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Magnetic fabrics and rock magnetism of the Xaltianguis intrusive, southern Mexico: Implications for the emplacement mode

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RESUMEN

Se reportan los resultados de un estudio de propiedades magnéticas y de fábrica magnética del intrusivo Xaltianguis, los cuales permiten documentar la mineralogía magnética dominante y discutir la forma de emplazamiento. Las mediciones de propiedades magnéticas incluyen los espectros de coercitividad y de temperaturas de bloqueo, curvas de adquisición de magnetización isotermal, la temperatura de Curie, la variación de la susceptibilidad magnética con bajas temperaturas, determinación de curvas de histéresis a temperatura ambiente y de nitrógeno líquido, las cuales indican la ocurrencia de magnetita y titanomagnetitas ricas en hierro con un comportamiento de dominio múltiple. De acuerdo con las propiedades magnéticas se pueden distinguir dos sectores, caracterizados por altos y bajos valores de intensidad de magnetización y de susceptibilidad, respectivamente. Estas variaciones son también observadas en otras propiedades y podrían estar relacionadas a una zonación petrográfica o un patrón de alteración posterior al emplazamiento. Los resultados provienen de un transecto que cruza el intrusivo y no es posible documentar patrones espaciales tales como zoneamiento concéntrico. La fábrica magnética es dominantemente oblata con planos de foliación horizontales o sub-horizontales, los cuales presentan un patrón consistente en el transecto medido, lo que puede ser interpretado en términos de un emplazamiento de esta parte del plutón como una intrusión sub-horizontal asociada a una fractura con orientación aproximada WNW-ESE.

PALABRAS CLAVE: Fábrica magnética, magnetismo de rocas, granito, plutón Xaltianguis, sur de México.

ABSTRACT

Rock-magnetic and magnetic fabric studies provide constraints on the emplacement mode of the I-type, magnetite-bearing Xaltianguis pluton, southern Mexico. Rock-magnetic measurements include AF coercivity and unblocking temperature spectra, IRM acquisition curves, comparison of NRM and saturation IRM coercivity spectra, Curie point determination, low-field susceptibility variation at low temperatures, room temperature and liquid nitrogen temperature determinations of hysteresis curves and ore microscopy observations. Pure magnetite and iron-rich titanomagnetites with dominantly multidomain state behaviour were found. Two distinct sectors (north and south) feature high and low NRM intensities and susceptibilities, respectively. These variations are also present in other rock-magnetic parameters and may be related to spatial petrographic zonation or to post-emplacement alterations. A single transect across the pluton was sampled, and it is not possible to document any spatial patterns such as concentric zonation. The magnetic fabric is well-defined, predominantly oblate, with almost horizontal foliation planes which are consistent through the measured transect, suggesting emplacement of this part of the body as a large sill-type intrusion possibly associated with a WNW-ESE trending crustal fracture.

KEY WORDS: Magnetic fabrics, rock magnetism, granite, Xaltianguis pluton, southern Mexico.

INTRODUCTION

The anisotropy of magnetic susceptibility (AMS) provides a simple method to investigate the fabrics of a wide variety of lithologies (Tarling and Hrouda, 1993). In low fields (less than 1 mT), the magnetic susceptibility is a linear function of the applied field. The spatial variation of susceptibility is described by a second-order tensor, which can be represented as a magnitude ellipsoid with maximum (k_1), intermediate (k_2) and minimum (k_3) axes (e.g., Nye, 1985). The axes are known as the AMS principal susceptibilities and conveniently represent the magnetic fabrics for comparison with other petrographic and structural elements.

The AMS can arise from preferential alignment of the axes of elongated grains when the susceptibility is high, as in titanomagnetite minerals, or of the crystallographic axes when the susceptibility is low, as in ilmeno-hematite minerals. The first case corresponds to shape anisotropy and characterizes magnetite-bearing rocks (e.g., island arc or I-type granites). The second case is known as magnetocrystalline anisotropy and characterizes ilmeno-hematite rocks (e.g., S-type granites). In shape anisotropy the spatial arrangement of principal susceptibilities depends on the domain structure (grain size) of the magnetic minerals, whether single domain (SD) or multidomain (MD). Thus, detailed information on the magnetic mineralogy and domain states is required for a meaningful interpretation of AMS data.

Preferential alignment of magnetic mineral grains may result from flow conditions or from the emplacement mode. In a fluid magma, hydrodynamic forces are dominant over gravitational forces and the fabric should be predominantly linear (Jeffrey, 1922; Khan, 1962; King, 1966). AMS studies yield both normal and parallel lineations to flow directions (King, 1966). Further studies of well-exposed granite bodies are needed to investigate changes in viscosity and flow rates, late-stage plastic deformation, influence of pre-existing fabrics, country rock assimilation, post-emplacement alterations, and so on (Tarling and Hrouda, 1993).

In this paper, preliminary results of a magnetic anisotropy study of the Xaltianguis pluton, southern Mexico continental margin (Figure 1), are reported. The pluton is well exposed and has recently been studied for paleomagnetism, rock-magnetism, petrology, opaque mineralogy, major and trace element geochemistry, isotopic dating, and other features. The magnetic fabric is discussed in terms of magma flow directions and stress state during emplacement.

GEOLOGIC SETTING AND SAMPLING

The Xaltianguis pluton is located in the Pacific continental margin of southern Mexico, some 30 km from the coast north of Acapulco. The pluton intrudes metamorphic rocks of the Xolapa Complex (De Cserna, 1965). Dominant lithologies in the Xolapa Complex are amphibolite facies migmatites, gneisses and schists, with mineral assemblages characteristic of a low pressure/high temperature belt. This margin is characterized by large granitic batholiths. The Xaltianguis pluton is located between two other large plutons: Ocotito or Tierra Colorada to the north, and Acapulco to the south. The outcrop of the Xaltianguis pluton measures about 250 square kilometers. It has been classified as a biotite-hornblende bearing granite and granodiorite (Negendank *et al.*, 1987), or as granodiorite and quartz monzodiorite (Morán-Zenteno *et al.*, 1993). It is calc-alkaline and corresponds to I-type granite (Chappel and White, 1974) or magnetite-bearing granite (Takahashi *et al.*, 1980).

Accessory minerals (0.01-0.001 % by volume) include chlorite, epidote, clinozoisite, zoisite (alteration product of plagioclase), zircon, xenotime, monazite, thorogummite, allanite, apatite, yttrosphene, thortveitite and several other Ce silicates and phosphates (Negendank *et al.*, 1987). The rare earth element (REE) pattern shows enrichment in light elements with a slight europium (Eu) anomaly. Most of the REE are concentrated in the accessory minerals, except Eu which is concentrated in the plagioclase. Negendank *et al.* (1987) interpret the REE pattern in terms of high differentation, resulting in alkali-feldspar granites. Magnetite is the major magnetic phase, with subordinate ilmenite. Titanomagnetite is dominant in the northern sec–

