COCORP SEISMIC TRAVERSE ACROSS THE RIO GRANDE RIFT

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INTRODUCTION

COCORP's deep seismic reflection surveys in the Rio Grande Rift of central New Mexico consist of six lines recorded in 1975 and 1976 (Figure 1). Two of these, lines 1 and 1A, constitute an east-west traverse across the southern end of the Albuquerque-Belen basin. Although collected during an early stage of the COCORP program when economic constraints limited the amount of 3-D control which could be obtained and data processing was less intensive, these seismic sections clearly map substantial buried structural relief, with the Albuquerque basin separated into two subgrabens by a central buried horst. Normal faulting in the eastern part of the rift may have been influenced by pre-existing Laramide thrust faults. Perhaps the most unique feature of these deep seismic data is evidence of an unusually strong mid-crustal reflection which is interpreted to correspond to an active magma body. This deep magma appears to have accumulated as series of sills beneath a mid-crustal barrier. The following summary is abstracted from a fuller discussion of the COCORP New Mexico results reported by Brown et al (1980).

GEOLOGIC SETTING

The Rio Grande is a north-northeast trending crustal break following the southern Rocky Mountain tectonic belt from southern Colorado to northern Mexico. Individual basins in the rift vary from 16 to 64 km (10 to 40 mi) in width, and contain from 120 m (390 ft) to as much as 4,500 m (14,760 ft) of Tertiary and Quaternary fill (Kelley, 1956; Davis et al, 1978). The younger rift units are underlain by Paleozoic and Mesozoic sedimentary rocks of varying thickness and Precambrian igneous and metamorphic rocks with ages of 1.0 to 1.8 m.y. (Condie and Budding, 1978). In the vicinity of the COCORP surveys, the Albuquerque basin is flanked on the west by the westward dipping Paleozoic rocks of the Sierra Lucero and on the east by the Precambrian and Paleozoic rocks of the Los Pinos Mountains. Similarities in the location and orientation of Tertiary features with earlier Laramide trends suggests that rifting may have reactivated older structures (Chapin and Seager, 1975). The Rio Grande rift was formed by crustal extension beginning about 32 to 27 m.y. ago and continuing to the present (Chapin, 1979). Volcanism concurrent with extension has occurred mainly along the mideal axis and west side of the rift, with periods of greatest activity being from 32 to 20 m.y. ago and from 5 m.y. ago to the present (Chapin and Seager, 1975). Contemporary activity in the rift is represented by a regional topographic bulge, fault scarps cutting alluvial fans and Pleistocene surfaces, seismic activity, high heat flow, and recent uplift as indicated by geodetic measurements (Cordell, 1978; Sanford et al, 1972; Reiter et al, 1979; Reilinger and Oliver, 1976).

Limited seismic refraction observations suggest that the crust is between 33 and 38 km (20.5 to 23.6 mi) thick in the region of the COCORP surveys (Figure 2; Toppozada and Sanford, 1976; Olsen et al, 1979). Of particular interest are the microearthquake studies of Sanford and colleagues (Sanford et al, 1972) which suggest the existence of a layer of magma at mid-crustal depths near Socorro, New Mexico. Electromagnetic soundings (Jiracek et al, 1979; Hermance and Pedersen, 1980) support the inference of molten rock at crustal and/or upper mantle depths beneath the rift.

THE EAST-WEST TRANSECT

Although six COCORP lines were collected in the rift, only three are presented here. Lines 1 and 1A (Figures 2, 4, and 5) best illustrate structural relief associated with the Albuquerque basin, while crossline 2A most clearly delineates an unusual mid-crustal reflection which has been interpreted as a magma chamber.

The most striking feature of Figure 4 is a series of marker horizons which delineate a major horst block beneath VP 250. This horst subdivides the southern Albuquerque basin and indicates buried relief approaching 4 km (2.5 mi). The horst lies just north of the Sierra Ladron, an uplifted block of Precambrian basement. This juxtaposition suggests that the horst is the buried northward extension, or nose, of the Ladrons.

The southeastern part of the Albuquerque basin is characterized by a shallow structural bench, corresponding to the Hubbell Springs-Joyita bench (Kelley, 1977). The west flank of this bench (between VP's 40 and 130) is overlain by a west dipping and onlapping alluvial apron. This clearly delineated layered sequence was probably rotated during deposition by subsidence of the basin.

The geometry of faulting responsible for this structural relief is not always obvious from the sections. Faults which offset the graben fill are difficult to identify in the underlying basement. Brown et al (1980) originally suggested that closely spaced high angle faults might be responsible. Cape et al (1980) suggested that highly listric normal faulting is indicated, an interpretation reflected in Figure 5 (line 2A). However, high angle, deeply penetrating faults are also consistent with the data, especially at the western rift boundary where migration indicates that the reflector (westernmost dotted line in Figure 5b) corresponding to the boundary dips as much as 65° to the east. If one allows that the dips (e.g. easternmost dotted line in Figure 5b) observed on the flanks of the central horst are apparent dips, then steep faults may also be appropriate to the east. The interpretation in Figure 5b incorporates the possibility of steeply dipping master faults. Arguments can be rallied in support of both interpretations. Some of this ambiguity can be attributed to lack of three-dimensional control, so that true dips of certain key reflections are not known. Furthermore, the formidable problems associated with penetrating and imaging beneath complex shallow structure with highly attenuating, low velocity sedimentary fill have yet to be fully corrected in this data set.

