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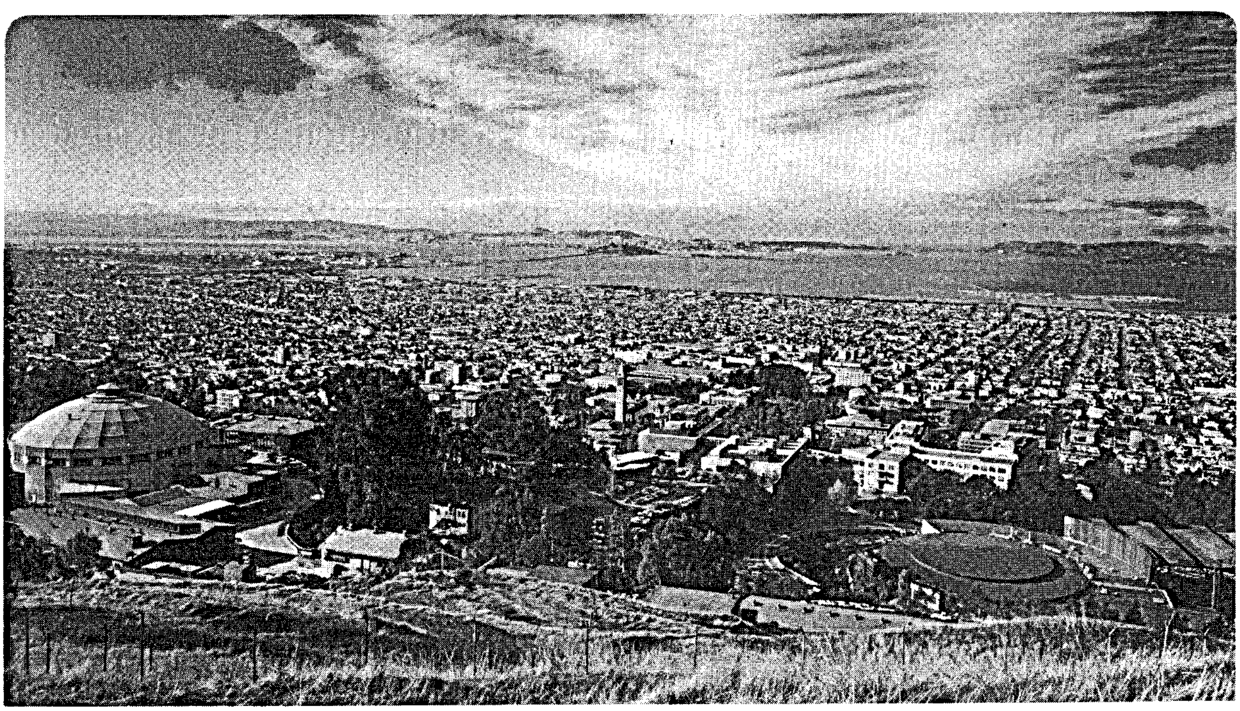

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DISCLAIMER

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A STRUCTURAL AND SEDIMENTOLOGICAL STUDY OF THE CERRO PRIETO GEOTHERMAL FIELD, BAJA CALIFORNIA, MEXICO

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INTRODUCTION

Since 1977 the Comisión Federal de Electricidad de México (1979) and the Lawrence Berkeley Laboratory (1978) have cooperatively studied the Cerro Prieto geothermal field, located approximately 35 km south of the Mexican-American border in the Mexicali-Salton Trough.

As part of these studies, geophysical and lithologic well logs from over fifty wells have been qualitatively and quantitatively analyzed using both manual and computer interpretation techniques. These logs were studied to make stratigraphic correlations throughout the Cerro Prieto field and to interpret the deltaic depositional environment of the field's lithologic units. Dipmeter and seismic data were of great value in making stratigraphic interpretations and extrapolations. Cross sections were constructed to illustrate lithofacies variations throughout the geothermal field. In turn, these sections were used to construct a three-dimensional model of the Cerro Prieto geothermal reservoir.

Petrographic microscopy, scanning electron microscopy, and x-ray diffraction analyses of well-bore cuttings and cores were utilized to determine the degree and distribution of hydrothermal alteration by fluids at temperatures up to 350°C, the origins of dissolution porosity, and the relative degree of fracture versus dissolution porosity. The results of these analyses were confirmed by log-derived determinations of formation fluid properties, porosity, and petrophysical properties and by studies of Cerro Prieto cores conducted under in-situ conditions. The results of this research were integrated into the Cerro Prieto reservoir model.

