Quaternary Fault Reactivation in the Fluorspar Area Fault Complex of Western Kentucky: Evidence from Shallow SH-wave Reflection Profiles

Article *in* Seismological Research Letters · September 2002

DOI: 10.1785/gssrl.73.5.628

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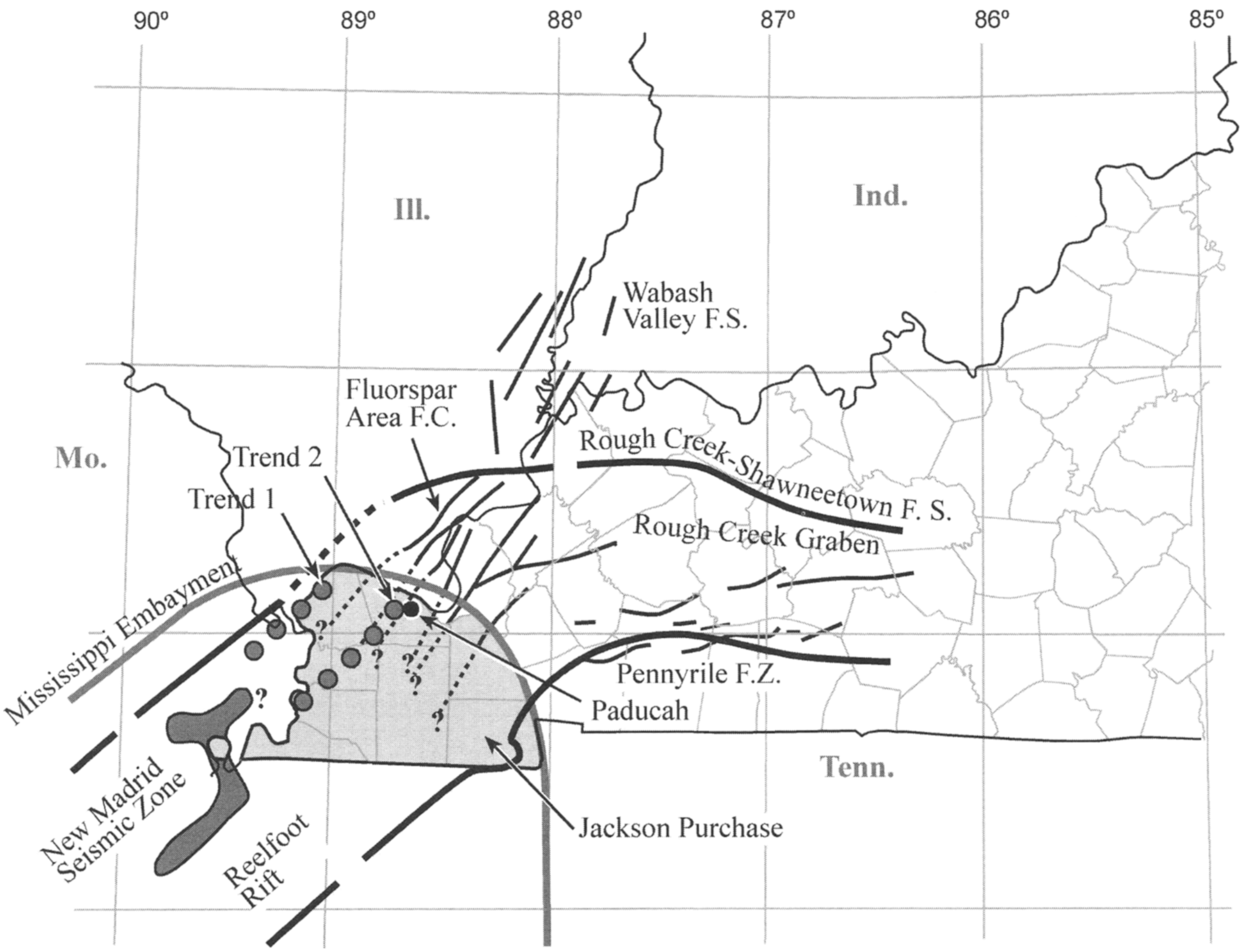
ABSTRACT

Shallow shear-wave seismic-reflection profiles were collected over the southwestern projection of the Fluorspar Area fault complex into the northern Jackson Purchase region of western Kentucky. The area lies at the northern end of the sediment-filled Mississippi embayment, where the Paleozoic carbonate rocks are masked by a relatively thin, approximately 100 m sequence of nonlithified Cretaceous, Tertiary, and Quaternary sediments. The interpreted profiles imaged clear evidence of fault and apparent fold propagation into the near-surface Quaternary units. The profiles also showed evidence of various structural styles associated with episodic movement. The exact timing of the latest tectonic episode exhibited on the profiles is not known because of the lack of more accurate stratigraphic detail coincident with the lines. However, physical evidence of Quaternary deformation less than 10 m below the ground surface, along with the instrumentally recorded seismic events located in the immediate vicinity of the study area, emphasizes the problematic nature of these fault segments for the design of critical or high-hazard structures.

INTRODUCTION

Accurate identification and characterization of near-surface geologic structures in the expansive river valleys of the seismically active central United States is often impeded by relatively thick sequences of nonlithified, water-saturated sediment. The soft sediment cover conceals neotectonic bedrock structure and, apart from a few notable exceptions (*i.e.*, Crowley's Ridge, Reelfoot scarp, Commerce Fault, and possibly Sikeston Ridge), the sediment's inherently weak mechanical properties commonly fail to transform near-surface propagated faults and folds into significant or noticeable surface geomorphic features. The northern Jackson Purchase region of western Kentucky is typical of this setting (Figure 1). It lies at the central juncture of two late Precambrian–early Paleozoic rifts, the Reelfoot rift and the Rough Creek graben (Kolata and Nelson, 1991), as well as near the northern end of the sediment-filled Mississippi embayment. Immediately north of the Jackson Purchase, in southern Illinois, is the intensely faulted Fluorspar Area fault complex that Nelson *et al.* (1997, 1999) described as a series of strike-slip pull-apart grabens bounded by N20°E- to N40°E-striking normal and reverse faults (Figure 1). In the Jackson Purchase, the Paleozoic bedrock is covered by several tens to a few hundred meters of Late Cretaceous and younger sediments. Wheeler *et al.* (1997), as well as Kolata and Nelson (1991), suggested the continuation of the fault complex into this area, but their evidence is inferred primarily from a north-south-oriented, low-resolution, proprietary seismic-reflection profile (J. Drahovzal, oral comm., 1998). More recently, the geologic data gathered by Nelson *et al.* (1999) and McBride *et al.* (2002) substantiate faults at least as far south as the Ohio River in Illinois.

