Shallow Deformation Along the Crittenden County Fault Zone Near the Southeastern Margin of the Reelfoot Rift, Northeastern Arkansas

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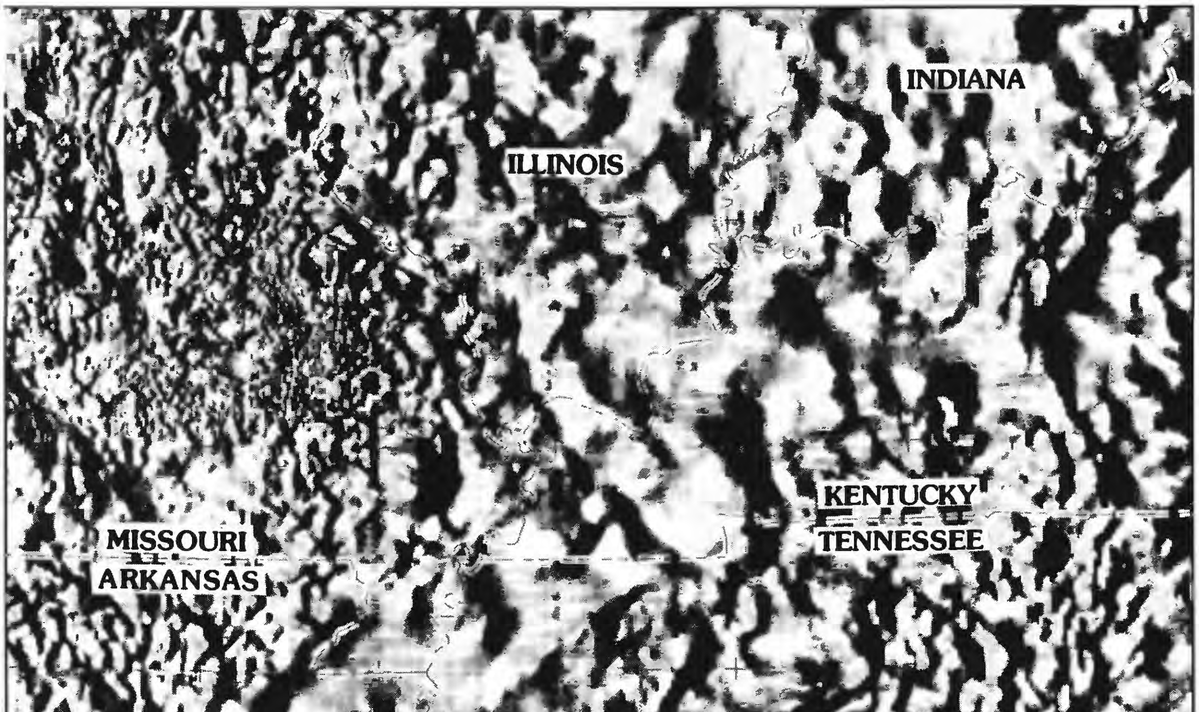

Cover. Gray, shaded-relief map of magnetic anomaly data. Map area includes parts of Missouri, Illinois, Indiana, Kentucky, Tennessee, and Arkansas. Illumination is from the west. Figure is from *Geophysical setting of the Reelfoot rift and relations between rift structures and the New Madrid seismic zone*, by Thomas G. Hildenbrand and John D. Hendricks (chapter E in this series).

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By Eugene A. Luzietti, Lisa R. Kanter, Eugene S. Schweig III,
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INVESTIGATIONS OF THE NEW MADRID SEISMIC ZONE
Edited by Kaye M. Shedlock *and* Arch C. Johnston

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Shallow Deformation Along the Crittenden County Fault Zone Near the Southeastern Margin of the Reelfoot Rift, Northeastern Arkansas

By Eugene A. Luzietti,[1] Lisa R. Kanter,[2] Eugene S. Schweig III,[3] Kaye M. Shedlock,[4] *and* Roy B. VanArsdale[5]

ABSTRACT

The Crittenden County fault zone (CCFZ) is located near the southeastern boundary of the northeast-trending Reelfoot rift, which formed by Late Proterozoic and Cambrian extension. The southeastern boundary of the rift has been characterized as an 8-km-wide zone of down-to-the-northwest displacement. The CCFZ, however, shows significant down-to-the-southeast reverse faulting of Paleozoic and Cretaceous rocks and flexure and thinning within the Tertiary sedimentary section. This fault zone is located only 30 km from Memphis, Tenn., a metropolitan center of more than 800,000 people. To improve understanding of the location, attitude, and sense of displacement across the CCFZ, we have acquired 16.3 km of high-resolution shallow-reflection data in Crittenden County, Arkansas.

Nine Mini-Sosie (MS) profiles, varying in length from 1 to 2 km, were collected across the projected surface locations of the CCFZ and the Reelfoot rift boundary. One second of two-way traveltime data was recorded, which corresponds to approximately 1.2 km of the crust. Sedimentary layers between 50 and 800 m deep are well imaged; deeper strata are evident but not well imaged.

Well data at one site on the CCFZ indicate approximately 63 and 82 m of vertical displacement of Cretaceous and Paleozoic rocks, respectively. Proprietary seismic reflection data show reverse displacement of these rock units, indicating compressional tectonics. From the Mini-Sosie profiles, we estimate structural relief across the CCFZ at the Fort Pillow Sand (Paleocene) level to range between 70 and 14 m. The overlying middle to late Eocene section shows a similar or slightly smaller amount of thinning, indicating that much of the movement on the CCFZ dates from this time. The amount of displacement, flexure, and thinning in the geologic section increases as the CCFZ converges with the Reelfoot rift boundary in the southwestern part of the area studied. Surface expression of the CCFZ has not been identified. The reflection from the Quaternary-Eocene unconformity, however, shows warping, dip, or interruptions in places over the CCFZ, suggesting that the CCFZ may have some very young movement as well.

INTRODUCTION

The New Madrid seismic zone (NMSZ), a branched concentration of earthquake epicenters in southeastern Missouri, northeastern Tennessee, and northeastern Arkansas, is the most seismically active area east of the Rocky Mountains; thus, the region around the NMSZ is the subject of ongoing research studies sponsored by the U.S. Geological Survey under the National Earthquake Hazards Reduction Program. Although a large percentage of the present-day NMSZ seismicity is microearthquake activity, possibly the largest known stable continental earthquakes in the world (M_W>8.0) occurred here during the winter of 1811–12 (Johnston and Kanter, 1990). A recurrence of these earthquakes would likely result in loss of life and billions of dollars in structural damage to homes and buildings in the area.

Seismic reflection data have been important in improving our understanding of the subsurface geologic structures and their relationships to current seismic activity in this region. Vibroseis seismic reflection data have revealed a major zone of disturbed reflectors, the Blytheville arch, which correlates with the northeast trend of NMSZ

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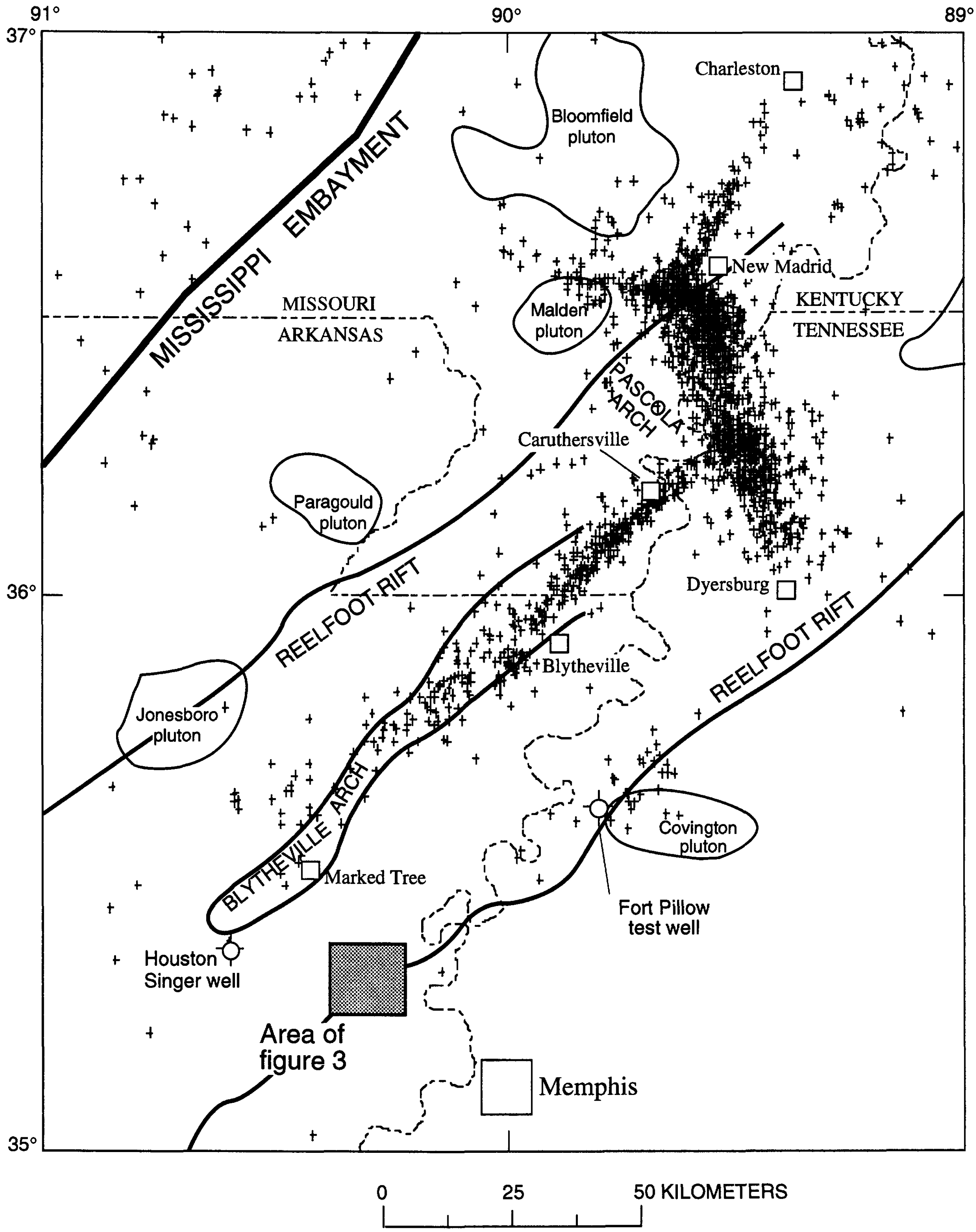

Figure 1. Index map showing the location of the Crittenden County seismic reflection surveys (shaded box) in relation to the margins of the Reelfoot rift and plutons (Hildenbrand, 1985), the Blytheville arch (Hamilton and McKeown, 1988), the Pascola arch (Grohskopf, 1955), and epicenters of microearthquakes (crosses) (Taylor and others, 1991) in the upper Mississippi Embayment. Notice epicenters along the southeastern side of the rift boundary just north of the Covington pluton. The Fort Pillow test and No. 1 Houston Singer wells are also shown.

Table 1. Location and names of selected drill-hole data identified in figure 3.

[Subsurface information from Dart (1990). Depth to top of Paleozoic in meters. Well ID is number keyed to locations shown on figure 3]

Well ID	Well name	Well location	Depth to top of Paleozoic
AR18	M.E. Davis No. 1 DeMange	SW¼SW¼NE¼ sec. 22, T. 8 N., R. 7 E.	902.21
AR19	J.K. Dobbs No. 1 Rowena D. Bond	NE¼SE¼SE¼ sec. 22, T. 8 N., R. 8 E.	932.26
AR20	H.L. Hawkins R.G. O'Neal	SW¼SW¼NE¼ sec. 22, T. 8 N., R. 7 E.	897.94
AR21	J.E. Stark, Jr. R.G. O'Neal No. 1-X	SW¼SE¼NE¼ sec. 22, T. 8 N., R. 7 E.	975.97
AR22	R.A. Johnson No. 1 L. Alpe	NW¼NW¼NW¼ sec. 23, T. 8 N., R. 7 E.	974.75
AR24	J. Painter, Jr. No. 1 P.M. Patterson	NW¼NW¼NW¼ sec. 35, T. 9 N., R. 7 E.	929.95
AR57	General Crude Oil No. 1 L. Carruth Est.	N½NW¼, sec. 5, T. 7 N., R. 8 E.	951.89
AR59	Wilson and Rankin No. 1 J.M. Leach	NE¼SE¼NE¼, sec. 5, T. 7 N., R. 7 E.	984.50

seismicity that extends from Marked Tree, Ark., to Caruthersville, Mo. (fig. 1) (Crone and others, 1985; Hamilton and McKeown, 1988; McKeown and others, 1990). Reflection data have also helped define subsurface structures (for example, the Cottonwood Grove fault) in the vicinity of the central NMSZ branch, which extends from Dyersburg, Tenn., to New Madrid, Mo. (Hamilton and Zoback, 1982; Crone and Brockman, 1982; Sexton and others, 1982). However, evidence of faulting is difficult to identify at the near-surface because of the intense geomorphic activity in the Mississippi River valley and the thick blanket of alluvium that covers this region.

