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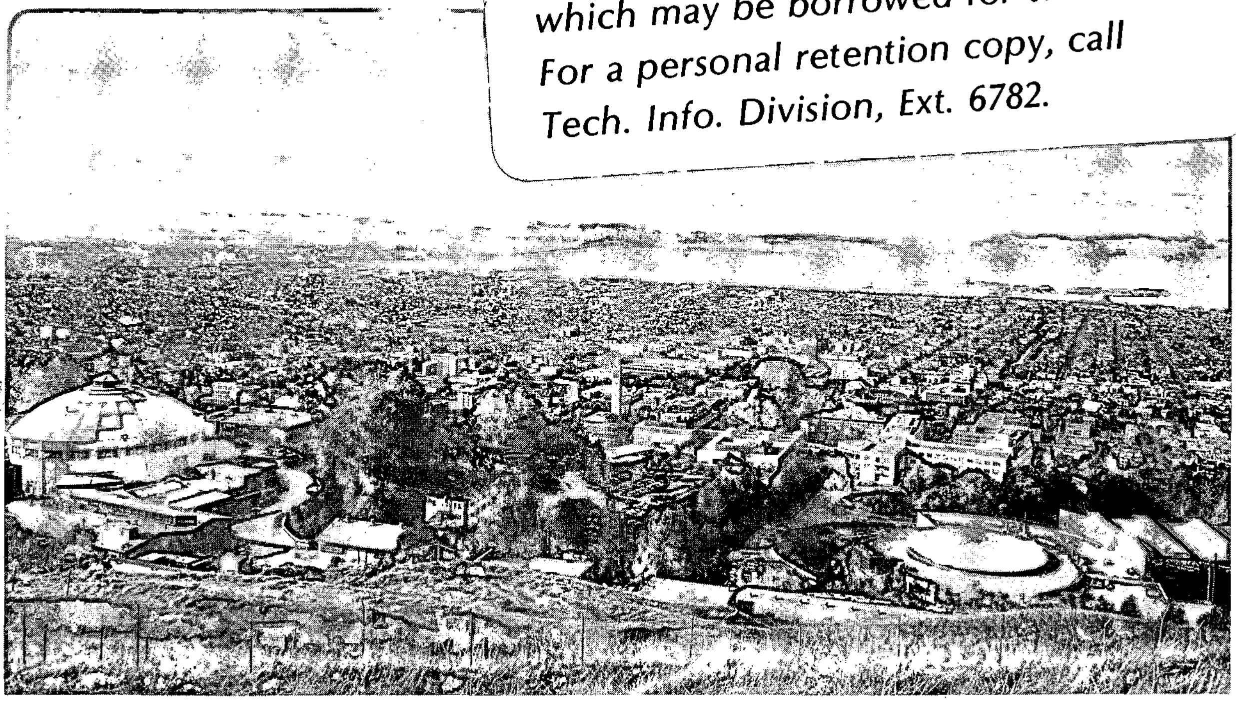

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DISCLAIMER

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CERRO PRIETO CASE HISTORY: USE OF WIRELINE LOGS TO CHARACTERIZE A GEOTHERMAL RESERVOIR

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ABSTRACT

The Cerro Prieto field, Baja California, Mexico, is located about 30 km south of the U. S. border in the Salton Trough, an actively developing structural depression filled mainly with Colorado River sediments. As part of a multidisciplinary study of this geothermal system, a comprehensive analysis of the available wireline logs was undertaken. It established the physical properties of the various sedimentary units; their depositional environment; their hydrothermal alteration; the location, attitude, and displacement of faults; and the circulation of the geothermal fluids in the field.

Resistivity, density, sonic, gamma-ray, and spontaneous potential logs were used to develop the geologic model of the field and to determine the porosity, permeability, alteration, and lateral and vertical continuity of the sedimentary layers. Dipmeter logs were used mainly to establish the depositional environment of the different units. This log-derived information, combined with temperature and well completion data, allowed us to establish the circulation of geothermal fluids through the system. The accuracy of the characterization of the Cerro Prieto geothermal reservoir has been confirmed by the results of recently completed wells.

The methodology used and the application of the results to further exploration and development of this high-temperature geothermal resource are discussed.

INTRODUCTION

The liquid-dominated Cerro Prieto geothermal field is located in Baja California, Mexico, about 30 km south of the U.S. border (Fig. 1). Over 100 deep exploration and development wells have been drilled in the field (Fig. 2), a few reaching the crystalline basement of the sediment-filled Mexicali Valley. The analysis of the vast amount of data collected from these wells has given us a good understanding of the geologic characteristics of this high-temperature (up to 360°C) geothermal resource. The exploration effort at Cerro Prieto has recently been summarized[1].

The purpose of this paper is to discuss the wireline log analysis that led (1) to the development of geologic and hydrogeologic models of the field; (2) to an understanding of the depositional environment of some of the geologic units identified in the subsurface; and (3) to the identification of postdepositional changes in these units. These studies have allowed us to determine the variations in porosity, permeability, thickness, and lateral continuity of the permeable (and less permeable) layers in the system--crucial parameters for designing the drilling and completion of new wells and for developing a reservoir management plan.

GEOLOGIC SETTING AND RECENT HISTORY OF THE AREA

The Mexicali Valley is part of the Salton Trough, an actively developing structural depression that resulted from tectonic activity that has created a series of spreading centers and transform faults that link the East Pacific Rise to the San Andreas fault system. The Cerro Prieto field is associated with one of these spreading centers, where the crust is being pulled apart by right-lateral strike-slip movement along the Cerro Prieto and Imperial faults[2,3] (Fig. 3).

During the early Pliocene (about 5 Ma b.p.), the present configuration of the Gulf of California began to develop by major crustal extension, splitting Baja California from the Mexican mainland[4]. At that time, the waters of the Gulf extended northward to about the present Salton Sea area. The progradation of the Colorado River delta into the Cerro Prieto area began in mid- to late Pliocene[5].

References and illustrations at end of paper.

By late Pliocene, the southwesterly advance of the delta was essentially complete, resulting in the conversion of the Salton basin to a nonmarine depositional basin[6]. By mid-Pleistocene time, the marine connection between the Gulf of California to the south and the Imperial Valley to the north was severed[5].

GEOLOGIC AND HYDROGEOLOGIC MODELS OF CERRO PRIETO

The subsurface stratigraphy at Cerro Prieto is characterized by vertical and lateral variations in lithofacies[6,7]. The upper part of the lithologic column consists of unconsolidated sediments (Unit A: mainly sands, silts and clays); the lower part by consolidated sediments (Unit B: mainly sandstones and shales)[8]. The hydrothermal alteration of the deeper layers, and the existence of hydrothermal mineral zonation around the reservoir has been documented by careful mineralogic studies of well cuttings and cores[9,10,11] and analysis of wireline well logs[6,7,12,13].

Following the general approach of Lyons and van de Kamp[6], Halfman et al.[7] used wireline and lithologic log data to delineate and classify the lithologic sequences penetrated by the wells into three lithofacies groups: sandstone, sandy-shale, and shale (Figs. 4 and 5). Basically, the sandstone beds are thick, permeable, and well defined (with some interbedded shales) in the sandstone group, but are thinner and less permeable (with a higher percentage of intercalated shales) in the sandy-shale group, and even thinner (<3 m) and less frequent in the shale group (e.g., Fig. 4). The main geophysical logs used to develop this model included gamma-ray (GR), spontaneous potential (SP), deep induction (ILD), and compensated formation density (RHOB) logs.

On the basis of this simplifed lithology, a geologic model of the field was constructed. A number of lithofacies cross sections were developed to show the lateral continuity and thickness of the different lithofacies groups and the location and geometry of major faults in the area. Next, by superimposing downhole temperature profiles and well production intervals onto the lithofacies cross sections, a fluid flow model for the geothermal brines was developed. Further details about these models and how they were constructed are discussed in a previous paper[7].

The hydrogeologic model indicates that two lithofacies groups largely control the subsurface circulation of geothermal fluids: Shale unit O and Sand unit Z. Shale unit O is a thick, relatively impermeable, low-porosity body that locally forms a cap rock for the geothermal reservoir. East of the railroad tracks that cross the field (Fig. 5), this unit is classified mainly as a shale lithofacies group. In this area, the lower portion of Shale unit O is composed of thin interbedded sandstones and shales (beds are often <3 m thick). The upper portion contains thicker shale beds with some sandstone beds, in addition to thin interbedded sandstone and shale beds. West of the tracks, this unit turns sandier. Along the western margin of the field (between wells M-9 to M-6), Shale unit O is no longer evident.

