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CERRO PRIETO -08
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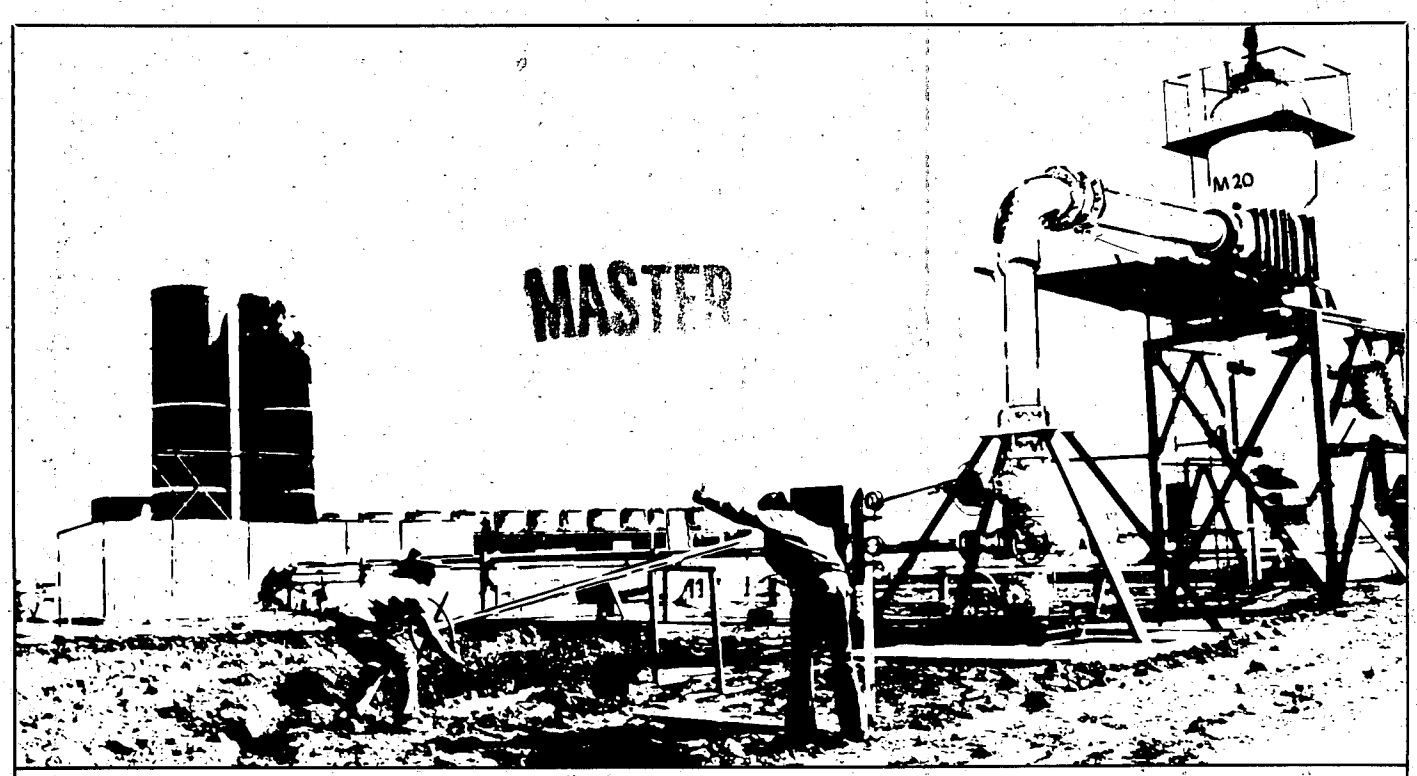
MEXICAN-AMERICAN COOPERATIVE PROGRAM AT THE CERRO PRIETO GEOTHERMAL FIELD



EARTHQUAKE MONITORING AT THE CERRO PRIETO GEOTHERMAL FIELD

E. L. Majer and T. V. McEvilly

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Division of Geothermal Energy
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ABSTRACT

A three-week study in spring 1978 revealed more moderate earthquake activity (one or two events/day, $M_L \geq 1$) in the Cerro Prieto production zone. Plotting these events on a Wadati diagram we estimated an 0.4 Poisson's ratio for the upper 1 to 2 km of the field. The events were centered near the western edge of the production zone, near well M-6, and indicated strike-slip movement on north-south faults.

