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PALAEOMAGNETISM AND ROCK-MAGNETISM OF SELECTED INTRUSIVE IGNEOUS BODIES FROM SOUTHERN MEXICO: I RECONNAISSANCE STUDY OF THE ACAPULCO AND TIERRA COLORADA INTRUSIVES

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RESUMEN

Se presentan resultados paleomagnéticos de 60 muestras orientadas, colectadas en dos intrusiones: el granito de Acapulco (datación de Rb-Sr en separado de biotita, 48 ± 0.5 m.a.) y la monzonita de Tierra Colorada (datación de Rb-Sr en separado de biotita, 36.6 ± 2 m.a.). La demagnetización por campos magnéticos alternos decrecientes y por altas temperaturas indica que el registro paleomagnético de los intrusivos es complejo. El análisis de las direcciones de magnetización sugiere que se registraron variaciones del campo geomagnético durante el emplazamiento de los intrusivos. Las explicaciones posibles consideradas son: (1) variaciones del campo geomagnético registradas durante el enfriamiento de los intrusivos; (2) remagnetización; (3) movimientos tectónicos internos; (4) movimientos tectónicos de los intrusivos; y (5) magnetizaciones inestables. La respuesta magnética de los intrusivos es dominada por las magnetizaciones inducidas (los coeficientes de Q son pequeños), las cuales son mayores en la monzonita.

ABSTRACT

Palaeomagnetic data from a total of 60 oriented samples collected from two intrusive bodies, the Acapulco granite (Rb-Sr date on biotite of 48±0.5 m.y.) and the Tierra Colorada monzonite (Rb-Sr date on biotite of 36.6±2m.y.), are reported. Alternating field and thermal demagnetization reveal that the palaeomagnetic record of the intrusives is complex. The results suggest that relatively rapid apparent geomagnetic variations are recorded by the intrusives, and different explanations are considered: (1) geomagnetic field variations being recorded by the cooling of the bodies, (2) remagnetization effects, (3) relative tectonic movements within the bodies, (4) tectonic movements of the bodies as coherent units, and (5) extreme magnetic instability. No definitive explanation is given. The magnetic response of the intrusives is dominated by the induced magnetizations (Q-coefficients are very low), which are higher in the monzonite than in the granite.

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1. INTRODUCTION

This work is part of a long-term project of investigation of rock suites associated with plate subduction processes. The project comprises three major divisions: (a) andesitic volcanogenic sequences, (b) granitic batholith belts, and (c) derivative greywacke-arkose sedimentary succesions. These rock suites have long been associated with magmatic arc-plate subduction tectonics (Dickinson, 1970). Thus, detailed study of the arc magmatism may provide valuable data on palaeosubduction zones, where no data on seismicity are available. Currently, studies are restricted to geologic, petrographic and geochemical surveys, but they do not distinguish time variations and the picture given may not correspond to the plate subduction at any one time (Urrutia-Fucugauchi, 1982). In this respect, radiometric and palaeomagnetic (magnetostratigraphic) studies may help in understanding the time variations and so the evolution of subduction zones. Further, the rock suites mentioned above contain relatively large amounts of iron minerals of the system FeO-Fe_2O_3-TiO_2, resulting in high susceptibility and high intensity of induced magnetizations, and these rocks are also able to acquire strong and stable remanent magnetizations. Thus, palaeomagnetic (rock-magnetic) data may give useful results for interpreting magnetic surveys, and also for further characterizing the magmatic arc rock suites.

This work reports results of a reconnaissance palaeomagnetic investigation of the Acapulco granite (Fig. 1) and the Tierra Colorada monzonite (Fig. 2) which are located in the Pacific coast of southern Mexico.

2. GEOLOGIC SETTING

Most of the Pacific margin from Cabo Corrientes, Jalisco to the Mexico-Guatemala border and beyond is characterized by metamorphic rocks which have been assigned a Precambrian or Palaeozoic age (de Cserna, 1965; Kesler and Heath, 1970). The geologic tectonic history of southern Mexico is poorly understood and there are several contrasting proposed models. Studies in terms of plate tectonics, suggest that plate convergence between southern Mexico and oceanic plates has been the dominant tectonic process for the past 100 m.y. or more (Malfait and Dinkelman, 1972; Walper and Rowett, 1972). Along the coast there are several Late Mesozoic-Early Cenozoic granitic bodies which may probably represent the roots of a magmatic arc. However, the distances to the present trench position are much less than those observed for other circum-Pacific magmatic arc-subduction zone systems. Accepting that the granites are related to subduction, then it follows that part of the continental margin has been removed by some process. Indeed, there are other observations which have long lead workers to propose large-scale displacements occurring in or near the present (Middle America) trench. Basically, they involve: left-lateral movements connected with the Caribbean-North America plate boundary (e.g. Hess and Maxwell, 1953; de Cserna, 1969; Malfait and Dinkelman, 1972; Walper and Rowett, 1972; Kesler, 1973), and right-lateral movements associated with differential movement or oblique subduction between the Farallon and North America plates (Karig *et al.*, 1978; Beck and Plumley, 1979).

