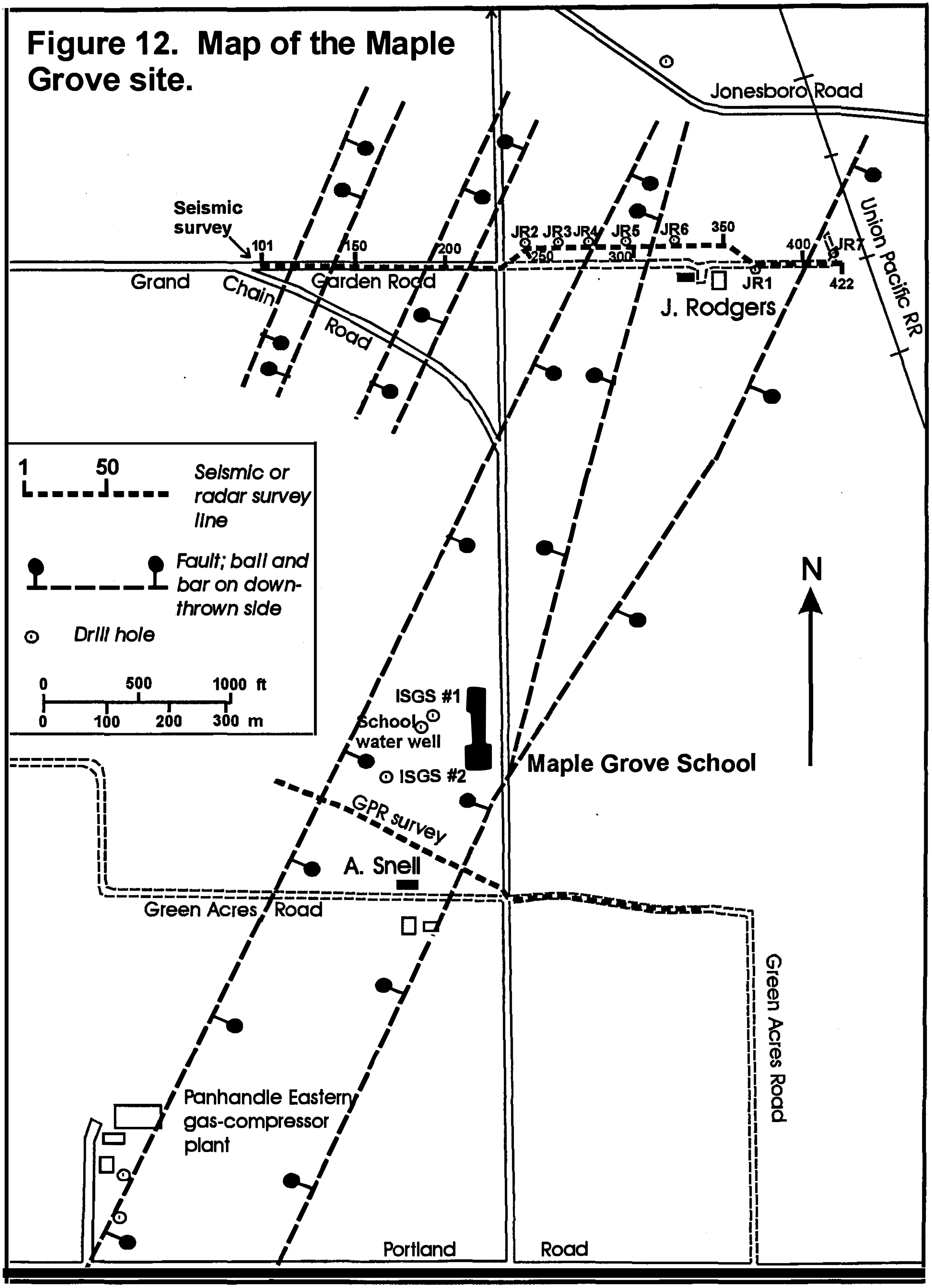


Figure 11. Cross section of the Choat structure at the Metropolis city landfill, based on drilling and surface geology. Note that vertical scale is 10 times horizontal scale.

Figure 12. Map of the Maple Grove site.



