WILLIAM LETTIS & ASSOCIATES, INC.

Final Technical Report

Geophysical and Paleoseismic Evaluation of the Penitentiary Fault and its Association with the Commerce Geophysical Lineament, Tamms, Southern Illinois

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FINAL TECHNICAL REPORT

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ABSTRACT

The Commerce geophysical lineament (CGL) is a 600-km-long, 5- to 10-km-wide, northeast-trending magnetic and gravity anomaly that extends from northeastern Arkansas to central Indiana and is associated with Quaternary deformation northwest of the New Madrid seismic zone. In southern Illinois, a previous study (Odum et al., 2002) imaged Quaternary sediments deformed across the Penitentiary fault (PF), a northeast-striking fault coincident with the CGL. In addition, numerous Late Pleistocene to Holocene faults associated partly with the Commerce fault have been documented in the Benton Hills, Missouri, about 25 km southwest of Tamms, Illinois (Harrison et al., 1999). The seven kilometer PF is coincident with a strikingly linear northeast-trending, east-facing bluff line that separates late Quaternary Cache River Valley (CRV) deposits on the east from Paleozoic upland rocks on the west. This study was designed to test existing observations and further document Quaternary deformation along the PF zone and the CGL north of Missouri where little data is available.

At the Tamms site, in southern Illinois, we completed a preliminary geologic and geophysical investigation that included detailed Quaternary geologic/geomorphic mapping and acquisition and interpretation of seismic reflection profiles. Our geologic mapping reveals prominent geomorphology associated with Shawnee Hills range front, however there is little sign of recent surface rupture where Holocene fan deposits (Chahokia Formation) intersect the surface projection of the PF zone. Two 1-km-long shear-wave seismic reflection profiles, intersecting the PF and CGL, were acquired near Tamms, Illinois. The seismic profiles recorded coherent reflectors marking the unconformable contact between bedrock and CRV Quaternary deposits, within the CRV Quaternary deposits and reveal a buried east-facing scarp coincident by the PF. Depth to bedrock was interpreted as approximately 30-50 meters deep east and 10 meters deep west respectively of the range front. Coincident with the bluff line and the PF is a complex zone of high-angle faults that project into overlying latest Pleistocene Henry Formation (older than ~25,000 years old) and possibly Holocene Cahokia Formation. Transpressive (?) faulting is interpreted as projecting upsection across several reflectors within the Quaternary CRV sediments. Vertical offset of reflectors in the seismic lines ranges from 2 to 6 meters. The results of this investigation indicate the PF, and by association the CGL, have produced surface rupture during the latest Pleistocene (possibly the early Holocene) and therefore, should be considered in seismic source characterizations.

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1.0 INTRODUCTION

The CGL is a 600-km-long, 5- to 10-km-wide northeast-trending gravity and aeromagnetic anomaly that trends subparallel to and west of the Reelfoot rift and extends from northeast Arkansas to central Indiana (Figure 1) (Langenheim and Hildenbrand, 1997). The Tamms area is located along the 150-km-long Commerce section of the CGL within the northwestern Mississippi embayment about 75 to 80 kilometers northwest of the active New Madrid seismic zone (NMSZ) (Figure 1). Recent geologic, geomorphic and geophysical studies performed along the CGL in southeastern Missouri provide direct and indirect evidence indicative of late Quaternary activity along faults coincident with the CGL (Figure 2). This evidence includes: (1) anomalous west-flowing drainages on Crowley's Ridge (Cox, 1988; Fischer-Boyd and Schumm, 1995) and the Bloomfield and Benton Hills; (2) displacement of late-Tertiary and Pleistocene to Holocene deposits (Groshkopf, 1955; Satterfield and Ward, 1978; Thompson, 1981; Harrison et al., 1999; Harrison et al., 2002; Baldwin et al., 2006) along northeast-striking faults that are consistent with the present-day stress field (Zoback, 1992); (3) paleoliquefaction features within the Western Lowlands that overlie the CGL (Figure 1; Vaughn, 1991; 1992; 1994; and Vaughn et al., 2002); (4) presence of diffuse microseismicity consisting of low to moderate magnitude earthquakes spatially associated with the CGL (Harrison and Schultz, 1994; Langenheim and Hildenbrand, 1997; Hildenbrand and Ravat, 1997); (5) geophysical evidence of about 20 meters of vertical separation of the Paleozoic/Cretaceous boundary, as well as poorly constrained Tertiary-Quaternary deformation coincident with the surface traces of previously mapped faults in the Bloomfield and Benton Hills (Stephenson et al., 1999); and (6) a prominent tonal lineament developed in late Wisconsin braided stream deposits that aligns partly with the Commerce and Idalia Hill faults (Heyl and McKeown, 1978). Furthermore, similar geologic, geophysical, seismologic, and paleoliquefaction data collected in Illinois and Indiana provide further support for Quaternary active structures spatially coincident with the CGL (Odum, et al., 2002, McBride et al., 2002).

Combined, this body of evidence strongly implies that previously mapped northeast-striking faults that overlie the surface projection of the CGL in southeast Missouri, but are outside of the active NMSZ, represent poorly characterized seismogenic structures that are capable of generating moderate to large magnitude earthquakes. A review, interpretation, and correlation of limited earthquake timing data collected from paleoseismic and paleoliquefaction studies appears to indicate that northeast-striking faults coincident with the CGL were active up to at least the Late Pleistocene and early Holocene (Vaughn,

1994; Baldwin et al., 2006), and possibly into the middle to late Holocene (Harrison et al., 1999). Clearly, the possible existence of a significant seismic source spanning up to 600 kilometers in length from Arkansas to Indiana, poses a major seismic hazard to the population, infrastructure, and lifelines of the central U.S., and thus, requires characterization of the style, timing and rate of deformation, and rupture boundaries for input into probabilistic earthquake hazard models.

The objective of this study was to evaluate the seismogenic potential of the Commerce geophysical lineament (CGL) by assessing the Late Pleistocene and Holocene deformation associated with the northeast-striking Penitentiary fault located along the CGL in southern Illinois (Figure 1). The Penitentiary fault bounds the southeastern margin of the Shawnees Hills (Odum et al., 2002; Devera and Follmer, in prep), and exhibits direct and indirect evidence of Quaternary deformation based on the alignment of topographic escarpments, and subsurface faulting of Quaternary deposits imaged in seismic reflection lines.

This research expands the regional coverage of paleoseismic investigations outside of the New Madrid seismic zone (NMSZ) to locate and assess other possible seismic sources, and to evaluate the spatial and temporal characteristics of prehistoric earthquakes in the central United States. Data from this study will contribute to the periodic update of the USGS national probabilistic seismic shaking hazard maps of the central United States and to site-specific ground motion studies for important facilities in the greater Illinois area. In particular, this study has determined that Late Pleistocene to Holocene faulting likely occurred along the Commerce section of the CGL extending into southern Illinois, thus expanding the existing northern boundary of the high ground shaking levels north of the NMSZ.

2.0 REGIONAL TECTONIC SETTING

The CGL is hypothesized to represent a 600-km-long series of mafic dike intrusions emplaced along pre-existing or coeval faults between Arkansas and southern Illinois during the Early Cambrian (intrusions accompanying origin of the Reelfoot rift), or possibly Precambrian (Langenheim and Hildenbrand, 1997). The CGL coincides with the northwest margin of the Reelfoot rift, as identified by gravity and aeromagnetic data. Faulting along the CGL appears to be complex and long-lived, and includes both dip-slip and strike-slip faulting. Hildenbrand et al., (2002) speculate that the Commerce geophysical lineament evolved in the Mesoproterozic (1.1 to 1.5 Ga) as a major cratonic rheological boundary that was reactivated during varying stress regimes throughout its history.

On the basis of variations in gravity, magnetic and geologic characteristics, portions of the CGL have been differentiated into the Newport, Commerce and Junction sections (Langenheim and Hildenbrand, 1997). The Commerce section exhibits the most prominent gravity and magnetic anomalies and extends from the Arkansas-Missouri border across Thebes Gap and into southern Illinois (Figure 1 and 3). The northern part of the Commerce section is associated with the mapped trace of the Commerce fault, near Commerce, Missouri, where recent neotectonic studies provide evidence of Pleistocene and Holocene deformation (Figure 1; Harrison and Schultz, 1994; Harrison et al., 1999; Harrison et al., 2002). To the southwest of Commerce, a well-defined photo-lineament and topographic escarpment along the southeastern margins of the Benton and Bloomfield Hills coincide with the Commerce section of the CGL (Heyl and McKeown, 1978). This photolineament is parallel to the Idalia Hill fault in the Bloomfield Hills, which offsets deposits as young as Quaternary in age (Figure 1; Stephenson et al., 1999; Palmer et al., 1997; Baldwin et al., 2006). The northern most mapped trace of the Commerce fault is both adjacent to the Penitentiary fault and CGL (Figure 3).

Geophysical surveys at the south end of the Benton Hills (Anderson, 1997) and the northern part of the Bloomfield Hills (Stephenson et al., 1999) image extensive faulting aligned with the CGL, and the Idalia Hill and Commerce faults. Between the Benton and Bloomfield Hills, the CGL underlies both the Quaternary-Holocene active Commerce fault and the inferred Quaternary active Idalia Hill fault (Stephenson et al., 1999) (Figure 2). Furthermore, northeast across Thebes Gap and into southern Illinois, more recent geophysical investigations link faults imaged in high-resolution seismic reflection and microgravity surveys with near surface faults that possibly offset Quaternary deposits directly west of the Cache River (Odum et al., 2002; discussed in detail below). Collectively, the data strongly suggest a

correlation between structural anomalies interpreted from geophysical profiles and near-surface northeast-striking faults and interpreted Quaternary deformation.

Diffuse contemporary seismicity occurs beneath, along, and adjacent to the CGL between Arkansas and southern Illinois (Harrison and Schultz, 1994; Langenheim and Hildenbrand, 1997). Focal mechanisms of 16 earthquakes that occurred between 1963 and 1990 are consistent with predominantly strike-slip and reverse modes of faulting along the entire length of the CGL. At least two M4.8 earthquakes with predominantly strike-slip components have occurred near or on the Commerce section of the CGL within this 17-year period (Figure 1). Investigators have shown that some of the focal mechanisms are consistent with NE-striking faults (Harrison and Schultz, 1994), and others have indicated that a few of the focal mechanisms are consistent with northwest-trending structures (Zoback, 1992). Further northeast, near Vincennes, Indiana, where it is hypothesized that the CGL forms a restraining left-step, the CGL is believed to be associated with the location of several large prehistoric earthquakes on the basis of a deflection in the Wabash River and a left-step in the magnetic anomaly (McNulty and Obermeier, 1999).

Paleo-liquefaction reconnaissance of drainages in the CRV near Tamms identified numerous liquefaction-related features are close to the CGL and PF (Tuttle et al., 1998; Tuttle and Chester, 2001; Munson et al., 1997) (Figure 2, 3, and 4). Tuttle and Chester (2001) searched 70 kilometers of river and ditch cutbanks, quarries, and terraces looking for earthquake-induced paleoliquefaction features in the CRV covering the Tamms study area. Along the Cache River south of Tamms, six dikes were found at four sites ranging from 1-9 centimeters wide within Cahokia Formation. Tuttle and Chester (2001) consider the possibility that two generations of liquefaction are recorded at these sites, with the youngest occurring after A.D. 1020. Estimating source area, timing, and magnitude from the available dike data is difficult. Liquefaction features in the CRV are considered too far from the M7.5 earthquake that occurred near Vincennes, Indiana about 6,100±200 years B.P. (Munson et al., 1997) to be generated by this earthquake (Tuttle and Chester, 2001). The narrow liquefaction dikes could have formed as a result of earthquakes in the New Madrid seismic zone (Tuttle and Chester, 2001) or are possibly due to past large earthquakes on faults linked with the CGL.

3.0 LOCAL GEOLOGIC SETTING

The study area lies within the Cache Valley, directly to the east of the Shawnee Hills (Figure 3). The Shawnee Hills lie within the northern part of the Mississippi embayment (Masters and Reinertsen, 1987), and elevations average about 60 meters above the adjacent alluvial lowlands of the Cache Valley (Figure 3 and Plate 1). The lowlands consist of Pleistocene braided stream channel deposits derived from the ancestral Ohio River (Esling et al., 1989) and alluvial fan deposits, overlain by Holocene alluvium and/or inset Holocene meander deposits (Figure 4; Esling et al., 1989; Nelson et al., 1999; Devera and Follmer, in prep). Along the eastern margin of the Shawnee Hills lie slightly younger Holocene alluvial fan deposits that formed following the abandonment of the Cache Valley by the Ohio River in the Late Pleistocene (Esling et al., 1989). The eastward diversion of the Ohio River occurred at about 17 to 16 ka (Saucier, 1974; Royall et al., 1991), or possibly even later between 11 and 10.5 ka (Blum et al., 2000).

