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PALEOMAGNETIC DATING OF THE CERRO PRIETO VOLCANO

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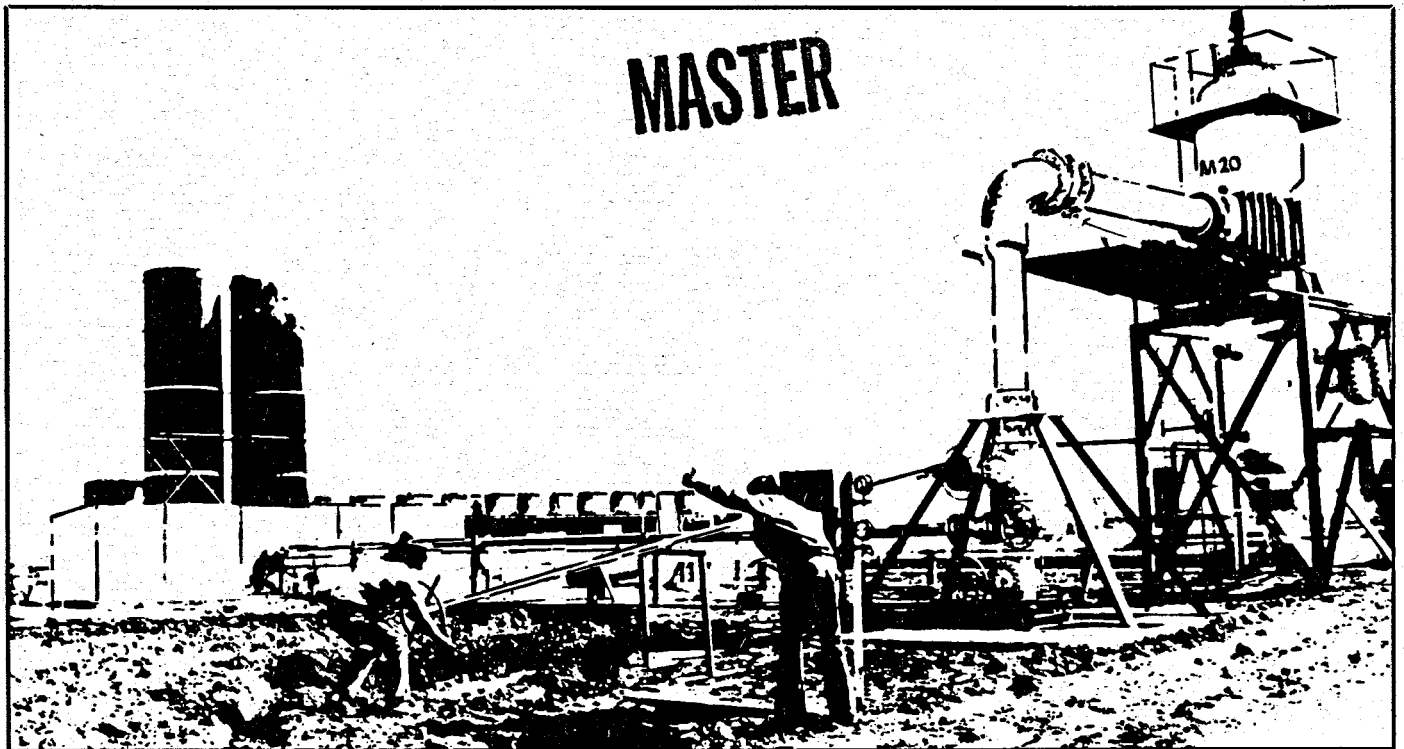
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PALEOMAGNETISM OF THE QUATERNARY CERRO PRIETO, CRATER ELEGANTE, AND SALTON BUTTES VOLCANIC DOMES IN THE NORTHERN PART OF THE GULF OF CALIFORNIA RHOMBOCHASM

Dr. Jelle de Boer

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CERRO PRIETO, CRATER ELEGANTE, AND SALTON BUTTES
VOLCANIC DOMES IN THE NORTHERN PART OF THE
GULF OF CALIFORNIA RHOMBOCHASM

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ABSTRACT

Deviating thermomagnetic directions in volcanics representing the second and fifth or sixth pulse of volcanism suggest that the Cerro Prieto volcano originated about 110,000 years B.P. and continued to be active intermittently until about 10,000 years ago.