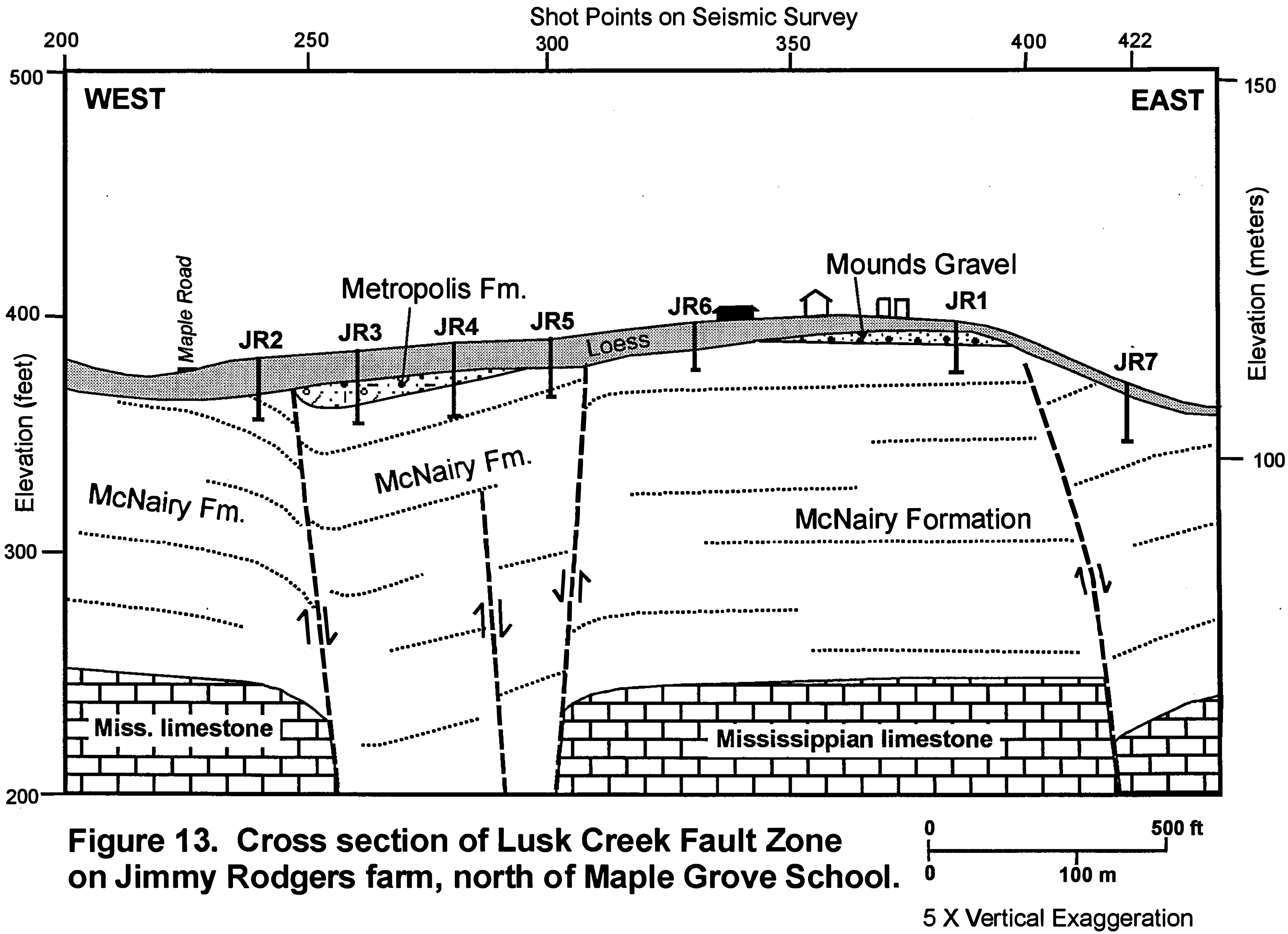
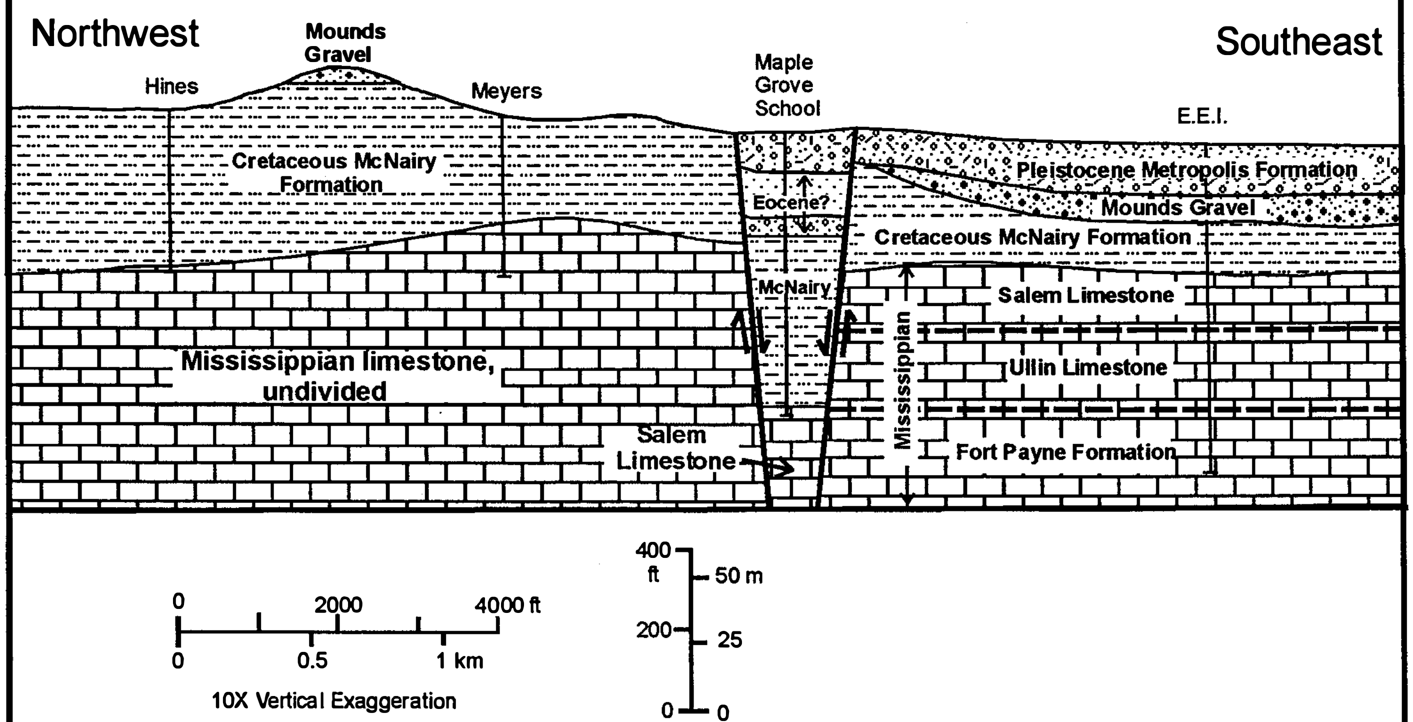