Table 1

Summary of radiometric dates

	Pb - α (Larsen *et al.*, 1958)	Pb - α (De Cserna *et al.*, 1974)	Rb - Sr (Fries and Rincón Orta, 1965)	Rb - Sr Guerrero, 1975)
Acapulco Granite	98 ± 10 m.y.	100 ± 10 m.y.	80 m.y.	43 ± 7 m.y.
			(Maximum age from K feldspar)	(isochron from 4 determinations whole - rock)
				48 ± 0.5 m.y.
				This may represent the time of intrusion and cooling of the body
Tierra Colorada (El Ocotito) Monzonite	96 ± 10 m.y.			36.6 ± 2 m.y.
				(biotite concentrate) (minimum age)

As a first step, palaeomagnetic sampling was restricted to granitic bodies previously studied by radiometric methods (Table 1), and where geologic, petrographic or geochemical data were also available. The Acapulco granite has an aereal extension of about 60 km^2, although some portions are covered by the Pacific Ocean waters, and detailed marine studies are still lacking (Fig. 1). The body is described as a medium to coarse grained hypidiomorphic biotite granite which in places presents a rapakivi texture. It has minor facies such as the syenite near Puerto Marquez (SE limit) and the doleritic dikes intruding the body near La Quebrada (near site 3). To the north along the road Acapulco-Mexico City, there are two other major intrusive bodies, the one farther from the coast known as the El Ocotito or Tierra Colorada intrusive was also selected for palaeomagnetic sampling (Fig. 2). The body has an aereal extension of about 70 km^2 and consists mainly of a medium grained, hypidiomorphic biotite quartz-monzonite. Numerous thin dikes of diabase and aplite cut the body, and minor facies are constituted by a tonalite.

3. PALAEOMAGNETIC RESULTS

For the present study a total of 60 hand samples and cores were collected and oriented *in situ* with magnetic compass. Thirty eight samples were collected from 7 sites in the Acapulco granite, roughly along a profile crossing its largest dimension (Fig. 1), and the remaining 22 samples were collected from 3 sites in the Tierra Colorada monzonite (Fig. 2).

In the laboratory one to three specimens were prepared from each sample, which gave some 110 specimens. The intensity and direction of natural remanent magnetization (NRM) were measured with a Digico complet result magnetometer (Molyneux, 1971). The low-field susceptibility was measured with a susceptibility bridge (Collinson *et al.,* 1963). The stability and vectorial composition of NRM were investigated by both alternating field (AF) and thermal demagnetization. AF demagnetization was carried out in 11-12 steps up to a maximum peak field of 900-950 Oe by using a digitally controlled three-axes demagnetizer (de Sa and Widdowson, 1974). Thermal demagnetization was carried out in 5-6 steps up to a maximum temperature of 605°-630°C by using a non-inductively-wound vertical furnace (Stephenson, 1967). Some two to four samples *per site* were subjected to detailed demagnetization. The optimum AF field or temperature ranges for bulk demagnetization were estimated by vector substraction analysis (Zijderveld, 1967). Results are illustrated in Figures 3-7.

3.1 *Acapulco Granite*

The initial NRM intensity and low-field susceptibility of the two sites at the northwestern edge of the body (Sites 1 and 2, Fig. 1) were considerably lower than

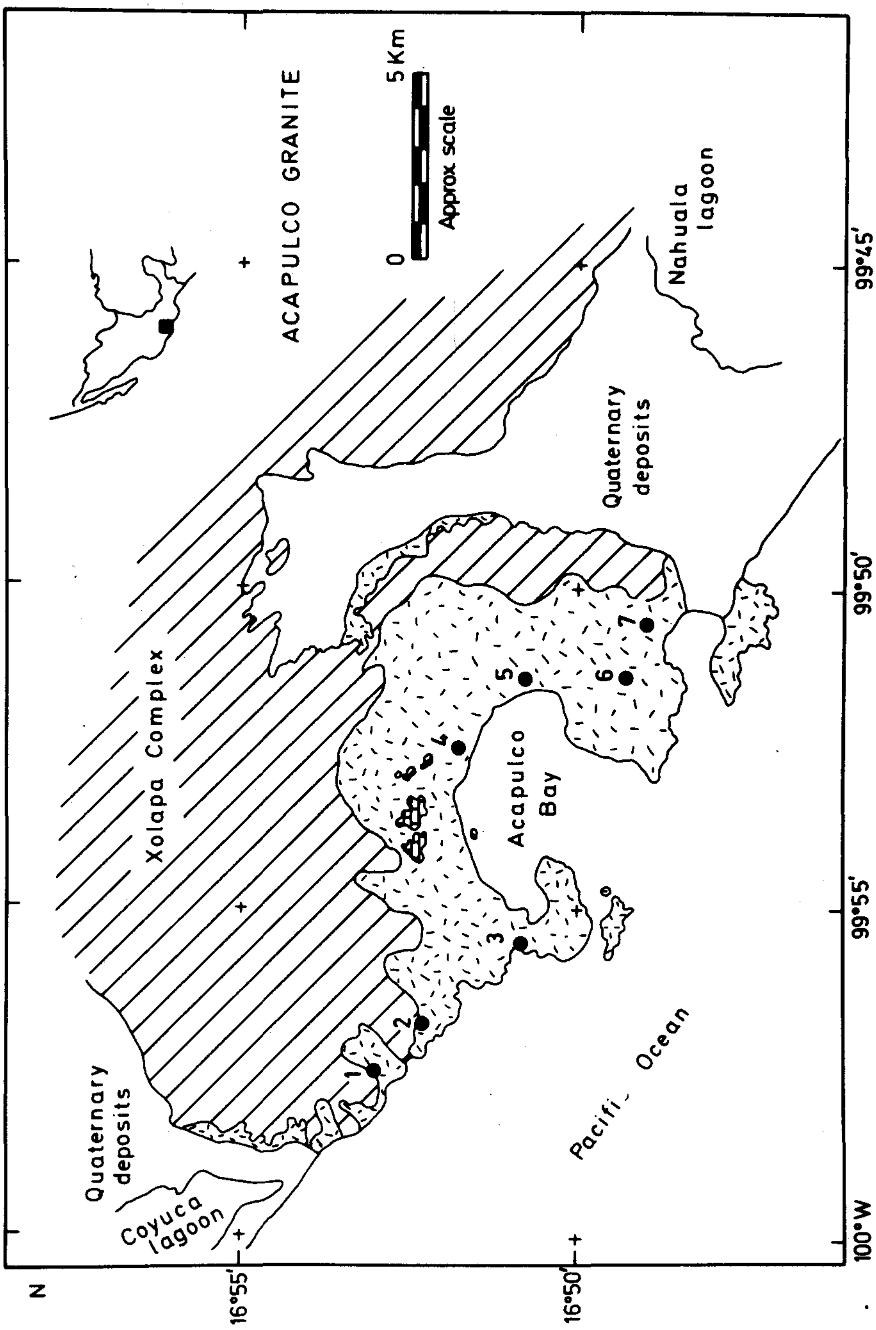

Fig. 1. Simplified geologic map of the Acapulco granite (after de Cserna, 1965) showing location of sampling sites.