Sand unit Z, underlying Shale unit O, contains thick, permeable, high-porosity sandstone beds that allow fluid circulation, and is the main stratigraphic unit of the geothermal reservoir. In this unit the sandstone beds are generally about 15 m thick, separated by shaly beds that are about 12 to 30 m thick.

The hydrogeologic model discussed by Halfman et al.[7] shows that under natural conditions the geothermal fluids enter the Cerro Prieto field from the east at depths greater than 3000 m, through Sand unit Z. The fluids move westward through this unit, rising to shallower depths through fault zones and sandy gaps in overlying Shale unit O. In the thick sandstones along the western margin of the producing field (west of well M-9), the geothermal fluids either mix with cold groundwaters or discharge to the surface as hot springs, mud volcanoes, and fumaroles.

The movement of geothermal fluids as indicated by this model has been corroborated by numerical modeling studies of heat and mass flow[14].

DEPOSITIONAL ENVIRONMENT FOR CERRO PRIETO RESERVOIR ROCKS

Critical to understanding the nature and characteristics of the geologic units governing to a large extent the flow of geothermal fluids in the reservoir, in particular Sand unit Z and Shale unit O, is an understanding of the depositional environment of these rock units. This environment controls largely the overall lithology of the units and the continuity, thickness, and intercalation of their sandstone and shale beds, all of which determine the hydraulic properties of the units.

Most researchers have first attempted to interpret the depositional environment of the unusually thick sandstones (>900 m) penetrated by wells M-96, M-3, M-6 and S-262 drilled along the western margin of the field (see M-6 in Fig. 5). Mañón et al.[15] have proposed that these sandstones represent an intertonguing of alluvial fan deposits from the Cucapá Range to the west and deltaic Colorado River sediments from the east. Prian[16] suggested that these thick sandstones represent a major deltaic paleochannel. Lyons and van de Kamp[6] showed from petrographic and well log studies that neither of these interpretations is feasible. Instead, they proposed--on the basis of their interpretation of the deeper part of the Cerro Prieto lithologic column as being deposited in a coastal deltaic environment (Fig. 6)--that those thick sandstones represent a "composite of many genetic sand types".

In this study a careful analysis of available dipmeter logs from 26 wells showed that the depositional environment of the thick sandstones, Shale unit O, and Sand unit Z was once part of a coastal system. Along a west-to-east line, one would find, in succession, longshore current, shoreline, and protected embayment deposits (Fig. 7). The significant sandstone thicknesses penetrated in the western part of the field are associated with northward-flowing longshore currents in an actively subsiding basin. The subsidence of this basin probably continues today, as Cerro Prieto is located on an active spreading center, as mentioned earlier[2,3]. Lyons and van de Kamp[6] have shown from petrographic studies that the thick sandstones were derived from Colorado River sediments. Therefore, longshore currents must have been carrying sediments northward to the Cerro Prieto area from an ancient Colorado River delta located to the south of the field.

Interpretation of the dipmeter logs show that at Cerro Prieto the deposits often associated with the longshore currents were from flood-and-ebb tidal deltas. The dipmeter patterns corresponding to these deltaic deposits are similar to the distributary front patterns described by Gilreath and Stephens[17]. The dip patterns characteristically show high-angle dips decreasing to lower ones (about a 10-20° span) over a depth interval of about 15 to 30 m. A good example of an ebb-tidal deltaic deposit is shown between 1143 and 1150 m in the dipmeter log for well M-96 (Fig. 8). The long axis of this deposit is oriented in a west-northwest direction. The general direction of the longshore currents is to the north, as evidenced by the northward dip patterns between 1128 and 1143 m and between 1173 and 1211 m (Fig. 8). Also shown in this figure are tidal flat deposits between 1158 and 1173 m. Other types of dipmeter patterns for these thick sandstones indicate shallow water[18] and river deposits[19] associated with a longshore current environment.

Once the depositional environment for the thick sandstones found in the western region of the field was established, it became easier to identify the environment of deposition of the sediments of Shale unit O. The dipmeter log for well M-150 from 1524 to 1859 m illustrates some of the typical patterns for Shale unit O (Fig. 9). These dips show a repeating pattern of high- to lower-angle dips, indicative of foreset bedding resulting from southwest- to northeast- flowing currents. The very orderly pattern shows that little, if any, reworking of the sediments occurred. To preserve the foreset beds, rapid deposition and burial must have occurred. The gamma-ray log for Shale unit O indicates typical thin interbedded sandstone and shale layers. Considering that this unit was deposited in an area between the longshore currents to the west and the mainland to the east and that its thin interbedded sandstone and shale layers were laid down in a very quiet and undisturbed environment, it can be inferred that the sediments were probably deposited in a protected embayment, as shown in Fig. 7.

Sand unit Z is also composed mostly of foreset beds deposited in a protected embayment. However, the sandstone and shale beds of the upper portion of Sand unit Z are generally much thicker than the beds of the lower portion of Shale unit O. The source of sediments for both units was the Colorado River[6]. Moreover, the dipmeter patterns of both units indicate the energy of the currents transporting the sediments into the protected embayment must have been similar. Therefore, the greater thickness of the sandstone and shale beds may be due to alternating high and low energy conditions of the Colorado River over longer periods of time and/or to erosion by the Colorado River through thicker sandstone and shale source rocks.

By establishing the characteristics of the coastal environment of deposition of the sedimentary rocks forming the Cerro Prieto geothermal reservoir and its (discontinuous or local) cap rock, it is simple to explain the more sandy nature and eventual disappearance of Shale unit O in the western part of the field. The sandier western portion of Shale unit O (from well M-10 to M-9) represents the beginning of a transition from protected embayment deposits (to the east) to longshore current deposits (to the west). The sandy-shale group within Shale unit O (between wells M-5 and M-29) is permeable enough to allow some geothermal fluids to flow westward through it.

The thick and highly permeable deposits associated with longshore currents bounding the reservoir to the west, lets westward-moving hot fluids mix with (colder) groundwaters, thus limiting the horizontal extent of the geothermal reservoir. Therefore, new wells should be drilled east of these thick sandy deposits, preferably south and southwest of NL-1, which is near the geothermal heat source.

HYDROTHERMAL ALTERATION OF SUBSURFACE SEDIMENTS

Following deposition, the sediments comprising the present-day Cerro Prieto geothermal system were hydrothermally alterated by circulating fluids. Changes in mineralogy, porosity, and density, caused by rock-water interactions, can be readily determined from the analysis of well cuttings, cores, and wireline log data.

On the basis of detailed mineralogic studies, Elders et al.[9] showed that the contact between the relatively unconsolidated sediments (Unit A) and the underlying indurated sediments (Unit B) is a gradational boundary between unaltered and hydrothermally altered sediments. A pattern of mineral zonation around the geothermal reservoir was also established[9,10,11]. At the top of Unit B, detrital or authigenic clay minerals, like montmorillonite and kaolinite, are progressively replaced by pore-filling chlorite, illite, and calcite. This sealing process causes the sediments to be highly indurated at the top of the reservoir. In the main production zone, above 225°C, there is a zone of progressive decarbonation, and calcium aluminum silicates are formed. At the highest temperatures so far measured, hydrothermal biotite and vermiculite form. This zonation can be correlated to present-day formation temperatures and chemistries of both brines and recharge waters.

Petrographic and scanning electron microscope studies[6,20] indicate that sandstones in Unit B show unusually high porosity, between 15 and 35%. This has been interpreted as secondary porosity due to dissolution of unstable framework grains and cements.

Wireline logs can be used to identify (1) the A/B contact, (2) the different hydrothermal alteration zones, and (3) the sandstones with secondary porosity. The well log responses for GR and ILD logs of well M-150 (Fig. 4) are rather typical of Cerro Prieto wells[7]. The sandstone and shale beds above Shale unit O show normal well log values for a sedimentary environment. Below the top of Shale unit O (within Unit B), the RHOB and ILD logs increase, indicating a decrease in porosity. The RHOB log between 1750 and 1800 m shows a density reduction. This decrease within Shale unit O is unusual; other wells at Cerro Prieto show a continual trend of increasing densities (and therefore decreasing porosity) toward the bottom of Shale unit O. In Sand unit Z, the RHOB and ILD logs show marked decreases in densities (indicating secondary porosity) for the sandstones, whereas the density log values for the shales remain high.