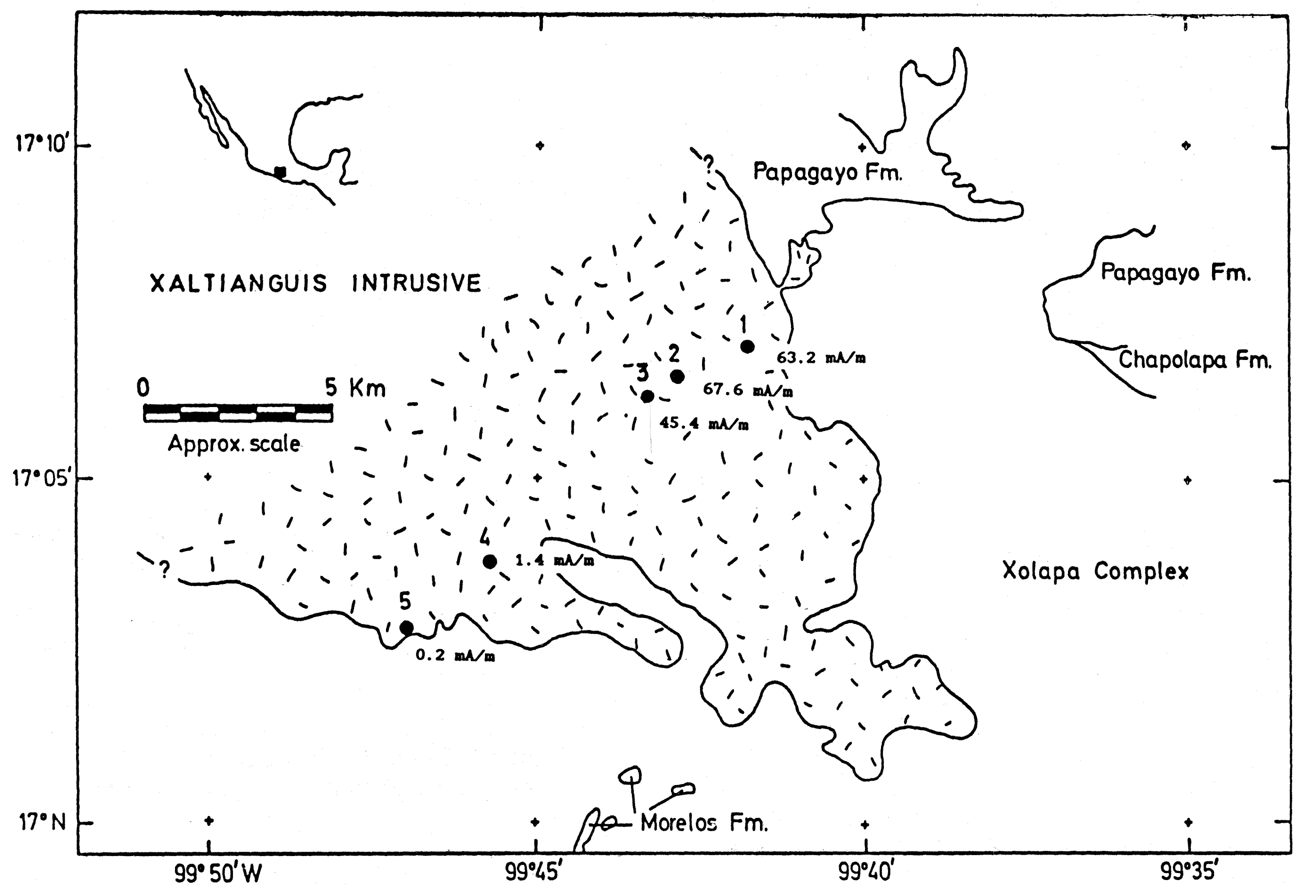


Fig. 1. Schematic map of the Xaltianguis pluton, southern Mexico, showing location of sampling sites. Base map modified from De Cserna (1965). The site-mean values for the NRM intensity are plotted for each site. Note that the sites in the north present higher values than those in the south. This pattern is also present in other rock magnetic parameters and in the magnetic fabric data.

tor, close to the contact with the metamorphic rocks. Magnetite constitutes some 0.1% by volume and features mean grain sizes between 10 and 500 µm, with an average grain size of 116-117 µm (Böhnel *et al.*, 1988).

The cooling age estimated from biotite concentrates and whole-rock Rb-Sr analysis for the Xaltianguis pluton is 30.5 ± 0.6 Ma (Morán-Zenteno, 1992; Morán-Zenteno *et al.*, 1993).

Five sites distributed across the southeastern sector of the pluton were initially sampled (Böhnel *et al.*, 1988) (Figure 1). Twenty-four oriented cores (39 specimens 2.54 cm diameter and 2.1-2.2 cm long) were collected with a portable drill and oriented with magnetic compass for this study.

METHODS AND ROCK MAGNETIC DATA

The intensity and direction of natural remanent magnetization (NRM) were measured with a Digico magnetometer. NRM intensities are high in sites 1, 2 and 3 (site mean values of 63, 68 and 45 mA/m, respectively; Figure 1) and low in sites 4 and 5 (site-mean values of 1.4 and 0.2 mA/m; Figure 1). There is no overlap of NRM intensity values for northern sites 1, 2 and 3 with those for southern sites 4 and 5 (Figure 2). The number of sites is small; yet an apparent tendency for lower values from north (site 1) to south (site 5) can be detected in the site histograms (Figure 2). The magnetizations present normal polarity. The vectorial composition and stability of NRM were investigated by stepwise thermal and alternating field (AF) demagnetization using Schonstedt instruments. Ten to sixteen steps up to maximum fields of 100 mT (miliTesla) and 10-12 steps up to maximum temperatures of 600°C were used. Thermal demagnetization generally provided better resolution than AF demagnetization (Figure 3). Two magnetization components with overlapping spectra were documented. The characteristic NRM (chNRM) component was obtained by vector subtraction and principal-component analysis (PCA) from the high temperature demagnetizing steps (Dunlop, 1979; Kirschvink, 1980). ChNRM directions are well grouped in sites 1, 2 and 3, but are scattered in sites 4 and 5 (Table 1). Directional results have been discussed in Böhnel *et al.* (1988).