Figure 13. Cross section of Lusk Creek Fault Zone on Jimmy Rodgers farm, north of Maple Grove School.

Figure 14. Cross section of Maple Grove structure based on well data



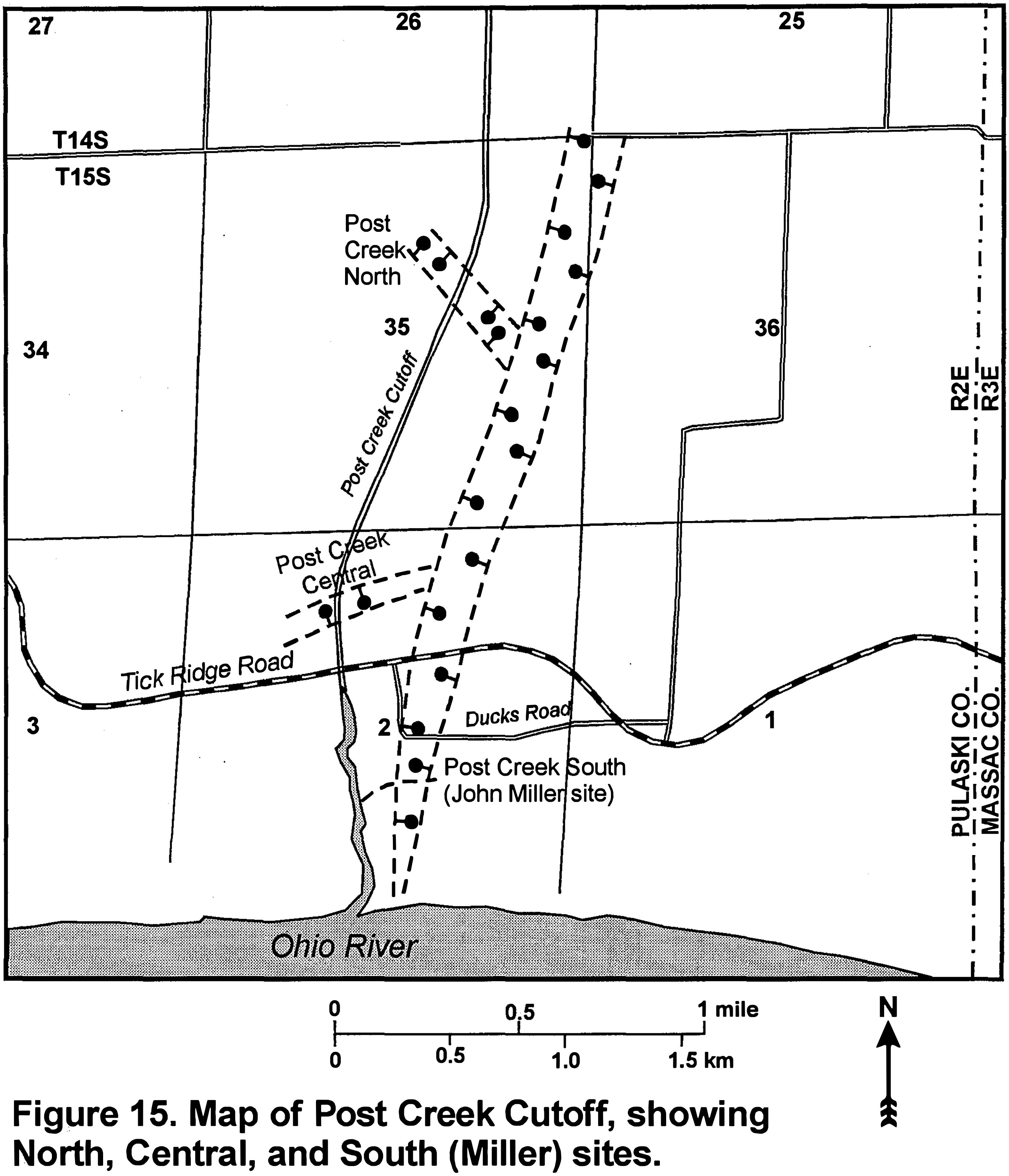


Figure 15. Map of Post Creek Cutoff, showing North, Central, and South (Miller) sites.