An interesting feature of line 1 is a steeply dipping zone beneath the Los Pinos fault (the eastern rift boundary, at VP 180) which is virtually devoid of reflections, in sharp contrast to the surrounding seismic section (Plate 1, Figure 2). It is suggested that this zone may represent a deeply penetrating shear zone (the rift boundary fault?), but the possibility that it is an artifact of data acquisition and processing is not yet ruled out.

MAGMA: A NEW KIND OF BRIGHT SPOT

Perhaps the most unique discovery of the COCORP work in New Mexico is the unusually strong reflection at about 7 secs (20 km; 12.4 mi) depth on lines 1, 1A and 2A. This feature is clearly visible, with a pronounced velocity pulldown. It is best delineated on line 2A, which is shown in conventional AGC and "true amplitude" format in Figure 5. The large amplitude of this reflection is quantitatively displayed in Figure 3.

The strong P-wave reflector in Figure 6 corresponds in depth with the unusual shear wave reflector previously identified by Sanford and colleagues at New Mexico Tech and interpreted as evidence of magma at depth. Other observations which support the magma interpretation include the swarmlike nature of local seismicity, regionally high heat flow, hot springs, late Cenozoic volcanism, and revealing evidence of contemporary uplift over the inferred body (Sanford et al, 1977). The large amplitudes observed on the COCORP lines are most easily explained by liquid material at mid-crustal depth (Brocher, 1981).

The reflection character on line 2A, together with results of teleseismic delay studies, suggest that the magma body is sill-like, perhaps a zone of interlayered magma pods. Conformity between the trend of shallow reflecting segments and the magma reflector suggests that the latter was emplaced along a pre-existing crustal fabric. Note that the magma occurs near the depth at which refraction surveys suggest an increase in seismic velocity (Figure 2).

MOHO REFLECTIONS

The excellent seismic penetration exhibited on line 2A, in contrast to line 1A, is probably due to simpler shallow structure and a thinner cover of attenuating sediments. As a result, particularly clear reflections from the base of the crust are evident. A band of layered, though discontinuous reflections at 11.5 to 12.0 secs on line 2A (Figure 6) occur at the estimated depth for the Moho in this area (Figure 2). It is suggested (Meissner, 1973) that the layered character results from interfingering of igneous intrusives and lower crustal granulite. Such intrusions need not be associated with development of the current rift structure. The discontinuous nature may be due to lateral Moho complexity, or raypath disruption in the overlying crust.

ACKNOWLEDGMENTS

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REFERENCES

Brocher, T. M., 1981, Geometry and physical properties of the Socorro, New Mexico, magma bodies: Jour. Geophys. Research, v. 86, p. 9420-9432.

Brown, L. D., et al, 1980, Deep structure of the Rio Grande rift from seismic profiling: Jour. Geophys. Research, v. 85, p. 4773-4800.

Cape, C. D., et al, 1980, Cenozoic normal faulting and the shallow structure of the Rio Grande rift near Socorro, New Mexico (abs.): EOS, v. 61, p. 1039.

Chapin, C. E., 1979, Evolution of the Rio Grande rift, *in* R. E. Riecker, ed., Rio Grande rift: tectonics and magmatism: Washington, D. C., Am. Geophys. Union, p. 1-5.

——— and W. R. Seager, 1975, Evolution of the Rio Grande rift in the Socorro and Las Cruces area: New Mexico Geol. Soc. Field Conf. Guidebook 26, p. 297-321.

Condie, K. C., and A. J. Budding, 1978, Geology and geochemistry of Precambrian rocks, central and south-central New Mexico: New Mexico Bur. Mines Mineral Resources Mem. 35, 58 p.

Cordell, L., 1978, Regional geophysical setting of the Rio Grande rift: Geol. Soc. America Bull., v. 89, p. 1073-1090.

Davis, G. H., G. K. Keller, and L. Cordell, 1978, A tectonic study of the San Luis Basin, Colorado, using gravity data (abs.): Internat. Symp. Rio Grande Rift (Sante Fe, N. M.).

Hermance, J. F., and J. Pedersen, 1980, Deep structure of the Rio Grande Rift: a magnetotelluric interpretation: Jour. Geophys. Research, v. 85, p. 3899-3912.

Jiracek, G. R., M. E. Ander, and H. T. Holcombe, 1979, Magnetotelluric soundings in major continental rifts, *in* R. E. Riecker, ed., Rio Grande rift: tectonics and magmatism: Washington, D. C., Am. Geophys. Union, p. 209-222.

Jurdy, D. M., and T. M. Brocher, 1980, Shallow velocity model of the Rio Grande rift near Socorro, New Mexico: Geology, v. 8, p. 185-189.

Kelley, V. C., 1956, Rio Grande depression from Taos to Sante Fe: New Mexico Geol. Soc. Field Conf. Guidebook, p. 109-113.

———, 1977, Geology of the Albuquerque Basin, New Mexico: New Mexico Bur. Mines Mineral Resources Mem. 33, 60 p.

Meissner, R., 1973, The Moho as a transition zone: Geophys. Surv., 1, p. 195-216.

Olsen, K. H., G. R. Keller, and J. N. Stewart, 1979, Crustal structure along the Rio Grande rift from seismic refraction profiles, *in* R. E. Riecker, ed., Rio Grande rift: tectonics and magmatism: Washington, D. C., Am. Geophys. Union, p. 127-143.