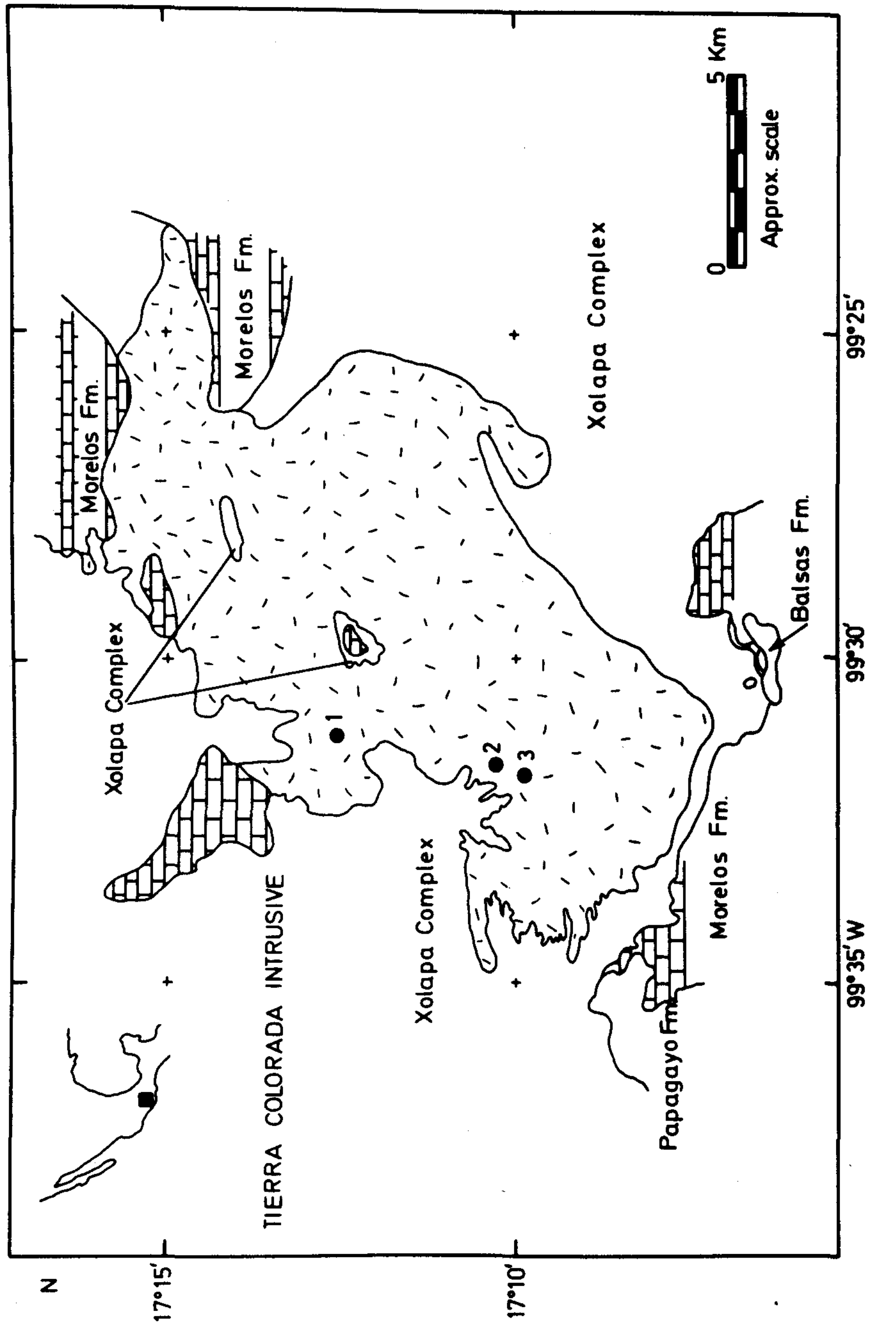

Fig. 2. Simplified geologic map of the Tierra Colorada (El Ocotito) intrusive (after de Cserna, 1965) showing location of sampling sites.

for the other 5 sites (Table 2). The weak intensities of some specimens produced some problems of repeatibility of results during NRM measurements. Additionally it was observed that specimen results from single samples showed variable intensity and directions, even after the demagnetization. The modified Köeningsberger coefficient (Q) was low, i.e. 0.04 and 0.03 (site means). The AF and thermal pilots showed apparently unstable magnetizations, although this can be attributed to the difficulty of accurately measuring the remanences, and perhaps to some problems with viscous magnetizations acquired in the laboratory during the procedure. Samples were kept as far as possible in 'zero' field during routine measurements, however the samples apparently picked up spurious effects, particularly the thermal pilots. Samples from the other sites showed higher intensities, but problems were also encountered during measurements. With the possible exception of site 3, samples from all other sites showed an apparently complex palaeomagnetic record of magnetic properties. Demagnetization of samples from site 3 apparently succeeded in retrieving the vectorial composition of NRM, giving stable end points while the intensity was being reduced, which can be easily appreciated from the linear segments going through the origin on the Zijderveld plots (Fig. 3). Thermal demagnetization apparently gave better results, since some effects (perhaps anhysteretic remanence, ARM, or rotational remanence, RRM, effects) were noticed at higher fields (Fig. 4). Thermal treatment of samples from sites 4 to 7 may have also produced acceptable results, although this is hard to ensure. Figure 5 presents one of the simpler records. To compute the site means all AF demagnetized specimen-results were not included; this restricted the data points to about half the initial population (Table 2). Even with this however, it is not certain that representative site mean directions and pole positions were retrieved although one may note that an apparent pattern seems to emerge. There is an apparent variation from the central part towards the edges of the body, which may suggest an effect associated with the cooling process. The good agreement between results of sites 4 and 5 and between sites 6 and 7 (Fig. 1 and Table 2) seems to support that possibility. However, the results imply large apparent polar movement, which may not necessarily reflect true geomagnetic field behaviour. Considering the laboratory difficulties, the results may reflect the effects of multiphase remanences, which were not totally separated during the treatments, together with real polar movement. From an experimental point of view, only the results from site 3 deserve some degree of confidence.

