QUATERNARY FAULTING IN THE NEW MADRID SEISMIC ZONE IN SOUTHERNMOST ILLINOIS

Final Technical Report to the U.S. Geological Survey
under the National Earthquake Hazards Reduction Program (NEHRP)
Award No. 1434-95-G-2525

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January 26, 1996

"Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award number 1434-95-G-2525. 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. Goverment."

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ABSTRACT

Tectonic faults that displace Tertiary and/or Quaternary strata have been documented along three fault zones or systems in far southern Illinois. These are the Fluorspar Area fault complex in Pope and Massac Counties, the Ste. Genevieve fault zone in Alexander and Union Counties, and the Commerce fault zone, which runs northeast from Alexander to Saline County and possibly beyond.

In the Fluorspar Area faults that strike NE and NNE displace the Mounds Gravel (late Miocene to early Pleistocene) and, locally, the Metropolis terrace gravel (Pleistocene; pre-Woodfordian). No displacement of Woodfordian or younger deposits has been detected. Faults typically outline narrow, linear grabens. The fracture pattern signifies extension with a component of strike-slip (probably left-lateral).

North-south to NW-trending faults near the southeast end of the Ste. Genevieve fault zone displace Eocene and older units. Again, the faults outline narrow grabens and show strong indications of strike-slip. No Quaternary sediments are known to be deformed. Trenching along one large fault revealed no displacement of Woodfordian loess and underlying colluvium.

The Commerce fault zone in Illinois is a subtle, discontinuous feature having small displacements. However, it coincides with a magnetic lineament and evidently represents a long-lived fracture zone in the basement. Mapping and trenching by the USGS and Missouri Geological Survey in Missouri, a few miles from Illinois, shows northeast-trending, right-lateral faults displacing units as young as the Peoria Silt (late Woodfordian). The foci of three magnitude 4 earthquakes in Illinois lay on or close to the Commerce structure; their focal mechanisms could fit the fault orientation. Thus far, we have found no Quaternary deformation along the Commerce fault zone in Illinois. Trenching at one site yielded negative results.

The current stress field in southern Illinois, having the principal compressive stress axis E-W to ENE-WSW, is consistent with observed right-lateral displacement along the Commerce fault zone, but not with observed displacements in the Fluorspar Area or Ste. Genevieve structures. Tertiary and early Quaternary displacements evidently took place under a stress field with the principal stress oriented NNE, N-S or NW-SE. Thus, the stress field apparently rotated during the mid-Quaternary. That change in stress may have shifted the center of tectonic activity southward from Illinois into the New Madrid area.

INTRODUCTION

Southern Illinois lies immediately north of the New Madrid seismic zone. Small to moderate earthquakes are a common occurence in southern Illinois. The area is heavily faulted; many faults line up with the New Madrid zone (fig. 1). Tertiary and possible Quaternary faulting have long been known in parts of Kentucky (Rhoades and Mistler 1941) and Missouri (Grohskopf 1955) directly adjacent to Illinois. Ross (1963) discussed evidence for tectonism involving units as young as the Mounds Gravel (Pliocene to early Pleistocene) in southernmost Illinois. In spite of these facts the opinion persists that Illinois has been tectonically inactive since late Mesozoic time. The latest comprehensive report (Kolata et al. 1981) concluded that no evidence existed for post-Cretaceous tectonic faulting in southern Illinois.

We uncovered new evidence for post-Cretaceous tectonism during detailed (1:24,000 scale) geologic mapping under COGEOMAP and STATEMAP. Faults that displace strata as young as the Pliocene to early Pleistocene Mounds Gravel were discovered in several areas of southernmost Illinois. Simultaneously Harrison and Schultz (1994a) documented tectonic faults that offset the Mounds Gravel at Thebes Gap on the Illinois-Missouri border (fig. 2). These findings inspired the present study.

This study involved a closer look at all sites in southern Illinois where faulting of Cretaceous and younger materials is known or suspected. We conducted detailed mapping and outcrop study, examined aerial photos, ran a seismic reflection profile, drilled, and trenched. This work shows that Quaternary tectonic faults are elusive, but they do exist in southern Illinois. Several sites newly discovered this year, are still under investigation. The precise timing, kinematics, and relationships to the New Madrid seismic zone remain the subject of ongoing study.

Location and Structural Setting

The study area comprises southernmost Illinois, with the principal focus on the four southernmost counties (Alexander, Pulaski, Massac and Pope). This area lies partly on the east flank of the Ozark dome and partly on the southern margin of the Illinois basin (fig. 1). Outcropping sedimentary rocks range in age from Ordovician through Pennsylvanian and dip regionally northeast and north from the dome into the basin. Overlapping the Paleozoic rocks are weakly lithified Cretaceous and early Tertiary sediments at the north edge of the Mississippi embayment.

The largest faults of the area are the ***Ste. Genevieve fault zone***, which trends southeast into the area from Missouri, and the ***Fluorspar Area fault complex***, which is composed mainly of northeast-trending fractures (figs. 1, 2). The latter links at its northern end with the Rough Creek fault system, running eastward into Kentucky. Another significant structure is the ***Commerce fault zone***. Although subtle and discontinuous, the Commerce is the only structure in the area having documented late Quaternary displacement.

Stratigraphy

Paleozoic bedrock of southern Illinois is principally limestone, sandstone and shale (fig. 3). In parts of Union and Alexander County the Devonian and lower Mississippian rocks, originally siliceous carbonates for the most part, have been silicified (Berg and Masters 1994). Lower Permian ultramafic intrusive rocks occur in southeastern Illinois.

Upper Cretaceous sediments are found in the Mississippi embayment and in small erosional and down-faulted outliers north of the embayment. The Tuscaloosa Formation (fig. 3) is largely gravel composed of light gray chert pebbles. The overlying McNairy Formation consists mainly of fine-grained, gray to reddish orange micaceous sand and silt, and gray laminated, silty clay.

Paleocene strata are restricted to Pulaski County. They comprise the Clayton Formation, a thin, glauconitic and sandy clay; and the Porters Creek Clay, a mixed-layer or smectitic clay mined for use as absorbants. Both Clayton and Porters Creek are marine units.

The Eocene Wilcox Formation also occurs in Pulaski County, where it is sand that contains small, well rounded granules of white quartz and gray to black chert. Eocene sediments north of the Mississippi embayment in Alexander and Union Counties include gravel of similar composition but much coarser grain, along with sand, silt, and clay formerly mined for making pottery. These materials are found as hilltop outliers, in sinkholes, and in grabens. Eocene age is based on pollen from lignite lenses (Nelson et al. in press).

The Mounds Gravel (called "Lafayette Gravel" in older reports, and "continental deposits" in Kentucky) is a unit of gravel and sand. The gravel is composed of well-rounded, brown chert pebbles that bear a distinctive bronze to yellow-brown patina. The sand is reddish orange to reddish brown, crossbedded, fine to coarse and commonly contains granules. Age of the Mounds, based on palynology from two sites in western Kentucky (Olive 1980) and relationships to fossiliferous units farther south (Willman and Frye 1970), is Miocene to early Quaternary.

The study area lies a short distance south of the maximum extent of Pleistocene continental glaciation. Uplands are mantled in colluvium and loess. Three loess units are known: Loveland Silt (Illinoian), Roxana Silt (Altonian; early Wisconsinan), and Peoria Silt (Woodfordian; late Wisconsinan). Lowlands contain sand and gravel of the Henry Formation, interpreted as Wisconsinan glacial outwash, and silt and clay of the Equality Formation, interpreted as Wisconsinan slackwater-lake sediments. These are overlain by Holocene alluvium. A prominent feature is the Cache Valley (fig. 3), which was the course of the Ohio River during Pleistocene time (Weller 1940; Masters and reinertsen 1987; Esling et al. 1989).

Several terrace systems are known in the Cache and modern Ohio River valleys, but the age relationships are not well established.

FINDINGS

Our findings are presented for three structural settings: the Fluorspar Area fault complex, the Ste. Genevieve fault zone, and the Commerce fault zone. Each setting has characteristic trend, style and timing of faulting.

Fluorspar Area Fault Complex

The Fluorspar Area fault complex represents the northeast part of a failed rift (Reelfoot rift or Mississippi Valley graben) that formed during continental breakup in Early or Middle Cambrian time (Ervin and McGinnis 1975). These faults were reactivated repeatedly: late Paleozoic, Mesozoic and Cenozoic episodes creating a complicated pattern of high-angle normal, reverse and strike-slip faults (Nelson 1991; Kolata and Nelson 1991). The same rifting event produced northeast-trending fractures that are active today in the New Madrid seismic zone. Thus, the Fluorspar Area is an obvious place to look for Quaternary tectonic faulting in Illinois.

Barnes Creek fault zone

The name Barnes Creek fault zone is used here for a fault zone that strikes N40°E across Massac, Pope and Hardin Counties, a distance of about 25 miles (figs. 2, 4). The name is taken from Barnes Creek, about 6 miles northeast of Metropolis in Massac County. Weller and Krey (1939) and Baxter et al. (1967) previously mapped segments of the Barnes Creek fault zone but did not name the structure.

In Mississippian bedrock the Barnes Creek fault zone is mapped as a single fault or a zone of subparallel faults that outline grabens and horsts less than 1/4 mile wide (fig. 4). Vertical separation is less than 100 feet along most of the zone. One graben may be downdropped about 200 feet; a horst near the northeast end of the fault zone is upthrown about 120 feet. Faults are marked by recrystallized and brecciated sandstone and clay gouge. Some faults near the northeast end bear veins mineralized with calcite, fluorite, and metallic sulfides. Away from immediate proximity to fault surfaces little or no deformation is seen, except for well-developed joints that strike parallel with the faults.

Slickensides and mullion were observed by Nelson in August, 1982 on a fault surface in an underground fluorspar mine near the northeast end of the Barnes Creek fault zone (northeastern Pope County). The striations and grooves on the northwest-dipping fault surface plunged 25 to 50° northeast. Right-lateral oblique slip is implied, assuming that the oblique slip that formed the grooves also produced the observed down-to-the-northwest throw component. These slickensides and mullion are the only clear kinematic indicators we found along the Barnes Creek fault zone.

Surface exposures. The Barnes Creek Fault Zone extends into the Mississippi Embayment on the southwest, where it displaces Cretaceous, Tertiary and early Quaternary sediments. Faults offsetting Quaternary strata are exposed along Barnes Creek in SW¼ NW¼ SE¼, Sec. 9, T15S, R5E, Massac County, Metropolis Quadrangle (site A, fig. 4). Here a Quaternary terrace gravel is faulted against clay and sand of the McNairy Formation (Cretaceous). The gravel is composed of rounded chert pebbles, crudely stratified, in a matrix of gray silt and clay. Some pebbles have the brown patina typical of the Mounds Gravel, but most are bleached, worn and pitted. The bleached pebbles evidently were derived from the Mounds Gravel, losing their patina during weathering and transport.

At Site A a normal fault that trends N45°E/70SE displaces Quaternary gravel and pebbly clay against McNairy (fig. 5). The throw at the base of the gravel is about 5 feet. West of the fault a graben trending N35°E contains Quaternary gravel downdropped into the McNairy. This structure is about 3 feet wide at the top and narrows downward (fig. 6). Another graben or fissure 2 to 4 inches wide is filled with gravel, striking N37°E and dipping nearly vertical. All of these structures are truncated at the top and overlain by horizontal, undisturbed Holocene sand and silt.

More small fault and gravel-filled fissures or grabens can be seen east of Site A along Barnes Creek. The structures trend N10°E to N40°E; reworked Mounds Gravel is displaced against, or downdropped into McNairy strata. The exposures are mainly on the flat bed of the creek and partly under water, obscuring details. All faults and fissures are truncated and overlain by horizontal, undeformed Holocene gravel and silt.

Approximately 1/4 mile east of Site A steeply dipping McNairy silt is exposed in the bed of Barnes Creek. The bedding strikes about N25°E and dips 50° to 70° southeast; the exposure is about 30 feet wide (along strike) and 70 feet long (along dip). Just east of the dipping McNairy, iron-cemented gravel that is either Mounds or reworked Mounds crops out in the streambed. The creek bed will have to be excavated to determine whether the contact is a fault or a normal depositional contact.

Deformed Quaternary sediment also can be viewed at Site B, a southwest-flowing tributary to Massac Creek located about 2300 feet south of the northwest corner of Sec. 36, T14S, R5E, Massac County, Brownfield Quadrangle. In the southeast bank is a complex horst or faulted anticline (fig. 7). The McNairy Formation is offset by numerous steeply dipping normal and reverse faults, some clay-filled, and all striking about N20°E. On the east side of the exposure Quaternary terrace gravel, containing pebbles reworked from the Mounds Gravel, is faulted against the McNairy. All faults are truncated by horizontal, dark brown Holocene gravel, overlain by silt.

Also at Site B (not shown in Figure 7) numerous vertical fractures in the McNairy Formation trend about N20°E. Some are filled with Quaternary chert gravel.

The structure at Site B appears to be extensional, with a component of strike-slip. No slickensides or other direct indicators of slip direction were observed. The narrow gravel-filled grabens and fissures generally strike NNE, slightly oblique to the overall N45°E trend of the fault zone in this area. They may be part of an en echelon fracture system, which would imply a sinistral (left-lateral) component of displacement.

Seismic profile. A seismic-reflection survey along Barnes Creek was conducted under subcontract by John Sexton and students of the department of Geology at Southern Illinois University (SIU), Carbondale. The profile is about 6100 feet long and it parallels the north side of the creek (fig. 8). The objectives of the seismic survey were to determine whether faults exposed at the subsurface extend into the subsurface, and to characterize the structural style of the Barnes Creek fault zone.

The seismic crew consisted of Dr. Sexton, Harvey Henson, Koffi N'Guesson and Mamadou Coulibaly. Data were collected using a Geometrics 24-channel StrataView digital seismograph. A 12-gauge down-hole shotgun was used as the seismic source; shotholes 3 feet deep were augered at each shot point. Shot points and geophones (one per channel) were spaced at 10-foot intervals. The near offset geophone was placed 140 feet from the corresponding shotpoint. Twelve-fold common-mid-point data resulted from this setup, with a subsurface cmp spacing of 5 feet. A digital sample rate of one millisecond was employed for recording data. The line was shot in three segments, separated by short gaps at a deep ditch and a highway.

All data were processed in the Geophysics Laboratory in the Department of Geology at SIU. Data were downloaded from seismograph memory to a PC computer and then transferred to aseismic reflection processing workstation. A variety of processing techniques were tried, including f-k filtering, deconvolution, migration, bandpass filtering, scaling, and different velocity analyses. The final processing sequence, which yielded the best results, comprised the following steps:

1. Trace edit
2. Sort shot records to CDPs
3. Automatic gain control
4. Bandpass filter
5. Static corrections
6. Automatic gain control (again)
7. Mute reflections
8. Normal move out (NMO) (velocity analysis)
9. Mute for NMO stretch
10. Automatic gain control (again)
11. Stack.

Data were recorded down to a 2-way travel time of 0.6 seconds, but few coherent reflectors were imaged below 0.2 seconds (Plate 1). The loss of deeper returns is probably due to the low energy of the source and energy-absorbant qualities of unlithified clay and sand of the McNairy Formation near the surface.

Structural interpretation of the seismic profiles was conducted by F. Brett Denny, with input from Joseph Devera and John Nelson (Plate 2). Our interpretations are tentative, and may be revised after further reprocessing of the seismic data and consultation with the SIU geophysical team.

The profile (Plates 1 and 2) images good reflectors mainly between 0.1 and 0.2 seconds. We interpret these reflectors as velocity interfaces within the Paleozoic bedrock, which consists of the mid-Mississippian Mammoth Cave Group (dominantly limestone) and the upper Mississippian Pope Group (interbedded shale, sandstone, and limestone). Specific units within the Mississippian cannot be identified on the seismic profile or from the scantly borehole data available in the area. The uppermost strong reflector, at depths of 0.10 to 0.13 seconds along most of the line, probably represents the contact between Mississippian rocks and the Cretaceous McNairy Formation. The McNairy itself is not imaged except, probably, at the easternmost end of the line, east of shot point 500 (SP 500).

We interpret numerous faults on this seismic profile (Plate 2). Some faults on the seismic profile correlate with structures exposed along Barnes Creek, but most represent faults that are concealed. Apparent dips of faults on the seismic line range from roughly 45° to vertical. Apparent vertical separation ranges from 0.01 to 0.08 second, corresponding to throws of several tens to several hundreds of feet.

Several faults, as interpreted from seismic, bifurcate near the surface and outline narrow grabens. Most are normal faults, but several high-angle reverse faults are evident. For example, two outward-dipping reverse faults outline a downdropped block near SP 100 and 110 on line segment 2. A similar structure of larger magnitude is at SP 475-495 on line segment 3. The latter feature corresponds with steeply dipping McNairy strata exposed along the streambed.

Narrow V- or Y-shaped grabens outlines by normal faults are seen on the seismic profile and resemble structures mapped at the surface. Grabens are shown near SP 100 on line segment 1 and between SP 240 and 410 on segments 2 and 3. The faults at SP 100 and SP 310 line up with faults observed in the streambed; both of these structures strike northeast. The other grabens are not visible at the surface. Grabens of this type are presumable products of either simple horizontal extension, or of strike-slip faulting with an extensional component (negative flower structures, or pull-apart structures).

The structure imaged near the west end of line segment 2 is of special interest. The main fault, at SP 35, is vertical (note that faint reflectors are discernable down to 0.3 seconds along this fault). Branching off the east side of the main fault are two reverse or thrust faults. One breaks into the McNairy near SP 43, producing a sharp kink fold. The other breaks out near SP 65, bifurcating again near the surface and outlining a narrow wedge-shaped slice. The entire feature is an excellent example of a "positive flower structure", and as such, is probably the result of wrench faulting with a component of compression (Harding 1985).

Cache Valley. The Barnes Creek fault zone crosses the Cache Valley in Pope County (fig. 4). The Cache Valley is a broad lowland that was occupied by the Ohio River during most of Pleistocene time. The Ohio shifted into its present channel between 8,000 and 25,000 years ago (Weller 1940; Masters and Reinertsen 1987; Esling et al. 1989). Distinct Pleistocene sedimentary deposits and landforms (such as terraces) within the Cache Valley constrain the timing of tectonic deformation along the Barnes Creek fault zone.

Inspection of aerial photographs showed an apparent shift in the trend of point bars where they cross the projected trace of the fault zone in the SE¼ NE¼, Sec. 8 and SW¼ NW, Sec. 9, T14S, R6E (fig. 9). Field study revealed that the aerial photographs were misleading as to the actual topography. The features probably are meander scrolls caused by the normal accretion of point bars, and do not appear to be tectonically related.

Aerial photographs also revealed light-colored patches of ground on a WNW-trending ridge near the center of the N½ NW¼ NW¼, Sec. 9 (fig. 9). The site was visited to check the possibility that the light patches are sand blows caused by liquefaction during earthquakes. The light patches indeed proved to be sand. We made a series of soil probes 1 foot apart along an east-west line 120 feet long, crossing the center of the largest sandy patch.

Probing showed that the sand is a thin surficial layer, a maximum of 18 inches thick, and within the plow zone of a cultivated field. The sand overlies compact sandy, clayey silt with a sharp contact, and grades laterally into a similar type of silt. Probing failed to detect any feeder dikes or other evidence that the sand was injected upward through the silt.

Another factor that strongly discounts the sand-blow hypothesis is that the Brownfield 7.5-minute topographic map (dated 1976) shows a farm pond at the site of the sand deposits. The pond has been drained and the berm leveled. The sand deposits very likely are man-made features formed during construction and/or removal of the pond.

To further investigate possible Quaternary tectonism in the Cache Valley we drilled a series of test holes across the Barnes Creek fault zone just west of Homberg, where a prominent terrace flanks the northeast side of the Cache Valley (fig. 9). A truck-mounted Mobile drill rig fitted with a hollow-stem auger coring outfit was used. This rig is capable of recovering (ideally) continuous core samples in unlithified materials. We completed five drillholes, each to depths of 70 to 75 feet. Sample recovery was excellent. Aside from some loss of water-saturated sand in the upper 20 feet of some holes, we achieved nearly 100% core recovery.

The following stratigraphic units were penetrated by the drill (fig. 10). They are described in increasing order of age.

Cahokia Alluvium: two alternations of silt to coarse fluvial sand of probable Holocene age, encountered only in hole 10 off the terrace.

Peoria Silt: light brown, unstratified, weathered silt interpreted as loess of late Woodfordian (latest Wisconsinan) age, encountered near surface in hole 8.

Parkland Sand: clean, very fine-grained, well-sorted sand, with no clay or silt layers and distinct dune morphology; an aeolian deposit of Woodfordian age.

Henry Formation: light brown, very fine-grained sand with laminae and lenses of silt and clay, probably of fluvial origin, Woodfordian age.

Homberg sequence: informal name for the interval of interbedded gray to reddish brown, partly calcareous clay and silt underlying the Henry Formation. A well-developed paleosol is at the top of the sequence, and another paleosol is 15 to 35 feet below the top.

Radiocarbon dating was performed on two samples of woody plant material from the top of the Homberg sequence in hole 9, by Chao-Li (Jack) Liu of the ISGS. The resulting dates are 18,160 ± 190 years for the upper sample (depth 47′5"-47′8") and 19,640 ± 210 years for the lower sample (depth 48′6"-48′10"). The older date is consistent with the Gardena soil, an informally-named paleosol of early Woodfordian age. The dates further imply that the lower paleosol in the Homberg sequence probably is the Farmdale Soil, developed within and overlying Altonian (early Wisconsinan) sediments.

As the cross section shows (fig. 10), there is no significant vertical offset of any sampled unit across the Barnes Creek fault zone. The fault zone probably passes beneath hole 7 and almost certainly runs between holes 6 and 9. The lack of any displacement detected by drilling is consistent with the absence of physiographic expression of the fault zone across the Cache Valley. Therefore, the Barnes Creek fault zone near Homberg probably has been inactive since the early Wisconsinan Stage.

An abrupt change of stratigraphy is found between holes 8 and 10. A distinctive red and gray mottled clay in the Equality (?) Formation is about 20 feet lower in elevation in hole 10 than in hole 8. The unit overlying this mottled clay does not match between the two holes, which are less than 500 feet apart. The elevation change is not likely due to tectonic faulting, because the two boreholes are well to the west of the projected fault line. A more plausible explanation is paleoslumping induced by failure of an undercut river bank. The position of borehole 10, off the terrace and within the younger Holocene (Cahokia) channel, supports the landslide interpretation.