In order for the exploitation of a geothermal resource to be economical, the reservoir porosity and permeability must be adequate and the distribution of that porosity and permeability must be well known. This study of Cerro Prieto suggests that the roles of fracture-dominated porosity and authigenic mineral plugging in the production reservoirs may have been overstated in earlier conceptualizations of geothermal systems (see DiPippo, 1980, for a worldwide summary of systems). The role of dissolution porosity is very important. As documented by Schmidt and McDonald (1979) for petroleum reservoirs, diagenetic processes determine porosity types and their distributions throughout the life span of a field. Studies of these processes will contribute to the estimation of reservoir porosity distribution and will assist in development of a management plan to optimize the utilization of the geothermal resource.

DISCUSSION

This report is an updated version of the poster session and oral presentation made at the 1980 annual meeting of the AAPG-SEPM-EMD in Denver, Colorado (Noble and Vonder Haar, 1980).

Figure 1 shows the location of the Cerro Prieto geothermal field in relation to the numerous faults in the Salton Trough (see Crowell and Sylvester, 1979; Elders, 1979; Vonder Haar and Puente, 1979; and Vonder Haar and Howard, 1981, for details on faulting related to geothermal development).

Figure 2 shows the well locations and a simplified version of major faults and fault zones. There are numerous tectonic analogs to the Cerro Prieto field.

One of the most useful has been the ocean-floor transform fault "A" system on the Mid-Atlantic Ridge (Figure 3).

Within the Cerro Prieto field, coring (Figure 4) has been carried out to clarify the deltaic facies of sandstones, siltstones, shales, and occasional conglomerates. Recovery rates have been variable, from 14 to 96%, and driller's reports of loose sand at depths of 1200 m or greater were the first clue that extensive dissolution of cement has occurred. Scanning electron micrographs with 200 to 5000 times magnification, as shown in Figure 5, provided evidence of dissolution of both carbonate and silicate minerals, as well as precipitation of clay minerals in pore throats.

Figures 6 and 7, derived from wireline density logs, suggest that the porosity in sandstones at depths of 5000 to 6000 ft could reach 15 to 45% in some wells. In Well M-103 (Figure 7) these zones of high porosity and low density are well below the A/B contact, a gradational contact which represents the transition from unconsolidated sediments to the hydrothermally altered and densified ones. In Well M-93 (Figure 6) the divergence of shale and sandstone density near the 7500-ft depth again suggested dissolution porosity. This interpretation is based on analogous log data found in petroleum studies (see Schmidt and McDonald, 1979). Thin-section analysis of cores confirmed that dissolution porosity results not only from the removal of cement but also of feldspar and quartz (see the report by Lyons and van de Kamp, 1980, for their interpretation).

The surface depicted in Figure 8 represents the first occurrence of 5% authigenic epidote in the sandstones of the Cerro Prieto field. This may indicate a zone above which there is extensive dissolution porosity. Below this surface, it is suggested that there is less dissolution porosity and a relative increase in microfracture porosity.