Bedrock in the Shawnee Hills is composed of Paleozoic bedrock (Devonian and Silurian carbonate and chert) dipping gently 3° to the northeast that is mantled by Pleistocene loess, which commonly obscure bedrock exposures (Devera et al. 1994; Nelson et al, 1999; Devera and Follmer, in prep; Nelson and Williams, 2004). Mapped faults within the Shawnee Hills are generally NE-striking and have short strike-length (1-2 km) and relatively minor displacements (10-30 meters). Within the study area, the Commerce and Penitentiary faults are the exceptions with strike-lengths of several to tens of miles. Several NW-striking faults have been inferred from geophysics, geomorphology, and geologic mapping (Odum et al., 2002; Devera et al., 1994; Devera and Follmer, in prep) (Figure 4).

3.1 Penitentiary Fault Zone

The existence of the northeast-striking, southeast-side down Penitentiary fault zone was hypothesized by Devera and Follmer (in prep) based on the distinct linear eastern range front of the Shawnee Hills, near Tamms, Illinois (Figure 4 and Plate 1). The fault is generally obscured by Quaternary sedimentary deposits, discussed below. However, a single northeast-striking southeast-side down fault offsetting Devonian Clear Creek Formation and St.Laurent/Grand Tower Formations bedrock is coincident with the mapped trace of the Penitentiary fault zone just north of the seismic line Tamms 2 along Newell Road (Figure 4) (Devera et al., 1994). Similarly minor NE-striking faults are mapped in the Tatumville quarry adjacent to the PF (Plate 1).

Through collaboration with Devera and Follmer (in prep), Odum et al. (2002) collected seismic reflection data across the Penitentiary fault to test the faulted range front hypothesis. Odum et al. (2002) acquired a 2.7-km-long, seismic reflection line in the Shawnee Hills across the surface projection of the CGL, near Tamms, Illinois (Figure 4). The seismic reflection line crosses the Commerce and Penitentiary faults, and imaged numerous faults displacing Paleozoic bedrock reflectors. Several faults (Faults F1 to F3) project upsection to the Quaternary-Paleozoic interface (Figure 5). According to Odum et al. (2002), a near-vertical fault (Fault F3) appears to vertically displace the Quaternary-Paleozoic reflector about 5 to 10 meters along trend with the near-linear N35°E-trending bluff of the Shawnee Hills and the Penitentiary fault within 25 meters of the ground surface. Odum et al. (2002) interpret Fault F3 as the Penitentiary fault. As discussed below Faults F1 through F3 could be interpreted as a broad zone of deformation composing the Penitentiary fault zone. Fault F2 forms an apparent synform and/or "flower structure" that is consistent with regional topography, and the interpreted "transpressive" pattern of faulting and folding observed elsewhere (Qulin Ridge, Holly Ridge and Benton Hills) on Quaternary active faults aligned with the CGL (Baldwin et al., in 2006) (Figure 2).

3.2 Commerce Fault zone

The Commerce fault is a northeast-striking Quaternary active strike-slip fault coincident with the CGL and the PF (Figure 3). The fault is mapped based on a prominent geomorphic lineament (similar to the Penitentiary fault) along the southern escarpment of the Benton Hills and is roughly parallel with the Idalia fault in Missouri (Harrison and Schultz; 1994). The fault exposures are generally poor, but evidence for Quaternary fault activity is well documented (Stewart and McManamy, 1944; Harrison and Schultz, 1994; Harrison et al., 1999). Devera and Follmer (in prep) map the northern end of the Commerce fault into the Tamms Study area (Figure 4). Odum et al. (2002) imaged potential Quaternary faulting in a seismic line that coincides with the mapped trace of the fault. Odum et al. (2002) continue to speculate that the prominent deflection of Wolf Creek against the Commerce fault may be related to Quaternary tectonic activity. The fault zone is mapped in bedrock along a road cut on Olive Branch Road where the Commerce fault is a 5-m-wide zone of brecciated and tilted Paleozoic Grassy Knob Chert. The northeasterly strike of the bedrock shears and minor fault displacement (3-6 meters) suggest that the Commerce fault is dying out and transferring slip easterly to the Penitentiary fault across a narrow (0.75 km wide) right-step in the valleys between Wolf and Sandy Creeks (Figure 3; Devera and Follmer, in-prep).

3.3 Approach and Methodology

To evaluate the Penitentiary fault with respect to the CGL, we developed a scope of work that included using aerial photography, field reconnaissance, and mapping along the fault zone to develop a detailed Quaternary geologic and geomorphic map in combination with data obtained through seismic reflection lines.

3.3.1 Quaternary geologic and geomorphic mapping

Our Quaternary geologic and geomorphic map was developed using black and white, 1:20,000 scale, stereo-paired aerial photography flown in September 1956. These photos form the primary data from which to interpret the regional geomorphology. Historical topographic maps (U.S. Geological Survey, 1920; 1923; 1933; 1934), more modern maps (U.S. Geological Survey, 1967, 1966, 1947), and the Alexander county soil survey (NRCS, 2002) also aided our analyses of the landforms and deposits. Geologic units and structural features were adapted mostly from existing geologic maps of the Mill Creek, McClure, Dongola, and Tamms 7.5 minute quadrangles completed by the Illinois State Geological Survey (Devera et al., 1994; Nelson et al., 1999; and Devera and Follmer, in prep) and modified based on our interpretation of the landforms.

Field reconnaissance included traverses across and along the Shawnee Hills to verify to the aerial photography interpretations and 1:20,000-scale mapping shown on Figure 4 and Plate 1. Much of the reconnaissance was limited to traverses along public roads. We performed more detailed reconnaissance along seismic reflection lines Tamms-1 and Tamms-2, where property owners granted access to private land. From the field reconnaissance, we field checked our geomorphic mapping and carefully searched for evidence of late Quaternary tectonic-geomorphic features coincident with the Penitentiary fault.

3.3.2 Seismic Reflection Data Acquisition

Seismic reflection data for two profiles (Tamms-1 and Tamms-2) were collected in SH mode (sensitive to horizontally polarized shear waves) on a 12-channel engineering seismograph. Seismic line locations are shown on Figures 4, 10, and Plate 1. The profiles intersect the Penitentiary fault zone along Old Diswood (Tamms-1, Figure 8) and Newell Roads (Tamms-2, Figure 9). Acquisition parameters are summarized in Table 1. The active spread consisted of 14 receivers (14 Hz horizontal geophones oriented perpendicular to the seismic line) spaced at 4-meter intervals. The seismic profiles were shot off-end with 4-meter

shotpoint spacings and 2-meter source offsets. Seismic energy was generated by five horizontal impacts of a 4.5-kg sledgehammer on a 5-kg steel I-beam oriented perpendicular to the spread. Processing followed a standard sequence for shallow common midpoint (CMP) reflection data and included: data reformatting and editing, CMP sorting, bandpass filtering (8-80 Hz), automatic gain control (200 ms window), velocity analysis, Normal Moveout (NMO) correction, surface-consistent residual statics, and 6-fold CMP Stacking. The findings of the seismic reflection survey are provided in Section 5.2.

4.0 REGIONAL GEOMORPHOLOGY

In the Tamms, Illinois, area, the regional geomorphology consists of the lowlands of the CRV and the Ozark Plateaus Province that are separated by an abrupt, linear topographic escarpment 60 meters high along the eastern margin of the Shawnee Hills (Figure 3). Possible fault-related geomorphic lineaments within the study area (Plate 1) include prominent east- and northeast facing-bluffs of the Shawnee Hills, linear drainage patterns, and possible deflected stream drainages. These features were interpreted on aerial photography, detailed geologic mapping, and verified by field reconnaissance. The Shawnee Hills are separated into two steep-sided east-facing bluffs that are traversed by Sandy Creek (Figure 3 and 4). As explained above, Devera and Follmer (in prep) inferred the PF along the range front based on the strikingly linear bluff line northeast of Sandy Creek. This bluff line trends approximately N50ºE from Sandy Creek for seven kilometers. Within the N50ºE trending segment, the topographic change across the range front is abrupt, especially considering the flat topography that characterizes the lowlands of the CRV. Tributary valleys within the Shawnee Hills are narrow and often carry coarse cobble-sized bedload. North of Newell Road, the prominent escarpment ends and the range front becomes more sinuous and eroded with isolated bedrock knobs surround by Quaternary deposits (Figure 3, 4, and Plate 1). In addition, drainages become wider and appear overwhelmed with sediment north of Newell Road. The bluff line south of Sandy Creek trends approximately N20ºE and becomes more arcuate towards the south, where the bluff line appears modified by a meander scroll of the Mississippi River.

Close to the eastern bluff line of the Shawnee Hills, several stream valleys trend northeast subparrallel to the Penitentiary and Commerce faults and are coincident with the mapped faults within or adjacent to the stream valley (Devera et al., 1994). As shown on Figure 4 and Plate 1, the east branch of Sandy Creek is strikingly linear, parallel to the Penitentiary fault, and coincident with mapped discontinuous faults to the north (Devera et al., 1994; Nelson et al., 1997). Similarly, the Commerce fault, as described above, is mapped along the southeastern margin of Wolf Creek. As described below, Odum et al. (2002) infer a possible northeast (e.g. right-lateral) deflection of Wolf Creek by the Commerce fault. These observations suggest that the geomorphology of the drainage basins in this area is to some degree controlled by underlying bedrock structure.

Despite these possible fault-related geomorphic lineaments and careful field work, no other convincing fault-related geomorphic features were mapped along the eastern margin of the Shawnee Hills or within the drainages of Wolf Creek or Sandy Creek (e.g. shutter ridges, tonal lineaments, fault scarps, springs).

At two locations two very small fan or terrace surfaces may be vertically separated at the Shawnee Hills range front. These features are along Old Diswood Road (NE ¼ of Section 11, T. 15S., R. 2W) and at Provo Cemetery (SE ¼ of Section 25, T. 14S., R. 2W) adjacent to the Shawnee Hills range front (Plate 1). Potential offsets are small (<1 meter or 2-3 feet), but these interpretations are isolated and speculative because both sites are adjacent to roads and offsets could be the result of road construction rather than surface faulting. The apparent lack of tectonic geomorphology maybe the result of several factors including discrete Holocene alluvial fan deposition along the Shawnee Hills, as well as anthropogenic influences (Eaton, 1992; Walter and Merritts, 2008), which may obscure signs of tectonic geomorphology (discussed in more detail in Section 7.0)

5.0 TAMMS STUDY AREA

We focused our study along the Shawnee Hills west of Tamms, Illinois because of the presence of: (1) Holocene alluvial and colluvial deposits, (2) prominent inferred tectonic-related geomorphology, (3) bedrock faulting previously documented in road cut exposures directly to the northeast and southwest (Devera and Follmer, in prep), and (4) Quaternary faulting imaged in seismic reflection lines coincident with the Penitentiary fault (Odum et al., 2002).

5.1 Geologic Mapping

We grouped all bedrock and other geologic units of Devera and Follmer (in prep), Devera et al., (1994), and Nelson et al., (1999) that are older than Late Pleistocene into unit pQ (pre-Quaternary). The description of Quaternary geologic units below is largely based on those within Devera and Follmer (in prep), Devera et al., (1994), Nelson et al., (1999), and Nelson and Williams (2004), combined with our own interpretations from stereo-paired aerial photography, topographic maps, seismic data, and field reconnaissance.

We developed a geologic cross section oriented east-west from the Illinois State Geological Survey digital online water well database and our geologic mapping (Figure 4 and 7; Plate 1). These driller logs contained simple lithologic descriptions, but aided our interpretation of the Tamms-1 seismic lines along Old Diswood Road. The water well logs show that several fining-upward sequences of pea gravel to sand or coarse-grained sand to fine-grained sand, and clay in the valley fill.

The stratigraphic relationships of major Quaternary geologic formations are shown in Figure 6 and a description of each deposit is detailed below. A simplified description of map units is provided in Table 2 and a description of mapping elements and individual geologic map units is provided in Appendix A.