Reilinger, R. E., and J. E. Oliver, 1976, Modern uplift associated with a proposed magma body in the vicinity of Socorro, New Mexico: Geology, v. 4, p. 583-586.

Reiter, M., A. J. Mansure, and C. Shearer, 1979, Geothermal characteristics of the Rio Grande rift with the southern Rocky Mountain complex, *in* R. E. Riecker, ed., Rio Grande rift: tectonics and magmatism: Washington, D. C., Am. Geophys. Union, p. 253-265.

Sanford, A. R., et al, 1972, Seismicity of the Rio Grande rift: New Mexico Bur. Mines Mineral Resources Circ. 20, 19 p.

——— et al, 1973, Geophysical evidence for a magma body in the crust in the vicinity of Socorro, N. M., *in* J. G. Heacock, ed., The earth's crust: Am. Geophys. Union Geophys. Mon. Series 20, p. 385-403.

Toppozada, T. R., and A. R. Sanford, 1976, Crustal structure in central New Mexico interpreted from the Gasbuggy explosion: Bull. Seismological Soc. America, v. 66, p. 877-880.

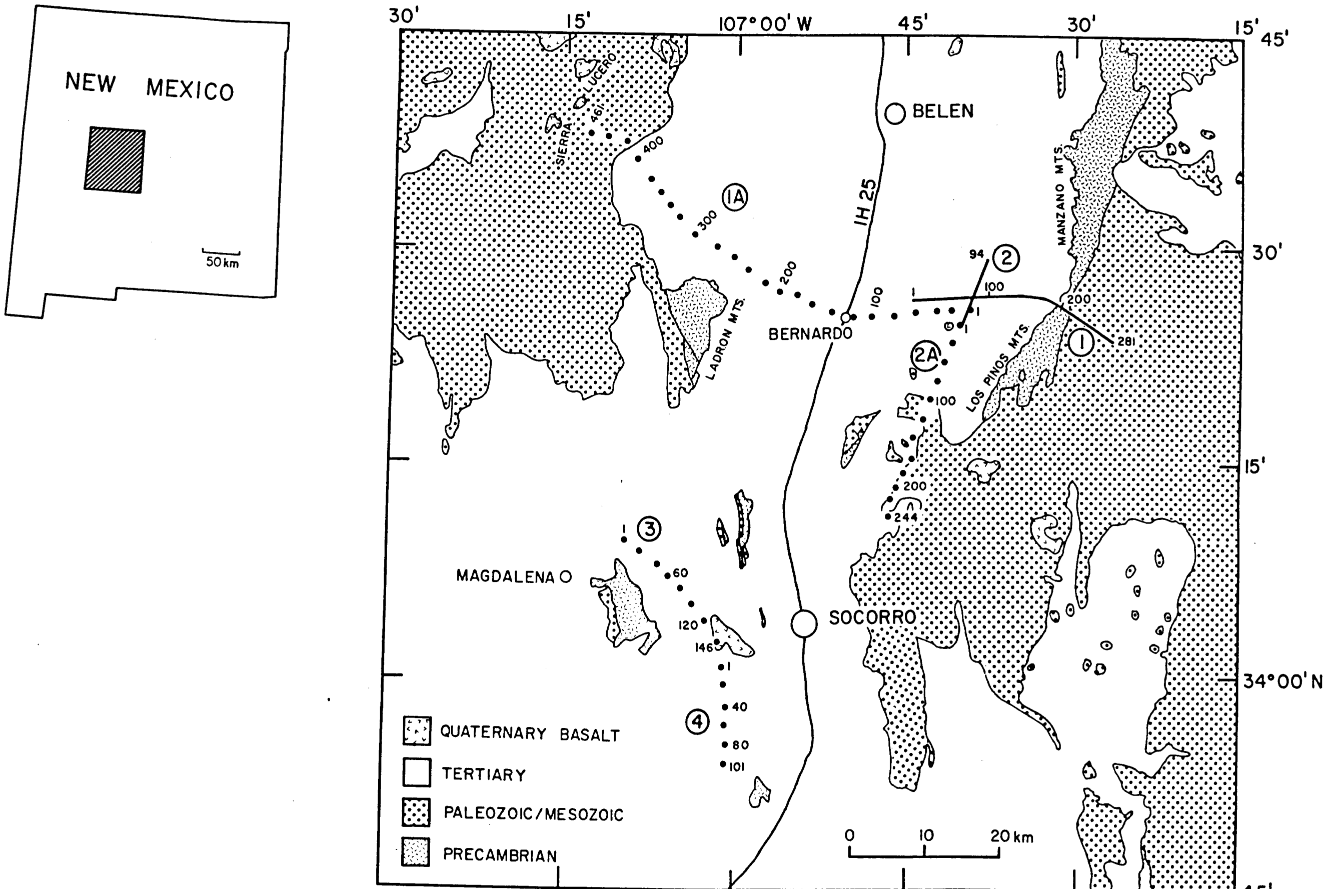


Figure 1: Location of COCORP lines in the southern Albuquerque basin from Brown et al (1980).