ACKNOWLEDGEMENTS

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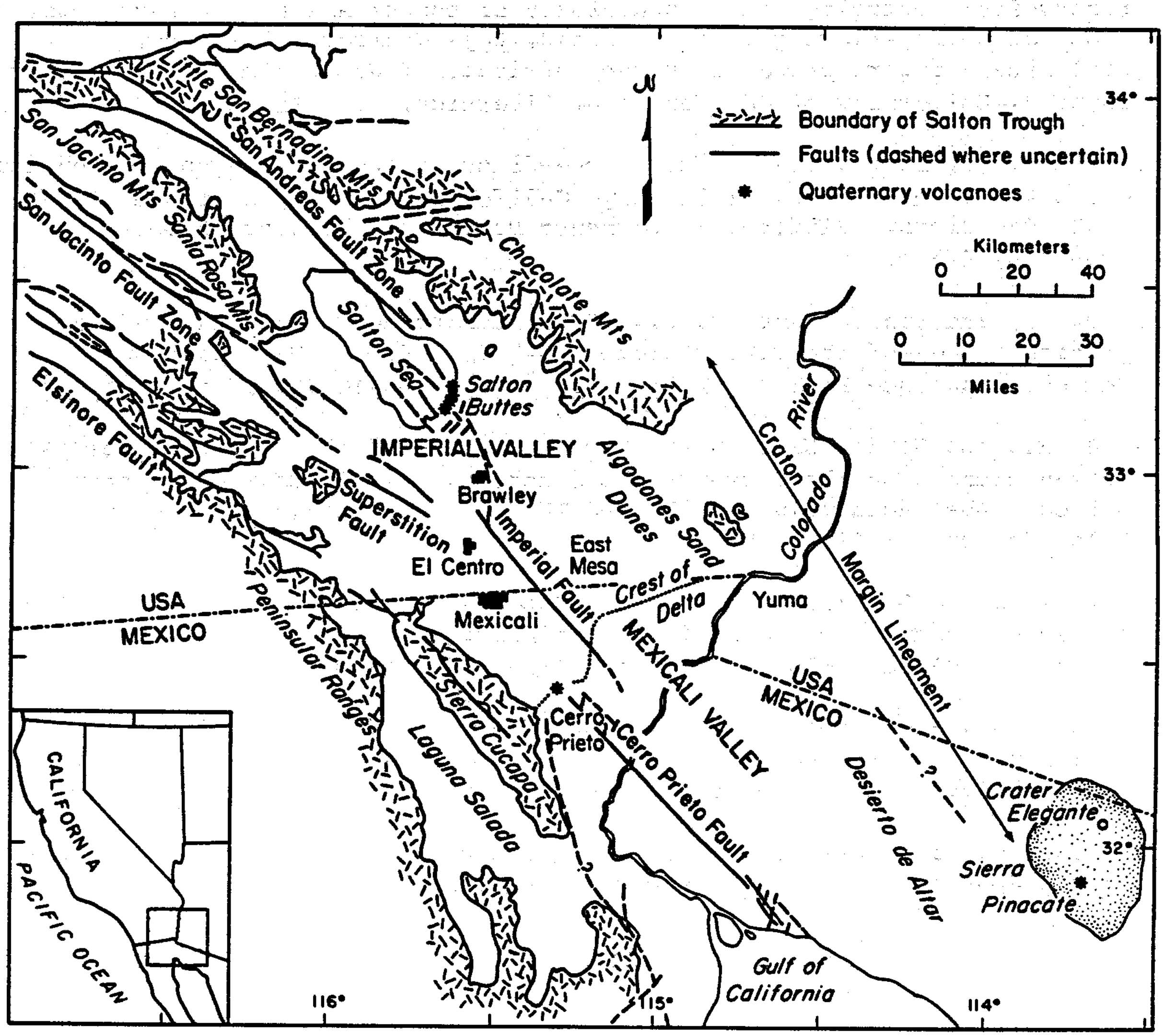

Figure 1. Regional geology of the Cerro Prieto geothermal field. Note the prevalence of long NW-SE trending faults intersected by much shorter faults with NE-SW trends.