At the A/B contact, both the shales and sandstones exhibit an increase in density; the relative change being larger for the shales[6]. These increases in rock density are greater than would be expected from only normal sediment compaction[12]. The density differences between shales and sandstones are larger below the A/B contact than above it (Fig. 10).

The hydrothermal alteration of the Cerro Prieto sediments is also reflected in other logs. For example, there is an anomalous increase in spontaneous potential and a decrease in formation conductivity[13].

The responses of the RHOB and ILD logs confirm the presence of high (secondary) porosities of sandstones[6,7] (Fig. 4) in the altered zone, especially within Sand unit Z.

Seamount and Elders[12] showed that it is possible to correlate the different hydrothermal alteration zones with changes in wireline log data (Fig. 11). Generally, they found that in the unaltered montmorillonite zone ($T<150°C$) the sandstone resistivity (Rsd) is higher (due to fresh pore water) than the shale resistivity (Rsh), and the density gradients with depth are low for both sandstones and shales. In the illite zone (150°-230° to 245°C) the lowest-temperature alteration zone, the density for sandstones and shales increases; high Rsd are uncommon. In the chlorite zone (235°to 300°C), both Rsd and Rsh begin to increase. Finally, in the feldspar zone (>300°C), Rsh shows a sudden increase and Rsd a decrease. The Rsd/Rsh vs. depth plot shows the montmorillonite zone to vary the most; in the illite zone, Rsd/Rsh values range from 0.75 to 4.0; in the chlorite zone, they range from 0.35 to 1.25; and in the feldspar zone, all values fall below 0.3. All four mineral zones can also be distinguished on a resistivity-density crossplot[12] (Fig. 12).

The top of Shale unit O corresponds approximately to the bottom of the montmorillonite zone (compare, for example, Figs. 5 and 11 for well M-107). Also the bottom of the chlorite zone roughly coincides with the bottom of Shale unit O. Thus this shale unit generally corresponds to the illite and chlorite alteration zones. On the other hand, the high-porosity sandstones of Sand unit Z correlate with the low-resistivity sandstones in the feldspar zone.

These results are consistent with our observations that Shale unit O is an effective barrier to the upward flow of geothermal fluids. The hydrothermal alteration of these sediments deposited in a protected embayment environment, has resulted in their densification (and self-sealing), decreasing their porosity and permeability. The sandstones within Sand unit Z, on the other hand, experienced dissolution of some of the grains and cement. This increased their porosity and permeability, making them effective conduits for the flow and storage of geothermal fluids.

FINAL REMARKS

The ultimate purpose of a reservoir engineering study of a geothermal field is to develop a reservoir management plan that optimizes the recovery of the heat stored in the subsurface. For this purpose, it is necessary not only to obtain accurate distributions of temperatures, pressures, and sources and sinks in the field, but also to determine the variations in porosity, permeability, thickness, and lateral continuity of the permeable (and less permeable) layers.

The Cerro Prieto case study showed that from wireline logs in a geothermal field it is possible to establish (1) the lateral and vertical continuity of the sedimentary layers; (2) the depositional environment of the geologic units; (3) the porosity, permeability, and hydrothermal alteration of the different lithologic units; and (4) the location, attitude, and displacement of faults. Then, by superimposing downhole temperature and well-completion data on a geologic model, one can determine the circulation of the geothermal fluids in the subsurface and the geologic features controlling their movement.

Our characterization of the Cerro Prieto geothermal reservoir was confirmed by the results of recently completed wells. Using the fluid flow model of Halfman et al.[7] (e.g. Fig. 5), the depths at which new wells would encounter the producing sandstones of Sand unit Z were successfully predicted (Table 1). This was done simply by projecting a proposed well onto one of the five lithofacies cross sections given by Halfman et al.[7] (e.g. Fig. 5). If the wells on either side of the proposed well had temperatures of 300°C or greater at the bottom of Shale unit O, then this depth--that is, to the first sandstone in Sand unit Z--was forecasted to be the depth of the top of the producing interval. If one of the wells (or perhaps both) was cooler than 300°C at the bottom of Shale unit O, then the 300°C isotherm was projected to the site of the new well based on data from nearby wells. The depth to the 300°C isotherm was assumed to correspond to that of the first producing sandstones.

The present understanding of the subsurface geology and fluid flow movement in the Cerro Prieto field is useful for locating and designing new production and injection wells. It also is important for any numerical modeling effort aimed at optimizing the exploitation of this geothermal resource. The methodology discussed would be applicable and helpful for exploring and developing other geothermal fields located in a sedimentary environment, especially in the Imperial Valley of Southern California.

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REFERENCES

1. Lippmann, M.J., Goldstein, N.E., Halfman, S.E., and Witherspoon, P.A.: "Exploration and Development of the Cerro Prieto Field," presented at 58th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, San Francisco, CA, October 5-8, 1983, SPE-12098 (1983).

2. Lomnitz, C., Mooser, F., Allen, C.R., Brune, J.N., and Thatcher, W.: "Seismicity and Tectonics of the Northern Gulf of California Region, Mexico - Preliminary Results," Geofísica Internacional (1970) 10, 37-48.

3. Elders, W.A., Rex, R.W., Meidav, T., Robinson, P.T., and Biehler, S.: "Crustal Spreading in Southern California," Science (1972) 178, 15-24.

4. Saunders, A.D., Fornari D.J., and Morrison, M.S.: "The Composition and Emplacement of Basaltic Magmas Produced During the Development of Continental-Margin Basins: The Gulf of California, Mexico," J. Geol. Soc. London (1982) 139, 335-346.

5. Ingle, J.C.: "Microfaunal Evidence of Age and Depositional Environments of the Cerro Prieto Section (Plio-Pleistocene), Baja California, Mexico," Lawrence Berkeley Laboratory Report LBL-13897 (1980).

6. Lyons, D.J. and van de Kamp, P.C.: "Subsurface Geological and Geophysical Study of the Cerro Prieto Geothermal Field, Baja California, Mexico," Lawrence Berkeley Laboratory Report LBL-10540 (1980).

7. Halfman, S.E., Lippmann, M.J., Zelwer, R., and Howard, J.H.: "A Geological Interpretation of the Geothermal Fluid Movement in the Cerro Prieto Field, Baja California, Mexico," Amer. Assoc. Petrol. Geol. Bull. (1984) 68, 18-30.

8. Puente, I. and de la Peña, A.: "Geology of the Cerro Prieto Geothermal Field," Geothermics (1979) 8, 155-175.

9. Elders, W.A., Hoagland, J.R., McDowell, S.D., and Cobo, J.M.: "Hydrothermal Mineral Zones in the Geothermal Reservoir of Cerro Prieto," Geothermics (1979) 8, 201-209.

10. Elders, W.A., Bird, D.K., Williams, A.E., and Schiffman, P.: "Hydrothermal Flow Regime and Magmatic Heat Source of the Cerro Prieto Geothermal System, Baja California, Mexico," Geothermics (1984) 13, 27-47.

11. Schiffman, P., Elders, W. A., Williams, A. E., McDowell, S. D., and Bird, D. K.: "Active Metasomatism in the Cerro Prieto Geothermal System, Baja California, Mexico: A Telescoped Low-Pressure, Low-Temperature Metamorphic Facies Series," Geology (1984) 12, 12-15.

12. Seamount, D. T., and Elders, W. A.: Use of Wireline Logs at Cerro Prieto in the Identification of the Distribution of Hydrothermally Altered Zones and Dyke Locations, and their Correlation with Reservoir Temperatures," Proc. 3rd Symp. Cerro Prieto (1981), Lawrence Berkeley Laboratory Report LBL-11967, 123-139.

13. Ershaghi, I. and Ghaemian, S.: "Detection of Hydrothermal Alteration in a Sedimentary Geothermal System using Well Logs," presented at 55th Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, September 21-24, 1980, SPE-9499 (1980).

14. Lippmann, M. J. and Bodvarsson, G. S.: "Numerical Studies of the Heat and Mass Transport in the Cerro Prieto Geothermal Field, Mexico," Water Resources Res. (1983) 19, 753-767.

15. Mañón, A., Mazor, E., Jiménez, M., Sánchez, A., Fausto, J., and Zenizo, C.: "Extensive Geochemical Studies in the Geothermal Field of Cerro Prieto, Mexico," Lawrence Berkeley Laboratory Report LBL-7019 (1977).