Time of faulting. The age of the youngest material displaced by the Barnes Creek fault zone is poorly known. The faulted alluvium at Sites A and B contains abraded chert pebbles derived from the Mounds Gravel. This material is probably reworked Mounds and, thus, is no older than Pliocene and likely is Quaternary. It is overlain by the Peoria Silt, a Woodfordian loess deposit.

West of the fault zone the alluvium forms a dissected terrace, the top of which is at an elevation of 410 to 420 feet. The terrace corresponds to the Metropolis terrace of Alexander and Prior (1968). Those authors observed that the Metropolis terrace is composed of reworked "Lafayette" (Mounds) Gravel and is overlain by Peoria Silt. They also recognized that the Metropolis terrace stands above and is therefore older than the Brownfield terrace. Radiocarbon dating indicates a Woodfordian age of about 13,000 to 14,000 years for the Brownfield terrace (Alexander and Prior 1968). The Metropolis terrace therefore is pre-Woodfordian.

To summarize, the Barnes Creek fault zone displaces the Metropolis terrace, which is probably Quaternary but pre-Woodfordian. The fault zone does not affect Woodfordian and older Altonian sediments in the Cache Valley at Homberg. This means the fault zone probably was active in early Pleistocene (Illinoian or older), and may have been active into early Wisconsinan time. The lack of Altonian offset at Homberg does not rule out younger offset along Barnes Creek, but the Holocene sediments are undisturbed everywhere we have observed them.

Better dating of the Metropolis terrace is necessary to pin down the age of faulting. For example, drilling or trenching should be conducted to determine whether the Sangamon Soil is present upon the terrace. The Sangamon overlies or is developed in the top of Illinoian sediments, and therefore is an important marker for correlation.

Massac Creek structure

Ross (1963 and 1964) observed McNairy Formation and Mounds Gravel with "steep dips" along a tributary of Massac Creek in Sec. 28, T14S, R5E, Massac County (figs. 2 and 4). Kolata et al. (1981, p. 19) revisited the site and noted that it occurs along a linear NNE-trending valley.[1] They also found that water-well records indicate a bedrock low along the valley. Seismic-refraction and earth-resistivity surveys were conducted, but shed no light on origin of the structure. Kolata et al. concluded (1981, p. 19), "The available data do not indicate whether this structure was caused by tectonic faulting, landsliding, solution collapse, or a combination of these processes."

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[1]Kolata et al. used the name Round Knob for this site, but we refer to it as Massac Creek, because the structure directly underlies Massac Creek in places, whereas the village of Round Knob is several miles distant.

Remapping the Reevesville Quadrangle, Nelson (in preparation) determined that the Mounds Gravel is downdropped into a narrow graben that is part of the Hobbs Creek Fault Zone (figs. 4, 11, and 12). Outcrops of tilted Mounds Gravel can be traced approximately 2,000 feet along the creek in Sec. 28, T14S, R5E. The Mounds is downdropped at least 60 feet relative to nearby exposures outside of the graben. Outcrops of the McNairy Formation exhibit contorted bedding, numerous faults and clastic dikes. Borehole data indicate that the structure extends at least another 4 miles farther southwest. The Massac Creek structure is part of the Hobbs Creek fault zone, a major element of the Fluorspar Area fault complex (figs 2 and 4). Hence, the Massac Creek structure is tectonic, and not the product of landsliding or solution-collapse.

Water-well data suggested a deep graben along the Massac Creek structure. The driller's log of James Weaver's well (fig. 4) showed 342 feet of clay, sand, and gravel were penetrated without reaching bedrock. The top of bedrock in the Weaver well is below 80 feet above sea level, compared to elevations of 325 to 360 feet in nearby wells outside of the graben. Thus, the top of bedrock is downthrown at least 245 feet in the Weaver well.

The Weaver borehole. No samples from the Weaver well being available, we arranged to redrill the Weaver well site about 300 feet from the original water well. A continuously cored test hole 301 feet deep was drilled in September, 1994. The following strata were penetrated:

Top	Bottom	Unit	Lithology
0	8	Loess	Silt, yellowish brown, pebbles at base
8	15	Alluvium	Silt, sand, and gravel with clay matrix
15	108	Mounds?	Silt, sand and gravel, red to orange and brown, chert pebbles with glossy patina
108	301	Unknown	Sand, silt, and lignitic clay; small gray to black chert pebbles; woody organic lenses.

The unit from 15 to 108 feet is composed of multi-colored silt to coarse sand with thin layers and lenses of chert gravel. The chert pebbles have the brown or bronze colors and patina typical of the Mounds; however, this unit is much finer grained (less gravelly) than normal Mounds, as seen in modern exposures adjacent to the Weaver property. A likely alternative is that this material is part of the Metropolis terrace, as found along the Barnes Creek fault zone.

The section below 108 feet does not match any previously known unit is southern Illinois. The sand is light gray to yellow, very fine to fine, well sorted, and composed of quartz with little or no mica. Scattered small, rounded granules of quartz and chert are present. Silt grades from medium gray through dark olive and brownish gray, and contains abundant coarse fibrous, peaty plant material. The abundance of plant material increases toward the bottom of the core. In the lower 70 feet are layers of tough, black, highly organic clay that can be classified as gyttia or sapropel. Morphologically, it looks similar to cumulic surficial horizons of interglacial soils.

Strongly deformed sediments were observed throughout the Weaver core. Steeply tilted and contorted laminations, brecciated materials, possible clastic dikes, and chaotically intermixed sand, silt, and clay were separated by intervals having more or less horizontal lamination.

Samples of peaty clay from 145.3-146.0 feet and sapropelic clay from 298.6-299.0 feet were submitted to Ron Litwin of the USGS for palynological analysis. Litwin reported (written communication dated 11/20/95) that both samples contained diverse pollen assemblages of nearly "modern" aspect. The pollens represent a variety of hardwood trees, conifers, grasses and herbs. Most are upland genera such as oak, hickory, hazelnut, and hemlock; aquatic vegetation such as cattail and water-lily also is present. The older sample Litwin interpreted as probably late Miocene or Pliocene (but possibly Pleistocene), and the younger sample as most likely early Pleistocene but possibly as old as Miocene. Litwin also reported, "The abundance of the alga *Botryococcus* in the (upper) sample suggests that this sample was deposited in standing to sluggish water, such as a channel cut-off, marsh, lake, or pond."

These findings lead to the conclusion that the Massac Creek structure is a tectonic graben, part of the Hobbs Creek fault zone and a product of extension (figs. 11, 12). The graben formed in Miocene to early Pleistocene time in an upland setting. As the graben sank a pond or swamp formed, serving as a trap for sediment, pollen, and plant debris. The youngest deposit in the graben is either the Mounds Gravel or the younger Metropolis terrace.

Further study is needed to constrain the age of the Metropolis terrace. This terrace actually may be a complex of two or more Pleistocene surfaces, most likely older than Sangamonian. Mapping, shallow drilling and excavation are needed to identify lithologies and terrace surfaces in the Massac Creek area.

New Columbia structure

A narrow, V-shaped graben southwest of New Columbia in northern Massac County was mapped by Devera and Nelson (in preparation). The graben contains McNairy Formation and Mounds Gravel downdropped into the Chesterian (Mississippian) West Baden Sandstone. The New Columbia structure lies approximately one mile northwest of and strikes parallel with the Lusk Creek Fault Zone.

The New Columbia structure follows a linear valley that trends N40°E along most of its length, bending to N70°E near its northeast end (figs. 2 and 13). The ridges that flank the valley are composed of nearly horizontal Mississippian sandstone. Along both margins of the graben, sandstone bedrock dips inward as steeply as 55° (fig. 14). The zone of steep dips probably is less than 100 feet wide. Strongly deformed sand and clay of the McNairy Formation is exposed along the bottom of the valley. Bedding is steeply dipping and contorted, offset by numerous faults, and riddled with clay-filled fractures.

An outcrop of Mounds chert-pebble conglomerate occurs along the east valley wall near the midpoint of the structure. Bedding trends N40°E/55°NW, parallel with the axis of the New Columbia structure. The tilted block of Mounds is 100 to 140 feet lower in elevation than horizontal Mounds that directly overlies Mississippian sandstone along the ridge crest southeast of the structure (fig. 14).

Undeformed, horizontal sand (New Columbia Sand) up to 50 feet thick overlies faulted and steeply dipping older units in the northern part of the New Columbia structure. The sand is fine to coarse-grained and is composed of 80 to 90% quartz grains, 10 to 20% chert grains, 1% or less of dark lithic grains and heavy minerals, and practically no mica. Festoon crossbedding is prominent, but portions are planar-laminated. Clay balls and rip-up clasts are locally present. The New Columbia Sand contains a truncated soil profile near the top, and is overlain by the Peoria Silt (late Wisconsinan). Grain size, sedimentary structures, and clay clasts point to fluvial origin of the sand. As such, the New Columbia Sand most likely was deposited prior to incision of the Cache Valley, which began roughly 0.5 million years ago.

The New Columbia structure lies a short distance northwest of, and may connect at one or both ends with larger faults that are concealed by alluvium in the Cache Valley southeast of New Columbia Bluff (fig. 13). These larger faults comprise the Lusk Creek fault zone, a major element of the Fluorspar Area fault complex. The Lusk Creek fault zone originated during Cambrian rifting, has undergone several episodes of activity, and is directly in line with the most active part of the New Madrid seismic zone (Nelson 1991; Weibel et al. 1993).

Another narrow, deep graben along the Lusk Creek fault zone is indicated by drilling 6 miles southwest of New Columbia. The School District No. 17 water well at the Maple Grove School north of Joppa (NE¼ NE¼ SE¼, Sec. 10, T15S, R3E) reached total depth in the McNairy Formation at a depth of 331 feet, indicating that top of Paleozoic bedrock is lower than 44 feet above sea level. Samples from this well were logged by T.W. Lambert, a geologist with the U.S. Geological Survey. In surrounding wells the bedrock surface is between 175 and 300 feet above sea level. These data indicate the McNairy is downdropped at least 133 feet. Strata younger than McNairy evidently are not displaced here.

We interpret the New Columbia structure to be a product of extensional tectonic stress and part of the Lusk Creek fault zone. The time of faulting is not well constrained, but it can be no older than Pliocene and no younger than early Wisconsinan. Most likely, it is early Quaternary.

Reineking Hill structure

A narrow graben that strikes N20°E contains the Upper Cretaceous McNairy Formation, downdropped at least 200 feet relative to Mississippian bedrock on either side. Mounds Gravel was found at the site, but its provenance is questionable.

The Reineking Hill[2] structure occupies a narrow, linear valley through bedrock hills on the southeast side of the Cache Valley in Secs. 13, 23 and 24, T14S, R4E, Massac County (figs. 4 and 15). The Illinois Central Railroad follows this valley. A railroad cut near the midpoint of the valley exposes the West Baden Sandstone (Chesterian; Upper Mississippian). On the southeast side of the tracks the sandstone is horizontal or dips gently northwest. On the northwest side of the railroad, along the edge of an abandoned and water-filled clay pit, outcrops of Mississippian sandstone and shale strike N20°E and dip 40 to 80° northwest.

Geologic mapping by Nelson (in preparation) shows that hills flanking the fault-controlled valley are composed of West Baden Sandstone. No McNairy or Mounds was found on either hilltop, 150 feet higher than the valley floor. The sandstone is nearly horizontal, except along the valley margins, where bedding dips inward along both sides at 10° to 35°, and locally nearly vertical (figs. 15 and 16). We found no McNairy exposures along the fault-controlled valley, but Lamar (1927), Lamar and Sutton (1930), and unpublished field notes by J.E. Lamar (ISGS, open files) indicate that a high rock face formerly existed on the northwest side of the railroad tracks. The old railroad cut showed Mississippian sandstone and shale overlain by sand and clay of the McNairy Formation, which in turn was overlain by clay containing "Lafayette" (Mounds) chert pebbles, and capped by loess. The McNairy and Mississippian rocks were folded and fractured; Lamar and Sutton (1930) attributed deformation to settling and creep rather than tectonic processes.

Some time between 1930 and 1961 the Illinois Clay Products Co. opened a clay pit northwest of the railroad. The northwest side of the railroad cut was removed and a pit was excavated at least 20 feet below grade. W.A. White of the ISGS visited the pit while it was active, and reported that the east wall of the pit appeared to be a nearly vertical fault surface, with clay on the west downthrown against sandstone on the east. A perpendicular fault, also vertical, formed the south wall of the pit. The downfaulted clay probably belonged to the McNairy Formation (W.A. White, field notes dated 1961 in ISGS open files, and personal communication to Nelson, 1991).

In about 1980 Dennis Kolata and John Masters bored several test holes with a hand auger near the flooded clay pit. They recovered sand and clay believed to be McNairy, but the section was disturbed by mining activities (Kolata, personal communication, 1991). Attempts to find fresh McNairy or Mounds exposures during the present study were unsuccessful. The site was thoroughly disturbed by clay mining, and extraneous material, including Mounds

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[2]The name probably refers to the Reineking family, which owns property nearby. The site was designated "Rineking Hill" in previous reports.

gravel, was brought in apparently to provide traction for heavy equipment.

The Reineking Hill graben is part of the Raum fault zone, a major component of the Fluorspar Area fault complex (fig. 2). More precisely, the Reineking structure lies along the west margin of a larger lozenge-shaped graben within the Raum fault zone (figs. 4 and 16). Faults in the larger graben strike N20°E and outline tilted blocks of Chesterian bedrock. These faults lie en echelon to the overall trend of the Raum Fault Zone, which is N40°E. Once again, the structural pattern suggests an extensional duplex created by left-lateral wrenching (Richard Harrison, written communication, 1994).

The Reineking Hill graben apparently continues at least 6 miles southwest of the railroad cut, as shown by subsurface data. Three wells southwest of the railroad cut show the top of Paleozoic bedrock downdropped 100 to more than 200 feet along a nearly straight N40°E trend. Which units are displaced is not certain because no samples from these wells are available. The drillers' descriptions of strata in the graben best fit the McNairy Formation.

In conclusion, the Reineking Hill structure is a tectonic graben and the McNairy Formation probably was downdropped at least 150 feet. Whether Mounds Gravel or younger units are displaced is not certain. Mounds pebbles reported in the old railroad cut may be merely slope wash of erosional remnants "let down" from a higher surface. The structure seemingly influenced Pleistocene fluvial sedimentation in the Cache Valley. Drilling and/or geophysical surveys across the structure near the edge of the cache Valley might clarify the relationships.

Metropolis structure

Kolata et al. (1981) described exposures of faulted McNairy Formation and Mounds Gravel along the north bank of the Ohio River adjacent to Fort Massac, on the east side of Metropolis (fig. 2). The faults were well exposed only at low stages of the river. Kolata et al. concluded that the origin of the faulting was unknown, but they considered solution-collapse or tectonic faulting the most likely hypotheses.

When we visited this site in April, 1995, we found that a barge-loading facility now stands where Kolata et al. observed the faults. Concrete and artificial fill now conceal the faults, so that field study is impossible. Exposures of Mounds and McNairy still can be seen on the bank just below Fort Massac and for several hundred feet east of the fort, when the river is low. The Mounds-McNairy contact is close to mean river level (elevation 290 feet), and it undulates gently, with 5 to 10 feet of erosional relief. Bedding of the Mounds and McNairy is horizontal, or nearly so, and the strata lack faults or systematic joints.

Referring to Kolata et al. (1981) and field notes by Kolata and J.D. Treworgy (ISGS, open files), five faults were observed (fig. 17). The easternmost and largest ran about N30°E and displaced the base of the Mounds Gravel about 50 feet down to the southeast. The fault surface was concealed and its dip not determined. Bedding in the Mounds Gravel northwest of the fault was nearly horizontal, whereas southeast of the fault it dipped northwest, toward the fault, as steeply as 27°. The other four faults all dipped vertically or nearly so, and had strike trends of N-S to N30°W. The amount and direction of slip along these faults was not determined, although the easternmost one had at least 10 feet of vertical separation. These faults displaced the McNairy Formation only. Nearly horizontal, unfaulted Mounds Gravel overlay tilted and faulted McNairy with an angular unconformity.

Kolata et al. (1981) stated that Quaternary alluvium and low terrace deposits (Brownfield terrace) that overlie the Mounds Gravel near the Metropolis structure are not deformed. The terrace surface is plainly visible in Fort Massac State Park, in line with the faults. No offset is apparent.

The Metropolis structure possibly extends several miles to the northeast. Logs of water wells about 3 miles northeast of Metropolis indicate the top of bedrock drops 30 to 60 feet in elevation to the southeast in line with the Metropolis structure. This relatively small elevation change, however, might represent uneven erosion rather than faulting. The Metropolis structure is more or less in line with the Barnes Creek fault zone (described above), but not enough data are available to show whether the two features connect.

Kolata et al. (1981) stated that the elevation of the base of the Mounds Gravel in the area between Metropolis and Brookport is "unusually low", about 300 feet compared to 450 feet in hills to the north. They suggested that the low-level Mounds might be tectonically downdropped or downwarped. Our subsurface data show that the base of the Mounds is at an elevation 260 to 280 feet in an area extending about 3 miles northwest of Metropolis and within 1 mile of the Ohio River. In addition, gravel that was probably the Mounds formerly was mined by dredge in a pit near Massac Creek in the NE¼, Sec. 36, T15S, R4E, about 2 miles northeast of Metropolis (Lamar 1929). These occurences fit the 280-foot buried erosion surface of "continental deposits" (Mounds), mapped by Olive (1980) in northern Ballard and McCracken Counties, Kentucky. Combining our mapping with that of Olive, the low-level Mounds forms a slightly arcuate belt close to the Ohio River. Olive (1980, text page 6) hypothesized that this low-level surface was incised and filled during late Miocene or Pliocene time by a river system that generally followed the lower Tennessee and Ohio River courses of today. Therefore, the presence of Mounds Gravel at low elevations near Metropolis is due primarily to normal fluvial processes rather than to tectonic faulting.

The Metropolis structure records two episodes of deformation, one before and the second during or after deposition of the Mounds Gravel. The first episode broke the McNairy Formation into gently tilted and folded blocks that are separated by nearly vertical faults striking N-S to N30°W (fig. 17). Such a pattern suggests tectonic strike-slip faulting; the small anticline at the west end of the exposure implies an element of compression. These early were beveled and truncated by horizontal Mounds Gravel.

The second episode of faulting created the large eastern fault that displaces the Mounds Gravel. This fault exhibits reverse drag on the downthrown block. Reverse drag is commonly the result of partial collapse of the hanging wall overlying a listric (concave-upward) fault surface (Hamblin 1965). Although some tectonic normal faults exhibit reverse drag, a more common setting is in rotational slump blocks that form during landslides (Jibson and Keefer 1988). The riverbank is a likely setting for a landslide.

Definite tectonic structures in the area such as Barnes Creek, Massac Creek, New Columbia and Reineking Hill all show plenty of steeply dipping strata, contorted bedding, intense fracturing and clastic dikes or veins. In contrast, Mounds and McNairy exposed near Fort Massac a few hundred feet east of the Metropolis structure are horizontal and undisturbed. Also, none of the tectonic structures listed above include faults that exhibit reverse drag. Instead they typically are narrow grabens with strata dipping sharply inward on both margins. Our preferred hypothesis is that the second episode of faulting at Metropolis involved landsliding induced by the Ohio River undercutting its bank.

Post Creek Cutoff

Kolata et al. (1981) described a narrow downdropped block of McNairy Formation and Mounds Gravel near the Post Creek Cutoff in eastern Pulaski County (fig. 2). The block is approximately 400 feet wide and its margins strike slightly east of north. Following field studies, they drilled three exploratory boreholes. McNairy and younger sediments were sampled by split spoon and Paleozoic bedrock was cored. Drilling confirmed that the Mounds is downdropped a minimum of 60 feet and the McNairy nearly 100 feet (fig. 18). However, Kolata et al. found that a lithologic contact in Mississippian limestone is not displaced within the structure. Based on that evidence, Kolata et al. concluded that the Post Creek structure is a product of solution collapse.

Post Creek Cutoff is an artificial channel that was dug to drain the Cache Valley for agriculture. It connects the Cache Valley to the Ohio River. Rapid downcutting in the gorge provides better-than-average geologic exposures. The downdropped block described by Kolata et al. (1981) is exposed in a side ravine on the east side of the cutoff.

We re-examined the Post Creek site early in 1995, and found the geologic relationships are essentially as reported by Kolata et al. (1981). The Salem Limestone crops out along the main Post Creek gorge. Elevation of the top of the limestone is about 310 feet. Water well records within a 2 mile radius of the gorge show the top of bedrock at elevations ranging from 290 to 340 feet. Overlying the Salem Limestone are Cretaceous strata: the Little

Bear Soil at the base, a few feet of Tuscaloosa Formation[3] (light-colored chert gravel), and 100 to 150 feet of McNairy Formation. Overlying the McNairy on hilltops is the Mounds Gravel. The base of the Mounds lies close to the 450-foot elevation contour both east and west of the Post Creek structure.

The Post Creek structure appears synclinal; no faults are exposed (fig. 18). Horizontal McNairy strata are exposed east and west of the structure. On the east margin the Mounds-McNairy contact strikes N25°E and dips 40-45° NW. Westward, the dip of bedding in the Mounds gradually decreases to horizontal and then reverses to a gentle eastward dip. Along the poorly exposed west margin the basal conglomerate of the Mounds appears to dip steeply eastward. The Mounds-McNairy contact at the west margin strikes approximately N5°E.

Clay-filled fractures penetrate the Mounds near the trough of the structure. Most of them strike N5-10°W and dip nearly vertically. They are as wide as 1 foot, and contain clay that is layered parallel with the walls of the fracture. Because several fractures die out downward, the clay evidently was introduced from above.

Throughout the Post Creek structure, Quaternary colluvium, alluvium, and loess are horizontal and undeformed, overlying deformed Mounds Gravel with an angular unconformity.

The structure is exposed only along the narrow ravine. Horizontal McNairy sand exposed near the mouth of Post Creek Cutoff indicates that if the structure is linear, it must trend nearly north-south, not northeast-southwest. No borehole records are available on or near the northward projection of the structure. A small valley that trends N10°E is about 1/2 mile north of the structure, and lines up with a small ridge having the same trend farther north (in the Karnak Quadrangle). The origin of this topography is unclear.

Kolata et al. interpreted the Post Creek structure as the product of solution collapse in the Mississippian limestone bedrock. They based their conclusion on apparent lack of offset in Mississippian bedrock in the three cored test holes they drilled at the site. Specifically, they placed the contact between the Harrodsburg (younger) and Ramp Creek Members of the Ullin Limestone at approximately the same elevation in two drill holes, one within the structure and the other just east of the structure. (The third drill hole did not penetrate deeply enough to intercept the Harrodsburg-Ramp Creek contact).

