Structural nature of the Humboldt fault zone in northeastern Nemaha County, Kansas

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Abstract

A six-fold CDP seismic-reflection survey was conducted across 5.3 km (3.3 mi) of partially glaciated land in northeastern Nemaha County, near Bern, Kansas. An 11° easterly dipping slope with a 12-m (40-ft) fault offset is interpreted in the Late Pennsylvanian and Early Permian beds where the seismic line crosses the Humboldt fault. West of this fault, over the Nemaha Ridge, Late Pennsylvanian rocks of the Cherokee Group overlie Precambrian granite basement rocks at a depth of 353 m (1,165 ft) and an elevation of 8 m (26 ft). To the east of the fault, over the Forest City basin, the deepest reflector interpreted is the top of the Cherokee Group at a depth of 563 m (1,845 ft) and an elevation of -166 m (–455 ft) at a well 4 km (2.5 mi.) east of the fault. All of the Late Pennsylvanian and Early Permian rocks in the Forest City Basin above the top of the Cherokee Group have very little structure or dip between the fault zone and the well.

The Kansas Geological Survey conducted a major re-evaluation of the geology and seismicity of Kansas in connection with design criteria for dams, nuclear-power plants, and other earthquake-sensitive structures. Northeast Kansas was chosen as a study area because of the concentration of seismic activity and the stratigraphic evidence for the maximum amount of vertical displacement of the Humboldt fault (Steeples et al., 1979). McCauley et al. (1978) searched for surface lineaments using LANDSAT–MSS, side-looking airborne radar, satellite, and conventional photography. DuBois (1978) investigated the origin of surface lineaments in Nemaha County and interpreted a post- Permian throw of 53–74 m (175–240 ft) on the Humboldt fault in the northern area of the county.

The purpose of this study was to determine the nature of the deformation on the Humboldt fault and to better resolve its lateral position and total vertical throw in the near-surface.

A major geologic feature in Nebraska, Kansas, and Oklahoma (fig. 1) is the north-south-trending asymmetrical Nemaha anticline, extending nearly 500 km (300 mi) from near Omaha, Nebraska, to Oklahoma City, Oklahoma. In northeastern Kansas, this approximately 50-km (30-mi)-wide anticline borders the west side of the Forest City basin and the east side of the Salina basin.

The core of the Nemaha anticline (the Nemaha Ridge) is composed of Precambrian granitic rocks. In northeast Nemaha County, this ridge is overlain by younger, post-Pennsylvanian and pre-Permian (Guadalupian), sedimentary rocks that have been folded and faulted into a long, narrow, north-south-trending, asymmetrical anticline. On the steeper eastern flank, the Precambrian granite basement has a maximum of 1,200 m (4,000 ft) of vertical displacement as a single fault. Other studies (DuBois, 1978; Berendsen et al., 1978) indicate this displacement is a fault zone.

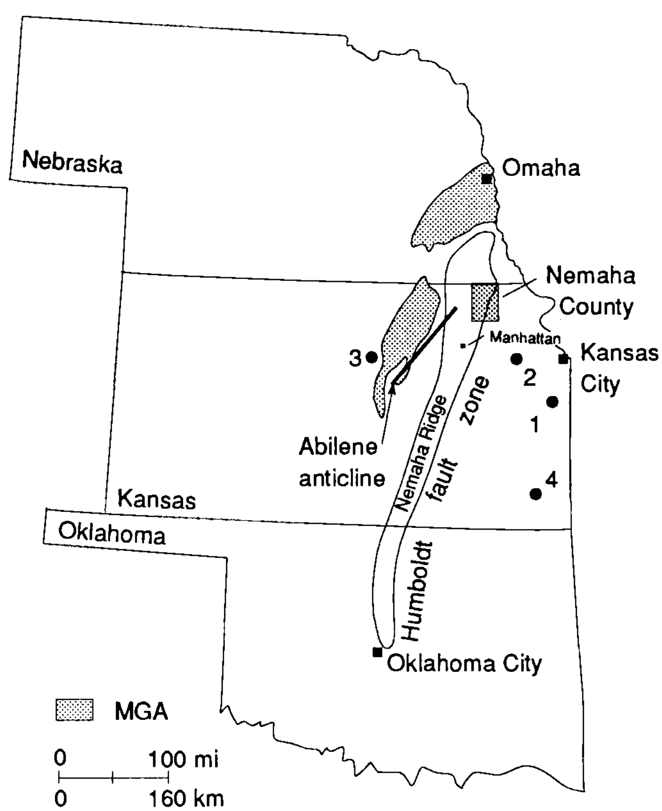

FIGURE 1—Major tectonic features associated with the Nemaha Ridge.

Bedrock exposures are scarce throughout northeastern Kansas because of the cover of Pleistocene glacial debris. Outcrops in Nemaha County are found only along stream-valley walls, except in the northeastern corner of the county where erosion has removed some of the glacial deposits from the uplands (Ward, 1974). Both the Nebraskan and Kansan glaciers deposited glacial materials that vary in thickness from 0 to 115 m (0–380 ft; Ward, 1974; Frye and Walters, 1950; Mudge et al., 1959). Alluvial deposits are found throughout the area.

The seismic-reflection profile of this study was located in northeastern Nemaha County (fig. 3), in a Pleistocene glaciated region underlain by bedrock of Late Pennsylvanian and Early Permian age (fig. 4). As a result of Late Permian and possibly post-Permian movements (Ward, 1974) along the Nemaha anticline, the general northwestward dip of the sedimentary strata in northeast Kansas is interrupted in Nemaha, Pottawatomie, and Jackson counties. Localized deformation of Permian beds occurs near Bern in Nemaha County where an eastward dip of up to 20° is recorded on the eastern flank of the anticline (DuBois,1978).

The Precambrian surface map of Kansas (Cole, 1978; fig. 2) shows the Humboldt fault at the eastern flank of the Nemaha Ridge extending through Nemaha County into Pottawatomie County in the south. The fault enters the northern edge of Nemaha County from Richardson County, Nebraska, 4.8 km (3 mi) northeast of Bern, Kansas.

Movement along the Nemaha Ridge has greatly affected the total thickness of the sedimentary section. To the east in the Forest City basin, within a few kilometers of the ridge axis, the sedimentary rocks attain a total thickness of 1,200 m (4,000 ft). Sedimentary rocks over the Nemaha Ridge, where the pre-Mississippian section has been eroded away, range in thickness from 175 m (600 ft) near Seneca to 300 m (1,000 ft) at the western border of Nemaha County (DuBois, 1978).

A 12-channel digital INPUT/OUTPUT 1632MS recording system was used to collect shallow, high-resolution seismic-reflection data. The sample rate was set at one sample per two milliseconds (msec), allowing two seconds of recording. The high-cut recording filters were out, while the low-cut recording filters were set at 60 Hz with a 24 dB per octave attenuation slope. Sixty-Hz interference noise was eliminated by a notch filter. The recording amplifier gain levels were set at the highest possible settings, to ensure maximum signal strength. Each seismic record was plotted on paper for data-quality control and field review and stored on a nine-track magnetic tape (SEG Y format).