During the past several years, seismic reflection profiles in this region have identified major faults that displace Paleozoic and Cretaceous rocks, but lack of resolution of Tertiary and younger strata has made it difficult to determine whether these faults continue into the Tertiary and Quaternary section. Several high-resolution shallow-reflection surveys undertaken in the NMSZ vicinity (Shedlock and Harding, 1982; Sexton and Jones, 1988; Luzietti and Harding, 1991) have been successful in identifying deformation and displacements in the Tertiary-age reflectors. However, little seismic reflection data is available that specifically targets the resolution or identification of near-surface faults that could generate destructive earthquakes or that identifies areas where trenching may yield recurrence rates of earthquakes.

The CCFZ lies off the NMSZ, close to the southeastern boundary of the Reelfoot rift. This boundary of the rift has been the locus of sparse seismicity (fig. 1) and is characterized by a zone about 8 km wide across which the cumulative vertical displacement is about 2 km at the level of the Precambrian-Cambrian basal clastic sequence (McKeown and others, 1990). Hildenbrand and others (1982) deduce a similar value for magnetic basement displacement along this boundary. Even though very little seismicity has been recorded in this area, these vertical displacements indicate a potential for earthquakes along the southeastern margin of the rift if recurrent movement should occur along these basement-controlled fault zones.

A detailed interpretation of two proprietary reflection lines shows a reverse fault in profiles A and B (fig. 2)—these reflection lines are located about 5 and 2.5 km, respectively, northwest of the southeast edge of the rift boundary. This fault can be projected southwest to connect with a fault, first identified by Caplan (1954), in the Paleozoic section between wells AR18 and AR21 (table 1). The faulting is best demonstrated by a cross section between wells AR20 and AR21 (table 1; figs. 3 and 4), which indicates that the Cretaceous and Tertiary sections are also involved in the deformation.

These observations indicate that there is a zone of deformation at least as young as Tertiary trending northeasterly near the rift boundary in Crittenden County, Arkansas. The fault interpreted on the cross section between wells AR20 and AR21, as well as the reverse faulting seen in the proprietary reflection data, will be referred to as the CCFZ.

In this paper, we use high-resolution shallow-reflection data to examine the extent, displacement, age, and deformation style of the CCFZ, particularly in the Cenozoic section. An understanding of the regional tectonic history and the identification of near-surface deformation is important in the determination of earthquake potential along the rift boundary, particularly in view of its close proximity to Memphis, Tenn.

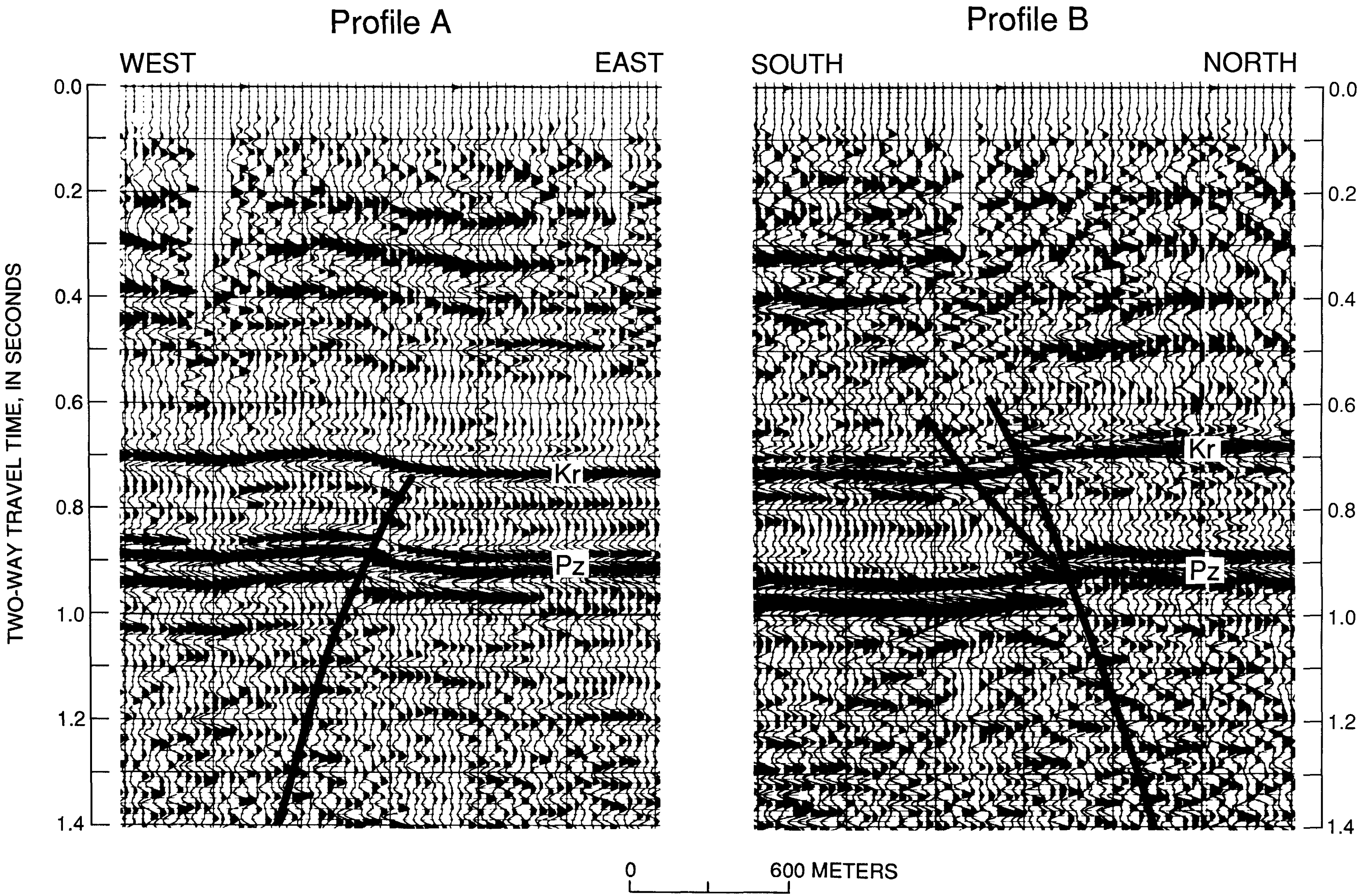

Figure 2. Coherency-filtered proprietary seismic reflection profiles showing reverse faulting. A minor, reverse, splay fault in the Cretaceous reflector is also apparent. Profile A is in the vicinity of Turrell, Ark.; profile B is in proximity to Mini-Sosie line GL-4—see figure 3. Using an average interval velocity (calculated from both profiles) of 2,335 m/s, we calculate 41 and 59 m of displacement or flexure in the Cretaceous (Kr) reflector and 45 and 74 m of displacement in the Paleozoic (Pz) reflector on profiles A and B, respectively.

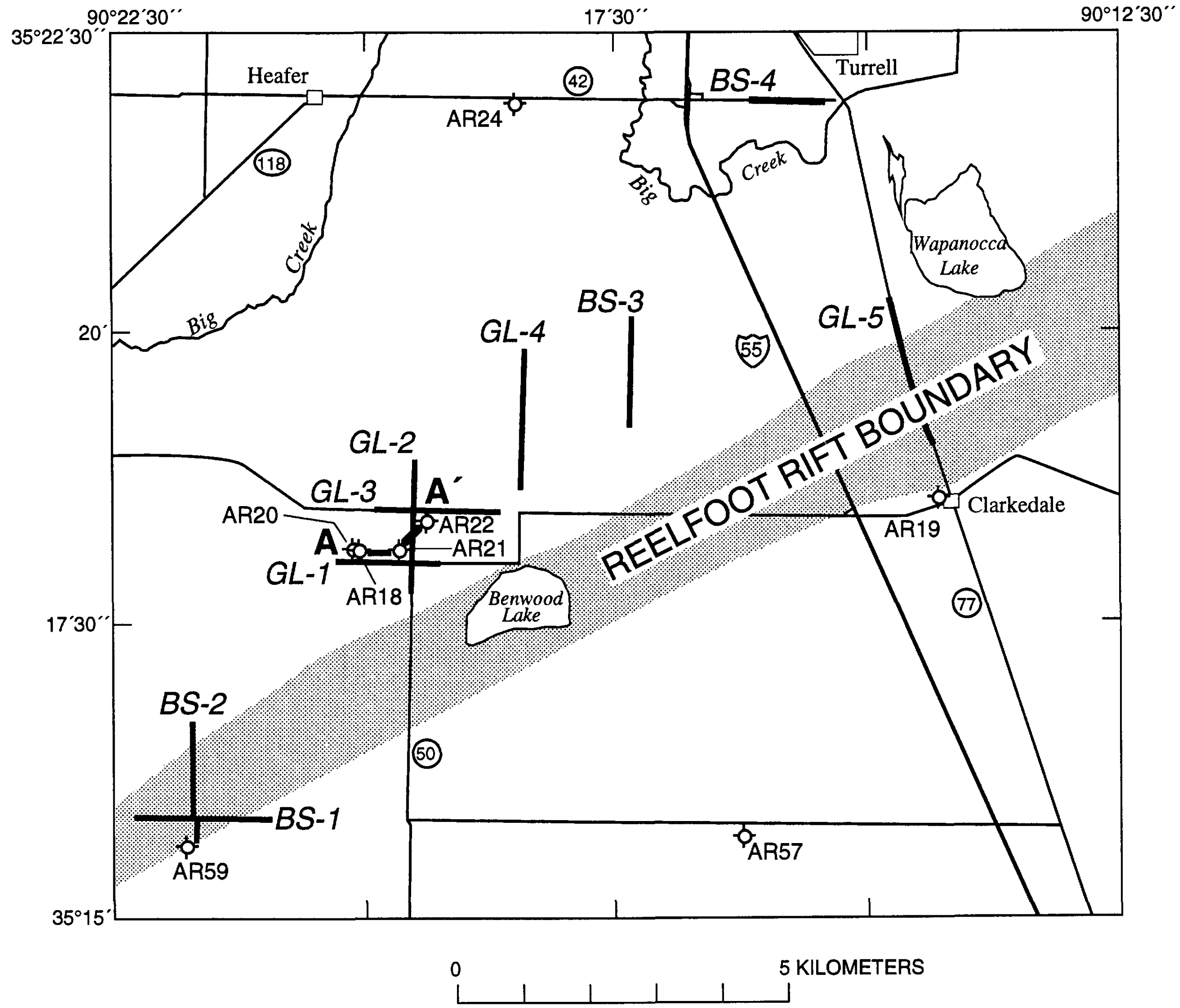

Figure 3. Index map showing locations of wells listed in table 1 and the nine seismic reflection lines (bold lines). Cross section A–A′ is shown in figure 4. Locations of Mini-Sosie reflection lines (except GL-5) represent the surface approximation of the Crittenden County fault zone (CCFZ). Rift boundary (shaded) is interpreted from proprietary reflection data and coincides with the general location defined by aeromagnetic data.

GEOLOGIC SETTING

The NMSZ lies within the upper Mississippi Embayment, a broad south-southwest-plunging syncline that formed during the Cretaceous. The embayment overlies the Reelfoot rift, a southwest-trending graben about 65 km wide and 320 km long (Hildenbrand, 1985). The Reelfoot rift formed in late Precambrian and Cambrian time and is filled with Precambrian and Cambrian clastics and Ordovician carbonates (Howe and Thompson, 1984). A major unconformity separates the Paleozoic rocks from the overlying Cretaceous and Tertiary sediments of the Mississippi Embayment. The Cretaceous and Tertiary strata are characterized by shallow-marine and fluvial, clastic sediments. The Fort Pillow test well (Moore and Brown, 1969), located 50 km northeast of our study area, penetrated the entire Mesozoic and Cenozoic section. Figure 5 shows a generalized stratigraphic column from this well using the ages of Frederiksen and others (1982).