Olive (1980) mapped a few faults in Tertiary and Quaternary deposits in the area but stated that these structures were based on indirect evidence and possibly attributable to nontectonic mechanisms. Subsequently, until Langston *et al.*'s (1998) study west of Paducah, Kentucky, which focused on the structural control of local ground-water movement, there has been no systematic effort to delineate the inferred extension of the fault complex into western Kentucky's Jackson Purchase. Because of the lack of geomorphic surface signatures indicative of subsurface structure, initial reflection profiles in the area were sited based on large anomalies seen in a low-resolution "sparker" survey conducted for the U.S. Army Corps of Engineers along the Ohio River (Alpine Geophysical Associates, Inc., 1966) (Figure 2). A previously

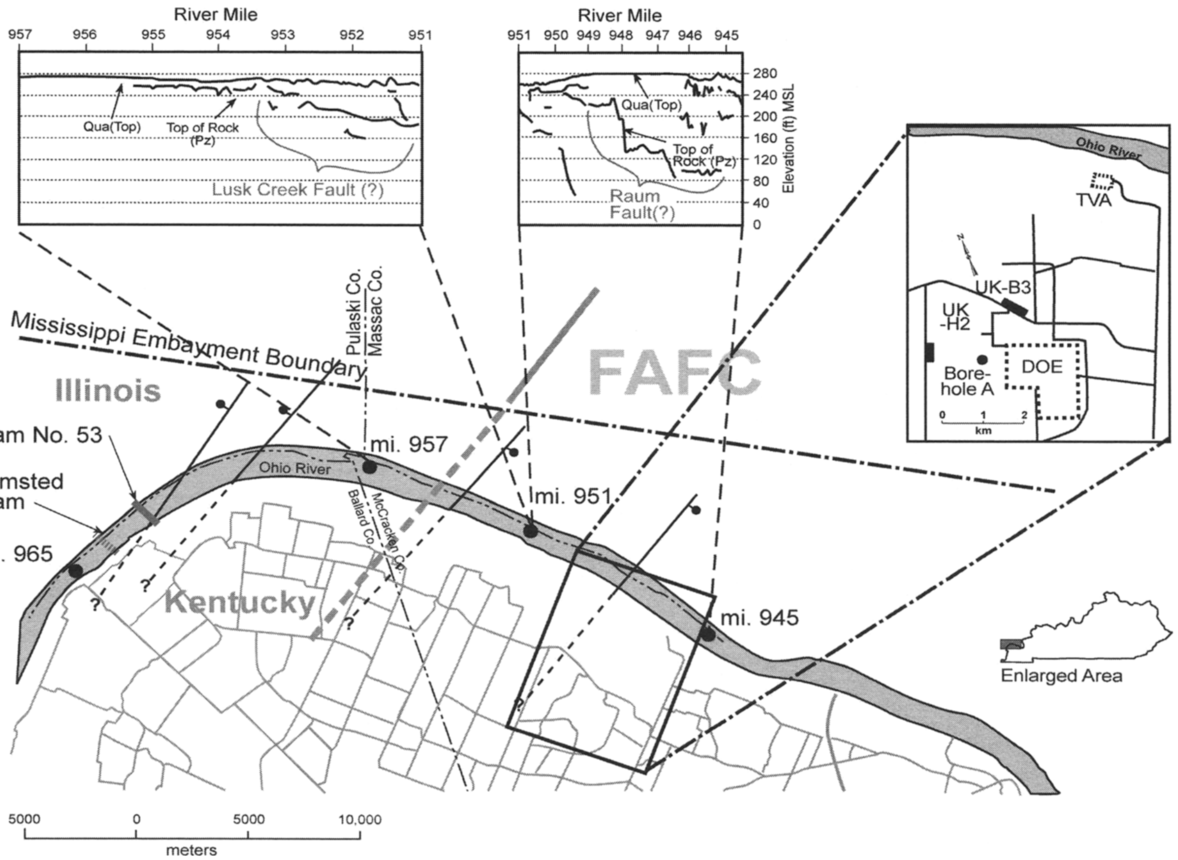


▲ **Figure 1.** Major structural features in the central Mississippi Valley (modified from Kolata and Nelson, 1997). The lines of shaded circles represent the locations of Wheeler's (1997) trends 1 and 2 seismicity in relation to the New Madrid seismic zone and the study area. The Jackson Purchase region of western Kentucky is also identified.

unpublished 710-m *SH*-wave seismic-reflection profile (UK-B3) from Langston *et al.*'s (1998) work and a recently acquired 400-m high-resolution *SH*-wave CDP profile (UK-H2) provide evidence for the southwestern continuation (Figure 2). In addition to the spatial extension for the faults, the most recent data show evidence of displacement and disruption of reflectors in the very near surface (~8 m). This Quaternary fault movement, along with the contemporary regional seismicity, emphasizes the necessity for detailed site-specific investigations, sensitive to seismic considerations, prior to the design of critical structures in the area.