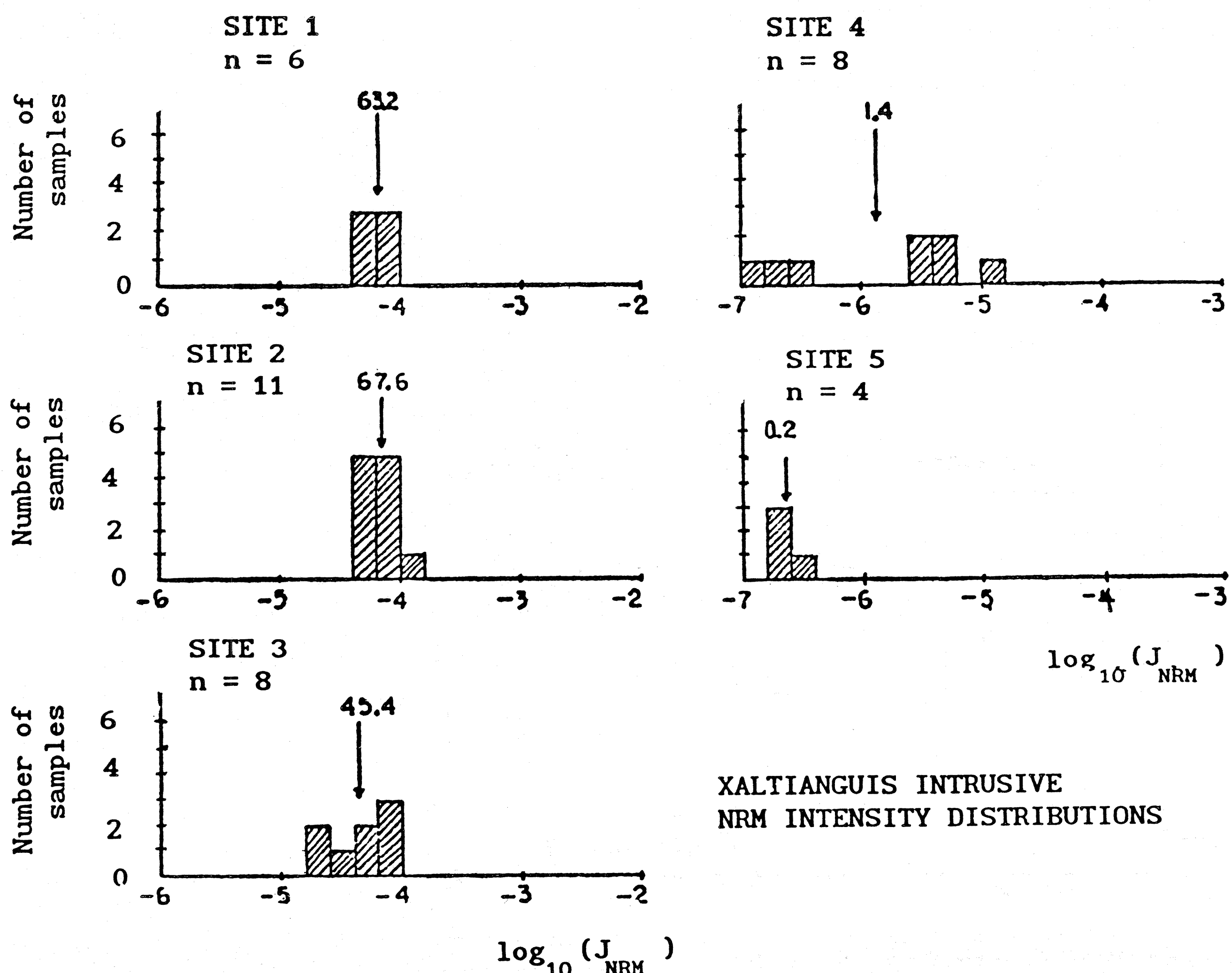


Fig. 2. Histograms for the NRM intensities. The numbers with an arrow in the histograms correspond to the site-mean values.

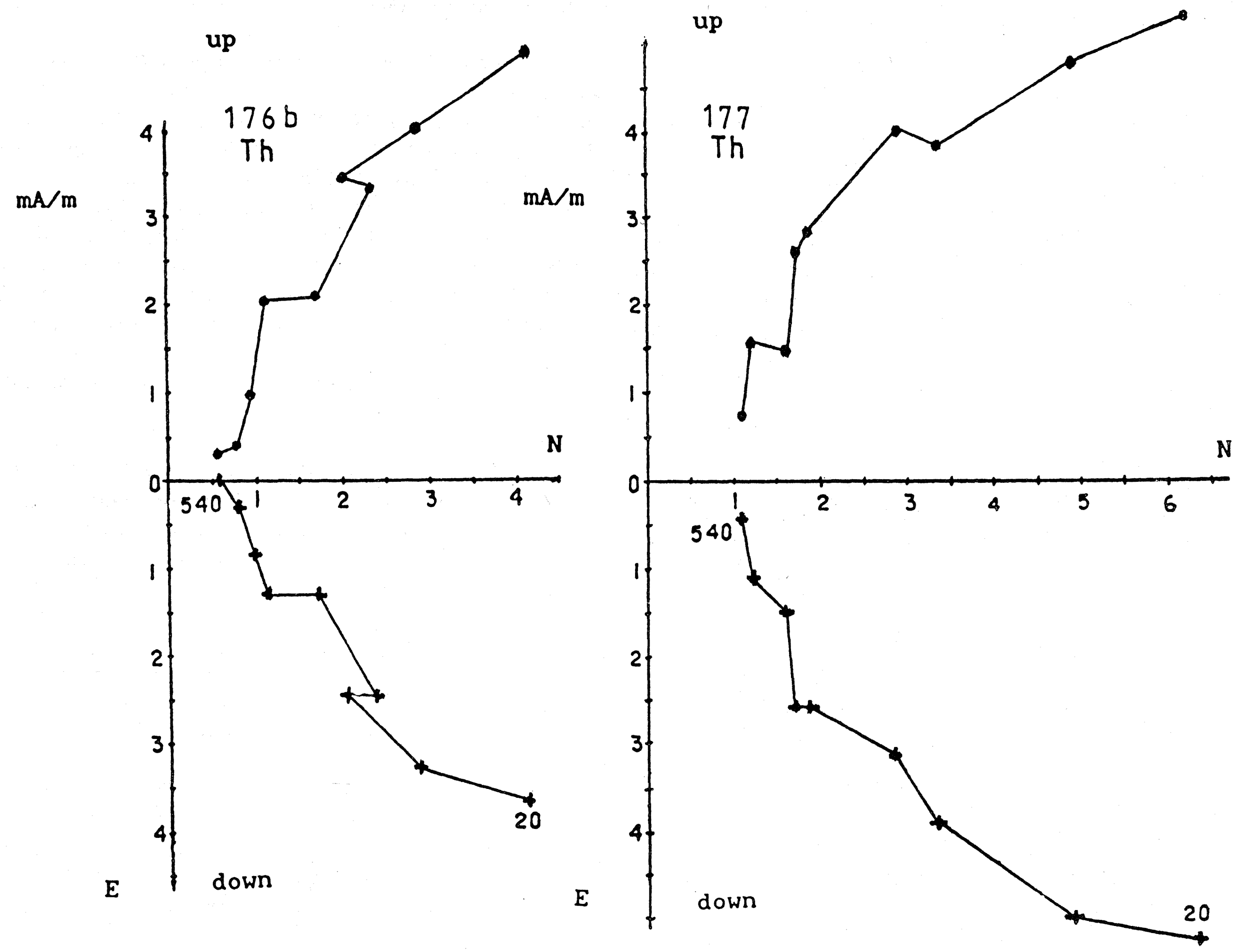


Fig. 3. Examples of thermal demagnetization vector plots for the Xaltianguis pluton.

Table 1

Summary of paleomagnetic data for the Xaltianguis Intrusive

Site	n/s	JNRM±σ	Suscept±σ	Dec	Inc	k	α95
1	4/8	63.2±11.0	11.0±1.3	338.7	24.8	34	11.6
2	7/11	67.6± 7.7	14.2±1.4	318.3	32.5	36	8.2
3	4/8	45.4±18.8	13.0±1.4	357.6	40.2	36	9.4
4	5/8	1.4± 3.9	0.25±0.04	4.6	-10.8	4	30.5
5	4/4	0.2±0.03	0.23±0.04	354.1	25.6	2	84.5

Note: n/s number of samples/number of specimens; JNRM±σ, NRM intensity and standard deviation (mA/M); Suscept±σ, low-field susceptibility and standard deviation (in 10^{-6}); Dec, Inc, site-mean declination and inclination; k, α95, Fisher's (1953) statistic parameters.

Titanomagnetites or magnetite with large grain sizes (MD states) are the dominant NRM magnetic carriers as indicated by low and intermediate AF coercivity spectra and maximum unblocking temperatures less than 500 - 600°C (Figure 4). Ore microscopy observations (Böhnel *et al.*, 1988) indicate that the major phase is pure magnetite, with ilmenite as a subordinate mineral. Titanomagnetites are observed in samples from the northern section. High coercivities are observed in samples from sites 4 and 5, which suggests the occurrence of hematites likely related to oxidation. Results are similar to those obtained for the Acapulco granite (Urrutia-Fucugauchi, 1983; Böhnel *et al.*, 1988), where they may can be related to weathering effects. However, no macroscopic indications of weathering similar to those in the eastern sector of Acapulco granite were observed for the southern sector of the Xaltianguis pluton. The multimodal nature of the magnetic parameters is further discussed below, in relation with the AMS data.