The data were collected using the MiniSOSIE recording method. The MiniSOSIE technique was developed by the Geophysical Research Center of Societe Nationale Elf Aquitaine in Pau, France. This method uses 151Y Wackers, engineering earth compactors, as the energy source, impacting the surface up to the seismograph's limit of 18 discrete time breaks per second. The reflection data from each energy pulse were cross-correlated, time shifted, and stacked together for each record.

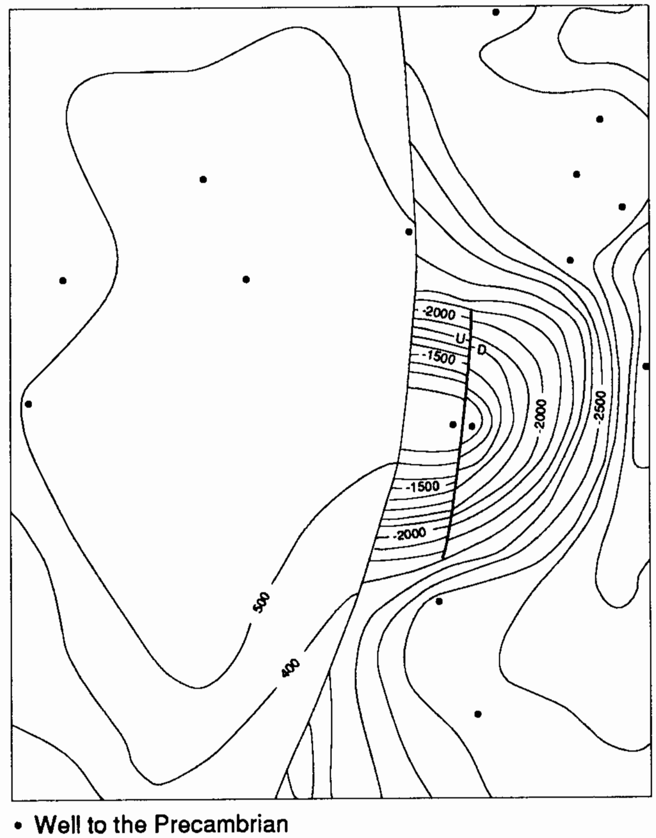

FIGURE 2—PRECAMBRIAN SURFACE (Cole, 1976).

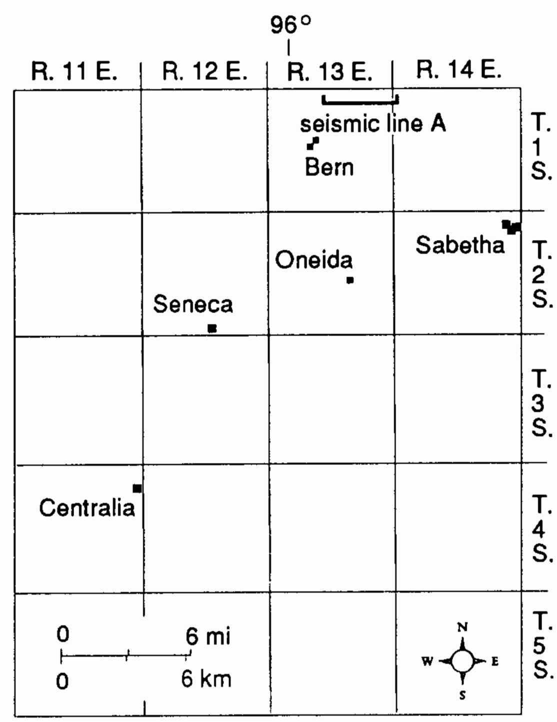

FIGURE 3—BASE MAP OF NEMAHA COUNTY, KANSAS (DuBois, 1978).