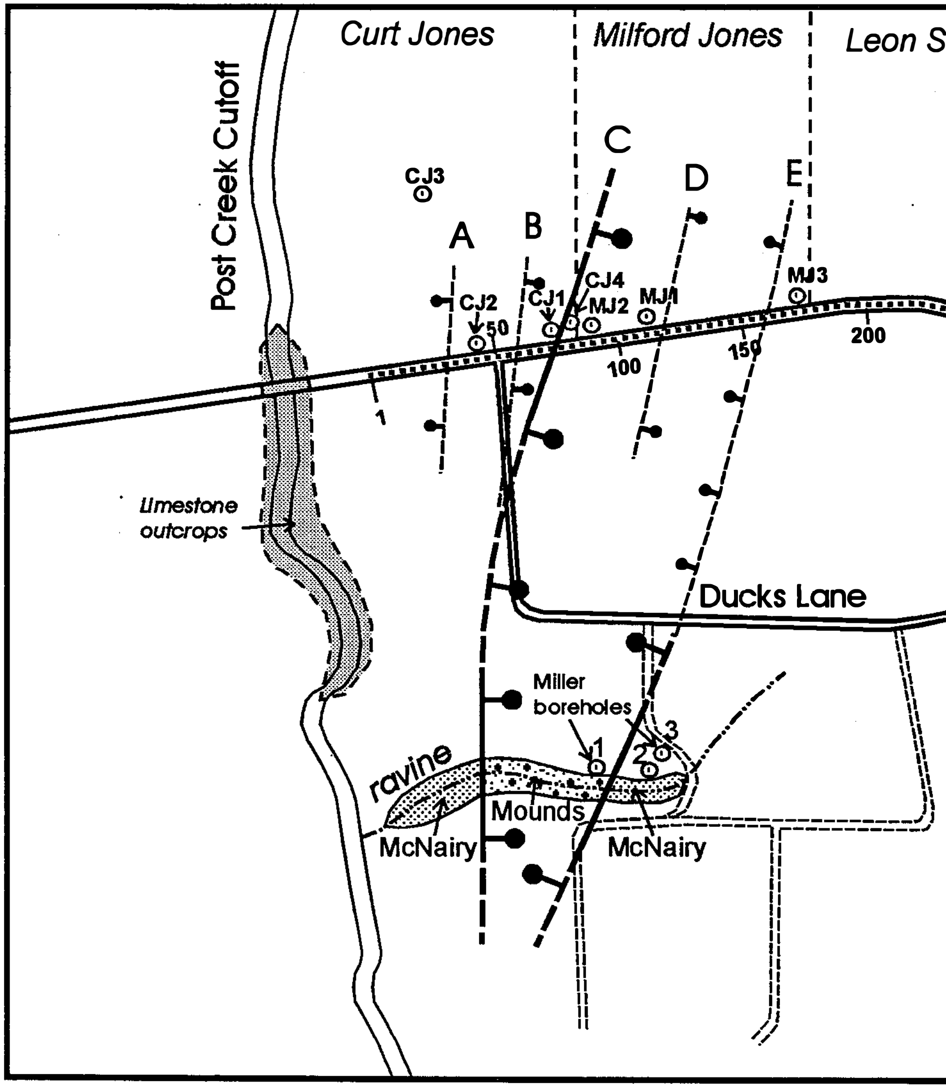


Figure 16. Map of Post Creek site.

Test hole
Fault, ball and bar on downthrown side
Seismic profile, with shot points numbered (0, 50)
Scale: 0, 500, 1000 ft; 0, 100, 200, 300 m

Figure 17. Cross section of Post Creek ravine, showing structure interpreted as a sinkhole. Modified from Kolata et al. (1981).