W.J. Nelson and Zakaria Lasemi re-examined the Post Creek cores in 1995. Our findings were inconclusive. Both cores show a change from light gray, coarsely speckled crinoid-bryozoan

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[3]Richard W. Harrison proposes to rename the Tuscaloosa Formation in Illinois the Post Creek Formation, because the unit called Tuscaloosa along the Post Creek Cutoff differs in age and lithology from the type Tuscaloosa. Pending formal publication of the name change, we continue to use the old name, Tuscaloosa.

limestone above, to darker, finer-grained siliceous and cherty limestone below. These rock types can be interpreted as Harrodsburg and Ramp Creek Members, respectively. However, "Harrodsburg" and "Ramp Creek" lithologies alternate in both cores, so that a "contact" cannot be placed precisely. Moreover, Lasemi et al. (1994) have documented that intertonguing of "Harrodsburg" and "Ramp Creek" lithologies is commonplace. These units are not simply tabular members in vertical succession as envisioned by Kolata et al. (1981). Waulsortian-type bryozoan mud mounds (Ramp Creek lithology) are both laterally separated by and overlain by bryozoan-rich grainstone and packstone (Harrodsburg lithology).

The Ullin Limestone between the drill cores at Post Creek may be offset by faults, but the displacement probably is less than the 150 feet of vertical separation of the Mounds Gravel. A displacement of 150 feet probably would juxtapose the Salem Limestone within the structure and the Harrodsburg Member of the Ullin outside of the structure.

Solution collapse remains as a possible hypothesis; however, it has problems. Solution that dropped the Mounds Gravel 150 feet should have produced large caverns and extensive rubble or water-laid cave-fill deposits. Only small-scale solution features, such as widened fractures and corroded bedding surfaces, are visible in outcrops and cores from Post Creek. Moreover, the bedrock surface in the Post Creek structure is 140 feet below the present water level in the Ohio River. It is also at or below the bedrock floor of the Cache Valley, 5 miles north of Post Creek. Karst features normally do not develop below drainage.

An alternative hypothesis is that the Post Creek structure is of tectonic origin. Supporting this theory, the structure trends slightly east of north, in line with mapped faults north of Cache Valley. It is a narrow syncline, similar to Reineking Hill, New Columbia, Massac Creek and other known tectonic structures. A solution-collapse structure might be polygonal and chaotic. The clay veins mostly run parallel to the margins of the structure. High-angle planar fractures, some filled with calcite, are common in the Ullin Limestone in the cores. Evidence against a tectonic origin includes near-horizontal bedding of limestone in the core within the structure, and the lack of faults in outcrops. The apparent lack of vertical offset in the Ullin Limestone, as shown by coring, also argues against tectonic origin. The lack of offset could be explained, however, by predominantly strike-slip displacement or multiple episodes of displacement with reversals in the direction of throw.

The Post Creek structure is nearly in line with the Little Cache fault zone north of the Cache Valley. The Little Cache is a zone of high-angle (nearly vertical) normal faults that strike slightly east of north and displace Mississippian and lower Pennsylvanian bedrock. Some faults outline grabens that have maximum vertical separation of about 250 feet. Nearly vertical slickenside striations and horizontal axes of small drag-folds signify essentially dip-slip displacements (Nelson et al. 1991;

Jacobson 1992; Nelson 1993). To evidence of strike-slip or of reversals of displacement have been found.

Summarizing, the Post Creek structure may be tectonic, but some features are difficult to explain in terms of tectonics. Origin by solution collapse appears possible, but less likely. A combination of tectonic and solution-collapse could explain the observed features. The structure is post-Mounds (Pliocene to early Quaternary), but pre-Holocene.

A seismic reflection survey and/or test drilling would determine whether the Post Creek structure is linear (tectonic) or polygonal (solution collapse). The least costly method would be to drill several shallow test holes along the north side of the county road, at the head of the small valley that aligns with the structure. If Mounds Gravel is found, a linear tectonic structure would be indicated, and trenching could be conducted to determine whether sediments younger than the Mounds are deformed.

Rock Creek graben

The Rock Creek graben is one of several major grabens in the Fluorspar Area fault complex. From Union County, Kentucky the Rock Creek graben crosses into Illinois on a heading of S55°W, then curves to S25°W, crossing back into Kentucky and finally re-entering Illinois in southern Pope County (fig. 1). The graben is composed of mostly high-angle normal faults and a few reverse faults that displace Mississippian and Pennsylvanian bedrock, with vertical separation locally in excess of 2,000 feet (Baxter and Desborough 1965, Trace and Amos 1984).

We mapped the Rock Creek graben where it crosses the margin of the Mississippi embayment in Pope County (fig. 4). Previous geologic maps by Weller and Krey (1939), Ross (1964) and Amos (1966) show faults, but indicate no displacement of units younger than Mississippian.

In Pope County the Rock Creek graben is composed of two smaller, parallel grabens that are a little less than 2 miles apart (figure 4). The western graben trends N25°E and is 1,000 to 1,500 feet wide. Its eastern border is a normal fault that dips 70° to 80° NW and has 200 to 400 feet of throw. Striations on the fault surface are nearly vertical, indicating dip-slip displacement. The western border fault has 600 to 750 feet of throw. Tippie (1944) observed the fault surface in the Compton Mine, an underground fluorspar mine that is now abandoned (fig. 4). He described the fault as a normal fault dipping 60° southeast. Outcrops of brecciated, slickensided sandstone about 2,000 feet southwest of the Compton Mine contain fractures that strike N40-50°E and N45°W and dip 60° to vertical. Slickenides and mullion on these fractures are nearly vertical, signifying dip-slip displacement. Also, joints along the western graben strike parallel with the faults, implying extension without a significant component of strike-slip.

The eastern graben strikes N10°E near its southern end, curving to about N50°E where it crosses the Ohio River. This graben is less than 1,000 feet wide; its bordering faults have 200 to 400 feet of throw. Faults are poorly exposed and no definite kinematic indicators were found. The best exposure is on the Ohio River bluff just south of Bay City, near the northwest corner of the Smithland Quadrangle. At this site the southeastern boundary fault displaces Cypress Formation (upthrown) on the southeast against the Glen Dean Limestone (downthrown) on the northwest. The fault surface dips steeply but is not clearly exposed. Sandstone immediately southeast of the fault dips sharply southeast, opposite to the expected direction of drag. Limestone northeast of the fault is folded into a series of tight, subparallel anticlines and synclines. These features signify either (1) two or more episodes of displacement, with reversals in the direction of throw, or (2) strike-slip motion, with a component of compression. The abrupt bend on the fault near Bay City would be a restraining bend (compressional) under left-lateral displacement.

Deformed McNairy Formation (Cretaceous) was observed along Mallard Creek in line with the western graben (fig. 4). In one exposure a clay-lined fault, which appears to strike northeast and dip gently southeast, penetrates the McNairy (fig. 19). Gravel overlying the McNairy truncates the top of the fault. The gravel is composed of well-rounded gray to black chert pebbles in a matrix of sand. A few white, red, and brown pebbles are present; they do not have a Mounds patina. This gravel is either an unidentified Tertiary unit (Eocene?) or the Metropolis terrace gravel (early Quaternary).

We mapped a number of clay-lined joints or dikes that strike N20°E to N50°E and dip vertically or nearly so. These features appear to be clustered near the projected lines of major faults in Mississippian bedrock. One exposure along Mallard Creek shows a clay dike, sourced from a clay bed in the McNairy and injected upward through overlying McNairy sand. Narrow clay veins also were observed in the Mounds Gravel at an abandoned quarry near Mallard Creek. Whether the clay in the Mounds came from above or below could not be determined. Clay mineralogic studies might help deduce the source of the clay that fills dikes and joints.

Other exposures along Mallard Creek showed McNairy clay beds dipping 25-30° northwest, and a small anticline trending N30°E in well-lithified McNairy sandstone. We could not determine whether units younger than the Mcnairy were deforemd at those outcrops.

We mapped the Mounds Gravel along the western graben northeast of Mallard Creek. The base of the Mounds is at approximately the same elevation (500 feet) inside the graben and on both sides of the graben. In the same area the contact between the McNairy Formation and Mississippian rocks shows little or no change in elevation across faults.

The Mounds Gravel also is exposed in a small quarry along the southeast side of Sevenmile Creek, about 3½ miles southwest of Mallard Creek (near center south line, Sec, 35, T15S, R5E, Metropolis Quadrangle). Bedding of the Mounds in the pit strikes northeast and dips about 4° northwest. Numerous near-vertical, clay-lined joints or fissures in the Mounds strike N20-50°E.

Water-well records near the quarry confirm that the Mounds-McNairy contact gently dips northwest in this area. This is the only evidence for tectonic disturbance of units as young as the Mounds along the Rock Creek graben. The gravel pit lies about one mile northwest of the projected trend of the western graben mentioned above.

In summary, the Rock Creek graben is a complicated structure that has undergone recurrent episodes of movement. The major displacements were pre-Cretaceous. The McNairy is deformed locally, but offsets are small. No displacement of the Mounds Gravel or younger units can be documented, although the Mounds is gently tilted and fractured along the southwest projection of the Rock Creek graben.

Saline River site

The geologic map of Baxter et al. (1963) shows a Holocene(?) "low terrace" segment terminating at a fault near the mouth of the Saline River (near center south line, Sec. 1, T11S, R9E, Hardin County, Saline Mines Quadrangle). The fault at which the terrace terminates is part of the Hogthief Creek fault system, in the central part of the Rock Creek graben. As mapped, the fault strikes N50°E and displaces Pennsylvanian strata down to the northwest. Baxter et al. did not mention in text the relationship of the terrace to the fault.

We visited the site and verified that the terrace terminates abruptly at the spot indicated by Baxter et al. However, a scarcity of bedrock outcrops and borehole data means that the Hogthief Creek fault system cannot be accurately located near the low terrace. The terrace segment may merely be eroded by the Saline River near the projected trace of the fault. Older (Wisconsinan) terraces in the same area appear to continue uninterrrupted across the trace of the fault.

A full investigation of this site would entail trenching and/or drilling to locate the fault and determine whether it actually displaces the terrace or other Quaternary deposits. Given the lack of supporting evidence for Quaternary tectonism here, we assigned the Saline River site a low priority.

Lockhart Bluff graben

Amos and Wolfe (1966) and Amos (1967, 1974) showed faults displacing Cretaceous rocks and "continental deposits" (Mounds Gravel) in the Lockhart Bluff Graben, Livingston County, Kentucky. Although we did not field-check Amos' mapping, it is worth comparing to structures in Illinois.

The Lockhart Bluff Graben is one of the major grabens in the Fluorspar Area Fault Complex, comparable to the Dixon Springs and Rock Creek Grabens (fig. 2). Faults along its southeast margin have vertical separation as great as 3,000 feet (900 m), the largest of any fault in the complex. An intricate array of faults is mapped in Livingston County. As the system crosses the Cumberland River it bends from about S30°W to S70°W, then it sharply narrows and curves to a nearly due south heading near the Tennessee River.

The faults mapped by Amos exhibit "scissoring" and reversals of displacement. For example, Paleozoic rocks are downthrown on the northwest side of the main graben-boundary fault that crosses the southeast corner of the Smithland Quadrangle (Amos 1967) into the northeastern Little Cypress Quadrangle (Amos and Wolfe 1966). The Fort Payne Formation (Osagian; Lower Mississippian) southeast of this fault is juxtaposed with the Caseyville Formation (Pennsylvanian) and various Chesterian units northwest of the fault. In the Smithland Quadrangle the McNairy and Mounds are downthrown on the southeast side of this fault. About 2 miles (3 km southwest of that point the Mounds is downthrown on the northwest side; a little farther south, the Mounds is again downthrown on the southeast side.

Possible strike-slip displacement of the Mounds Gravel is indicated on a fault about 7,000 feet from the north line and 10,000 feet from the east line of the Little Cypress Quadrangle. The fault strikes northeast and cuts across a west-trending spur. The contacts of the Mounds are shifted about 400 feet in a dextral sense across the fault.

Ste. Genevieve Fault Zone

The Ste. Genevieve fault zone extends more than 120 miles across southeast Missouri into southernmost Illinois (figs. 1, 2). It is a complex zone of high-angle normal, reverse and strike-slip faults, some of which have undergone more than one episode of movement (Clendenin et al. 1989, Harrison and Schultz 1994b, Schultz and Harrison 1994). The principal episodes of displacement previously documented were: normal faulting during the Devonian Period and reverse faulting during the Pennsylvanian Period (Weller and St. Clair 1928, Nelson and Lumm 1985). The Ste. Genevieve may have originated as a crustal plate boundary or suture zone during the Proterozoic (Heigold and Kolata 1993).

The Ste. Genevieve abruptly changes character near Cobden in Union County, Illinois. To the northwest it it is a single fault or narrow zone of high-angle reverse faults having the southwest side upthrown more than 2,000 feet. To the southeast the zone splits into a series of southeast- and south-trending extensional faults having much smaller displacements. These faults run parallel to strike of bedding of Paleozoic bedrock units, along the flank of a monocline that widens and flattens toward the southeast (fig. 2).

Iron Mountain fault zone

One branch of the Ste, Genevieve is called the Iron Mountain fault zone (Devera and Nelson 1995). This structure extends along the crest of Iron Mountain for about 3 miles. Its trend changes from NW-SE at the north end to nearly N-S at the south end (fig. 21). Width of the zone varies from 400 to 2,500 feet. Component faults strike parallel with the overall trend of the zone and outline narrow downdropped blocks. A few short, perpendicular cross-faults also are mapped. Maximum displacements are poorly known, probably reaching several hundred feet.

The Iron Mountain fault zone displaces Eocene strata and possibly younger units (figs. 20, 21). A cut bank along Clear Creek shows steeply dipping Tertiary conglomerate apparently in fault contact with Middle Devonian limestone. Along the crest of Iron Mountain, outcrops of Tertiary conglomerate heavily impregnated with iron oxide (possibly the source of the name Iron Mountain) are juxtaposed with silicified fault-breccia. During the early 20th century Tertiary strata were exposed in clay pits along and within the Iron Mountain fault zone. Geologists who visited the clay mines while they were active reported that the clay lies in vertical-walled depressions in Mississippian limestone. St. Clair (1917) described one wall as a fault, striking east-west and having as much as 15 feet of throw down to the south. Otherwise, these geologists interpreted the depressions as sinkholes that existed concurrent with deposition of the clay (St. Clair 1917; Parmelee and Schroyer 1921; Lamar 1948).

Eocene age of the deposits is based on palynological analysis of lignite recovered from waste piles adjacent to abandoned clay pits (Aureal T. Cross, 1984, oral communication to Nelson; D.J. Nichols, letter to Nelson dated March 23, 1993). Also the gravel, composed of well rounded gray to black chert pebbles with no patina, is similar except in grain size to Eocene gravels of southern Illinois (Kolata et al. 1981) western Kentucky (Olive 1980) and southeastern Missouri (Johnson 1985; Harrison in preparation). The coarser clast size of gravel along the Iron Mountain fault zone may reflect its upland position compared to finer gravels in the Mississippi Embayment. The Mounds Gravel has not been observed in the area.

Although previous geologists attributed the clay deposits to sedimentation in sink holes, we favor tectonic grabens because the magnitude of downdrop seems too great for solution collapse. Eocene clay formerly was mined at elevations below 350 feet, but is absent on nearby hilltops as high as 1,000 feet above sea level. No solution features, such as rubble zones, cave sediment, or chaotic structure, were observed or reported along the Iron Mountain structure.

No indication of Quaternary displacement is evident along the Iron Mountain fault zone; however, such evidence would be difficult to detect on the densely wooded ridges. The fault zone crosses under short segments of valley fill along Clear Creek; no lineaments or offsets were detected in alluvium. The clay pits are totally backfilled or flooded; no useful exposures are available there. In 1994 (prior to NEHRP) we attempted to expose the Iron Mountain fault zone by backhoe excavation in a highway cut. This effort was aborted when we realized we were undercutting the toe of a large landslide.

Cooper Creek structure

Several faults that displace Cretaceous and early Tertiary strata were discovered during geologic mapping in the Jonesboro and Mill Creek Quadrangles (Nelson and Devera 1995; Nelson, Devera and Masters 1995a and b). Most of these faults lie in a north-south belt that appears to be a southward continuation of the Iron Mountain Fault Zone.

A fault along Cooper Creek (SW¼ SW¼ NE¼, Sec. 1, T14S, R2W, Mill Creek Quadrangle) was selected for trenching. Prior to trenching, the natural cutbank revealed a zone of high-angle faults that strike N-S to N10°W and juxtapose silicified Paleozoic bedrock on the west with Cretaceous (?) gravel on the east. Of special interest was Quaternary colluvium that appeared to be tilted on the eastern, downthrown side of the structure.

Trenching was conducted in October, 1995. First the streambank was cleaned off to better expose the structure. Then a cut was made along the top of the bank to uncover loess and colluvium directly above the major fault. An east-west trench about 100 feet long was dug across the fault zone about 200 feet south of the creek. The southern trench failed to expose any faults because the backhoe could not dig through well-indurated colluvium beneath the loess.

As shown in the sketch (fig. 22), the exposure contains three large parallel faults. Fault A is a normal fault, Faults B and C are reverse. West of Fault A is hard, thin to medium-bedded chert with shale laminae, probably the Fort Payne Formation (Lower Mississippian). Between Faults A and B is soft, granular silica (ganister) derived from hydrothermal alteration of Fort Payne chert. The vertically-dipping slice between Faults B and C is composed of variegated clay mixed with fragments of chert and representing an unidentified Paleozoic unit that has been subject to intense hydrothermal alteration. East of Fault C is weakly stratified, light-colored chert gravel in a matrix of sand, silt and clay. Its identity is uncertain, but most likely it is the Tuscaloosa Formation of Late Cretaceous age.

Trenching showed conclusively that Quaternary sediments are not affected by the Cooper Creek structure. These materials comprise, in ascending order, (1) reddish-brown chert-rich colluvium, probably early to mid-Pleistocene, at the east end of the exposure, (2) horizontally bedded sand and fine chert gravel, of fluvial origin, and (3) the Peoria Silt, a windblown (loess) deposit of late Wisconsinan age. The base of the colluvium is inclined, but this merely conforms to the slope of the hillside and is not due to tectonic tilting.

Another north-south fault is exposed in the bank of Cooper Creek about 300 feet east of the trenching site. This fault strikes N-S, dips nearly vertical, and has silicified Paleozoic bedrock on both sides. The direction and amount of movement are not known. Holocene colluvium across the top of the fault exposure shows no trace of deformation.

Commerce Fault Zone

Previous findings

The name Commerce fault zone is used here for a fracture zone that extends NE-SW across southeastern Missouri and southern Illinois (figs. 1, 2). The name refers to the town of Commerce, Missouri, which is located where the fault zone crosses the Mississippi River. Although this is an obscure structure, the Commerce fault zone exhibits the youngest Quaternary deformation in the region and there are indications that it is currently active.

Faults displacing Tertiary and possibly Quaternary strata near Commerce were described by Stewart (1942), Stewart and McManamy (1944) and Grohskopf (1955, p. 26-28). These authors reported that the Mounds Gravel is strongly folded and faulted in Thebes Gap. Also they stated that Pleistocene loess is faulted against the Wilcox Formation (Eocene) in a roadcut (no longer extant) near English Hill about 4 miles southwest of Commerce. According to Grohskopf, the loess was downthrown "probably not greater than 30 feet" in a graben that strikes N30°E.

Harrison and Schultz (1994a) and Harrison (in preparation) mapped and described a complex array of faults at Thebes Gap, Missouri and Illinois. The Commerce Fault strikes northeast and displaces Mounds Gravel on both sides of the Mississippi. Branching NNE off the Commerce Fault are many shorter faults that also offset units as young as the Mounds. Harrison and Schultz state that these faults have undergone numerous episodes of displacement dating back at least to the Ordovician. The latest episode, affecting the Mounds, involves primarily right-lateral strike slip.

In May and August of 1995 Richard Harrison and geologists from the Missouri Geological Survey excavated trenches across the English Hill fault about 4 miles southwest of Commerce. The English Hill fault branches NNE off the Commerce fault and is the structure previously reported to displace loess. We visited the trenches with Harrison and examined the structures exposed therein.

A trench west of English Hill Road reveals a zone of parallel high-angle normal faults that outline horsts and grabens. These faults displace Peoria Silt (Woodfordian), Loveland Silt (Illinoian) and Mounds Gravel. The planar fault surfaces, lack of rotation, and orientation of faults (striking oblique to the slope, with the uphill side downthrown on some faults) all are consistent with a tectonic origin rather than slope failure.

A trench east of English Hill Road shows various Cretaceous, Tertiary and Quaternary units as young as the Peoria Silt, all intensely faulted and folded. In the uphill (northwest) part of the trench, a series of nearly vertical faults and a thrust fault displace the McNairy upward against younger units. This structure may be a positive flower structure created by wrench-faulting. In the downhill part of the trench are several large listric normal faults having well-developed rollover or reverse drag in the hanging walls. These faults are likely products of landsliding.

In Illinois, the Commerce fault zone is a discontinuous zone of fractures in late Paleozoic bedrock. Displacements are small, less than 100 feet in most places. The zone extends from Alexander County at least to Saline County, and may continue through White County to the Indiana border (figs. 1, 2). Portions of the Commerce fault zone coincide with other fault zones or structures, such as the New Burnside anticline and (possibly) the northern part of the Wabash Valley fault system. The only place in Illinois where units younger than Pennsylvanian are affected is in the Thebes Quadrangle, where the Mounds Gravel is displaced (Harrison, in preparation)

The Commerce fault zone lies along a prominent magnetic lineament that extends from northeastern Arkansas to near Vincennes, Indiana. This lineament is best shown on Figure 5 of Hildenbrand and Hendricks (1995), a shaded-relief map of the first-vertical derivative of the reduced-to-pole magnetic anomaly data. Hildenbrand and Hendricks interpreted the northwest margin of the Reelfoot rift in Illinois as lying along this anomaly. Following that interpretation, the Commerce fault zone originated as a normal fault during Cambrian rifting and has been reactivated under subsequent stress fields.

Earthquakes

Harrison and Schultz (1994) identified twelve earthquakes, having body-wave magnitudes ranging from 3.0 to 4.8, that possibly are related to movement along segments of the Commerce fault zone. Three of these are in Illinois; a fourth earthquake on or near the Commerce fault zone in Illinois took place after Harrison and Schultz' paper went to press (fig. 2).