16. Prian R.: "Development Possibilities at the Cerro Prieto Geothermal Area, Baja California Norte," Proc. 2nd Symp. Cerro Prieto, Comisión Federal de Electricidad, Mexicali (1979), 146-161.

17. Gilreath, J. A. and Stephens, R. W.: "Interpretation of Log Responses in a Deltaic Environment," American Association of Petroleum Geologists Marine Geology Workshop, (1975).

18. Gilreath, J. A., Healy, J. S., and Yelverton, J. N., "Depositional Environments Defined by Dipmeter Interpretation," Transactions - Gulf Coast Association of Geological Studies (1969) XIX, 101-111.

19. Schlumberger Dipmeter Interpretation Fundamentals, Schlumberger Limited, New York (1981).

20. Vonder Haar, S. and Howard, J. H.: "Intersecting Faults and Sandstone Stratigraphy at the Cerro Prieto Geothermal Field," Proc. 2nd Symp. Cerro Prieto, Comisión Federal de Electricidad, Mexicali (1979), 118-134.

TABLE 1

Comparisons between predicted depths to the top of the producing geothermal fluids and the actual top of the production zone.

Well	Predicted Depth to Geothermal Fluids	Top of Production Zone*
	m	m
M-119	2650	2601
M-121	1770	1824
M-124	2195	2097
M-126	2925	2740 2984**
M-191	2225	2225
M-197	2635	2578
T-350	2710	2692

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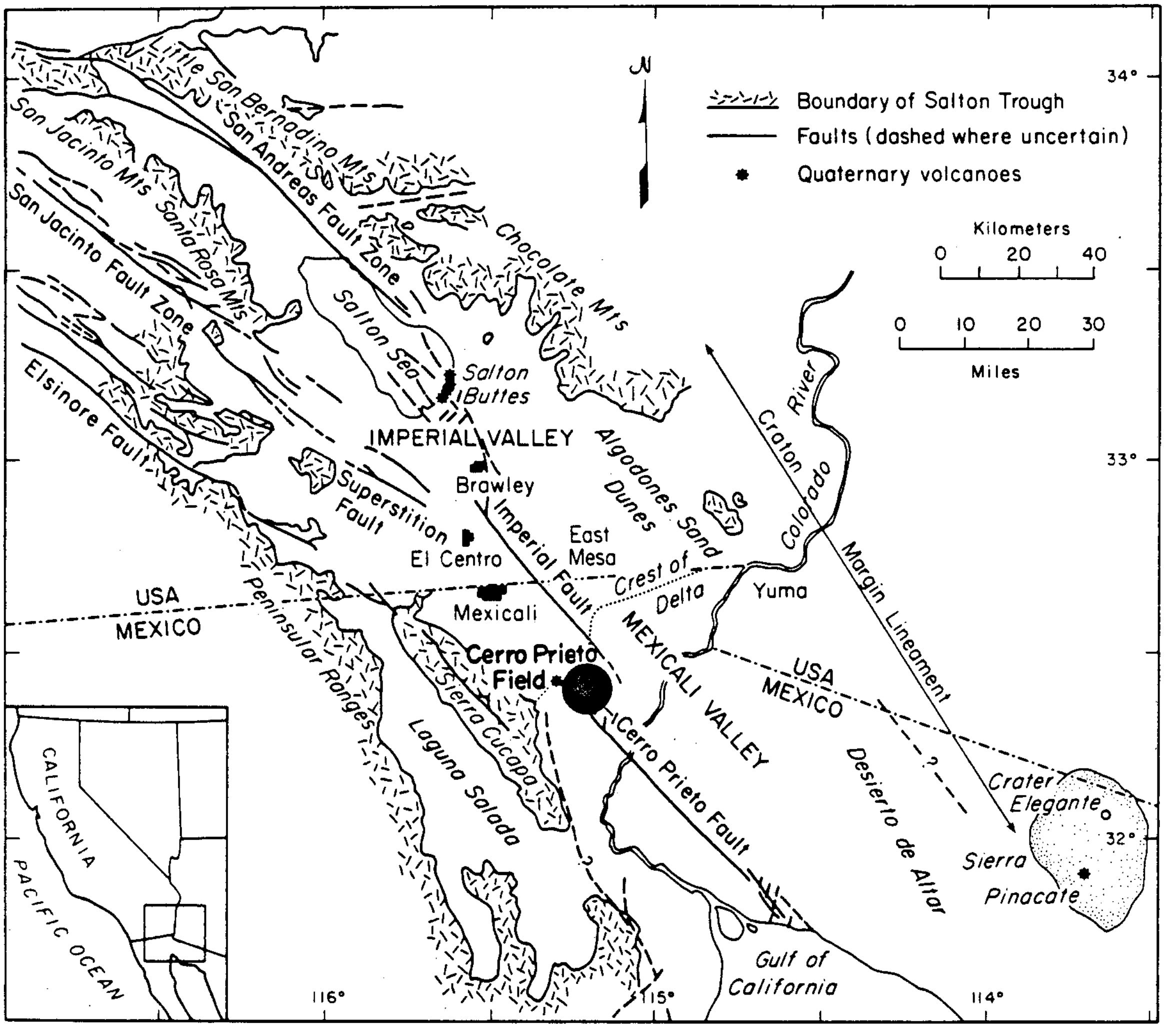
*Written communication from Comisión Federal de Electricidad.

**The top of a second producing zone in M-126.



XBL 801-6718A

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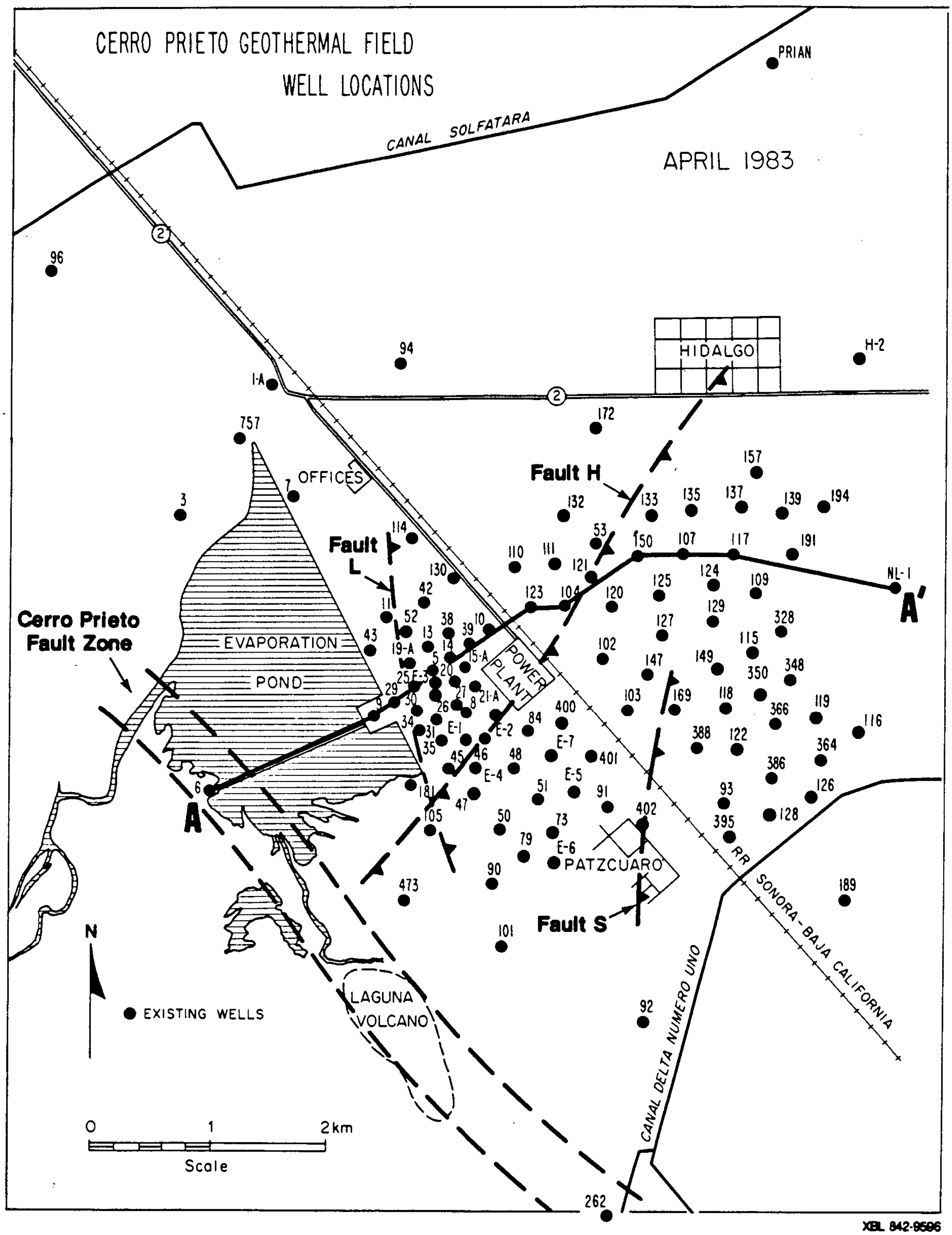