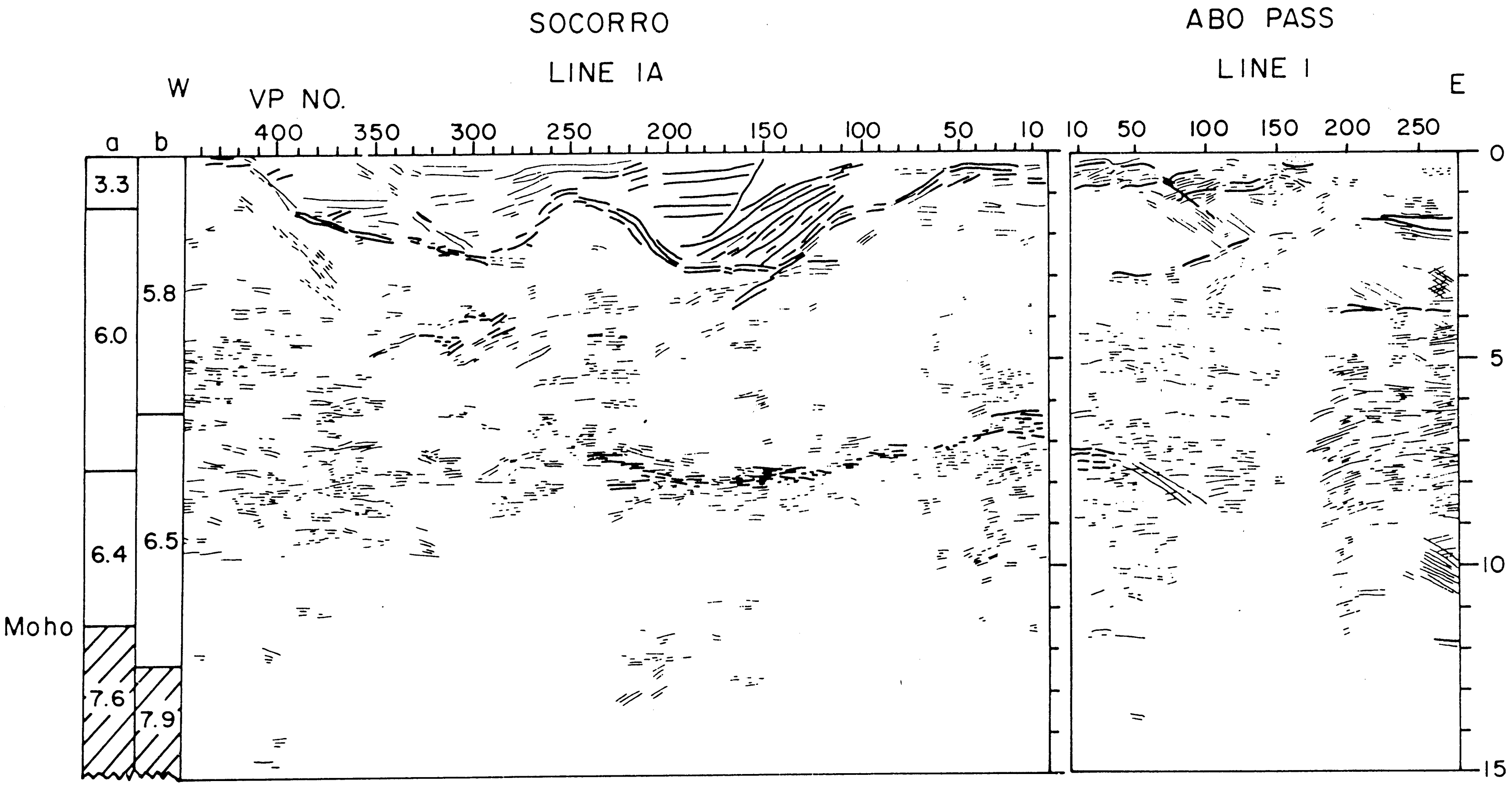


Figure 2: Line drawings of COCORP New Mexico lines 1 and 1A, after Brown et al (1980). Columns on the left represent crustal structure from refraction observations interpreted by **a** Olsen et al (1979) and **b** Toppozada and Sanford (1976).

