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PALAEOMAGNETIC ESTIMATION OF EMPLACEMENT TEMPERATURE OF PYROCLASTIC DEPOSITS – PRELIMINARY STUDY OF CALDERA DE LOS HUMEROS AND ALCHICHICA CRATER

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RESUMEN

Se reportan resultados paleomagnéticos de un estudio preliminar de depósitos piroclásticos de la caldera de Los Humeros y del cráter Alchichica. Los datos son analizados siguiendo un criterio simple de clasificación que usa los resultados iniciales del magnetismo remanente y los obtenidos por desmagnetización. Los depósitos estudiados en el cráter de explosión de Alchichica fueron depositados con temperaturas de emplazamiento de 100°C a 300°C. El depósito estudiado en la caldera de Los Humeros se emplazó a una temperatura mayor, de aproximadamente 450°C o mayor.

ABSTRACT

Preliminary palaeomagnetic results from pyroclastic deposits of a large caldera (Los Humeros) and a small explosion crater (Alchichica) are reported. The data are analyzed in terms of a simple classification scheme based on the directional properties of initial remanent magnetization and demagnetized remanent magnetizations. The deposit studied in Los Humeros caldera is an ignimbrite with an emplacement temperature of about 450°C or higher. Deposits studied in the Alchichica explosion crater were deposited with emplacement temperatures between 100°C and 300°C with some of the lithic clasts cooling before and some cooling during the final deposition.

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INTRODUCTION

Deposits of volcanic rock debris such as pyroclastic flows, surge and airfall deposits, lahars, rock avalanches, and glacier deposits may often present similar superficial appearance, thus making it difficult to distinguish them and to determine their modes of emplacement. To solve this problem, Aramaki and Akimoto (1957) used a simple technique based on the measurement of the direction of natural remanent magnetization (NRM). These authors showed that NRM directions of clasts from deposits emplaced at temperatures above the maximum Curie point (T_c) of the magnetic carrier present a well-grouped distribution parallel to the ambient magnetic field direction at the time of emplacement and that below the Curie point present a scattered distribution. Thus, the technique distinguishes between 'high temperature' and 'low temperature' deposits, by estimating the temperature range (relative to T_c) of final emplacement. This note is a progress report of a work concerned with palaeomagnetic estimation of emplacement temperature of pyroclastic deposits by using the data of thermal and alternating field (AF) demagnetization and statistical tests as well as the initial NRM results. Preliminary results of deposits from the caldera de Los Humeros and the Alchichica explosion crater are presented.

Magnetic properties and emplacement temperature

The magnetization acquired by cooling from the Curie temperature to room temperature in the presence of a magnetic field is known as thermoremanent magnetization (TRM) and is the vectorial resultant of magnetizations (partial TRMs or pTRM) acquired in given temperature intervals according to the blocking temperature (T_B) distribution of the magnetic grain assemblage. Partial TRM_s are independent of those acquired at previous or subsequent temperature intervals, so that reheating of a material (in the absence of chemical changes) to a temperature $T<Tc$ will destroy the pTRM of grains with $T_B \lesssim T$. The magnetization acquired by cooling from T will depend on the applied magnetic field and if cooling is in a 'zero' magnetic field there will be no new pTRM. This property forms the basis of the method of thermal demagnetization, and suggests a relationship between the 'demagnetization' temperature (T_D) and the T_B. Previous studies have considered a linear relation between T_D and T_B (e.g. Hoblitt and Kellogg, 1979; Kent *et al.*, 1981), but recent work indicates a more complex relationship. Nevertheless, for relatively fast cooling systems such as those considered in this note, the relationship can be taken as linear (Dodson and McClelland - Brown, 1980). Thus, laboratory determination of demagnetization temperature T_D gives an estimate for the blocking temperature T_B of given magnetizations and permits to trace the magnetization acquisition history (in particular, relative changes in orientation with respect to ambient magnetic field) of lithic clasts and matrix of pyroclastic deposits.