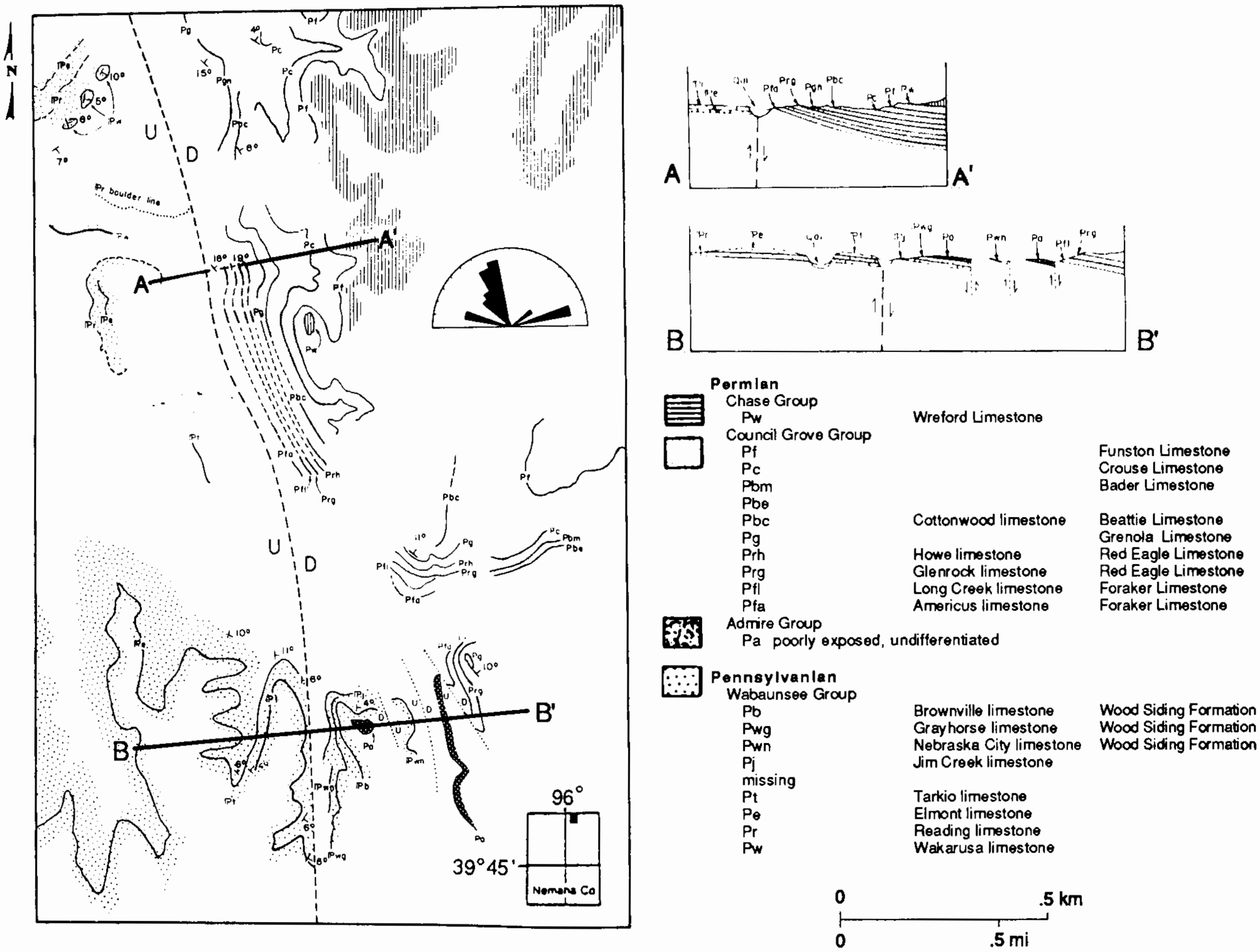

FIGURE 4—Geology northeast of Bern, Kansas (DuBois, 1978).

By field testing, a conventional split-spread, six-fold reflection survey was determined to produce high quality results. Receiver geophone groups were placed 16 m (53 ft) apart. At each receiver location, 12 Mark Products, Inc. L-25D geophones were spread out evenly along 32 m (106 ft). The near source-receiver distance was 32 m (106 ft) and the maximum source-receiver distance was 112 m (370 ft). Two thousand wacks from the rammer, distributed and centered along the seismic profile about each source location, were found to be optimum.

The magnetic-field tapes were sent to Amoco Production Company Processing Center in Tulsa, Oklahoma, to be computer processed. At several locations along the seismic line, time-velocity pairs were picked from computer-generated velocity scans (Dobrin, 1976, p. 233). The velocity scans were used to correct the reflection times to simulated zero-offset group distance. This normal moveout correction is small for short offset distances of less than 112 m (370 ft; fig. 6) and thus was of secondary importance in the processing.

Initial processing included formatting tapes, adding field information, applying a large-window digital volume-control (DAVC) scaling program, and sorting the records into common depth points. Several static analysis programs were used iteratively to remove time delays caused by near-surface velocity inhomogeneities. The final processing included deconvolution, scaling, filtering, and stacking into a six-fold CDP section (fig. 7). This section covers 5.3 km (3.3 mi) from east to west starting near the Edelman Number One dry test well (SW SW SW sec. 6, T. 1 S., R. 14 E.).

The Wacker rammer produces high-frequency energy as seen in the amplitude spectrum (fig. 8) of a typical filtered data trace. Peak frequency is at 80 Hz and the bulk of the energy recorded is between 30 and 100 Hz. The lack of frequencies below 30 Hz is due to attenuation by the geophones and low recording filters.

The subsurface stratigraphic section, corresponding to the seismic reflections, was determined from electrical logs (fig. 9) of the McCulloch Oil Company, Venus Oil Company, and Alex W. McCoy and Associates, Inc. Edelman Number One wildcat test well drilled in 1971 (SW SW SW sec. 6, T. 1 S., R. 14 E., Nemaha County). Interval velocities were estimated from the bulk-density log (Gardner et al., 1974). A sonic log was then computed from the interval-velocity log. Finally 40-, 80-, and 120-Hz synthetic seismograms were generated from the sonic log.

The 80-Hz synthetic seismogram (column C) in fig. 10 correlates well with the field data (column B). The 40-Hz synthetic seismogram (column A) is comparable to the lower frequency industry seismic data while the 120-Hz synthetic

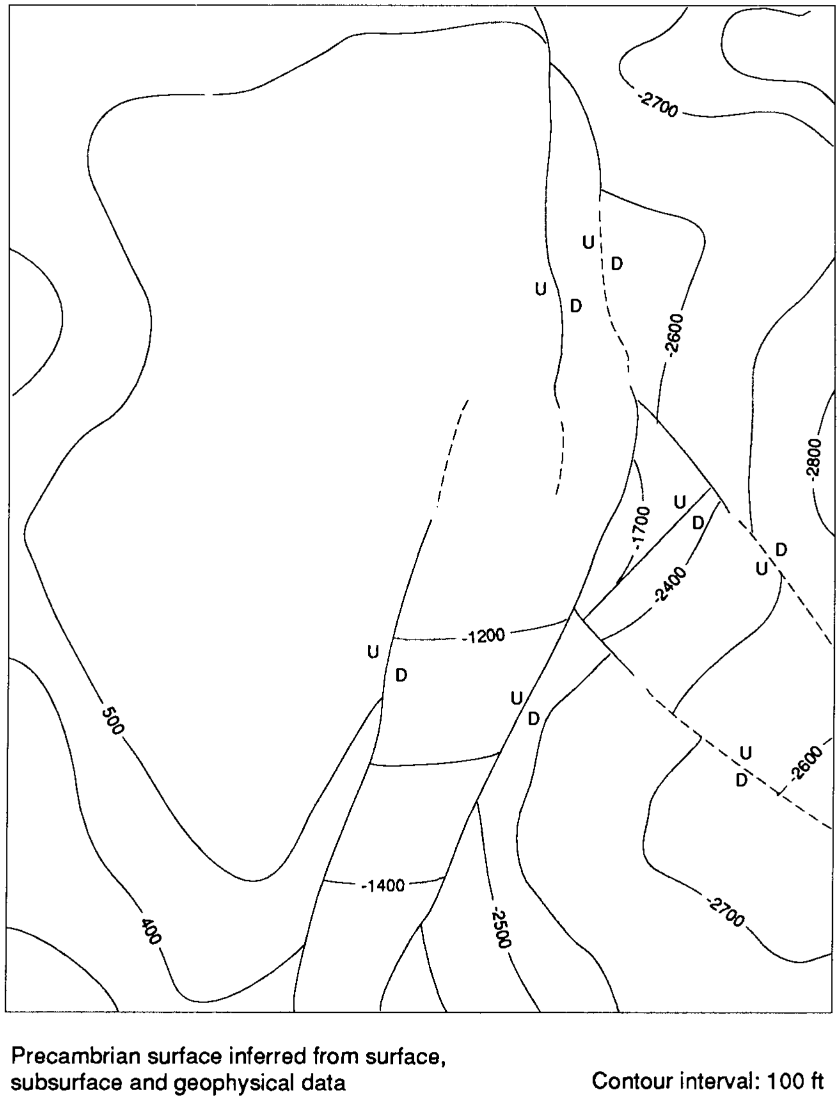

FIGURE 5—PRECAMBRIAN SURFACE (DUBOIS, 1978).

seismogram (column D) indicates the possible improvement in bed resolution with a higher frequency source. Interval velocities are plotted in column E.