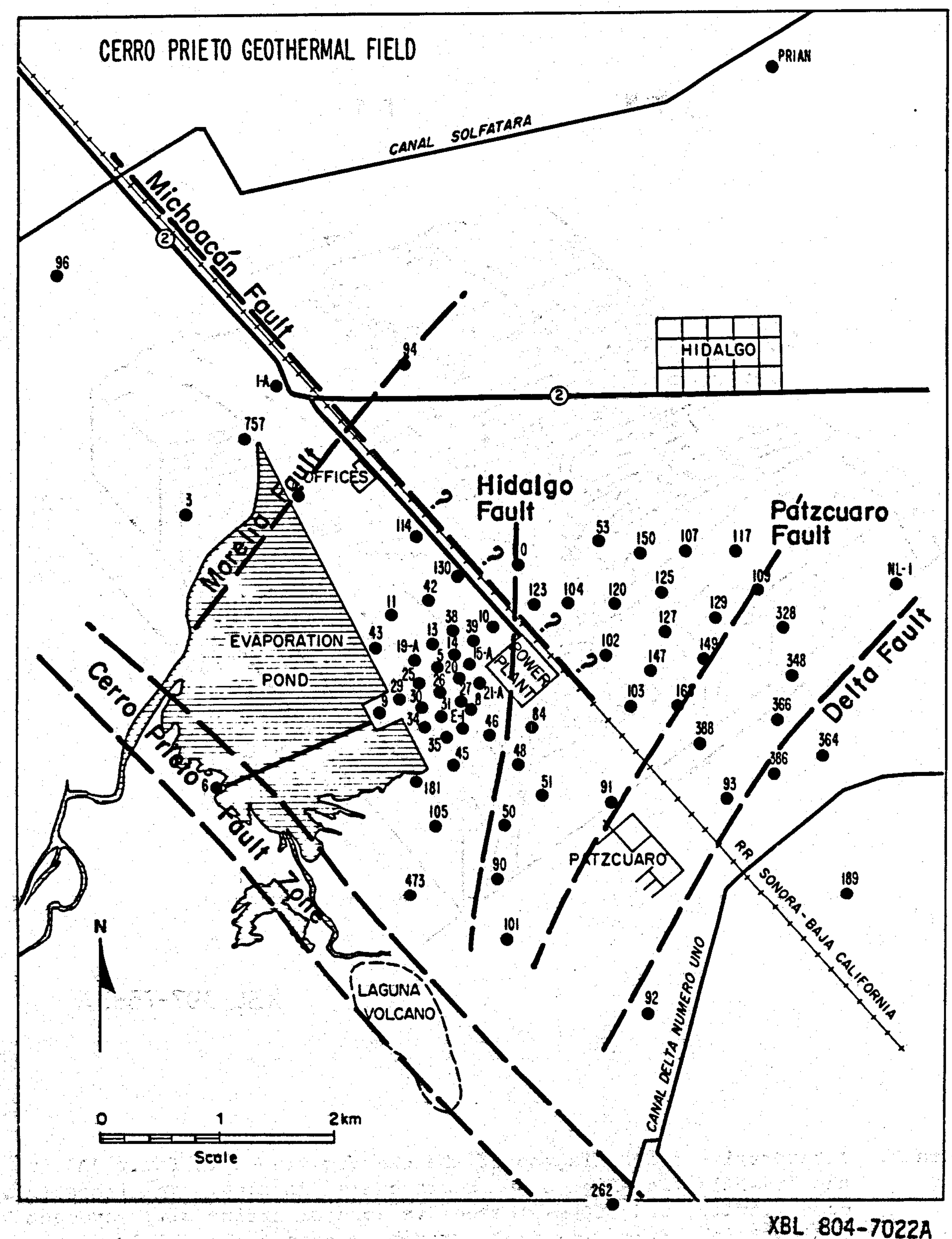

Figure 2. Map of the Cerro Prieto geothermal field with a simplified fault system.