In the Fort Pillow test well, the Cretaceous section consists of alternating sands and clays with minor silt. The sands range from consolidated and cemented to friable to loose. The overlying lower Paleocene section begins with a thick, homogeneous clay unit that includes the Clayton Formation and the Porters Creek Clay. Capping the lower Paleocene sediments is a sandy, micaceous silty clay known as the Old Breastworks Formation. The exact boundary between the lower Paleocene Old Breastworks Formation of the Midway Group and the upper Paleocene Fort Pillow Sand of the Wilcox Group is ambiguous (fig. 5). The Wilcox Group is subdivided into the Fort Pillow Sand and the Flour Island Formation, which consists of silt and clay with minor sand. The Paleocene-Eocene boundary is believed to fall within

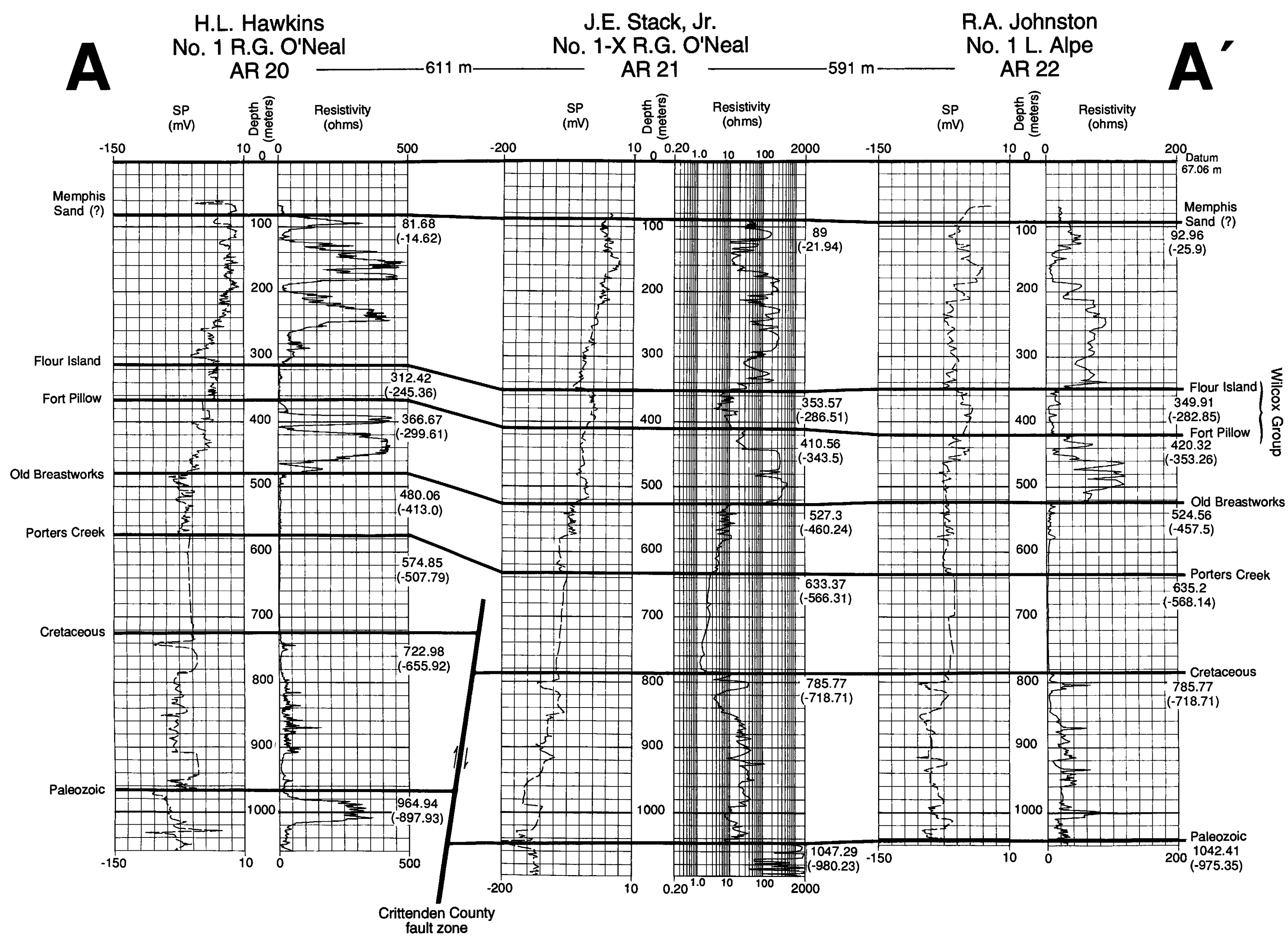

Figure 4. Cross section A–A′ (location shown on fig. 3) shows the Crittenden County fault zone as having 63 and 82 m of relief at the top of the Cretaceous and Paleozoic, respectively. Structure in the Tertiary is evident. This figure shows about 34 m of westward thinning in the Memphis Sand.

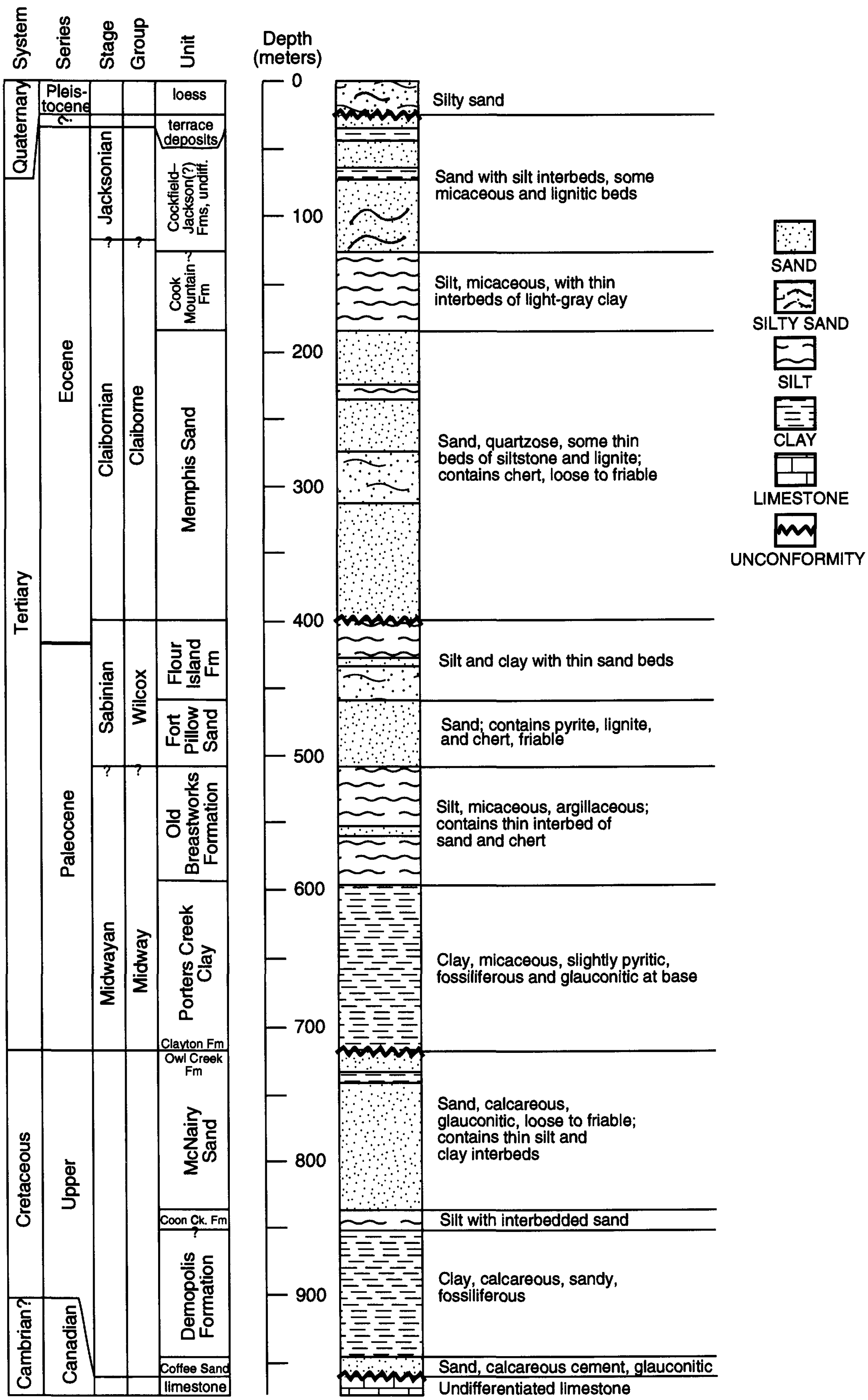

Figure 5. A modified stratigraphic column taken from the Fort Pillow test well, Lauderdale County, Tennessee. Ages adjusted according to Frederiksen and others (1982). Upper boundary of the Clayton and lower boundary of Owl Creek are uncertain. The Cockfield is the upper formation of the Claiborne.

the Flour Island Formation. The Claiborne Group, which overlies the Wilcox, is entirely of Eocene age and is represented by the thick Memphis Sand and silt and clay of the Cook Mountain Formation. The Cockfield Formation lies at the base of a series of interbedded sands and silts that are not subdivided in this well. The upper part of this series may belong to the Jackson Formation. The Tertiary sediments are much less consolidated than the Cretaceous section. An unconformity separates the Tertiary sediments from the Pliocene-Pleistocene terrace deposits, which is referred to here as the Quaternary section, and Pleistocene loess, which is not present in our study area. We used the spontaneous potential and resistivity logs from this well to identify the stratigraphy on additional logs obtained for our study area.

DATA ACQUISITION AND PROCESSING

Four east-west seismic reflection profiles and four north-south profiles were run across the surface projection of the CCFZ, and profile GL-5 was collected east of the CCFZ over the Reelfoot rift boundary defined by McKeown and others (1990) and Hildenbrand (1985) (this boundary does not coincide with the surface projection of the CCFZ; see fig. 3). These data were collected on paved and dirt roads—this provided compact soil conditions and ease of acquisition.

The Mini-Sosie acquisition method is a versatile, portable, high-resolution shallow-reflection technique that uses earth compactors as a source of random pulse energy. An earth compactor is a gasoline-driven machine operated by one person. At the foot of each compactor is a source sensor that identifies a time break for each impact and transmits it to the recording truck by radio where 1,000 samples of signal received by a geophone array are stored (time-record of the pulse onset). Time-records of seismic information overlap from all depths, but the final seismic record is produced in the field by a cross-correlation of previously stored time-records and succeeding incoming signals (Wiles, 1979). The cross-correlation increases the signal-to-noise ratio of alike reflected energy and attenuates random noise. In this survey, three compactors advance parallel and (or) perpendicular to the profile line. A total of 2,000 random pulses from three simultaneously operating compactors is received and cross-correlated for each shotpoint. Table 2 lists acquisition parameters in detail.

A great deal of testing and experimentation went into the reflection-survey-parameter design. The most critical aspect in acquiring good data was operating the compactors at a random and slow speed. When the operators exceed 24 impulses per second, the recording system does not accept the radio-transmitted time breaks, and thus, the data cannot be cross-correlated with the incoming signal being measured by the geophones. Proper operation prevents the reflected signal from being contaminated by an oversaturated correlator in the recording truck.

Table 2. Data-acquisition parameters.

Parameter	Description
Source type:	Three earth compactors
Source array:	5-m spacing, parallel/perpendicular to profile line
Source duration:	2,000 impulses per shotpoint
Source point interval:	15.24 m (50 ft)
Geophone array:	12 geophones in a cluster
Geophone spacing:	15.24 m (50 ft)
Line array:	24 channels, on line, 0–30.48 m–381 m
Field filters:	40–180 Hz, 24 dB/octave
Recording system:	I/O DHR 2400
Sampling rate:	1 millisecond
Trace length:	1 second

The high water table and compact near-surface clays and sands provided ideal conditions for allowing energy to be transmitted into the ground without attenuating the relatively weak random signal. The subsurface geology is favorable, with a fairly uniform lateral velocity field and significant velocity and density contrasts at depth that reflect seismic energy back to the surface. The group interval and source to near-trace offset for these profiles were systematically designed to image reflectors between 50 and 800 m, targeting the Cretaceous unconformity as the deepest geologic objective. The top of the Paleozoic carbonate rocks, some 200–250 m below the top of the Cretaceous, was also imaged but was purposely truncated in the display because of migration end effects. The interval velocities in the upper 1 km of the subsurface range between 1,100 and 2,800 m/s. In this data set, we were able to obtain a signal with a frequency range between 60 and 110 Hz. Using the "quarter wavelength rule" for vertical resolution (Yilmaz, 1987), features as thin as 5 m are resolvable.