5.1.1 Description of Quaternary Geologic and Geomorphic Units

The Pearl Formation is composed of sand, subrounded to well-rounded gravel up to 3 inches in diameter, and sandy clay in a single, upward-fining sequence (Nelson et al., 1999) (Figure 6 and 7). The Pearl Formation is not expressed at the surface within our map area but we recognize it from driller's logs. Chert pebbles dominate with quartz, metamorphic, and igneous clasts making up 10-20% of the gravel content. From driller's logs in the central CRV, we interpret the Pearl Formation to be up to ~15 meters

thick and directly overlies crystalline bedrock (Figure 7). Nelson and Williams (2004) interpret the Pearl Formation to represent an Illinoian Age (170 to 120 kya) fluvial channel deposit derived from the ancestral Ohio River.

Sand, gravel, and minor silt and clay make up the Henry Formation (map units Qh, Qch, and Qch1) (Nelson et al., 1999) (Figure 4). The Henry Formation is similar to the underlying Pearl Formation but is finer-grained. The Henry Formation consists of sand with gravel clasts ranging from 0.5 inch to 1.25 inches in diameter. The Henry Formation is at least 37 meters (120 feet) thick in most locations and commonly stands out in relief as ridges and small hills along the length of the Cache River Valley. The Henry Formation represents fluvial channel, point bar, longitudinal bar, natural levee deposits, and eolian sands largely derived from Wisconsinan (120,000 to 10,000 years ago) glacial outwash (Esling et al., 1989, Nelson et al., 1999). Map unit Qchl emphasizes the ridge and swale topography of the Henry Formation by highlighting the most prominent intra-bar channels cut into the top of the unit during the last stages of occupation of the Cache Valley by the Ohio River. The top of the Henry Formation was dated at 25,343 ± 450 B.P. (Esling et al., 1989).

The Equality Formation consists of silt and clay, with minor sand and gravel (map units Qce) (Nelson et al., 1999). Limonite concretions and organic matter, such as wood and plant fragments, are common (Nelson and Williams, 2004). The Equality Formation is over 21 to 24 meters (70 to 80 feet) thick and its lower contact is erosional, resting on Paleozoic bedrock in most locations. The upper contact is gradational with the overlying Cahokia Formation (Nelson et al., 1999). The Equality Formation underlies all the major tributary valleys of the Cache Valley and interfingers laterally with the Henry Formation near the margins of the Cache Valley. Within the map area, Equality Formation was grouped with Cahokia Formation in the upland tributary valleys and mapped as Unit Qce (Figure 4; Plate 1). The Equality Formation is interpreted as Wisconsinan interglacial overbank and lacustrine sediments (Esling et al., 1989; Nelson et al., 1999)

The Peoria Silt is common throughout the central United States as the youngest surface-mantling loess unit (Follmer 1996; Hansel and Johnson, 1996). Within the study area, the Peoria silt is very low in clay content, well drained, usually dry and crumbly, and has an angular blocky structure (Nelson et al., 1999). Although not shown as a geologic map unit on Plate 1, the Peoria silt blankets nearly all upland areas and is up to 9.1 meters (30 feet) thick in the CRV (Nelson et al., 1999; Devera and Follmer, in prep). This

loess was deposited during glaciation in the late Wisconsinan (10-25 ka) (Nelson et al., 1999; Follmer 1996; Hansel and Johnson, 1996)

Silt, sand, clay, gravel, and rock debris comprise the Cahokia Formation (Nelson et al., 1999) (Figure 4 and 6). The gravel portion consists primarily of well-rounded chert pebbles with lesser amounts of quartz, igneous and metamorphic clasts (Nelson et al., 1999). In the broad valleys Cahokia Formation is dominated by upland-derived silt whereas in the small upland valleys it consists of silt and angular rock fragments derived from the local weathered bedrock. In the broad valleys, surface soils are weakly developed but buried soils are common. Nelson et al., (1999) also recognize an alluvial fan facies (map unit Qcf) and a wetland facies (map unit Qcw). Map unit Qcf is a mixed silt alluvial fan deposit with angular rock fragments and is mapped along the margin of the Shawnee Hills. Map unit Qcw is organic-rich silt and clays deposited in low-lying areas such as abandoned channels, swales, and wetlands. The Cahokia Formation's lower contact may be sharp (erosional), or more commonly gradational with the underlying Equality and Henry Formations. The Cahokia Formation ranges between 1.5 to 10.5 meters thick in the Pulaksi 7.5 minute quadrangle (Nelson and Williams, 2004) and up to 14 meters thick in the Tamms 7.5 minute quad (Devera and Follmer, in-prep). In the upper Cache Valley, organics 8.30 meters deep in the Cahokia Formation were dated at 8160 ± 180 B.P. (Graham, 1985).

We also mapped additional landforms and deposits to improve our understanding of the geomorphic processes occurring in the study area and how those processes could reflect neotectonic activity. For example, map unit Qf is similar to Qcf, but unit Qf describes smaller and steeper alluvial fans that have formed at the mouths of small drainages along the bluff line that defines the eastern margin of the Shawnee Hills. We interpret these fans to be middle to late Holocene because of their steep slopes and position relative to the lower relief Cahokia Formation found in the Cache Valley. Map unit Qt denotes the location of small terraces that now lie above the modern floodplain. These landforms are probably of Holocene age, but their genesis could date to the Late Pleistocene. Map unit Qcol denotes the location of colluvium along hill slopes. Areas of perennially or seasonally saturated landscape that may or may not be a result of human activity are shown as Qw. Stream channels active in the Holocene are shown by map unit Hch. Holocene oxbows are included in map unit Hox. These features are abandoned or cut-off channels that may still contain water or could be infilled with fine-grained deposits.

5.1.2 Summary of Quaternary Geologic History

The middle Pleistocene and younger geologic history of the Cache Valley is dominated by the effects of the Illinoian and Wisconsinan glacial periods. During these times, the Ohio River flowed through the Cache Valley and deposited glacial outwash as the Pearl and Henry Formations (Esling et al., 1989, Nelson et al., 1999, Nelson and Williams, 2004). During periods of high discharge, the Cache Valley was overwhelmed with sediment and the tributary valleys were essentially dammed to create slackwater lakes into which the finer-grained Equality Formation was deposited (Esling et al., 1989; Lineback, 1979; Shaw, 1911; William and Frye, 1970; Ray, 1963). Loess deposition accompanied each glacial advance and retreat and today this loess blankets the uplands surrounding the Cache Valley (Nelson and Williams, 2004). Sometime between 25 ka and 8 ka years ago, the Ohio River abandoned the Cache Valley and established its present course to the east (Esling et al., 1989). Then, local streams and overflow from the Ohio River reworked the glacial outwash and loess, depositing the Cahokia Formation (Elsing et al., 1989). Holocene-age streams were sometimes controlled by the ridge and swale topography of the glacial outwash and established well-developed meander belts within the swales. In other locations, Holocene streams cut across the trend of the ridges and swales and have incised into the Cahokia and Henry Formations. Alluvial fans formed at the mouths of the tributary valleys that join the Cache Valley. In recent times, humans have straightened and channelized streams, drained wetlands, and installed subsurface tile drains.

5.2 Seismic Reflection Survey

As part of this study, we conducted multiple detailed shear-wave seismic reflection surveys across the Shawnee Hill range front to identify potential Quaternary deformation elsewhere along the Penitentiary fault and to identify potential paleoseismic targets (Figure 4, 8, and 9).

The processed seismic profiles, Tamms-1 and Tamms-2, show coherent seismic reflection energy to depths greater than 100 meters, and as shallow as 10 meters (Figure 8 and 9). Based on correlation with local borehole data from the ISGS well-database (Figure 7) and previously acquired seismic reflection data (Odum et al., 2002) (Figure 5), reflections from Holocene and Late Pleistocene deposits (Unit 3), Late Pleistocene gravels (Unit 2), and Paleozoic bedrock (Unit 1) were identified on the shear-wave reflection profiles (Figure 8). Offset reflections and changes in reflection amplitude and coherency suggest the presence of high-angle faults in the subsurface.

Bedrock (Unit 1) imaged in Tamms-1 is characterized by two strong reflectors that mark the sediment-rock contact (Figure 8). Overall the profile shows prominent reflectors below the bedrock-sediment contact. Bedrock in Tamms-1 varies between 10 and 40 meters in depth and reveals a 30 meter high buried east-facing scarp. The bedrock reflector is overlain by Late Pleistocene sand and gravel (Henry Formation, Unit 2). The angularity between the east-dipping bedrock contact and horizontal reflectors within Unit 2 suggest that Unit 2 unconformably overlies bedrock Unit 1. Holocene and Late Pleistocene deposits (Cahokia and Henry Formation, Unit 3) overlie the Unit 2 and are characterized by generally weak discontinuous reflectors. These interpretations nicely corroborate our findings from geologic mapping (Figure 10), available boring logs, and cross sections (Figure 7).

The seismic stratigraphy imaged in the Tamms-2 seismic line is poorly characterized (Figure 9). The unconformity between bedrock (Unit 1) and Late Pleistocene sand and gravel (Unit 2), imaged in Tamms-1, is difficult to identify in Tamms-2 (Figure 9). The Holocene to Late Pleistocene deposits (Unit 3) are easily identified and are characterized by generally weak discontinuous reflectors. The contacts within Unit 2 are unidentifiable despite coherent reflectors. A bedrock high is identified at the east end of the profile (similar to Tamms-1) and is coincident with a bedrock ridge at the northern margin of the valley (Figure 10). We interpret the disrupted incoherent reflectors in the middle of the profile (stations 400 to 600 meters) as likely due to faulting.

5.2.1 Faulting and Folding Interpreted from Seismic Lines

Faulting and folding interpreted from Tamms-1 and Tamms-2 shows coherent reflectors offset by four high angle faults that are within 10-15 meters of the ground surface (Figure 7 and 8). Within Tamms-1, faults are labeled with a number and fault splays are labeled with a letter (e.g. fault 1a). The faults coincident with Shawnee Hills range front (faults 1 and 2) consist of near vertical faults that mark a buried east-facing scarp and east-side down bedrock step, but these faults do not appear to offset Quaternary geologic units. Faults interpreted in the eastern portion of the profile (faults 3 and 4) offset both the prominent bedrock reflector and Henry Formation. Bedrock offsets along faults 3 and 4 vary between < 2 and 6 meter and commonly with apparent reverse displacements. Displacements of Henry Formation reflectors vary between 2 and 3 meters. The poor reflector quality in the youngest geologic units prevents confidently projecting faults upward into the youngest overlying deposits; however, several of these near surface reflectors (i.e. above Unit 2) appear warped and disrupted (Figure 7). Splay 4d appears to offset the basal Pleistocene to Holocene package between 2 and 4 meters. These data suggest

that the Penitentiary fault was active during latest Pleistocene to possibly early Holocene time. The eastern fault zone is interpreted as possibly a 'flower structure' associated with transpressive deformation consistent with observations by Odum et al. (2002) along Sandy Creek.

Individual faults are difficult to identify within the Tamms-2 profile (Figure 9). One fault zone is interpreted in profile Tamms-2 based on a highly-disrupted zone near the central part of the profile. Interestingly, this zone has coherent reflectors on either side and is coincident with a mapped bedrock fault interpreted to be the Penitentiary fault (Figure 4, Plate 1). We hypothesize that this disrupted zone is caused by deformation along the Penitentiary fault zone. Based on the overall poor quality of the reflectors within the fault zone, we are unable to delineate individual fault offsets, or Holocene fault activity, however the location of this inferred zone of formation is coincident with the mapped bedrock trace of the Penitentiary fault.

In summary, the complex near-surface pattern of faulting interpreted from profiles Tamms-1 and Tamms-2 aligns with the broad, complex faulting previously observed in seismic lines to the south along Sandy Creek (Odum et al., 2002) (Figure 10). This latest study demonstrates that one of the faults associated with the Penitentiary Fault zone comes within 10-15 meters of the ground surface and displaces latest Pleistocene, to possibly Holocene deposits. Quaternary deformation along the Penitentiary fault includes apparent vertical deformation that ranges from 2 to 6 meters. The faulting of Pleistocene and possibly Holocene deposits imaged in Tamms-1 and Tamms-2 is best explained as transpressive dextral deformation associated with the Penitentiary fault zone and the larger CGL.

6.0 DISCUSSION

Our review of aerial photography and field reconnaissance, coupled with geophysical, seismicity, and liquefaction data, provide indirect and direct evidence for Pleistocene, and possibly Holocene deformation, aligned with the Penitentiary fault and the CGL. The direct observations that indicate the Penitentiary fault zone is Quaternary active include three seismic lines intersecting the fault that image deformation of Pleistocene and, possibly early Holocene deposits, located directly east of the prominent Shawnee Hills bluff line (Figure 3 and Plate 1). Data from the seismic lines indicate the area of imaged Quaternary deformation is approximately 0.5-0.7 km wide. Indirect evidence for Quaternary activity includes the: 1) association of several earthquake swarms near the junction of the Penitentiary fault and the Commerce fault ; 2) evidence of paleoliquefaction in the Cache River Valley; 3) close spatial association of the fault zone and orientation with the Quaternary active Commerce fault; and 4) spatial association of the fault zone with the CGL. We believe that collectively, these data support the conclusion that the Penitentiary fault has produced surface rupture within Quaternary time.