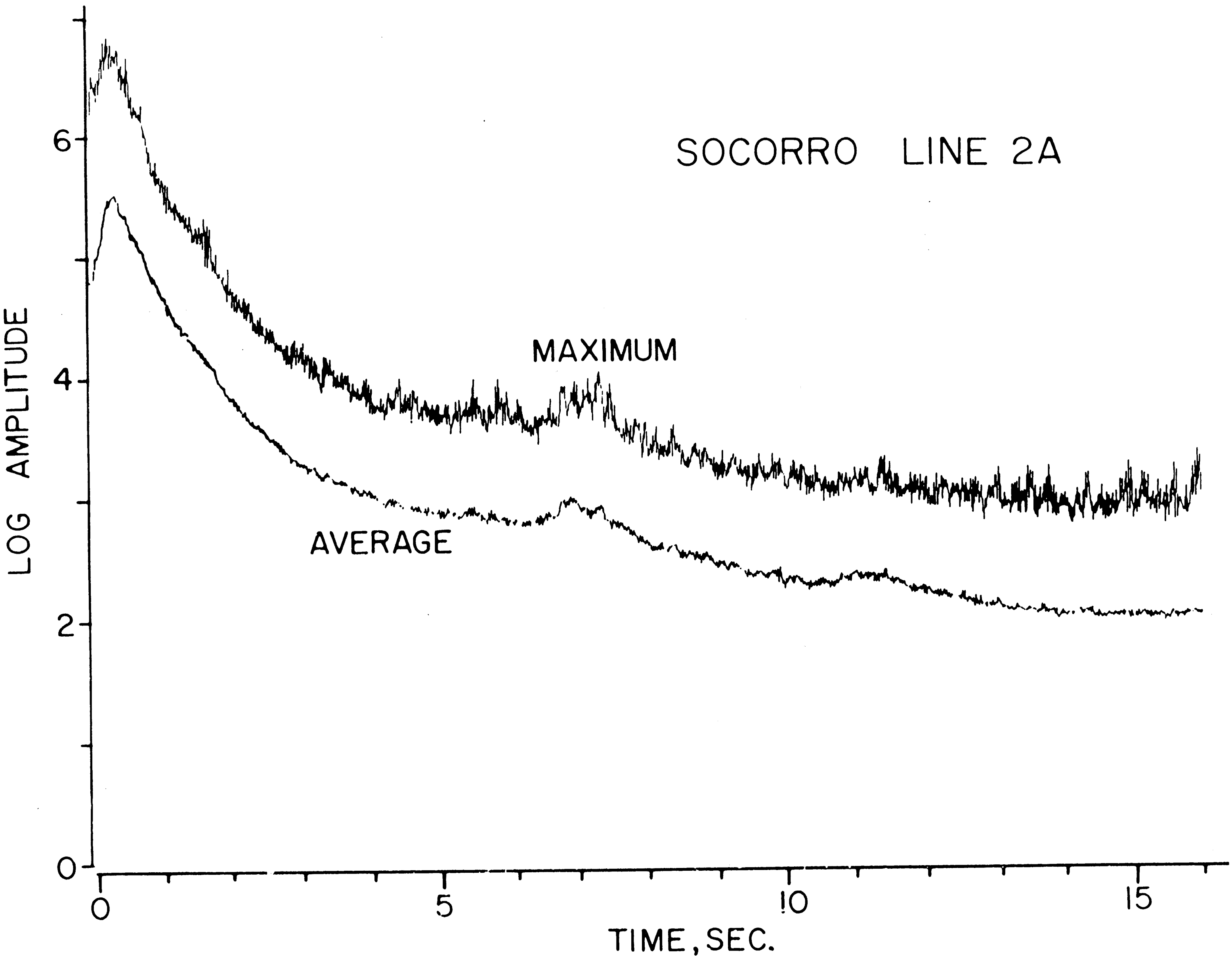
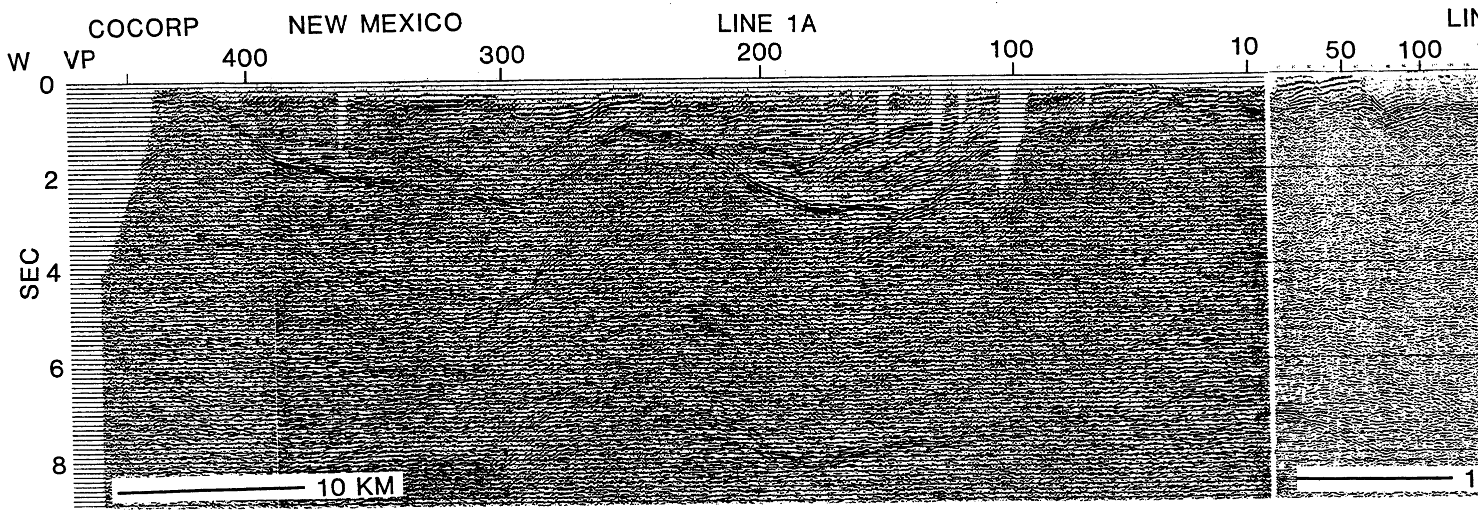


Figure 3: Amplitude decay curve for seismic traces on New Mexico line 2A.