GEOLOGIC SETTING

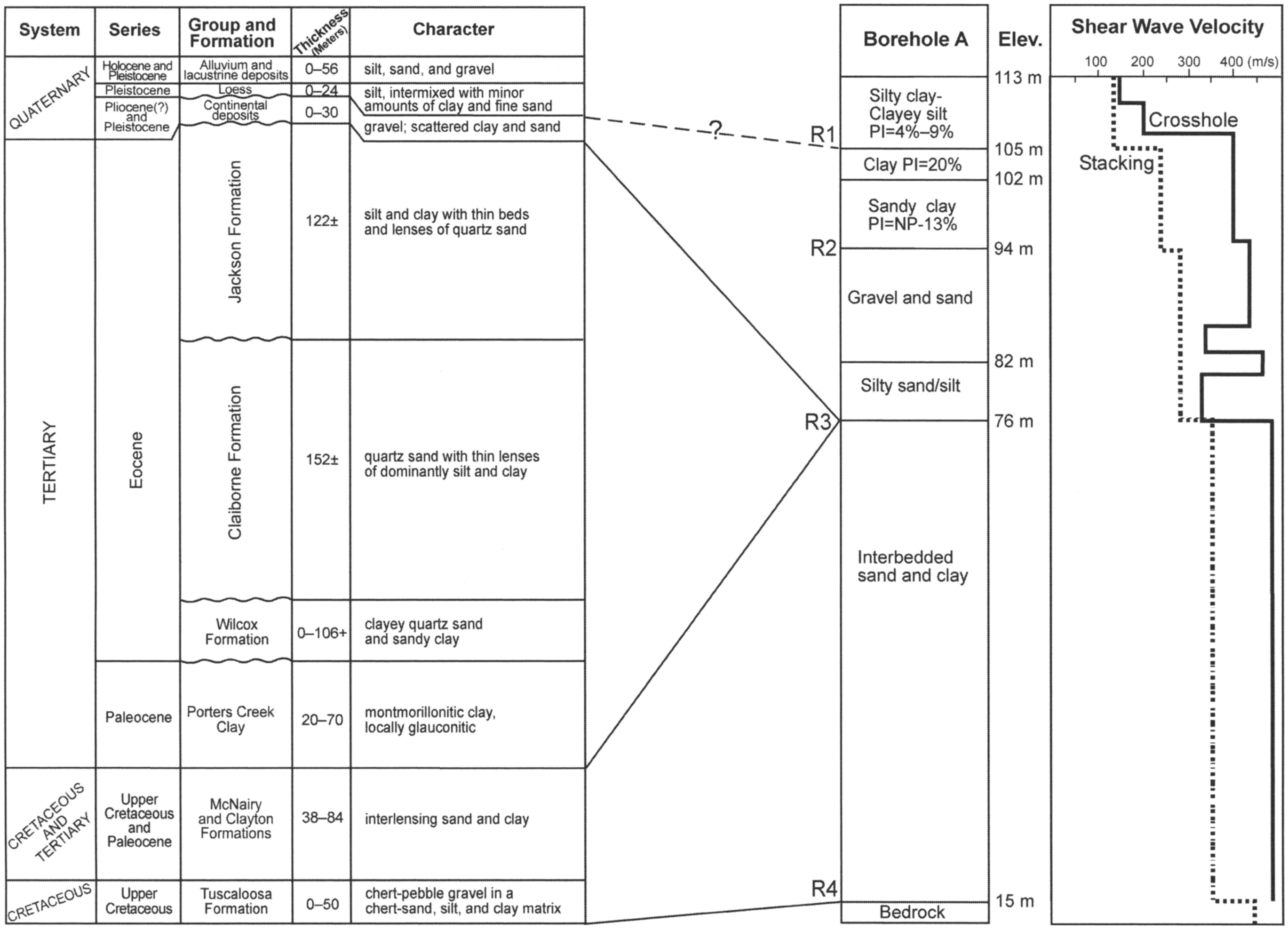
A lack of scientific consensus exists regarding the complex structural relationship between the Reelfoot rift, the most seismically active of the central and eastern United States rifts, and the Rough Creek graben, one of the least active major structures (Wheeler, 1997; Street *et al.*, 2002). The Rough Creek graben, which lies mainly in western Kentucky, is bounded on the north by the Rough Creek–Shawneetown Fault system and on the south by a series of faults that include the Pennyrile Fault system (Figure 1). The Rough Creek–Shawneetown Fault system extends from Kentucky into southern Illinois for about 25 km, then turns abruptly to the southwest and joins the Lusk Creek and Raum Fault zones, which form the northwestern boundary of the Fluorspar Area fault complex (Nelson and Lumm, 1987). The fault complex is believed to continue southwest across the Jackson Purchase of western Kentucky, beneath sedimentary cover of the northern Mississippi embayment, where it appears to form the northwest margin of the Reelfoot rift, the host geologic structure of the New Madrid seismic zone (Kolata and Nelson, 1991). This interpretation is supported by potential field data (Hildenbrand and Hendricks, 1995). The faults that make up the fault complex are thought to have originated in the Cambrian; some exhibit evidence of multiple episodes of dip-slip, as well as strike-slip movement into the Quaternary (Nelson *et al.*, 1999). Nelson *et al.* (1999) found evidence of Pliocene to early Pleistocene displacement along the Lusk Creek Fault zone in southern Illinois, although they saw no instance of Holocene sediment displacement. Holocene sediments were also found undisturbed in their observations of the neighboring Raum Fault.



▲ **Figure 2.** Vicinity and site map of the study area. Inset at upper right identifies the specific locations of *SH*-wave reflection profiles and geotechnical borehole. The two panels across the top show the large anomalies in the Corps of Engineers' "sparker" profiles between river miles 940 and 957 (modified from Alpine Geophysical Associates, Inc., 1966). The solid lines with barbs and balls identify the major offsets seen in the "sparker" data. The balls are placed on the downthrown side. The Fluorspar Area fault complex (FAFC) is defined by the thick, northeast-trending solid and dashed line. The gray network of lines in Kentucky and the thin black network of lines in the inset represent the local highways.

Our study area is located along the Ohio River, approximately 10 km west of Paducah, Kentucky and near the northern end of the Mississippi embayment (Figure 2). The area is also situated near Wheeler's (1997) "trend 2" projection of New Madrid seismicity (Figure 1). The post-Paleozoic stratigraphy for the area is shown in Figure 3. The Mississippian limestone bedrock is unconformably overlain by approximately 100 m of nonlithified sediments of Late Cretaceous, Paleocene, Eocene, Pliocene, Pleistocene, and Holocene age (Olive, 1980). Late Cretaceous gravel and sand associated with the Tuscaloosa Formation or undifferentiated Late Cretaceous and Paleocene interbedded sands and clays belonging to the McNairy and Clayton Formations rest directly on the bedrock. The McNairy-Clayton Formations are overlain by the Paleocene, montmorillonitic (locally glauconitic) Porters Creek Clay. Undifferentiated Eocene silty sands and clays unconformably overlie the Porters Creek Clay. The Eocene sands and clays are separated from the Pleistocene loess by Pliocene-Pleistocene sands and gravels, locally referred to as the Continental Deposits. Above the continental sands and gravels is Pleistocene loess. The loess is composed primarily of silt intermixed with minor amounts of clay and fine sand. The stratigraphic column is capped by Pleistocene and Holocene silt, sand, and gravel deposits.