The overall geomorphic signature of the Penitentiary fault remains consistent with other Quaternary active faults along the CGL to the southeast where the expression of faulting is subtle (Baldwin et al., 2006; Harrison et al., 1999). No prominent or distinct tectonic geomorphology was mapped along the Penitentiary fault, with the exception of the 60-m-high Shawnee Hills range front. In addition, at two locations within the mapped area, two very small fan surfaces exhibit possible vertical deformation at the Shawnee Hills range front; however, these two locations are isolated and the observed vertical separation can also be explained by possible human-related landscape modifications. The overall apparent lack of tectonic geomorphology in the Tamms study area can be explained by the absence of surface faulting during the middle and late Holocene, as well as significant late Holocene deposition of alluvial fans burying any evidence of past surface fault rupture. If the Penitentiary fault last ruptured the ground surface in the early Holocene, as suggested by the seismic line profiles, signs of deformation likely are buried and/or eroded by Holocene deposition of the Cahokia Formation and younger fan deposits (Figure 4). This is especially true if the return period for large earthquakes is long and the deformation is dominantly dextral transpression with only a minor vertical component (discussed below). Another possible explanation for the subdued tectonic geomorphology may be anthropogenic landscape modification caused by logging and farming (Eaton, 1992; Walters and Merrits, 2008). This may have caused the latest deposition of alluvial fans (Unit Qf1) obscuring evidence of surface rupture. In

summary, the absence of recent and prominent feature geomorphic and geologic mapping appears to suggest latest Pleistocene to early Holocene deformation consistent with the seismic profiles.

The genesis of the Shawnee Hills bluff line could be explained as either a fluvial, tectonic, or a fault-line scarp. Without direct geologic observations (e.g. trench or borehole data) this uncertainty is difficult to resolve. The Tamms-1 profile and the geologic cross section confirm a buried east-facing scarp (Figure 7 and 8). This relief could have been generated by the scouring of the CRV before the deposition of the Pearl Formation gravels during Illinoian time (Masters and Reinertsen, 1987). Although faults are imaged coincident with the bluff line (e.g. faults 1 and 2), these faults do not offset the Quaternary stratigraphy suggesting these faults did not create the entire scarp. In addition, the linearity of the scarp suggests it is not a fluvial scarp when compared to the arcuate fluvial scarps to the northeast (Figure 3). Thus, the most likely explanation of the Shawnee Hills range front is likely a combination of a fault-line scarp (e.g. more erodible deposits on the southeastern side) and reactivation of the old Paleozoic (?) fault (Penitentiary Fault) during the Quaternary. A scarp generated solely by faulting would likely have more evidence of classic tectonic geomorphology (e.g. uplifted fluvial surfaces, shutter ridges etc).

Faulting imaged in three separate seismic lines confirms offset of late Quaternary deposits along the entire seven kilometer long mapped trace of the Penitentiary fault (Figure 10). South of the Penitentiary fault zone and Sandy Creek, strain is likely transferred onto the Commerce fault to the southwest were Quaternary faulting is well documented through geophysical and geologic investigations (Harrison and Schultz, 1994; Harrison et al., 1999). The continuity of faulting north of the Tamms-2 seismic profile is difficult to asses because the prominent geomorphic signal of Shawnee Hills range front becomes less prominent, drainages become embayed/drowned with sediment, and CRV trends away from the trace of the CGL to the east northeast (Figure 3). To the northeast of the PF there are no obvious faults mapped that may represent further surface deformation along the CGL. Nelson et al. (1997) speculates that Quaternary faulting may continue to the northeast as a series of discontinuous small northeast-striking faults forming a right-stepping en echelon pattern. Nelson et al. (1997) continue to suggest that a 4.2 Mb earthquake near Dongola, Illinois, located 15 kilometers northeast of the Tamms study area may be associated with these faults and the northeastern extension of the CGL.

Available geologic and seismic data along the Commerce section of the CGL indicate the entire length of the CGL has ruptured in Quaternary time (Figure 2), but whether the CGL ruptures in discrete segments or throughout its length remains to be resolved. Previous studies along the Commerce segment of the

CGL interpret that several surface rupture events have occurred in Pleistocene and early Holocene time (Baldwin et al., 2006; Vaughn, 1994; Harrison et al., 1999). No earthquake timing information is available in the Tamms, Illinois area; however, the compilation of seismic profile and seismic data suggest that latest Pleistocene to possibly early Holocene faulting may also continue north into Illinois from the Benton Hills of Missouri. Further work at the Tamms site and north along the northern Junction segment of the CGL could provide constraint on the rupture dimensions of the CGL.

Our compilation of existing geologic and geophysical data indicates the Penitentiary fault zone accommodates dextral transpression in the contemporary strain field. Although no kinematic indicators have been measured along the fault zone, the evidence for dextral transpression includes: 1) faulting and folding consistent with transpressional 'flower structures' (Figure 5 and 8) (Odum et al., 2002); 2) dextral strike-slip focal mechanisms of historical seismicity (Harrison and Schultz, 1994; Harrison et al., 1999); 3) strike-slip kinematic indicators along the Commerce fault at Olive Branch Road (Devera and Follmer, in-prep); and 4) the alignment of the Penitentiary fault with present day east-northeast-directed stress-field is consistent with dextral transpression (Harrison and Schults, 1994; Odum et al., 2002). In addition, similar transpressive structures have been interpreted in geophysical profiles along Qulin Ridge, Holly Ridge, and the Benton Hills overlying the CGL in southeast Missouri (Figure 2). Seismic lines Tamms 1 and 2, agree with the regional topography and strongly support the conclusion that Quaternary active northeast-striking faults are accommodating transpressive deformation along the CGL.

7.0 SUMMARY OF FINDINGS

Our investigation of the Penitentiary fault and its inferred connectivity with the Commerce geophysical lineament provides additional direct and indirect evidence for linking observed Pleistocene-Holocene deformation with previously mapped faults directly overlying the CGL. The seismic reflection data acquired during this study image steeply dipping faults that offset reflectors within Late Pleistocene and possibly Holocene deposits. The style of faulting captured in the seismic lines indicates the fault is accommodating dextral transpression, which agrees with regional focal mechanisms, geomorphic data (i.e. deflected streams), regional topography, and previous studies in southeastern Missouri. In addition, the sum of the available geologic data suggest the Penitentiary fault is likely a Paleozoic (?) fault that developed into a fault-line scarp during pre-Quaternary time that has been reactivated in late Quaternary time.

This geologic and paleoseismic investigation of the eastern margin of the Shawnee Hills improves our understanding of the likelihood of potentially active seismogenic sources existing outside of the NMSZ and in the mid continental United States. The existing paleoseismic and paleoliquefaction event timing data for pre-historic large magnitude earthquakes in the Western Lowlands is sparse and poorly constrained, but collectively, the data indicate that future earthquakes on northeast-striking faults aligned with the CGL, like the Penitentiary fault, should be considered in probabilistic seismic hazard studies of the central United States. Additional event timing information are needed along the Commerce section of the CGL to ascertain the possibility of middle to late Holocene earthquakes along structures aligned with the CGL, assess temporal clustering of large earthquakes in the upper Mississippi embayment between the NMSZ and CGL structures, and refine the initial Late Pleistocene to early Holocene event chronology for the Commerce section of the CGL.

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9.0 REPORTS/ABSTRACTS PUBLISHED

As part of this U.S. Geological Survey NEHRP-funded research an abstract was presented to discuss the initial findings of the study:

Elliot, E.T., Harris, J.B., Baldwin, J.N., Brossy, C.C., and Givler, R.W., 2008, Shallow Seismic Reflection Imaging of the Penitentiary Fault and its Association with the Commerce Geophysical Lineament, Tamms, southern Illinois, Geological Society of America Abstracts with Programs, Vol. 40, No. 5, p. 80.

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U.S. Geological Survey, 1934, Thebes Quadrangle, Illinois-Missouri, scale 1:62500, 1 sheet.

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Tables

Table 1. Data acquisition table for shear-wave seismic reflection survey for SR-1

Energy Source	1.8 kg sledge hammer 5kg I-beam (5 impacts)
Source Offset	2 meters
Receiver	12 channel shear-wave landstreamer with 14 Hz horizontally polarized geophones
Receiver Intervals	4 meters
Spread Configuration	Off-end, split spread
Recording System	Seistronix RAS-24

Table 2: Formal, recognized formations within the study area

Unit	Composition/Description	Thickness (meters)	Age	Reference
Pre-Quaternary Bedrock (pQ)	Crystalline bedrock and other geologic units older than Late Pleistocene	variable	pre-Quaternary	This study
Pearl Formation (subsurface only)	Upward-fining sand, gravel up to 3 inches in diameter, and sandy clay	0-15	Illinoian	Nelson and Williams (2004)
Equality Formation (Qce	Mostly silt and clay, with minor sand and gravel. Limonite concretions, organic matter (wood and plant fragments) and even peat are common.	0-21	Wisconsinan (Coeval with Henry)	Nelson et al. (1999); Nelson and Williams (2004)
Henry Formation (Qh, Qch)	Mostly sand, some gravel, and minor silt and clay. Finer grained that Pearl.	0-38	< 25,343 ± 450 B.P. (Esling et al., 1989).	Nelson et al., (1991); Devera and Follmer (in prep)
Peoria Silt (not mapped, covers bedrock)	Clay-poor loess mottled by light to medium gray, yellowish gray, and yellowish brown colors. The modern soil developed in this unit.	<9 meters thick	Late Wisconsinan	Nelson et al., 1999; Devera and Follmer (in prep)
Cahokia Formation (Qc, Qch, Qce, Qcw, Qchl, Qcw)	Silt, sand, clay, gravel, and rock debris. Locally an alluvial fan facies and wetland facies exist.	0-14	Holocene <8160 ± 180 B.P. (Graham, 1985)	Nelson et al. (1999); Devera and Follmer (in prep)

APPENDIX A

Detailed Description of Geologic map units

APPENDIX A:

Description of mapping and map units for Quaternary geologic and geomorphic map of the Penitentiary fault

Methods

We used black and white, 1:20k scale, stereo-paired aerial photography flown in September 1956 as the primary data from which to interpret the geomorphology. Historical (US Geological Survey, 1920; 1923; 1933; 1934) and modern (US Geological Survey, 1967, 1966, 1947) topographic maps also aided our analyses of the landforms and deposits. Geologic units and structural features were largely adapted from existing geologic mapping of the Mill Creek, McClure, Dongola, and Tamms 7.5 minute quadrangles completed by the Illinois State Geological Survey (Devera et al., 1994; Nelson et al., 1999; and Devera and Follmer, in prep) and modified based on our interpretation of the landforms.

Map unit contacts delineated by a solid line are accurate to within about 30 feet (9.1 meters). Where possible, channels were bounded by two lines—one along each line of vegetation that represents the bank location. Many channels were 30 feet (9.1 meters) or less in width and could only be accurately shown by delineating a single line down the channel's centerline.

Description of map units (generally oldest to youngest; landforms are mostly described here; for descriptions of formal geologic units see map explanations on the ISGS maps)

pQ- Pre-Quaternary geologic units undifferentiated: All crystalline bedrock and other geologic units interpreted to be older than Quaternary are included in this unit.

Qchl- Quaternary channel: a broad and linear channel that is usually 60-80 meter wide with gently sloping banks. I interpret most are related to the ancestral Ohio River because they often cut across the Henry Fm.

- — - — - (swale): a dash-dot-dash line that marks the centerline of a diffuse channel that is poorly constrained by topographic relief and has gently sloping banks, usually interpreted to relate to a braided stream or a ridge and swale environment of the ancestral Ohio river (similar to and possibly the same as unit Qchl just poorly expressed)

Qal- Quaternary alluvium: undifferentiated Qce, Qch, Ql, and Qcf

Qcol- Quaternary colluvium: Unsorted material on hillslopes subject to mass movement, usually cleared and used for agriculture, probably composed mostly of silt but also local bedrock (chert?), probably mostly Holocene.

