Title
SEISMOLOGICAL STUDIES AT THE CERRO PRIETO FIELD: 1978-1982

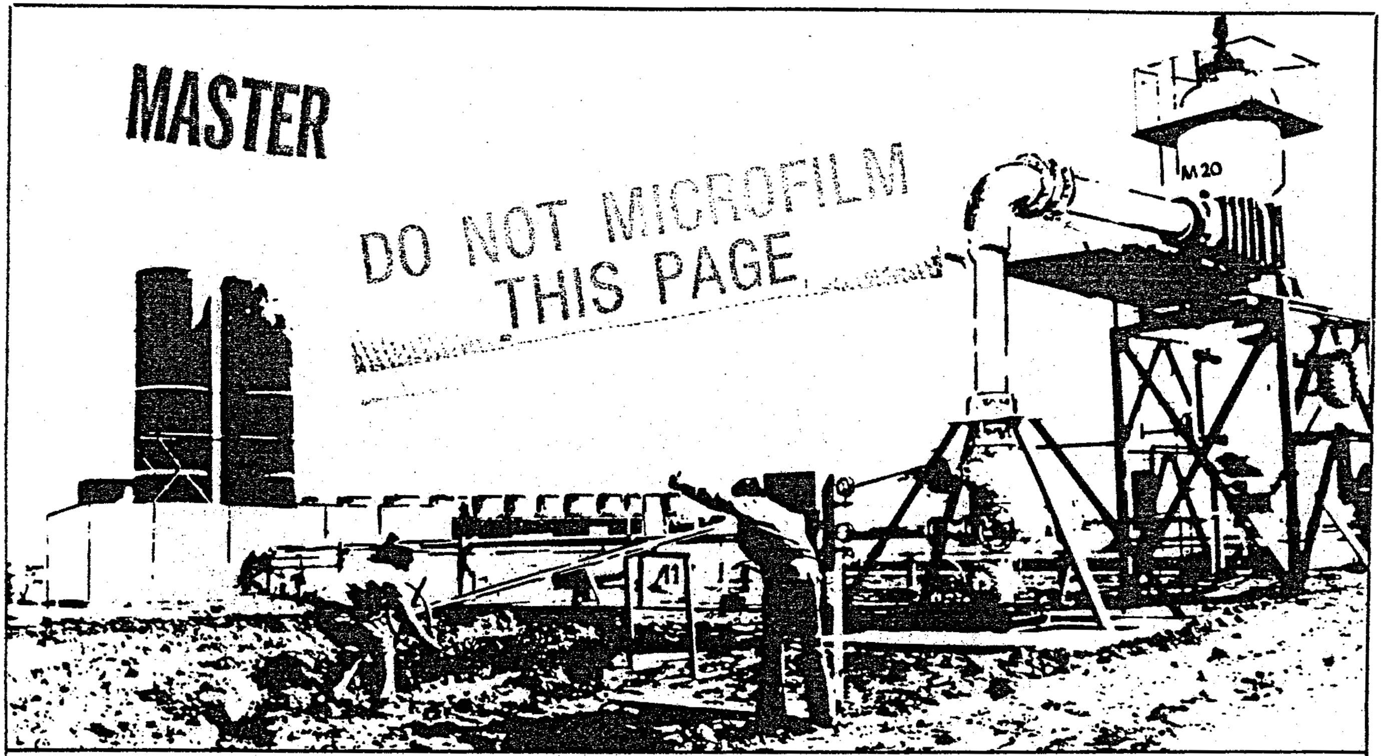
Authors
Majer, E.L.
McEvilly, T.V.

Publication Date
1982-10-01

CONF-8308109--7

LBL-14896
CERRO PRIETO-24

MEXICAN-AMERICAN COOPERATIVE PROGRAM AT THE CERRO PRIETO GEOTHERMAL FIELD



MASTER

DO NOT MICROFILM
THIS PAGE

Presented at the Fourth Symposium on Cerro Prieto Geothermal Field,
Guadalajara, Mexico, August 10-12, 1982

SEISMOLOGICAL STUDIES AT THE CERRO PRIETO FIELD: 1978-1982

E. L. Majer and T. V. McEvilly

October 1982

A Joint Project of

COMISION FEDERAL DE ELECTRICIDAD México	DEPARTMENT OF ENERGY Division of Geothermal Energy United States of America

Coordinated by

Coordinadora Ejecutiva de Cerro Prieto Apdo. Postal No. 3-636 Mexicali, Bja. Cfa., México and P. O. Box 248 Calexico, Ca. 92231	Lawrence Berkeley Laboratory Earth Sciences Division University of California Berkeley, California 94720 Operating for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

DISCLAIMER

Presented at the 4th Symposium
on the Cerro Prieto Geothermal
Field, Guadalajara, Mexico,
August 10-12, 1982.