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Line 1, 5.3 km/in (3.3 mi/in)
Vertical Scale (either in time and/or depth): 1.78 sec/in

Insert 1,
p. 1 of 2

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Deconvolution: Yes
Frequency Filtering: 8-32 Hz bandpass
Other: AGC with 1 sec window
Migration: No
Source of Velocities for Processing: Velocity Spectra

GEOPHYSICAL T

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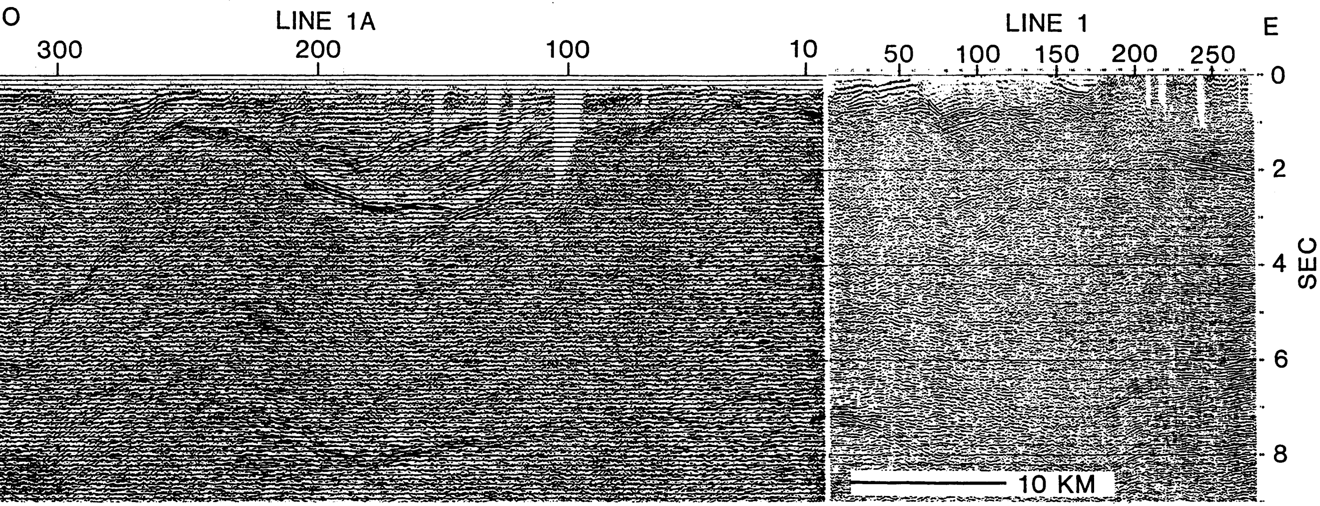

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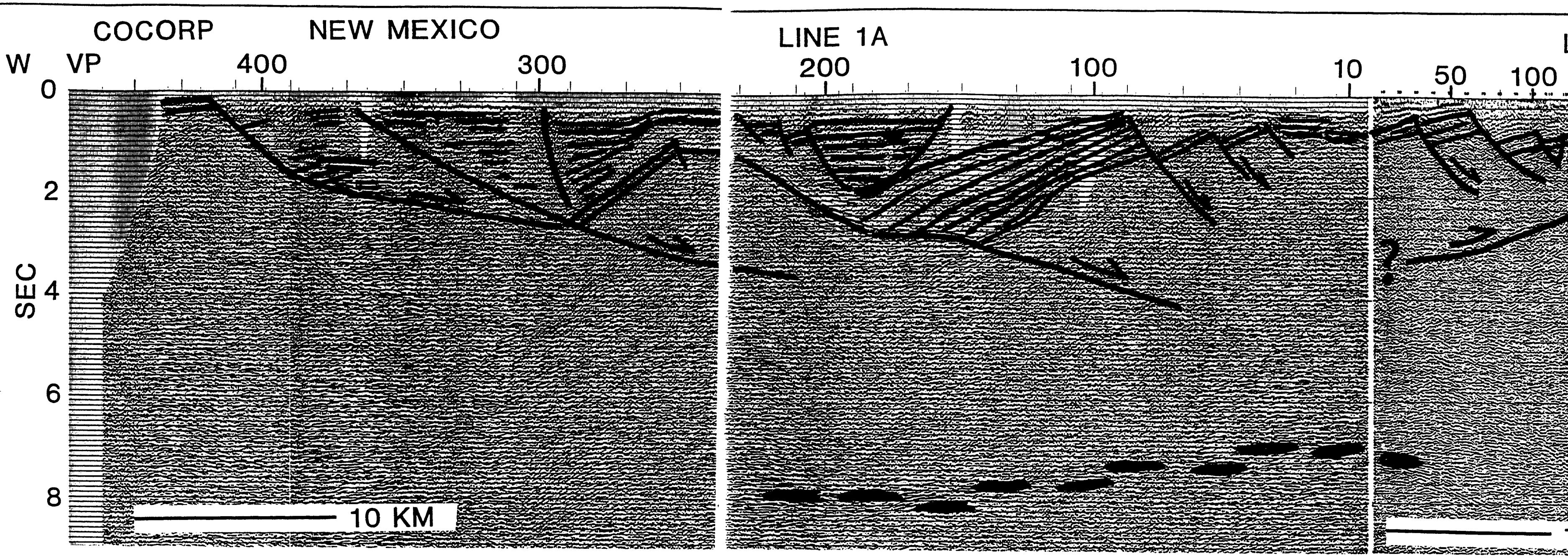