The field data were processed with a standard sequence of processing steps at the U.S. Geological Survey facilities in Denver, Colo. Processing steps include: (1) tape reformat, (2) trace edit, (3) geometry definition, (4) 12-fold common midpoint (CMP) sort, (5) automatic gain control (AGC) with a 250-ms gate, (6) prestack spectral whitening, (7) two passes of normal moveout (NMO) velocity analyses every 50 CMP, (8) residual surface-consistent statics, (9) mute and stack, (10) post-stack, second zero-crossing deconvolution, (11) post-stack finite-difference migration using 100 percent of the NMO velocities, and (12) bandpass filtering (25–35–140–160). The datum for these seismic profiles is 67.0 m above sea level, which corresponds to the surface elevation in this area. The resulting record sections consist of 1-s two-way traveltime, corresponding to the upper 1.2 km of the crust. All the profiles presented in this paper are migrated and are approximately 1:1 in scale.

INTERPRETATION

The nine reflection profiles show a great deal of lateral continuity and similarity in reflector character and structure. We were able to resolve coherent reflectors from about 0.090 to 0.825 s (depths from about 50 to 800 m). Using the lithologic data and logs from the Fort Pillow test well as a guide, we obtained spontaneous potential (SP) and resistivity logs from wells in the area (table 1) and used them to identify geologic formations. None of these wells has a sonic log available to provide direct identification of the seismic reflectors and formations. The closest available sonic log, from the Houston Oil and Minerals No. 1 Singer well, 38 km west of our study area (fig. 1), showed excellent correlation between velocity contrasts and geologic formation breaks on the SP and resistivity logs in the study area. We thus identify the following reflectors on our profiles:

- Q/E_O: Approximate location of the Quaternary-Eocene unconformity.
- E_Of: Top of the Eocene and Paleocene Flour Island Formation. Reflectors identified as E_Of represent the top of the Wilcox Group, which corresponds to Eocene.
- P_Af: Top of the Paleocene Fort Pillow Sand.
- P_Ap: Top of the Paleocene Porters Creek Clay.
- Kr: Top of undifferentiated Cretaceous rocks.

Proprietary reflection profiles with deeper resolution indicate the Crittenden County fault has reverse displacement in the Cretaceous and Paleozoic section (fig. 2). This information was helpful in providing the foundation of our interpretations of the Mini-Sosie data. Down-to-the-southeast displacement of the Cretaceous (Kr) reflector is interpreted as a zone of reverse faulting and is visible on all our profiles (figs. 6, 7, 9, 10, 11, 12, 13, and 14) except GL-5 (fig. 15). On GL-2, GL-3, and GL-4, the reverse faulting appears to involve the Porters Creek Clay (P_Ap). Higher in the Tertiary section, in the Wilcox Group (E_Of and P_Af), this deformation is expressed primarily as a large down-to-the-southeast flexure accompanied by minor faulting. The strata involved appear to maintain fairly constant thicknesses. Although several of these minor faults directly overlie the reverse faults in the Cretaceous section, it is not clear that they are continuous or connected with the deeper reverse fault. In fact, some of the minor faults in the Wilcox Group have a sense of displacement opposite to that of the reverse faults in the Cretaceous reflectors, for example, GL-1 and GL-3.

The sedimentary section on the northwest side of the CCFZ is significantly thinner than that to the southeast of the CCFZ. The majority of this thinning occurs within the Claiborne Group (Memphis Sand and overlying units), indicating that relief existed on the CCFZ during this period of time. In contrast, no substantial thinning is seen between the Cretaceous and the Porters Creek reflector or between the Porters Creek and the Flour Island reflectors.

Each seismic reflection profile is accompanied by a line drawing that delineates the prominent reflectors and marks the approximate location of geologic formations. At the right of each seismic profile, the depth is estimated every 0.1 s. Depths across the time section may vary slightly. The accuracy of the depths below 0.7 s diminishes because the poor signal-to-noise ratio provides no accurate velocity control, although we still attempted to quantify the amount of displacement in the Cretaceous reflector if the record quality was adequate. Quantitative values for structural relief and thinning are based on interval velocities calculated between the Quaternary-Eocene reflector and the specific geologic interval being measured. The seismic reflection profiles all run south to north, or west to east, oblique to the CCFZ. Seismic reflection profile GL-5, located across the rift boundary, is described last.

BS-1 AND BS-2

Shotpoint 155 of BS-1 (figs. 3 and 6) ties with shotpoint 323 of BS-2 (figs. 3 and 7). The Wilson and Rankin No. 1 J.M. Leach well (AR59; fig. 8, table 1) can be projected 150 m along strike to the southern end of BS-2, allowing us to identify reflectors on these profiles with some confidence even though velocity or density information is not available. The top of the Cretaceous reflector is faintly imaged on both of these lines between 0.750 and 0.850 s. The poor velocity control below 0.7 s makes it difficult to quantify a displacement across the CCFZ.

BS-1 is of particular interest because it shows the maximum amount of structural relief seen in the study area, and this is accomplished without major faulting in the Tertiary section. The reflectors associated with the Wilcox Group show a monoclinal flexure, with the apex of curvature approximately located over the area we interpret as the location of the CCFZ. Within the Wilcox section, we calculate approximately 70 m of structural relief on the top of the reflector identified as the Fort Pillow Sand, assuming the interval velocity is about 2,000 m/s in both BS-1 and BS-2.

BS-1 clearly shows that most of the thinning in the geologic section occurs in the interval representing the Claiborne Group (between the reflectors labeled E_Of and Q/E_O). This can be illustrated by the onlapping and truncation of high-amplitude reflectors between 0.10 and 0.225 s. The presence of onlapping reflectors suggests that the eastern side of BS-1 was subsiding relative to the western edge during Claiborne deposition, as opposed to having differential uplift and subsequent planar erosion after Claiborne deposition. We have calculated approximately 60–70 m of thinning between the top of the Flour Island and the Quaternary-Eocene unconformity boundary, assuming the interval velocity is approximately 1,960 m/s.

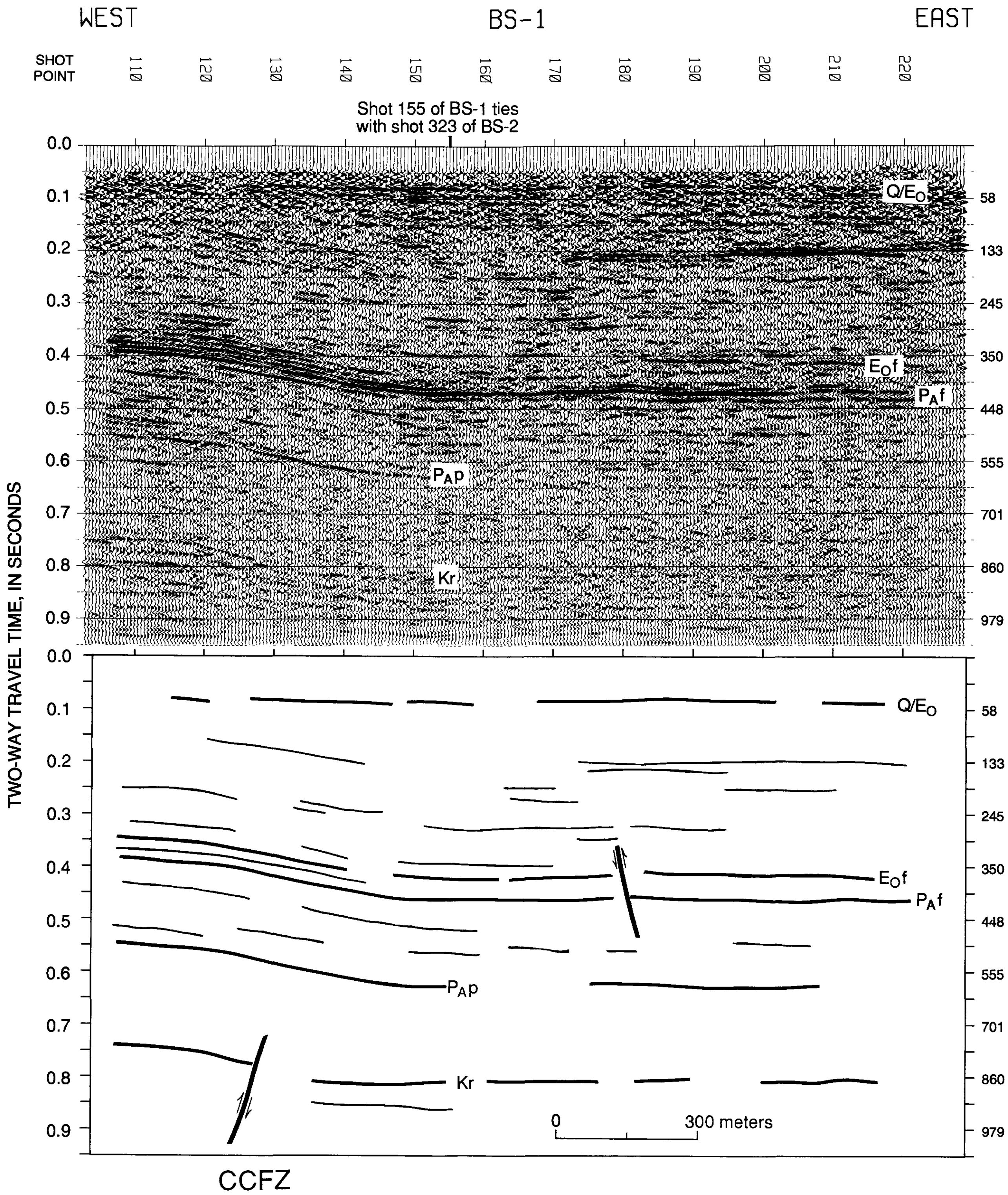

Figure 6. Migrated seismic reflection profile BS-1 and line drawing. Q/E$_O$, Quaternary-Eocene unconformity boundary; E$_O$f, Eocene Flour Island Formation; P$_A$f, Paleocene Fort Pillow Sand; P$_A$p, Paleocene Porters Creek Clay; Kr, Cretaceous rocks. The Crittenden County fault zone (CCFZ) is shown by a reverse fault below shotpoint 130. Notice the onlapping and high-amplitude reflectors between 0.100 and 0.250 s, suggesting thinning of the geologic section occurred in the middle to late Eocene.