QUATERNARY VOLCANIC CENTERS

The tectonic entity comprising the Salton Sea, Imperial Valley, Mexicali Valley, and Gulf of California contains several volcanic complexes that are considered to be of Quaternary age. The largest complex (Sierra Pinacate) is located in the Sonora desert (Fig. 1). Smaller, single domes or groups of domes occur along the southern shore of the Salton Sea (Salton Buttes), in the Mexicali Valley (Cerro Prieto), and in the Gulf of California (Consag Rock, Isla San Luis, Isla Tortuga). To enable relative dating of Cerro Prieto, samples were also collected from radio-metrically dated domes and craters in the Salton Sea and Pinacate regions.

Salton Buttes

Four of the five Salton Buttes (Obsidian Butte, Rock Hill, Red Hill, and Red Island) occur on a northeast-trending lineament which coincides with the long axis of a major magnetic anomaly (Griscom and Muffler 1971). The fifth (Mullet Island) is located further north in the same magnetically anomalous area. The volcanics are low calcium, alkali rhyolites containing tholeiitic and granitic xenoliths (Robinson et al., 1976). The domes are locally modified by wave-cut benches carved during various stands of prehistoric Lake Cahuilla (Robinson et al., 1976). A single K/Ar age (16,000 to 55,000 B.P.) was obtained from Obsidian Butte (Muffler and White, 1969). Paleomagnetic samples were collected from Obsidian Butte along a northwest-southeast traverse across the center, and from Red Hill in a quarry in its southwestern flank.

Crater Elegante

The Pinacate volcanic field is located in northwest Sonora, near the northern end of the Gulf of California. The field is dominated by the Sierra Pinacate, a large, broad, composite volcanic pile (maximum elevation 1206 m) which contains eight collapse features. Crater Elegante is a caldera, about 1.6 km in diameter, 244 m deep, located on the northeast flank of the Sierra Pinacate (Gutmann, 1976). Paleomagnetic samples were collected from two flows and a dike exposed in the eastern wall of the depression. K/Ar data provided by Lynch (1979) gave ages of 0.465 ± 0.065 m.y. for the oldest flow, and 0.461 ± 0.036 m.y. for the dike.

Cerro Prieto

The Cerro Prieto volcano consists of two slightly overlapping volcanic centers which developed on a fracture zone trending N. 38° E. (Puente Cruz and de la Peña L., 1979). The centers rise 260 m above the floor of the Imperial Valley and have diameters of approximately 1000 m. The northeastern cone contains a small crater 200 m in diameter and 60 m deep. Both cones consist of rhyodacitic intrusives and flows (Reed, 1976). A stratigraphic analysis of a section along the southeastern flank of the northern complex revealed at least five eruptive phases. At the base of the section is a layer of arkosic sands, probably of aeolian origin. Overlying this unit is 30 cm of fluvial sands. Secondary sorting and the presence of small volcanic fragments indicate a phreatic

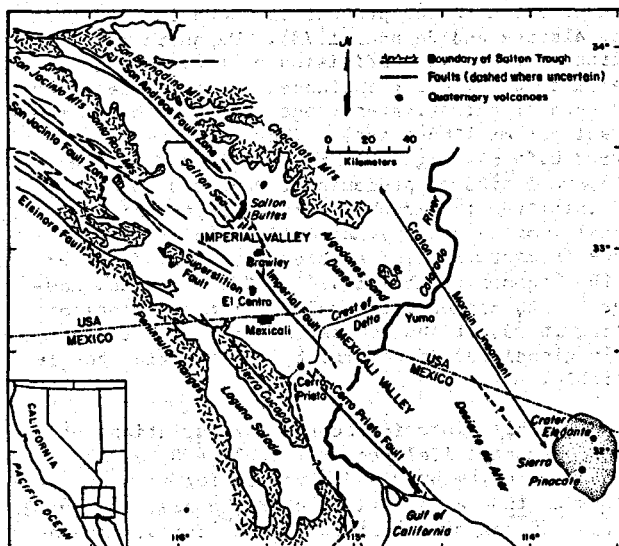


Figure 1. Location of sampling areas in the Salton Trough.