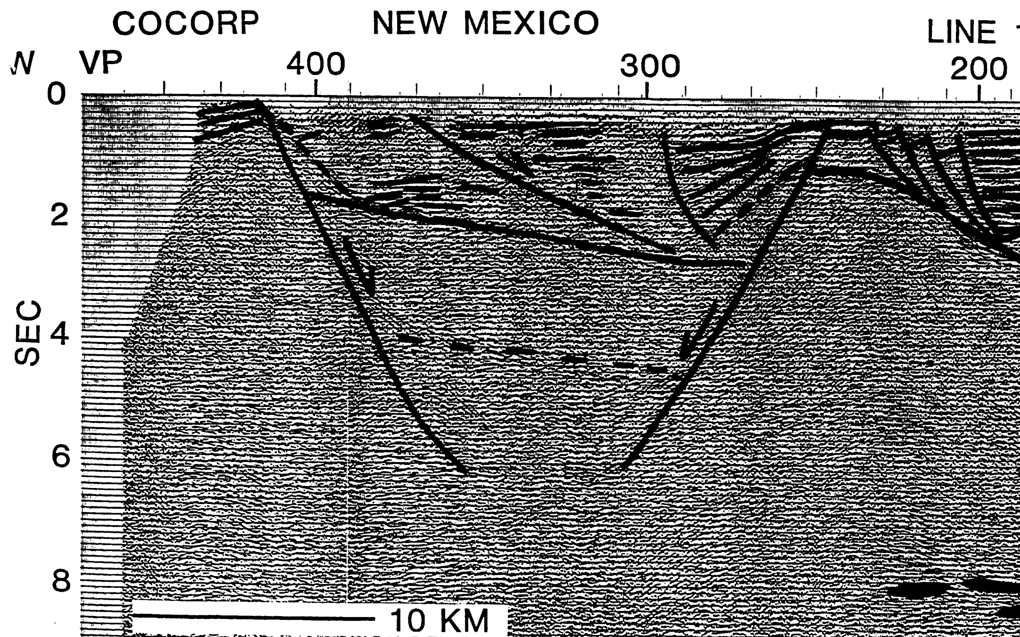

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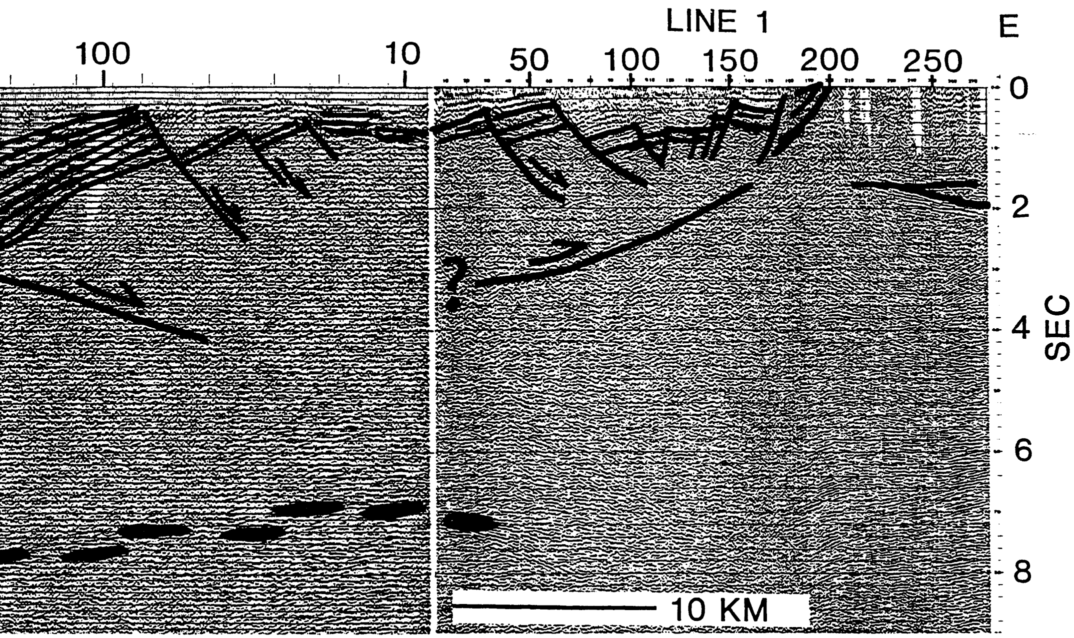
Vertical Scale (either in time and/or depth): 1.78 sec/in