With respect to the magnetic response of the granite, the low Q-coefficient values indicate that the induced magnetization (the one due to the present geomagnetic field) effectively dominates the magnetizations. Also, it seems that the magnetic response is weaker over the northwestern part than over the rest of the body, with a possible increase towards its southeastern portion (Table 2).

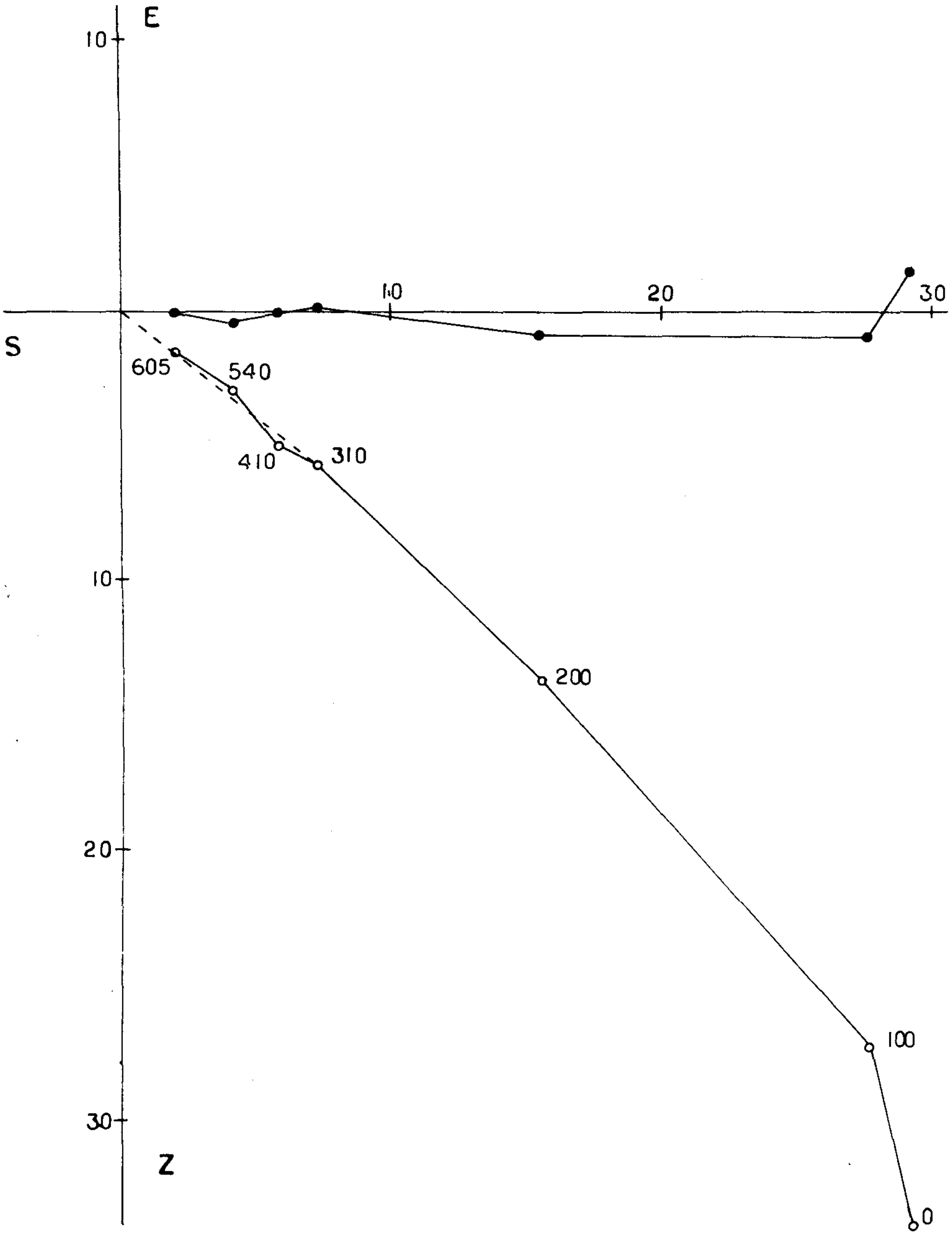

Fig. 3. Vectorial plot of thermal demagnetization results for a specimen of site 3 (sample A-39). Units in 10^{-6}emu/cm^3. The treatment steps are indicated in °C. The NS-EW component is given in full circles and the NS-Z component is given in open circles.