Qw- Quaternary wetland: Unit Qw is similar to the unit Qcw of Devera et al., (in prep) but Qw need not be associated with the Cahokia Fm. Unit Qw could contain meander scars, oxbows lakes, and other areas of saturated and well-vegetated landscape.

Qt- Quaternary terrace: a former floodplain or channel location that is now elevated above the modern river, possibly Holocene in age, these features are not well expressed and are may not be real terraces but rather some sort of in-channel bar or meander scar, or could be related to human activity

Qf- Quaternary alluvial fan: a conical sloping surface that radiates from a central point. Qf is distinct from Devera's Qcf unit in that unit Qf are small fans that are typically much more local landforms that stand out in relief from the surrounding wide and more gentle Qcf surface. I mapped Qf as a landform whereas it appears that Qcf is more of a deposit. Qf could be Holocene in age, but also could range back into the Pleistocene.

Hf- Holocene fans: similar to unit Qf only clearly Holocene in age.

Hch- Holocene channel: This landform may be well defined by relief and vegetation along its banks or could be filled and obscured by agriculture. It is defined as Holocene in age because it cuts channels interpreted to be from the ancestral Ohio River that are within the Henry Formation or it flows across and is incised into the Cahokia Fm.

Hox- Holocene oxbow (lake): a roughly horseshoe-shaped former channel location, now abandoned due to the stream cutting across a meander neck, may or may not have enough standing water to be classified as a lake.

Hms- Holocene meander scar: a former channel location, could be wet and well vegetated but not a lake. comma-shaped or oddly amorphous but not highly sinuous as in the case of Hox.

d- drain: a drainage ditch or subsurface tile drain related to agricultural activity, often strikingly linear and may cutoff and insect with natural channels.

Quarry- a quarry: a location where humans have excavated the native material leaving behind a pit or alcove in the landscape.

AF- Artificial Fill: fill material emplaced by human activity.

References (Topographic Maps)

U.S. Geological Survey, 1967, Tamms Quadrangle, scale 1:24000, 1 sheet.

U.S. Geological Survey, 1966 (Photorevised 1990), Dongola Quadrangle, scale 1:24000, 1 sheet.

U.S. Geological Survey, 1947 (Photorevised 1990), McClure Quadrangle, scale 1:24000, 1 sheet.

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U.S. Geological Survey, 1934, Thebes Quadrangle, Illinois-Missouri, scale 1:62500, 1 sheet.

(Geologic Maps)

Devera, J.A., Nelson, W.J., and Masters, J.M., 1994, Geologic Map of the Mill Creek and McClure Quadrangles, Alexander and Union Counties, Illinois: Illinois State Geological Survey IGQ-15, scale 1:24,000, 1 sheet.

Devera, J.A., and Follmer, L.R., In prep, Geologic Map of the Tamms Quadrangle, Alexander and Pulaski Counties, Illinois: Illinois State Geological Survey IGQ-??, scale 1:24,000, 1 sheet.

Nelson, W.J., Follmer, L.R., and Masters, J.M., 1999, Geologic Map of the Dongola Quadrangle Alexander, Pulaski, and Union Counties, Illinois: Illinois State Geological Survey IGQ-19, scale 1:24,000, 1 sheet.

Nelson, W.J. and L. Williams, 2004, Geology of Pulaski Quadrangle, Pulaski County, Illinois: Illinois State Geological Survey, Illinois Preliminary Geologic Map, IPGM Pulaski-G, scale 1:24,000, 2 sheets.

FIGURES

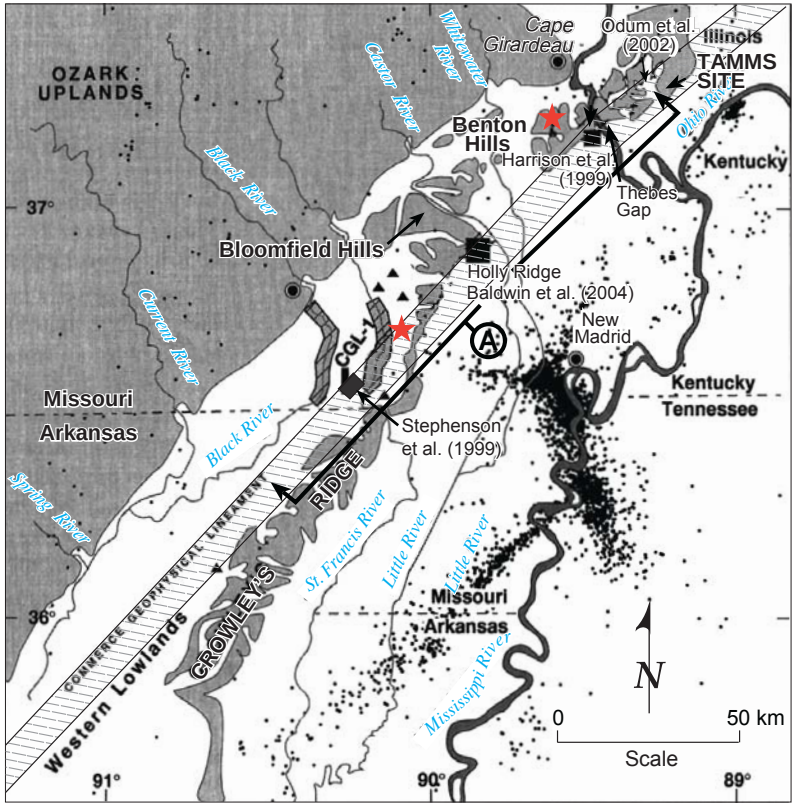


Figure 1. Regional map of the southeastern Missouri showing the surface projection of the Commerce geophysical lineament (horizontal hatch pattern). The pre-Quaternary deposits (light gray fill pattern), Quaternary (white), and main rivers (medium gray) are also shown. Sites of paleoliquefaction (Vaughn, 1994) are shown by triangles. Epicenters of recorded seismicity from 1974 to 1995 are shown by black dots. Epicenters of M4.8 are shown by stars. Letter Ⓐ shows Commerce section of the CGL. Newport and Junction sections are to the southwest and northeast of map edge, respectively. Modified from Stephenson et al. (1999).

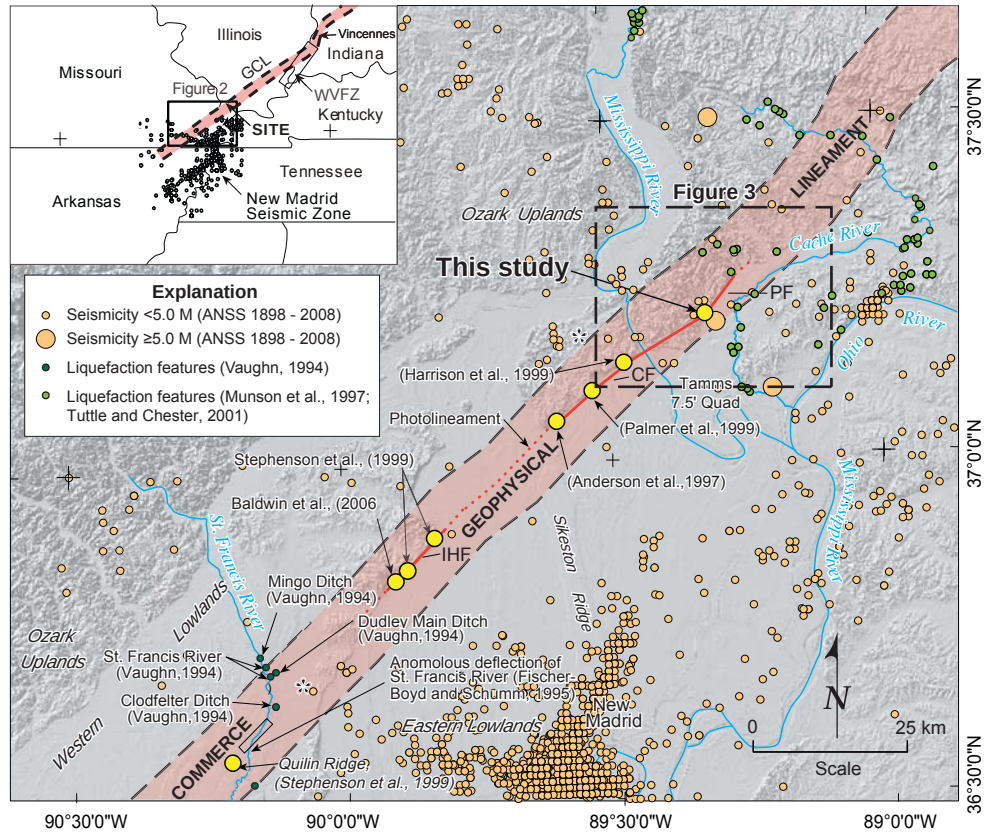


Figure 2. Regional location map of the New Madrid seismic zone and the Commerce geophysical lineament based on latitude and longitude coordinates provided by Hildenbrand (personal communication, 2002) and modified partly from Stephenson et al. (1999). IHF = Idalia Hill fault; CF = Commerce fault; PF= Penitentiary fault. Star (∗) = epicenters of M4.8 earthquakes. WVFZ = Wabash Valley Fault Zone.

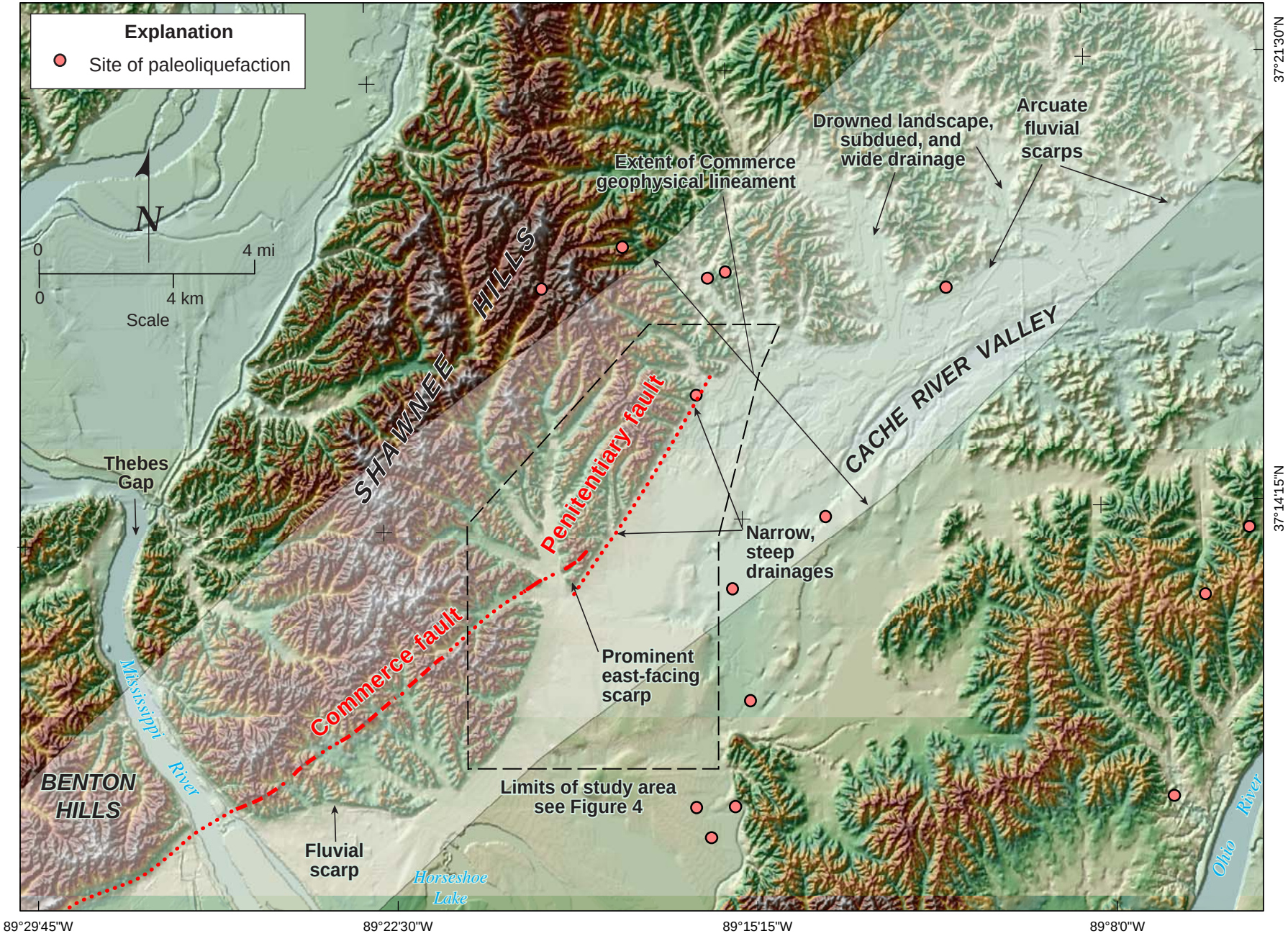


Figure 3. Digital elevation model (DEM) of the Cache River Valley, Shawnee Hills, and Benton Hills in southern Illinois and Missouri. 30-meter DEM downloaded from National Elevation Dataset (January, 2006). Site of paleoliquefaction from Munson et al. (1997) and, Tuttle and Chester (2001).