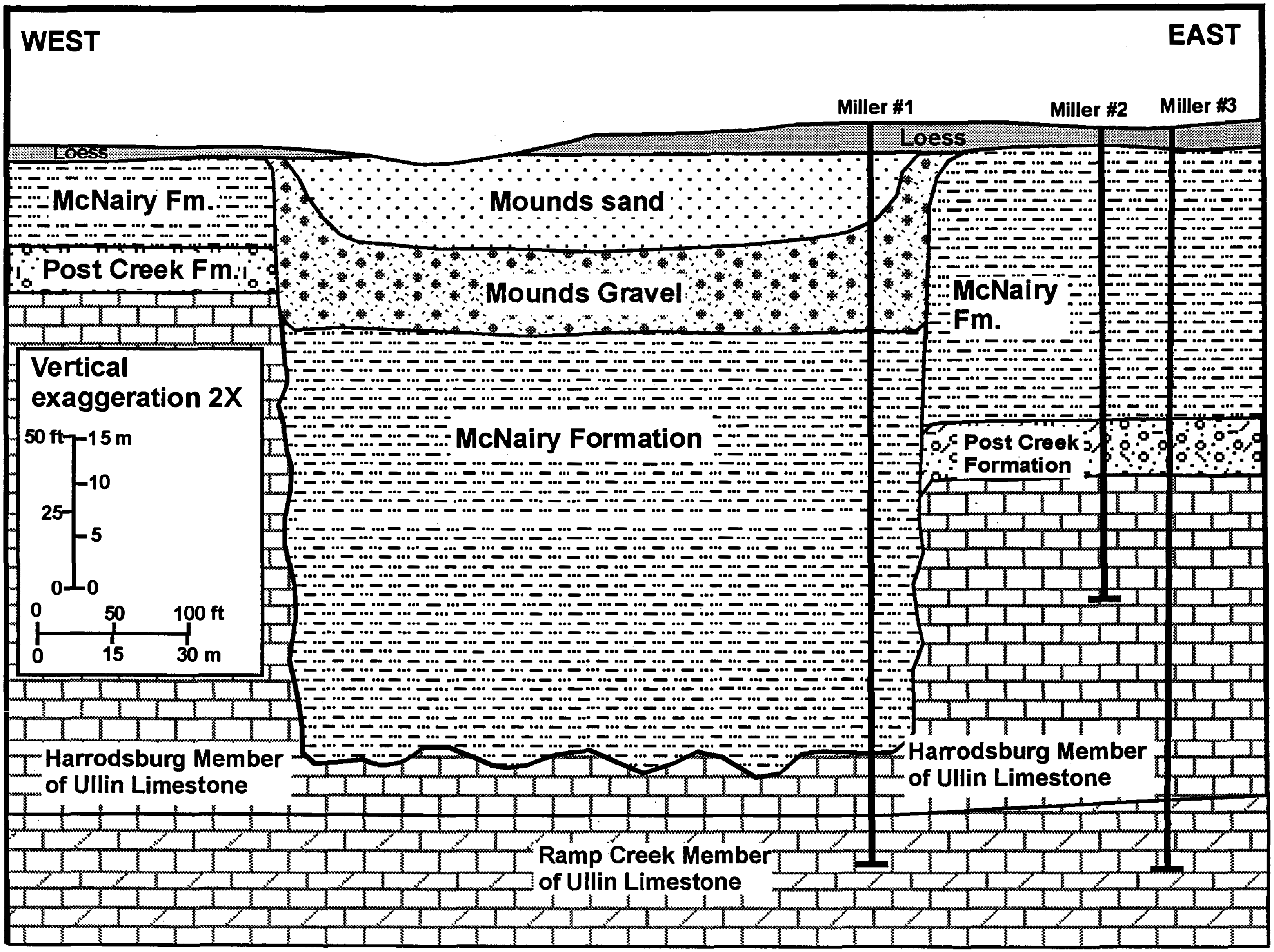
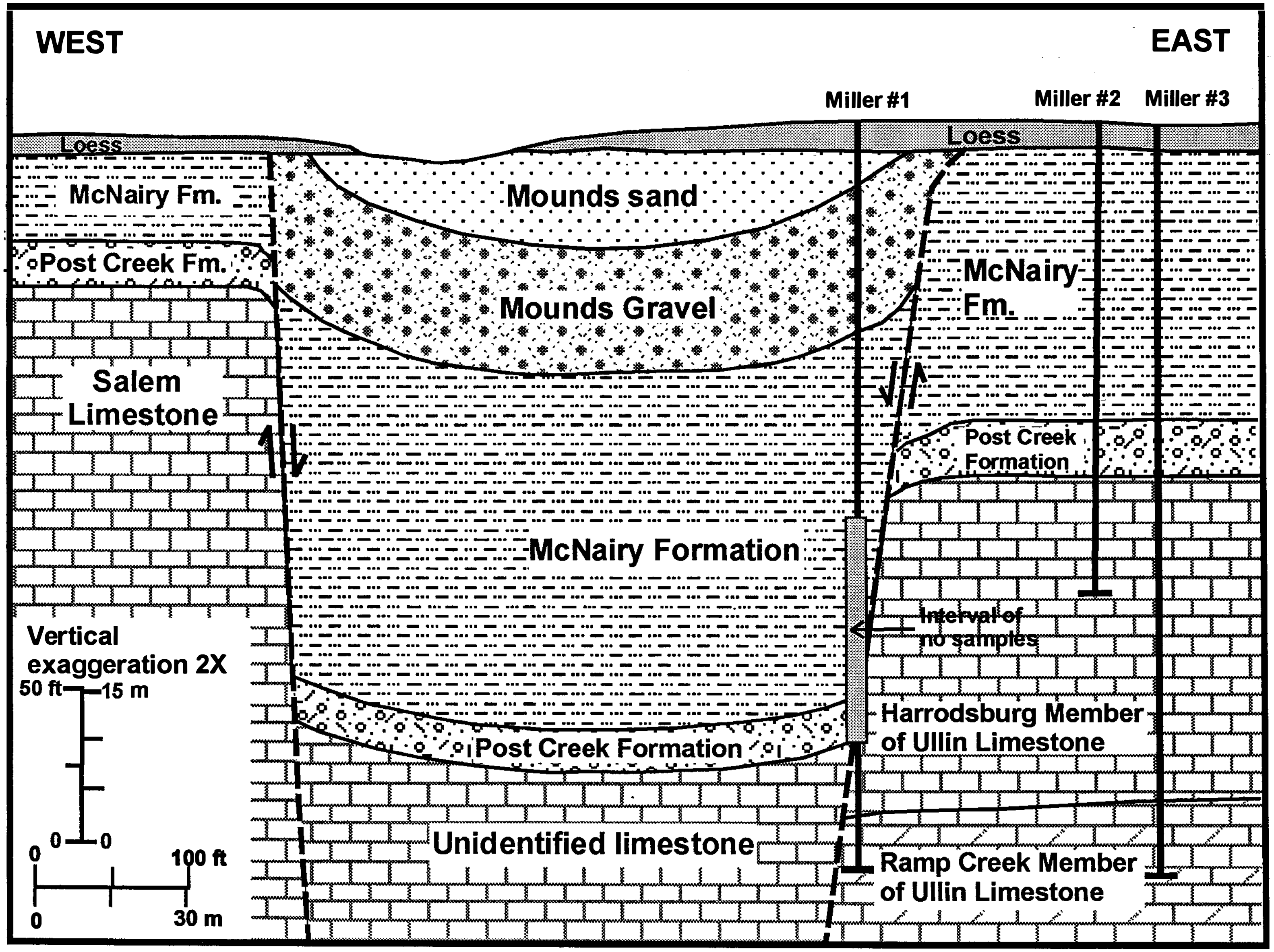