origin. This unit is overlain by 30 cm of gray pyroclastics which include several volcanic bread bombs. An additional four units can be recognized, each consisting of phreatic sediments capped by pyroclastics. The youngest unit is composed of 8 to 10 m of silts and fine sands with isolated clay clasts, leached pyroclastic fragments, and bread bombs (up to 100 cm in diameter) overlain by a 150 m thick accumulation of reddish gray brecciated rhyodacite flows. The flows were probably fed by magmas ascending along a northeast-trending fracture which is exposed in the caldera. The feeder dike can be distinguished from the flows by subvertical northeast foliation and by magnetic intensity values an order of magnitude lower than those for the flows.

The age of the domes is in question. Steam escapes along the northeast flank of the northern dome, suggesting a young volcanic mass. Examination of cores by Reed (1979, written commun.) revealed the presence of apparently fresh crystal vitric tuffs at a depth of 191 m in well M-21, 6.5 km southwest of Cerro Prieto. Reed suggested that this material may have come from the Salton Buttes. There is, however, no evidence there for explosive activity that could have sent tuffs more than 100 km southward. The M-21 tuff therefore probably represents the eruption which breached the northern dome. A subrounded clast of Cerro Prieto rhyodacite, 6 cm in diameter, was recovered in a core from well M-26 at 1275-m depth (Reed, 1979, written commun.). Sedimentation rates in the Imperial Valley are high. An average rate of subsidence of 3 mm/yr was calculated for the last 2 m.y. (Lofgren, 1974). Assuming this rate, the tuff could be 60,000 years old and the clast 425,000 years old. Since Cerro Prieto is located on/in the Colorado delta, rates are probably higher (sediments at 2500-m depth contain upper Pleistocene ostracodes; M. Reed, pers. comm.). At a rate of 10 mm/yr, the tuffs could be as young as 19,000, the pebble 120,000 years old. In view of the location of Cerro Prieto on the Colorado delta, the latter numbers appear more probable.

Paleomagnetic samples were collected from four geologic units:

1. A northeast-trending dike-like feature (Fig. 2, sites 1 and 2). This unit appears to represent the youngest volcanic event in the complex.
2. Flows on the flanks of the northern and on the crest of the southern dome (sites 3 to 6).
3. Steeply inclined silts and clays, probably previous caldera deposits (site 7).
4. Horizontal pyroclastics, cemented by partial welding and caliche (site 8). These volcanics represent the second phase of explosive volcanism and are among the oldest of the complex.

PALEOMAGNETISM

The magnetic field's behavior is characterized by excursions and reversals. To enable use of

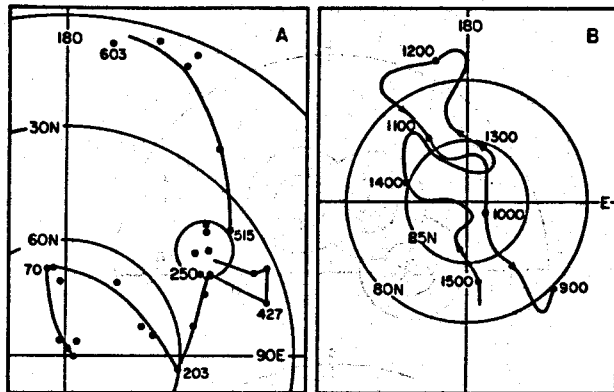


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Figure 2. Location of sampling sites on Cerro Prieto.

paleomagnetism for dating purposes, detailed knowledge of time, location, and polarity of paleopoles is required. The polar path for North America from Cambrian to the present is shown in Figure 3A (Van Alstine and de Boer 1978). Magnetic polarity differences enable subdivision of this path. In the last 70 m.y., for instance, reversal frequency has been high (estimates range from 0.2 to 1.0 reversal per million years). The last reversal occurred 0.69 m.y. ago. It marked the end of the Matuyama period of predominant reversed polarity, and initiated the Brunhes period of predominant normal (north-seeking) magnetism. Major excursions (semi-reversals) enable further subdivision of the Brunhes epoch (Fig. 4). Such periods, however short, are of great value for the purpose of dating rocks, if the events can be proven to be truly global and if control by radiometric ages is reliable.