The epicenter of the Tamms earthquake of 1965 (magnitude 3.8) lies in the Cache Valley approximately 1½ mile southeast[4] of the mapped trace of the Commerce structure. The focal depth of 1.5 km (Herrmann 1979) is within Paleozoic bedrock, probably near the base of the Ordovician System. This is an unusually shallow focal depth for earthquakes in the region. The focal-plane solution indicates the fault responsible for the Tamms quake was either a high-angle, right-lateral strike-slip fault striking about N15°E or a left-lateral fault striking N75°W (Herrmann 1979). The former alternative would fit the Commerce fault zone.

The Harrisburg earthquake of 1984 (magnitude 4.1) had an epicenter 1 mile northwest of the trace of a mapped fault (fig. 2). The fault, indicated by coal-test boreholes, strikes northeast and has the northwest block downthrown about 65 feet in Pennsylvanian strata (Nelson and Lumm 1986). Focal depth of the quake again was

[4]Epicentral locations are calculated with an uncertainty range of several miles.

shallow, about 2 km; this would be in or near Upper Ordovician strata. Missing section in boreholes that penetrated the fault plane indicate a normal fault that dips northwest. The fault surface therefore dips toward the earthquake's focal point at depth. Focal analysis (Otto Nuttli, personal communication, 1984) indicated slip on a high-angle normal fault striking ENE, which is a close match for the mapped fault segment.

The most recent earthquake, near Dongola in February 1994 (magnitude 4.2), is nearly in line with a segment of the Commerce fault zone mapped by Nelson and Follmer (in preparation). The focal depth of 16 km or nearly 53,000 feet is deep in the Precambrian basement. The focal-plane solution indicates the fault was oriented either N20°E/70°SE with right-lateral slip or N59°W/62°SW with left-lateral slip. The principal compressive stress axis was oriented N72°E (Robert Herrmann, written communication 1995).

Whether the Tamms, Dongola and Harrisburg tremors involved the Commerce fault zone or not, levels of seismicity are no higher along the Commerce structure than in the surrounding area. Thus the Commerce appears no more "active" than any other fault in southern Illinois. Although earthquakes in Illinois, as elsewhere, presumably are caused by slippage along faults; most earthquakes in Illinois cannot be attributed to any mapped fault. The Commerce is one of many structures in southern Illinois that contains fractures that are oriented favorably for slippage under the contemporary stress regime.

Further research

Because we did not recognize the significance of the Commerce fault zone until a few months ago (following Harrison's trenching in Missouri) he have had little opportunity to investigate the structure in Illinois. One site was trenched, with negative results.

The site we trenched was along the northwest border of the Cache Valley in the NW¼, Sec. 30, T14S, R1W, Alexander County (fig. 2). The northwest bluff face here is remarkably linear, trending N35°E for about 3 miles and coinciding a with mapped segment of the Commerce fault zone (Nelson, Devera and Masters 1995b, Devera and Follmer in preparation). Old diggings in the borrow pit revealed the Peoria Silt overlying an older loess and Devonian bedded chert. The Peoria contains faint laminations, unusual for this unit and possibly products of floods in the Cache Valley during deposition of the silt. In places these laminae are deformed into small, disharmonic folds, some of which are monoclinal and suggested the possibility of tectonic faulting.

A backhoe trench about 80 feet long and trending east-west was dug across the hillside, exposing the top of bedrock and passing through the area of disturbed laminations. The top of bedrock was found to be nearly horizontal and no offsets were evident. The silt units were uniform in thickness and conformable to both the bedrock and the ground surface. Many fragments of chert derived from bedrock were found intermixed with the lower part of the pre-Peoria silt. These imply colluviation (downslope mass-movement of the silt, chert fragments being intermixed with the silt). Such colluviation readily explains the distorted laminae in the Peoria Silt at this site.

Previously Nelson and Lumm (1984) examined faults associated with the Commerce fault zone in southern Saline County, about 8 miles southwest of the epicenter of the 1984 Harrisburg earthquake. The faults were exposed in surface coal mines that are now reclaimed. Observed were northeast-striking, high-angle normal faults that outlined horsts and grabens. Mullion, slickenside striations, and drag features indicated dip-slip displacements. These faults obliquely cross the northern flank of the New Burnside anticline. Pennsylvanian rocks were deformed; overlying Quaternary loess was not disturbed at any of the sites examined.

More study of the Commerce fault zone clearly is in order. The most promising area is in the Thebes Quadrangle, close to the Mississippi River. Richard Harrison has pointed out several places where faults he mapped (Harrison, in preparation) seem to offset Quaternary terraces. Another area that should be studied is the epicentral area of the Harrisburg earthquake. At this point thick lacustrine silt and clay of the Equality Formation (Wisconsinan) overlies Pennsylvanian bedrock. The location of the fault in bedrock is known from borehole data. A high-resolution seismic profile could be run here to determine whether bedrock surface is offset; trenching in the Equality Formation might show faulting or earthquake-related liquefaction features.

CONCLUSIONS

Fluorspar Area Fault Complex

The Mounds Gravel and, locally, younger sediments of early Pleistocene age are displaced in the Fluorspar Area Fault Complex of southeasternmost Illinois. Faults that displace Quaternary sediments strike N20°E to N40°E and outline narrow, linear grabens. Offsets range from a few inches to at least 245 feet in the Massac Creek structure. Strata within grabens are steeply tilted and cut by numerous high-angle and reverse faults parallel to the larger structure. In contrast, rocks bordering grabens are generally horizontal or near so, and exhibit little or no net displacement across the grabens.

No displacement of late Pleistocene or Holocene units has been detected. Streambanks reveal horizontal, undisturbed Holocene alluvium overlying folded and faulted early Pleistocene deposits. Drilling on the Homberg terrace shows that the Barnes Creek fault zone does not offset Altonian (early Wisconsinan) or younger fluvial sediments. The New Columbia structure displaces Mounds Gravel but not the overlying New Columbia Sand, a unit believed to be pre-Illinoian.

Quaternary faulting in the Fluorspar Area probably was strike-slip. This is shown by parallel normal and reverse faults in the same fault zone, and the narrow grabens that are typical of strike-slip pull-apart features. The NNE trend of many grabens, slightly oblique to the overall NE fault trend, suggests left-lateral faulting. However, mullion and slickensides along the Barnes Creek fault zone (in Mississippian wall rocks of an underground mine) indicate right-lateral oblique slip. The Fluorspar Area fault complex has experienced multiple episodes of displacement, dating back to Precambrian time (Heyl and Brock 1961; Hook 1974; Nelson 1991). Deciphering the sense of slip in the latest movement awaits discovery of clear kinematic indicators in Quaternary materials.

Ste. Genevieve Fault Zone

Faults near the southeast end of the Ste. Genevieve fault zone in Union and Alexander Counties, Illinois displace Tertiary strata. Eocene deposits were downdropped into grabens along the Iron Mountain fault zone in Union County; Cretaceous and probable Tertiary (Eocene ?) units are displaced along other faults farther south. The trend of faulting curves from NW-SE at its northern end to nearly N-S at its southern end. Vertical separation is at least several hundred feet along the Iron Mountain fault zone.

The faulting apparently was post-Eocene and pre-Quaternary. No mid- to late-Tertiary units are known in the area. Trenching across a large fault zone on Cooper Creek in Alexander County showed that the Peoria Silt (Wisconsinan) and older colluvium are not affected by the faulting.

The style of faulting was extensional with a component of strike-slip. Wrenching is indicated by parallel normal and reverse faults, "flower structures", and a few occurences of horizontal slickensides. Whether left- or right-lateral slip was involved has not been determined.

The Ste. Genevieve fault zone has a long history of activity. It was active during the Devonian Period and again, with opposite sense of throw, during the Pennsylvanian (Weller and St. Clair 1928; Nelson and Lumm 1985). Various lines of geologic and geophysical evidence imply a Precambrian ancestry for this feature (Clendenin et al. 1989; Heigold and Kolata 1993).

Commerce fault zone

The Commerce fault zone in the Thebes Gap area, Missouri-Illinois, is a northeast-striking, right-lateral fault zone that displaces the Peoria Silt of Woodfordian (late Wisconsinan) age. The fault zone extends across southern Illinois at least to Saline County and possibly continues into the Wabash Valley as far as Vincennes, Indiana. The Commerce structure coincides with a magnetic lineament that may represent the northwest margin of the Reelfoot rift. The foci of three magnitude 4 earthquakes in southern Illinois lie on, or very close to the Commerce fault zone;

focal mechanisms of these quakes could fit right-lateral or normal slip on northeast-trending fractures.

The suggestion that this is an active fault zone must be tempered with contrary evidence. In Illinois the Commerce fault zone is discontinuous, and in most places it makes less than 100 feet of vertical separation in Paleozoic bedrock. The youngest unit demonstrably offset in Illinois is Mounds Gravel, near Thebes Gap. Loess was not affected by faults exposed on mine highwalls in Saline County. Trenching across part of the structure near Tamms in Alexander County showed no disturbance of loess. The level of seismic activity is no greater along the Commerce structure than elsewhere in southernmost Illinois.

The Commerce fault zone obviously deserves further study. We did not recognize its significance until midway through this project. The Thebes Gap area is most promising for new study, in view of possible offset terraces and proximity to known late Quaternary faulting.

Stress field and faulting

The greatest horizontal compressive stress axis of the modern stress field in southern Illinois is oriented east-west to ENE-WSW. This trend is shown by numerous lines of evidence, including earthquake focal mechanisms, borehole breakouts, strain-gauge and overcoring measurements, and roof-failure trends in underground mines (Nelson and Bauer 1987). The stress field in the New Madrid seismic zone has a similar orientation (Rhea and others 1994).

The modern stress field in Illinois would tend to produce slippage along fractures having the following orientations:

(1) Thrust-faulting along low-angle (dip less than 45°) fractures that strike N-S to NNW-SSE (normal to maximum stress axis).
(2) Normal faulting or pull-apart along vertical or steeply dipping fractures that strike E-W to ENE-WSW (parallel to maximum stress axis).
(3) Right-lateral faulting along vertical or high-angle fractures that strike NE or NNE.
(4) Left-lateral faulting along vertical or high-angle fractures that strike SE to ESE.

In the Thebes Gap area the Commerce fault zone is composed of right-lateral faults that strike northeast to NNE. Such slippage is consistent with the modern stress field.

Faults that displace late Tertiary and Quaternary deposits in the Fluorspar Area fault complex strike NE to NNE and involve extension with a component of strike-slip. The direction of strike-slip is uncertain, but the fracture pattern favors left-lateral. Extension should not occur on NE- to NNE-trending fratures under the present stress regime. Extension with left-lateral slip would occur in a stress field with the principal compressive stress axis oriented approximately north-south.

The faults that displace Tertiary strata along the Ste. Genevieve fault zone are near-vertical, strike N-S to NNW, and exhibit extension (pull-apart grabens) and/or strike-slip. Faults having such an orientation should not slip under the current stress field. The observed fault pattern implies the principal compressive stress axis was either NNE (for right-lateral slip) or NW (for left-lateral slip).

Hence it appears that only the Commerce fault zone exhibits slip consistent with the contemporary stress field. The Commerce is the only structure having documented late Pleistocene displacement (in Missouri), as well as earthquake activity that possibly matches the fault orientation and the stress field.

During late Tertiary and early Quaternary time the stress field in southern Illinois apparently was oriented with the maximum compressive stress axis NNE, N-S, or NW-SE when faults in the Ste. Genevieve and Fluorspar Area systems were active. Therefore, the stress field must have rotated 45° to more than 90° from early Quaternary to its modern configuration. As the stress field rotated, faults in the Fluorspar Area and Ste. Genevieve became inactive.

The greatest activity today, of course, is in the New Madrid seismic zone south of Illinois. Many observers have noted that the amount of surface deformation in the New Madrid area is small in comparison to other earthquake zones that have a similar degree of activity. The lack of prominent scarps, depressions, shear zones, etc. in the New Madrid area suggests that this region has not been seismically active for a very long time. Our findings in Illinois imply that the stress field rotated in mid-Quaternary time. That stress change likely activated the New Madrid seismic zone in relatively recent time.

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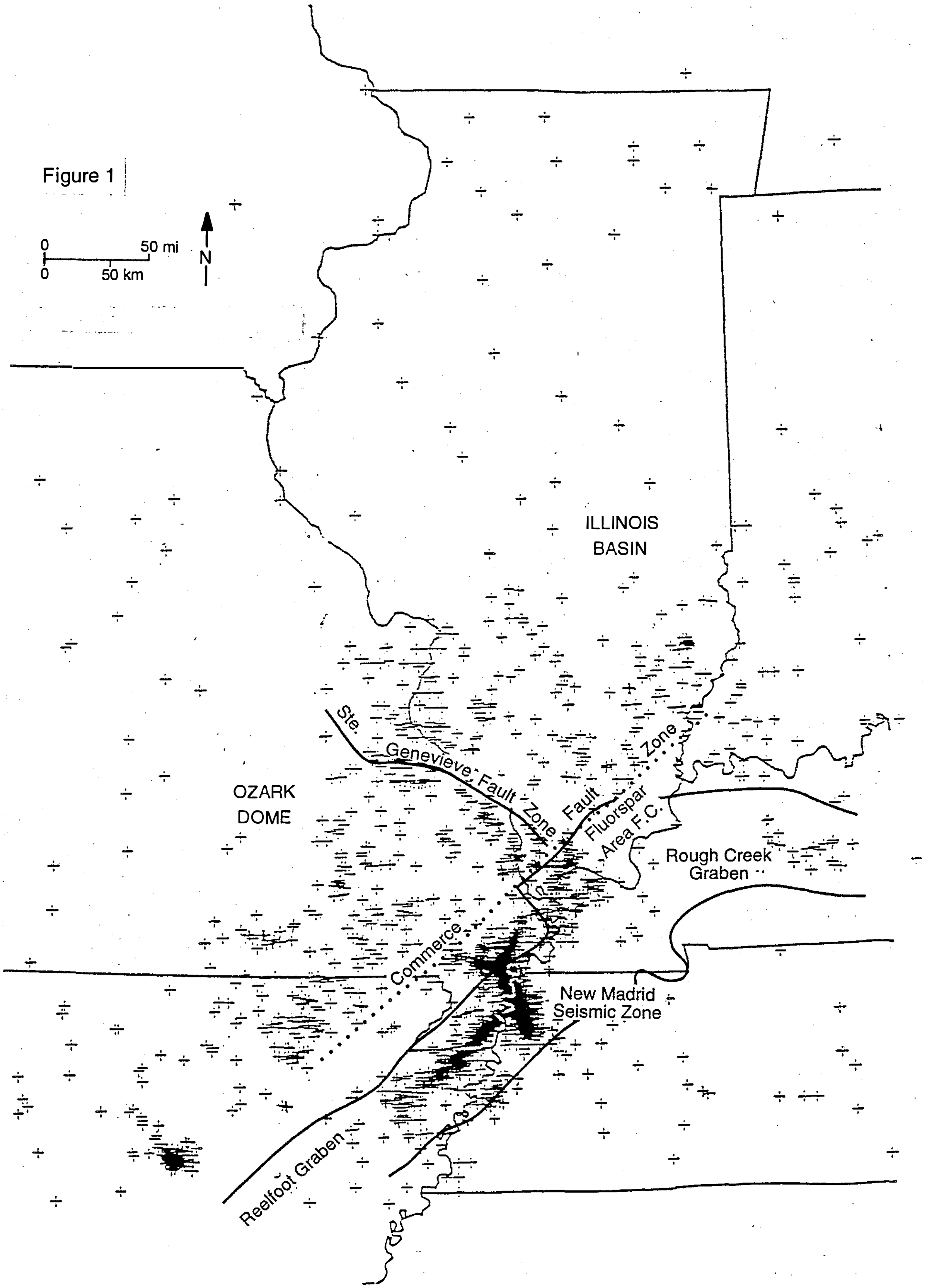
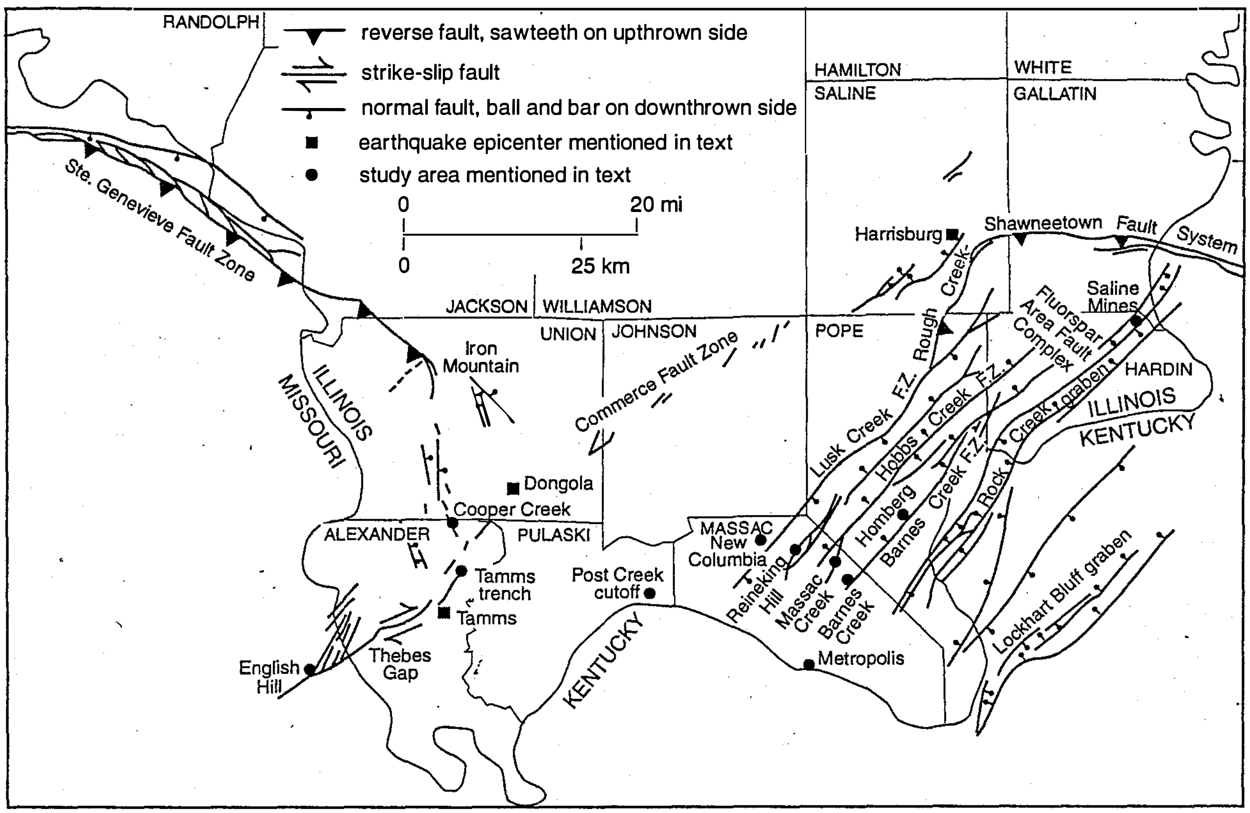


0
50 mi
0
50 km
N
ILLINOIS
BASIN
OZARK
DOME
Ste. Genevieve Fault Zone
Fault Zone
Fluorspar
Area F.C.
Rough Creek
Graben
Commerce
New Madrid
Seismic Zone
Reelfoot Graben

Figure 1

Figure 2


RANDOLPH
reverse fault, sawteeth on upthrown side
strike-slip fault
normal fault, ball and bar on downthrown side
earthquake epicenter mentioned in text
study area mentioned in text
0
20 mi
0
25 km
HAMILTON
SALINE
WHITE
GALLATIN
Ste. Genevieve Fault Zone
Harrisburg
Shawneetown Fault System
Rough Creek
JACKSON
WILLIAMSON
UNION
JOHNSON
POPE
Saline Mines
Fluorspar Area Fault Complex
HARDIN
Iron Mountain
Commerce Fault Zone
ILLINOIS
MISSOURI
Lusk Creek F.Z.
Hobbs Creek F.Z.
Rock Creek graben
ILLINOIS
KENTUCKY
Dongola
Cooper Creek
ALEXANDER
PULASKI
MASSAC
New Columbia
Homberg
Barnes Creek F.Z.
Tamms trench
Tamms
Post Creek cutoff
Reineking Hill
Massac Creek
Barnes Creek
Lockhart Bluff graben
English Hill
Thebes Gap
KENTUCKY
Metropolis

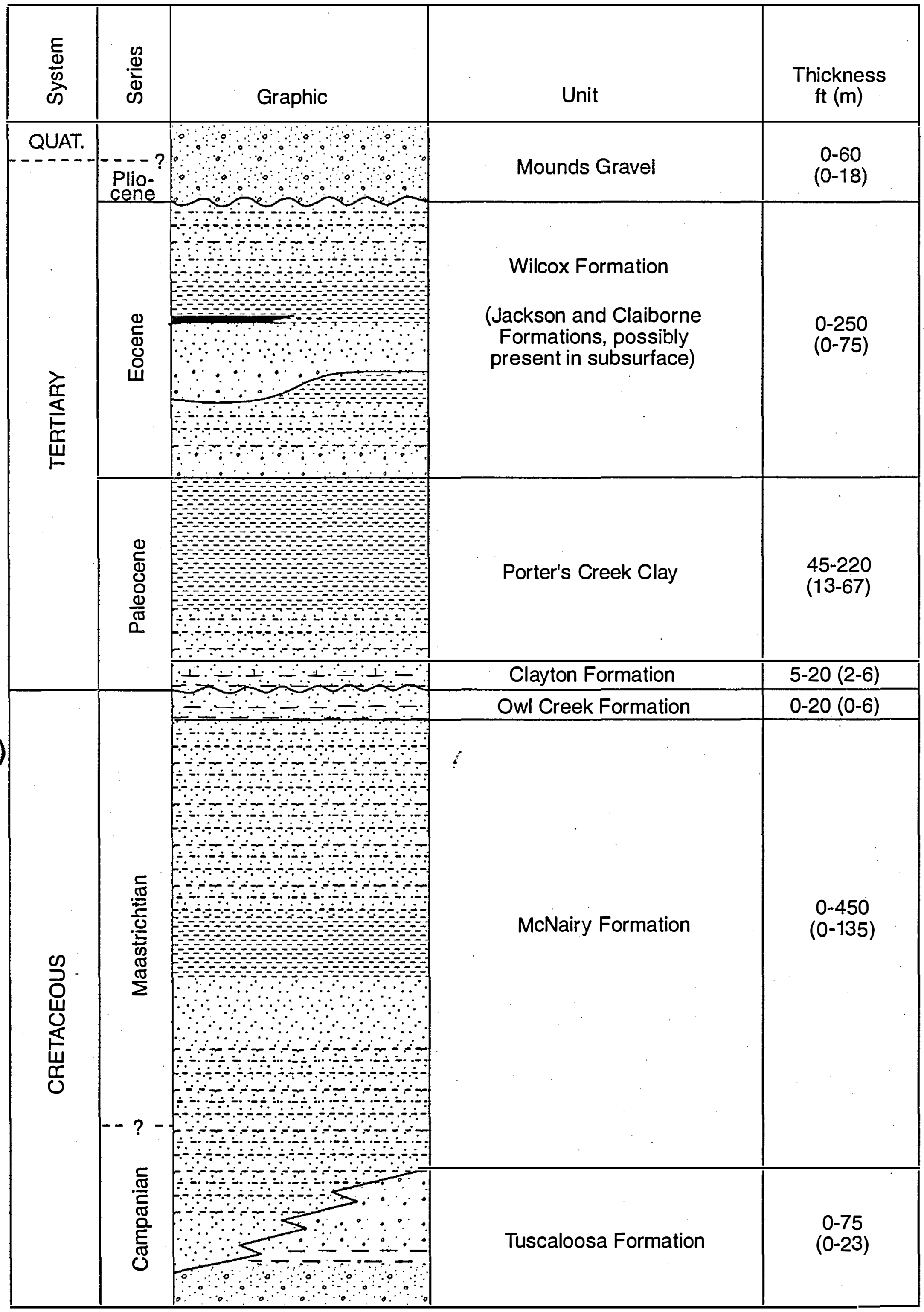
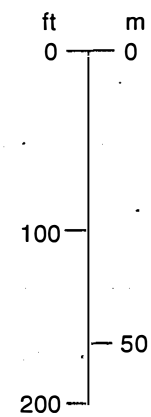