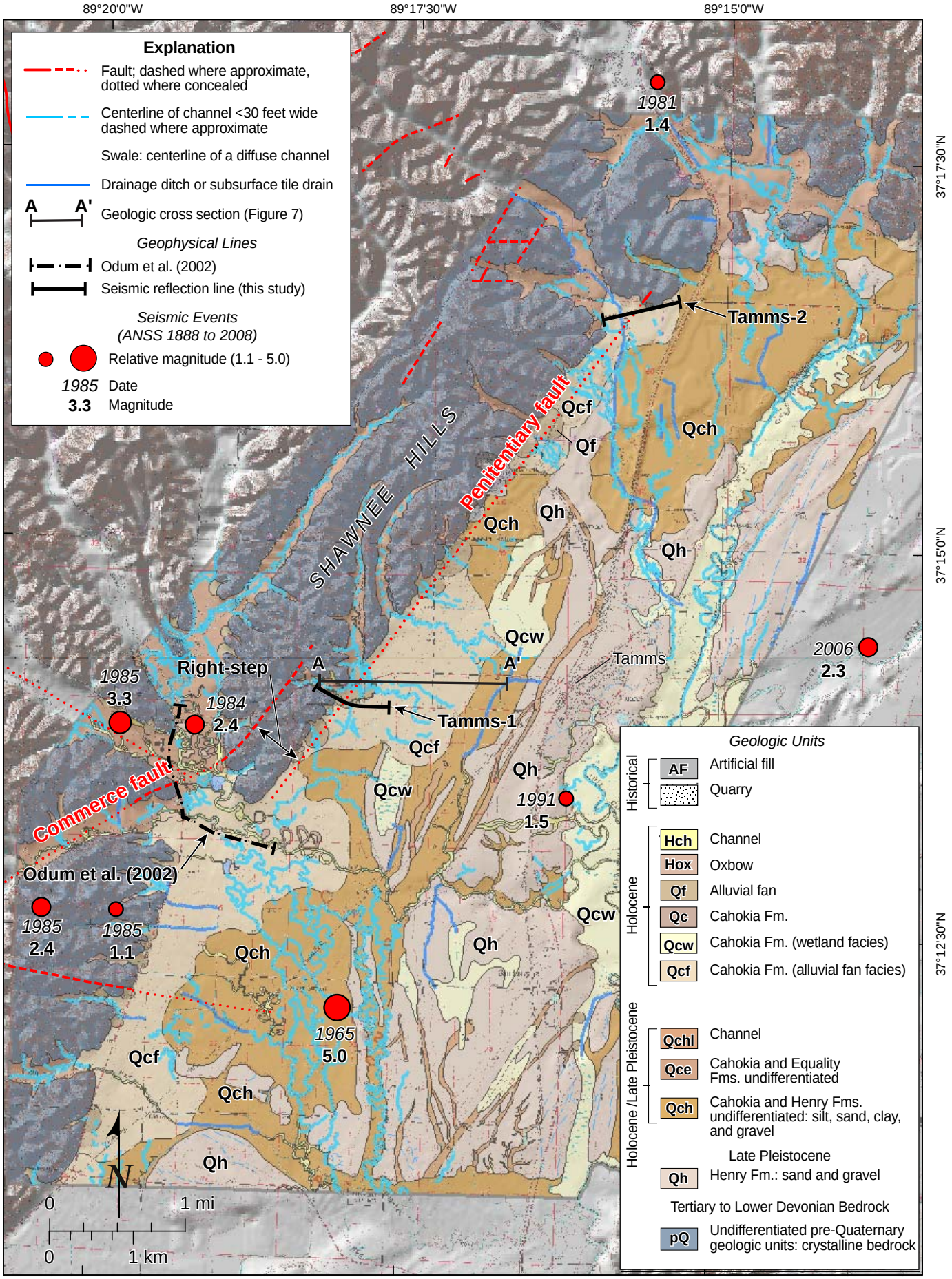


Figure 4. Quaternary geomorphic and geologic map of the Tamms area, southern Illinois. Note the four small magnitude earthquakes that occur near the step-over between the Commerce and Penitentiary faults. See Plate 1 for full-scale version of geologic mapping.

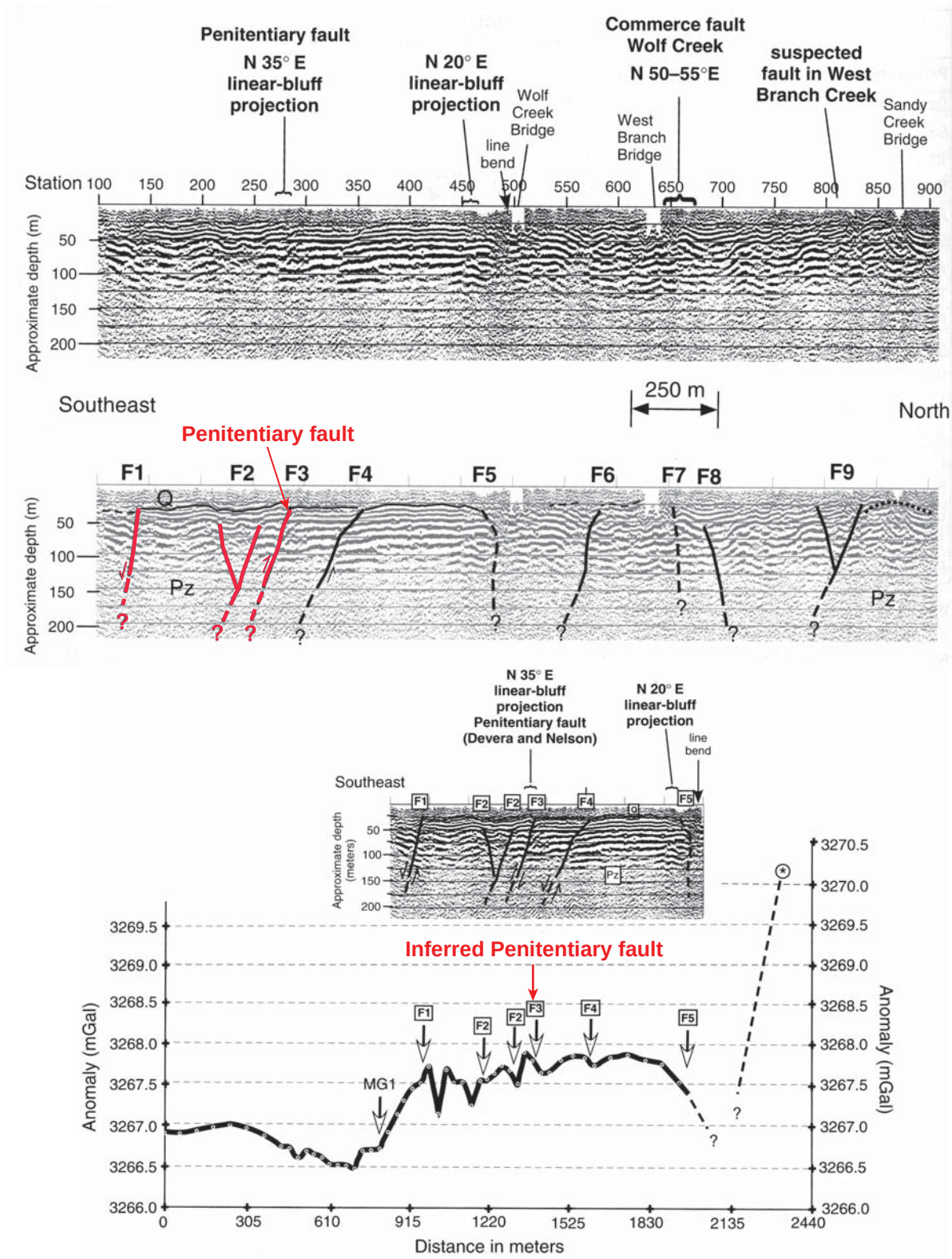
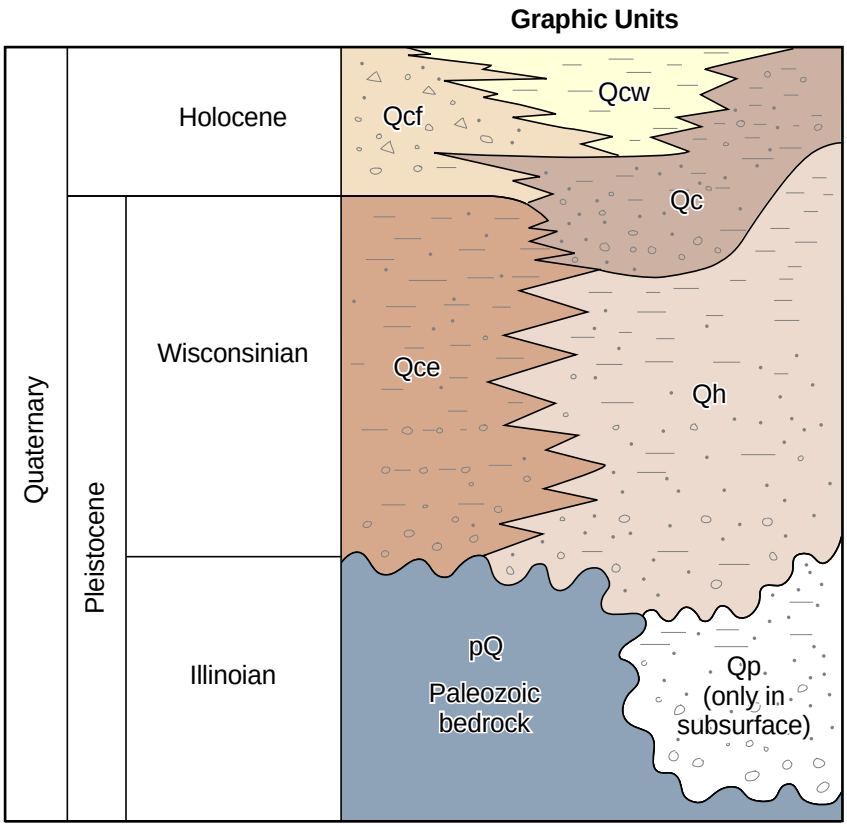


Figure 5. Uninterrupted migrated depth-converted seismic-reflection profile of Odum et al. (2002). Odum et al. (2002) interpret the reflective package observed across the profile to be predominantly Paleozoic with small amount of overlying Quaternary deposits. The profile shows substantial folding and faulting. Much of the deformation coincides with the projections of topographic bluff fronts (suspected fault-line scarps) and the projected trace of the Commerce fault. Faults F1 to F3 of Odum et al. (2002) are the focus of this investigation.



Note: Peoria silt not shown, covers bedrock in upland areas. Modified from Devera and Follmer (in prep.).

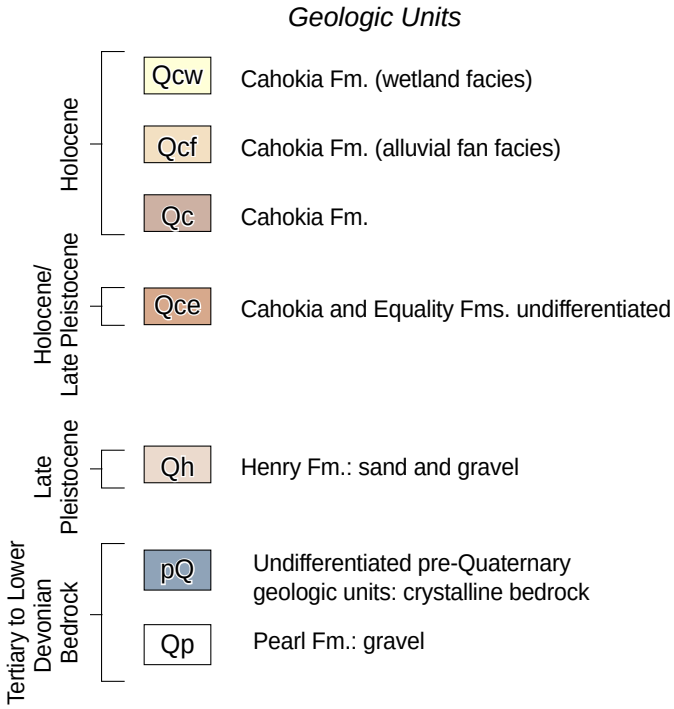


Figure 6. Schematic showing stratigraphic relationship between major geologic units in the map area. For a detailed description of map units see Section 5.1.1 or Appendix A.