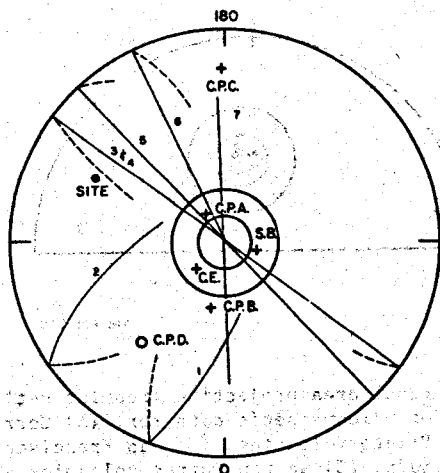
Reliable historic records for variations of the geomagnetic field cover roughly 400 years. Archaeomagnetism provided a record for secular variations of the earth's field over the past 10,000 years. In the southwestern United States, chronological control for the archaeomagnetic data is provided by ^{14}C dates on Indian fireplaces and dendrology. The polar path extending from A.D. 600 to the present shows that the magnetic pole circled the geographic pole in counterclock fashion. Three



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Figure 3. Apparent polar wandering paths with respect to North America: (A) 600 m.y. to present (Van Alstine, and de Boer 1978); (B) 900 to 1500 B. P. (Dubois, 1974).

smaller loops, suggesting clockwise motion over periods of 250 years, overprint the counterclockwise loop. Polar motion in the period from A.D. 900 to 1500 was mostly longitudinal. The pole moved back and forth in undulatory fashion across the geographic pole, as shown in Figure 3B (Dubois, 1974).



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Figure 4. Polar paths for major excursions in Brunhes period: (1) Gothenburg, (2) Starno, (3) Lake Mungo, (4) Laschamp, (5) Lake Biwa, (6) and (7) Blake. Virtual geomagnetic poles for Cerro Prieto (CPA, CPB, CPC, CPD), Salton Buttes (SB), and Crater Elegante (CE). (CPD represents pole dike of site 2 at Cerro Prieto with a pole in the southern hemisphere; + southseeking field, 0 northseeking field.

Data from sediment cores collected in oceans and lakes and young volcanics suggest that major excursions or incomplete reversals may have occurred 12,000, 18,000, 30,000, and 110,000 years B.P. Excursions in the period from 8,000 to 19,000 years B.P. have been grouped together and referred to as the Laschamp event (Bonhommet and Zahringer 1969; Noel and Tarling 1975). Confusion exists, however, since researchers were impressed by the radiometric ages but failed to compare the actual polar paths for the data obtained. The Starno path, 12,077 to 12,103 \pm 150 years B.P. (typical Laschamp according to Noel and Tarling, 1975) resembles that of the Gothenburg excursion (12,350 to 13,750 years B.P.) of Morner et al. (1971) and Morner and Lanser (1975), but is very different from the polar path of the Laschamp rocks (Fig. 4). The meridional path of the latter is almost orthogonal to that of the former two. Evidence for a major excursion, approximately 18,000 years B.P., comes from Nakajima et al. (1973), Freed and Healy (1974), and Noltimier and Colvinaux (1976). The pole again moved meridionally (136°W.) and reached equatorial latitudes. Interestingly enough, this event (Lake Biwa I) is compared with the Lake Mungo event. Polar paths are indeed close, but ages differ significantly.