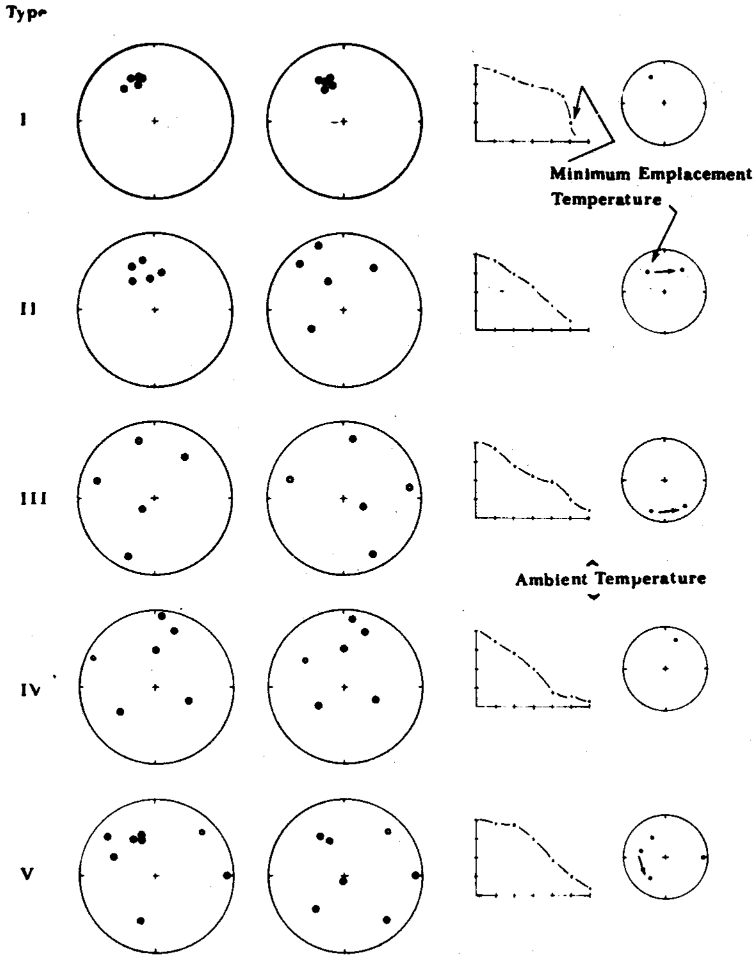


Fig. 1. Simplified representation of the classification scheme of pyroclastic deposits based on the remanent magnetization. Dots represent TRM direction on stereographic projections, before demagnetization (left) and after demagnetization at optimum treatment (right). Possible examples of demagnetization of pilot specimens are plotted in stereographic projections and intensity plots.

In this context, we have distinguished five major types of deposits (Fig. 1):

Type I deposits. Directions of TRM from individual clasts are well grouped around the Earth's magnetic field direction at emplacement time, and agree with TRM directions recorded by the matrix. TRM directions are stable to both thermal and AF demagnetization, and the maximum blocking temperature of the clasts is a maximum of the final emplacement temperature.

Type II deposits. Directions of TRM from individual clasts are distributed around or somewhat farther from the Earth's magnetic field direction. With thermal and AF demagnetization, given clasts will reveal a multi-vectorial composition of TRM. Low-blocking temperature components record the Earth's field direction, whereas higher blocking temperature components are randomly distributed. This suggests that clasts were deposited at a temperature intermediate between the maximum blocking temperature and the ambient temperature. The maximum demagnetization temperature of the low-blocking temperature component is an estimate of the emplacement temperature. The distribution of directions and vectorial composition depend on the relative magnitude and orientation of the pTRM components.

Type III deposits. Directions of TRM are randomly distributed and a multi-vectorial composition is revealed by thermal and AF demagnetization. No common TRM component direction is observed after treatment. This indicates that the clasts were emplaced at ambient temperature, and that transport occurred during cooling of the clasts.

Type IV deposits. Directions of TRM are randomly distributed. The directions are stable with AF and thermal demagnetization showing a univectorial composition. This indicates that the clasts were emplaced at ambient temperature, and that transport occurred after cooling of the clasts.

Type V deposits. These deposits are a mixture of two or more of the types described before without any obvious spatial dependence arising from sampling.

This classification of deposits is similar to that proposed by Hoblitt and Kellogg (1979), but with the difference that this classification distinguishes between deposits finally emplaced at ambient temperature in which transport occurred during cooling of the lithis clasts (Type IV).

In practice, it seems that distinction between 'hot' and 'cold' emplacement modes is relatively simple, but a more detailed information concerning the emplacement temperature and nature of a deposit is not easy to obtain. With respect to the 'palaeomagnetic' classification of the pyroclastic deposits, the nature and properties of secondary remanent magnetization of clasts and matrix should be examined and their effects corrected. Among the common secondary components present in volcanic rocks one has viscous remanent magnetization (VRM) and isothermal remanent magnetization (IRM). These components may be recognized from the analysis of AF and thermal demagnetizations. Also, since the measurements involve a number of samples, simple statistical tests may assist in distinguishing between the different types. Statistical analysis has been partially used in this work, and it requires further refinement. Type I deposits are characterized by k-values (Fisher, 1953) larger than 10 and often in the order of 100 for both the initial TRM and the demagnetized TRM. Type II deposits are characterized by $k > 10$ for the low blocking temperature TRM and a decrease in precision after demagnetization, for the high-blocking temperature components. This can be tested statistically by comparing the precision parameter (ki) of the low-blocking temperature directions with that after demagnetization (kc), so that the ratio Ki/kc can be compared with F-ratio values calculated with 2N-1 degrees of freedom, where N is the number of directions (McElhinny, 1964). Types III, IV and V are characterized by scattered distributions of directions with $k < 10$, for both initial and demagnetized TRM directions. Type IV deposits are characterized by similar distributions of directions before and after demagnetization and by univectorial demagnetization plots of individual samples.