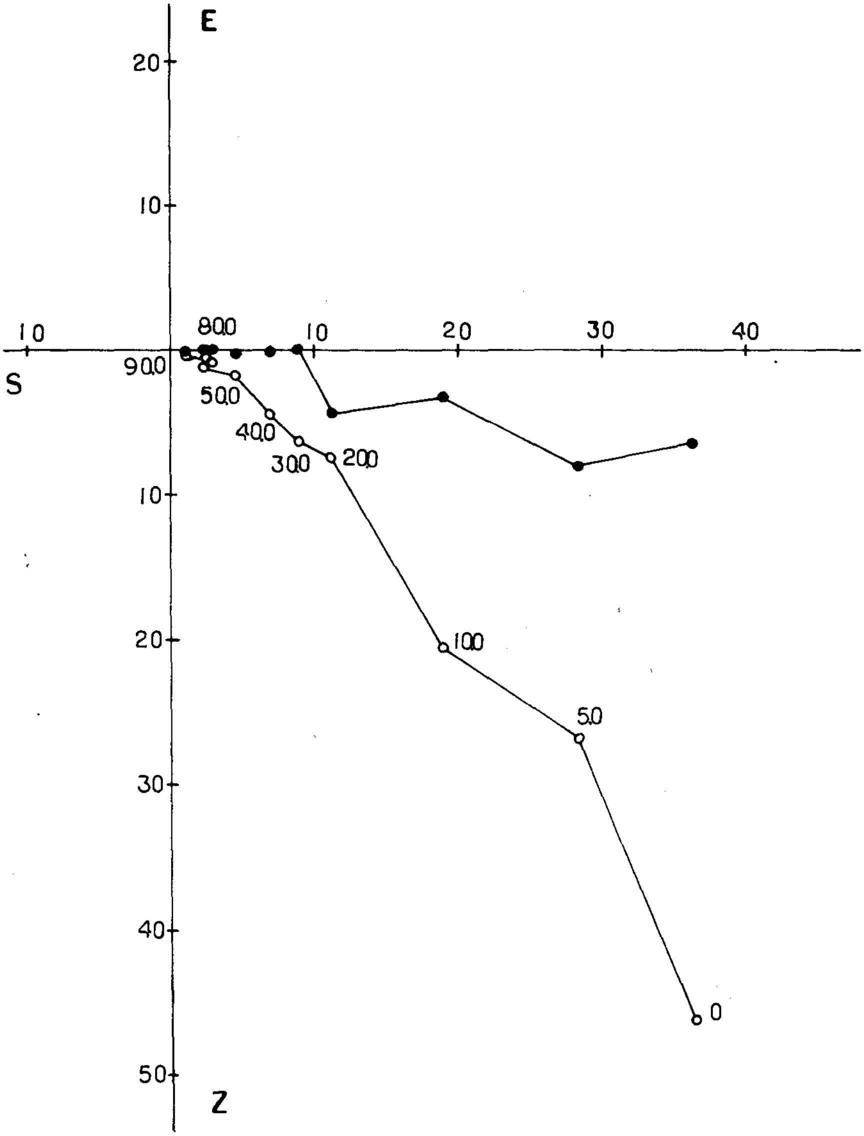

Fig. 4. Vectorial plot of alternating field demagnetization results for a specimen of site 3 (sample A-38). The treatment steps are indicated in Oe (x^{10}). See figure 3 for explanation.

Table 2

Summary of palaeomagnetic data for the Acapulco Granite, Guerrero State, Mexico.

Site	N/n_s	J_{NRM}	X	Q	DEC	INC	k	α_{95}	LAT	LONG	k	A_{95}
1	7/7	0.09±0.07	5.01±0.06	0.04	121.0	−34.5	2	67.8	34.1S	1.8E	3	68.0
2	5/5	0.08±0.07	5.08±0.40	0.03	207.2	−2.3	8	28.0	58.7S	197.3E	14	21.1
3	8/8	49.53±7.74	322.30±41.82	0.34	358.2	46.5	125	5.0	78.6N	251.2E	112	5.3
4	4/5	30.05±1.11	582.14±16.79	0.11	329.7	39.3	36	15.9	61.7N	186.4E	30	17.1
5	3/4	28.51±1.26	438.25±15.10	0.14	337.9	38.4	59	16.2	68.9N	187.0E	49	17.9
6	3/5	42.33±6.02	734.72±11.07	0.13	43.3	27.2	157	9.9	48.3N	347.2E	133	10.7
7	3/4	52.33±3.41	876.37±15.25	0.13	38.5	−3.2	10	42.3	48.0N	12.0E	34	21.4

Note: N/n_s = number of samples used/number of samples initially collected; J_{NRM} = initial NRM intensity in 10^{-6} emu/cm^3 (plus standard deviation); X = low-field susceptibility in 10^{-6} emu/cm^{3}Oe; Q = Koenigsberger coefficient with H = 0.45 Oe; DEC, INC = direction of cleaned RM; k = precision parameter; α_{95} = cone of 95% confidence about mean direction; LAT, LONG = Latitude and longitude of pole position; A_{95} = cone of 95% confidence about mean pole.

Table 3.

Summary of palaeomagnetic data for the Tierra Colorada Monzonite, Guerrero State, Mexico.

Site	N/n_s	J_{NRM}	X	Q	DEC	INC	k	α_{95}	LAT	LONG	k	A_{95}
1	6/6	99.04±35.05	1935.32±28.29	0.11	66.0	−61.2	23	14.2	5.1N	37.8E	14	18.8
2	6/6	74.54±15.37	1925.85±181.95	0.09	22.1	−61.5	10	22.3	26.8N	62.4E	6	28.9
3	10/10	66.15±29.34	1809.58±285.17	0.08	318.0	−42.0	11	15.3	31.8N	126.3E	6	21.2
3*	8/10	52.71±6.66	1644.13±111.49	0.07	317.3	−30.7	21	12.3	36.1N	134.0E	44	8.5

Note: * Two divergent sample means (unstable, higher intensity and susceptibility, etc.) are not considered. Explanation of column headings as in Table 2.