Although oil wells penetrating the Precambrian granite are sparse and widely distributed in Nemaha County (figs. 2 and 5) they provide enough control to map 1,200 m (3,960 ft) of throw on the Humboldt fault a few miles south of the Nebraska–Kansas line. The Precambrian surface, down the axis and near the center of the ridge (between Seneca, Kansas, and Tecumseh, Nebraska), is uniform in elevation at 150 m (500 ft). Burchett (1980, personal communication) has generally found continuous rock sequences in the upper 100 m (330 ft) along strike in Richardson and Pawnee counties of Nebraska.

At Stevens and Vhri Number One Robert Harlow oil well (drilled April 1939, SE NE sec. 32, T. 1 N., R. 13 E., Pawnee County, Nebraska), the top 33 m (109 ft) of the Cherokee Group rests on the Precambrian granite surface at an elevation of 111 m (362 ft). This well is about 1 1/2 mi north and 1/4 mi west of the west end of the seismic line. The Precambrian surface would be near 200 msec on the seismic section, suggesting that events later than 200 msec on the west end of seismic line A (figs. 7 and 13) are due to either multiple reflections, geologic structure, or low dip.

Steep gradients across the seismic line on both the aeromagnetic (fig. 11) and Bouguer gravity maps (fig. 12) indicate a possible fault.

DuBois (1978) interpreted a fault based on stratigraphic evidence. The highest dip observed in the area mapped is 19° NE in the south-central portion of sec. 3, where Permian rocks of the Council Grove Group are exposed. Alluvial and glacial deposits cover the area west of these outcrops for several hundred meters, at which point gently dipping (2°E) ledges of Reading and Wakarusa Limestone are found on the knob in the southwest corner of sec. 3. A post-Permian throw of 53–74 m (180–250 ft) is estimated, depending on the exact location of the fault. Between the top of the Reading limestone and the bottom of the Council

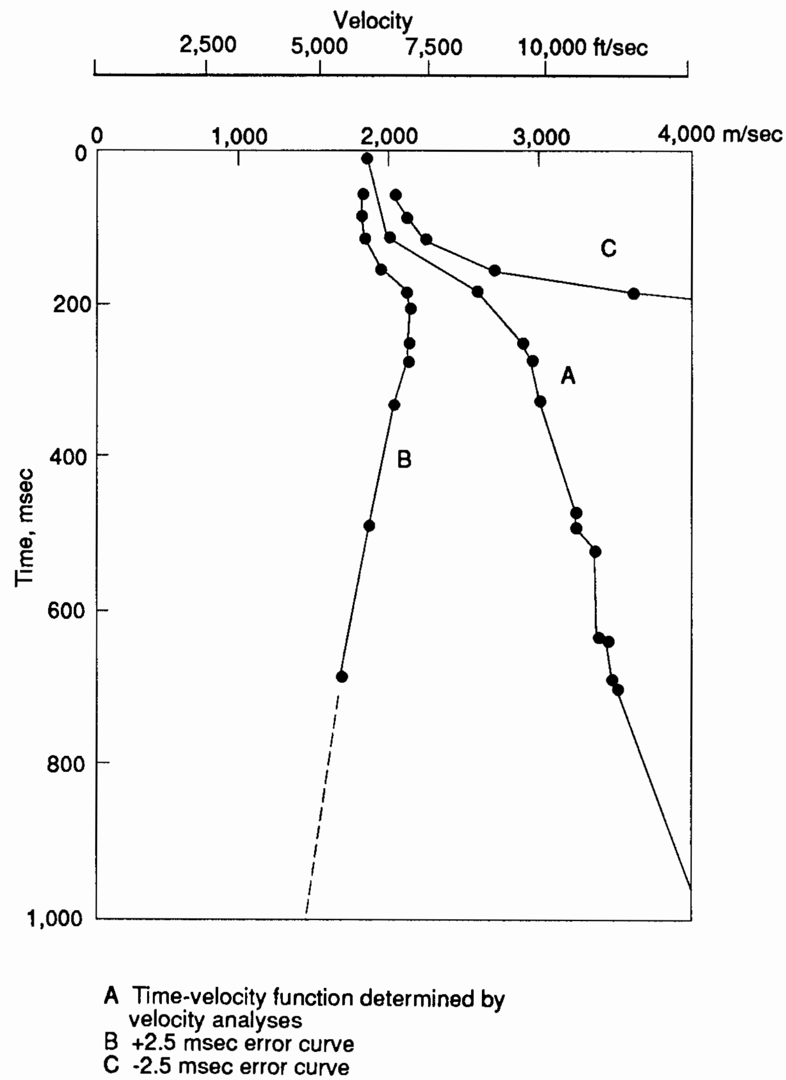

FIGURE 6—DEPTH-VELOCITY FUNCTION.

Grove Group is 123 m (403 ft) of stratigraphic section (based on a typical section).

Geological interpretation is constrained by the geophysical limitations of the seismic data. Interpretative limitations are influenced by source penetration, frequency content, record quality, processing techniques, velocity control, and even surface and deep geology.

On the Nemaha County seismic line (fig. 7), the maximum depth of penetration for the Wacker source is about 600 m (2,000 ft), which corresponds with a time of about 350 msec. From the amplitude spectrum (fig. 8) and from the seismic section (fig. 7), the dominant frequency is 80 Hz, which (assuming average velocity of 4,000 m/sec) corresponds to a wavelet with a wavelength of 50 m (165 ft). With this wavelength, bed thicknesses of 12.5 m (41 ft) and vertical fault offset of 5 m (17 ft) or more can be detected.

With poor velocity control, identification of individual rock units is at best an educated guess. Useful aids for identifying rock units are approximate depth, average velocity, rock type (for determining reflection coefficient), relationships with surrounding rocks, and synthetic seismograms.

The geological interpretation can be divided into three sections: the Forest City basin, the Humboldt fault, and the Nemaha Ridge. In the Forest City basin, four major reflections (figs. 7 and 13) are recognized at the east end of the seismic line near receiver-location 185: 1) Admire Group at 105 msec; 2) Tecumseh Shale Group at 180 msec; 3) the Drum–Dennis Limestones at 285 msec; and 4) top of the Cherokee Group at 375 msec. In addition, nearly 40 other limestone and shale units are resolved on the section. Generally the units are about 15 m (50 ft) thick. The rock units are uniformly flat (less than 1°) between receiver group 187 and group 35. A small monocline, with 12 m (40 ft) of vertical displacement, is seen between groups 35 and 25. The rock units are essentially flat between group 25 (line B) and group 25 (line A) at the west edge of the basin.