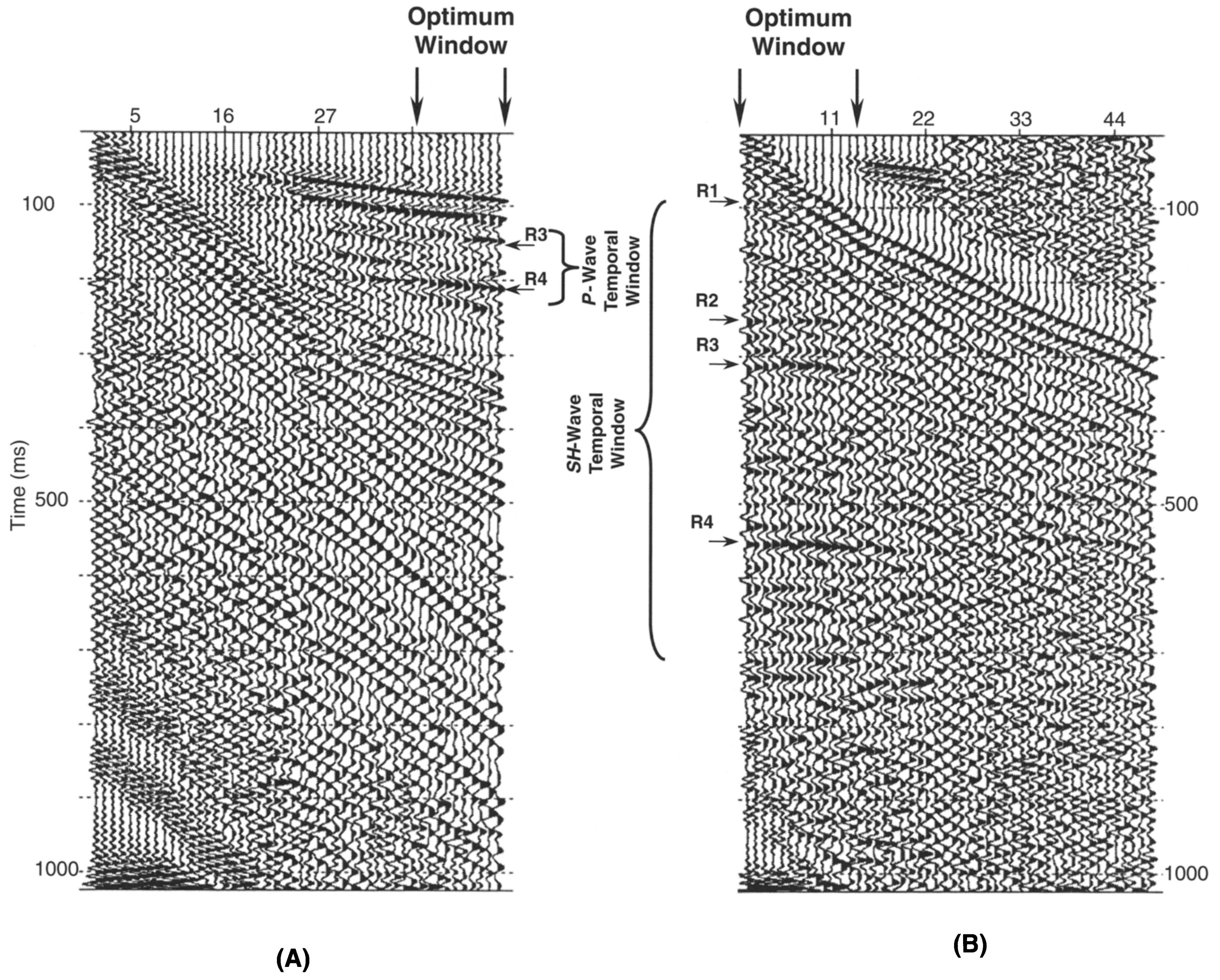
We interpreted four consistent reflectors across the study area, identified as R1 to R4 on Figures 3 and 4. The seismic stratigraphy was defined by walkaway soundings (Figure 4) that were correlated to lithologic changes and cross-hole-derived impedance boundaries identified in a nearby geotechnical borehole (A) (Sykora and Davis, 1993) (Figures 2 and 3). Sykora and Davis' (1993) visual and laboratory-derived soil characteristics for these units were compared with Olive's (1980) descriptions for final stratigraphic correlation. From this information, we believe that the Paleozoic bedrock (R4) in our study area is overlain by approximately 60 m of the undifferentiated sands and clays (interbedded) of the McNairy-Clayton Formations (R3). The Paleocene Porters Creek Clay, as well as the Eocene silts and clays, appear to be missing in this area. Unconformably separating the McNairy and Clayton Formations from the Pleistocene loess at the surface are nearly 30 m of the predominantly sand and gravel typically associated with the Continental Deposits. This is consistent with stratigraphic investigations performed for the Department of Energy's (DOE) gaseous diffusion facility



▲ **Figure 3.** Local stratigraphy and interpreted correlation to the nearby geotechnical Borehole A (modified from Olive, 1980; Sykora and Davis, 1993). The plasticity indices (PI) are given as a range of moisture contents between the soil's plastic and liquid limits. NP defines a nonplastic soil (*i.e.*, sand or gravel).

approximately 1 km east of the study area (Clausen *et al.*, 1992) (Figure 2). Clausen *et al.* (1992) reported that most of the Tertiary sediment north of the DOE's southern boundary, in the vicinity of our seismic lines, has been removed by the ancestral Tennessee River. Therefore, the Continental Deposits unconformably overlie the McNairy-Clayton Formations. From the limited information available in the visual and laboratory soil classifications, it is very difficult to distinguish and separate horizons reliably within the Continental Deposits. However, an impedance boundary (R2) does manifest in our profiles at an elevation consistent with that separating a gravel and sand unit from overlying sandy clay and clay units in borehole A (Figures 3 and 4). The description of the former is consistent with the Mounds Gravel; this reflector may therefore represent the boundary between the Mounds Gravel and the Late Miocene–Early Pleistocene sand, silt, and clay unit that Nelson *et al.* (1999) named the Metropolis Formation. Supporting proprietary data suggest that borehole A penetrates a graben that would likely have protected this material from erosion. This environment is similar to that found by Nelson *et al.* (1999) for the unit. Without further information, however, this assessment remains speculative.

An impedance boundary (R1) was also interpreted on line UK-H2 at an average depth of 8 m. This horizon correlated well with the shear-wave impedance boundary and material index changes in borehole A. The relatively low-velocity material above this boundary represents the surface deposits and is composed predominantly of silt, similar to that described by Olive (1980) for the loess units; we therefore interpreted the boundary as separating the loess and Metropolis Formation. This interpretation is based on non-traditional, but credible, independent physical data sets (*i.e.*, sharp changes in the shear-wave velocities and measured geotechnical index properties of the two units). Although the Sykora and Davis (1993) geotechnical data included visual and laboratory grain-size analyses of the samples, we specifically considered their results showing an abrupt change in plasticity index (Blackall, 1952) for our interpretation. Because of a particle's physical and chemical properties, visual identification, as well as grain-size analyses (*i.e.*, hydrometer), can often be misleading in discerning silts and clays. Simply



▲ **Figure 4.** Optimum recording windows from (A) *P*-wave and (B) *SH*-wave walkaway tests at UK-H2.

stated, plasticity is a measure of relative change in soil consistency with water content. Clays are very plastic and silts only slightly plastic, whereas sands and gravels are nonplastic (see any elementary soil mechanics text for specific ranges; *e.g.*, Lambe and Whitman, 1969). Therefore, we took advantage of the objective notion that soil plasticity is a more demonstrative indicator of silt content (relative to a field geologist or engineer's visual classification) in our attempt to identify the loess in Sykora and Davis's (1993) geotechnical field and laboratory information. The sharp velocity contrast (*i.e.*, much lower shear-wave velocity of the overlying sediments) between the two units suggests lithologic change as well as a potential geologic age difference (Krinitzsky *et al.*, 1993; Kramer, 1996). Although our correlations are reasonable given the level of detail, more stratigraphic study of the near-surface loess material is required in order to differentiate the individual units (*i.e.*, Peoria, Roxana, and Loveland). This additional information will allow us to resolve neotectonic timing better.