To monitor the earthquake activity and propagation characteristics within the production zone, a five-station, semi-permanent array was put into operation in September 1979. The stations are closely spaced (1 to 2 km), surrounding a central station at M-6. Each station consists of a three-component 4.5-Hz geophone in a 100-m well connected to a 12-bit triggered-digital-cassette recorder. Although each station operates independently, they are interconnected via a hard-wire link to a central site. The purpose of this link is twofold: first, to allow telemetry of any selected station to the central site for visual monitoring; second, to provide an automatic daily time calibration to keep inter-station errors to less than 5 ms. The data from these stations will be used to monitor earthquake activity and wave propagation characteristics associated with fluid withdrawal and/or injection in the geothermal reservoir.

INTRODUCTION

The utility of microearthquake studies in geothermal regions is not restricted to exploration applications. Information from these studies may be important in delineating reservoir boundaries and in monitoring environmental effects such as subsidence and induced seismicity. By using the variation in propagation characteristics of P and S waves as well as the source characteristics of microearthquakes, information relating to the stress field, temperature, and fluid state can be obtained. Continuous monitoring of these properties in producing geothermal fields may provide a means to detect dynamic reservoir boundaries, areas of recharge, and changing fluid state.

As a reservoir is produced, there will be relatively large stress and thermal gradients produced by the withdrawal and reinjection of fluids. Stress gradients may affect the nature of seismicity, especially in a region as tectonically active as the Salton Trough. Although the Cerro Prieto field and other geothermal regions in the Imperial Valley (such as East Mesa) are fluid dominated, continued production may induce areas of steam domination. Recent laboratory wave propagation studies (Nur and Winkler 1979) indicate that relative P- to S-wave attenuation studies may be particularly useful for delineating regions of partial saturation. Therefore, we hope that continuous microearthquake monitoring with occasional detailed wave propagation studies will be able to detect subtle changes in the static and dynamic properties of the reservoir.

MONITORING PROCEDURES

In February 1978 a velocity, attenuation, and preliminary microearthquake study was carried out at Cerro Prieto (Majer et al., 1979). With the results of that study a permanent five-station array was designed to monitor continuously the temporal and spacial variation in seismicity throughout the production zone. The five closely spaced stations were located to supplement the data from the CICESE stations surrounding the production region (Fig. 1). Also shown in Figure

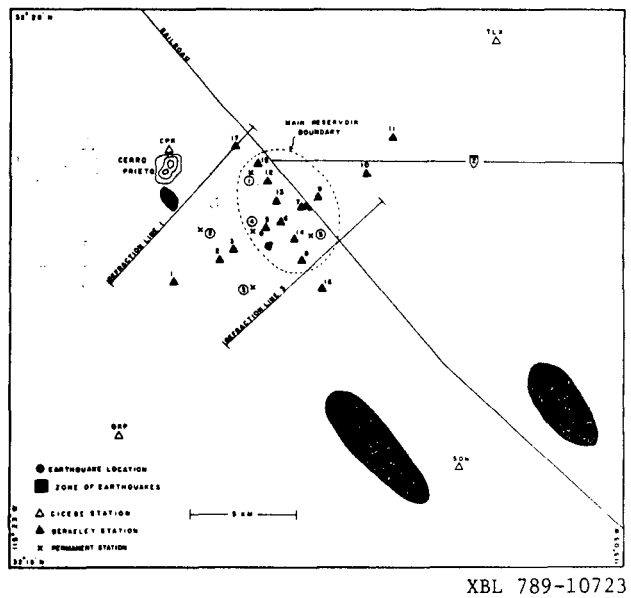

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Figure 1. Station location of permanent array relative to 1978 study; seismic activity is indicated by the shaded regions.