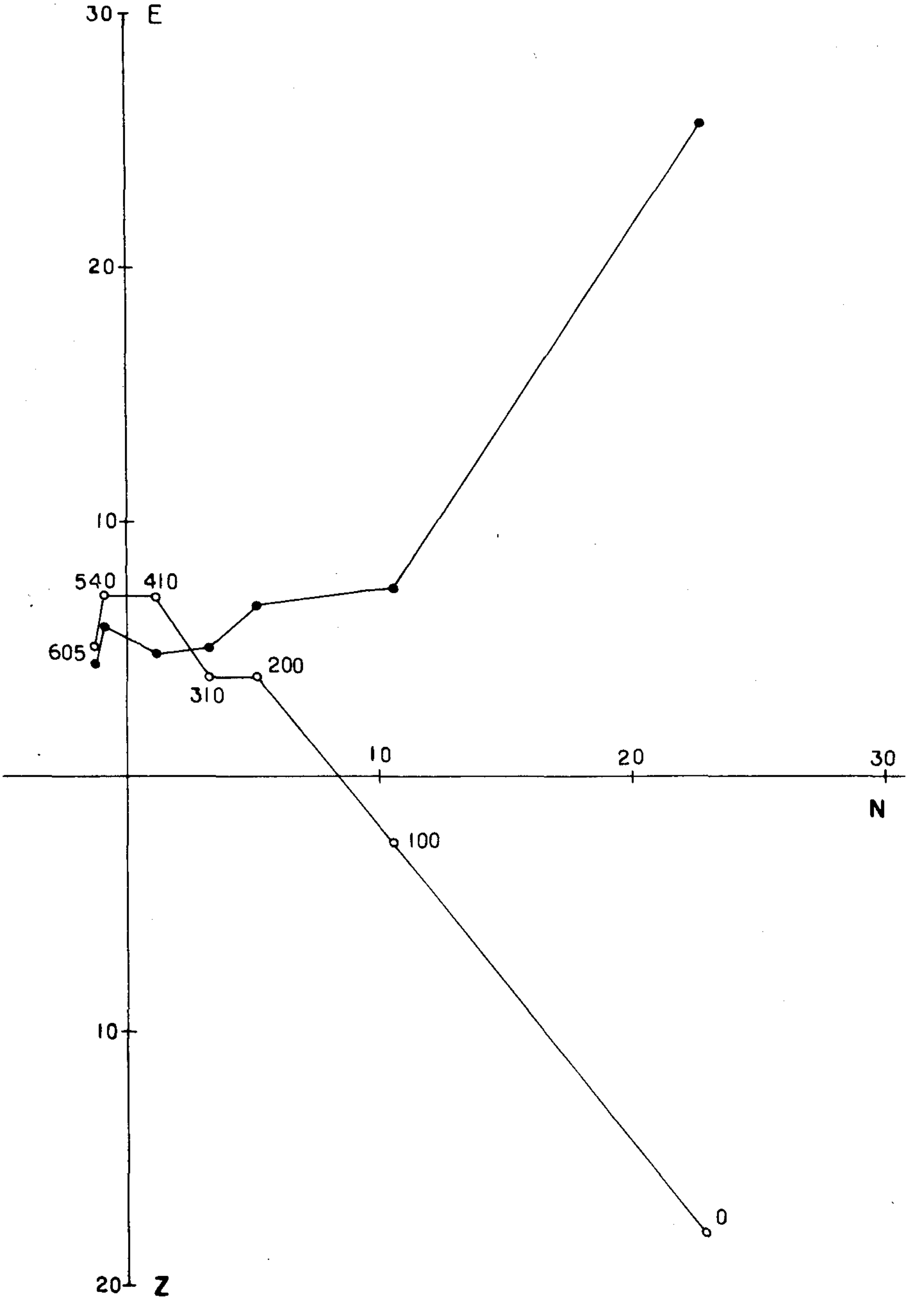

Fig. 5. Vectorial plot of thermal demagnetization results for a specimen of site 6 (sample A-44). The treatment steps are indicated in °C. See figure 3 for explanation.

3.2 *Tierra Colorada Monzonite*

The initial NRM intensity of the three sites was similar to those observed for most of the Acapulco granite sites, and the low-field susceptibility was more than twice as high (Table 3). Sampling was restricted to only three sites (Figure 2), so that the coverage is poorer than that for the Acapulco granite. AF and thermal demagnetization of ten selected specimens reveals in general the presence of multiphase magnetizations. Specimens from sites 1 and 2 showed initial directions of northward declinations and negative inclinations, which with the laboratory treatment changed to easterly declinations and steeply negative inclinations (site 1), and steeper negative inclinations (site 2, Figure 6). The relative scatter of directions after the treatment however remained almost the same, particularly for site 2 (Table 3). Specimens from site 3 showed more stable behaviour during the treatments, except two thermally demagnetized specimens which showed apparently high blocking temperature components and may have been altered during the last part of the treatment (Figure 7). Specimens from these two samples showed initial NRM intensities and low-field susceptibilities different from the rest of the specimens of the site (Table 3). Elimination of these two samples from this site does not alter significantly the mean direction, but the precision improves considerably (Table 3). The results seem to show some sort of variation (Table 3) with the relative location of sites (Figures 2). The polar movement involved is of less magnitude than that found for the Acapulco granite.

The magnetic response of the monzonite, assuming the values are representative of a considerable portion of the body, seems to be effectively dominated by the induced magnetization.