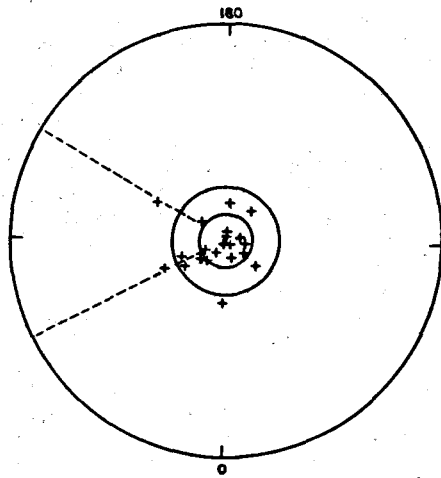
Evidence for a major excursion approximately 30,000 years ago has been supplied by Ninkovitch et al. (1966), Bucha (1970), Barbetti and McElhinny (1972), and Freed and Healy (1974). The only good polar path and age determinations (^{14}C) come from the Lake Mungo archaeological site (Barbetti and McElhinny, 1972). It represents a meridional path at approximately 127°W. (Fig. 4). The Lake Mungo and Laschamp paths virtually overlap, suggesting that they represent one and the same excursion. Evidence in support of this hypothesis was obtained recently by Hall and York (1978) who redated Laschamp-Olby materials and obtained ages ranging from 21,500 to 61,500 years with a weighted average at 45,400 \pm 2,500 years B.P.

Evidence for the Blake event was first presented by Ninkovitch et al. (1966). Smith and Foster (1969) proved this event to be truly global, and estimated an age range from 108,000 to 119,000 years B.P. Supporting evidence was provided by Wollin et al. (1971), Kukla and Koci (1972), Kawai et al. (1972), Denham and Cox (1971), and Menabe (1977). Data by the Menabe show a meridional path at approximately 155°W. or 175°W. (Fig. 5).

Ninkovitch et al. (1966) and Wollin et al. (1971) believe that other events have occurred approximately 180,000, 260,000, and 400,000 years ago. Insufficient data exist at this time to support their existence. Thus, a major data gap exists for 5/6 of the Brunhes period.

PALEOMAGNETIC DATA

The distribution of Brunhes poles for North America generally shows tight clustering around the geographic pole (Fig. 5). Some poles trend toward lower latitudes and may indicate excursions. If the Quaternary volcanics of the Salton/Imperial Trough region are truly Brunhes, their paleomagnetic poles should theoretically

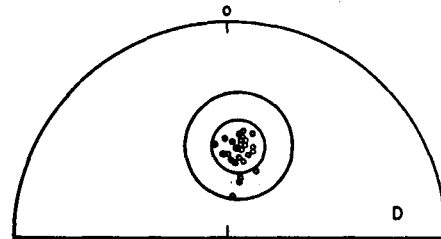
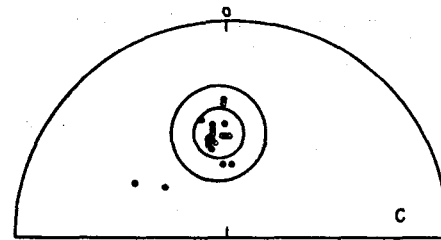
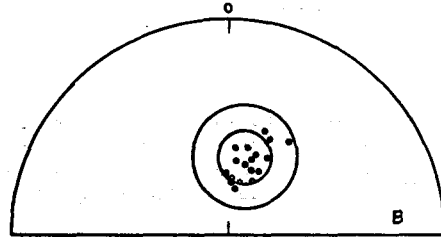
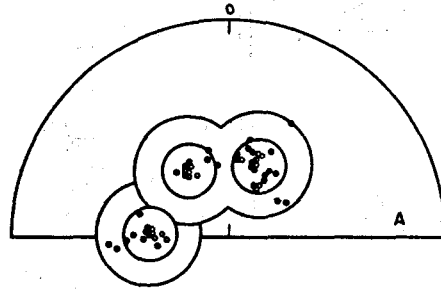


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Figure 5. Quaternary virtual geomagnetic poles for western United States (Irving et al., 1976).