1 are regions of the high seismicity detected during the 1978 study. None of the seismically active regions (shaded) lie within the production zone. Only several events with magnitude greater than 1 were detected in the reservoir region, all occuring on one day. The permanent stations were located so that minimum ambiguity would occur in fault plane solutions for events within the reservoir. The 1978 study indicated that the events within the field were on northwest-southeast trending faults with right lateral strike-slip motion. However, if the Cerro Prieto field is in a region of transverse faulting, normal faulting would be expected.

Data are collected at each station with a three-component 4.5-Hz geophone in a 100-m borehole. The holes were drilled and cased by CFE. At the top of each hole an instrument box houses a Sprengnether DR-100 and five 2.5-V McGraw-Edison air cell batteries (Fig. 2). Air cell batteries were chosen due to their high amp-hour rating (≈1200 A-hr), although their peak output is only between 1/2 and 1 A. The batteries should last one year with the DR-100. The DR-100 is a triggered digital cassette recorder. The recorder was set at 200 samples/sec with triggering levels (short-term average and long-term average) set for microearthquake detection (Fig. 3). Although the signal-to-noise ratio is improved by 20 dB by placing the geophones at depth, other problems were encountered. In addition to the disadvantage of permanent borehole sites, the warm temperature of the water (50 to 100°C) produced O-ring deterioration in the sondes thus causing the geophone packages to leak. Standard O-rings should be replaced with viton or silicon rings. We also found that the standard rubber cable deteriorates in warm temperatures. The normal rubber shielded cable was replaced with a polyurethane shielded cable.

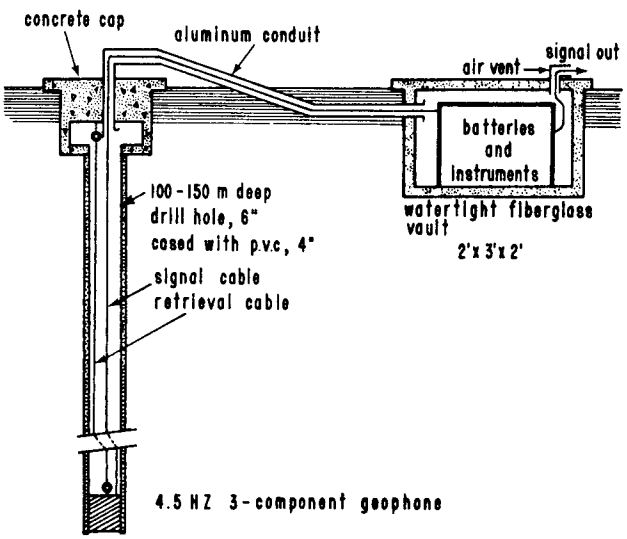

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Figure 2. Station configuration; instruments are buried for temperature control.

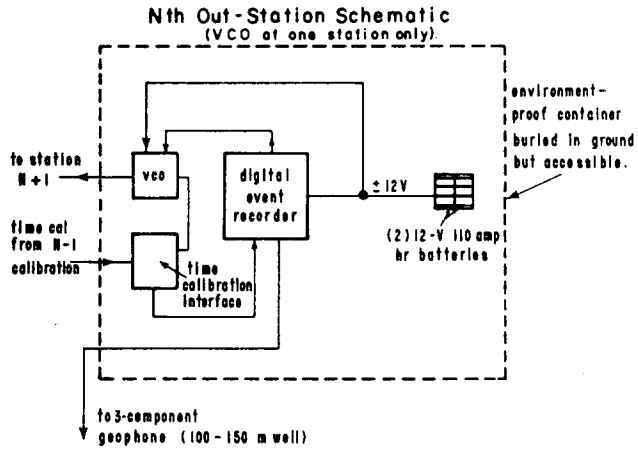

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Figure 3. Station electronics showing trigger control for time fiducial and vco for visual monitor at control site.