LBL-14896
CP-24

LBL--14896

DE83 013844

SEISMOLOGICAL STUDIES AT THE CERRO PRIETO FIELD: 1978-1982

by

E.L. Majer[1] and T.V. McEvilly[2]

[1]Lawrence Berkeley Laboratory, University of California

[2]University of California, Department of Geology and Geophysics
Berkeley, California 94720

October 1982

This work was supported by the Assistant Secretary of Conservation and Renewable Energy, Office of Renewable Technology, Division of Geothermal and Hydropower Technologies of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

SEISMOLOGICAL STUDIES AT THE CERRO PRIETO FIELD: 1978-1982

E.L. Majer[1] and T.V. McEvilly[2]

[1]Lawrence Berkeley Laboratory, University of California
[2]University of California, Department of Geology and Geophysics
Berkeley, California 94720

INTRODUCTION

Since February of 1978, the University of California at Berkeley Seismographic Station (UCB) and Lawrence Berkeley Laboratory (LBL) have conducted varied seismological studies to determine the static and dynamic properties of the Cerro Prieto geothermal field. Sought have been the relation of wave propagation characteristics and microearthquake activity to such features as production boundaries, recharge zones, heat sources, fluid strata, lithology and structure Discussed here will be the results of the studies carried out by UCB-LBL since 1978 in light of the current knowledge of the Cerro Prieto field. Also included will be the interpretation of the reflection surveys carried out in the immediate production areas.

SEISMICITY

The Cerro Prieto geothermal field lies within the tectonically active Salton Trough which is dominated by right lateral strike-slip faulting. It has been hypothesized by others that the occurrences of geothermal activity within the Salton Trough coincides with areas of transform faulting It is argued that these spreading centers result in crustal thinning and allow magma to ascend to shallow depths providing a heat source for geothermal activity.

If transform faulting is the cause for the heat source at the Cerro Prieto geothermal field one could expect the earthquake mechanisms to be consistent with northwest-southeast tension, i.e. normal faulting in the transformed zone. Also due to the relativly active tectonic nature of the Salton Trough, it would not be unreasonable to expect these areas to be seismically active (assuming near normal b-values). The Imperial and Cerro Prieto fault systems, which form the strike-slip portions of the transform faulting in this region, have been the location of several large earthquakes in the past several years (M_L=6.6, 10/79; M_L=6.7, 8/80)(Albores et al., 1980; Wong and Frez, 1981). This indicates that due to this high activity, the earthquake activity in the Cerro Prieto field area should be quite high, assuming transform faulting.

In addition to the active tectonic nature of this region, there may be other contributing factors to the seismicity in the production zone. Work at The Geysers geothermal field in northern California has shown a definite relation between increases in production activities and earthquake activity (both in maximum magnitude and number of events) (Marks et al., 1978).

Several different mechanisms have been hypothesized to explain this phenomenon. Allis (1981) reasons that the area is undergoing a transformation from aseismic creep to discrete failure. Two different mechanisms to produce this "stick-slip" behavior are proposed:

1) reduction of pore pressure resulting in an increase in effective stress, and

2) an increase in the coefficient of friction.

Denlinger and Bufe (1981) and Denlinger et al (1981) have put forth another possible cause for the seismicity increase. They postulate that due to cooling of the reservoir, the thermal contraction of the rocks causes a decrease in the effective stress, thus causing an increase in the seismicity. Still yet another cause may be the increase in pore pressure due to injection activities, however, the injection pressures are well below the hydrostatic gradient, injection is probably not a major cause of the seismicity.

RESULTS AT CERRO PRIETO

Shown in Figure 1 is a summary of the measured seismicity in the immediate production zones from three periods of monitoring by UCB-LBL. The 1980 and 1981 studies were identical using the same station placement and instrumentation (4.5 Hz vertical geophones with the data FM telemetered to M-6 where they were digitized at 100 samples/sec and processed on-line in real time with ASP) (McEvilly and Majer, 1982). The 1978 study used slightly different station placement but the dimensions were similar and the data were obtained with the same instrumentation. However, the data in the 1978 study were recorded on magnetic tape (bandwidth, DC to 80 Hz) and returned to Berkeley for analysis.