The coercivity spectrum was further investigated by an isothermal remanent magnetization (IRM) applied in steps up to maximum steady magnetic fields of 1.0 T (Tesla) (Dunlop, 1972). IRM acquisition curves indicate saturation at low fields (Figure 5a). The saturation (or last step) IRM was subsequently AF demagnetized in steps up to 50 or 100 mT and the AF coercivity spectrum was compared with the corresponding AF spectrum for NRM. The comparison of the IRM and NRM spectra may yield informa–

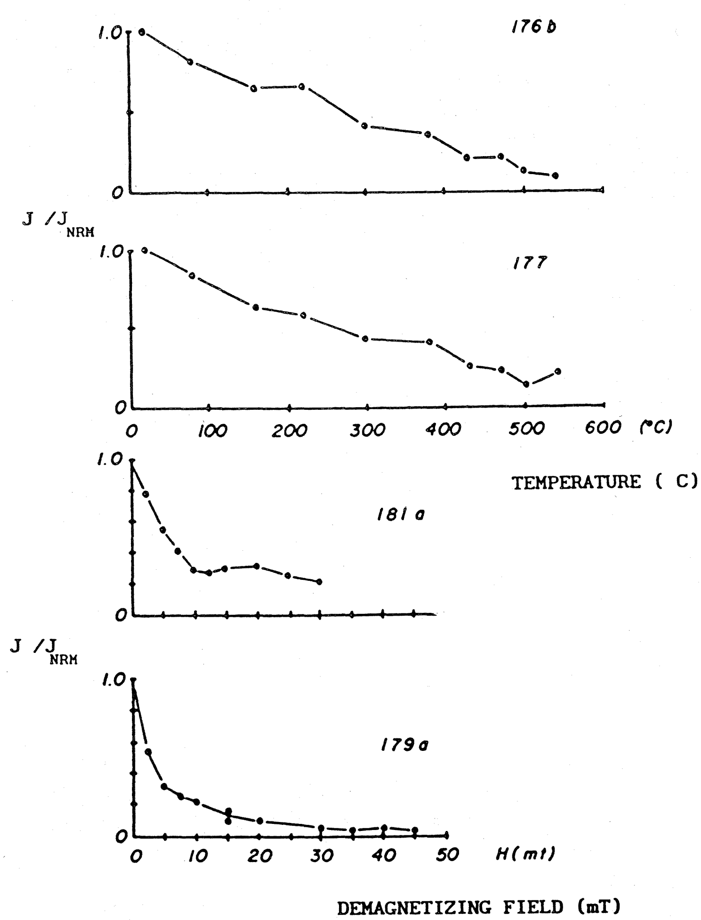


Fig. 4. Examples of normalized intensity changes plotted as a function of applied AF field or temperature.

tion on the domain structure (Lowrie and Fuller, 1971). Results indicate slightly lower coercivities for IRM (Figure 5b), suggesting mainly MD behaviour.

The variation of low-field susceptibility with low temperatures down to liquid nitrogen temperature (approximately from 293 K to 78 K) has been investigated with the instruments used by Radhakrishnamurty *et al.* (1981). The change of susceptibility versus temperature provides indications concerning the domain state of the magnetic minerals (Radhakrishnamurty *et al.*, 1981; Senanayake and McElhinny, 1981; Urrutia-Fucugauchi *et al.*, 1984). Susceptibility-temperature curves (Figure 6) correspond to type-3, which indicates MD magnetite or iron-rich titanomagnetites. Comparison of the hysteresis loops measured at room temperature and at liquid nitrogen temperature also indicates MD magnetite.

Thermomagnetic curves were measured using a horizontal Curie balance for three samples. The curves for samples from sites 1 and 3 are very similar; they are nearly reversible, with well-defined Curie temperatures of around 550°-575°C (Figure 7), corresponding to magnetite or iron-rich titanomagnetite. The thermomagnetic curve for a sample from site 5 was noisy because of the weak intensity, and no Curie temperature was determined.

4. MAGNETIC FABRICS

The AMS principal susceptibilities ($k_1>k_2>k_3$) and axial bulk susceptibility (k) were measured with a susceptibility anisotropy system interfaced with the Digico spinner magnetometer. Details of the method may be found in Tarling and Hrouda (1993). The analysis of AMS

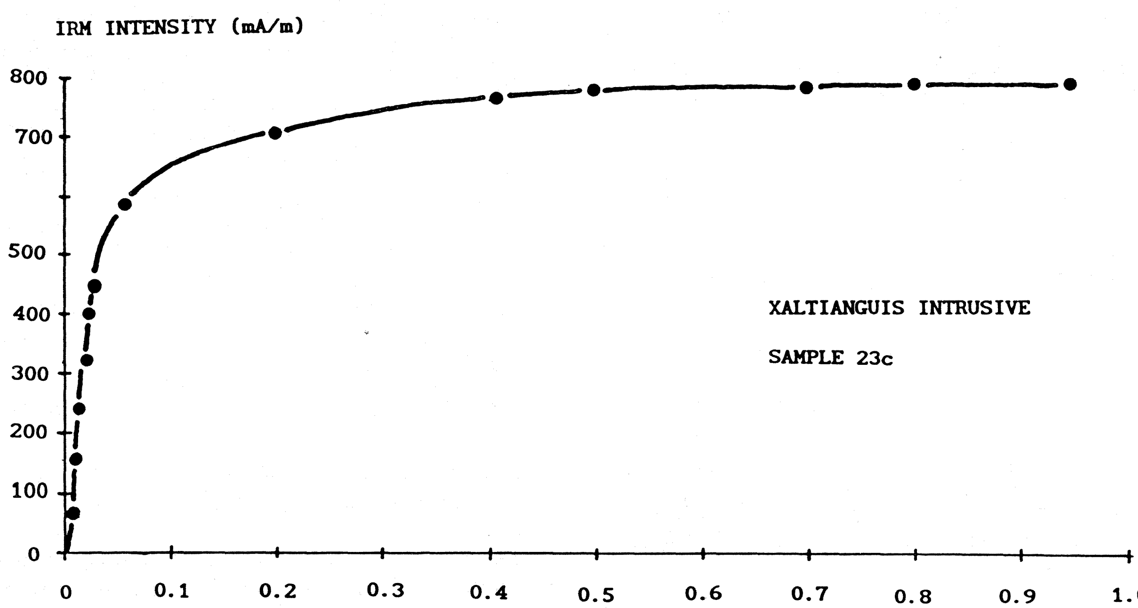


Fig. 5. (a) Example of an IRM acquisition curve. The curve shows saturation in low fields, indicating the dominance of low coercivity minerals of the titanomagnetite series. (b) Comparison of the AF coercivity spectra for NRM (squares) and saturation IRM (circles). The pattern corresponds to multidomain magnetite (Lowrie and Fuller, 1971).

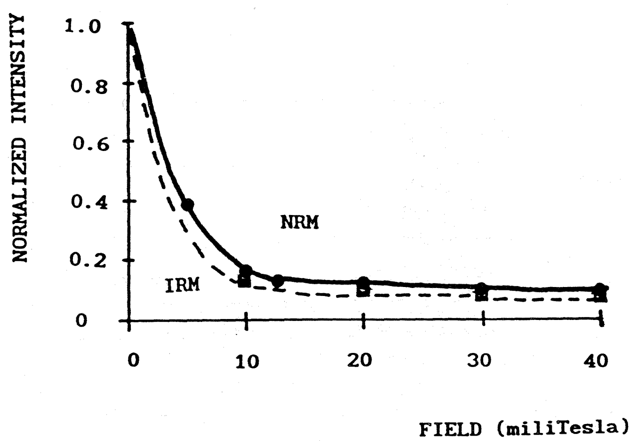


Fig. 5. (Cont.).