Figure 18. Cross section of Post Creek ravine, showing structure interpreted as fault zone.



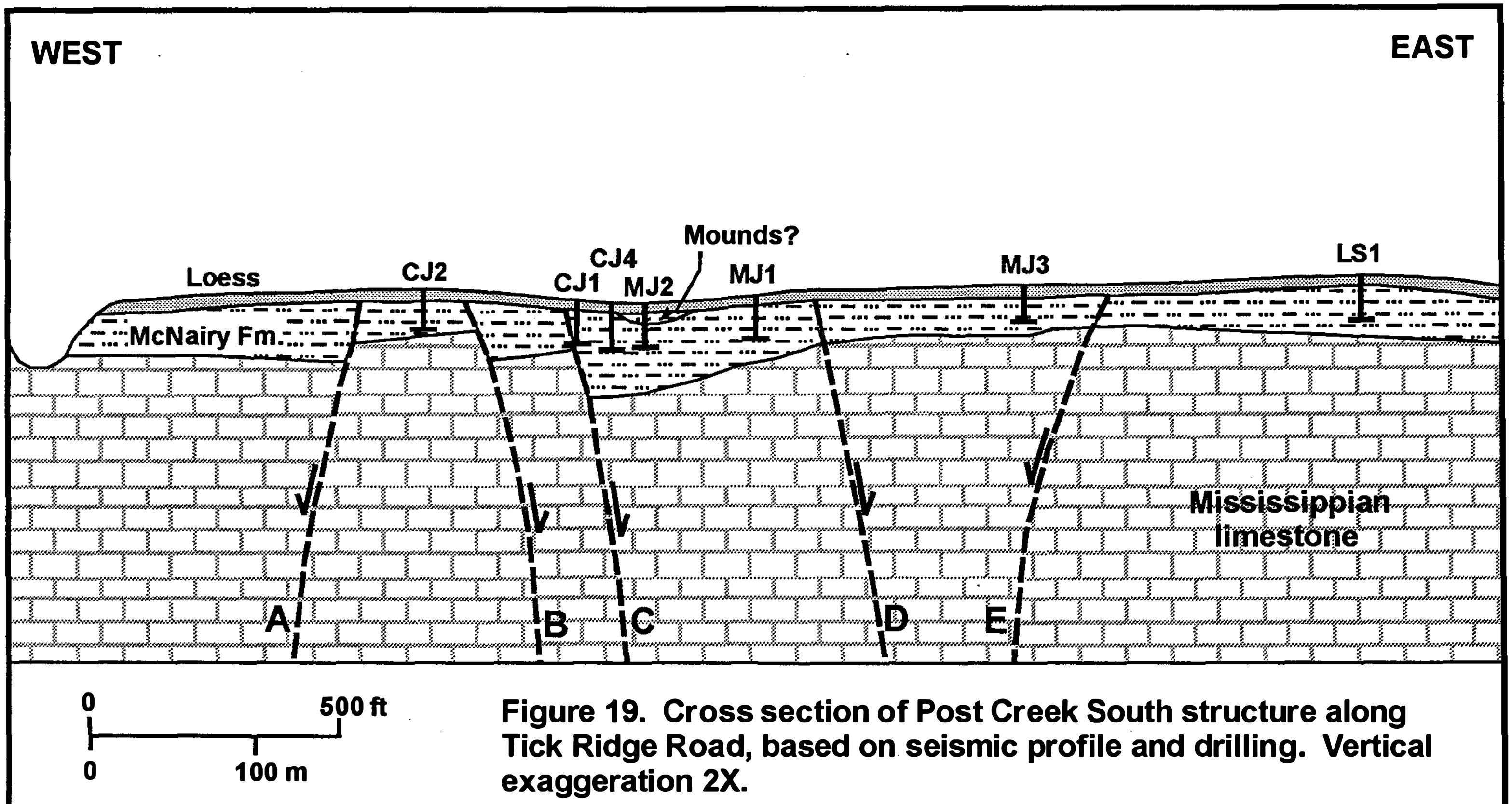


Figure 19. Cross section of Post Creek South structure along Tick Ridge Road, based on seismic profile and drilling. Vertical exaggeration 2X.