Figure 3 (part 1)



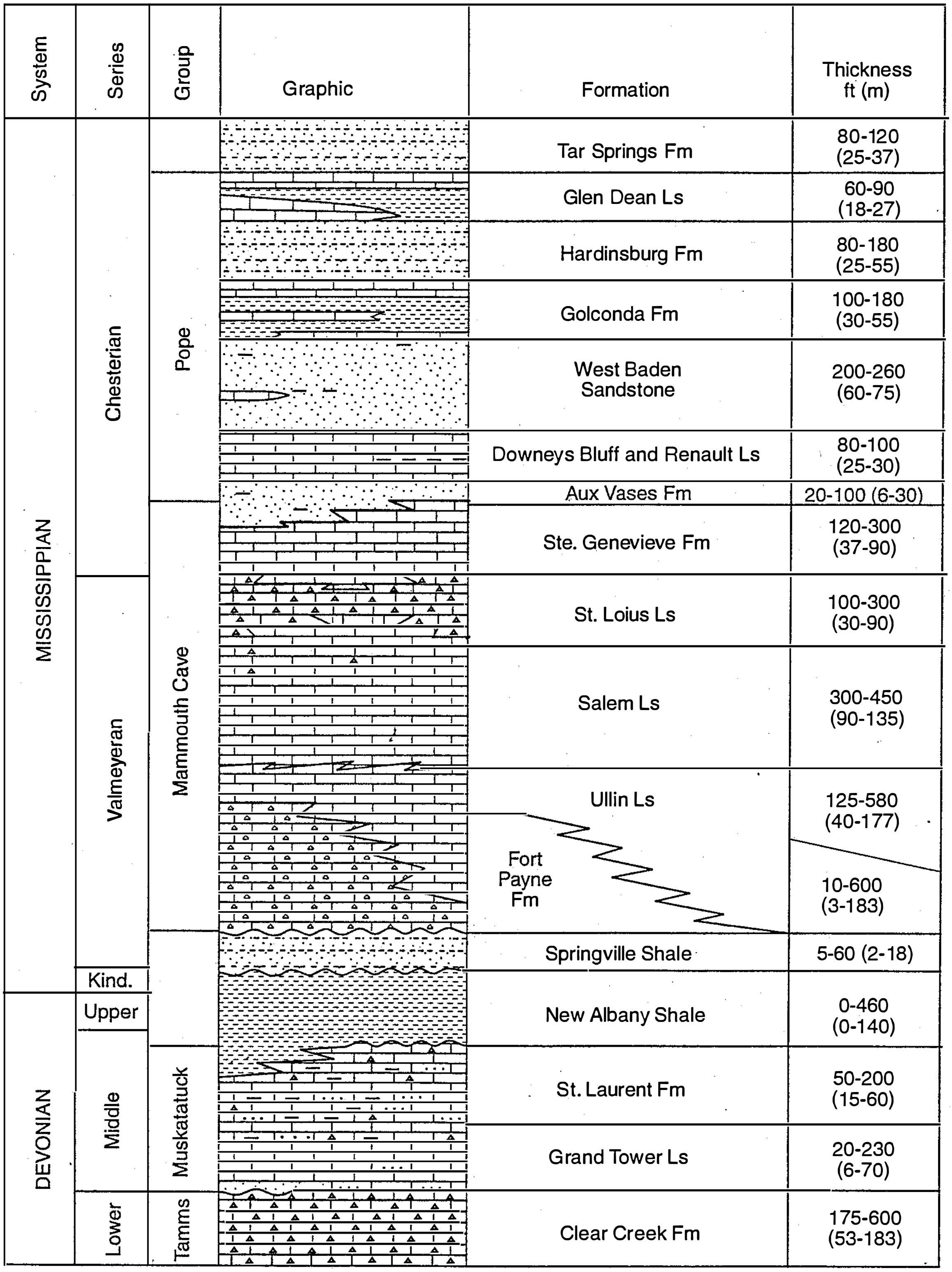
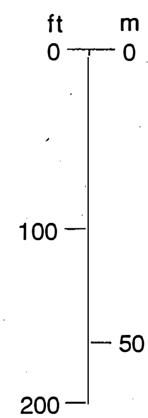


Figure 3 (part 2)



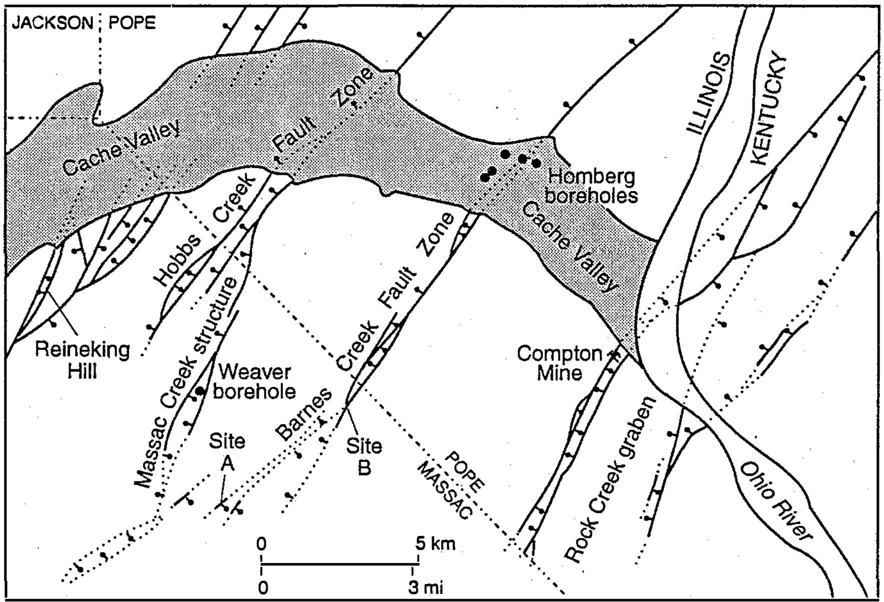
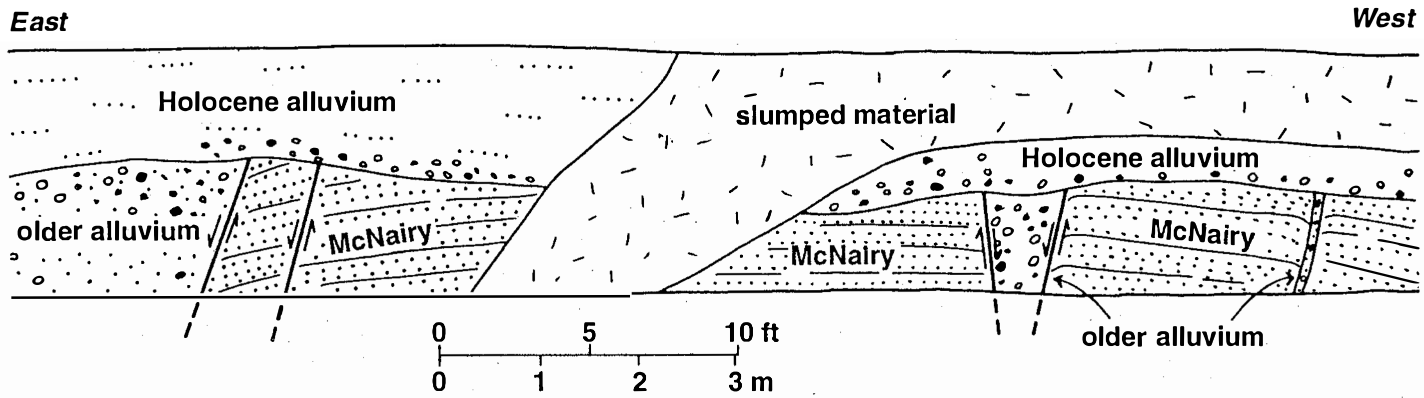

JACKSON
POPE
Cache Valley
Fault
Zone
Hobbs
Creek
Homberg
boreholes
Cache Valley
ILLINOIS
KENTUCKY
Zone
Fault
Creek
Massac Creek structure
Reineking
Hill
Weaver
borehole
Compton
Mine
Barnes
Site
A
Site
B
POPE
MASSAC
Rock Creek graben
Ohio River
0
5 km
0
3 mi

Figure 4

Figure 5



East
West
Holocene alluvium
slumped material
Holocene alluvium
older alluvium
McNairy
McNairy
McNairy
older alluvium
0
5
10 ft
0
1
2
3 m

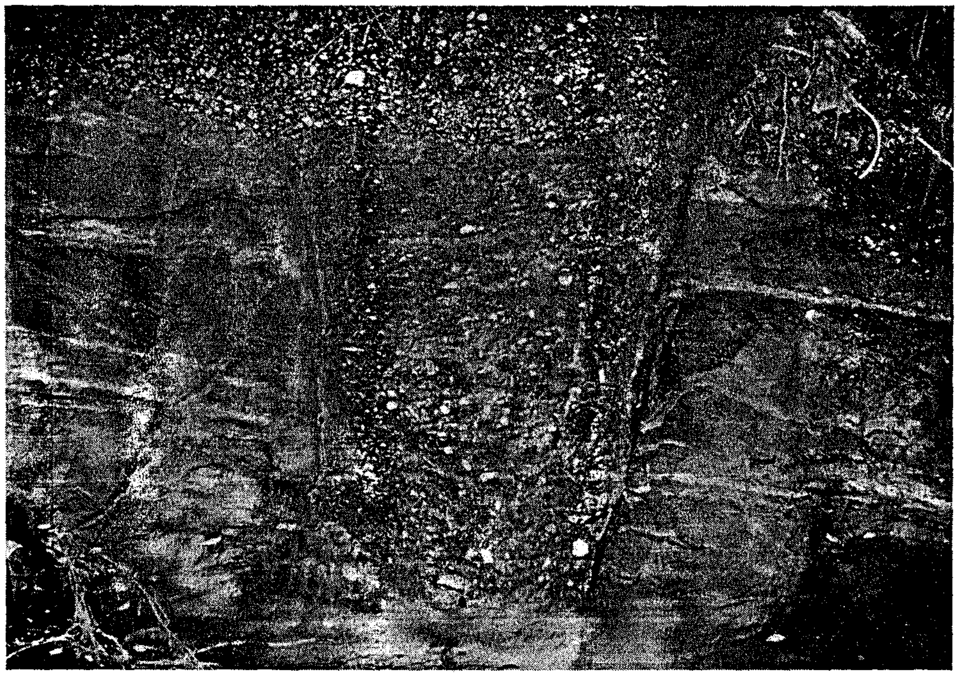


Figure 6

Figure 7

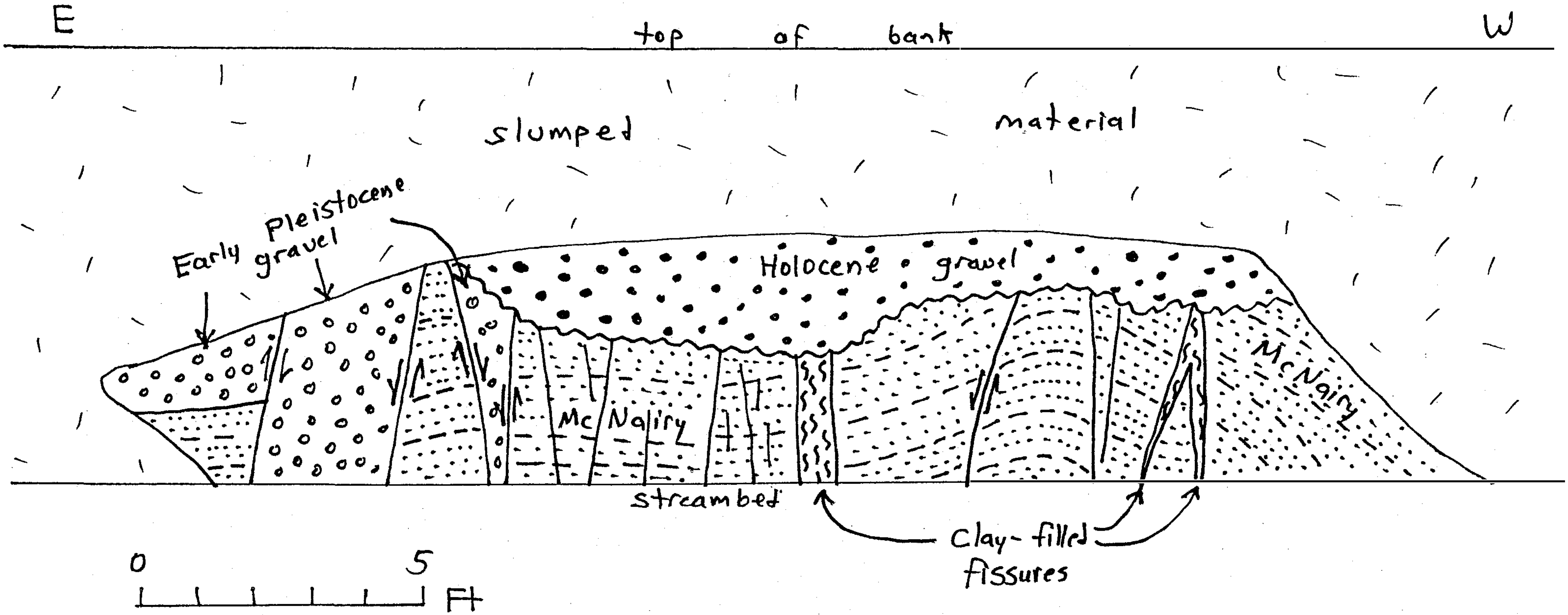

E
top of bank
W
slumped material
Early
Pleistocene
gravel
Holocene gravel
McNairy
McNairy
streambed
Clay-filled fissures
0
5
Ft

Figure 8 Map showing seismic line and structures along Barnes Creek.
Faults solid where observed, dashed where inferred from seismic, dotted where concealed.

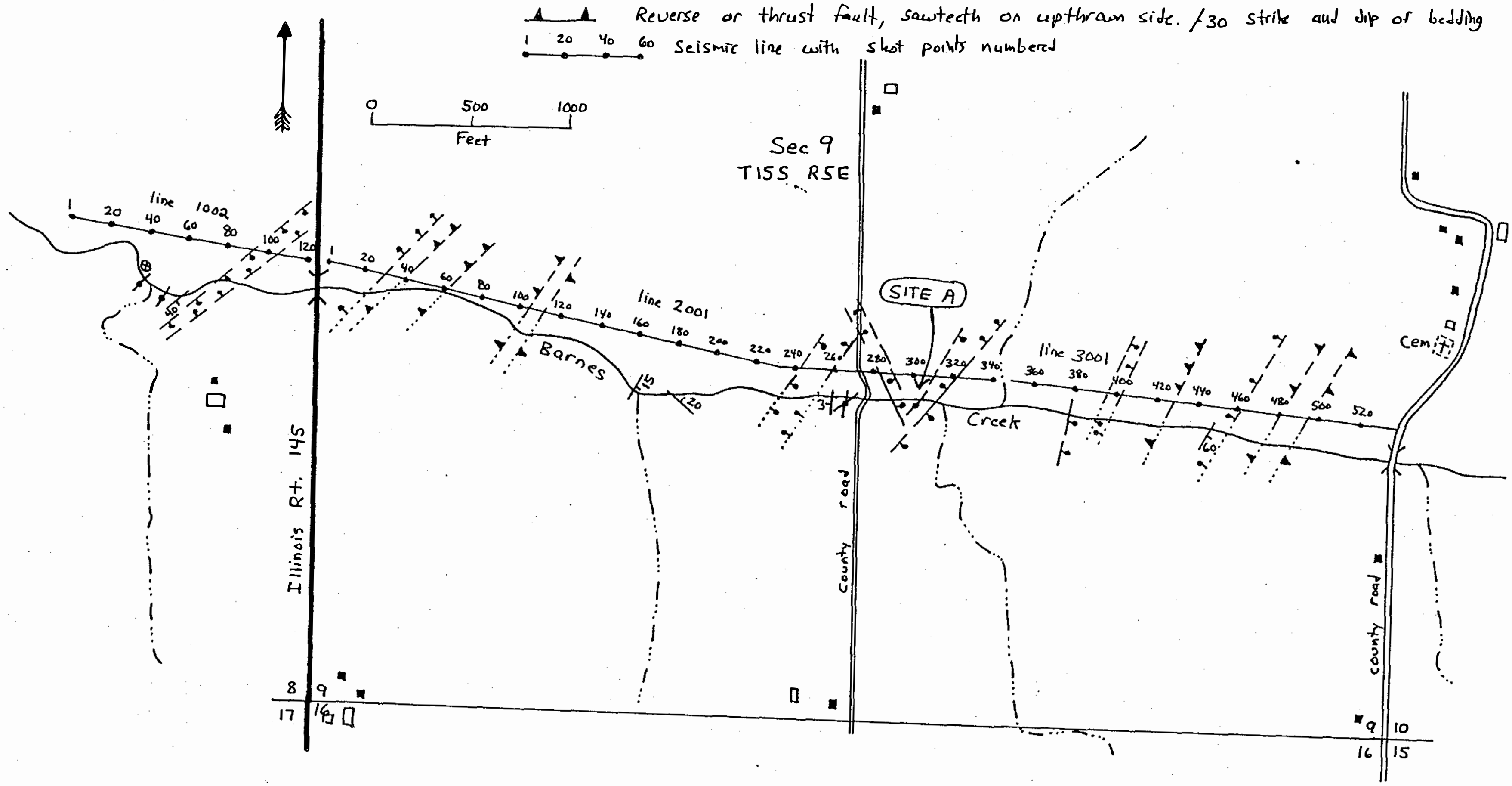
Normal fault, ball and bar on downthrown side

Reverse or thrust fault, sawteeth on upthrown side.