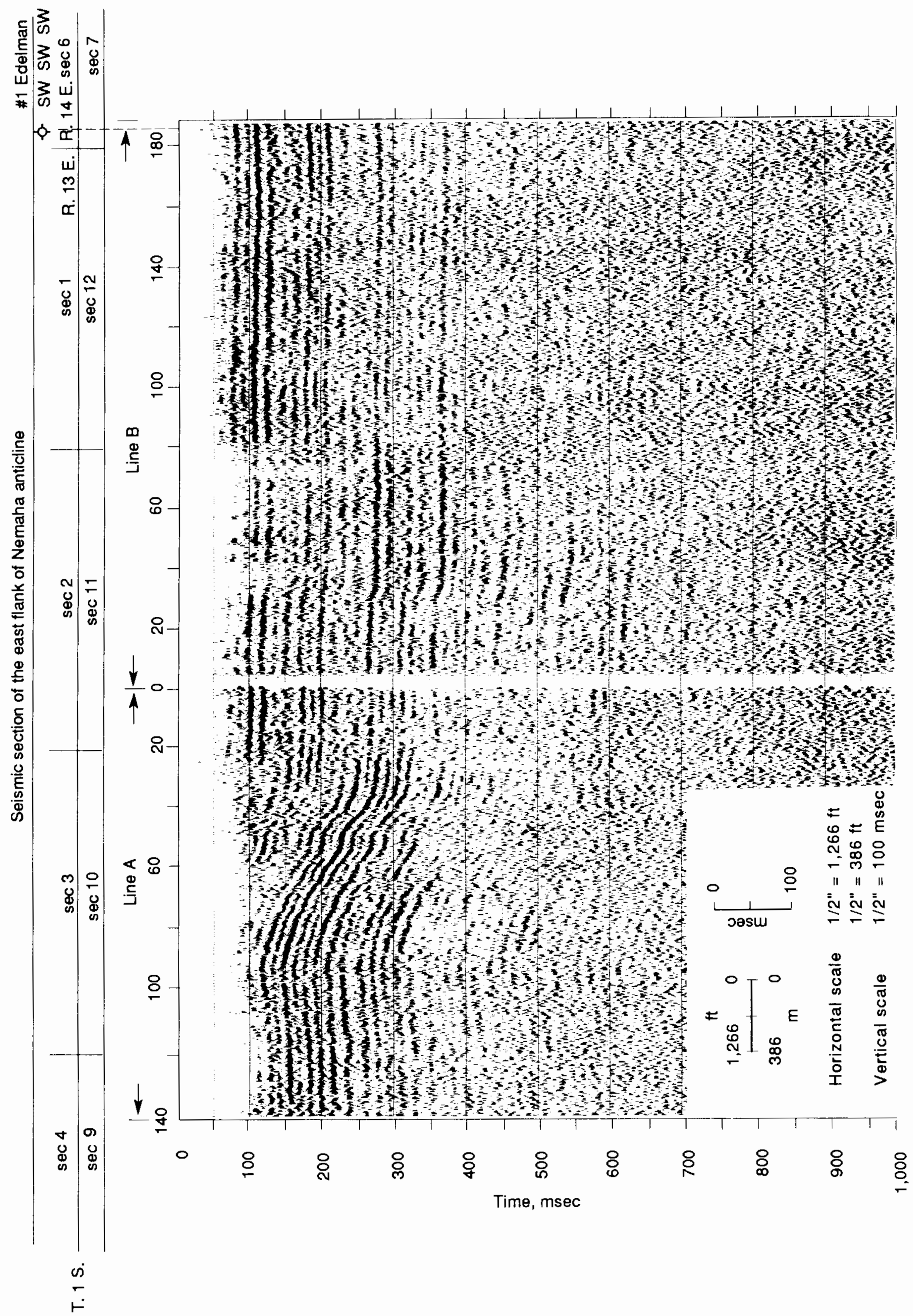

FIGURE 7—DECONVOLVED CDP SECTION.

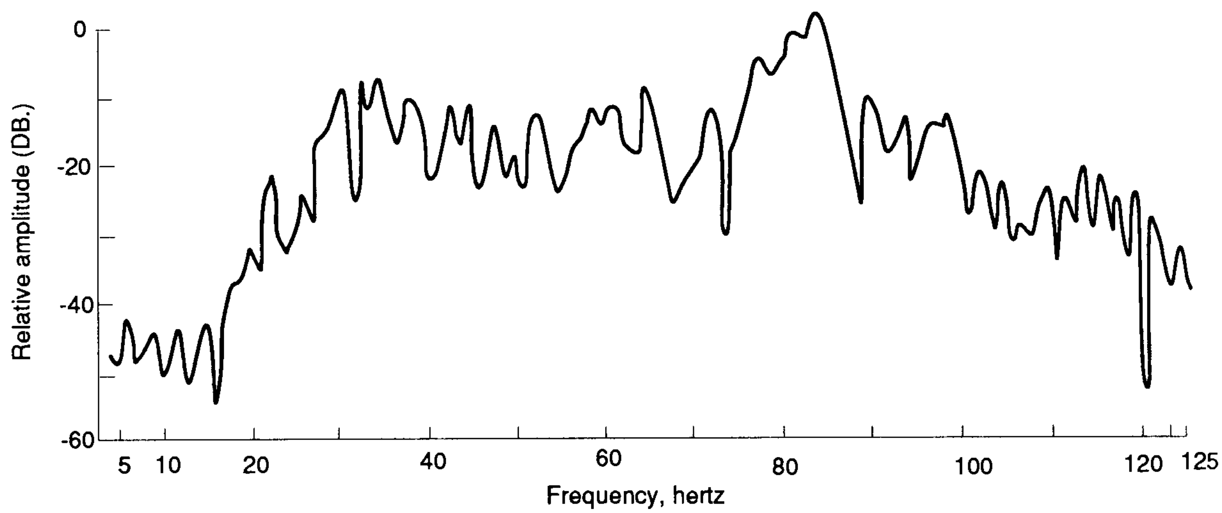

FIGURE 8—AMPLITUDE SPECTRUM OF A STACKED TRACE.

The Humboldt fault region begins at group 215 on line A and ends at group 95 on line A. For the 1,120 m (3,700 ft) between groups 25 and 95, the rock units above the basal Kansas City dip at an average of 11° eastward. At the east edge of the region, between groups 40 and 50, a relatively steep slope of 23° permeates the entire section, cropping out at the surface where DuBois (1978) measured 19° of dip on Permian rocks in the Council Grove Group.

A nearly flat bench extends west for 80 m (260 ft) between groups 50 and 55. At the west end of the bench at group 55, the easterly dipping slope of 12° continues smoothly up to the crest of the ridge to group 95, interrupted only by a small vertical fault. At the crest of the ridge, low dips are observed throughout the section, including at the surface where DuBois (1978) measured dips of 2° on ledges of the Reading and Wakarusa limestones.

The one small fault is located at group 62 with 7 msec of vertical offset corresponding to 12 m (40 ft) of throw estimated from the seismic section. A post-Permian throw is estimated at 32 m (106 ft) on the fault if the average dip of 11° observed on the seismic section is used instead of the 19° used by DuBois from surface-dip observations. Thus the fault throw estimated directly from the seismic section and the throw estimated from the combination of dip and stratigraphic thicknesses measured at the surface now agree within 20 m (66 ft).