fall within these clusters. Barnard (1968) and Reed (1976) have stated that the Cerro Prieto volcanic eruption occurred during the Brunhes epoch. To be able to determine this more accurately, first it is necessary to establish what is known about the Brunhes magnetic field pole position in the region. Although information on paleopoles is scarce in this region, two important studies exist. Measurements of the magnetization in recent sediments of the Gulf of California and San Francisco Bay provide virtually identical directions (Irving et al., 1976; Graham, 1974). The vectorial distribution of the bay muds is shown in Figure 6B and provides a reliable measure for the present direction of magnetization in northern Mexico and California. Paleomagnetic research of Quaternary lava flows from the Medicine Lake Highlands of northern California has shown that the virtual geomagnetic pole (VGP) for these volcanics occur in far-sited positions with respect to the present pole. Brown and Mertzman (1979) compared these data with other poles for the western United States and concluded that the observed inclination anomalies that cause this deviation may be due to a large-scale regional field variation. Such a field variation should also affect the Quaternary volcanics of southern California and northern Mexico.

The paleomagnetic results are shown in Figure 6. With the exception of two concentrations for Cerro Prieto, all data appear to overlap. This overlap, however, does not indicate similar age since the pole positions computed from these data indicate clear differences. This is shown in Figure 4, depicting the pole positions computed from averages of directions given on Figure 6. The VGPs for the Salton Buttes and Cerro Prieto CFB group are clearly far-sited with regard to the present pole. The Crater Elegante and Cerro Prieto CPA group are



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Figure 6. Equal area projection (Schmidt net) of paleomagnetic data for: (A) Cerro Prieto volcanics, (B) San Francisco Bay muds, (C) Salton Buttes volcanics and (D) Crater Elegante volcanics. (See Table 1 and Figure 4.)

near-sited, as are the poles for the Baja California and San Francisco Bay muds. This suggests that the regional field variations of Brown and Mertzman (1975) could only have been temporary.

The following conclusions can be drawn from the data:

TABLE 1. PALEOMAGNETIC DATA

Sample group	N	Decl.	Incl.	α 95	P Lat.	P Long.
Salton Buttes (SB)	18	354.9	49.9	3.3	78.2 N	74.1 E
Crater Elegante (CE)	27	8.6	57.1	2.3	75.3 N	45.6 W
Cerro Prieto (CPA) (Dikes, sites 1 and 2)	13	333.2	59.8	2.4	76.7 N	144.7 W
Cerro Prieto (CPB) (Flows, sites 3 to 6)	24	23.3	60.0	3.2	63.6 N	11.6 W
Cerro Prieto (CPC) (Pyroclastics, site 8)	15	269.6	57.8	3.3	9.9 N	177.8 W
Cerro Prieto (CPD) (Dike, site 2)	4	129.9	-19.9	4.7	38.9 N	129.5 E
San Francisco (tidal muds)	6	14.3	60.3	3.7	78.3 N	55.3 W
Baja California (recent muds)	16	19.0	57.0	7.5	79.0 N	50.0 W
New Mexico (Valles Caldera)	22	359.0	48.0	5.0	83.0 N	83.0 E
California (Lousetown Lavas)	23	22.7	45.3	8.4	67.3 N	3.2 W
California (Wilson Creek Form.)	60	0.3	49.3	4.5	82.2 N	59.1 E
Mexico (Iztaccihuatl Volc.)	232	0.9	34.4	8.2	88.8 N	34.3 E

1. Paleomagnetic pole positions for Cerro Prieto deviate significantly from those of the Salton Buttes and Crater Elegante. The data thus suggest that the Cerro Prieto volcano may not have been active in the period from 16,000 to 50,000 and from 461,000 to 465,000 years B. P. The former age, however, is questionable.

2. The paleomagnetic data obtained for the Cerro Prieto cluster in three distinct groups. These groups provide different poles, suggesting differences in age between the partially welded pyroclastic (old event), rhyodacitic flows both cones), and rhyodacite dike (young event).