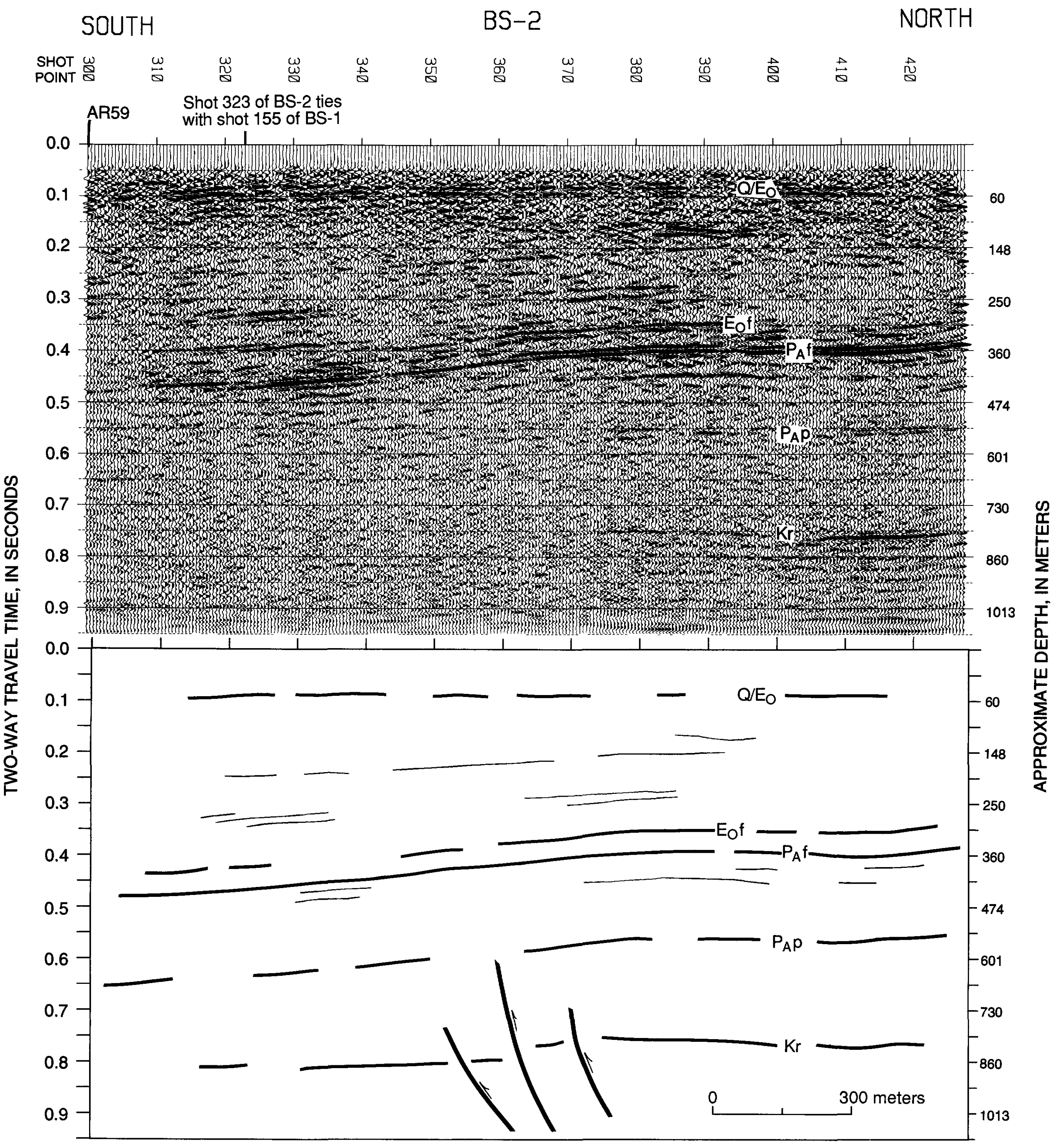

Figure 7. Migrated seismic reflection profile BS-2 and line drawing. Q/E_O, Quaternary-Eocene unconformity boundary; E_Of, Eocene Flour Island Formation; P_Af, Paleocene Fort Pillow Sand; P_Ap, Paleocene Porters Creek Clay; Kr, Cretaceous rocks. The Crittenden County fault zone is shown by a series of three reverse faults between shotpoints 350 and 375.

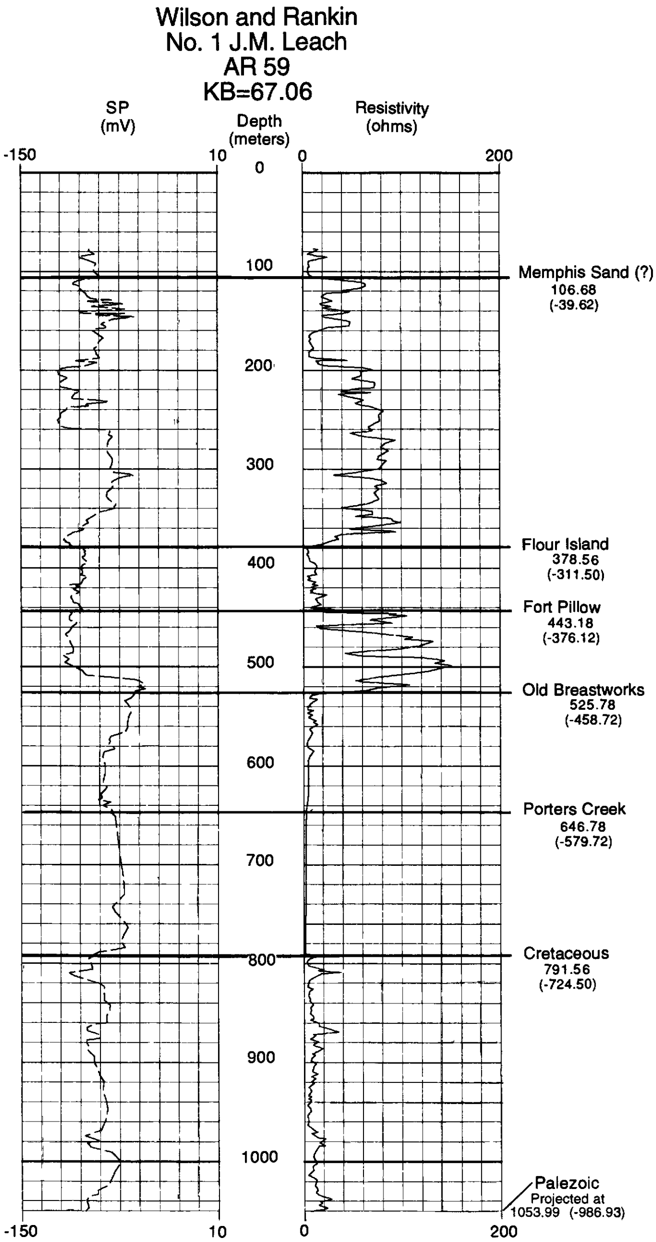

Figure 8. Spontaneous potential (SP) and resistivity logs of the Wilson and Rankin No. 1 J.M. Leach well (AR59) located in sec. 5, T. 7 N., R. 7 E. This well projects 150 m onto the southern end of seismic reflection profile BS-2.

GL-1, GL-2, AND GL-3

This is a series of three intersecting seismic lines, two running east-west (GL-1 and GL-3; figs. 3, 9, and 10) and one north-south (GL-2; figs. 3 and 11). Shotpoint 175 of GL-1 ties with shotpoint 331 of GL-2. Shotpoint 384 of GL-2 ties with shotpoint 419 of GL-3. Well AR21 was projected onto GL-2 and well AR 22 was projected onto GL-3 to identify common reflectors associated with the same formation depths. These reflectors were then correlated with reflectors on GL-1 at the appropriate tie point. Some discrepancies exist between formation depths and the reflectors identified from line to line. The discrepancies suggest that the interval velocities may not be accurate and reflect either poor estimations of the RMS velocities or wide variations in lithologic units across the fault zone.

Poor signal quality in the Cretaceous reflectors makes it difficult to calculate displacements in GL-1 and GL-3. However, using an interval velocity of about 2,800 m/s, the top of the Cretaceous reflector is displaced about 60 m in GL-2. This estimation of vertical displacement is consistent with the displacement in the Cretaceous shown in cross section A–A′ (fig. 4). The reflector package corresponding to the Wilcox Group (E_Of and P_Af) indicates more brittle behavior than seen on BS-1 and BS-2. Each line has two broken regions, which we interpret as southeast-dipping reverse faults with an opposite sense of motion when compared with the deeper reverse fault in the Cretaceous. The fault geometry in the Wilcox Group makes it impossible to connect these faults to the deeper faults in the Cretaceous section.

We calculate 70, 35, and 65 m of structural relief on the reflectors identified as the Fort Pillow Sand (P_Af) in GL-1, GL-2, and GL-3, respectively. The geologic section representing the Claiborne Group thins over the Wilcox Group flexure. We calculate 60 m (GL-1), 35 m (GL-2), and 55 m (GL-3) of thinning in the Claiborne Group to the northwest. These discrepancies and inconsistent values of structural relief and thinning between these reflection profiles can be attributed to the poor velocity estimations. However, GL-2 shows the best correlation between values calculated from the reflection profiles and cross section A–A′.

On GL-2, the time interval between 0.1 and 0.250 s shows the presence of high-amplitude and onlapping reflectors, indicating subsidence to the south during Claiborne time. In all of these lines, a reflector identified as the Quaternary-Eocene unconformity boundary (Q/E_O) shows warping and bulging directly over the main flexure in the Wilcox Group and the Cretaceous reverse fault (that is, GL-2, between shots 355 and 400). The Quaternary-Eocene reflector is at a depth equivalent to where this boundary has been mapped by Saucier (1964).

GL-4

GL-4 (figs. 3 and 12) is a north-south reflection profile that crosses the CCFZ between shots 715 and 760. The CCFZ is defined by a series of three reverse faults in the Cretaceous, with one possibly extending through the Porters Creek Clay. The reflectors within the Porters Creek Clay (P_Ap) and the Wilcox Group (P_Af and E_Of) show flexure to the south over the CCFZ. A minor fault is seen at shot 800 in this reflector package. Using an interval velocity of 1,900 m/s, we calculate

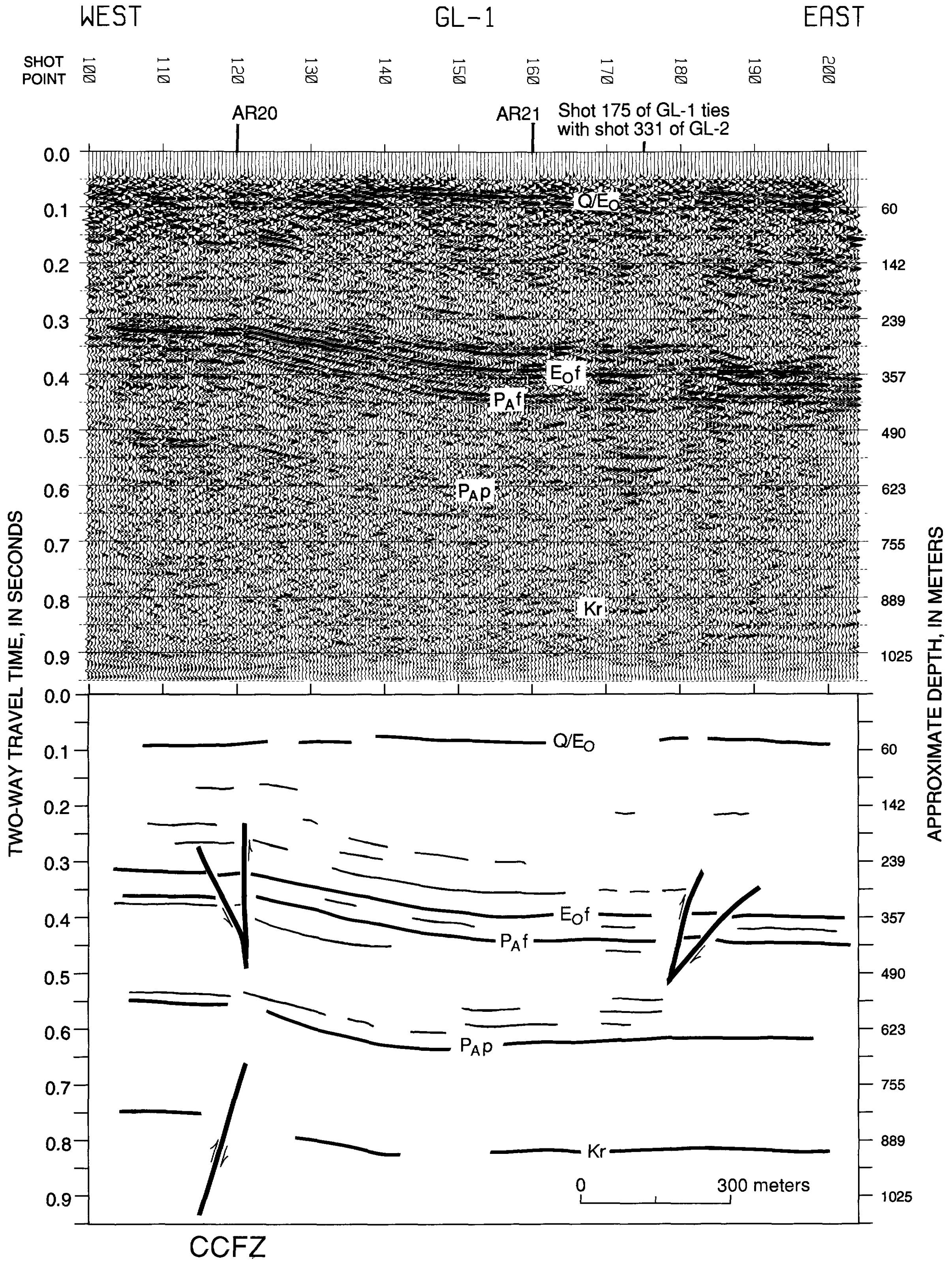

Figure 9. Migrated seismic reflection profile GL-1 and line drawing. Q/E_O, Quaternary-Eocene unconformity boundary; E_Of, Eocene Flour Island Formation; P_Af, Paleocene Fort Pillow Sand; P_Ap, Paleocene Porters Creek Clay; Kr, Cretaceous rocks. The Crittenden County fault zone (CCFZ) is shown by at least one reverse fault beneath shotpoint 120. Notice the minor normal and reverse displacements in the Wilcox reflectors and the substantial thinning of the time section above 0.3 seconds.