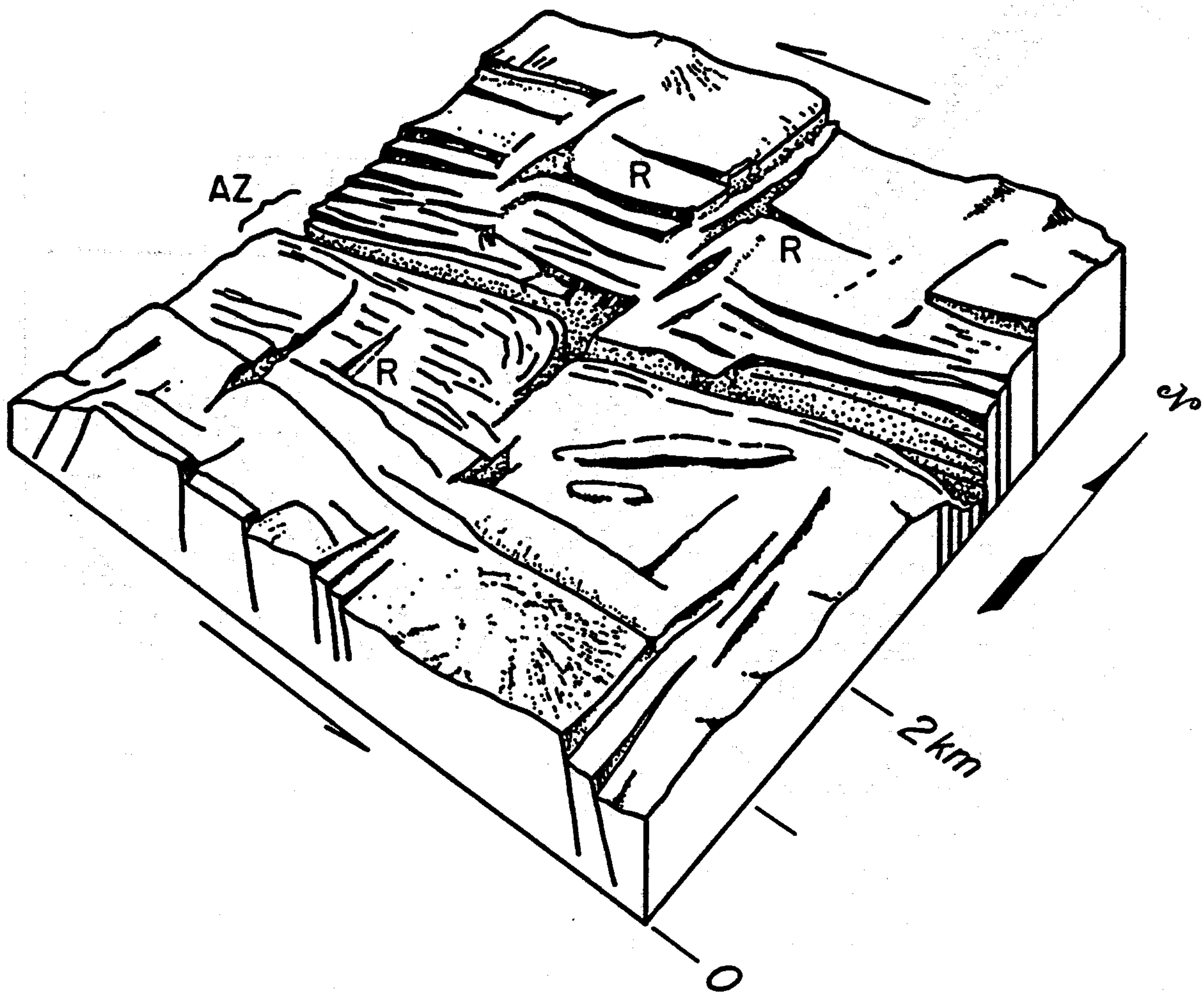

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Figure 3. Interpretive block diagram of the oceanic transform fault "A" in the Mid-Atlantic Ridge showing structural domains. The ramps (R), cross-faults, and 200-m-wide active zone of strike-slip movement (AZ) within a 4-km-wide fault trough suggest the possible complexity of faulting along the Cerro Prieto and Imperial faults and within the producing geothermal fields (after Choukroune et al., 1978).