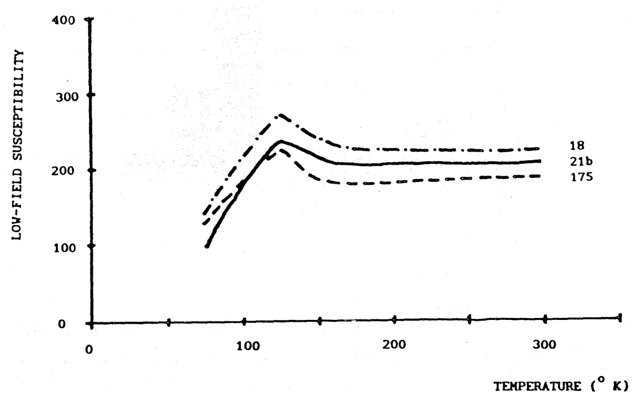


Fig. 6. Examples of the variation of low-field susceptibility with low temperatures, from room temperature to liquid nitrogen temperature. The pattern corresponds to multidomain state titanomagnetites or magnetite (Radhakrishnamurty *et al.*, 1981; Senanayake and McElhinny, 1981). The maximum and minimum values normalized to the room temperature susceptibility are: 1.20 and 0.63 for sample 18; 1.13 and 0.47 for sample 21b; and 1.18 and 0.67 for sample 175.

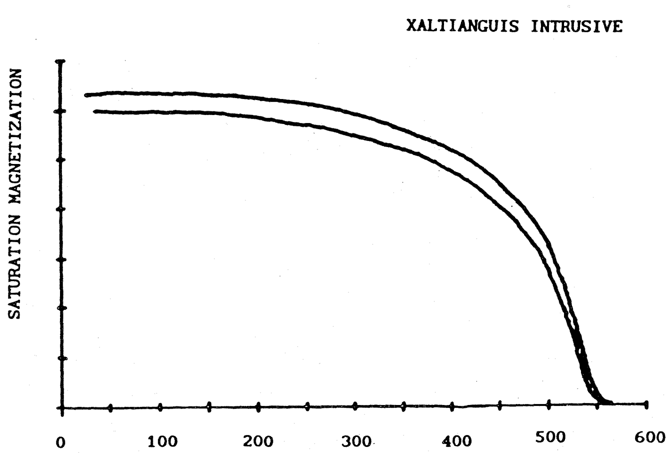


Fig. 7. Example of a thermomagnetic curve. Note that the heating and cooling curves are similar and the Curie point of about 550°C.

data makes use of the magnitudes and orientations of the principal susceptibilities. A wide range of parameters based on ratios and differences of axis magnitudes has been proposed. For this study we use the parameters listed in Urrutia-Fucugauchi (1980) and Tarling and Hrouda (1993; p. 18-19). For simplicity we refer to the following parameters: (a) mean susceptibility (km), (b) anisotropy degree (A), (c) lineation (L), (d) foliation (F), and (e) ellipsoid shape indicator (S). Data using other parameters may be obtained directly from the authors, though the choice of parameters does not appear to affect the interpretation. The parameters are defined as follows:

Anisotropy degree (A) (Graham, 1966):

$$A(\%) = 100\,(k_1 - k_3)/k_1 \quad (1)$$

Lineation (L) (Khan, 1962):

$$L = (k_1 - k_2)/km \quad (2)$$

Foliation (F) (Khan, 1962):

$$F = (k_2 - k_3)/km \quad (3)$$

Shape indicator (S) (Urrutia-Fucugauchi, 1980):

$$S = (k_1k_3 - k_2)/(k_1k_2 - k_1k_3) \quad (4)$$

Results are summarized in histograms, for the following statistical parameters: lineation (Figure 8a), foliation (Figure 8b), anisotropy degree (Figure 8c) and shape indicator (Figure 8d).

The mean susceptibility is higher at the sites in the northern sector, δ ranging from about 9 to 16 10^{-3} SI, and lower at the sites in the southern sector, ranging from about 0.1 to 0.4 10^{-3} SI. A similar pattern seems to separate a northern and a southern section for the rock magnetic data (Figure 1). The anisotropy degree has a high overall mean value of 19.6 %, and ranges between 5.4 % and 30.2 %. The anisotropy is higher in the southern sector, which might reflect effects of a changing magnetic mineralogy (and alteration), or differences in the emplacement mode. The shape of the AMS ellipsoid is predominantly oblate, i.e., the fabric is dominantly foliated. Predominantly oblate fabrics appear to be typical for large plutonic rocks (e.g., King, 1966; Heller, 1973; Urrutia-Fucugauchi, 1980; Hrouda, 1982; Cogne and Perroud, 1988).

The AMS directional data also show differences between the northern and southern sectors (Figure 9). The sites in the south have their AMS axes well grouped (particularly site 4; Figure 9b), whereas those in the north present k_1 and k_2 axes scattered over the foliation plane (Figure 9a). The mean foliation plane is close to horizontal (Figures 9a,b,c).

The mean site orientations for foliation and lineation are plotted in Figures 10a and 10b. The foliation is very homogenous along the transect in the pluton, with slight changes from NNE-SSW in the north to N-S in the south. The consistency suggests that this part of the pluton may have been emplaced as a large sill-type body. Similar

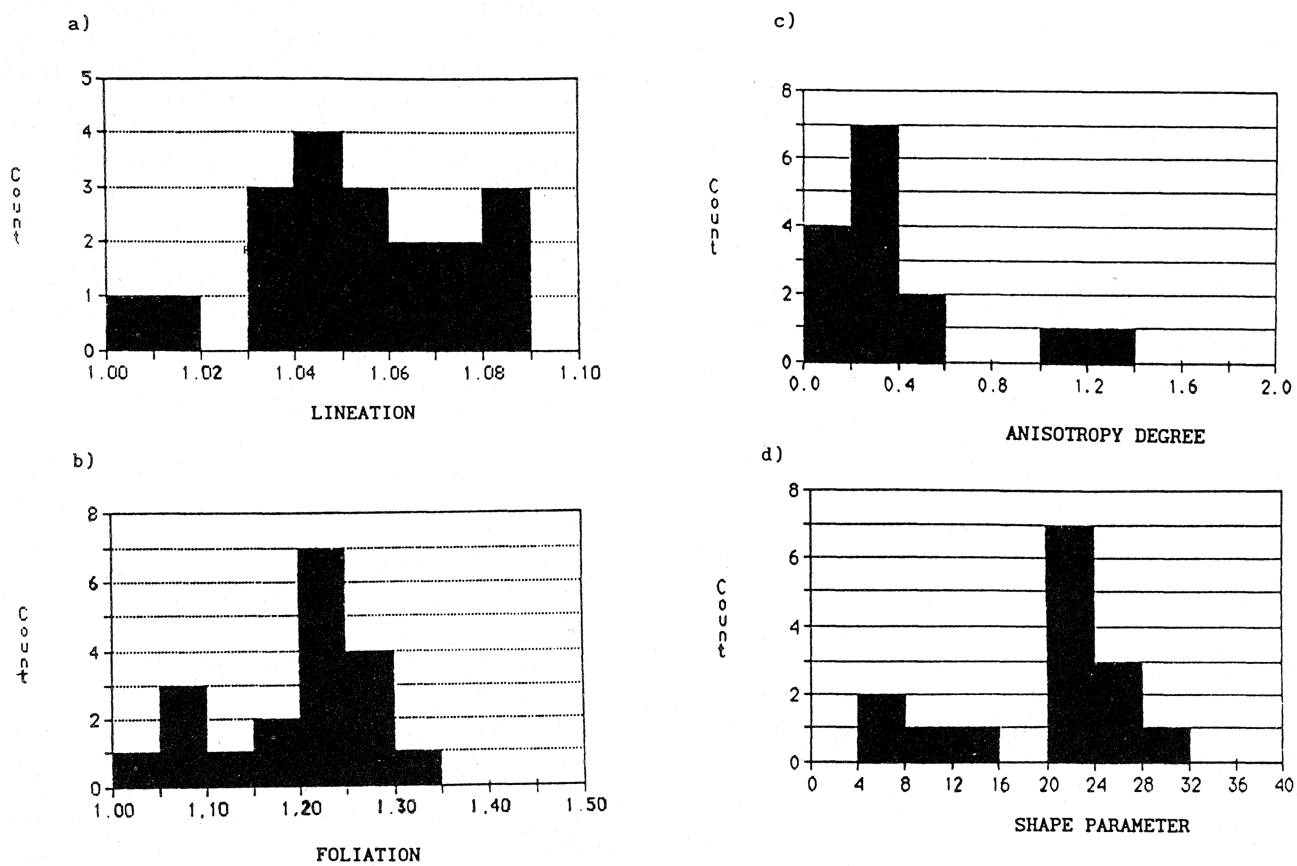
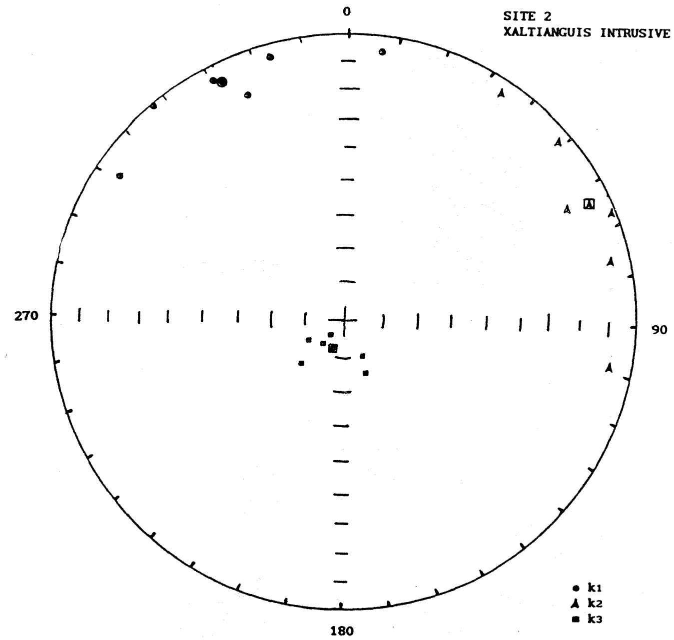