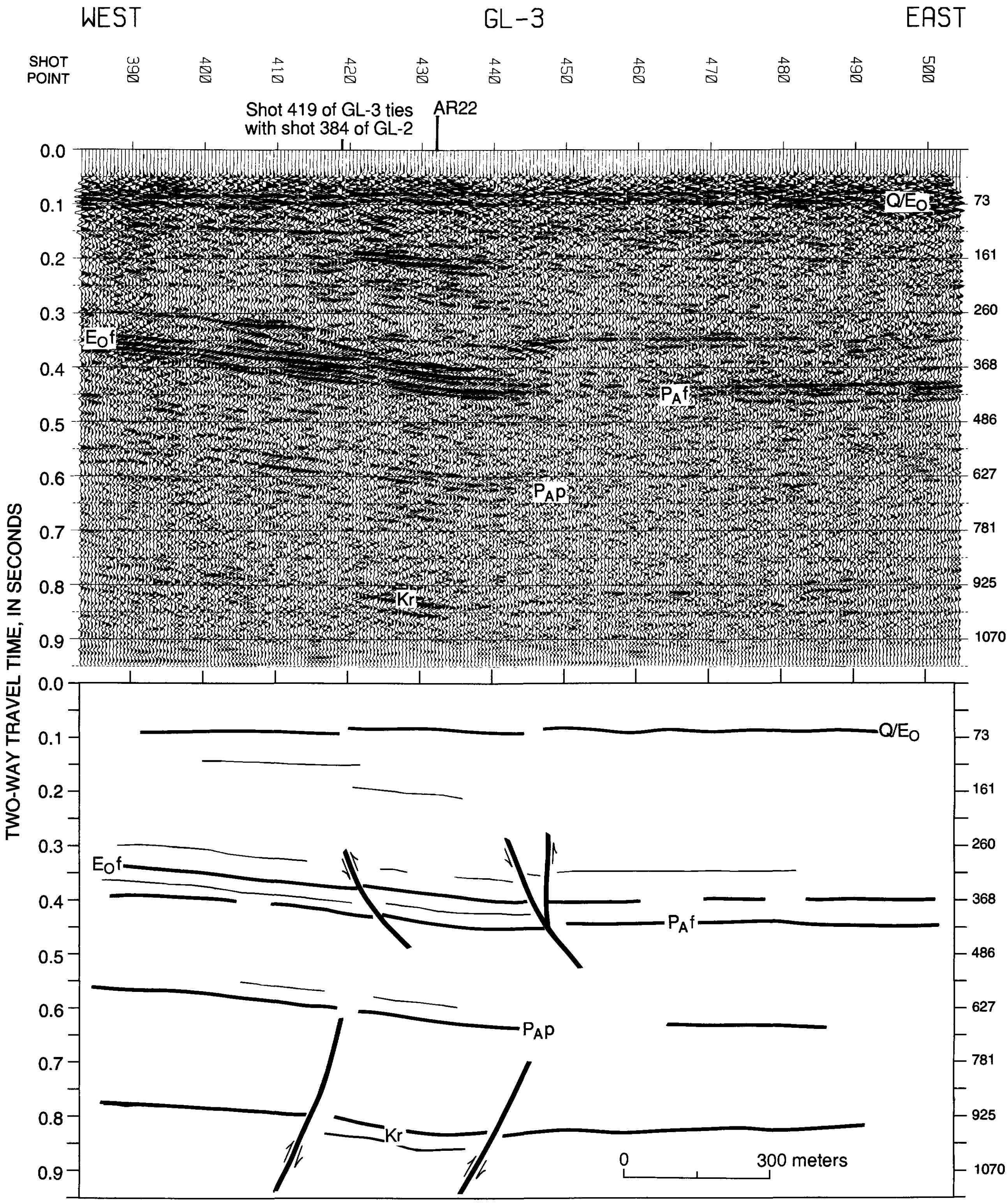

Figure 10. Migrated seismic reflection profile GL-3 and line drawing. Q/E_O, Quaternary-Eocene unconformity boundary; E_Of, Eocene Flour Island Formation; P_Af, Paleocene Fort Pillow Sand; P_Ap, Paleocene Porters Creek Clay; Kr, Cretaceous rocks. The Crittenden County fault zone is shown by two reverse faults between shotpoints 420 and 445. Notice the high-amplitude seismic event at 0.2 s pinching out as the time section thins to the west. Structural warping and possible displacement is apparent in the Quaternary-Eocene reflector.

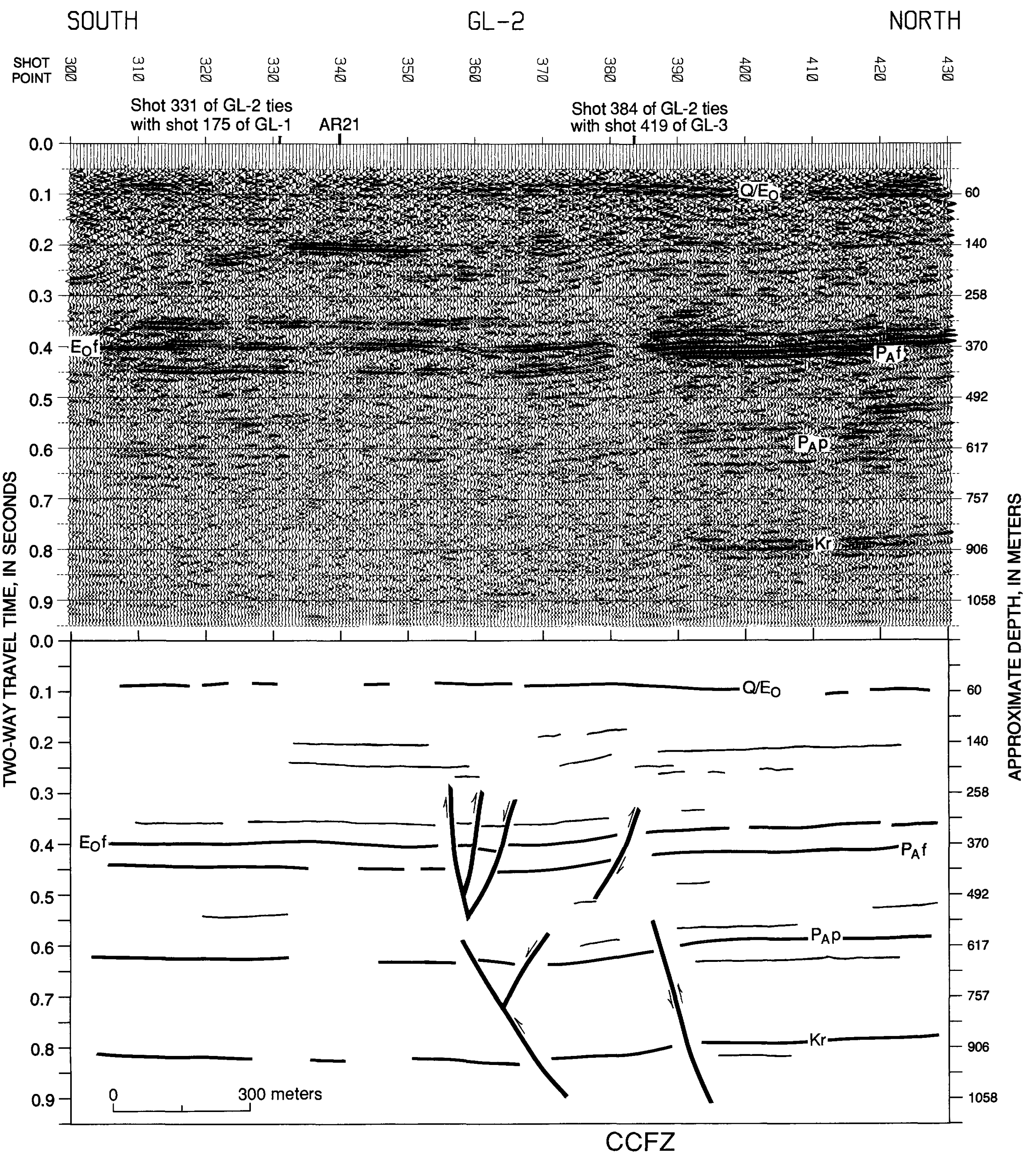

Figure 11. Migrated seismic reflection profile GL-2 and line drawing. Q/E_O, Quaternary-Eocene unconformity boundary; E_Of, Eocene Flour Island Formation; P_Af, Paleocene Fort Pillow Sand; P_Ap, Paleocene Porters Creek Clay; Kr, Cretaceous rocks. The Crittenden County fault zone (CCFZ) is shown by two reverse faults between shotpoints 360 and 390. A noncoherent zone of energy is seen in the Wilcox reflectors between 0.350–0.450 s below shotpoint 380. This zone ties with the fault interpreted in GL-3. Notice the arching Quaternary-Eocene boundary over the zone of noncoherent energy and the CCFZ.

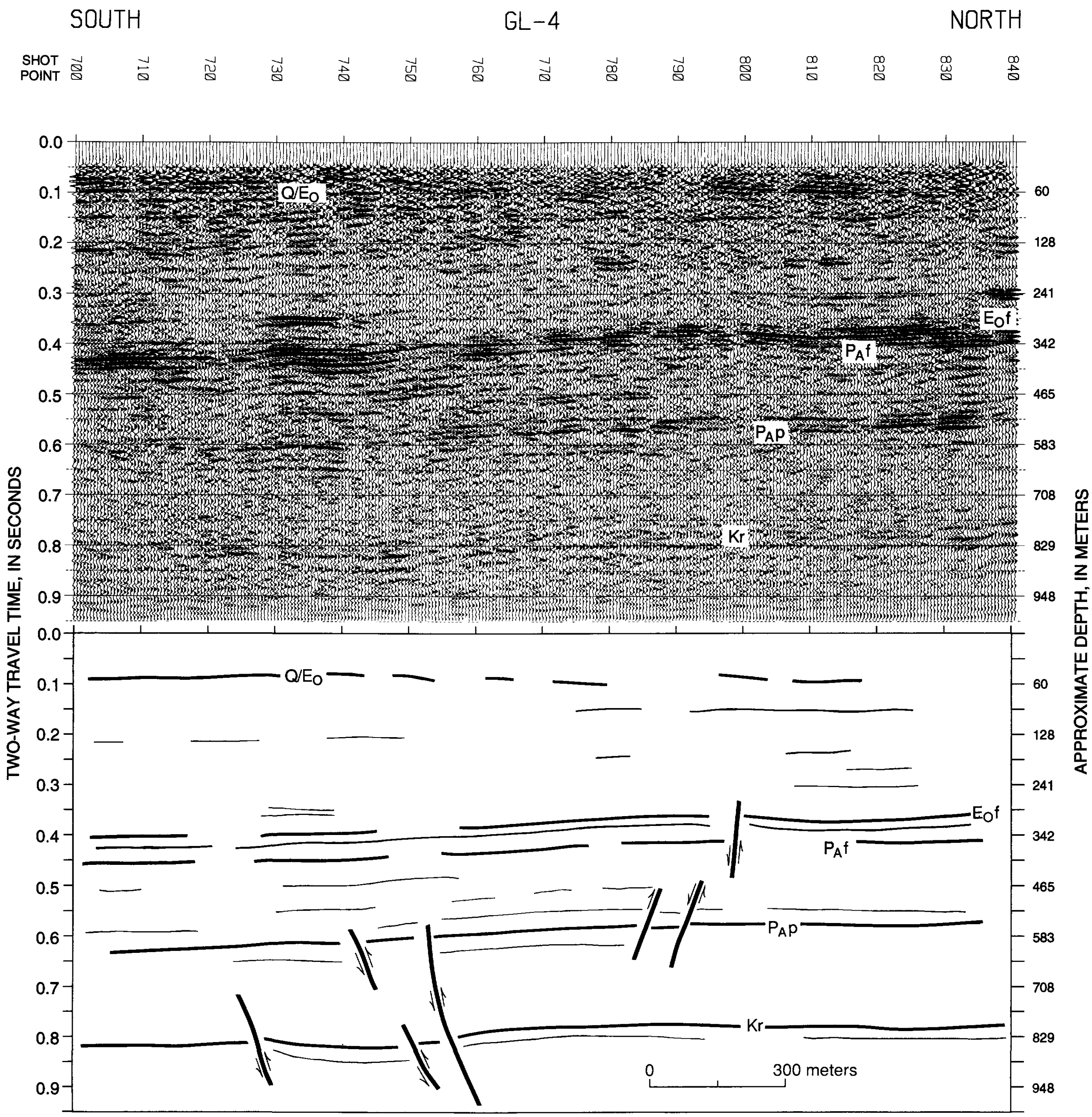

Figure 12. Migrated seismic reflection profile GL-4 and line drawing. Q/E_O, Quaternary-Eocene unconformity boundary; E_Of, Eocene Flour Island Formation; P_Af, Paleocene Fort Pillow Sand; P_Ap, Paleocene Porters Creek Clay; Kr, Cretaceous rocks. The Crittenden County fault zone is shown by three reverse faults between shotpoints 725 and 760.