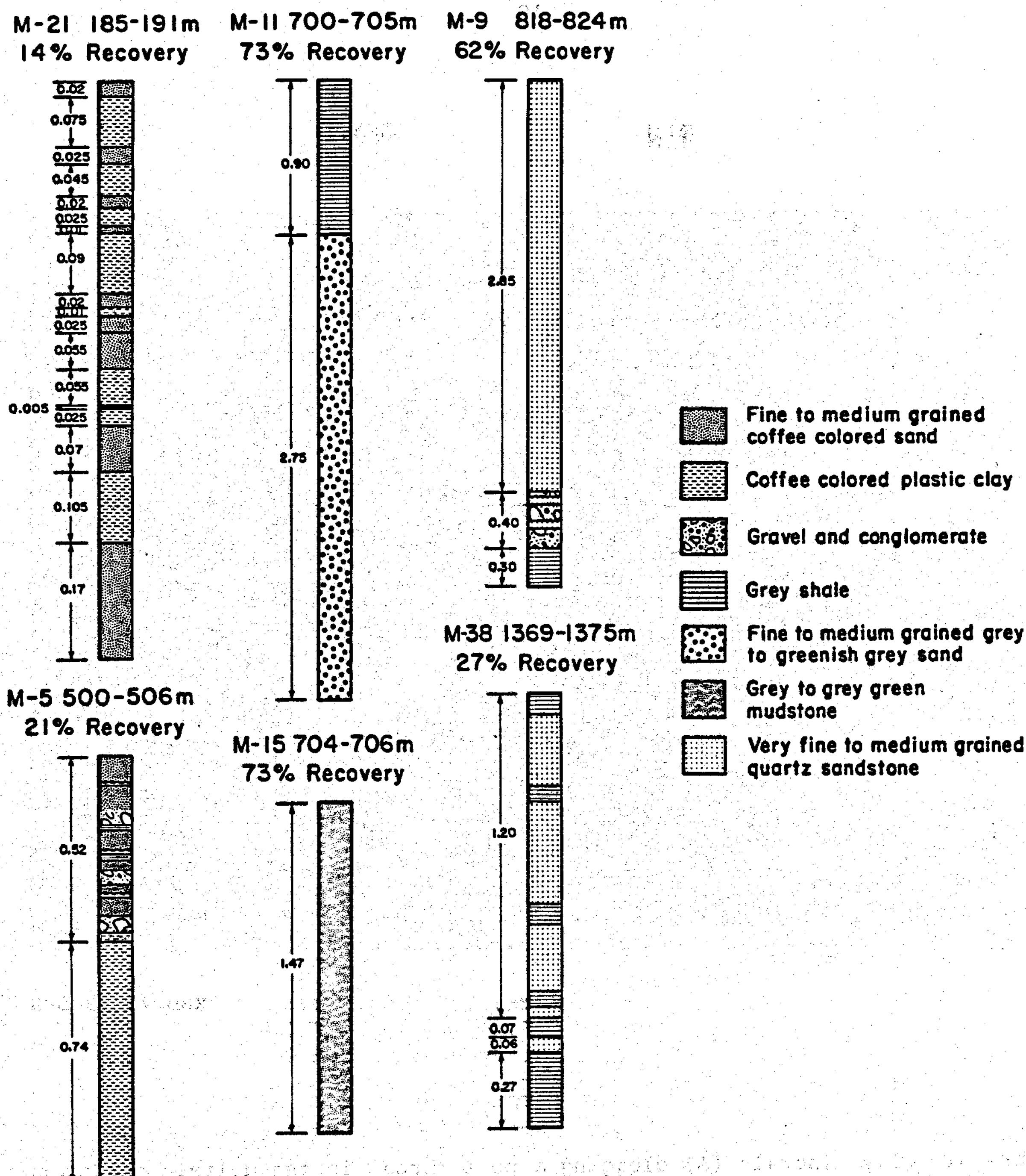

Figure 4. Composite core section from the earliest developed wells at Cerro Prieto field. Note the transition from unconsolidated sand and clay to hydrothermally densified sandstones and shales between 700 and 900 m depth. These cores helped confirm ideas on deltaic facies later greatly altered by fluids of 250 to 350°C. Numbers such as 0.90 next to cores indicate the length in meters of individual core segments.

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Figure 5. Clay minerals (A) clogging a pore throat in the deltaic sandstone at 1215 m depth in well M-38. Note also the framework mineral overgrowth (B) in the lower center of the figure. Such pore throat reduction may be present even when porosity is 25%. Field of view across the scanning electron micrograph is 0.1 mm.