DATA ACQUISITION AND PROCESSING

Traditionally, *P*-wave (compressional wave) seismic-reflection methods have been used to image the neotectonic deformation that propagates into the unconsolidated, water-saturated fill of the upper Mississippi embayment (Sexton and Jones, 1986; Schweig *et al.*, 1992; Williams *et al.*, 1995; Odum *et al.*, 1998; Stephenson *et al.*, 1999). Common-depth-point (CDP) reflection surveys using the horizontally polarized shear-wave (*SH*) mode (Woolery *et al.*, 1993, 1996; Harris, 1996; Harris *et al.*, 1998), however, have been found to be more amenable for imaging neotectonic features in near-surface sediment (< 100 m). We believe that shear waves are superior for near-surface imaging because they are "framework waves" (*i.e.*, not affected by the degree of water saturation) and therefore sample the geologic medium more accurately than the fluid-sensitive *P* wave. The choice of *SH* as the preferred phase is based on the idea that *SH* signals are easy to identify, unlike *SV* (vertically polarized shear wave) signals, because of the lack of mode conversion at the refracting and reflecting boundaries. The lower-velocity *S* mode also shifts the optimal acquisition window to the nearer offset and provides expansion of the spatial and temporal optimal window (Figure 4). The increased temporal window permits easier, more accurate identification of the reflecting boundaries as a result of the increased separation of the signal and coherent noise events. The broader spatial window at the near offset permits application of increased fold without introducing adverse wide-angle reflection effects. In addition, our experience shows that although *S* waves commonly have frequencies only one-half to one-third those of *P* waves, the *P* waves have velocities five to ten times higher than do *S* waves. Consequently, we estimate that resolution can be improved by a factor of 2 to 3 through the use of *S* waves. This point is very important when considering small fault displacements (*i.e.*, 2 to 3 m). For example, UK-H2 has a measured 50 Hz dominant frequency and a 150 to 500 m/s velocity range. This yields a temporal resolvable limit (*i.e.*, calculated by the one-quarter wavelength criteria of Sheriff and Geldart, 1989) ranging between 0.75 m in the very near surface to 2.2 m at the top of bedrock. The detectable limits are considerably smaller (*i.e.*, 1/10 λ to 1/20 λ). The spatial resolution of R1 to R4 is constrained between approximately two and four shotpoints based on the radius of the first Fresnel zone.

The reflection data from the two example sites, UK-B3 and UK-H2, were collected in *SH* mode with a 48-channel engineering seismograph. Both surveys were shot off-end with an active spread of forty-eight 30-Hz geophones oriented perpendicular to the seismic line. UK-B3 targeted the rock-sediment interface and was acquired at zero offset as defined by the optimal window. The group and shotpoint intervals were 4 m. The seismic energy was generated by five to ten horizontal impacts of a 4.5 kg hammer on a 12 kg modified H-pile section oriented perpendicular to the spread. To ensure the initial accurate identification of *SH* events, impacts were recorded on each side of the energy source for the walkaway tests; however, impacts were recorded on only one side during general production because of the good data quality. The group and shotpoint intervals for UK-H2 were decreased to 2 m in order to improve sampling of the very near surface (< 30 m). In an attempt to generate higher frequencies, the energy source used for UK-H2 was a smaller 1.8 kg engineer's hammer and 6 kg H-pile section. Nine impacts were applied at each shot location. Again, double-sided hammer impacts and acquisition polarity reversals were performed on the initial walkaway tests but not during general production. Seismograph acquisition variables for line UK-B3 included filter settings of 25 Hz (lowcut) and 250 Hz (highcut), and a 1-second record length. The sampling interval was 0.5 ms. Acquisition filters for UK-H2 were set at 25 Hz lowcut and 60 Hz notch; the highcut filter was out. The sampling interval was decreased to 0.25 ms and the record length remained 1 s.

All seismic data were processed on a personal computer using the commercial signal-processing software *VISTA* 7.0. The processing sequence applied to the shallow CDP reflection data is shown in Table 1. Coherent noise muting, digital filtering, trace editing, appropriate trace balancing, and careful correlation statics were the primary processes in improving the prestack quality of the events seen in the raw field file. This is an acceptable, routine processing sequence for most high-resolution, shallow (< 100 m) seismic-reflection work (Steeples and Miller, 1990; Baker, 1999). These standard near-surface data-processing procedures are similar to those used in the petroleum industry but are scaled down and conservatively applied. Other, nontraditional shallow-reflection processing methods such as f-k filtering, deconvolution, and migration were considered, but because some degree of resolution degradation occurs with the application of any processing step, significant improvement in the signal quality had to be demonstrated before such applications were justified. Improvement of the UK-H2 data quality from an f-k filter was found to warrant the application; however, the filter slopes were very gentle in order to minimize artifact generation and the "wormy" appearance of a more severe application. Deconvolution is also often considered a nontraditional procedure in shallow reflection work. The process has basic assumptions (*i.e.*, random reflectivity series, high signal-to-noise ratio data) that are often violated by the shallow data sets (Baker, 1999). Although the data (UK-H2 only) appeared to have a sufficient number of reflectors with a relatively high signal-to-noise ratio for constructing an operator, the resulting section had a "smeared" appearance that was judged to be detrimental to overall resolution. The deconvolution was therefore not applied to the final section. Another frequently abused shallow processing procedure is migration. The migration of data with shallow reflector depths and relatively low velocities, particularly in shear-wave exploration, often provides insignificant image improvement. One reason for this is that a shallow reflector's energy is already concentrated at the diffractor's apex, and migration simply doesn't make a significant difference (Black *et al.*, 1994). In addition,

TABLE 1
Processing Steps

1	Reformat
2	Spherical Divergence Gain
3	Elevation Statics
4	Bandpass Filter
5	Sort to CDP Gathers
6	Velocity Analysis
7	First-break and Surgical Muting
8	Normal Moveout Corrections
9	Surface Consistent Statics (10 ms max. shift)
10	CDP Stack
11	Automatic Gain Control
12	f-k Filtering

as noted by Black *et al.* (1994), the diffraction tails often have amplitudes lower than the background noise, and the migration procedure can cause an overall lowering of the data coherency. Migration was not applied to our lines because the procedure did not improve the image quality (*i.e.*, again producing a "smearing" effect) or change any interpretation; the degradation of resolution could not be justified. After preliminary processing, we also concluded that higher fold stacks were adversely affected by lateral discontinuities and wide-angle frequency distortions (including NMO stretch); consequently, a 12-trace window was selected for both lines (see optimum window in Figure 4) that produced six-fold stacked sections and maintained optimal data coherency.