In addition to these three detailed studies in February 1978, November 1980 and November 1981 of five, four, and four weeks respectively, a 3-component 4.5 Hz downhole geophone has been in a 100 meter well near well M-6 since November of 1980. The data are FM telemetered to the office complex and recorded on a pen and ink drum recorder at 60 mm/sec. The purpose of this single station is to tie the seismicity rates observed in the detailed studies to the overall seismicity rates. In this way, a baseline of seismicity rates can be maintained.

The 1978 study (Majer et al.) indicated low seismicity levels ($M_L \geq 1$) within the immediate production zone. During the five week study, only two days had any significant activity. Only six events were recorded on six or more stations. These events were located at depths of 2-3 kilometers south of well M-9 (shaded area in Figure 1).

The 1980 and 1981 studies revealed significantly different earthquake patterns and rates of activity. Shown in Figure 1 are the locatable events. Although there were a similar number in 1980 and 1981, the total number of events detected on four or more stations increased from 3 per day in 1980 to 7 per day in 1981. Although there was a major earthquake in June of 1980 which could account for the increase from 1978 to 1980 it is difficult to explain the 1980-1981 increase by aftershock activity. The same number of events that are locatable indicates that although the number of events detected is increasing, the magnitude of the events is not increasing. This may be due to a limited source region and/or the upper threshold on the strength of the materials in the production zone has been reached.

Although reliable source mechanisms were difficult to obtain, the 1978 events indicated strike-slip faulting on northwest-southeast trending faults. The 1980 and 1981 studies were ambiguous and fault planes consistent with either normal or strike-slip faulting could be fitted to the P-wave first motion patterns.

The distribution in space of the 1980 and 1981 events is worth noting. In 1980, the events were clustered near the center of the production zone on a nearly north-south line extending from M-101 to the power plant. The depths varied from 2 to 5 kilometers and formed a fairly well defined plane. However, the 1981 study revealed a rather diffuse pattern of events concentrated on the western edge of the field. This diffuse pattern with no defined fault system is also characteristic of earthquakes at The Geysers. Although the two areas are geologically quite different, mechanisms which trigger the events may be similar. At Cerro Prieto, the well log information, geophysics, and geological mapping have shown a very complex zone of faulting in the production field. Depending upon the age and state of the transform faulting, there may be additional faulting superimposed upon the transform system. The diffuse pattern of these events and the increase in seismicity may be an indication that this area is undergoing a transformation from aseismic creep to stick-slip behavior, accelerated by production activities.

Continuous monitoring by the single station of M-6 has revealed no abatement in earthquake activity within the field. Construction and production activities make it difficult to monitor seismic activity, but due to the complex nature of the field, the microseismicity may offer important clues to the dynamic behavior of the reservoir. Goldstein et al. (1982) from magnetic data has indicated a possible dike complex on the eastern edge of the field. If this is the elusive heat source, the cooling and intrusion would be a source of microearthquake activity, although not on a continuous basis if the intrusion process were episodic. Although no earthquake activity was detected in this region, it may be due to lack of station coverage and high noise levels. By emplacing several down-hole geophones in this region, important information could be obtained.

ANALYSIS OF SEISMIC REFLECTION RESULTS

Shown in Figures 2, 3, 4, and 5 are reflection sections A, B, D, and E, respectively obtained by CFE. The location of these lines is shown in Figure 6. The processing scheme with the parameters are listed in Table 1.

TABLE 1

Parameters of the Seismic Reflection Survey

Sample Rate	4 milliseconds
High cut filter	60/80
Low cut filter	16/24
Number of vibrators	3
Number of sweeps/vibration	4
Sweep parameters	16-64, 16-72, 20-80 Hz linear, varisweep 4.8 sec listening
Station interval	110 ft

Coverage

Line A	24 fold
B	47 fold
D	97 fold
E	22 fold
F	33 fold

Processing

1. Demultiplex
2. Vari sweep-crosscorrelation
3. Line geometry
4. Elevation statics
5. Residual statics
6. CDP gathers
7. NMO velocity
8. Front and tail mute
9. NMO and multifold stack
10. Frequency filtering
11. Final display

As can be seen, the processing was conventional with no migration analysis performed The sections are also time sections with no time to depth conversion done. Due to this lack of processing it would be hazardous to interpret these sections in any great detail. However, several significant features can be noted, especially with the aid of the extensive well log analysis carried out by Halfman et al. (1982). Shown in Figure 8, is a cross-section of the field from well log analysis. Of note are the A/B contact, the fault at M-150 to M-117, and formations 3, 4, 5, and 6. These features also appear on the seismic cross-section and can be correlated from line to line. In general the A/B contact is traceable as the top of the zone of no reflections The A/B contact appears at its shallowest depth in the area of M-9 and deepens towards the edges of the field and finally disappears altogether. As can also be seen, the A/B contact cuts across the bedding planes.