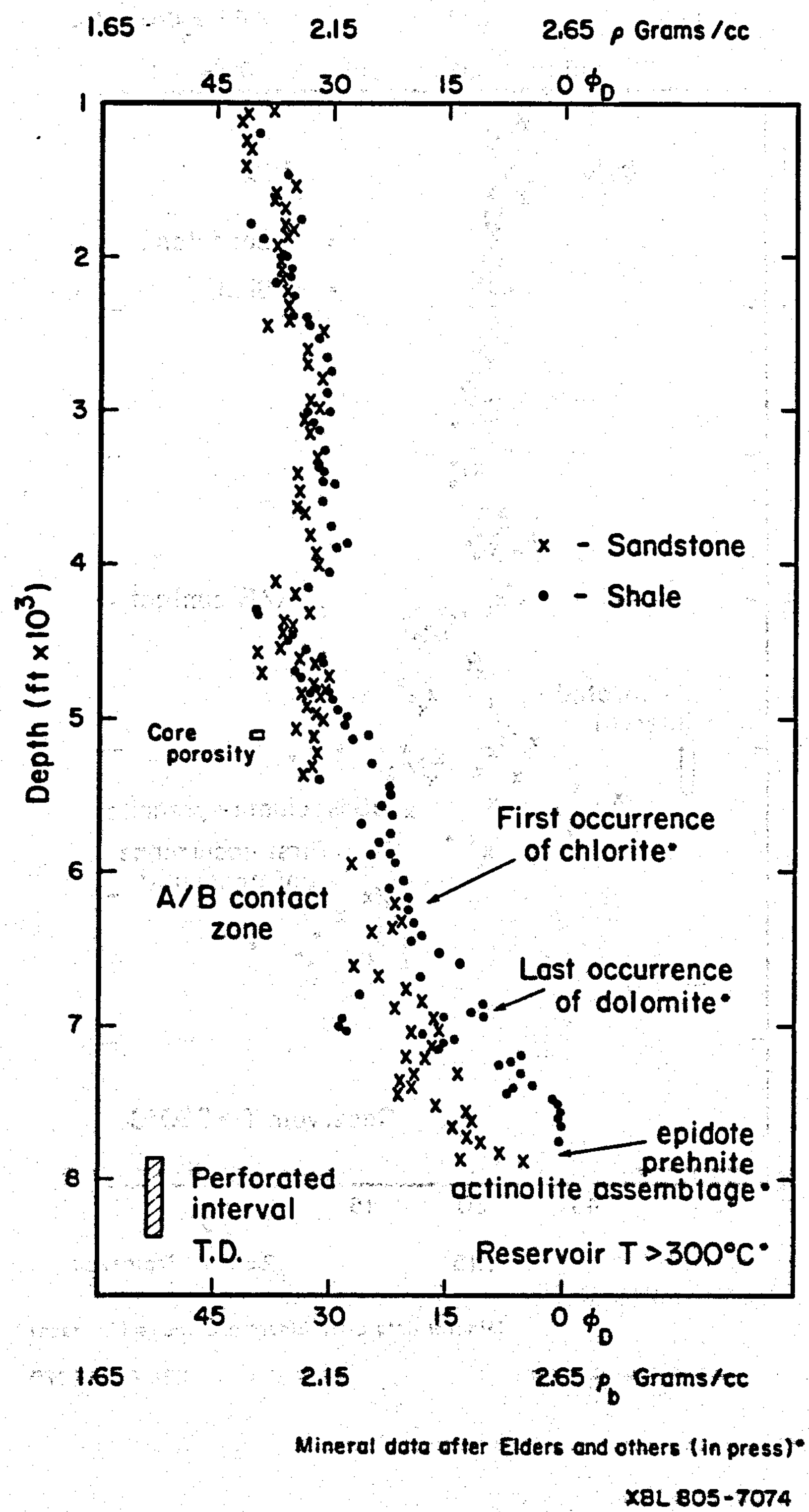

Figure 6. Density versus depth plot for well M-93. Note the similarity of density in the sandstones and shales to approximately 5000 ft depth and the decrease in relative density of sandstone to shale below this depth. This is interpreted as an indication of moderate dissolution porosity.