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Figure 2

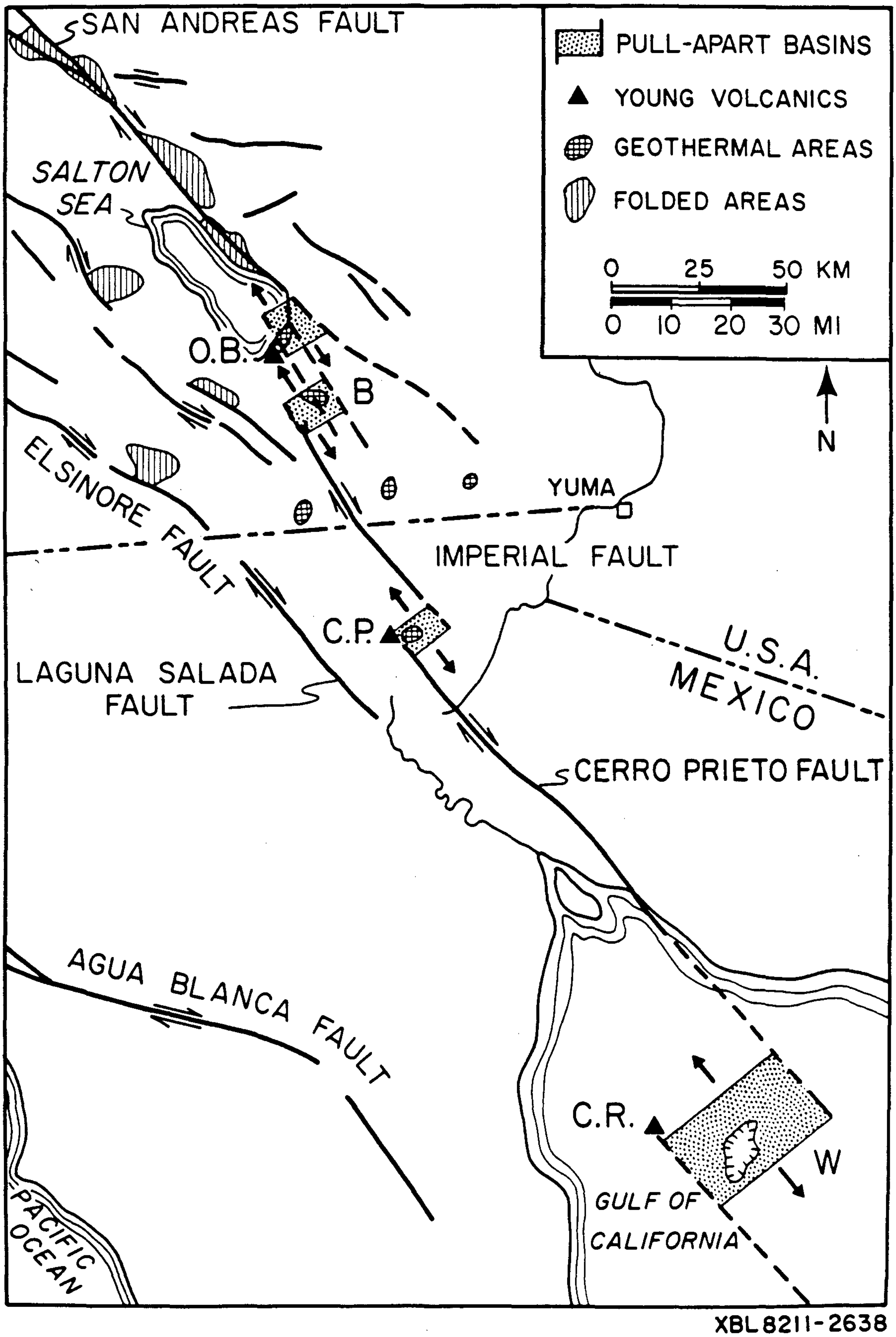

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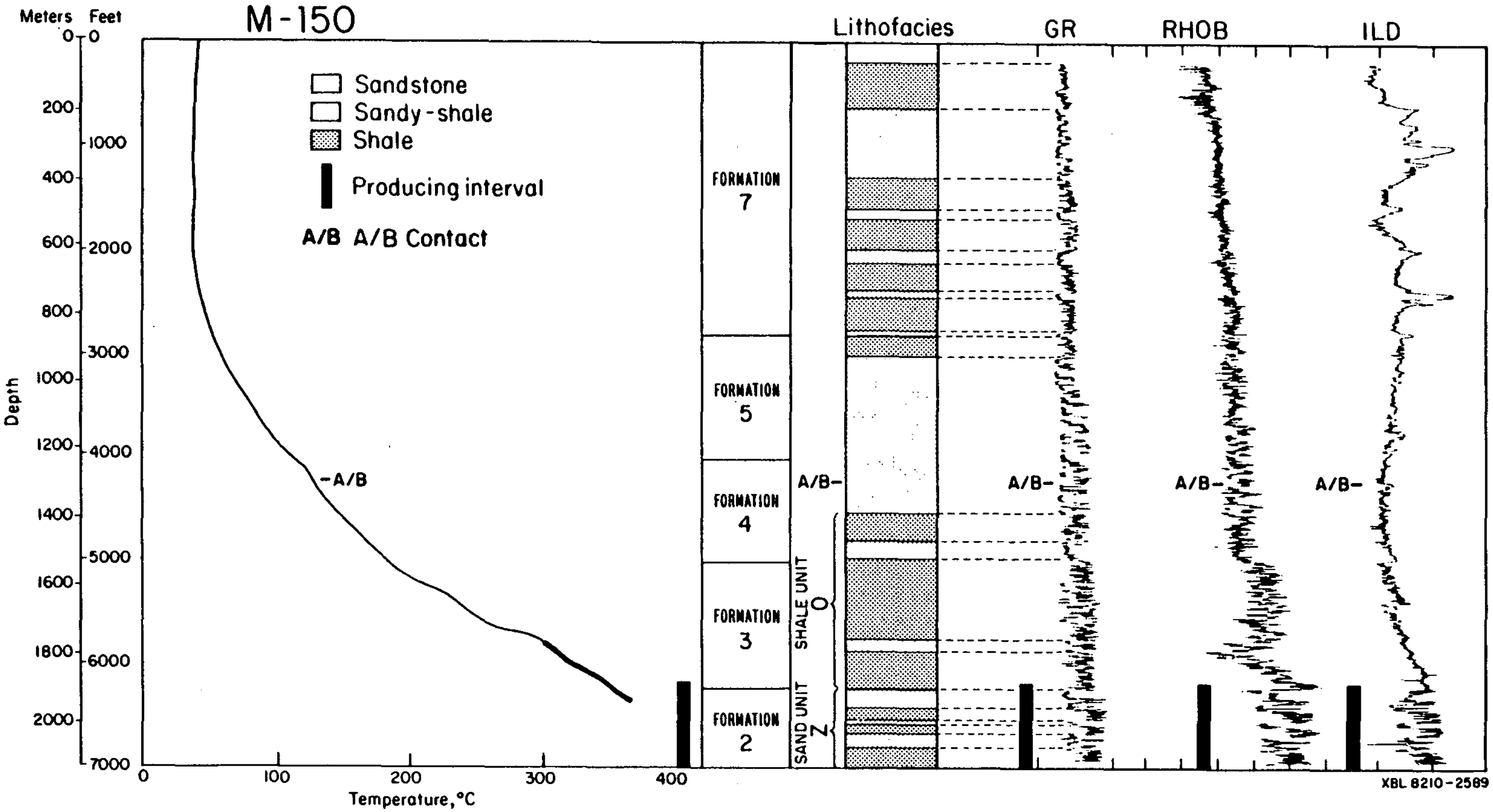
Figure 3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2000
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4000
5000
6000
7000
Temperature, °C
0
100
200
300
400
Sandstone
Sandy-shale
Shale
Producing interval
A/B A/B Contact
-A/B
FORMATION 7
FORMATION 5
FORMATION 4
FORMATION 3
FORMATION 2
A/B-
SHALE UNIT O
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Figure 4