Above the Nemaha Ridge, beyond group 95 (line A), the Pennsylvanian rocks lie unconformably on the granite surface of the Nemaha Ridge. The rocks dip slightly eastward over this section although the seismic line seems to show westward dip (this was introduced by the trimming technique in the processing). At 235 msec (group 140), the upper section of the Cherokee Group overlies the Precambrian granite surface at a depth of 353 m (1,165 ft). At this location, the Drum–Dennis limestones are at 145 msec (207 m [683 ft] depth).

Post-Pennsylvanian draping over the Humboldt was observed 150 to 200 km (90–120 mi) to the south in Chase and Butler counties by Berendsen (1980, personal communication).

The observed fault of 12 m (40 ft) on the seismic line is now in closer agreement with the missing stratigraphic rock section of 53–74 m (175–250 ft) estimated by DuBois (1978). A detailed drilling program across the Humboldt fault is needed to remove the differences between the geologic (DuBois, 1978) and the seismic interpretation of the post-Pennsylvanian faulting and draping.

The initial goal of determining the location and nature of the Humboldt fault 1.6 km (1 mi) south of the Nebraska–Kansas line in Nemaha County was accomplished by conducting a 5.3-km (3-mi)-long six-fold CDP seismic-reflection survey. High seismic-data resolution was obtained by using short group spacings (16 m [50 ft]) and high-frequency source energy (Wacker rammer).

The eastern two-thirds of the seismic survey (figs. 7 and 13) show nearly flat beds with only a small monocline near the center of the line. Limestone and shale units with thickness between 15 and 30 m (50–100 ft), were resolved within the upper 600 m (2,000 ft). The four prominent reflectors are 1) Admire Group at 105 msec, 2) Tecumseh Shale at 180 msec, 3) Drum–Dennis limestones at 285 msec, and 4) the top of the Cherokee Group at 375 msec.

The Humboldt fault region has four features in the upper 600 m (1,980 ft) of the rock section. First, at the east edge, a relatively steep slope of 23° permeates the total vertical section. Then a nearly flat bench extends 80 m (260 ft) to the west. The rest of the easterly dipping slope gradually flattens from 12° to 0° with only the last feature (the small vertical fault) interrupting the smooth incline. The vertical fault at group number 62 has a small offset of 12 m (40 ft) and

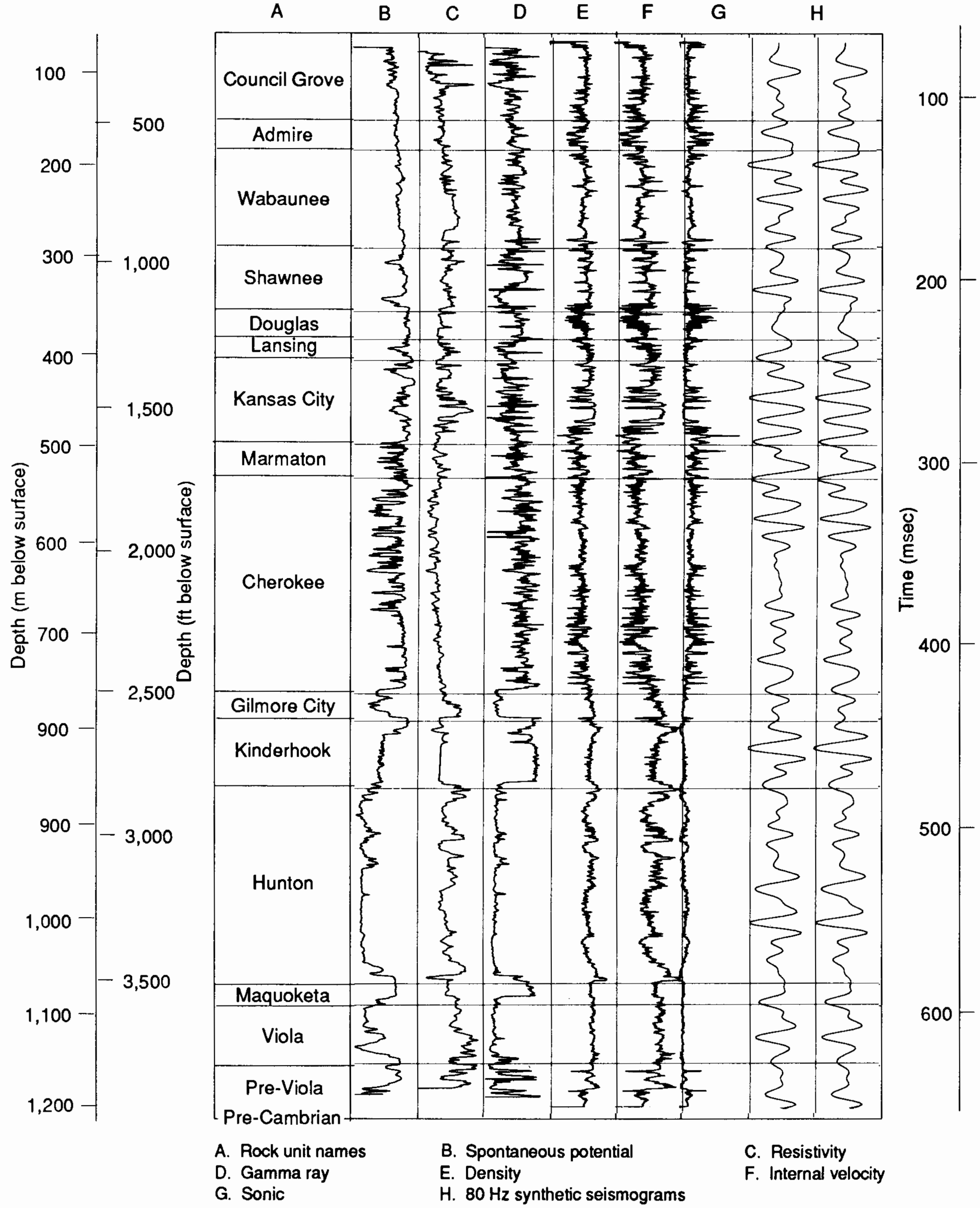

FIGURE 9—EDELMAN NUMBER ONE ELECTRIC LOGS AND SYNTHETIC SEISMOGRAMS.