Also of note is one significant fault, identified by Halfman et al. (1982) in the well logs. This fault is best seen on Line D of the seismic data. This fault is in the approximate location of the Hidalgo fault, although according to Halfman it is not the same fault and there is no evidence on the well logs for the Hidalgo fault. The A/B contact, as well as units 4 and 5, can be traced on Lines A, and B. Also, at the western edge of Lines A, and especially D and E, the bedding can be seen dipping and truncated by the Cerro Prieto fault system. In general the faults are difficult to identify; no migration was performed, and the lateral heterogeneity adds another complication from side reflections. Also a time to depth conversion using varying velocity analysis as well as sonic logs would greatly add to the interpretation of the data.

CONCLUSIONS

1) Sesimicity has increased from 1978 from 1-2 events/day to 7-8 events per day in the immediate production zone ($M_L \geq 1$).

2) These events appear to be production related and weakly connected to the major tectonic events in the area.

3) Monitoring should continue with detailed studies covering the newer production area east of the railroad track.

4) The reflection data indicate definite reflections associated with the A/B contact

5) This A/B reflector is seen only in certain parts of the reflection sections, indicating it is not a lithologic boundary but possibly alteration associated with the hotter parts of the field. It may possibly be used for exploration purposes.

6) Detailed reprocessing should be carried out in the zones of interest to define better the structure associated with the production zone. Techniques such as migration before stack and time-to-depth conversions should be applied.

7) The sesimic data, both passive and active, if used correctly, is a powerful method to analyze structure and reservoir characteristics.

ACKNOWLEDGEMENTS

We would like to acknowledge the CFE and LBL field personnel and geophysicists whose expertise was crucial to collecting the data used in this paper. We also thank CFE for providing us with the seismic reflection data. This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Renewable Technology, Division of Geothermal and Hydropower Technologies of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

REFERENCES

Albores, A., A. Reyes, J.N. Brune, J. González L. Garcilazo and F. Suárez, 1980. Seismicity studies in the region of the Cerro Prieto geothermal field, Geothermics, Vol. 9, p. 65-77.

Allis, R.G., 1981. Comparison of mechanisms proposed for induced seismicity at The Geysers geothermal field. Proceedings of N.Z. Geothermal Workshop, University of Auckland.

Denlinger, R.P., and C.G. Bufe, 1981 Seismicity induced by steam production at The Geysers steam reservoir, northern California: manuscript in preparation.

Denlinger, R.P., W.F. Isherwood, and R.L. Kovach, 1981. Geodetic analysis of reservoir depletion at The Geysers steam field in northern California: Journal of Geophysical Research, Vol 86, p. 6091-6096.

Goldstein, N.E., M.J. Wilt, and D.J. Corrigan, 1982. Analysis of the Nuevo Leon magnetic anomaly and its relation to the Cerro Prieto Magmatic-Hydrothermal system, (this volume).