1 20 40 60 Seismic line with shot points numbered

Clastic dike or gravel-filled fissure

/30 strike and dip of bedding



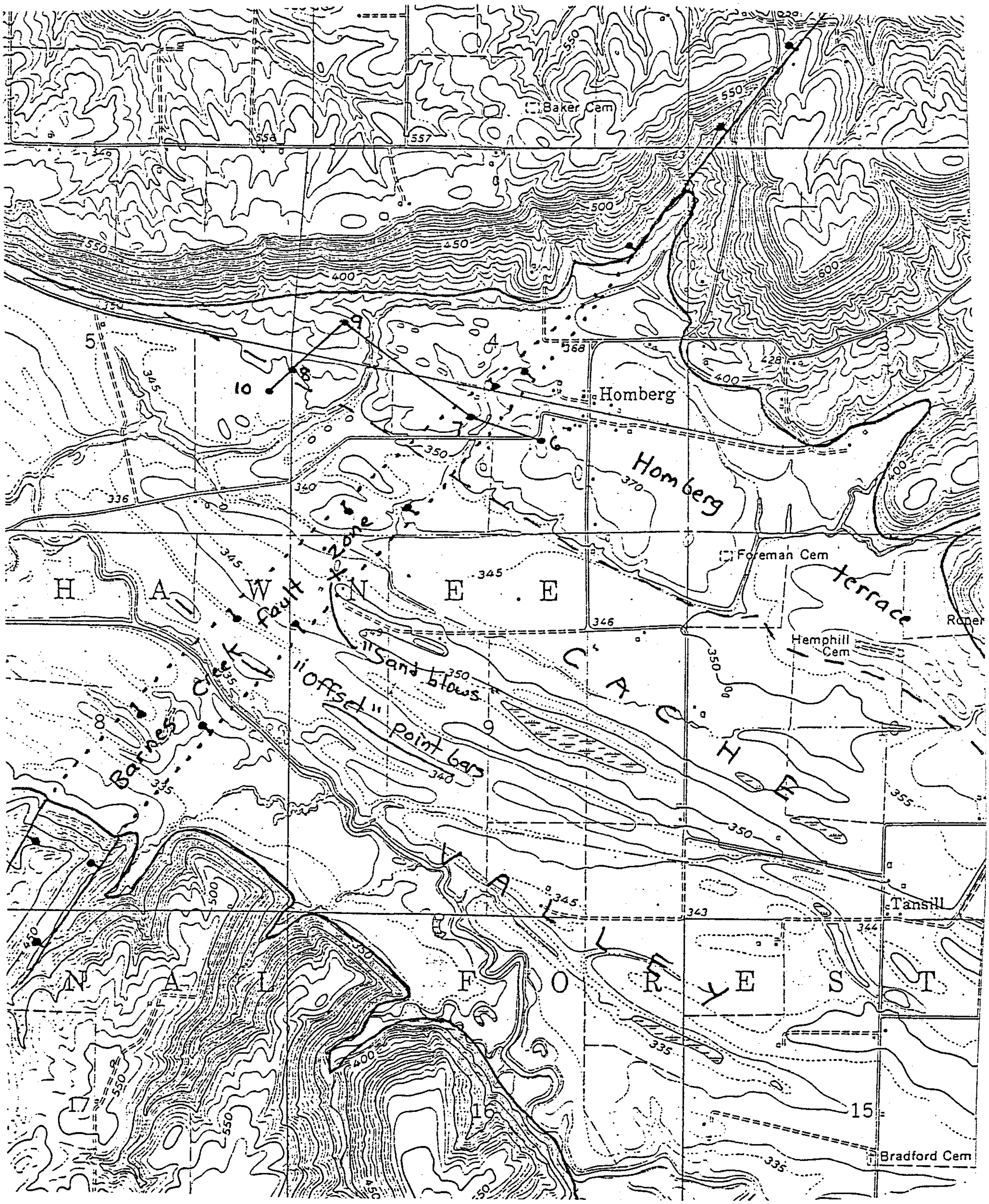

Baker Cem
Homberg
Homberg terrace
Foreman Cem
Hemphill Cem
Roper
Tansill
Bradford Cem
H A W N E E
N A L F O R E S T
C A C H E
V A L L E Y
fault zone
"Sand blows"
"offset" point bars
Barnes Cr.
550
500
450
400
600
350
345
340
336
335
370
355
343
344
346
368
428
556
557
5
4
8
9
15
16
17
6
7
10

Figure 9

Figure 10

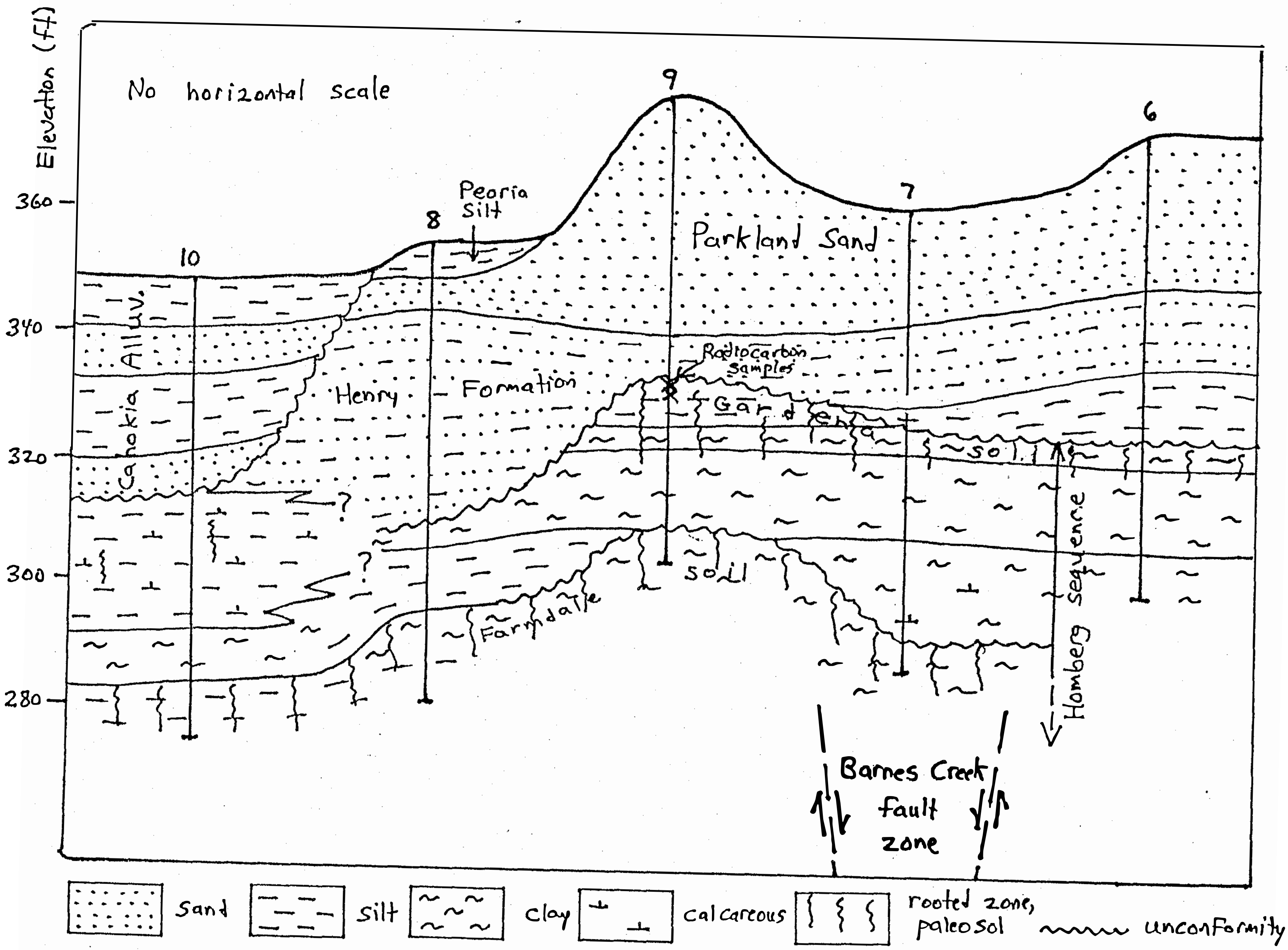
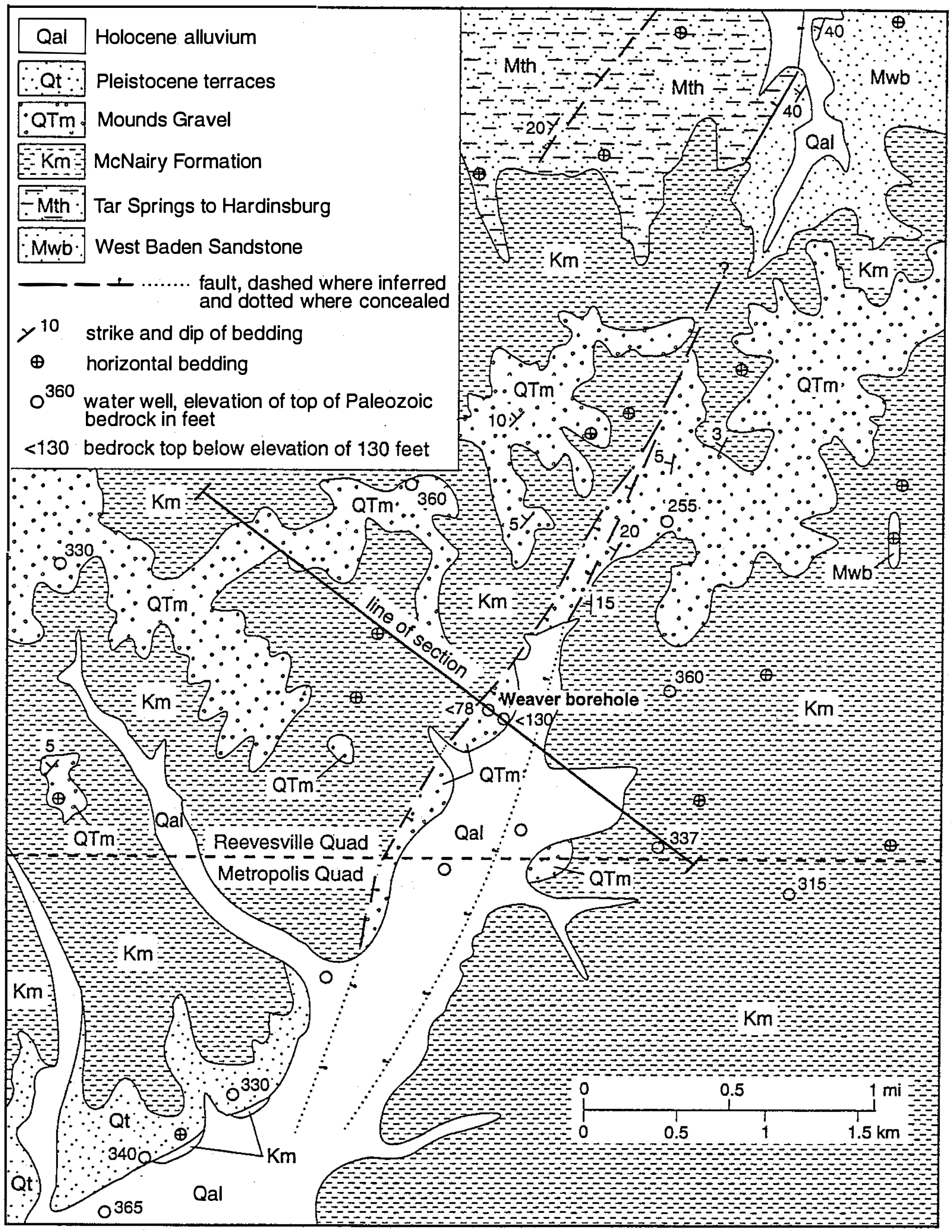
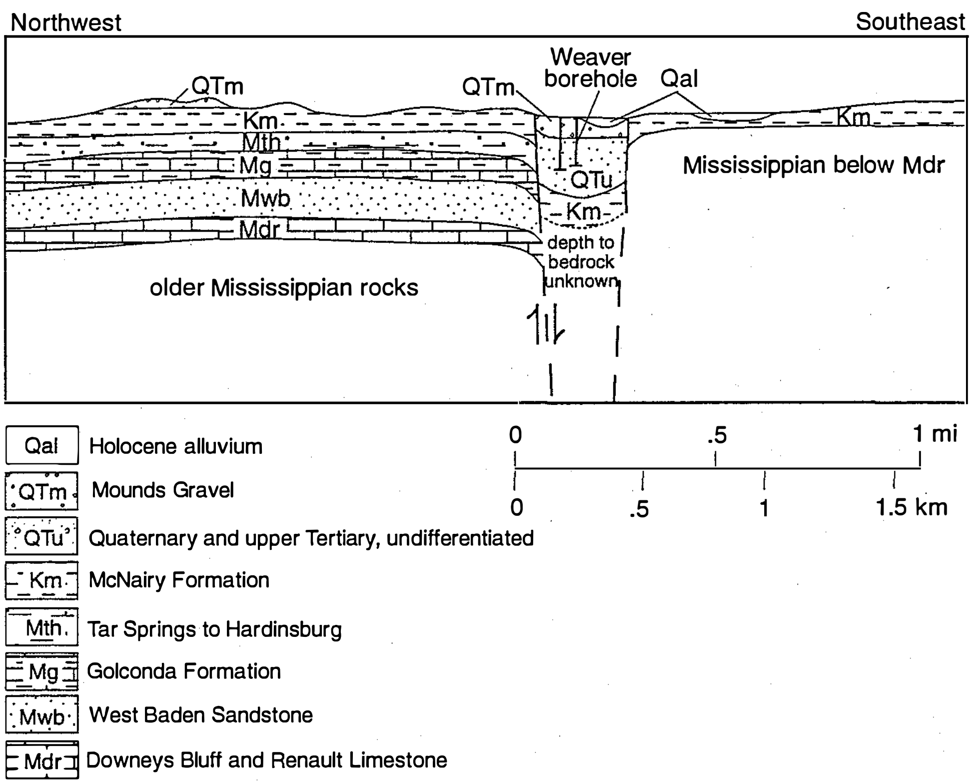

Elevation (ft)
360
340
320
300
280
No horizontal scale
10
8
9
7
6
Peoria Silt
Parkland Sand
Cahokia Alluv.
Henry Formation
Radiocarbon samples
Garden
soil
Farmdale
Homberg sequence
Barnes Creek fault zone
sand
silt
clay
calcareous
rooted zone, paleosol
unconformity

Figure 11



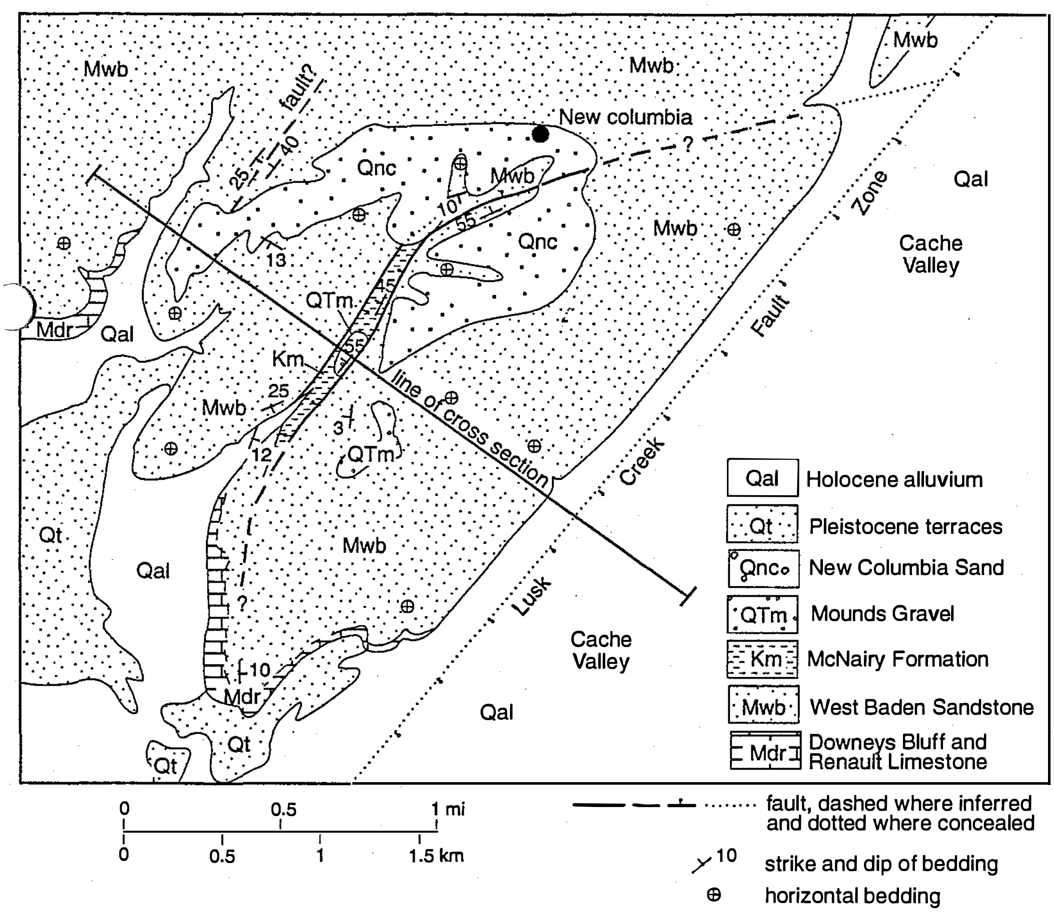
Qal Holocene alluvium
Qt Pleistocene terraces
QTm Mounds Gravel
Km McNairy Formation
Mth Tar Springs to Hardinsburg
Mwb West Baden Sandstone
fault, dashed where inferred and dotted where concealed
10 strike and dip of bedding
horizontal bedding
360 water well, elevation of top of Paleozoic bedrock in feet
<130 bedrock top below elevation of 130 feet
Mth
Mwb
Qal
Km
QTm
line of section
Weaver borehole
<78
<130
360
330
255
337
315
340
365
Reevesville Quad
Metropolis Quad
0 0.5 1 mi
0 0.5 1 1.5 km

Figure 12.



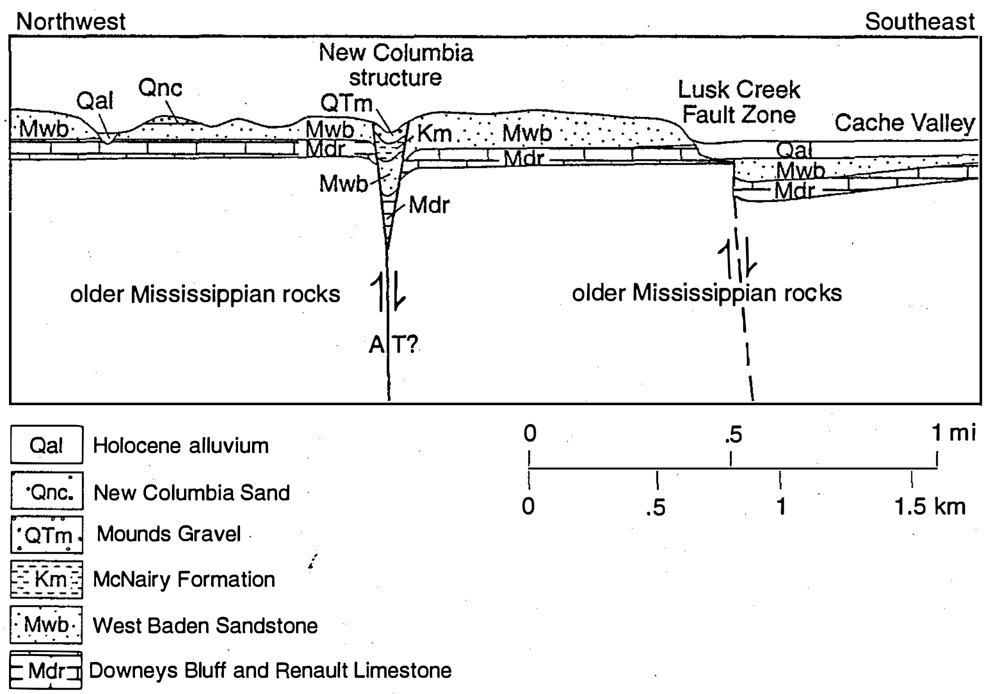
Northwest
Southeast
QTm
QTm
Weaver borehole
Qal
Km
Km
Mth
Mg
Mwb
Mdr
QTu
Km
depth to bedrock unknown
Mississippian below Mdr
older Mississippian rocks
0
.5
1 mi
0
.5
1
1.5 km
Qal Holocene alluvium
QTm Mounds Gravel
QTu Quaternary and upper Tertiary, undifferentiated
Km McNairy Formation
Mth Tar Springs to Hardinsburg
Mg Golconda Formation
Mwb West Baden Sandstone
Mdr Downeys Bluff and Renault Limestone

Figure 13



Mwb
Mwb
Mwb
fault?
New columbia
Qnc
Mwb
Qnc
Mwb
Qal
Cache
Valley
Fault
Zone
QTm
Km
Mwb
line of cross section
QTm
Mdr
Qal
Qt
Qal
Mwb
Mdr
Qt
Qt
Cache
Valley
Qal
Lusk
Creek
Qal Holocene alluvium
Qt Pleistocene terraces
Qnc New Columbia Sand
QTm Mounds Gravel
Km McNairy Formation
Mwb West Baden Sandstone
Mdr Downeys Bluff and Renault Limestone
0 0.5 1 mi
0 0.5 1 1.5 km
fault, dashed where inferred and dotted where concealed
strike and dip of bedding
horizontal bedding

Figure 14



Northwest
Southeast
New Columbia structure
Qal
Qnc
QTm
Mwb
Mdr
Km
Mwb
Mdr
Mwb
Mdr
Lusk Creek Fault Zone
Cache Valley
Qal
Mwb
Mdr
older Mississippian rocks
older Mississippian rocks
A T?
Qal Holocene alluvium
Qnc New Columbia Sand
QTm Mounds Gravel
Km McNairy Formation
Mwb West Baden Sandstone
Mdr Downeys Bluff and Renault Limestone
0 .5 1 mi
0 .5 1 1.5 km