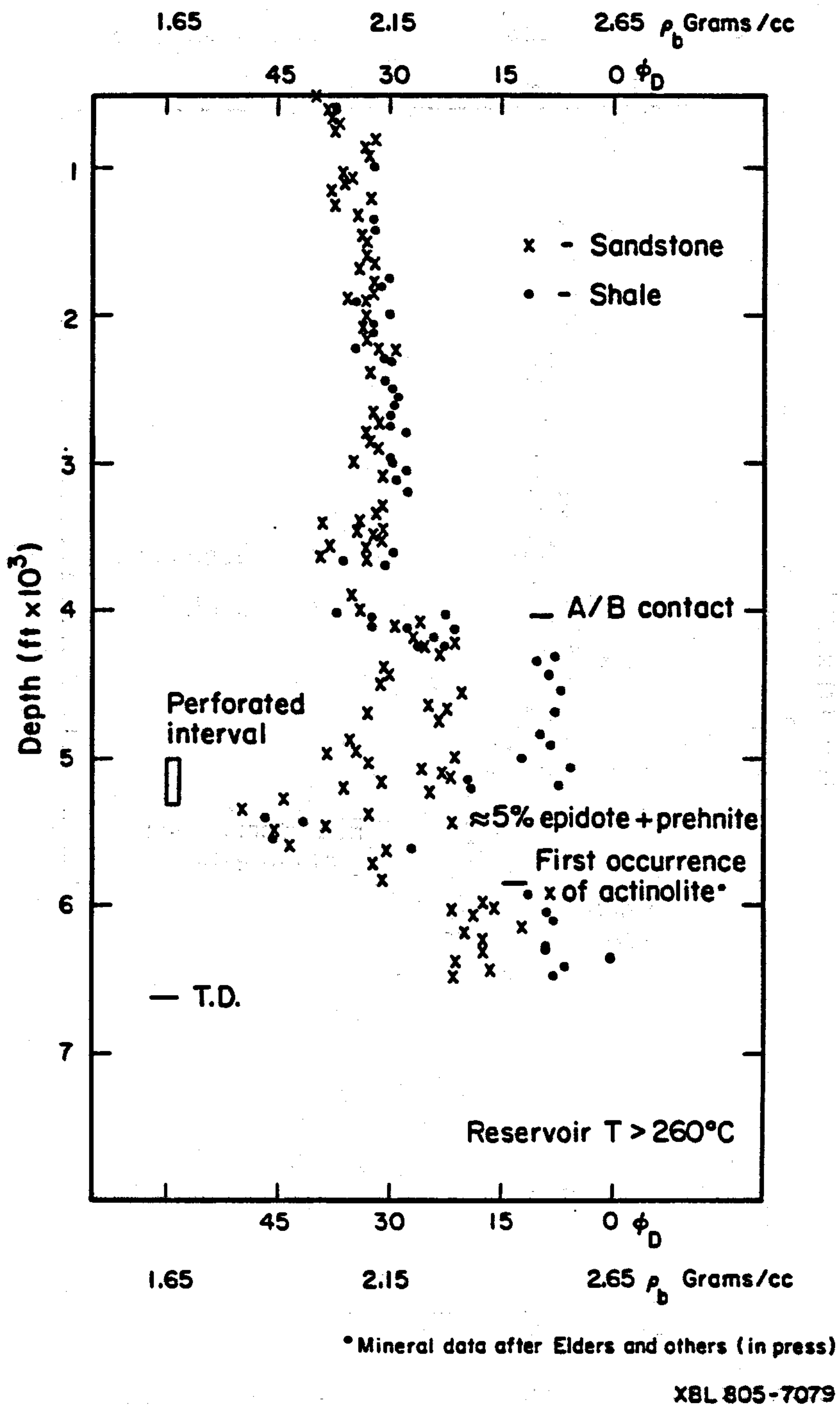

Figure 7. Plot of porosity and density versus depth for the very productive well M-103 as determined from well logs and cuttings. The high porosity in the perforated interval indicates extensive dissolution porosity. Note the marked density increase at 4000 ft depth at the A/B contact. This contact is the zone reported by CFE geologists as the transition from unconsolidated sands and clays to sandstone and shale.

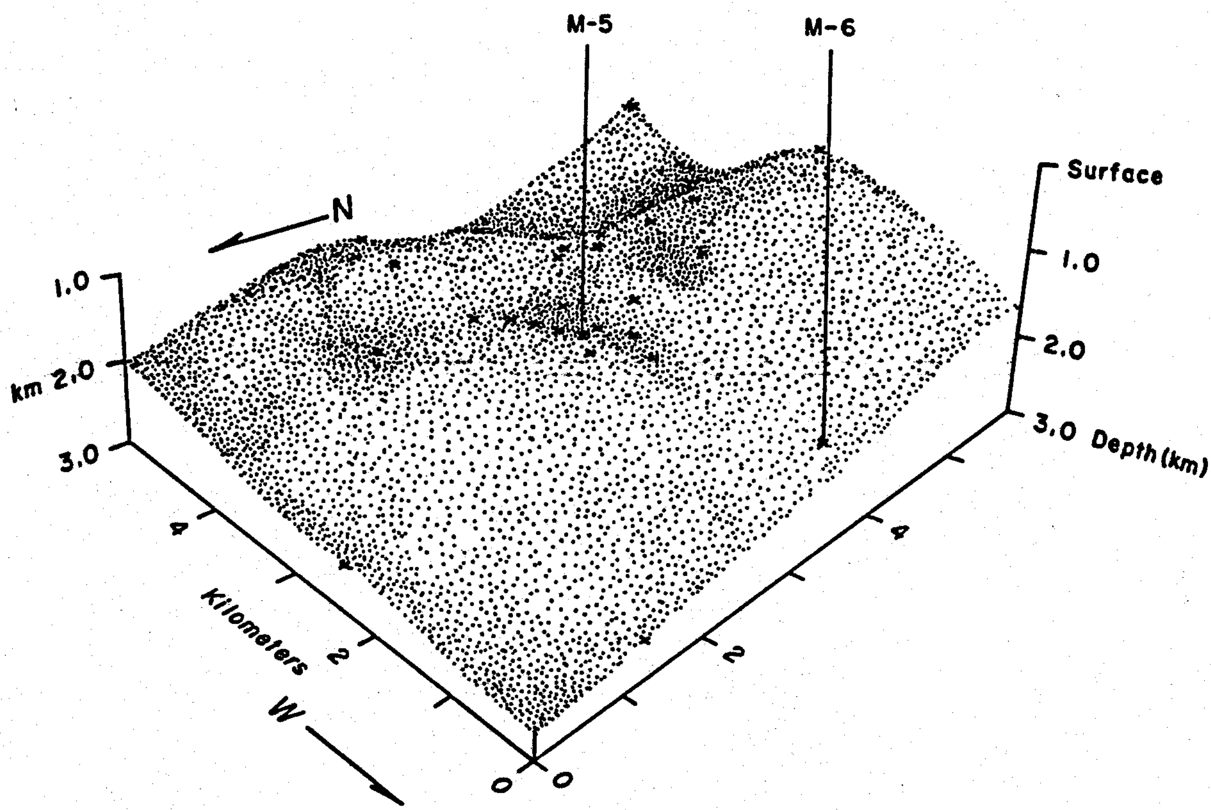

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Figure 8. Three-dimensional computer plot of the first occurrence of 5% epidote in well cuttings. Quantitative x-ray diffraction data are from Elders et al. (1981). The 29 wells used are indicated by "X," with wells M-5 and M-6 shown for orientation. This 5% epidote surface may be a diagnostic horizon above which dissolution porosity may reach 35%, at least in patchy or lenticular zones. See Figure 7 for the 5% prehnite and 5% epidote zone near the base of the suggested region of extensive dissolution porosity and good permeability.