DATA OBSERVATIONS

Profile UK-B3

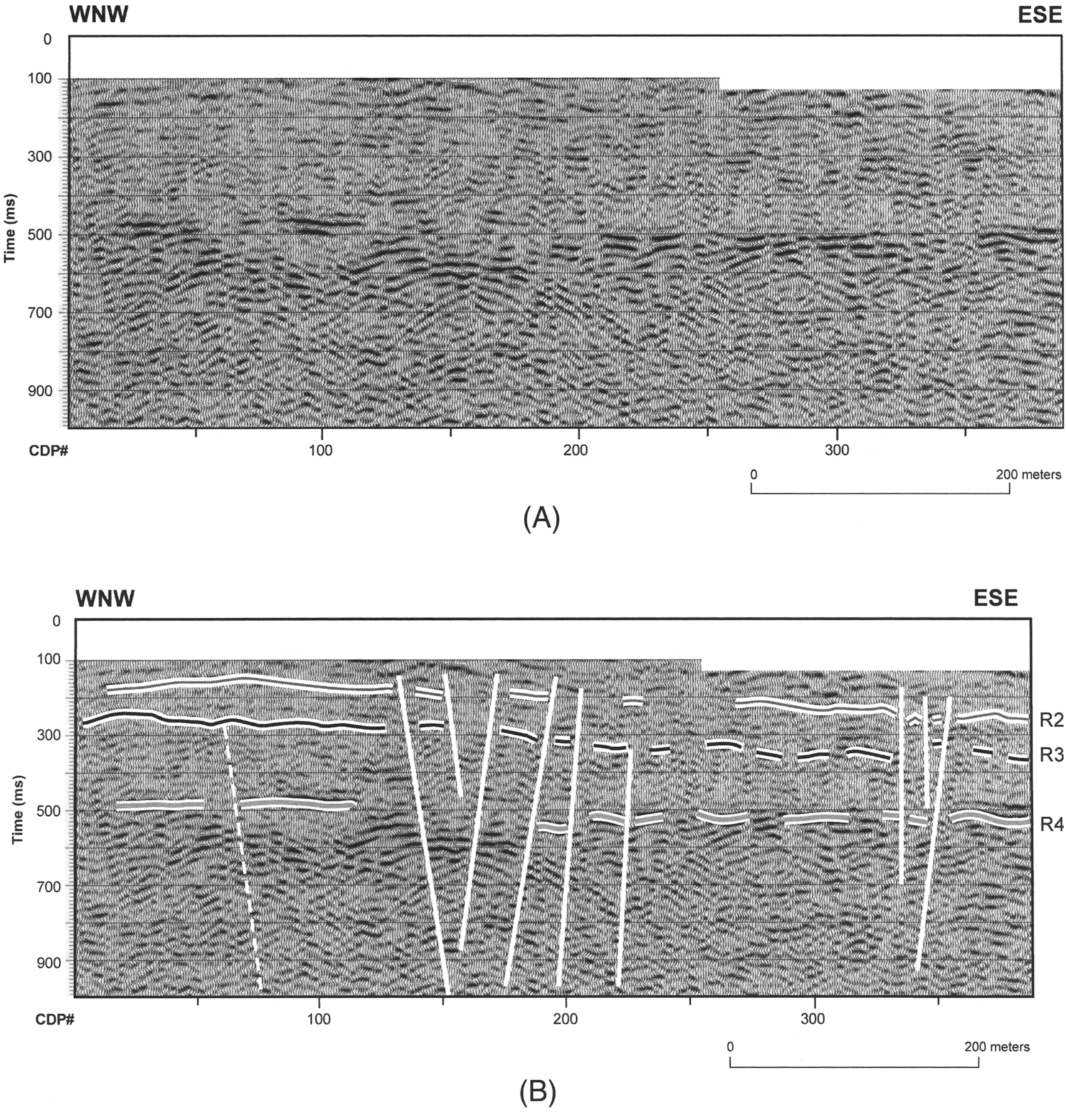
The 710-m-long west-northwest–east-southeast–oriented profile is a segment from a previously unpublished 4.6 km line collected for a nearby groundwater study (Figure 2) (Langston *et al.*, 1998). This nonproprietary section was acquired along a paved highway and was part of Langston *et al.*'s (1998) general area reconnaissance. The data quality is fair and is representative of the entire line. Three reflecting horizons (R2, R3, and R4) are identified in the section (Figure 5). The most prominent reflector is R4, interpreted as the top of the Paleozoic bedrock (Pz), at approximately 500 ms (Figure 6). Although reasonably coherent, the horizon appears highly disrupted along the profile length as evidenced by the numerous diffraction patterns. The R3 (~300 ms) and R2 (~200 ms) reflectors are interpreted as the top of the McNairy and Mounds Gravel Formations, respectively, but both appear weak and discontinuous throughout most of the profile. Geologic structure in near-surface seismic-reflection profiles is interpreted from noticeable vertical and horizontal reflection discontinuities, as well as from the diffracted wave patterns. These criteria indicate clear geologic structure (Figure 5) between CDP numbers 125 and 200. The interpreted fault zone, comprised of six fault strands, has an apparent throwdown to the southeast. The measured displacement across the R4 horizon is nearly 30 m. Most of the displacement occurs on the most northwestern south-dipping fault strand. This suggests a predominant normal slip for this fault; four of the six faults in the zone dip to the northwest, however, and most of the southeast-downthrow on the R3 reflector occurs across two of these northwest-trending strands. The deformation area also broadens in the nearer surface. These observations support an overall reverse motion across the fault zone in post-R3 (Cretaceous) time. Although it is evident that the disruptions have crossed the Pliocene-Pleistocene horizon (Mounds Gravel), the data are not sufficiently clear to estimate displacement magnitude reasonably. In addition, these data give no clear indication as to the presence, or magnitude, of a strike-slip component.

A second area of deformation is interpreted at CDP number 340. The relatively strong R4 reflector exhibits downthrow to the northwest; however, offset reversal is evident along the R3 and R2 horizons. The displacement is approximately one-half that measured between CDP numbers 125 and 200. Again, the data quality does not allow for a confident displacement estimate in the nearer surface. Other structures may be interpreted along the R4 horizon but are not discussed because it is unclear that they affect the entire time section.