METHODS

For this work, hand samples oriented by magnetic compass were collected from the ash and clasts of the deposits. In the laboratory, cores of 2.5 cm diameter were drilled from clasts and the matrix, and one specimen, 2.2-2.5 cm long was sliced from each core. The direction and intensity of NRM were measured on two spinner magnetometers: a PAR-SM2 meter was used for initial measurements of clasts-specimens, and a DIGICO meter was used for the other measurements. The vectorial composition and directional stability were investigated by AF or thermal demagnetization. AF demagnetization was carried out in a three-axis thumbler instrument which is digitally controlled for fields up to 1000 Oersteds (de Sa and Widdowson, 1971). Thermal demagnetization was carried out in a non-inductive vertical electrical furnace which is provided with an automatically controlled field free space for the cooling cycle (Stephenson, 1967).

The anisotropy of magnetic susceptibility (AMS) was measured with an anisotropy attachment to a Digico complete result meter. The axial susceptibility was measured with a susceptibility bridge.

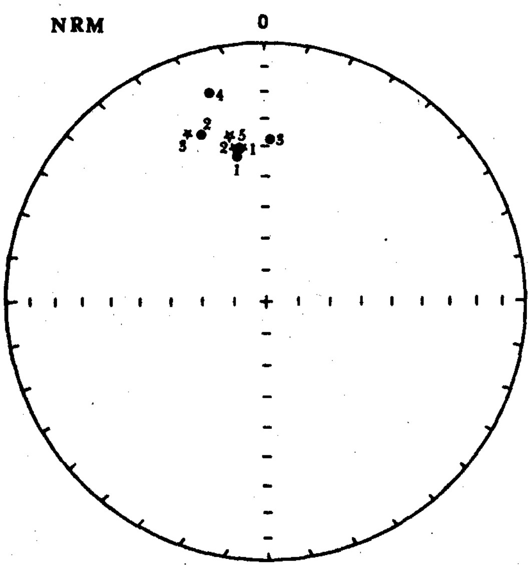
Additional details are included together with the results obtained in the next section.

RESULTS

Caldera de Los Humeros

The caldera de Los Humeros is located at the easternmost end of the Trans-Mexican volcanic belt, with approximate coordinates of 19.67° N and 97.40° W. This caldera has been recently studied because of its potential for geothermal energy (Yáñez-García and CasiqueVázquez, 1980). The oldest caldera units rest on folded and eroded limestones of the Turonian Agua Nueva Formation. Timing of events during the caldera development is not well established. The unit studied corresponds to the late stages of activity (Late Pliocene-Early Pleistocene) and is exposed in several places outside and within the caldera. This unit, the Xaltipan ignimbrite, exhibits all stages of welding and compaction, from densely welded tuffs to unconsolidated ash materials. Sampling was restricted to two sites of poorly consolidated material, in order to obtain an estimate of minimum temperature of emplacement. One site is located in the western flank of the caldera rim along a narrow creek, and the other site is located close to Los Humeros village within the caldera. Three clast samples and twelve matrix samples were collected. Drilling of the matrix material was difficult and seven cores were later destroyed in the laboratory.

Initial NRM directions for both clasts and ash are very well grouped (Fig. 2) the



Los Humeros Caldera

Fig. 2. Directions of initial NRM for a site at Los Humeros caldera. Lithic clasts are represented by closed stars, and the matrix is represented by closed dots. The mean direction is given by the open star. Inclinations are all positive.