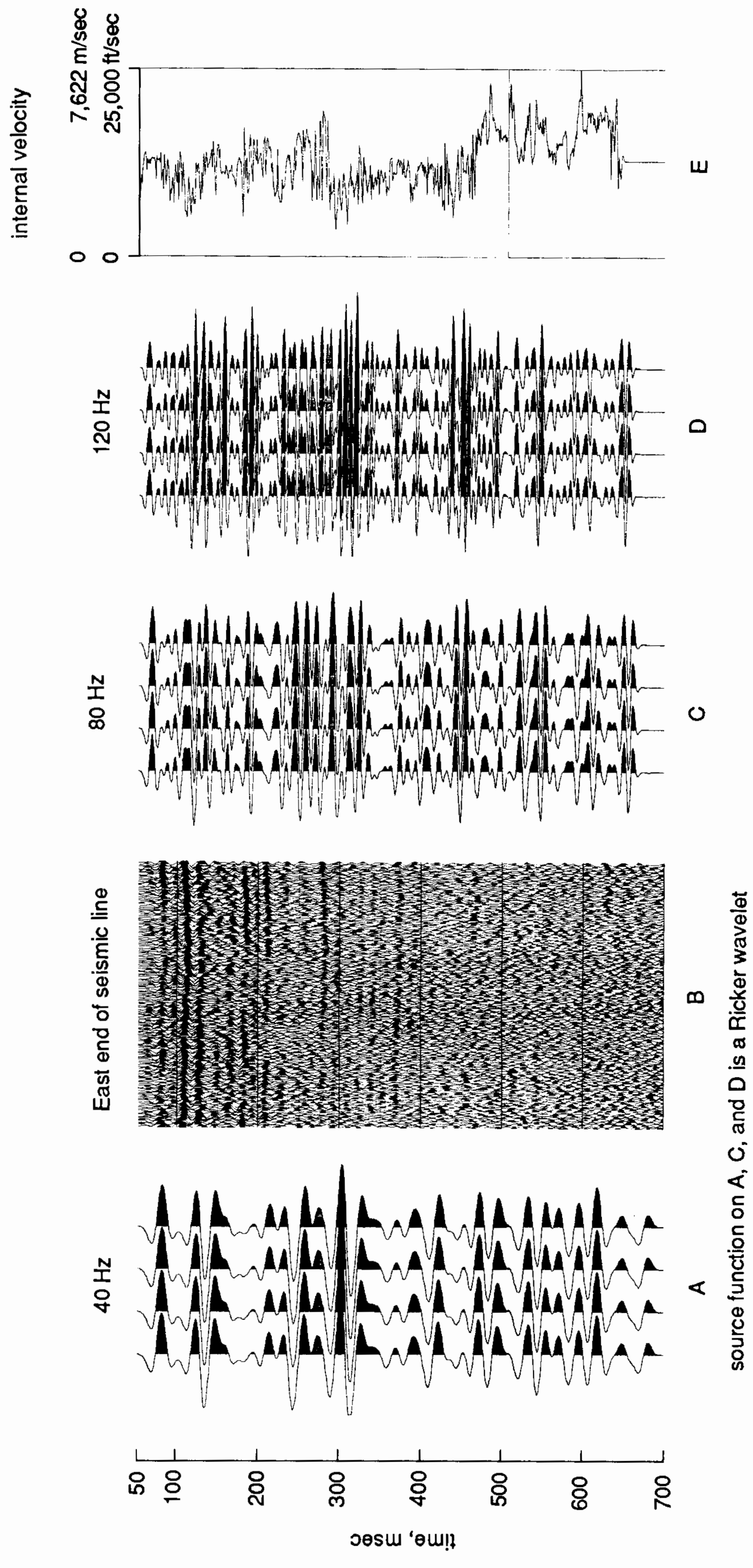

FIGURE 10—SYNTHETIC SEISMOGRAM.

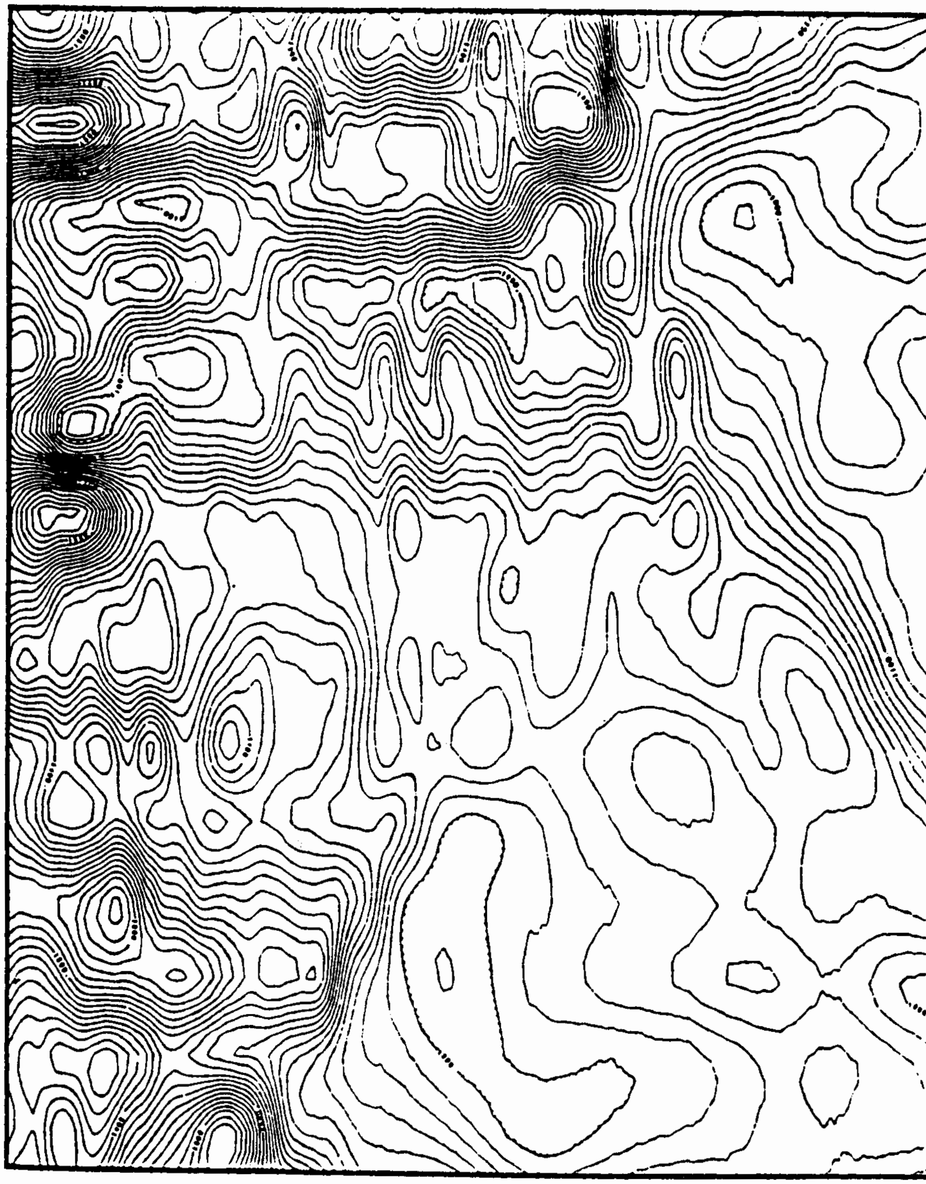

FIGURE 11—AEROMAGNETIC MAP (DuBois, 1978).

definitely offsets the Drum–Dennis limestones. The observed fault throw from the seismic line and the fault interpreted from the stratigraphic section by DuBois (1978) are now in closer agreement if the average dip of 11° is used to compute rock thickness.