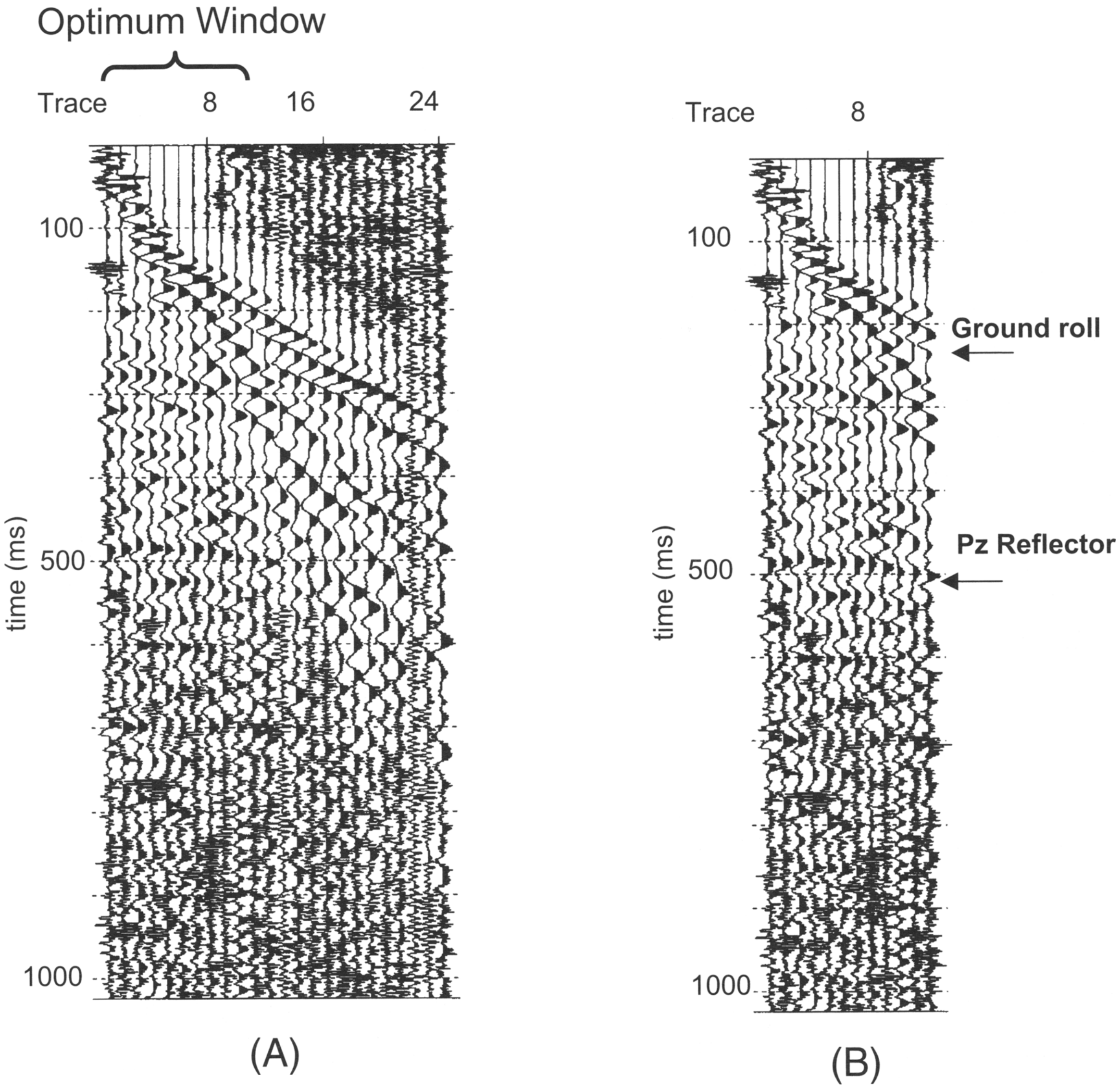
Profile UK-H2

The 400-m profile is part of a 1.2-km northeast-southwest-oriented line sited to intersect structure seen in proprietary lines to the northeast (Figure 2). A decreased sampling interval, tighter acquisition geometry, and a more compact energy source (higher-frequency energy generation) were adopted to enhance the images of the Quaternary horizons compared to previously acquired reconnaissance lines. The profile was collected along a paved highway, and special attention was given to the source-to-ground energy coupling. The resulting data quality is considered excellent for this area (Figure 7). Four reflection horizons (R1, R2, R3, and R4) that closely correlate to the material changes identified in the Borehole A data are shown in the section. The most prominent reflector (R4) was interpreted as the top of the Pz bedrock at approximately 500 ms; the horizon is continuous and coherent throughout most of the section. In addition, the R3, R2, and R1 horizons are observable at approximately 300 ms, 200 ms, and 75 ms, respectively. These shallow reflection horizons were interpreted as the top of the McNairy-Clayton, the top of the Mounds Gravel, and the base of the loess deposits (top of Metropolis Formation), respectively. All horizons are relatively strong and coherent throughout most of the profile. Two faulted areas are interpreted between CDP numbers 100 and 200 (Figure 7B). The more prominent is centered near CDP number 175 and has a relative throw along the R4 (Pz) reflector down to the southwest. The total measured displacement across this horizon is nearly 35 m. Moreover, the discontinuity appears to propagate through the entire time section. Measured offsets of 18 m and 4 m affect the Cretaceous-aged R3 (K) and Pleistocene R1 (QPt) horizons, respectively. The predominant character is normal slip displacement across the Pz reflector. However, slight offset reversals in the apparent throw along the R3 horizon and above emphasize the episodic nature of these features. An oblique intersection angle of the seismic line and the fault planes may obscure the actual displacement and exaggerate the width of the overall structure. The presence of a broad flexure and lack of sharp displacement is also consistent with a later southwest-up displacement, exactly reversing an initial southwest-down displacement.

In addition to the structural relief, a seismically opaque, or "washed out", zone appearing between CDP numbers 300 and 360 is also indicative of intense deformation. This anomalous zone, bounded by relatively strong, coherent reflectors, appears across the entire time section. Although the bounding reflections do not exhibit a definitive displacement, the presence of diffractions and the broken, uneven character of



▲ **Figure 5.** (A) Uninterpreted and (B) interpreted stacked *SH*-wave reflection profiles from UK-B3.