3. The data for the Cerro Prieto pyroclastics provide a tight cluster, indicating that temperatures were above the Curie point during deposition. The magnetic declinations deviate by as much as 90° from that of the igneous rocks in the same complex. Since these deposits are horizontal and undisturbed tectonically, this deviation must have been caused by a major excursion of the pole. Comparison of different excursion paths (Fig. 4) suggests that the pyroclastics were emplaced during the Blake excursion, which occurred in the period from 119 to 108,000 years B.P. This age compares

favorably with the hypothetical age of the rhyodacitic pebble found in well M-26 at 1275-m depth.

4. The paleomagnetic direction of a segment of the rhyodacitic dike differs significantly from that of the flows. The northeast dike, which is exposed presently, therefore does not appear to represent the original feeder dike for the flows. Multiple injection, however, is likely to have occurred and the feeder dike of the flows may be covered by its related volcanics. Although difficult to prove, injection of the dike may have been responsible for the formation of the small explosion crater in the northern dome. Four samples collected along the dike's southwest contact show consistent deviations and reversed magnetization. Since susceptibility and intensity values do not differ appreciably, this effect cannot have been caused by lightning impact. It may, therefore, represent another excursion. The pole computed for these data is located near the polar paths of the Starnø and Gothenburg events (12,000 to 13,750 years B.P.). Such an age would again compare favorably with that obtained for vitric tuffs in well M-21 at 191 m, which could be as young as 19,000 years.

ROCK MAGNETIC DATA

In addition to providing information on the possible age of the volcanics, paleomagnetic data can also be useful for analyzing magnetic anomalies. Magnetic anomalies can only be modeled accurately if rock magnetic properties such as susceptibility (X) and the Koenigsberger ratio (Q) are known for the area. The first provides a measure of intensity contrast, the second of intensity variation of the magnetic vectors. Natural remanent magnetization (NRM), X, and Q are shown in Figure 7 for samples from Cerro Prieto, Crater Elegante, and Cucapa Range. Q values for the Cerro Prieto rhyodacites and Crater Elegante hawaiites persistently have Q of 2 and greater, indicating that the thermoremanent magnetization (TRM) direction predominates. Q values for the Cucapa Range granodiorites are low (± 0.2), suggesting that the induced magnetization predominates. Because the volcanics are young, they have a magnetization more or less parallel to the present field and can thus be modeled using present magnetic flux lines. For most granodiorites, the magnetic intensity is one or two orders lower than that of the volcanics. This implies that different anomalies can be expected and that spectral analyses of the data would be useful. Several small anomalies occur southeast of Cerro Prieto. One or two of these magnetic anomalies, such as the one over the present geothermal field, does not coincide with a gravity anomaly. It appears possible that we are dealing here with a basement complex which is pervasively intruded by rhyolitic or rhyodacitic dikes (and sills). In such an area, magnetic contrast would be sufficient for anomalies, but density contrasts are minimal and no gravity anomalies would be expected.

CONCLUSION

The volcanic materials from the Salton Buttes, Crater Elegante, and Cerro Prieto provided excellent directions of magnetization and paleo-

magnetic poles. With the exception of a sample group CPD (site 2), the directions were normal and most poles cluster around the geographic pole, suggesting a Brunhes age. The Salton Buttes, Crater Elegante, and Cerro Prieto poles differ enough to conclude that volcanic activity occurred at different times.

Sample group CPD provides a pole located close to the polar path for the Gothenburg and Starvo events ($\pm 12,000$ years B.P.), and CPC a pole near the excursion path of the Blake event (110,000 years B.P.). These directions cannot be explained by statistical error, lightning impact, incomplete tectonic correction, or other common errors, and must be considered reliable magnetic deviations. A high probability therefore exists that the Cerro Prieto volcanism was initiated about 110,000 years B.P. and continued intermittently until about 10,000 years ago.