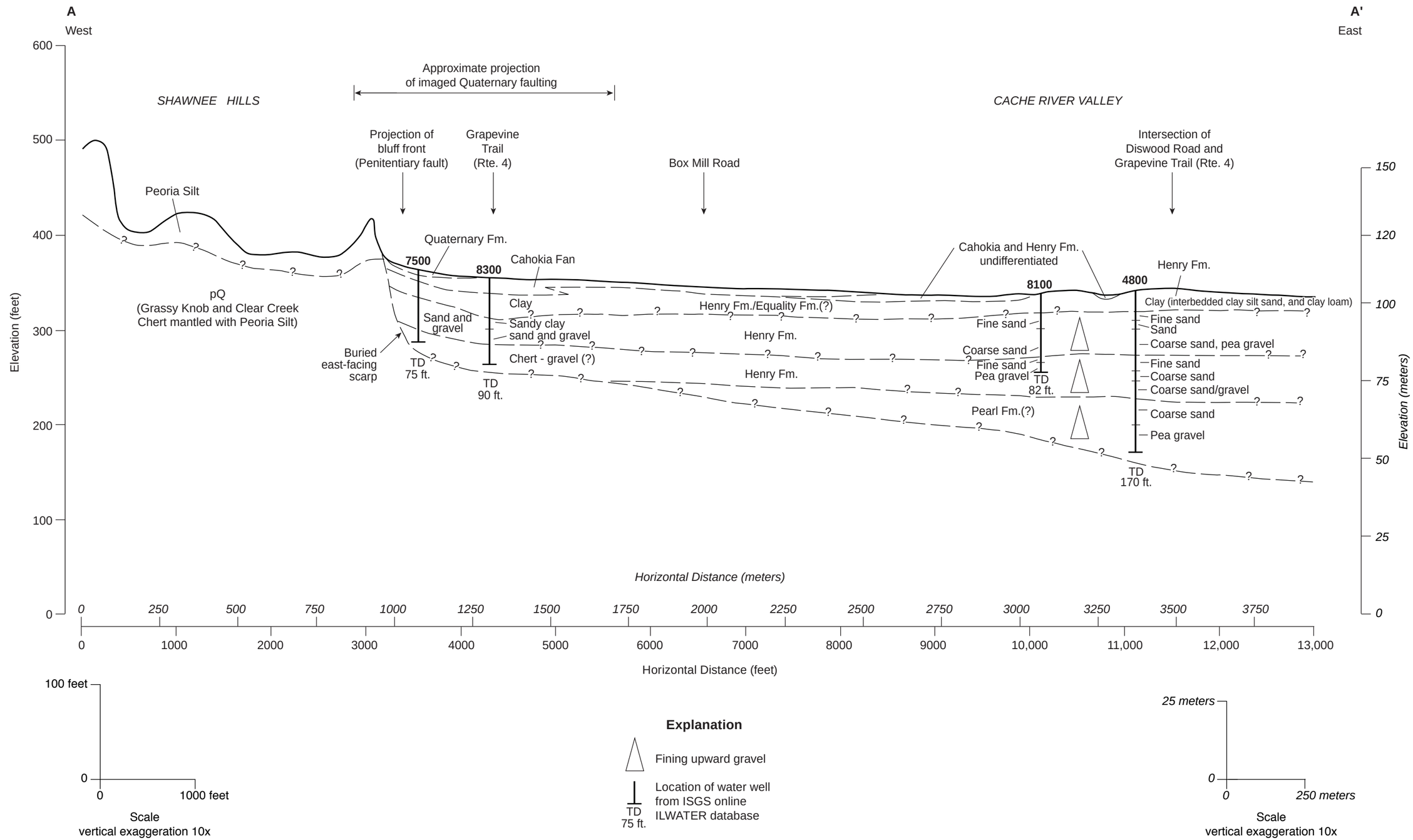


Figure 7. Geologic cross section A - A' across the Penitentiary fault and Shawnee Hills range front. Note the buried east-facing scarp coincident with the Penitentiary fault and imaged Quaternary faulting. At the base of well numbers 7500 and 8300 only chert was noted on driller's logs. These descriptions are likely fluvial chert-rich gravels based on the Tamms-1 seismic line and personnel communications with IGS geologist J. Nelson (April, 2008).

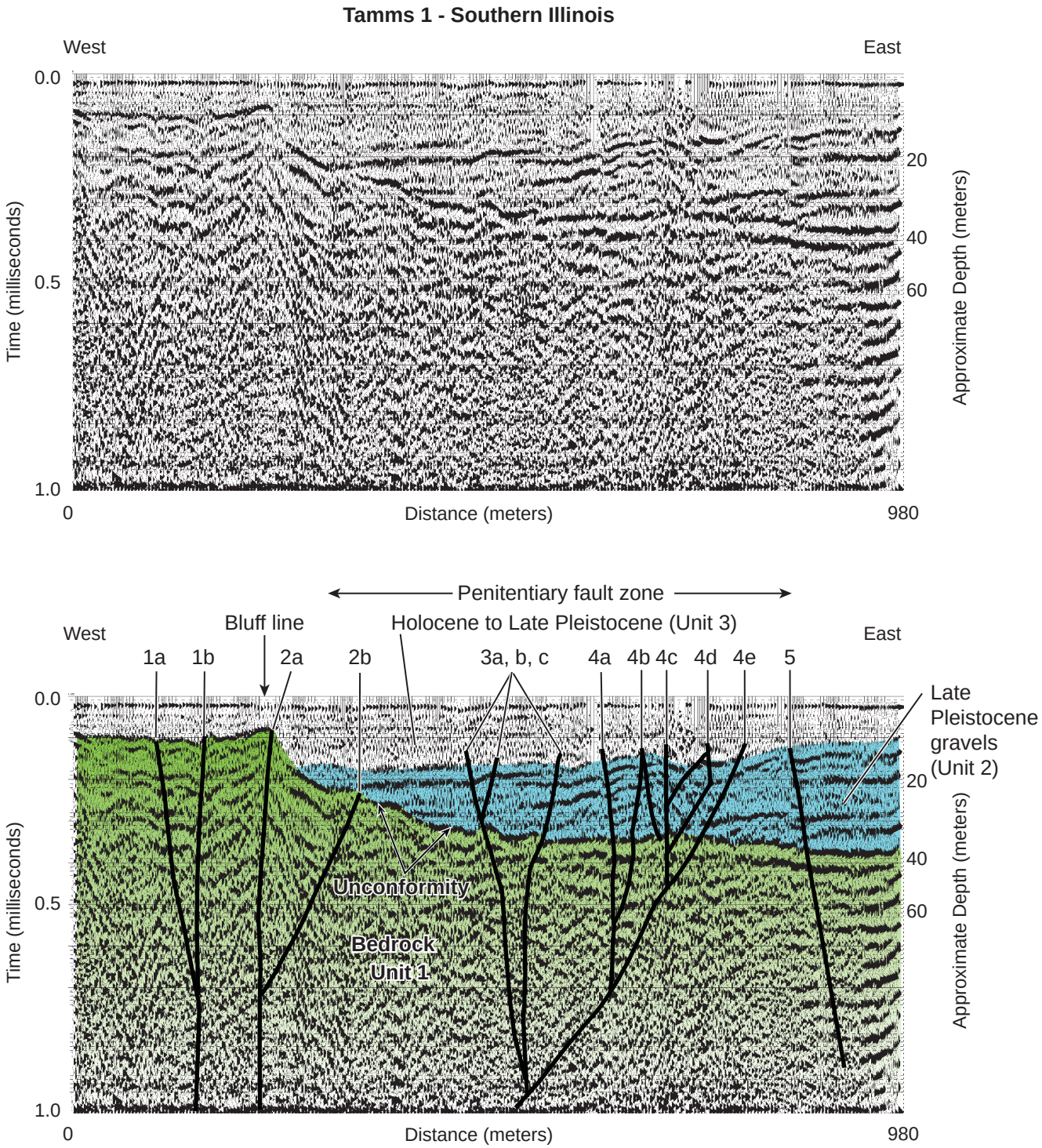


Figure 8. Shear-wave seismic reflection survey of Tamms-1 along Old Diswood Road. Interpreted profile shows the top of bedrock (Paleozoic bedrock), Late Pleistocene gravels, and Holocene to Late Pleistocene alluvium, and interpreted faults. Faults are labeled with integers and individual fault splays are labeled with letters.

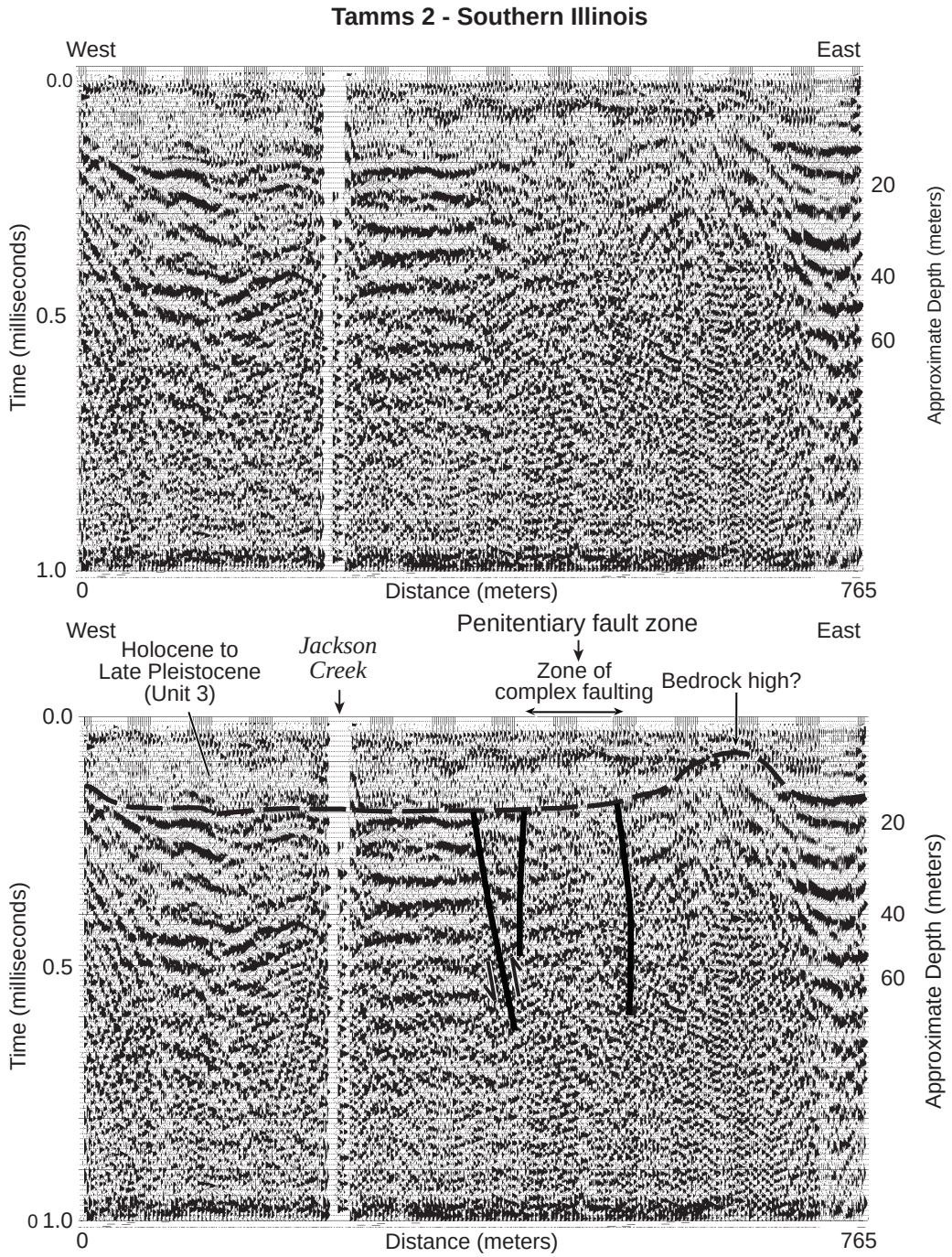


Figure 9. Shear-wave seismic reflection survey Tamms-2 along Newell Road. Interpreted profile shows bedrock adjacent to an area of poor reflector quality interpreted as faulted bedrock which coincides with a mapped bedrock fault (Figure 4; Plate 1). The bedrock (Unit 1) contact with Late Pleistocene gravels (Unit 2) is not resolvable.