Each station is connected by a single twisted pair of wires, forming a loop around the array (Fig. 4). Also in the loop is a central site housing a visual monitor and time code clock. On one wire of the twisted pair loop a daily trigger pulse is carried to each station at a specified time to correct for clock drift at the remote stations (Fig. 5A). The other wire of the twisted pair carries an FM signal from one of the five stations to a discriminator at the central site whose output is

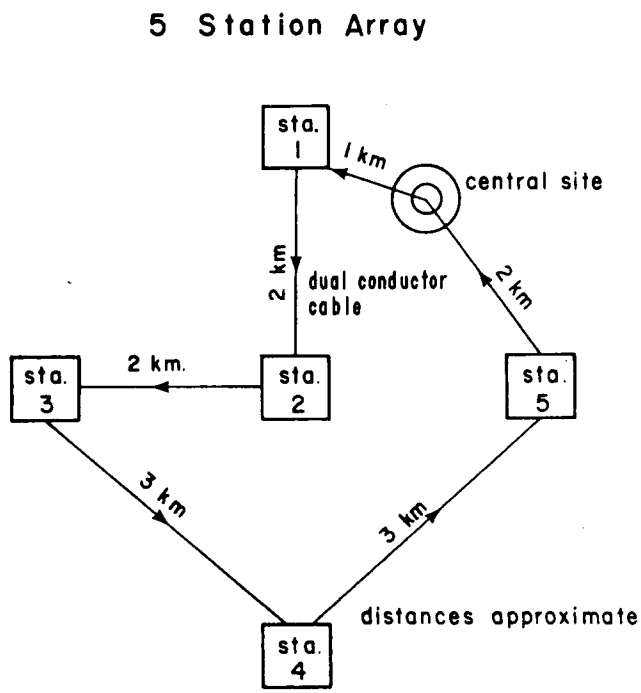

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Figure 4. Array plan showing connection to central site with single twisted pair.

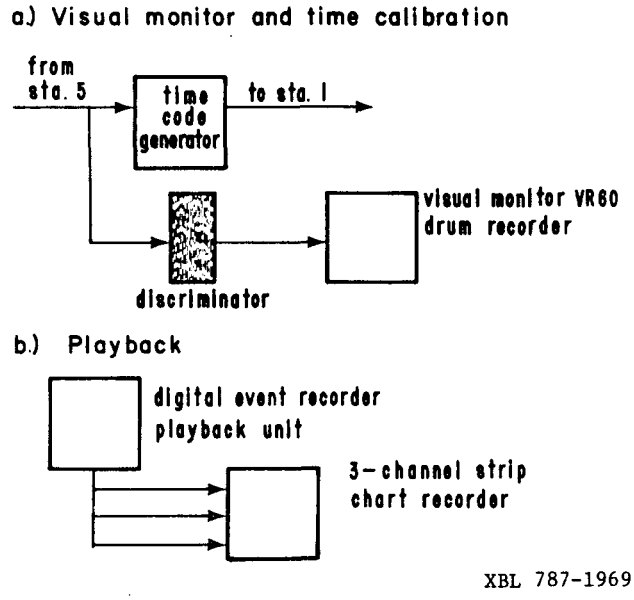

Figure 5. Central site configuration with time clock for fiducial information for each out station and visual monitoring and playback equipment.

put on a drum recorder for visual monitoring. Periodically, the tapes are picked up from each station and sent to LBL for analysis.

The array became operational in September 1979. However, since the magnitude 6.5 Imperial Valley earthquake of October 15, 1979, the array has been saturated with aftershocks. Other problems that are being addressed include high noise levels in the field (particularly when downhole packages failed and we resorted to surface geophones), high ambient temperatures in the summer, and wire breakage due to construction activity. Once these problems are overcome and downhole sensors are again operational, a five-station, 15-component array providing high quality digital data will enable us to make detailed studies of the microearthquake activity associated with the production of the Cerro Prieto geothermal reservoir. Such seismic source parameters as fault orientation and slip direction, in addition to moment and corner frequency, will provide details of source dynamics relative to the withdrawal and reinjection of fluids. Complementing the data will be extensive geophysical, hydrological, and geochemical studies currently being carried out.

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