4. DISCUSSION

By assuming that the Rb-Sr dates (Table 1) given by Guerrero (1976) reflect the time of intrusion and cooling of the intrusives, the age of the Acapulco granite in Eocene and that of the Tierra Colorada monzonite is Early Tertiary (perhaps Late Eocene-Early Oligocene). This permites to compare the palaeomagnetic results of these intrusives with results reported for rocks from other parts of Mexico. See Table 4 in Urrutia Fucugauchi, this issue. There are some five pole positions reported for Eocene and Oligocene rocks from northern Mexico and five pole positions reported for Eocene-Palaeocene rocks from southern Mexico. Thus for northern Mexico may be more representative if only because the number of units and samples studied is larger. Some results from the Acapulco granite (sites 1, 3, 4, and 5) are similar to the Eocene-Oligocene results from northern Mexico. Other site results from this granite present larger differences, particularly in longitude values (site 8). The results for the Tierra Colorada monzonite present lower latitudes than those

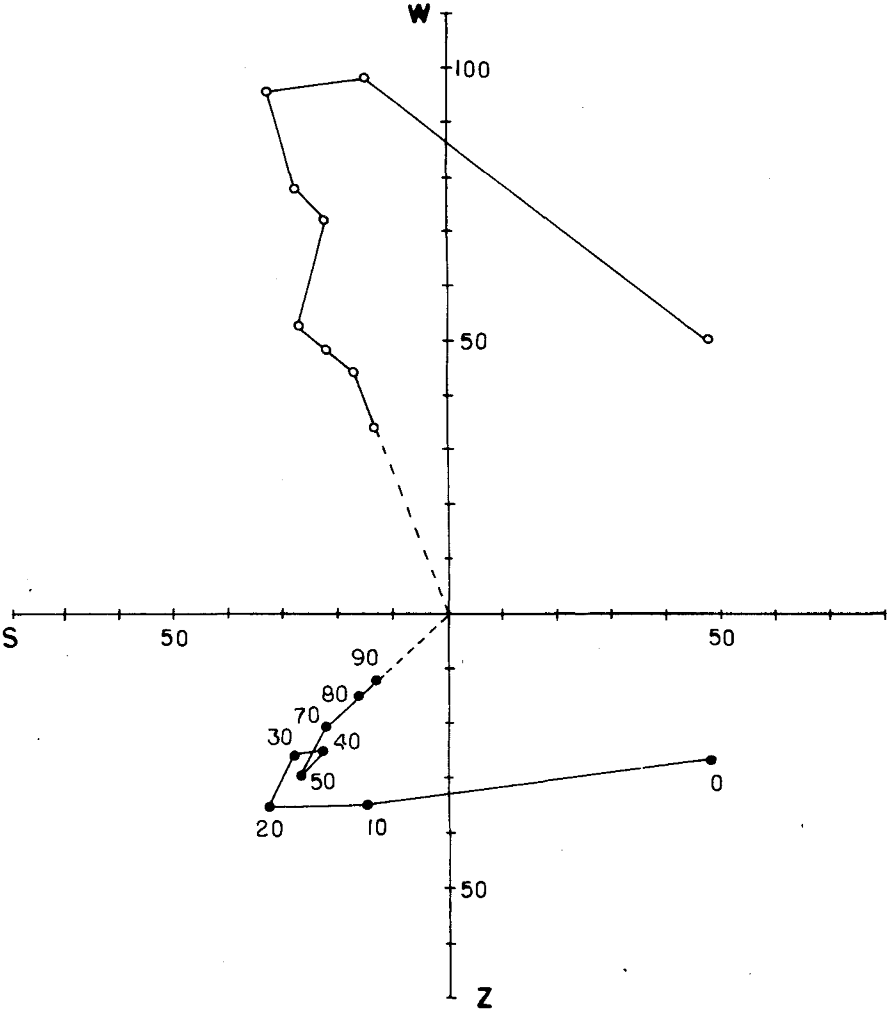

Fig. 6. Vectorial plot of alternating field demagnetization results for a specimen of site 1 (sample TC1). See Figure 3 for explanation.

expected, and also some differences in longitude values (Figure 8). The main difficulty in interpreting these results lies directly with the question of how reliable is the record of the geomagnetic field derived from the intrusives.

In the Acapulco granite, the sites (1, 2 and 7) near the 'edge' of the body (Figure 1) present larger dispersion ($A_{95} \geqslant 20^{o}$) than those 'closer' to the center ($A_{95} < 20^{o}$). One may think that the cooling of the body was more or less concentric towards