Figure 15

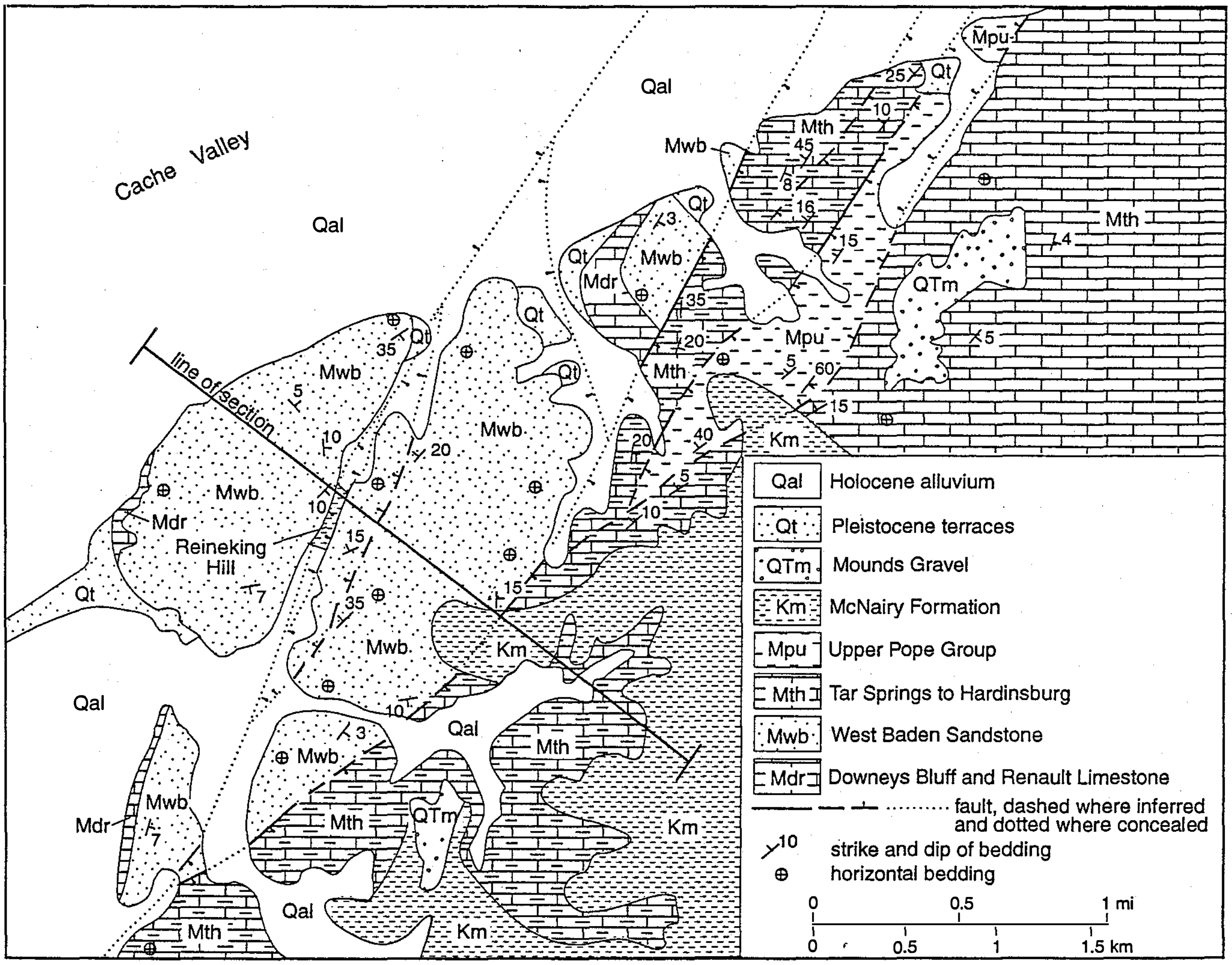
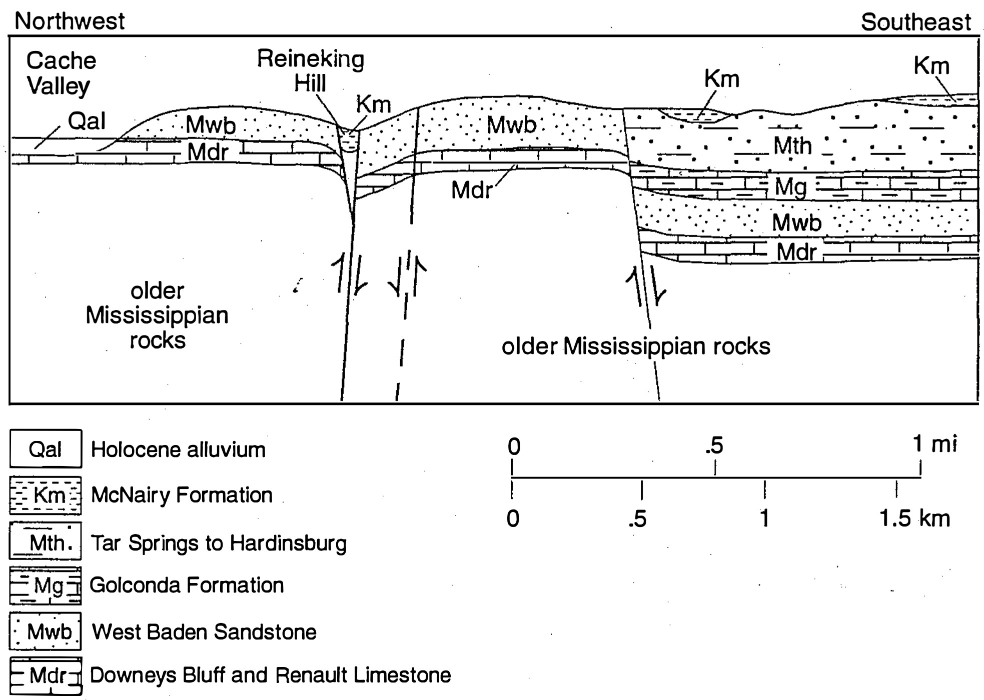
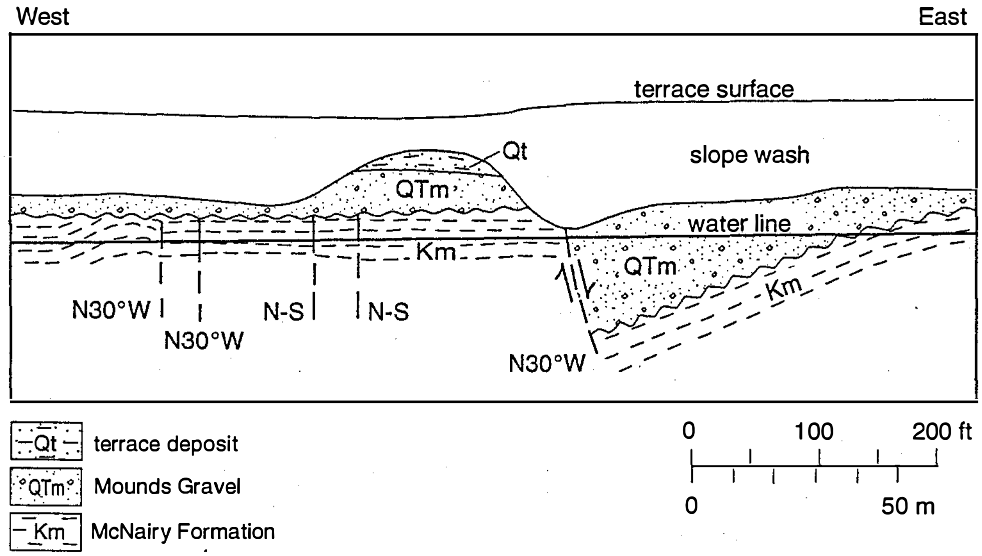

Cache Valley
Qal
Mwb
Mth
Mpu
Qt
QTm
Mdr
Km
Reineking Hill
line of section
Qal Holocene alluvium
Qt Pleistocene terraces
QTm Mounds Gravel
Km McNairy Formation
Mpu Upper Pope Group
Mth Tar Springs to Hardinsburg
Mwb West Baden Sandstone
Mdr Downeys Bluff and Renault Limestone
fault, dashed where inferred and dotted where concealed
10 strike and dip of bedding
horizontal bedding
0 0.5 1 mi
0 0.5 1 1.5 km

Figure 16



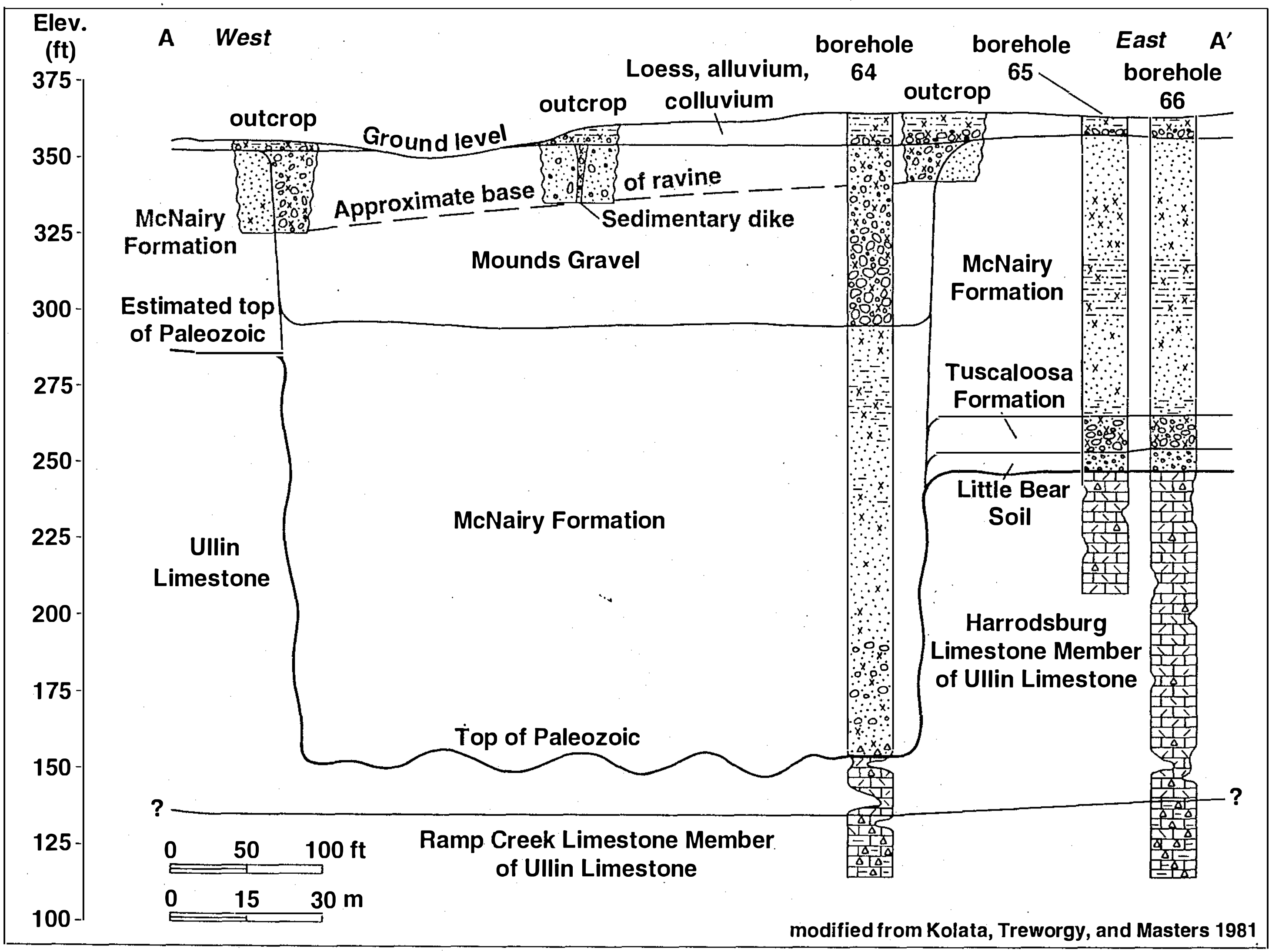
Northwest
Southeast
Cache Valley
Reineking Hill
Km
Km
Km
Qal
Mwb
Mdr
Mwb
Mdr
Mth
Mg
Mwb
Mdr
older Mississippian rocks
older Mississippian rocks
Qal Holocene alluvium
Km McNairy Formation
Mth. Tar Springs to Hardinsburg
Mg Golconda Formation
Mwb West Baden Sandstone
Mdr Downeys Bluff and Renault Limestone
0
.5
1 mi
0
.5
1
1.5 km

Figure 17



West
East
terrace surface
slope wash
Qt
QTm
water line
Km
QTm
Km
N30°W
N30°W
N-S
N-S
N30°W
Qt
terrace deposit
QTm
Mounds Gravel
Km
McNairy Formation
0
100
200 ft
0
50 m

Figure 18


Elev. (ft)
375
350
325
300
275
250
225
200
175
150
125
100
A West
East A′
borehole 64
borehole 65
borehole 66
outcrop
outcrop
outcrop
Loess, alluvium, colluvium
Ground level
Approximate base of ravine
Sedimentary dike
McNairy Formation
Mounds Gravel
Estimated top of Paleozoic
McNairy Formation
Tuscaloosa Formation
Little Bear Soil
Ullin Limestone
McNairy Formation
Harrodsburg Limestone Member of Ullin Limestone
Top of Paleozoic
?
?
0 50 100 ft
0 15 30 m
Ramp Creek Limestone Member of Ullin Limestone
modified from Kolata, Treworgy, and Masters 1981

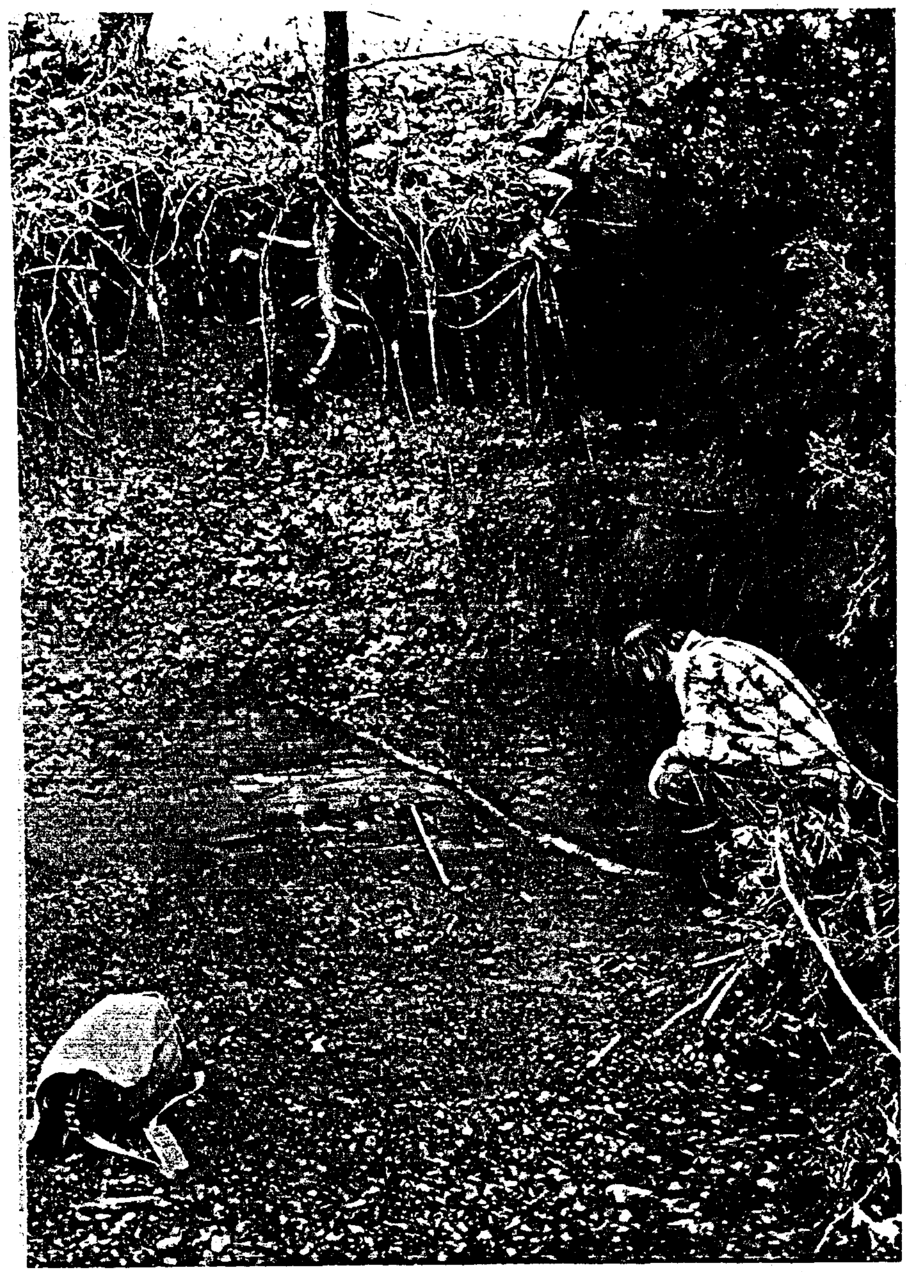


Figure 19

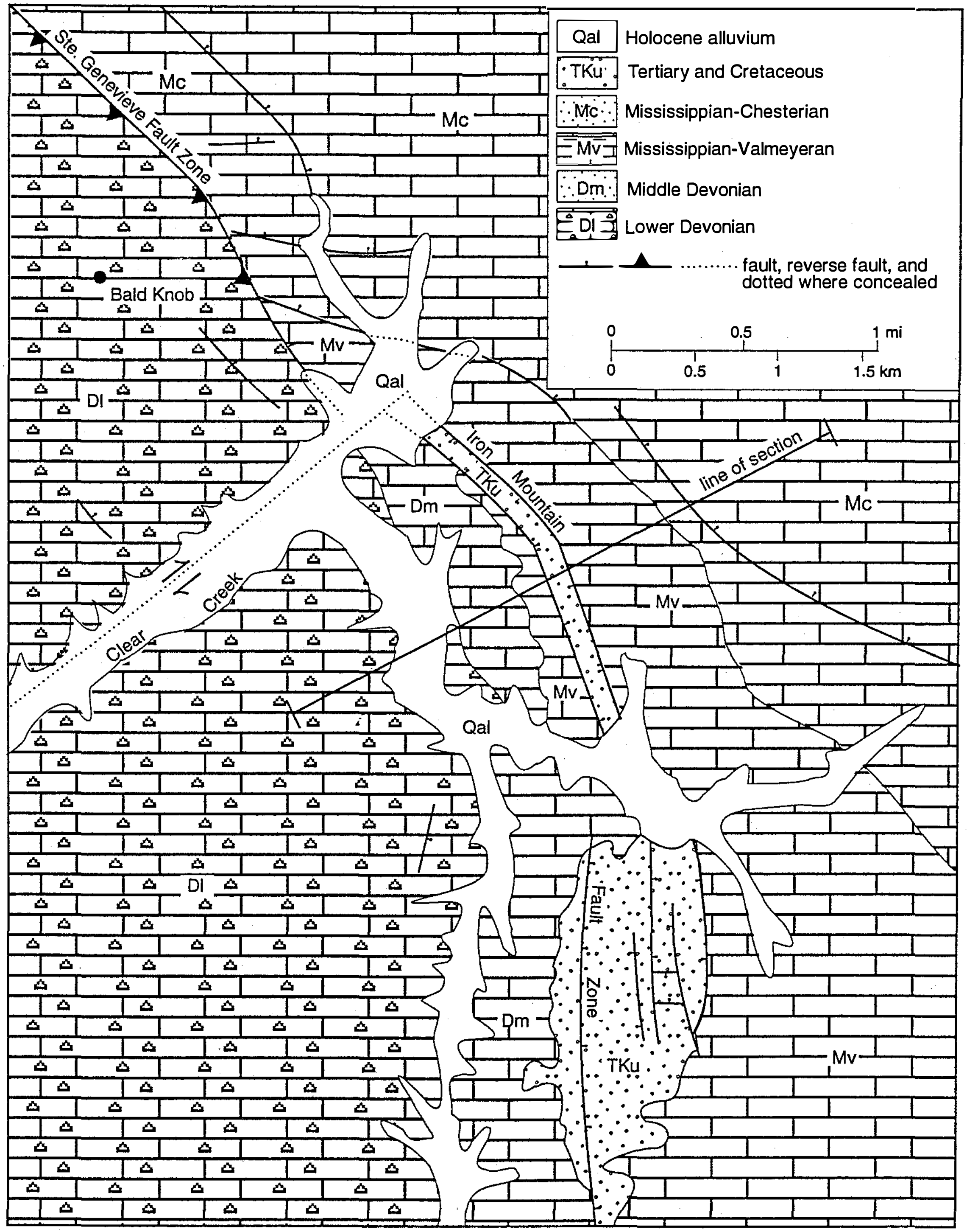
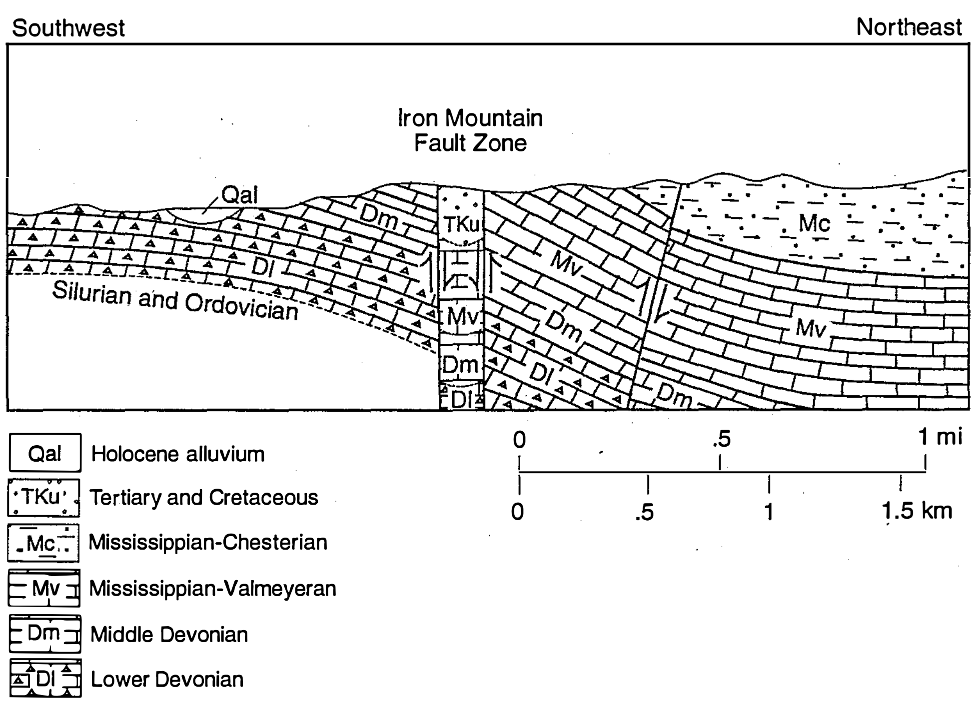

Qal Holocene alluvium
TKu Tertiary and Cretaceous
Mc Mississippian-Chesterian
Mv Mississippian-Valmeyeran
Dm Middle Devonian
Dl Lower Devonian
fault, reverse fault, and dotted where concealed
0 0.5 1 mi
0 0.5 1 1.5 km
Ste. Genevieve Fault Zone
Mc
Mc
Bald Knob
Mv
Qal
Dl
Iron Mountain
TKu
Dm
line of section
Mc
Clear Creek
Mv
Mv
Qal
Dl
Fault Zone
Dm
TKu
Mv