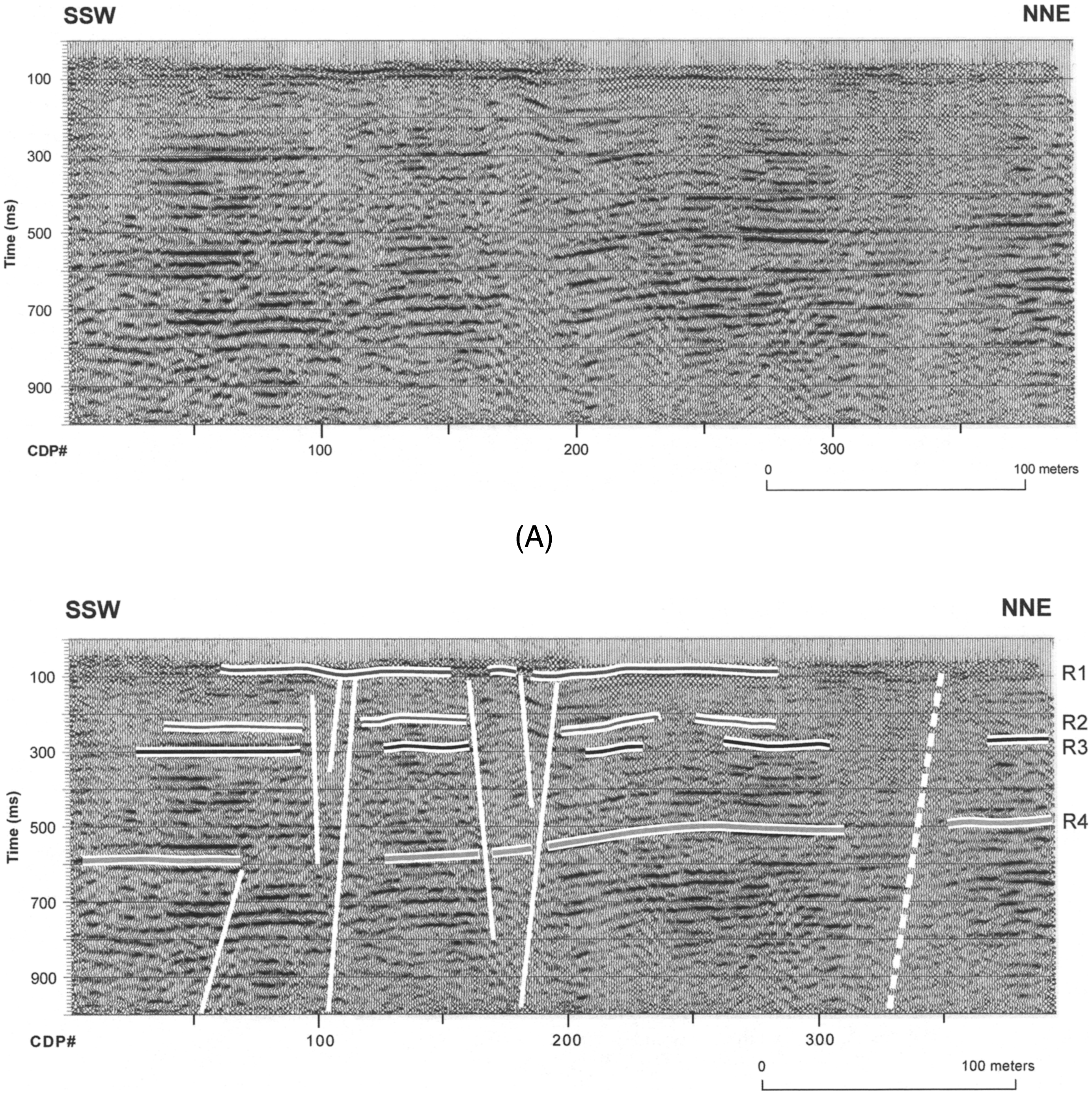
▲ **Figure 6.** Raw field file from the southeastern end of UK-B3. Note the relatively strong reflection event at approximately 500 ms.

the weak R1 horizon suggest structural deformation. Again, the presence of a strike-slip component is indeterminate.

DISCUSSION AND SUMMARY

Complex geologic structures associated with the Fluorspar Area fault complex have been well known for several years; however, Nelson *et al.* (1997, 1999) have only recently documented episodic tectonic movement along fault complex structures through surface mapping investigations at the northern end of the Mississippi embayment in southern Illinois. They reported long, narrow, relatively steep grabens bounded by both normal and reverse faults that suggest pull-apart structures produced by strike-slip faults. Nelson *et al.* (1999) found evidence of widespread neotectonic displacements that extend into the Miocene and early Pleistocene sediment. Their mapping also indicates that faults typically strike N20°E to N40°E and outline narrow grabens.

Large, complex signal anomalies are seen in the marine "sparker" reflection surveys acquired for the U.S. Army Corps of Engineer's construction projects along the lower Ohio River. These anomalies are believed to be low-resolution images of the extension of the fault complex beneath the embayment sediment cover of western Kentucky (Figure 2) (Alpine Geophysical Associates, Inc., 1966). We used these data and strikes interpreted by Nelson *et al.* (1997, 1999) to site the shallow *SH*-wave seismic-reflection surveys. The structures imaged by these lines are near the northwestern boundary of the Raum Fault zone that was described by Nelson *et al.* (1999). They placed the Raum Fault zone 2 to 3 km southeast of and parallel to the Lusk Creek Fault zone (Figure 2). The Raum Fault zone widens to nearly 2 km in their southern study area (southern Illinois) and exhibits a change



(A)

(B)

▲ **Figure 7.** (A) Uninterpreted and (B) interpreted stacked *SH*-wave reflection profiles from UK-H2.

in the net throwdown to the southeast. They also reported at least two episodes of post-Pennsylvanian, pre-Cretaceous movement: reverse faulting that raised the northwest block, followed by normal faulting that lowered the northwest block, although strike-slip motion also may have occurred. These investigations found no Holocene movement, however. Not surprisingly, the "sparker" data are inadequate to resolve detail at this level. Based on the anomalies and the local and regional strike, additional structure associated with the Raum Fault zone may lie a short distance (1 to 2 km) to the west of our *S*-wave profiles. Nonetheless, episodic movement can also be seen in the Raum Fault zone's ancillary structure imaged in this investigation. Differential offset, throw reversal in the post-Cretaceous horizons, and a slight local thickening of the R4-R3 and R2-R1 sections in the vicinity of the faults (*i.e.*, UK-H2) provide evidence. The data also show that neotectonic movement has affected the Quaternary section to at least the base of the loess deposits.

Whether the displacement is placed at the base or within the loess deposit depends on the correlation accuracy of the assigned near-surface stratigraphy.

Both profiles lack a strong, coherent, and continuous reflection from the ideally sharp bedrock/soil impedance boundary; we believe this indicates an intensely weathered/faulted Paleozoic bedrock surface. Difficult drilling conditions encountered at the sediment-bedrock boundary (Clausen *et al.*, 1992, study) are corroborative evidence. However, the most important fact is that some of the geologic structures identified along this horizon clearly propagate higher into the nonlithified sediment overburden, and if our interpretation is correct, then faulting is present across the Metropolis Formation (*i.e.*, Illinoian) to the base of the loess (Illinoian–Wisconsinan?). This neotectonic activity will have implications for the seismic design loads of critical or high-hazard structures in the area.

Although these *SH*-wave profiles represent the first high-resolution images of Quaternary Fluorspar Area fault complex reactivation in the Mississippi embayment sediment of western Kentucky, the data are too limited to provide a definitive understanding of the fault kinematics or their potential relationship to Wheeler's (1997) projected New Madrid seismicity. The extent of faults and their potential relationship to through-going Reelfoot rift structure is critical for delineating the inferred boundary separating the seismically active Reelfoot rift from the relatively sparse seismicity in the area of the Rough Creek graben and Fluorspar Area fault complex in southern Illinois. Therefore, acquisition of additional shallow seismic-reflection and ground-penetrating-radar profiles is planned for the coming year. ◼

ACKNOWLEDGMENTS

This research was supported by the U.S. Geological Survey, Department of the Interior, under award number 01HQGR0044. Additional support came from the Kentucky Geological Survey (KGS). We thank Don Steeples, John McBride, and Robert Bodziak for their helpful comments. Additional editorial comments provided by Rus Wheeler, Tiku Ravat, and Meg Smath improved the clarity and quality of this paper. Graphical assistance provided by Collie Rulo (KGS) was greatly appreciated. We also thank Mr. A. B. Puckett for granting us access to his property. The views and conclusions contained in this document are those of the authors and do not necessarily represent those of the U.S. government or Commonwealth of Kentucky.

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