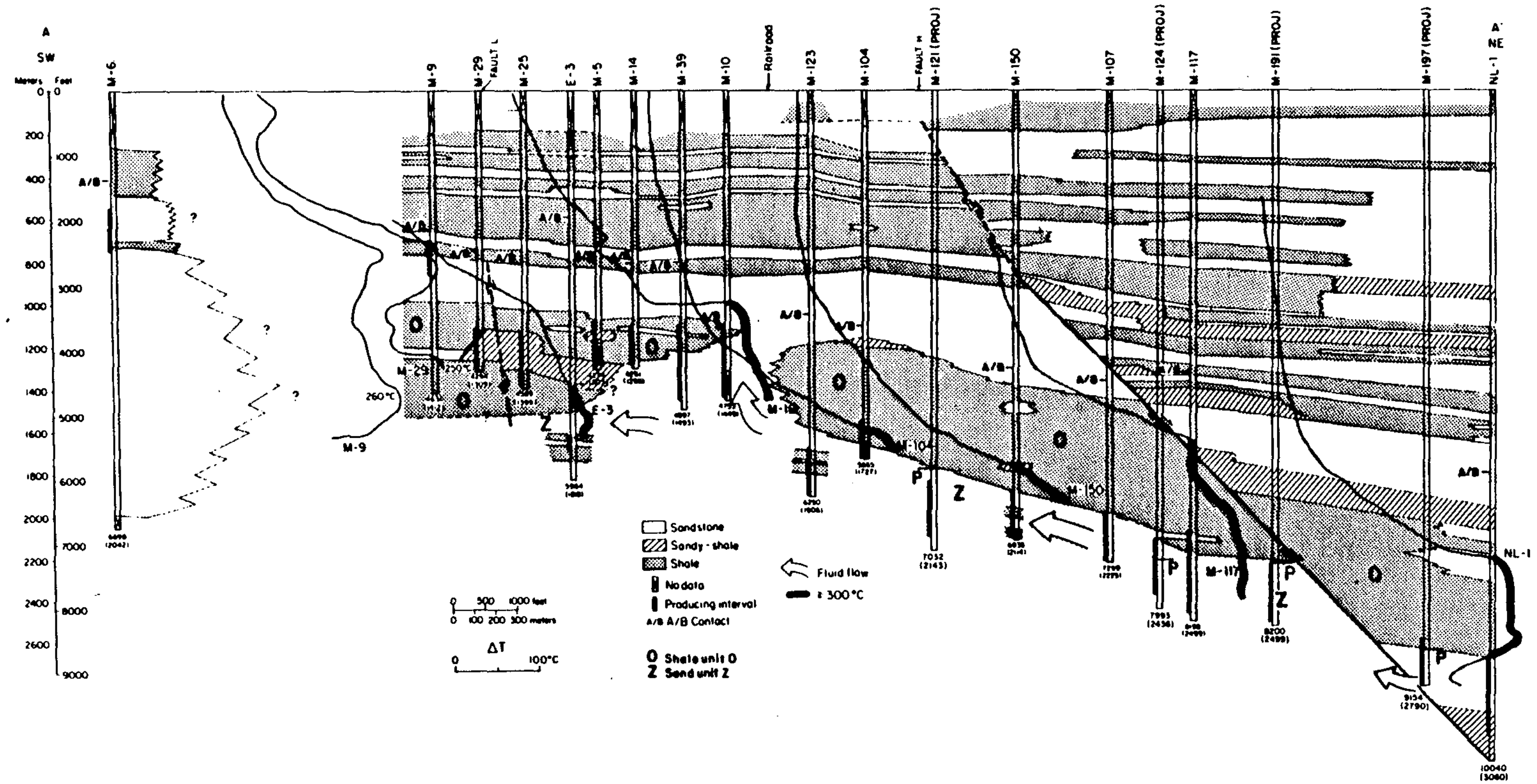

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Figure 5

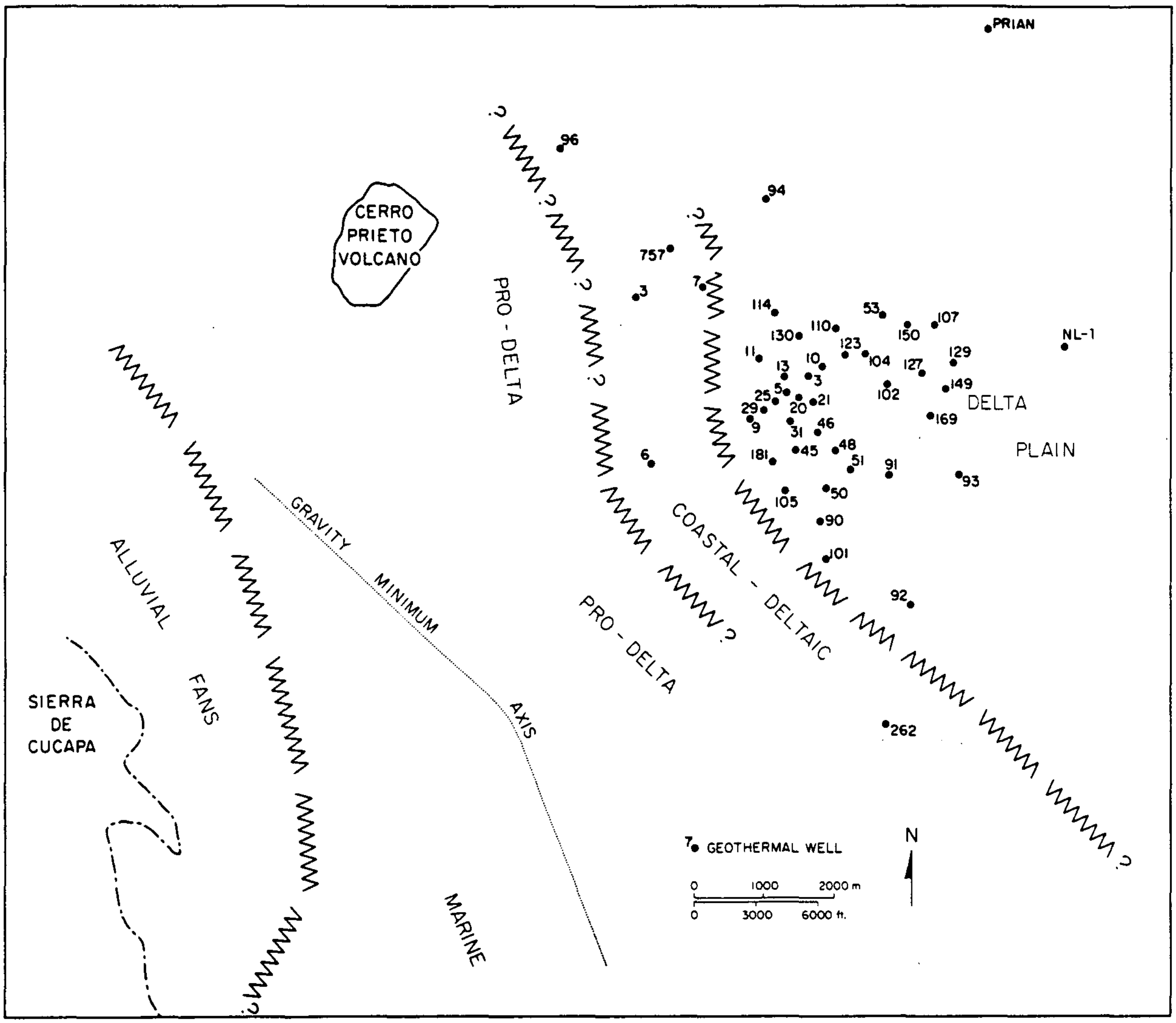