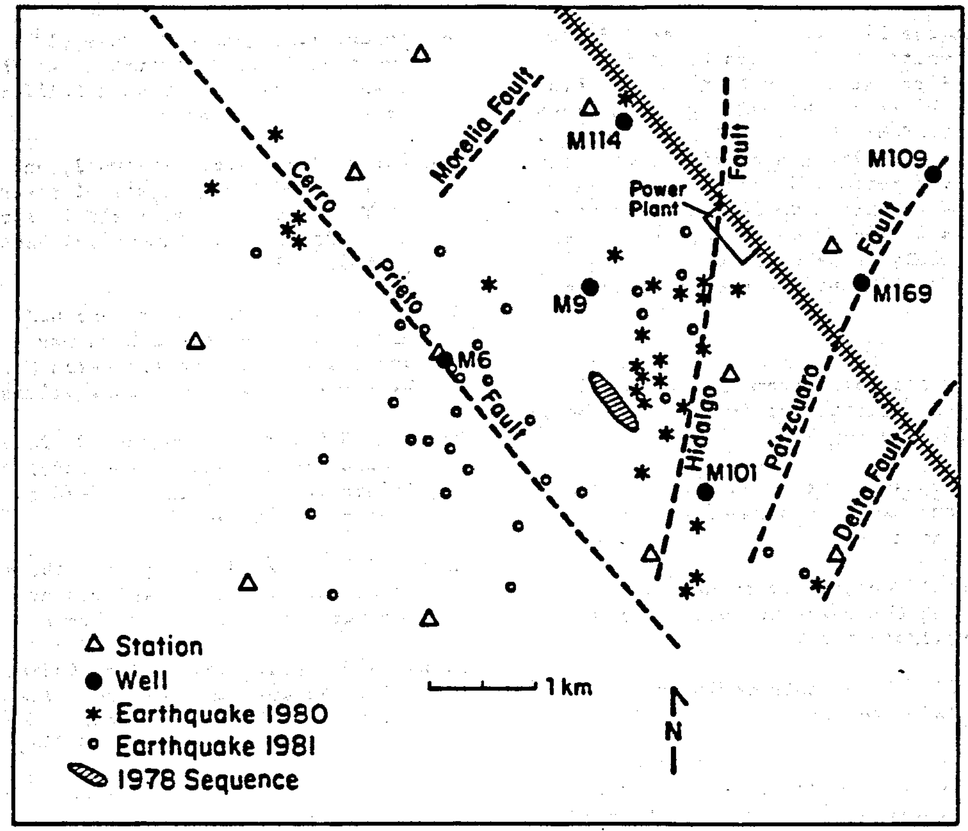
Halfman, S.E., M.J Lippmann, R. Zelwer and J.H. Howard, 1982. Fluid flow model of the Cerro Prieto geothermal field based on well log interpretation, (this volume).

Majer, E.L., T.V. McEvilly, A. Albores. and S. Díaz, 1980. Seismological studies at Cerro Prieto, Geothermics, Vol. 9, pp. 79-88.

Marks, S.M., R.S. Ludwin, K.B. Louie, and C.G. Bufe, 1978. Seismic monitoring at The Geysers geothermal field, California U S. Geological Survey, open-file report 78-798, 26 p.

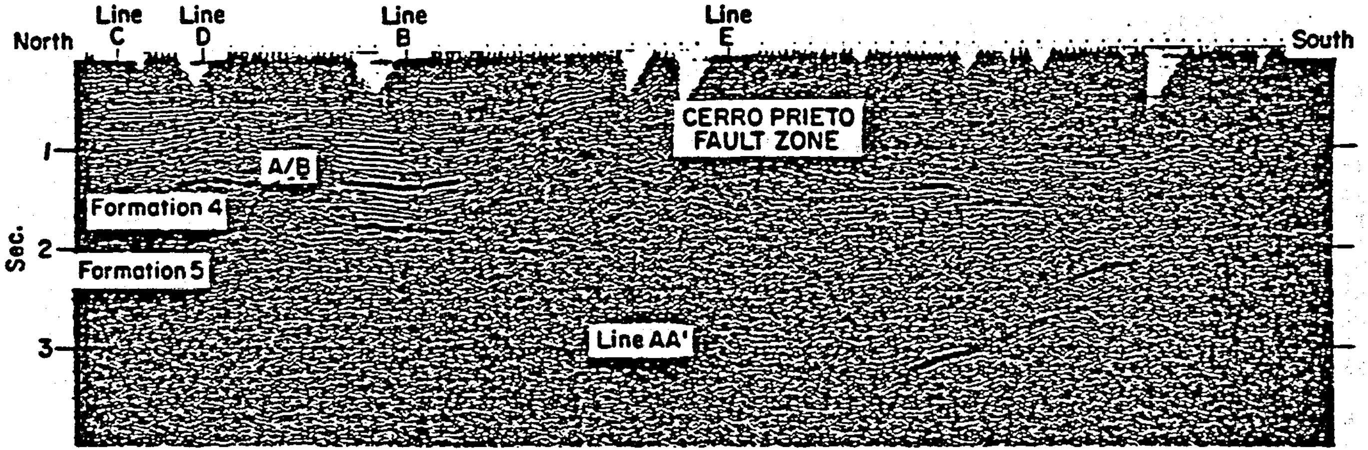
McEvilly, T.V., E.L. Majer, 1982. ASP: An Automated Seismic Processor for microearthquake networks. Bulletin of Seis. Soc. of Am., Vol. 72, No 1, p. 303-325.