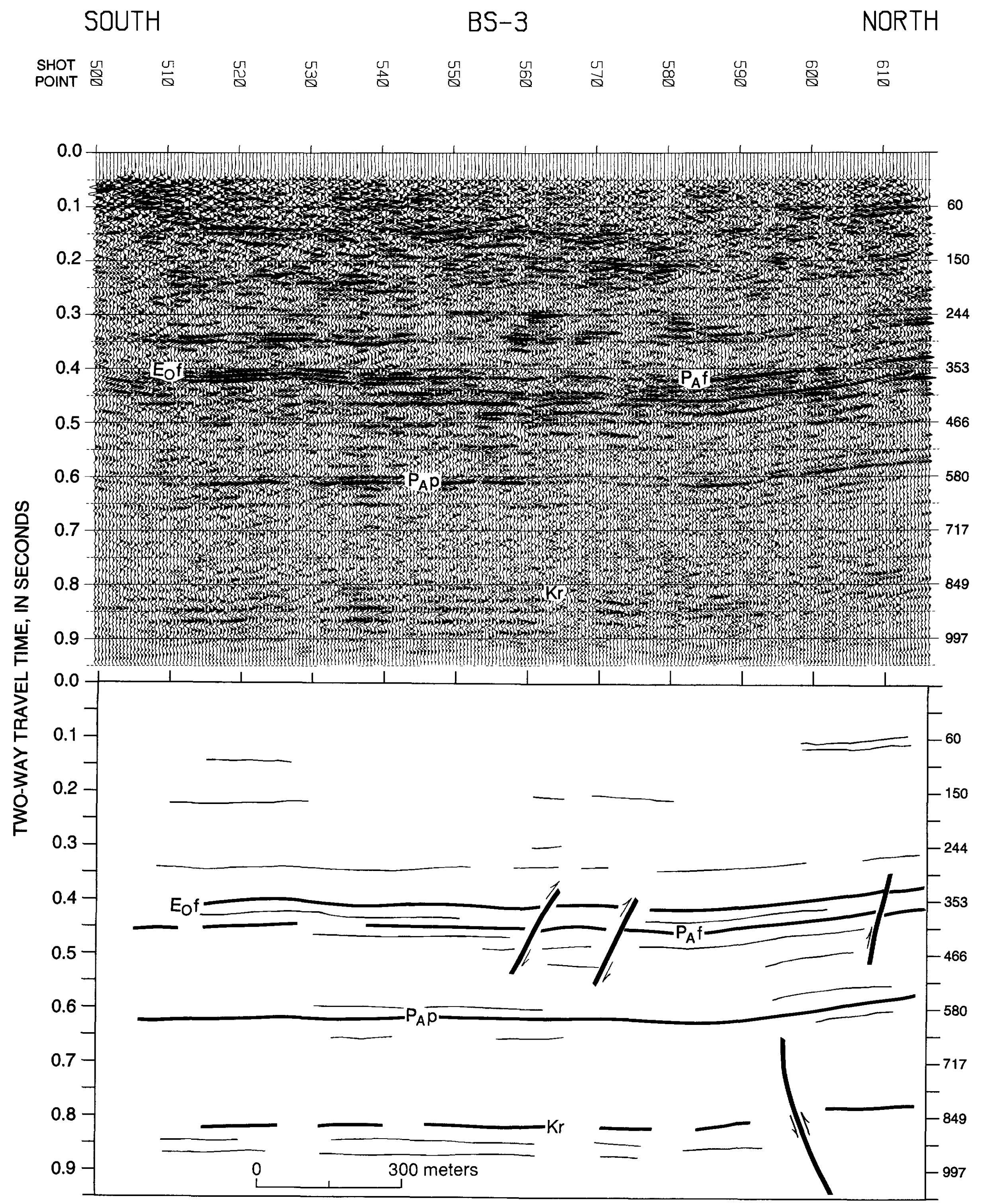

Figure 13. Migrated seismic reflection profile BS-3 and line drawing. E_Of, Eocene Flour Island Formation; P_Af, Paleocene Fort Pillow Sand; P_Ap, Paleocene Porters Creek Clay; Kr, Cretaceous rocks. The Crittenden County fault zone is a reverse fault below shotpoint 600.

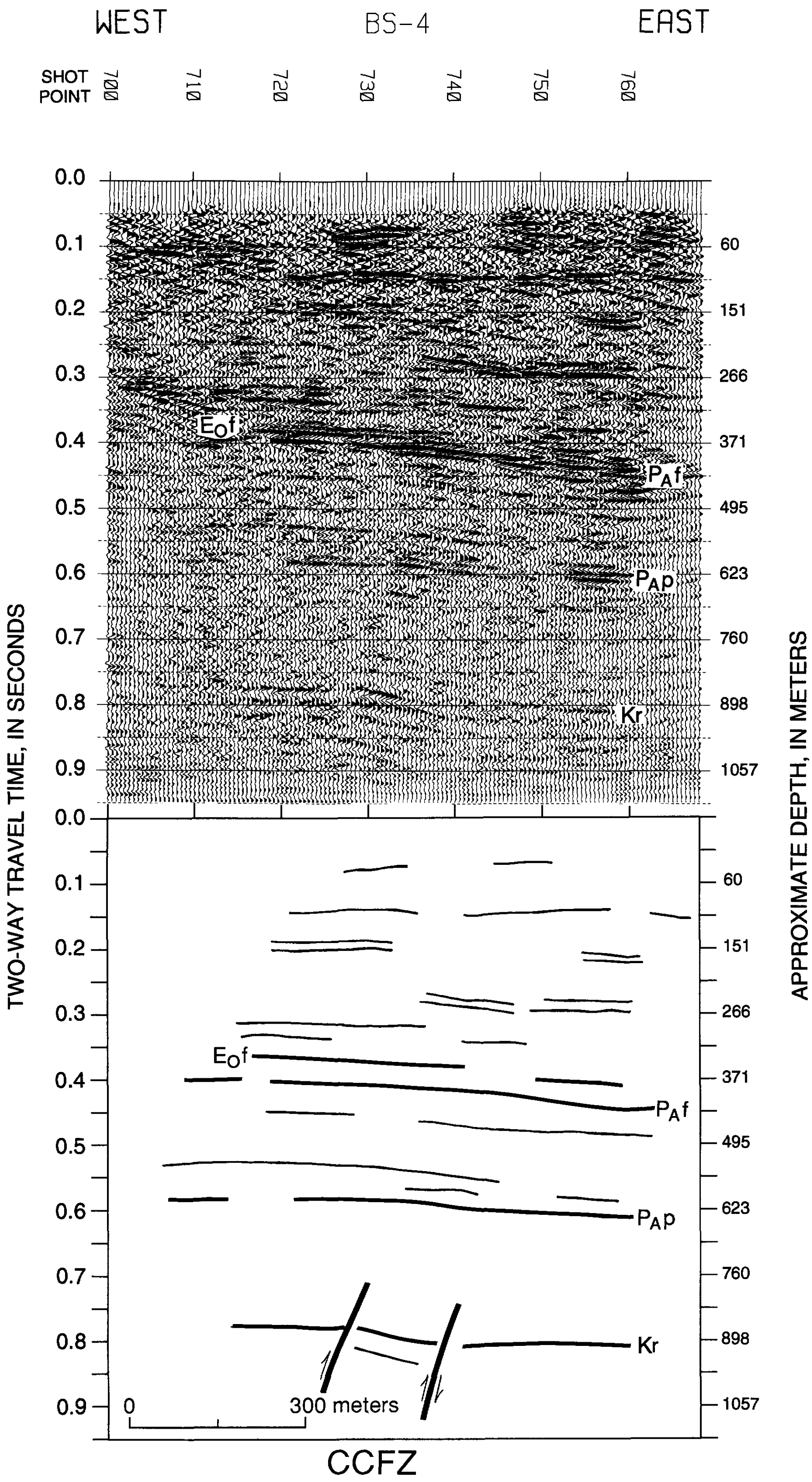

Figure 14. Migrated seismic reflection profile BS-4 and line drawing. E_Of, Eocene Flour Island Formation; P_Af, Paleocene Fort Pillow Sand; P_Ap, Paleocene Porters Creek Clay; Kr, Cretaceous rocks. The Crittenden County fault zone (CCFZ) consists of two reverse faults between shotpoints 730 and 740.

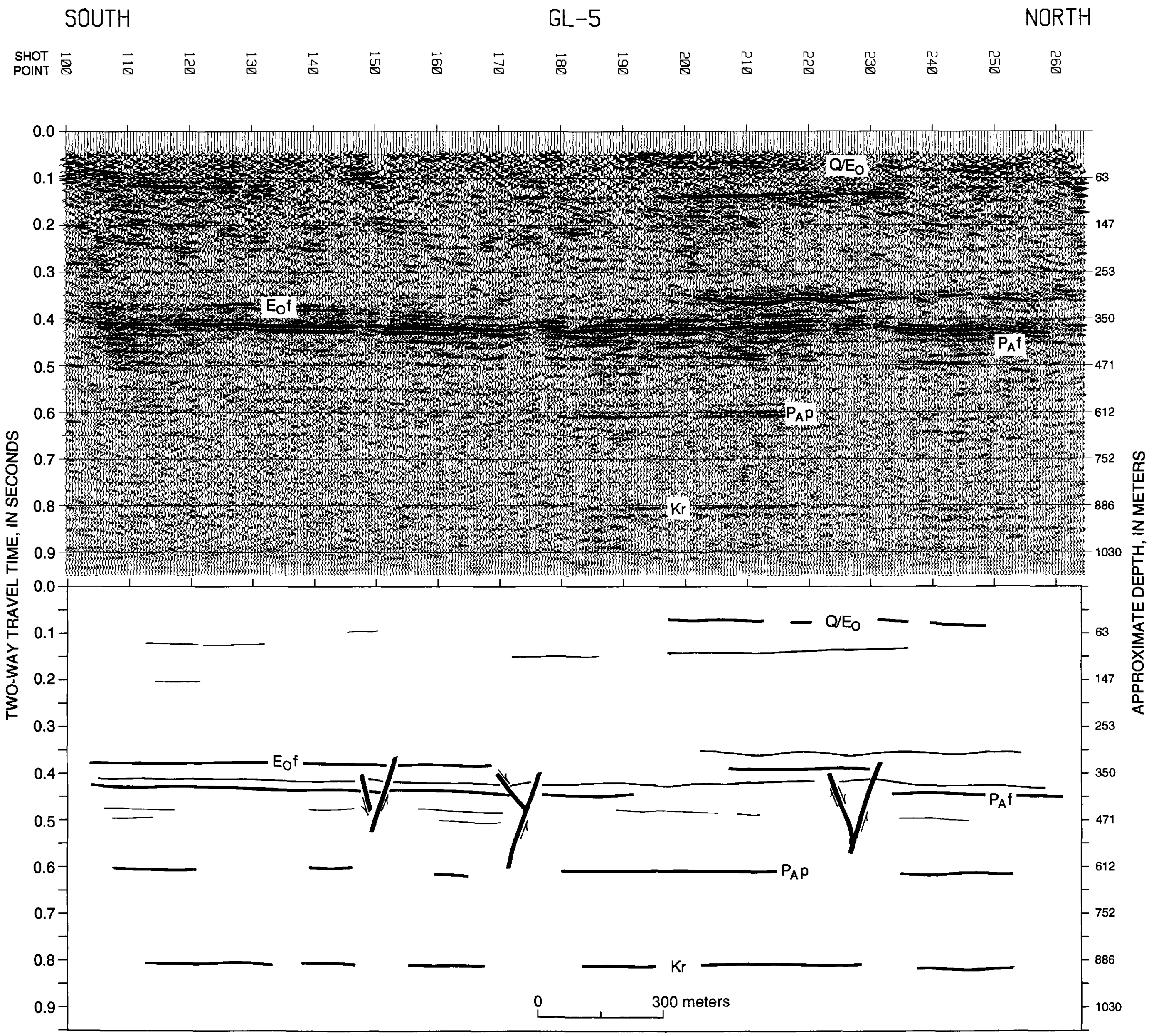

Figure 15. Migrated seismic reflection profile GL-5 and line drawing. E_Of, Eocene Flour Island Formation; P_Af, Paleocene Fort Pillow Sand; P_Ap, Paleocene Porters Creek Clay; Kr, Cretaceous rocks. GL-5 shows no displacement in the Cretaceous reflector. However, minor normal and reverse faulting and reflector warping are apparent in the Wilcox reflectors.

about 20 m of structural relief on the reflector interpreted as the Fort Pillow Sand. Over this flexure, we calculate about 7 m of thinning to the south in the Claiborne Group.