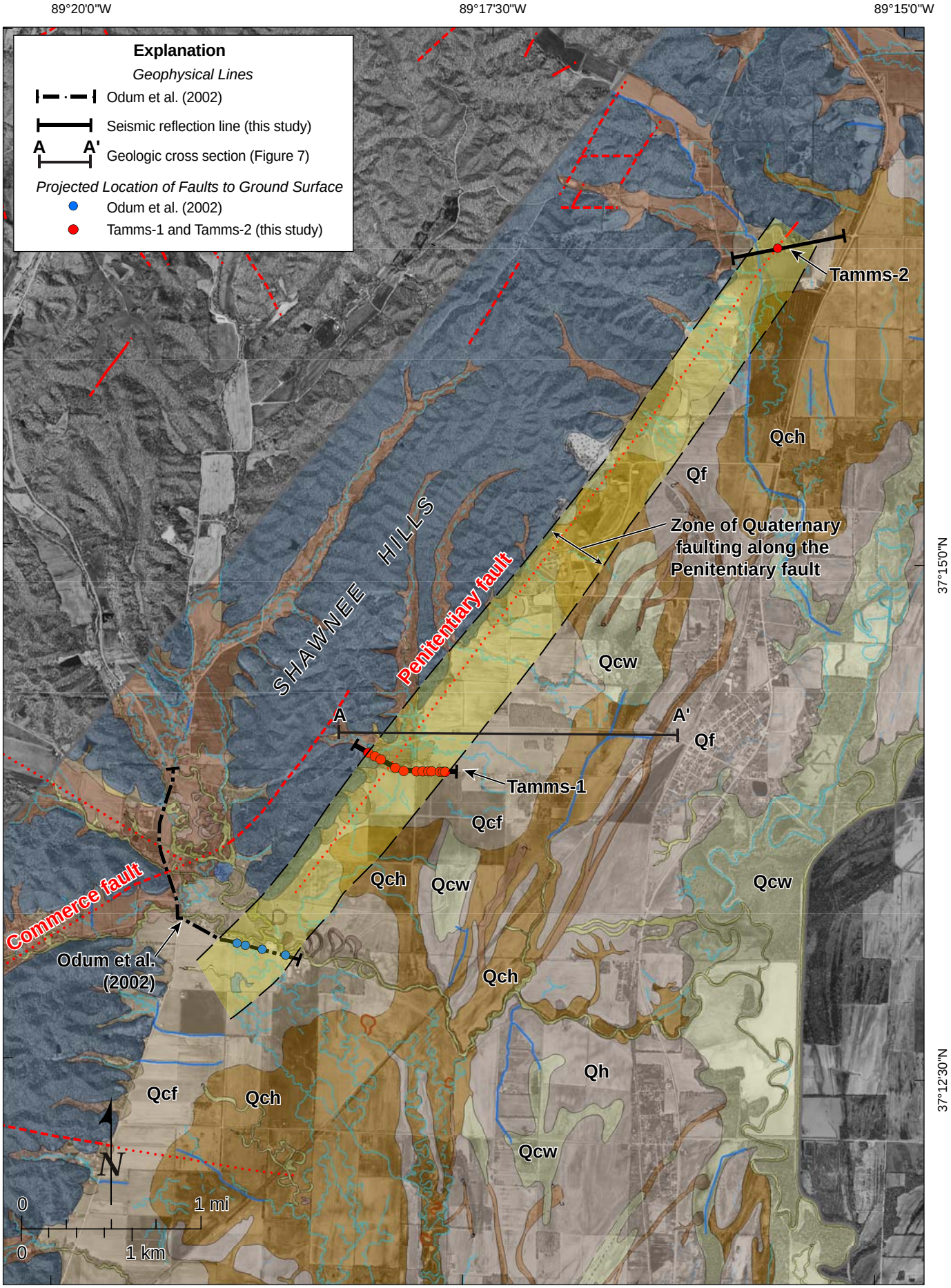


Figure 10. Quaternary geomorphic and geologic map of the Tamms area with a USGS digital orthophoto Quadrangle (DOQ) base illustrating geophysical profiles and the surface projection of faults imaged in geophysics.

Plate 1: Quaternary Geomorphic and Geologic Map of the Tamms Area, Southern Illinois (accompanies Baldwin et al., 2008 Final Technical Report)

Explanation

Geologic contact; dashed where approximate, dotted where concealed, queried where uncertain; solid contacts within 30' of line shown on map.

Centerline of channel <30ft in width. Likely contains sorted gravel, sand and silt. Dashed where approximate.

Swale: centerline of a diffuse channel that is poorly constrained by topographic relief.

Oxbow (lake): sorted silt and clay and some sand.

A — A' Geologic cross section location (Figure 7 of this report).

Geophysical Lines:

Odum et al. (2002); Seismic reflection lines

Tamms-1; Tamms-2. Shear-wave reflection profiles (this study).

Faults:

Approximate

Certain

Concealed

Seismic events from ANSS from 1898 to 2008 (displayed by Magnitude and labeled with year and magnitude)

Magnitude

1974-1.1 — 1.0 - 1.9

2.0 - 2.9

3.0 - 3.9

4.0 - 4.9

5.0 - 5.6

Boreholes (shown with boring ID):

5 — Oil test hole

20217 — Water well from ISGS maps

3052 — IDOT bridge borehole

Water wells from 1995 Alexander County Wells and Boring Database developed by ISGS

Description of Geologic Units

HISTORICAL

- AF — Artificial fill.
- Quarry.
- Drain: drainage ditch or subsurface tile drain related to agricultural activity.

HOLOCENE

- Hch — Channel: sorted silt, sand, and gravel.
- Hox — Oxbow (lake): sorted silt and clay and some sand.
- Qw — Wetland: undifferentiated meander scars, oxbows lakes, and other areas of saturated landscape. Predominantly silt and clay, with some sand and gravel.
- Qf — Alluvial fan: sorted and unsorted silt, sand, and gravel.
- Qc — Cahokia Fm: silt, quartz sand, clay, and chert gravel.*
- Qcw — Cahokia Fm (wetland facies): gray to dark gray, soft, organic-rich clay.*
- Qcf — Cahokia Fm (alluvial fan facies): angular chert clasts within a colluvial silt and sand matrix.*
- Qcol — Colluvium: Unsorted material on hillslopes subject to mass movement, usually cleared and used for agriculture, probably composed mostly of silt and possibly mixed local bedrock.
- Qt — Terrace: former flood plain or channel location that is now elevated above the modern river.

PLEISTOCENE TO HOLOCENE

- Qce — Cahokia and Equality Fms undifferentiated: silt, sand, clay, and gravel.*
- Qchl — Channel: sorted sand and gravel with minor silt and clay.
- Qch — Cahokia and Henry Fms, undifferentiated: silt, sand, clay, and gravel; mapped in low Cache Valley where Cahokia formation is > 10 ft thick.*
- Qms — Meander scar: sorted silt, sand, and some gravel.

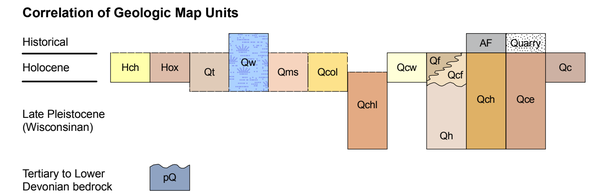
LATE PLEISTOCENE

- Qh — Henry Fm: sand (dominantly quartz) and gravel (chert, igneous, and metamorphic pebbles) with minor amounts laminated to massively bedded of silt and clay.*

TERTIARY TO LOWER DEVONIAN BEDROCK

- pQ — Undifferentiated pre-Quaternary geologic units: All crystalline bedrock and other geologic units interpreted to be older than Quaternary are included in this unit.

Correlation of Geologic Map Units



* Formal geologic unit modified from the following maps:

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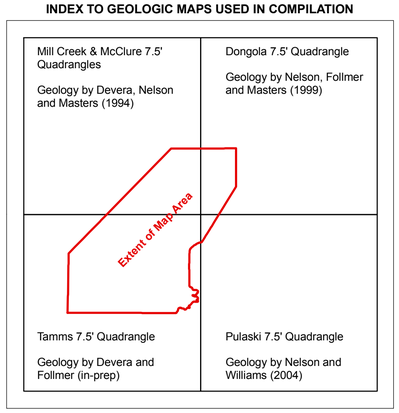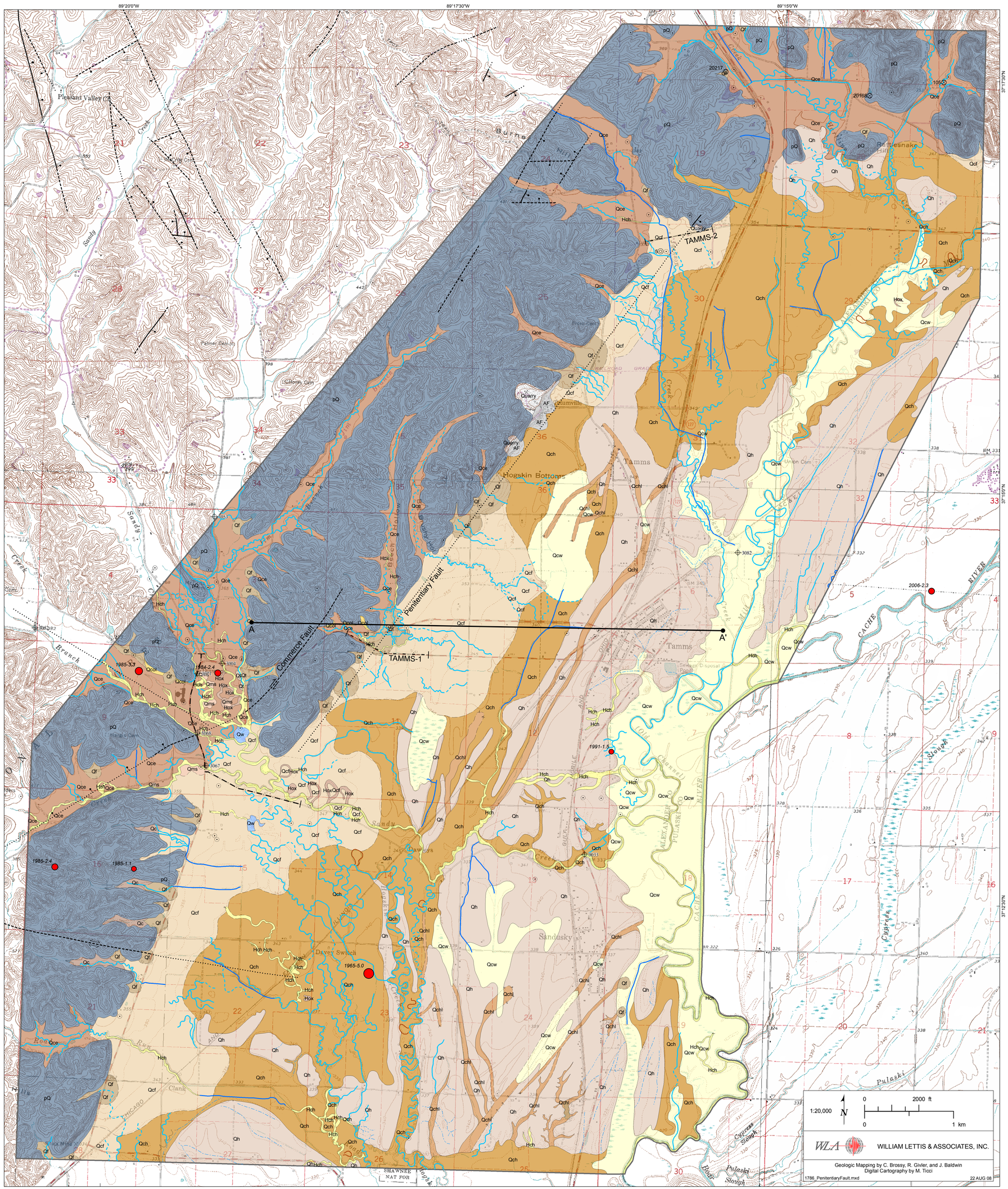
INDEX TO GEOLOGIC MAPS USED IN COMPILATION