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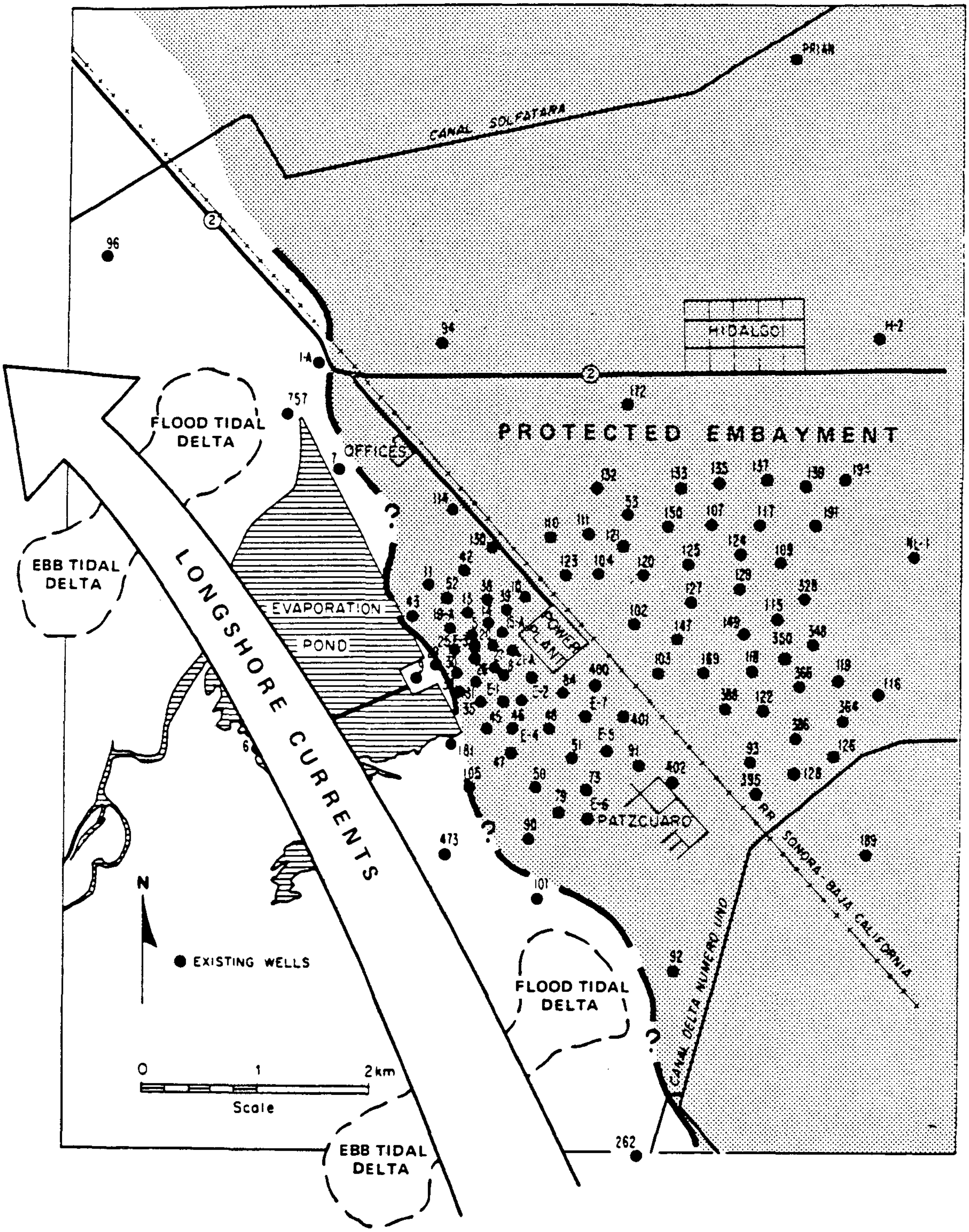
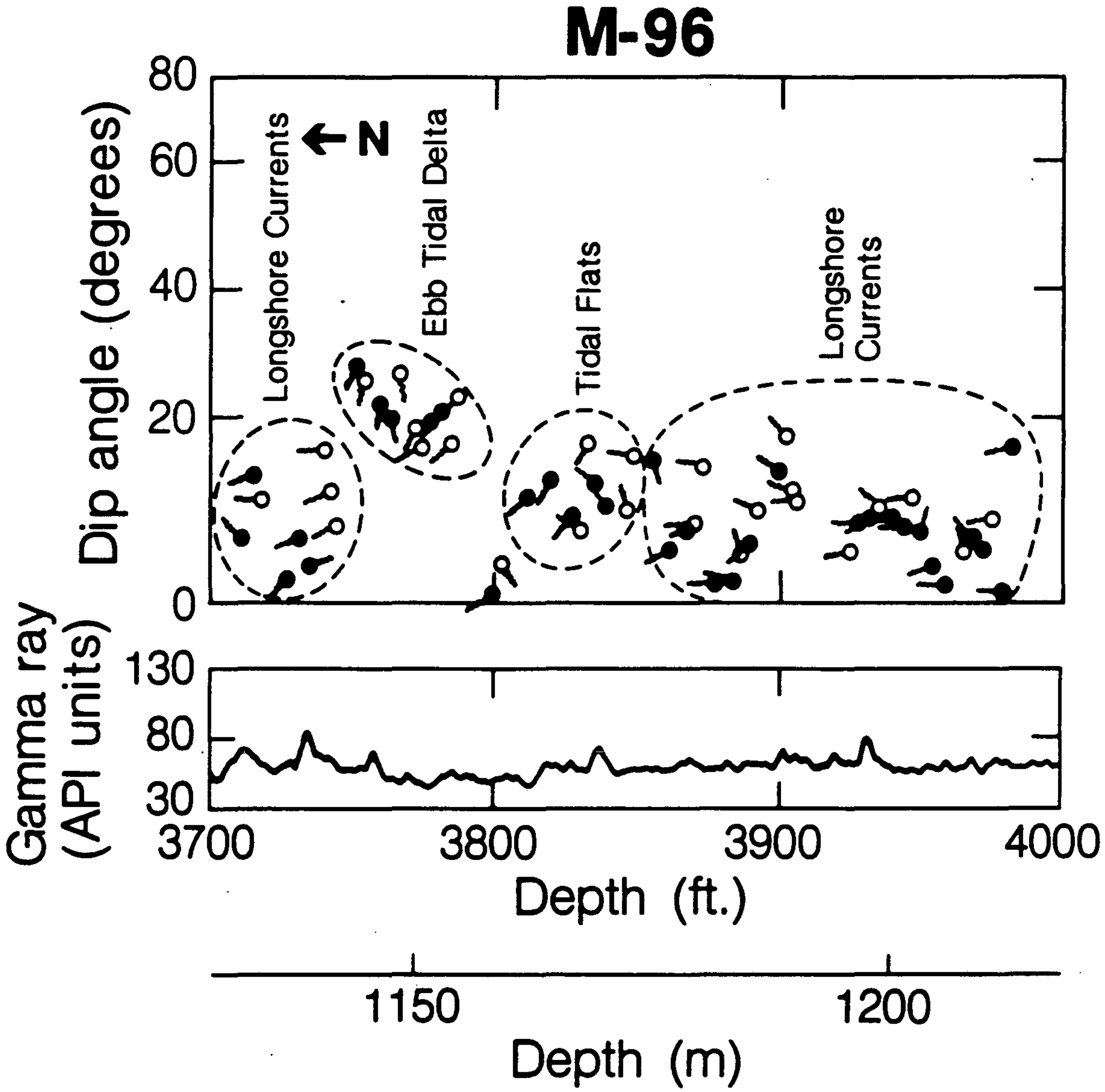
Figure 6