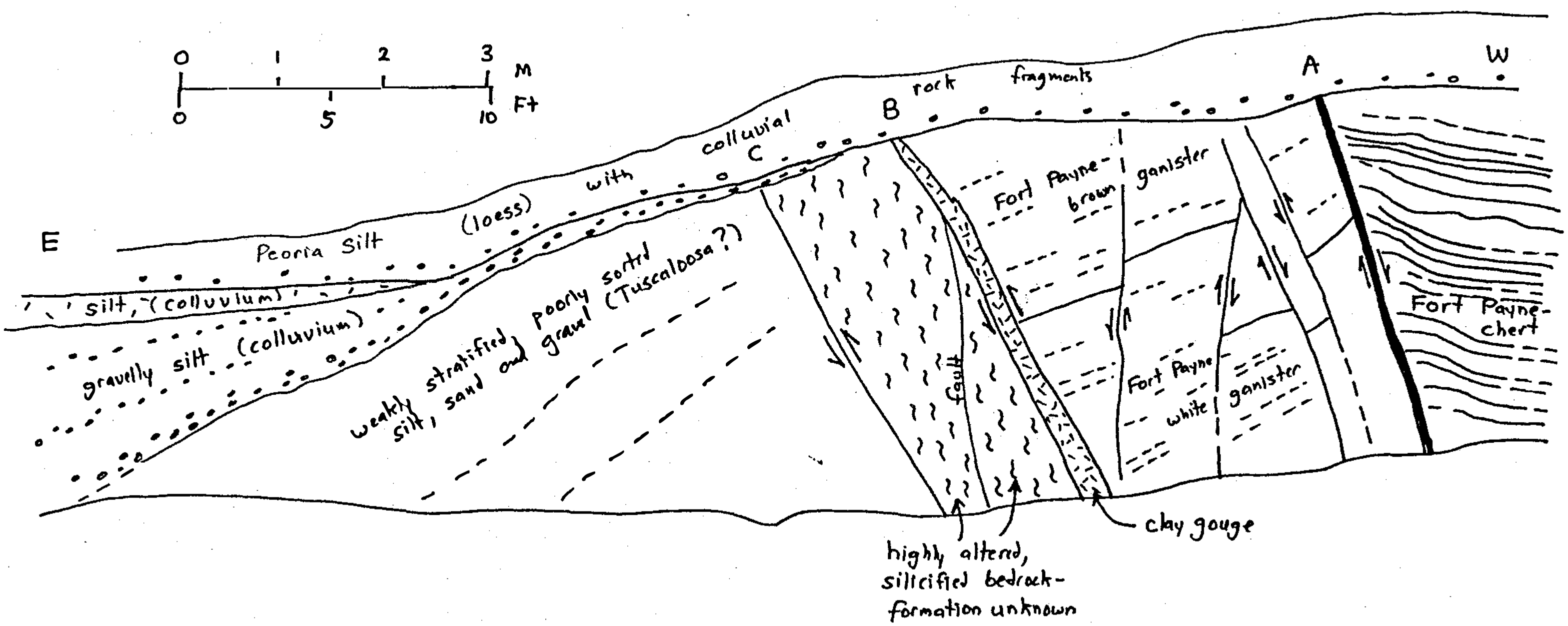
Figure 20

Figure 21

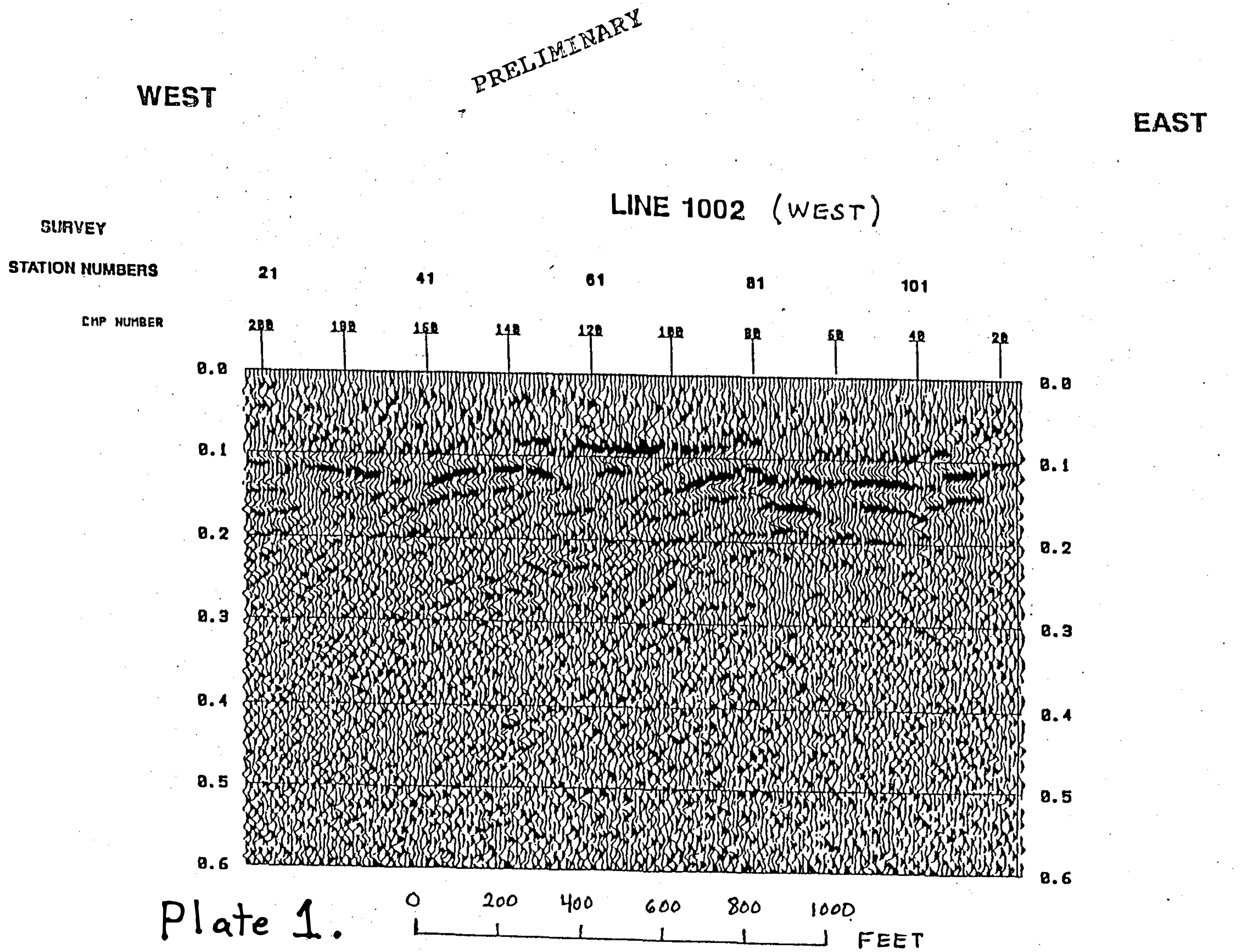


Southwest
Northeast
Iron Mountain
Fault Zone
Qal
Dm
Dl
Silurian and Ordovician
TKu
Mv
Dm
Dl
Mv
Dm
Dl
Dm
Mc
Mv
0
.5
1 mi
0
.5
1
1.5 km
Qal Holocene alluvium
TKu Tertiary and Cretaceous
Mc Mississippian-Chesterian
Mv Mississippian-Valmeyeran
Dm Middle Devonian
Dl Lower Devonian

Figure 22



0
1
2
3
M
0
5
10
Ft
E
W
A
B
C
Peoria Silt
(loess)
with
colluvial
rock
fragments
silt, (colluvium)
gravelly silt (colluvium)
weakly stratified, poorly sorted
silt, sand and gravel (Tuscaloosa?)
fault
Fort Payne brown ganister
Fort Payne white ganister
Fort Payne chert
clay gouge
highly altered, silicified bedrock-
formation unknown



PRELIMINARY
WEST
EAST
LINE 1002 (WEST)
SURVEY
STATION NUMBERS
21
41
61
81
101
CMP NUMBER
200
180
160
140
120
100
80
60
40
20
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
200
400
600
800
1000
FEET

Plate 1.

PRELIMINARY

WEST **EAST**

LINE 2001 (MIDDLE)

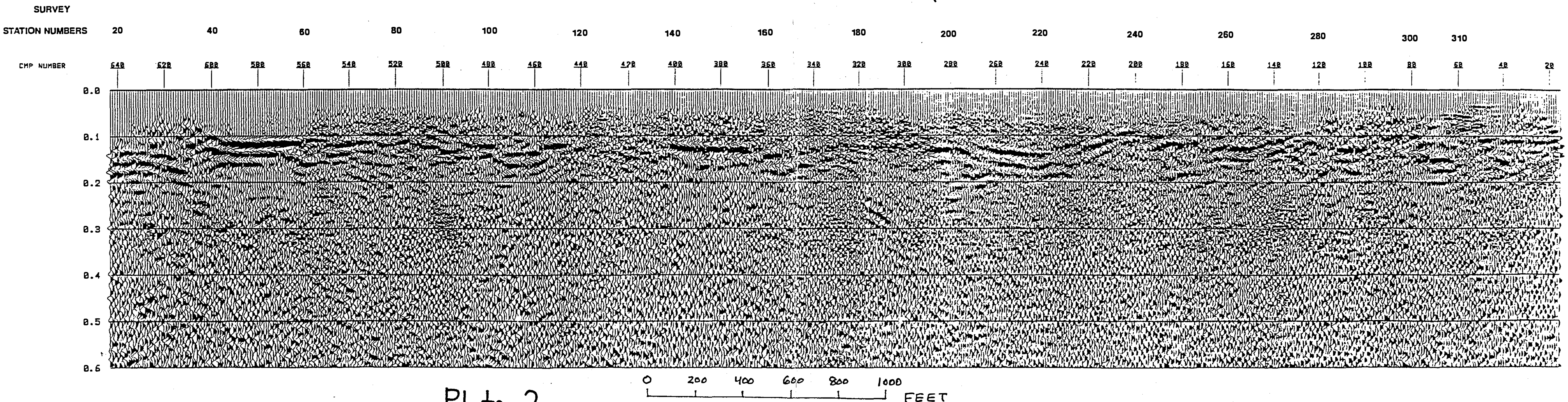


Plate 2.

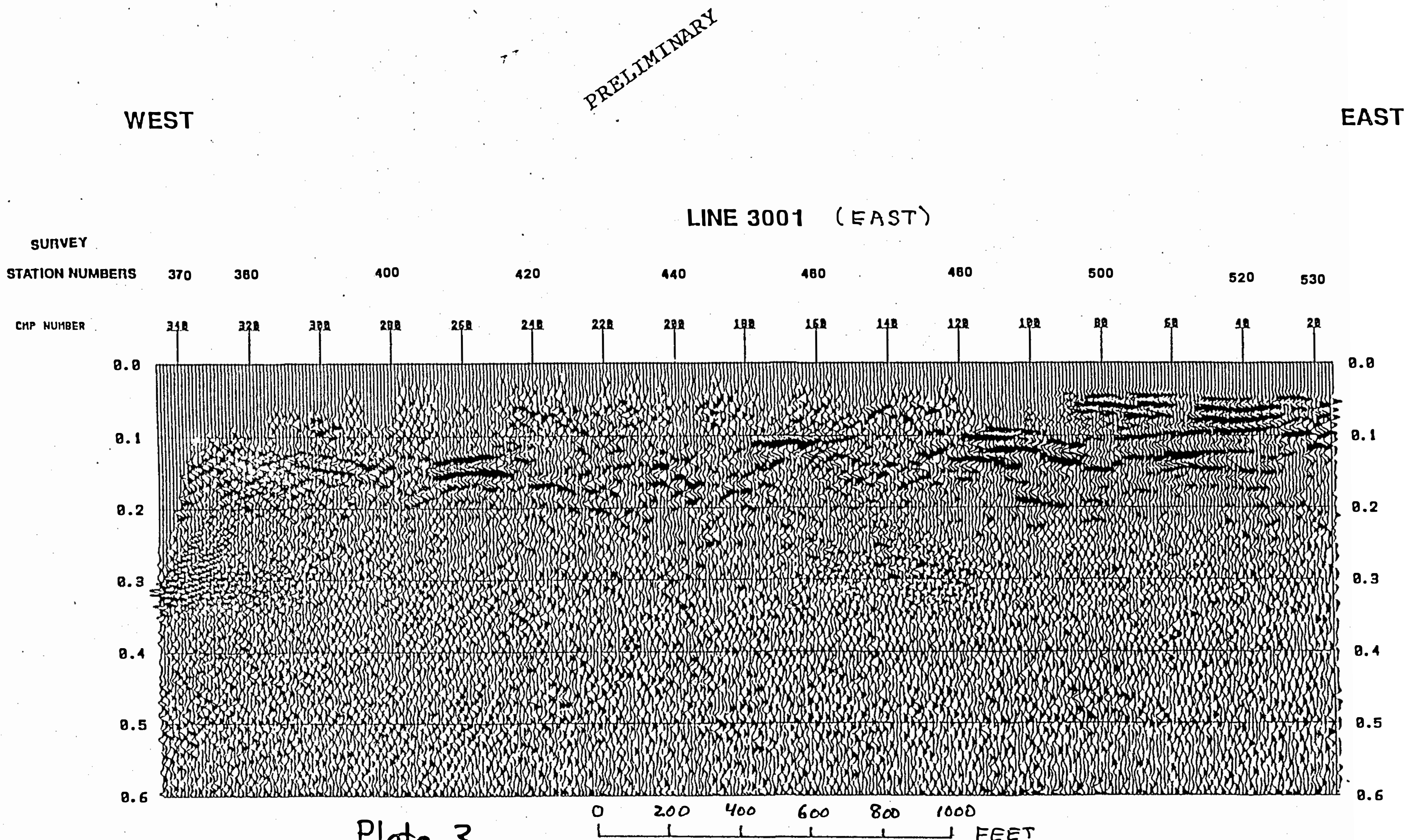

WEST
EAST
PRELIMINARY
LINE 3001 (EAST)
SURVEY
STATION NUMBERS
370 380 400 420 440 460 480 500 520 530
CMP NUMBER
340 320 300 280 260 240 220 200 180 160 140 120 100 80 60 40 20
0.0 0.1 0.2 0.3 0.4 0.5 0.6
0 200 400 600 800 1000 FEET

Plate 3.

PRELIMINARY

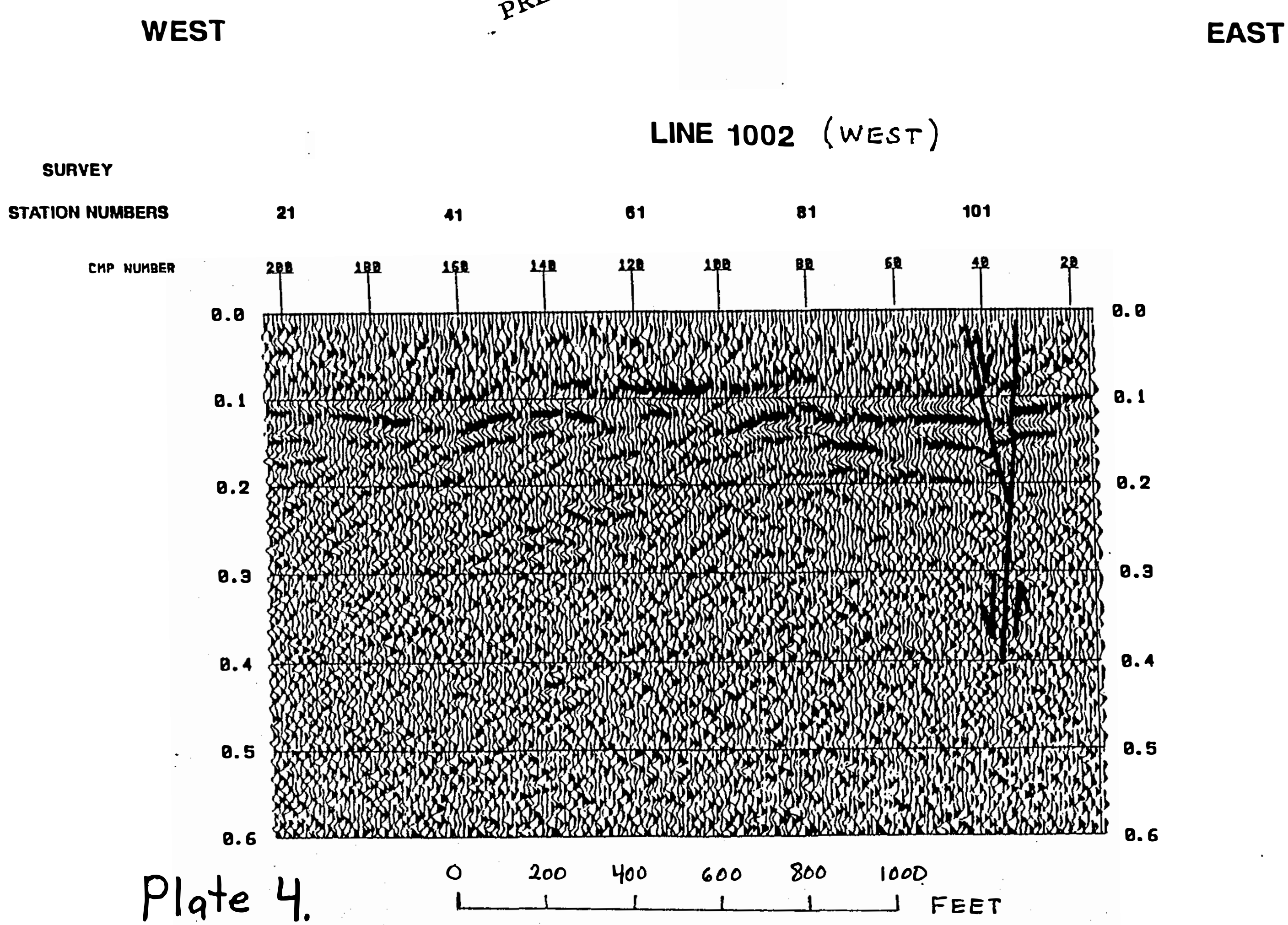


Plate 4.

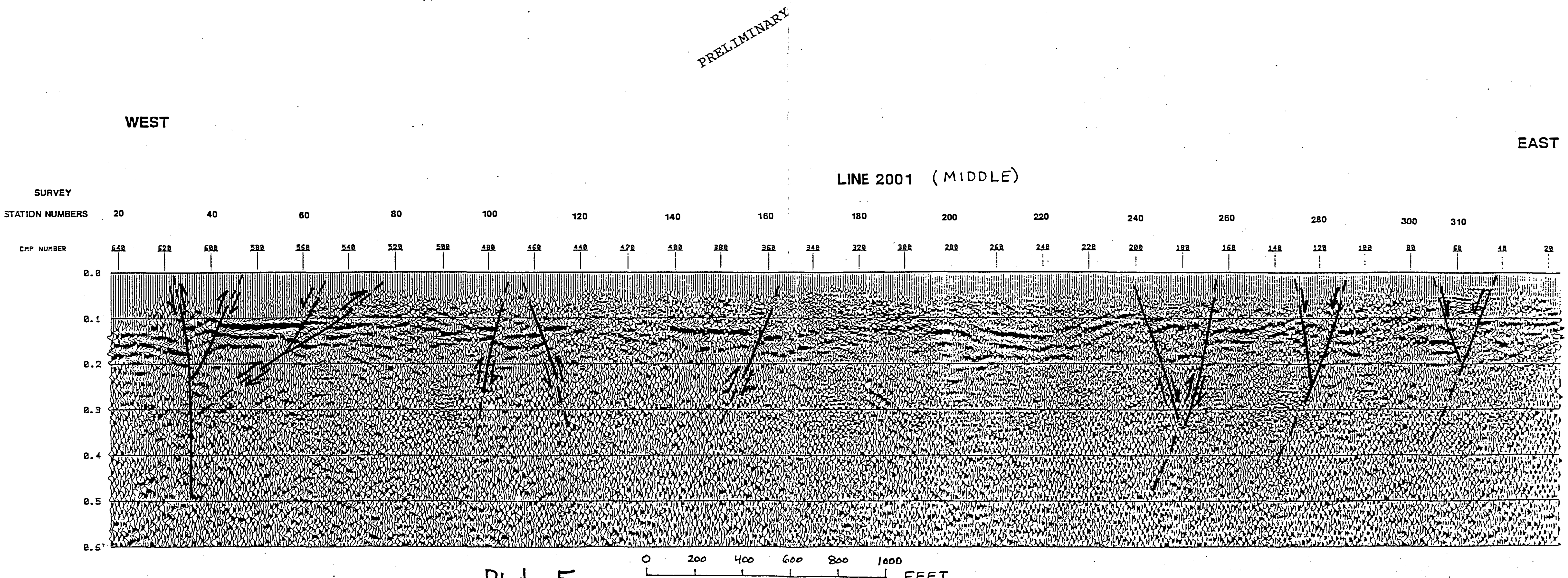

PRELIMINARY
WEST
EAST
LINE 2001 (MIDDLE)
SURVEY
STATION NUMBERS
20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 310
CMP NUMBER
640 620 600 580 560 540 520 500 480 460 440 420 400 380 360 340 320 300 280 260 240 220 200 180 160 140 120 100 80 60 40 20
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0 200 400 600 800 1000
FEET

Plate 5.

PRELIMINARY

WEST **EAST**

LINE 3001 (EAST)

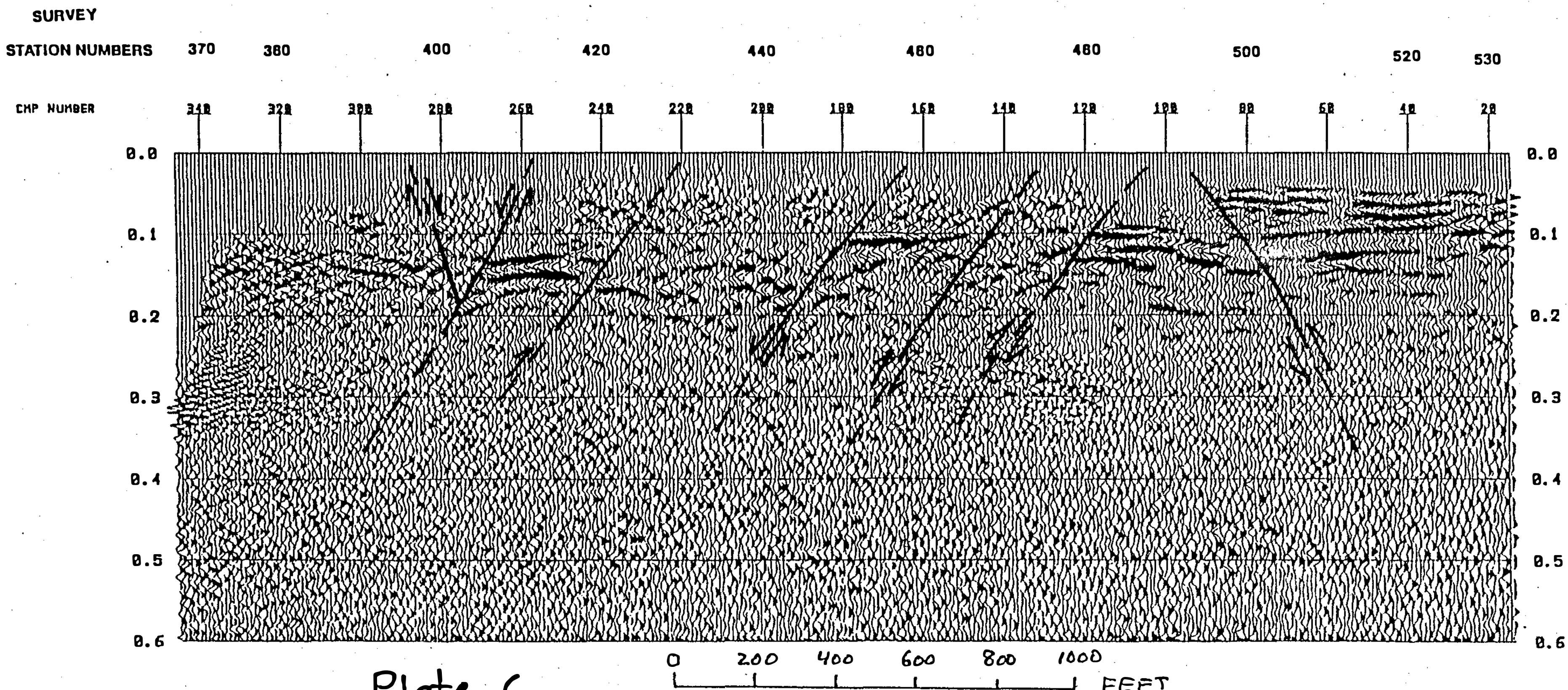


Plate 6.