Fig. 8. (a) Histogram of the magnetic lineation parameter (Khan, 1962). Mean=1.1, median=1.0, range= 0.1, std. dev.=0.01, skewness = -0.1, and kurtosis = -0.9. (b) Histogram of the magnetic foliation parameter (Khan, 1962). Mean = 1.2, median=1.2, range = 0.3, std. dev = 0.1, skewness = -0.5, and kurtosis = -0.8. (c) Histogram of the anisotropy degree (Graham, 1966). Mean=19.55%, median=21.88%, range=24.77, std. dev.=7.34, skewness=-0.74, and kurtosis=-0.78. (d) Histogram of the ellipsoid shape indicator (Urrutia-Fucugauchi, 1980). Mean=0.41, median=0.31, range=1.16, std. dev.=0.35, skewness=1.51, and kurtosis=0.96.

AMS results have been obtained for the Elberton granite, Georgia, USA (Ellwood and Whitney, 1980; Ellwood *et al.*, 1980). The mean foliation plane for the northern sites is shallow (about 6°), whereas for the southern sites it is steep (about 18°). This seems to rule out any significant tilting of the pluton since emplacement. It gives useful constraints for the paleomagnetic data. The overall paleomagnetic direction and pole position for Xaltianguis are similar to those for the early Tertiary of northern Mexico, or of cratonic North America (Urrutia-Fucugauchi, 1984). Paleomagnetic data from plutonic rocks frequently cause problems for estimating the paleohorizontal. Undetected tilts may result in a change in the paleoinclination, which affects the paleolatitude estimates. Data from magnetic fabrics, overlapping sediments, etc are therefore important for the tectonic interpretation of paleomagnetic data. The lineation is almost E-W for site 5, parallel to the pluton margin. It changes to ENE-WSW for sites 4 and 3 and to NW-SE for site 2 (also sub-parallel to the pluton margin).

The foliation and lineation planes for site 1 are not included in Figure 9, because of the larger directional scatter in the AMS axes. A possible interpretation might be in terms of effects in the contact zone between the magma and the metamorphic rocks (forced intrusion, country rock assimilation, etc). Note that this sector of the pluton is different from the sectors to the south as it shows a granodioritic composition and presence of titanomagnetites, in contrast to granitic composition and a main phase of pure magnetite.

Compositional gradients in granitic bodies may be associated with discrete magmatic pulses (Pitcher, 1979). Gleizes *et al.* (1993) report sharp magnetic susceptibility gradients for the Mount-Louis Andorra granite. They interpret the multimodal susceptibility distribution in terms of granodioritic, monzogranitic and leucogranitic pulses. Another possible interpretation may be in terms of differentiation processes, particularly when the changes are not sharp but gradational. Spatial zonation with concentric patterns are characteristic for shallow level calcalkaline intrusives (e.g., Atherton, 1981); this pattern can be readily mapped with magnetic bulk susceptibility measurements (e.g., Bouchez *et al.*, 1990; Gleizes *et al.*, 1993). These patterns have been observed in dominantly paramamagnetic granites, where the ferromagnetic contributions are negligible (Gleizes *et al.*, 1993). In the Xaltianguis pluton, on the other hand, magnetite and iron-rich titanomag–



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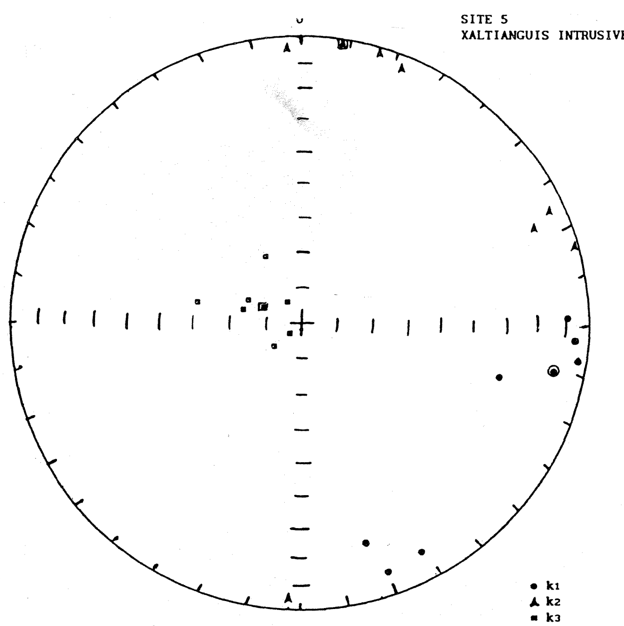

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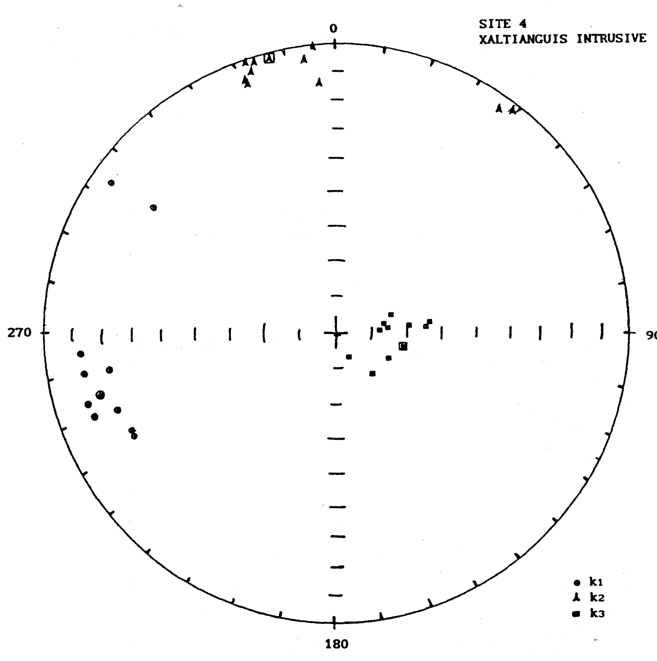

b

Fig. 9. Equal-area stereonet with the AMS orientation data for the Xaltianguis intrusive. The symbols correspond to: circles=major (k_1); triangles = intermediate (k_2), and squares= minimum (k_3) principal susceptibility axes. (a) Site 2. (b) Site 4. (c) Site 5.

netites are dominant and the susceptibility signal is due to the ferromagnetic fraction overshadowing the paramagnetic contribution of iron-bearing silicates and diamagnetic quartz minerals.