Wong, V. and J. Frez, 1981. Seismicity and arrival-time residuals from the Victoria Earthquake of June 9, 1980 in Proceedings, Third Symposium on the Cerro Prieto Geothermal Field, Lawrence Berkeley Laboratory, Berkeley, California, LBL-11967, p. 338-343.



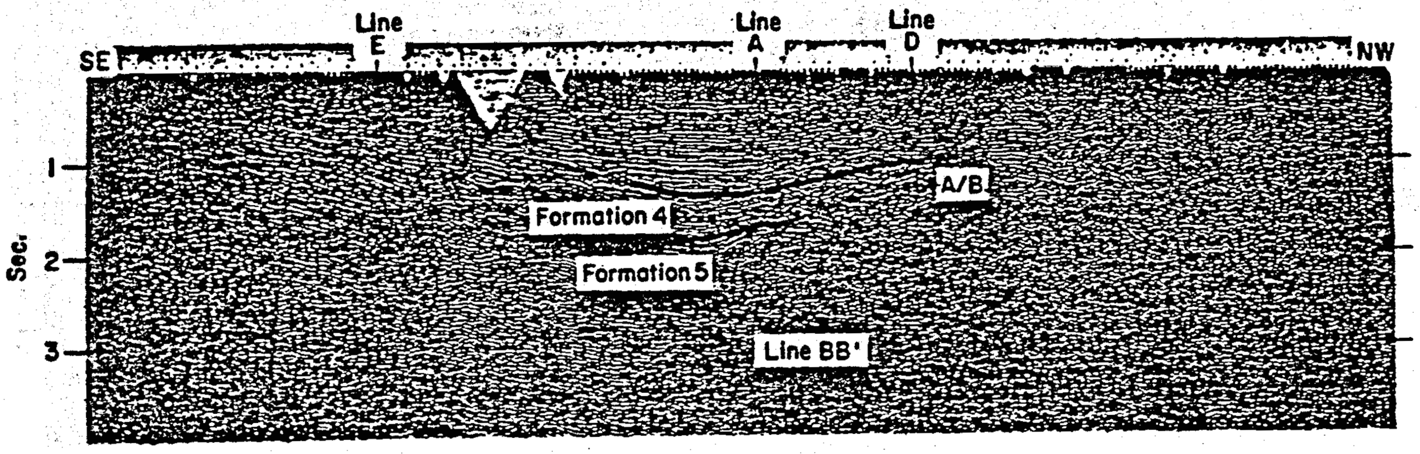
XBL 821-1773A

Figure 1. Location of earthquakes during the 1978, 1980, and 1981 detailed microearthquake surveys.