Figure 20. Overall view of Post Creek North, based on a field sketch. Length of view is roughly 600 feet and height of bank is 25 to 30 feet, so there is vertical exaggeration. QTm = Mounds Gravel, Km = McNairy Formation.

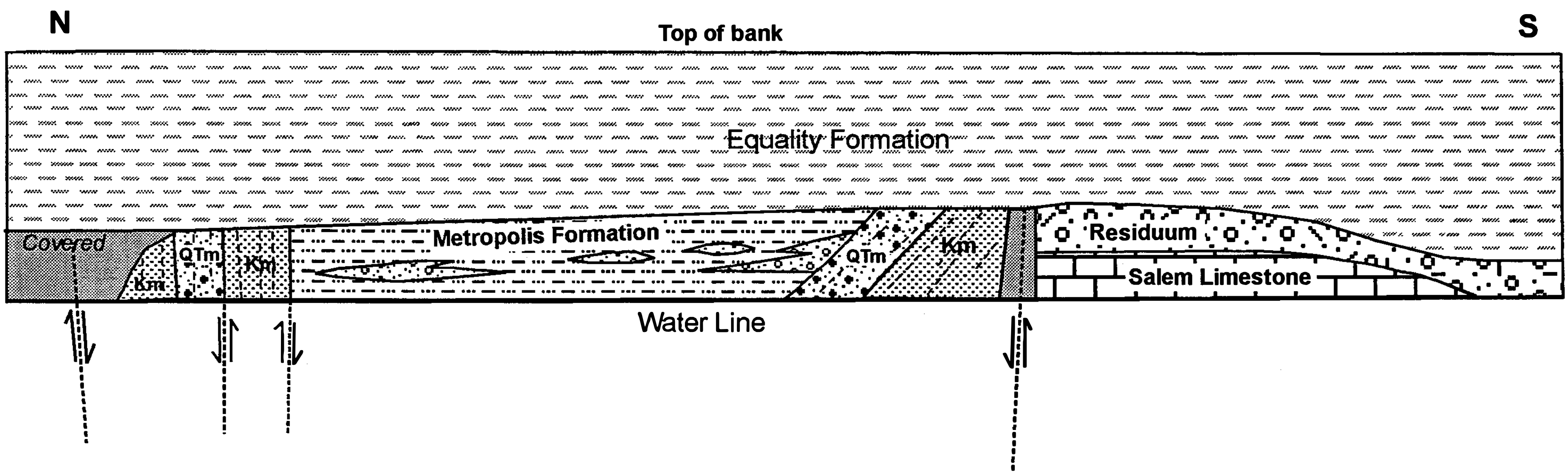
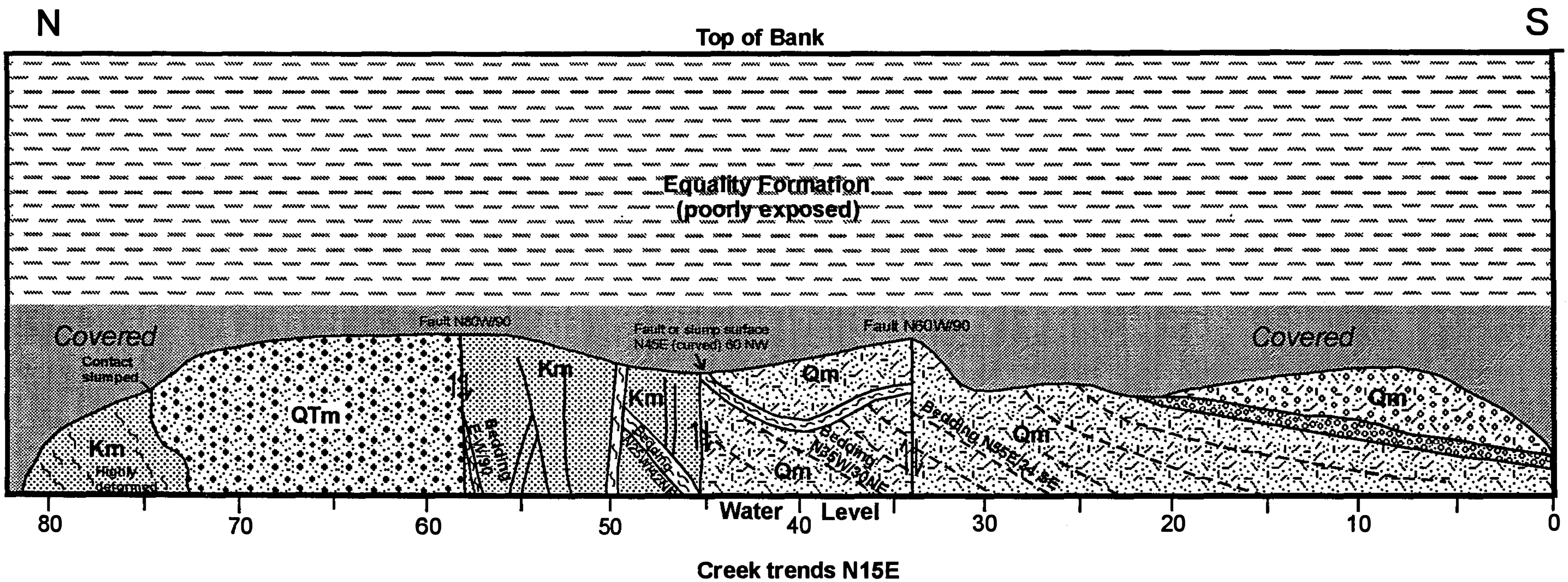