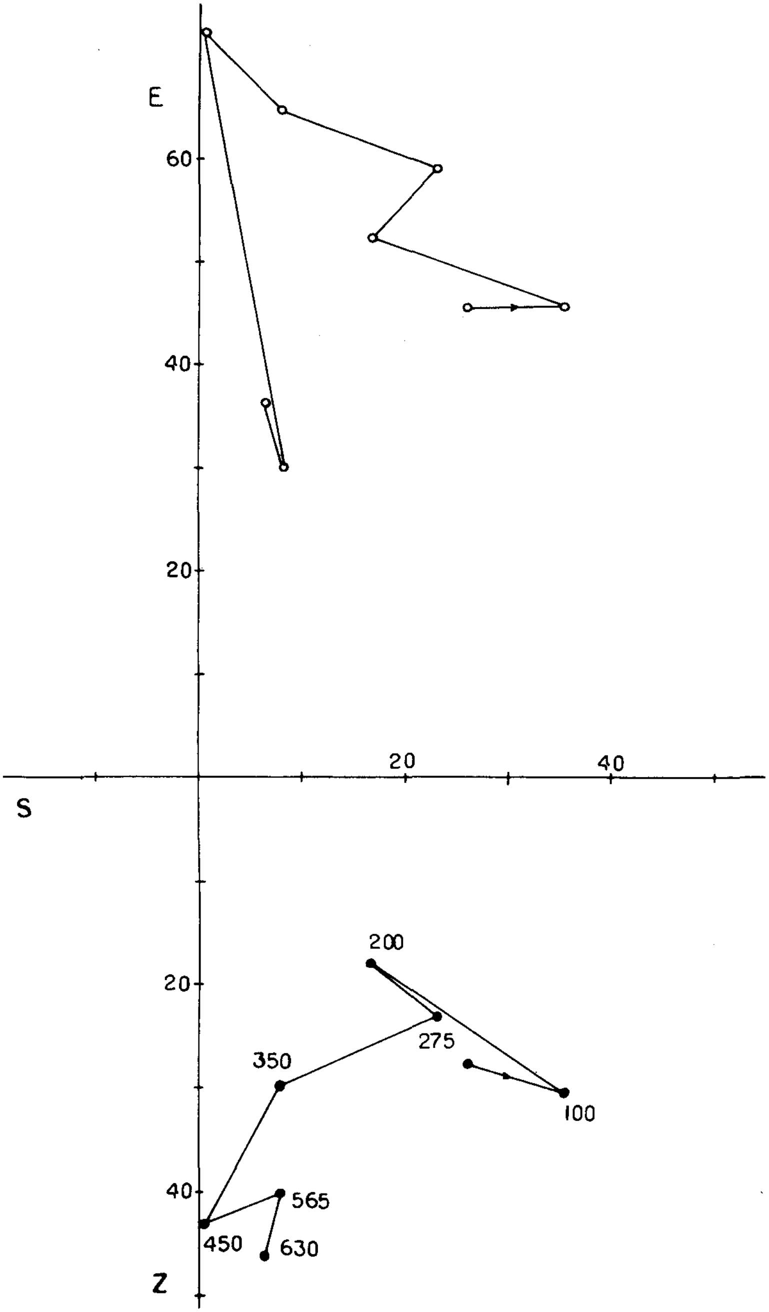

Fig. 7. Vectorial plot of thermal demagnetization results for a specimen of site 3 sample TC 6B). See Figure 3 for explanation.

the center and that during the initial cooling the geomagnetic field presented rapid variations (perhaps including polarity transitions and excursions), or that the magnetic record of the outer portions was affected (during or after the initial cooling and remanence acquisition interval) differently than the more central portions. There is also the possibility of relative tectonic movements within the granite, which however is not supported by available geological studies. The results from the central portion are in agreement with other results for the Early Tertiary of Mexico (Figure 8) which seems to suggest that the palaeomagnetic record isolated is reliable and may support the absence of large scale movements of the granite with respect to other portions of Mexico. Alternatively, the record may not be reliable and the apparent agreement may be only fortuitous. The results from the Tierra Colorada monzonite (Table 3) also present variation with relative location of the sites (Figure 2). They may also imply rapid variations of the geomagnetic field (if the remanences relate to the time of cooling of the intrusive), undetected relative

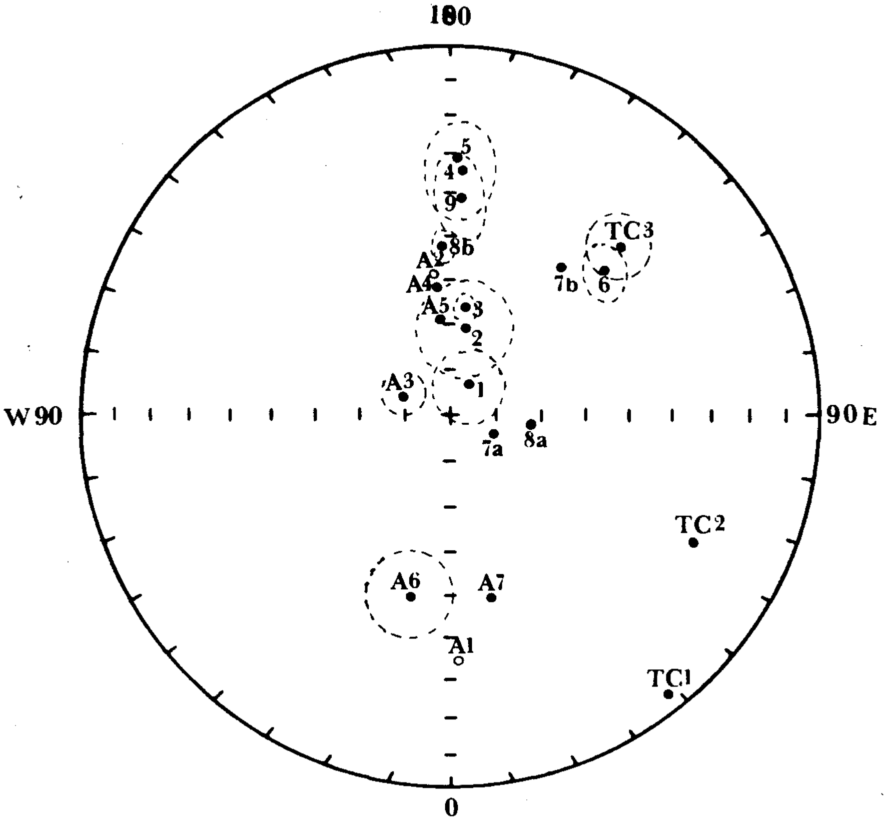

Fig. 8. Comparison of site-mean pole positions of the Acapulco and Tierra Colorada intrusives with those of other rock units of northern and southern Mexico. Results with large statistical uncertainties (> 20°) are plotted without the error limits. Pole numbers 4 and 5 have been combined for the figure (mean pole Lat 33.7°N, long 176.3°E, N = 9, A_{95} 9.5° and k30). See Table 4 in Urrutia-Fucugauchi (this issue) for explanation.

movements between sites, or problems in isolating the magnetic record. A preferred explanation for these results is in terms of extreme magnetic instability, which is not uncommon in intrusive rocks with such low Q-ratios. This may explain at least partially most of the scatter in directions observed for within - and between - sites. Additionally, remagnetization effects due to secondary intrusive events (e.g. doleritic dikes intruding the Acapulco granite) may have complicated the palaeomagnetic record.

Because of the difficulties in interpreting the results, they are not considered useful for tectonic interpretation. Also, one of the initial objectives of the study was to obtain palaeomagnetic data from radiometrically dated igneous rocks to be used for correlation and dating of other less-well studied rock units of the area. This expectation is not fulfilled. Finally, a third major objective was related to obtain rock-magnetic data for magnetic and aeromagnetic survey interpretation. The results indicate that the magnetic response of the intrusives is mainly due to the induced magnetization, and that the magnetic response of the monzonite may be higher than that of the granite.

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