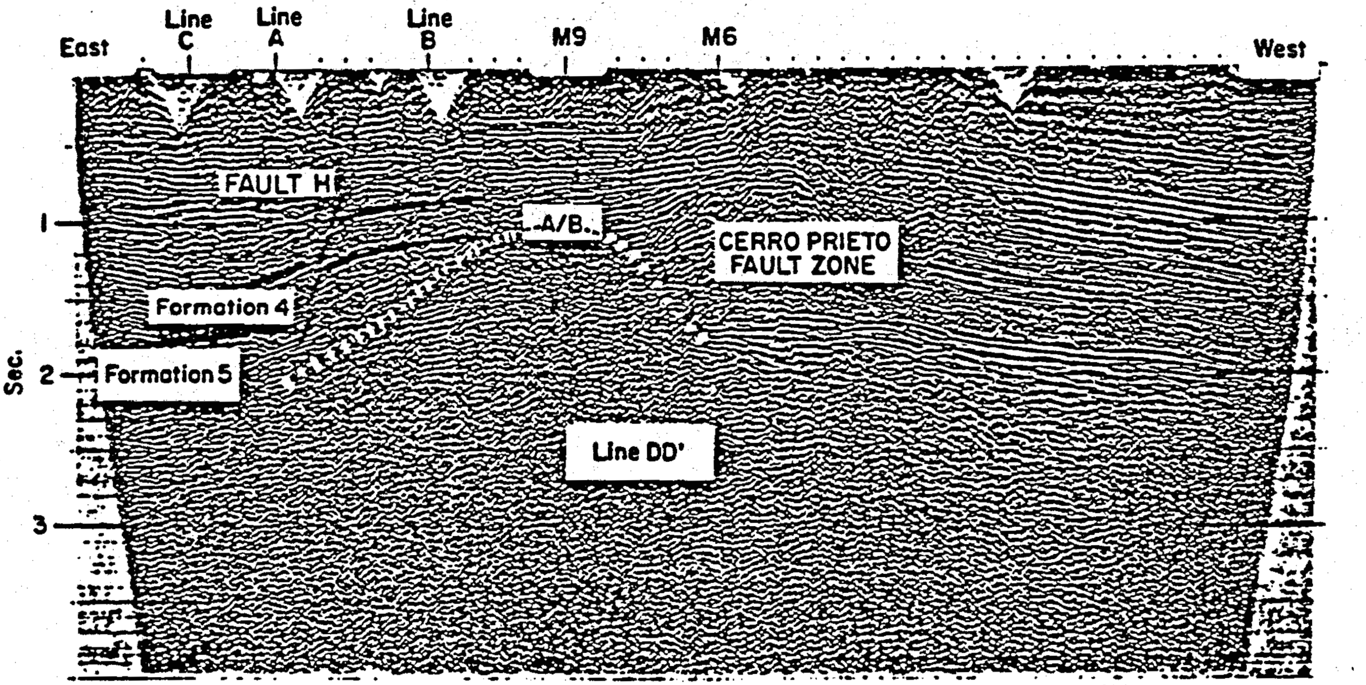
XBB 828-6852A

Figure 2. Reflection section AA'. Notice the A/B contact reflection and its relation to lithologic units in contact with it. Formations 4 and 5 are described in Halfman et al. (this volume). Also notice the north dipping units at the southern end of the line, and the zone of no reflection in the center, corresponding to the Cerro Prieto fault system.



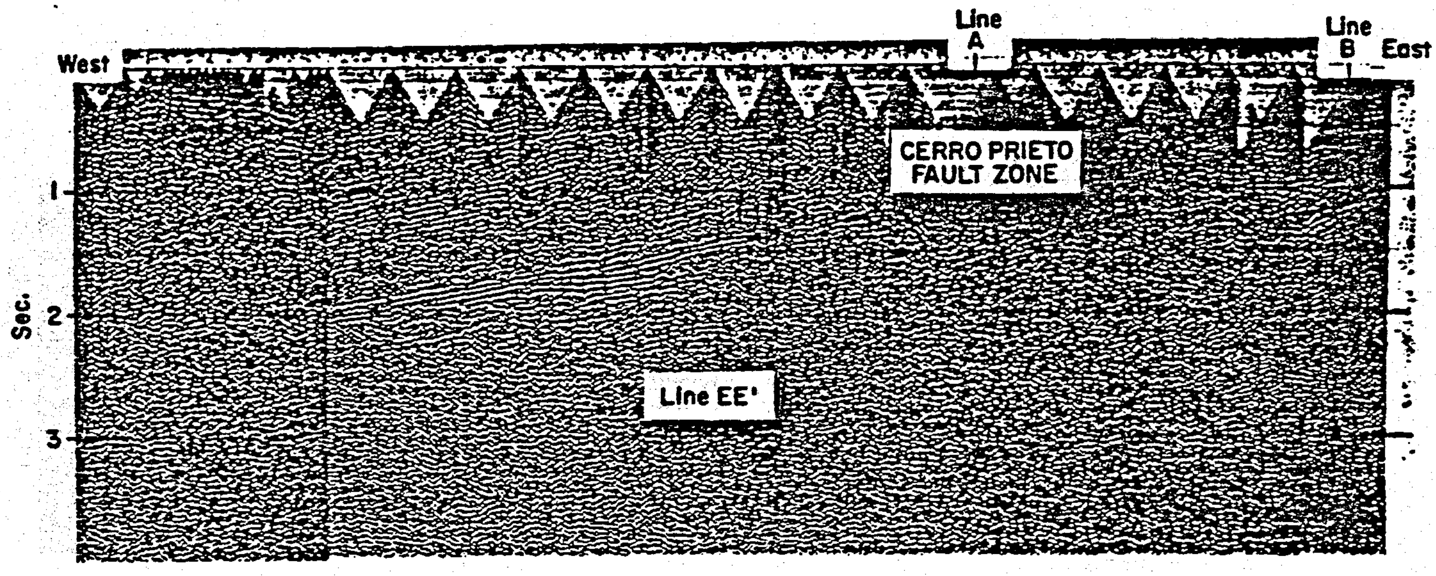
XBB 828-6846A

Figure 3. Reflection section BB'. Notice, formations 4 and 5 and the A/B contact. Also notice the relatively good reflector along most of the line, indicating fairly continuous lithology.