Figure 21. Scale drawing of northern part of Post Creek North structure, as seen in east bank of Post Creek Cutoff. Scale (in feet) at water line. No vertical exaggeration.

Equality Formation - poorly exposed olive-gray to brown soft clay and silt, Wisconsinan age
Qm= *Metropolis Formation*, gray to orange mottled, burrowed silt and sandy silt, with chert pebbles reworked from Mounds Gravel. Early to middle Pleistocene age.
QTm= *Mounds Gravel*, reddish brown sandy chert gravel, late Miocene to early Pleistocene age.
Km= *McNairy Formation*, white, pink, and orange soft, fine sand and light gray sticky clay with abundant mica, Late Cretaceous age.



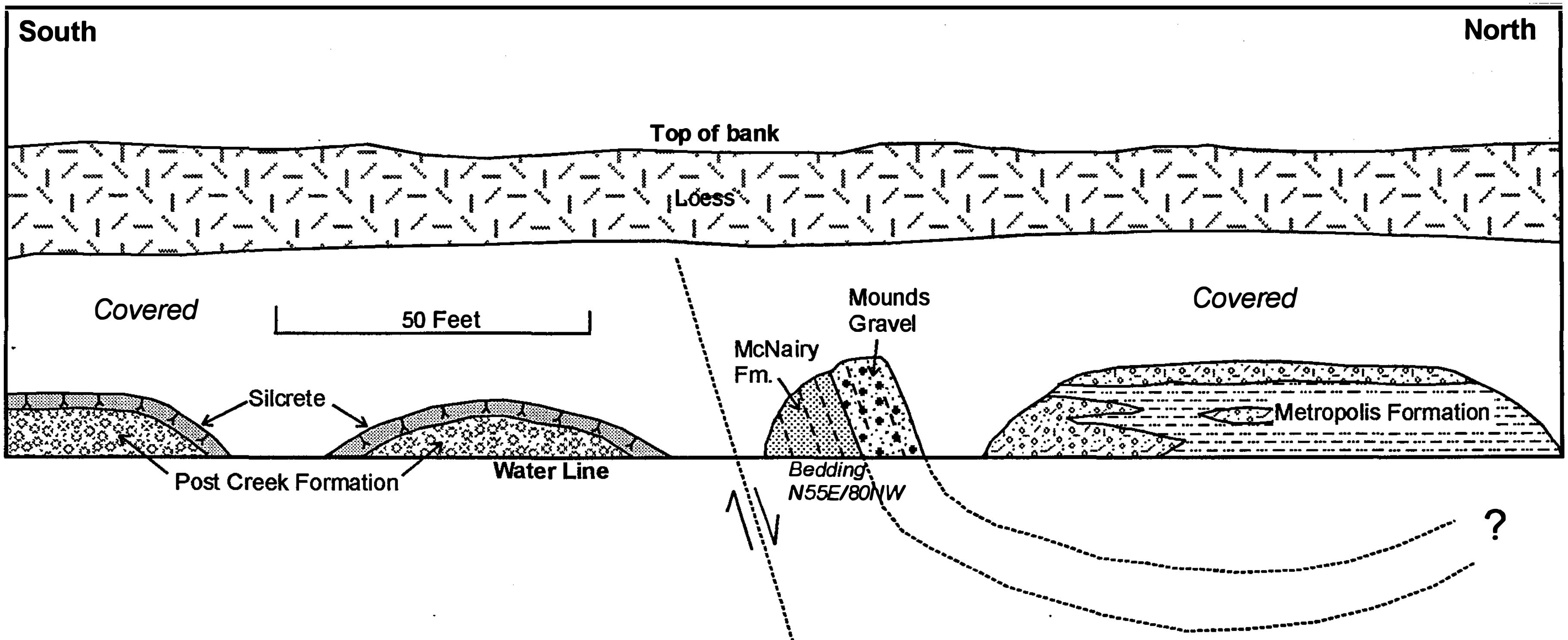


Figure 22. View looking west at the Post Creek Central structure, based on a field sketch. Scale is approximate.