The AMS directional pattern could be associated with magma emplacement along crustal fractures with a WNW-ESE preferential orientation. This agrees with the elongated shape of the intrusive. Note that the Papagayo river follows a major fracture with this orientation within the Xolapa Complex, just north of the Xaltianguis pluton. The pluton is essentially undeformed (Morán-Zenteno, 1992; Morán-Zenteno *et al.*, 1993), and it lacks the fabrics denoting tectonic emplacement deformation (Hutton, 1988; Ingram and Hutton, 1994). Granitic plutons are often found in geographic association with major faults and shear zones, and we must distinguish whether the emplacement mechanism is related to tectonics or to buoyancy processes. Adjacent plutons in the Acapulco region, such as Tierra Colorada-Ocotito, San Marcos-El Limon, Cruz Grande, and Acapulco, are now being studied in order to describe their emplacement mechanism. Comparison of AMS results may help evaluate the possible occurrence of a single large batholithic mass beneath the Xaltianguis and Tierra Colorada-Ocotito plutons (Morán-Zenteno *et al.*, 1993), as it may also contribute toward understanding the emplacement mechanism.

5. CONCLUSIONS

The dominant magnetic mineralogy is pure magnetite and iron-rich titanomagnetites with a multidomain state

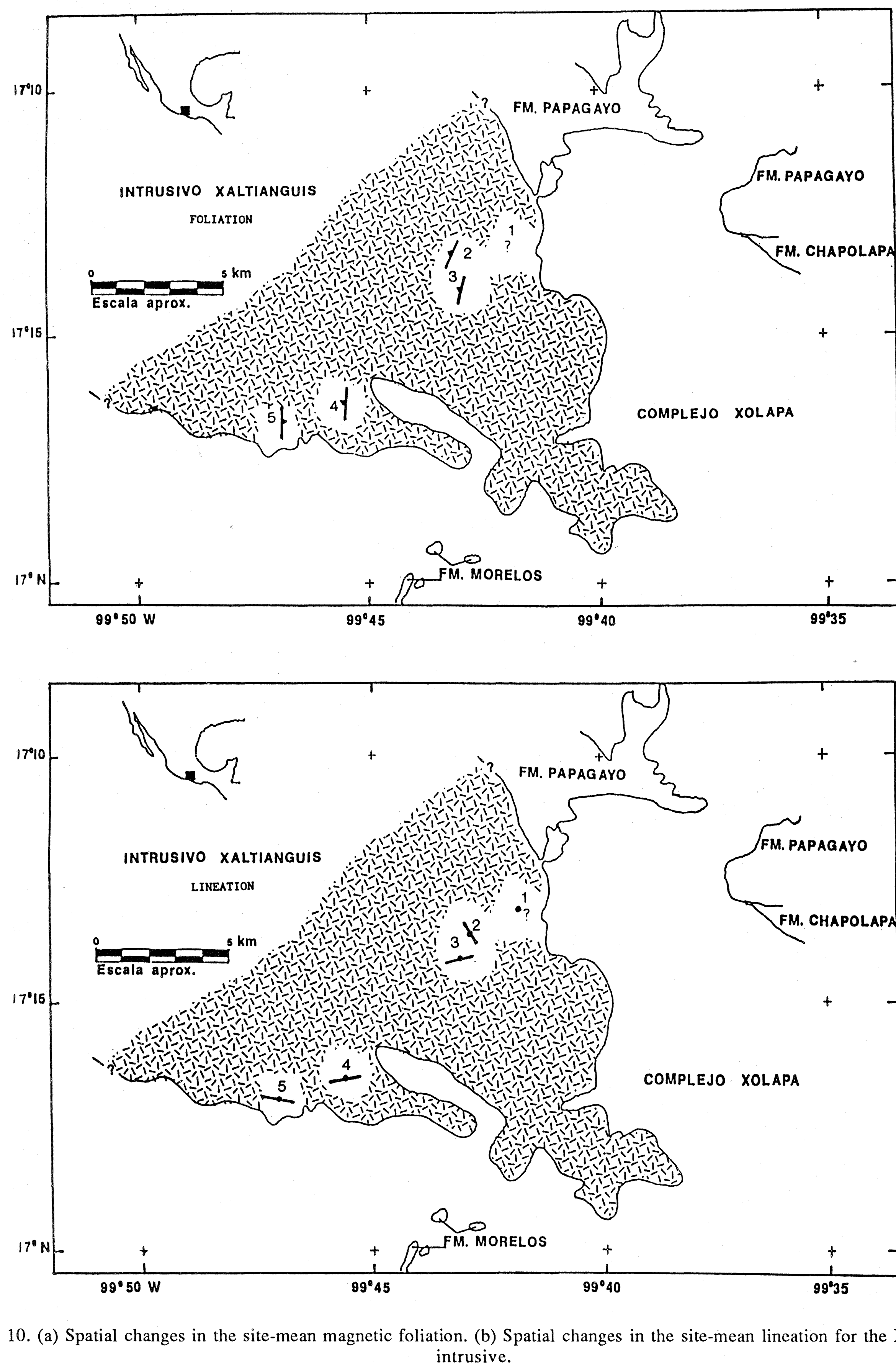

Fig. 10. (a) Spatial changes in the site-mean magnetic foliation. (b) Spatial changes in the site-mean lineation for the Xaltianguis intrusive.

behaviour. Two distinct sectors within the pluton can be distinguished: north and south. They feature high and low NRM intensities and low-field susceptibilities (Figure 1). The differences show up in other rock-magnetic parameters and may be related to spatial petrographic zonation or to post-emplacement alterations. We stress that the results come from a single transect across the pluton and that the spatial distribution of magnetic parameters has not been documented.

The magnetic fabrics arise from the orientation of the ferromagnetic minerals (shape anisotropy) and are well defined, with oblate AMS ellipsoids. The foliation planes are almost horizontal (Figure 9) and appear to be consistent through the measured transect, suggesting that emplacement of this part of the pluton occurred as a large sill-like intrusion. This also provides evidence for an absence of significant post-emplacement tilting which agrees with the interpretation of the paleomagnetic data. The overall mean direction and pole position are similar to early Tertiary data for northern Mexico and cratonic North America (Urrutia-Fucugauchi, 1984).

The magnetic fabrics provide information on the emplacement of the intrusive body. Magnetic lineations show a simple spatial pattern; sites towards the pluton margins show lineations parallel to the margins and a slight variation for the interior (Figure 10). Lineation and foliation patterns along the measured transect may be related to emplacement along a WNW-ESE regional fracture system.

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BIBLIOGRAPHY

ATHERTON, M. P., 1981. Horizontal and vertical zoning in the Peruvian Coastal batholith. *J. Geol. Soc. London, 138,* 49-54.