The western fifth of the seismic line shows the Pennsylvanian–Permian rock section overlying the Precambrian granite surface. Two prominent reflectors are observed: the Drum–Dennis limestones at 145 msec and the top section of the Cherokee Group at 235 msec, resting unconformably on the Precambrian granite.

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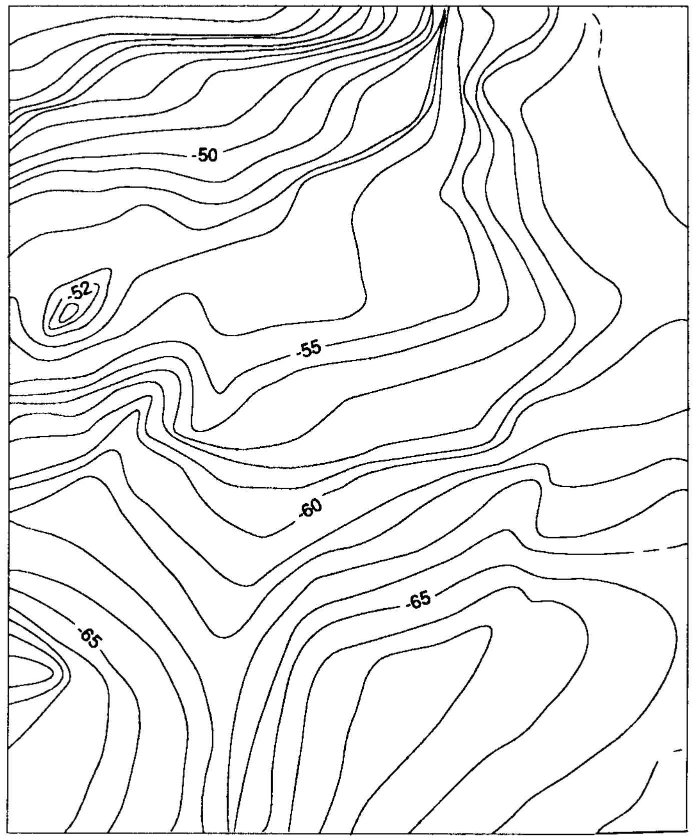

FIGURE 12—BOUGUER GRAVITY MAP (DuBois, 1978).

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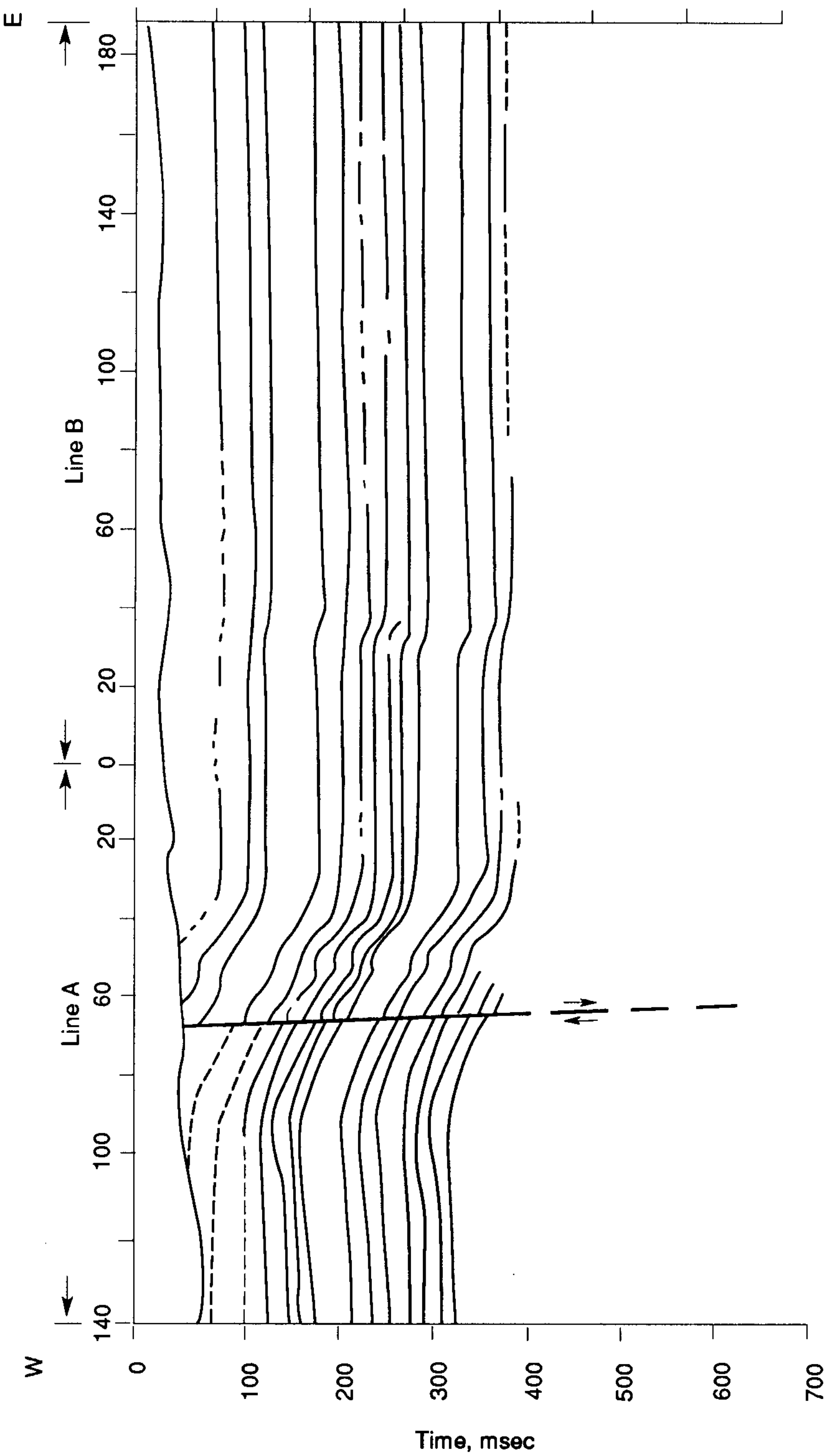

FIGURE 13—INTERPRETED GEOLOGIC CROSS SECTION.