BS-3

BS-3 (figs. 3 and 13) is a north-south reflection profile that crosses the CCFZ between shots 590 and 615. The Porters Creek Clay and Wilcox Group reflectors drape over the CCFZ to the south. Only minor faulting and reflector warping is seen in the Wilcox Group. We cannot obtain an accurate estimate of the amount of structural relief and thinning over the CCFZ here because the end of the line was reached before the structure completely flattened.

BS-4

BS-4 (figs. 3 and 14) is an east-west line that crosses the CCFZ between shots 730 and 740, where two reverse faults are interpreted. Although the location of the Q/E_O reflector is somewhat ambiguous, we attempt to quantify structural flexure and thinning by approximating its location at 0.1 s. Using an interval velocity of approximately 1,900 m/s, we estimate about 15 m of structural relief on the Fort Pillow Sand and about 10 m of thinning in the Claiborne Group. The amount of relief on the flexure and thinning in the upper part of the Eocene section becomes significantly smaller than on profiles located farther to the southwest as the CCFZ converges on the rift boundary.

GL-5

GL-5 (figs. 3 and 15) is located approximately where McKeown and others (1990) identified the rift boundary as an 8-km-wide fault zone within Paleozoic-age rocks. The rationale for the placement of GL-5 was to try to understand how the northeast projection of the CCFZ and the margins of the Reelfoot rift boundaries are related. The profile shows clear, flat-lying, coherent reflectors that image the Cretaceous, Porters Creek Clay, and Wilcox Group. GL-5 apparently does not cross the CCFZ. Minor faulting and reflector warping that is interpreted in the Wilcox Group is not associated with deeper faulting and reflector flexure, as seen in the other profiles.

DISCUSSION AND CONCLUSIONS

Proprietary reflection data and well information at one location indicate that the CCFZ is a reverse fault that displaces Cretaceous and Paleozoic rocks as much as 60 and 83 m, respectively. Faulting of this style is characteristic of compressional tectonics, as opposed to the extensional tectonics responsible for the formation of the Reelfoot rift during the Precambrian and Cambrian. The major flexure seen in the Tertiary section is consistent with compressional deformation.

The CCFZ intersects the rift boundary at its southern end and diverges from the rift boundary as it strikes northeast. Mini-Sosie reflection data indicate that time displacement of the Cretaceous reflector increases toward the southwest as the CCFZ converges with the rift boundary. However, poor velocity control below 0.7 s makes it difficult to quantify those displacements.

The interpretations of the Mini-Sosie reflection data and well-log information have allowed us to identify deformation associated with the CCFZ over a surface distance of 16 km. Deformation of the Tertiary sediments appears as a monoclinal, southeast-dipping zone of flexure about 0.5 km wide—this is, thus, opposite in sense to the rift. Figure 16 illustrates the location of the flexure zone. A maximum of 70 m of structural relief on the Fort Pillow reflector (P_Af on profile BS-1, fig. 16) is found at the southwestern edge of our study area.

The Quaternary and Tertiary section in the Mississippi Embayment consists of unlithified sediments rather than competent rock. We can thus expect ductile deformation in Tertiary rocks in response to recurrent movement along preexisting faults. The ductility of the Cenozoic sediments accounts for several features seen on the Mini-Sosie profiles: (1) the CCFZ reverse faults do not extend up into the Eocene section, although movement along the fault clearly occurred in the middle to late Eocene, (2) faulting interpreted in the Wilcox Group does not connect with that of the deeper reverse faults seen in the Cretaceous reflector, and (3) CCFZ movement is expressed as a large monoclinal flexure in the Tertiary section.

The lack of significant thinning between either the top of the Cretaceous section and the Porters Creek Clay (Paleocene), or the Porters Creek Clay and Flour Island Formation (Paleocene and lower Eocene), indicates that movement along the CCFZ was minimal during those geologic times. However, all the seismic reflection profiles (with the exception of GL-5) exhibit a substantial amount of thinning in the geologic section between the top of the Flour Island Formation and the Quaternary-Eocene unconformity. Coincident with the thinning is stratigraphic onlap within the Claiborne, indicating that most of the deformation probably occurred during Claiborne deposition.

The absolute age of the top of the Flour Island Formation is not well constrained, but falls somewhere in the early Eocene, perhaps around 52 Ma. The age of the base of the Quaternary is about 2 Ma, although the sediments we here call Quaternary may actually include some late Pliocene strata. We, therefore, can loosely bracket the majority of the deformation on the CCFZ to occur between 52 and 2 Ma. Using a maximum value of 70 m of thinning in the geologic section (BS-2), we calculate an approximate minimum vertical deformation rate of 1.4 m/m.y., which is a very slow rate.

The rock present between the top of the Flour Island Formation and the Quaternary-Eocene unconformity represents only about 18.5 m.y. and includes the Claibornian and Jacksonian Stages of the Eocene; the remainder of the Tertiary section is missing. If all of the deformation is pre-unconformity, we obtain an average vertical deformation rate of 3.8 m/m.y. for the CCFZ during the middle to late Eocene.

We have not identified any laterally continuous reflectors between the top of the Flour Island Formation and the Quaternary-Eocene unconformity. Examination of the reflector packages, however, indicates that nearly all of the thinning over the CCFZ occurs in the upper half of the Claiborne-Jackson section, which means that deformation rates were correspondingly higher. Within this upper half of the section, thinning appears to be distributed, perhaps with several pulses. On several of the profiles, at least some of the thinning occurs very near what we believe is the Quaternary-Eocene unconformity (for example, BS-1, shotpoint

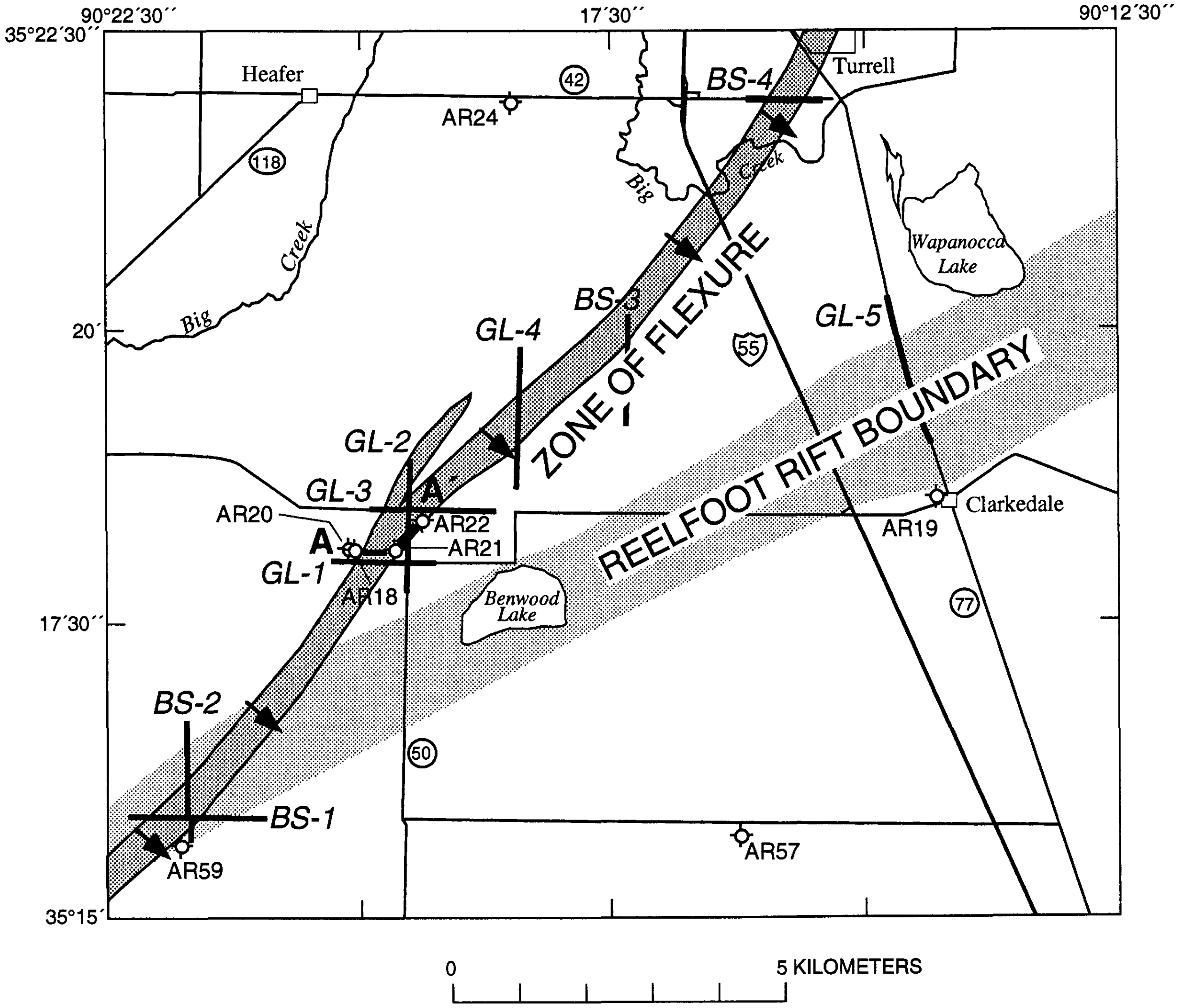

Figure 16. The location of the main zone of flexure in the Wilcox Group overlying the Crittenden County fault zone. The main zone of flexure dips to the southeast, indicating that the fault and flexure is opposite to the down-to-the-northwest normal displacement that marks the southeast boundary of the Reelfoot rift.

150, 0.1 s; BS-2, shotpoint 360, 0.1 s). It is possible that deformation continued during the time of the unconformity.

The evidence for compressional tectonics in the middle to late Eocene along the CCFZ is in accordance with the findings of Hamilton and Zoback (1982), who suggest that the reverse displacement along the Cottonwood Grove fault, in western Tennessee, occurred during middle to late Eocene time. We now have evidence of regional compressional forces that have affected an area of 85 km^2 that spans from at least Cottonwood Grove, Tenn., to central Crittenden County, Arkansas.

The amount of Tertiary deformation and thinning decreases to the northeast as the CCFZ diverges away from the rift boundary. The proximity of the CCFZ to the rift boundary and its subparallel trend suggest that the CCFZ may be related to a zone of high-angle faults in basement rocks that defines the rift boundary. The Reelfoot rift has a complex history of reactivation; recurrent movement of this zone of weakness along the rift boundary driven by regional stress may be responsible for the deformation we see in Tertiary sediments. Further evaluation of deeper reflection data is needed to resolve the structural relationship between the CCFZ and the southeast-bounding faults of the Reelfoot rift.

A detailed examination of wells AR20 and AR21 (cross section A–A′, fig. 4) indicates that the displacements from the Paleozoic up through the Flour Island Formation increase with depth and that the strata of the downthrown side are thicker than the correlative strata of the upthrown side. These differences may be due to differential compaction or original stratigraphic variations, but they likely indicate that the CCFZ itself has a history of reactivation. The different amount of vertical displacement at the top of the Paleozoic and Cretaceous gives direct evidence of this.

Presently, the region is under east-northeast-directed compression (Zoback and Zoback, 1989; Dart and Swolfs, 1991). Although microearthquake activity along the CCFZ is sparse (fig. 1), the presence of arching, disruption, and dip in the Quaternary-Eocene boundary (BS-2, BS-3, GL-1, GL-2, and GL-3) suggest that the CCFZ may have Quaternary activity. Focal-mechanism solutions for the arm of the NMSZ that trends from Marked Tree, Ark., to Caruthersville, Mo., indicate right-lateral strike-slip motion (Herrmann and Canas, 1978; Herrmann, 1979; Yang and others, 1991). It is reasonable to consider a right-lateral, strike-slip component along with reverse movement for the similarly oriented CCFZ. Pure strike-slip is very difficult to detect in seismic profiles. A combination of strike-slip and reverse displacement, however, might help to explain some of the minor faulting and arching seen on the profiles.

Reactivation of the CCFZ has resulted in reverse displacement of Paleozoic and Cretaceous rocks and flexure of overlying unconsolidated Tertiary sediments. The CCFZ may be currently undergoing strike-slip and (or) reverse compressional deformation in response to the present-day stress regime.

Additional work is needed to delineate the extent of the CCFZ to the northeast and southwest, to determine whether other, similar zones are present in the embayment, and to further examine the nature and amount of deformation in the Quaternary section.

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