BÖHNEL, H., J.F.W. NEGENDANK and J. URRUTIA-FUCUGAUCHI, 1988. Palaeomagnetism and ore petrology of three Cretaceous-Tertiary batholiths of southern Mexico. *N. Jb. Geol. Paläont. Mh., 1988 H-2,* 97-127.

BOUCHEZ, J. L, G. GLEIZES, T. DJOUADI and P. ROCHETTE, 1990. Microstructure and magnetic susceptibility applied to emplacement kinematics of granites: The example of the Foix pluton (French Pyrenees). *Tectonophysics, 184,* 157-171.

CHAPPEL, B. and A. J. R. WHITE, 1974. Two contrasting granite types. *Pacific Geol., 8,* 173-174.

COGNE, J. P. and H. PERROUD, 1988. Anisotropy of magnetic susceptibility as a strain gauge in the Flamanville granite, NW France. *Phys. Earth Planet. Int., 51,* 264-270.

DE CSERNA, Z., 1965. Reconocimiento geológico de la Sierra Madre del Sur de México, entre Chilpancingo y Acapulco, Estado de Guerrero. *Bol. Inst. Geol., UNAM, 62,* 1-76.

DUNLOP, D. J., 1972. Magnetic mineralogy of unheated and heated red sediments by coercivity spectrum analysis. *Geophys. J. R. Astr. Soc., 27,* 37-55.

DUNLOP, D. J., 1979. On the use of Zijderveld vector diagrams in multicomponent paleomagnetic studies. *Phys. Earth Planet. Int., 20,* 12-24.

ELLWOOD, B. B. and J. A. WHITNEY, 1980. Magnetic fabric of the Elberton granite, northeast Georgia. *J. Geophys. Res., 85,* 1481-1486.

ELLWOOD, B.B., J. B. WHITNEY, C. B. WENNER, D. MOSE and C. AMERIGIAN, 1980. Age, paleomagnetism and tectonic significance of the Elberton granite, northeast Georgia Piedmont. *J. Geophys. Res., 85,* 6521-6533.

FISHER, R. A., 1953. Dispersion on a sphere. Proc. R. Soc. Lond., A217, 295-305.

GLEIZES, G., A. NEDELEC, J.-L. BOUCHEZ, A. AUTRAN and P. ROCHETTE, 1993. Magnetic susceptibility of the Mont-Louis Andorra ilmenite-type granite (Pyrenees): A new tool for the petrographic characterization and regional mapping of zonned granite plutons. *J. Geophys. Res., 98,* 4317-4331.

GRAHAM, J. W., 1966. Significance of magnetic anisotropy in Appalachian sedimentary rocks. *In:* J.S. Steinhart and T.J. Smith (Eds), The Earth Beneath the Continents. *AGU Geophys. Monogr., 10,* 627-648.

HELLER, F., 1973. Magnetic anisotropy of granitic rocks of the Bergell Massif (Switzerland). *Earth Planet. Sci.Lett., 20,* 180-188.

HROUDA, F., 1982. Magnetic anisotropy of rocks and its application in geology and geophysics. *Geophys. Surv., 5,* 37-82.

HUTTON, D. H. W., 1988. Granite emplacement mechanisms and tectonic controls: Inferences from deformation studies. *Trans. Roy. Soc. Edinburgh, 79,* 245-255.

INGRAM, G.M. and D.H.W. HUTTON, 1994. The Great Tonalite Sill: Emplacement into a contractional shear zone and implications for Late Cretaceous to Early Eocene tectonics in southeastern Alaska and British Columbia. *Geol. Soc. Am. Bull., 106,* 715-728.

JEFFREY, G. B., 1922. The motion of ellipsoid particles immersed in a viscous fluid. Proc. R. Soc. Lond., A102, 162-279.

KHAN, M. A., 1962. The anisotropy of magnetic susceptibility of some igneous and metamorphic rocks. *J. Geophys. Res., 67,* 2873-2885.

KING, R. F., 1966. The magnetic fabric of some Irish granites. *J. Geol., 5,* 43-66.

KIRSCHVINK, J. L., 1980. The least-squares line and plane and the analysis of palaeomagnetic data. *Geophys. J. R. Astr. Soc., 62,* 699-718.

LOWRIE, W. and M. FULLER, 1971. On the alternating field demagnetization characteristics of multidomain thermoremanent magnetization in magnetite. *J. Geophys. Res., 76,* 6339-6349.

MORAN-ZENTENO, D.J., 1992. Investigaciones isotópicas de Rb-Sr y Sm-Nd en rocas cristalinas de la región de Tierra Colorada- Acapulco-Cruz Grande. Ph.D. Thesis, Geophys. Postgraduate Progr., Univ. Nac. A. México, 186 pp.

MORAN-ZENTENO, D.J., P. SCHAAF, H. KOHLER, H. BÖHNEL and J. URRUTIA-FUCUGAUCHI, 1993. Consideraciones acerca de la petrogénesis de los intrusivos de la región de Acapulco, basadas en datos isotópicos de Sr y Nd. *In:* L.A. Delgado-Argote and A. Martín-Barajas (Eds), Contribuciones a la Tectónica del Occidente de México, UGM Monogr., 1, 305-326.

NEGENDANK, J.F.W., R. EMMERMANN, N. NUN, B. SCHULTZ-DOBRICK, H. TOBSCHALL and R. KRAWCZYK, 1987. The granitoid complexes of Acapulco, Xaltianguis and Ocotito (Sierra Madre del Sur, Mexico). *Zbl. Geol. Paläont. Teil I, 1987 H. 7/8,* 705-718.

NYE, J. F., 1985. Physical Properties of Crystals. Clarendon Press, 2nd Ed., Oxford, 329 pp.

PITCHER, W. S., 1979. The nature, ascent and emplacement of granite magmas. *J. Geol. Soc. London, 136,* 627-662.

RADHAKRISHNAMURTY, C., S. D. LIKHITE, E. R. DEUTSH and G. S. MURTHY, 1981. A comparison of the magnetic properties of synthetic titanomagnetites and basalts. *Phys. Earth Planet. Int., 26,* 37-46.

SENANAYAKE, W. H. and M. W. McELHINNY, 1981. Hysteresis and susceptibility characteristics of magnetite and titanomagnetites: Interpretation of results from basaltic rocks. *Phys. Earth Planet. Int., 26,* 47-55.

TAKAHASHI, M., S. ARAMAKI and S. ISHIHARA, 1980. Magnetite series/ilmenite series vs. I-type/S-type granitoids. *In:* S. Ishihara and S. Takenouchi (Eds) Granitic Magmatism and Related Mineralization, *Japan Mining Geol. Soc. Sp. Publ., 8,* 13-28.

TARLING, D. H. and F. HROUDA, 1993. The Magnetic Anisotropy of Rocks. Chapman and Hall, UK, 217 pp.

URRUTIA-FUCUGAUCHI, J., 1980. Palaeomagnetic studies of Mexican Rocks. Ph.D. Thesis, Univ. Newcastle upon Tyne, UK, 689 pp.

URRUTIA-FUCUGAUCHI, J., 1983. Palaeomagnetism and rock magnetism of selected intrusive igneous bodies from southern Mexico I. Reconnaissance study of the Acapulco and Tierra Colorada intrusives. *Geofís. Int., 22,* 39-56.

URRUTIA-FUCUGAUCHI, J., 1984. On the tectonic evolution of Mexico: Paleomagnetic constraints. *Am. Geophys. Union Geodyn. Ser., 12,* 29-47.

URRUTIA-FUCUGAUCHI, J., C. RADHAKRISHNAMURTY and J.F.W. NEGENDANK, 1984. Magnetic properties of a columnar basalt from central Mexico. *Geophys. Res. Lett., 11,* 832-835.

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