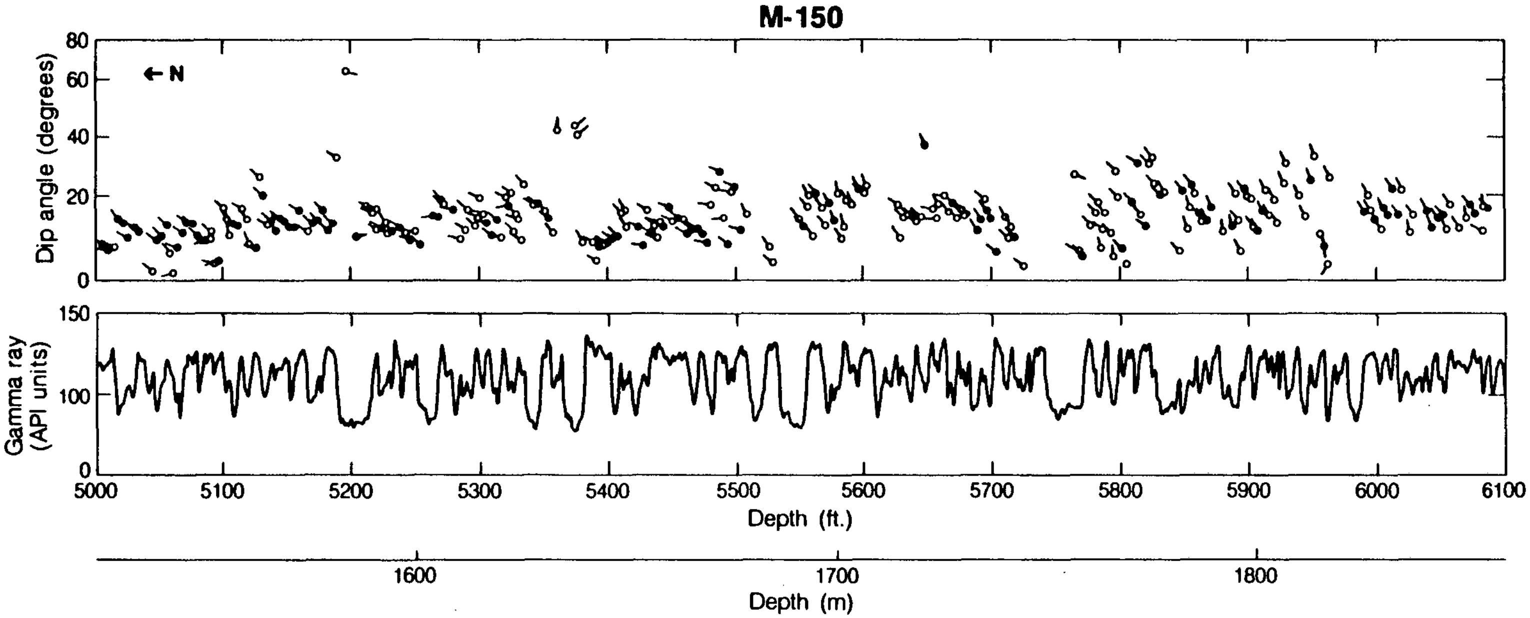
XBL 835-1804B

Figure 7



XBL 842-9592

Figure 8



XBL 842-9595

Figure 9

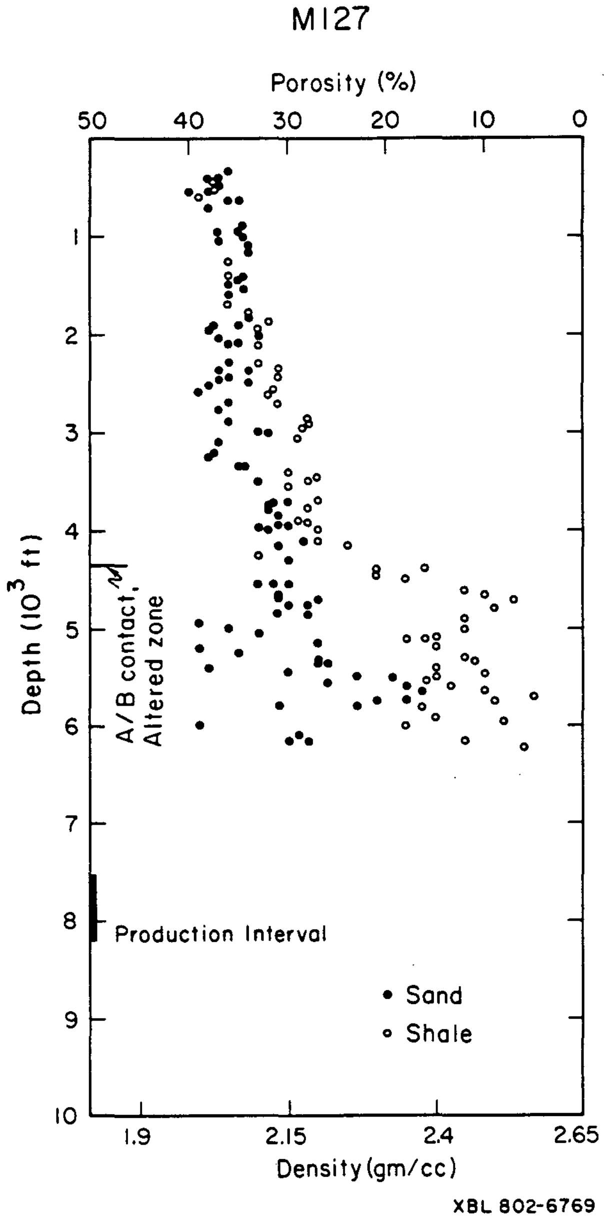
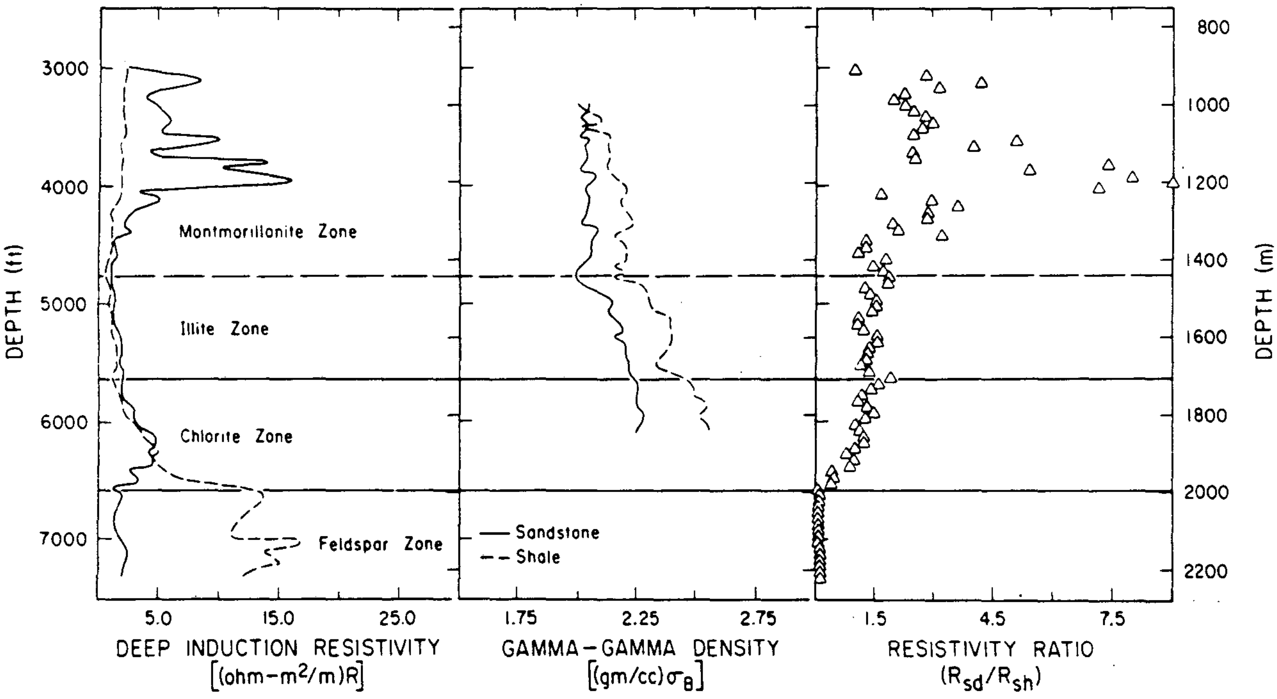
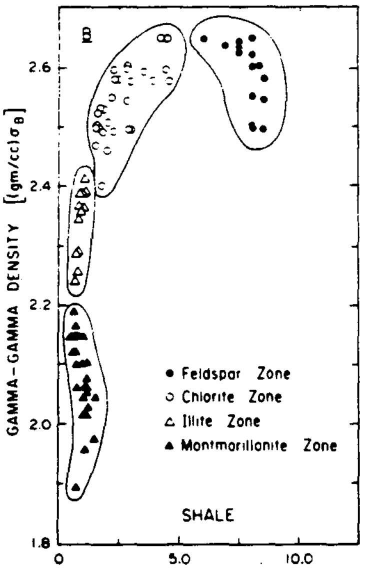

M127
Porosity (%)
50
40
30
20
10
0
Depth (10^3 ft)
1
2
3
4
5
6
7
8
9
10
A/B contact, Altered zone
Production Interval
● Sand
○ Shale
1.9
2.15
2.4
2.65
Density (gm/cc)
XBL 802-6769

Figure 10



XBL 826-726

Figure 11



XBL 826-731A

Figure 12

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