Insert 2, p. 1 of 2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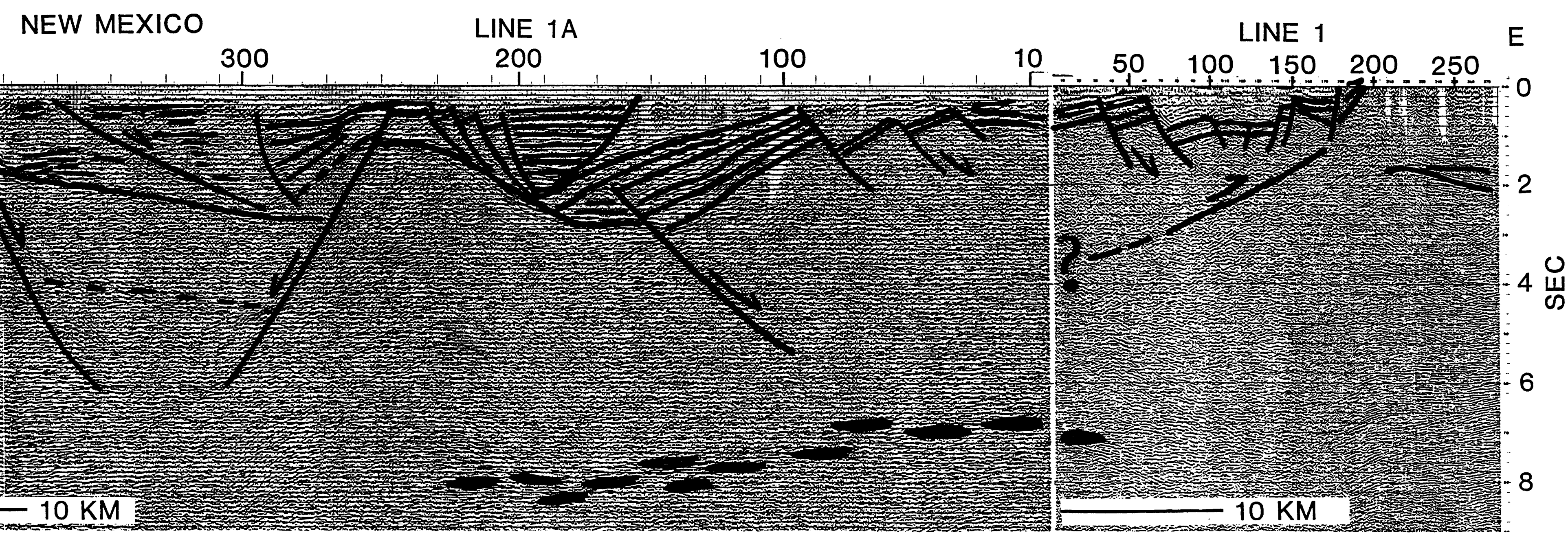
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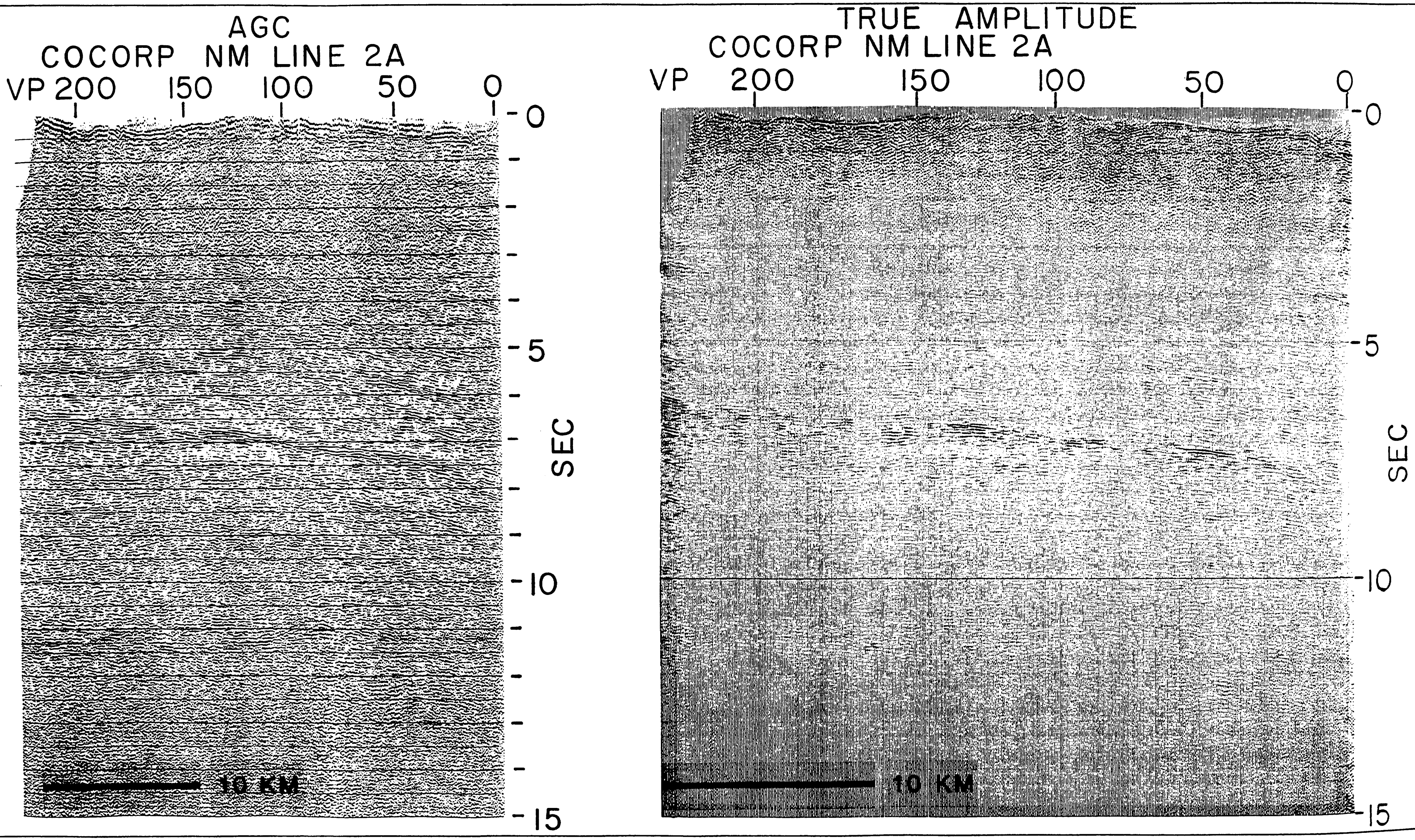
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MAIN TITLE BLOCK

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Vertical Scale (either in time and/or depth): 2.0 sec/in

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