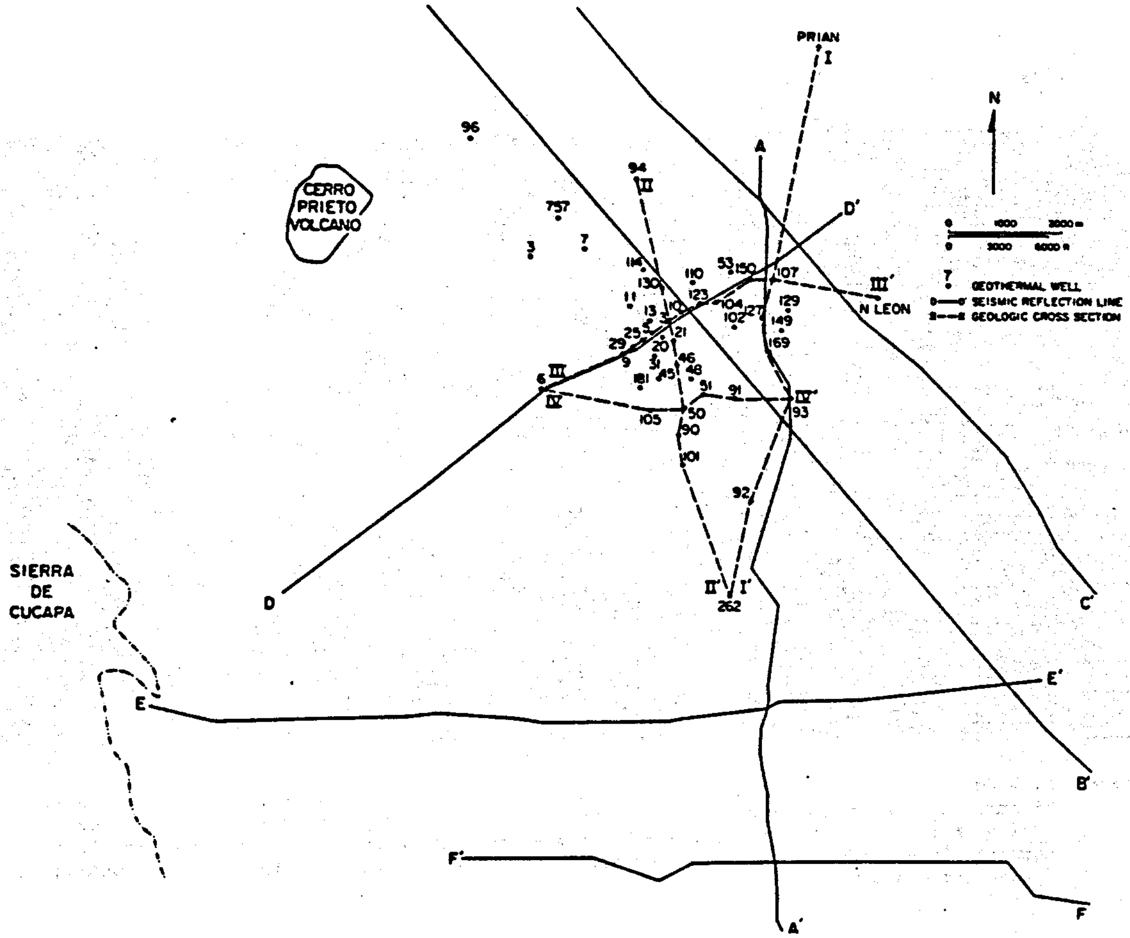
XBB 828-6850A

Figure 4. Line DD'. Probably the most interesting seismic profile. This line extends from several kilometers west of the production zone, through the center of the field, to the eastern edge of the field. Of note is the well-defined bedding to the west, the discontinuity and unconformities near well M-6, the definition of the A/B contact and the faulting cutting formations 4 and 5.



XBB 828-6848A

Figure 5. Line EE'. A good example of the structure in this region, notice the lact of reflectors around the intersection of Line A, the Cerro Prieto fault system, and the dipping beds.



XBL 801-6752

Figure 6. Index map showing the location of the seismic reflection lines.