The twin domes and their hydrothermal zones provide an ideal model for the Cerro Prieto field. As shown in Figure 8, the Laguna Volcano, a zone

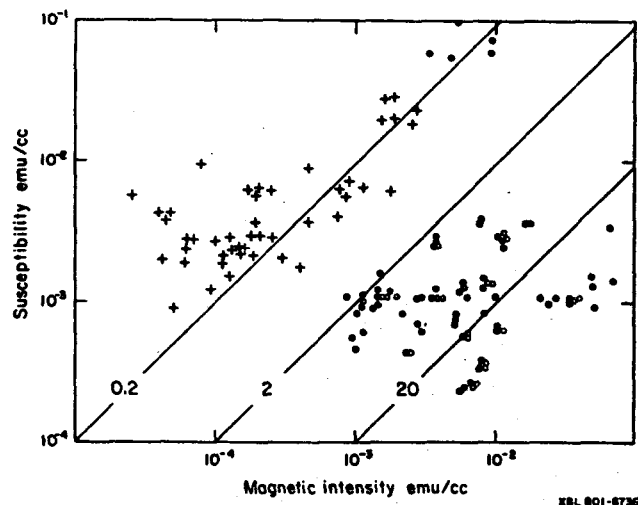


Figure 7. Q (Koenigsberger) plot of magnetic susceptibility versus intensity of NRM. Dots are Quaternary volcanics, crosses are Cucapa Range granodiorites.

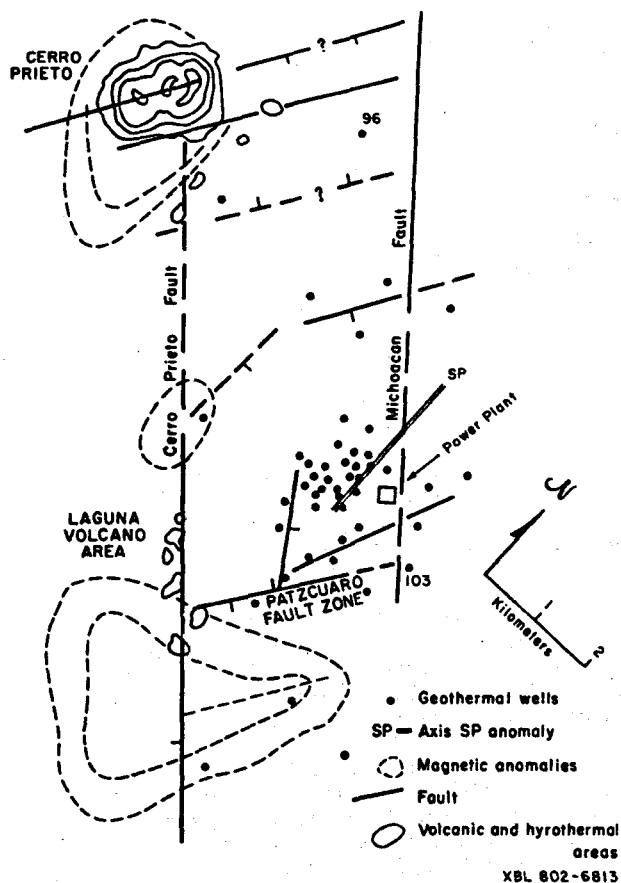


Figure 8. Volcanotectonic map of the Cerro Prieto-Laguna Volcano area with approximate location of magnetic anomalies (based on this work and Evans, 1972), self-potential anomaly (Corwin et al., 1979), major fault and fracture zones (based on Vonder Haar and Howard, 1980, and de la Peña, pers. commun.), drill holes and volcanic and hydrothermal zones.

of sedimentary ridges made up mostly of phreatic deposits, is located over a minor magnetic anomaly at the intersection of the northwest Cerro Prieto and northeast Pátzcuaro faults. This anomaly can be explained by the presence of rhyodacitic dike material in the basement complex below the sediments. Such a dike or dikes would trend northeast and either intrude or parallel the Pátzcuaro fault. As is the case in the Cerro Prieto volcano, hydrothermal activity is concentrated along the northeastern segments of the fault(s) where vertical ascent of the steam is not blocked by the dike(s). The Laguna Volcano may represent the initial stage in the development of a volcanic complex of the Cerro Prieto type.

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