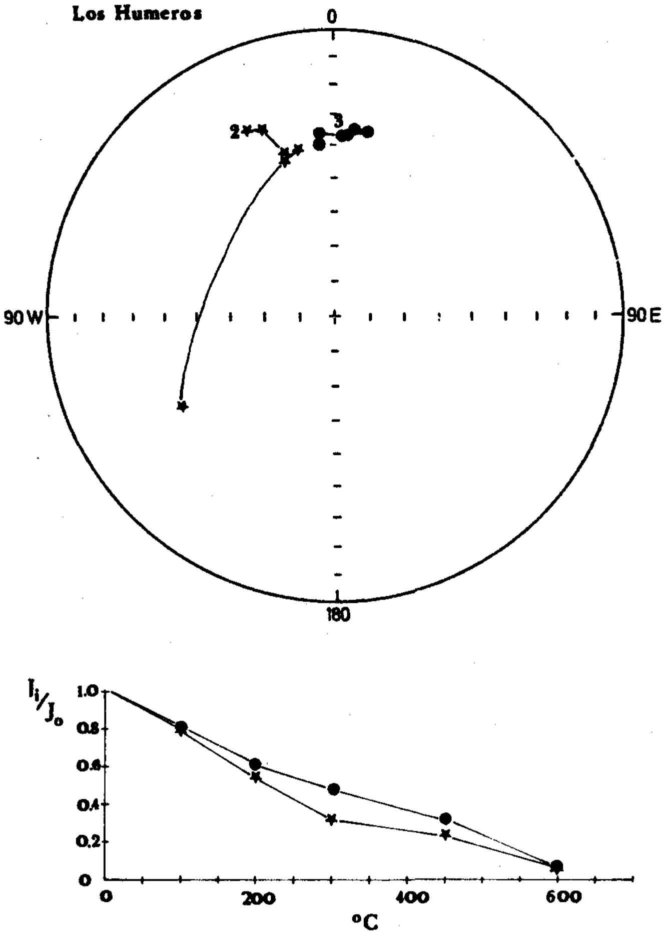
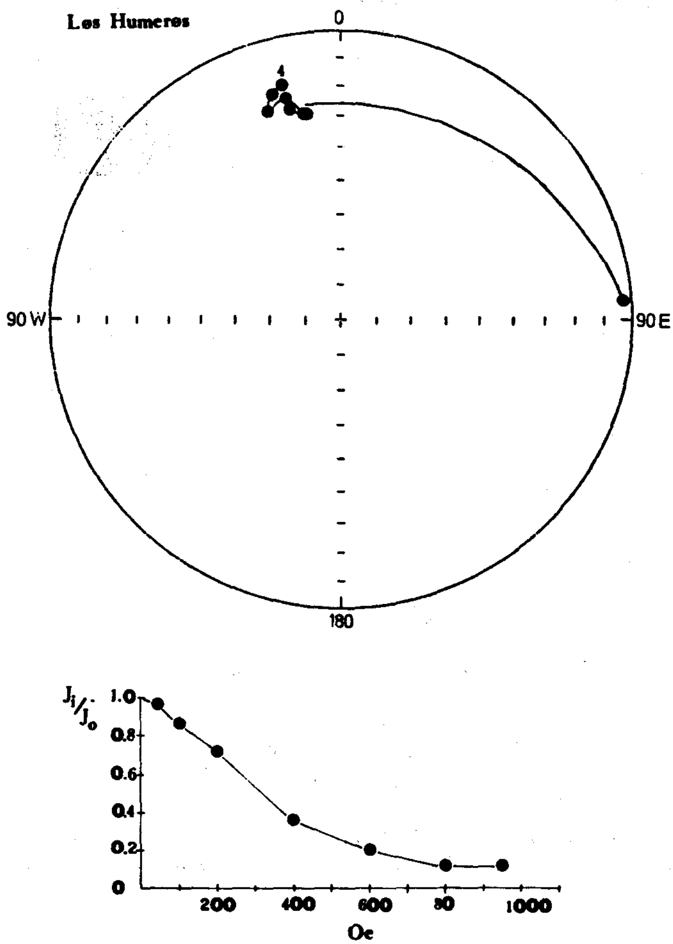


Fig. 3. (a) Thermal demagnetization of a lithic clast (stars) and a matrix sample (dots). Initial directions are marked by the sample numbers. (b) AF demagnetization of a matrix sample.

directions are stable during AF and thermal demagnetizations (Fig. 3a, b). This deposit is classified as 'high' temperature deposit, with an approximate minimum emplacement temperature higher than 450°C. Matrix samples were very stable up to the Curie point of magnetite, whereas some of the lithic clasts showed apparent



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high blocking temperature components or components arising from the laboratory heating. Since these components were not properly isolated, the minimum estimate is here set at 450°C (Table 1).

Table 1

Summary of palaeomagnetic data for the pyroclastic deposits

1. *Los Humeros caldera*

Sampling	3 lithic fragments and 5 matrix samples			
Mean direction and statistics of NRM	D = 348°	I = 35°	K = 58	α_{95} = 7°
Main type	~Type II (minimum emplacement temperature ~450°C)			

2. *Alchichica crater*

(Site 1)

Sampling	5 lithic fragments			
Mean direction and statistics of NRM	D = 358°	I = 22°	K = 14	α_{95} = 33°
Mean direction and statistics of cleaned NRM	D = 337°	I = 15°	K = 1	α_{95} > 90°
Main type	~Type II (emplacement temperature close to 100°C) (Type III)			

(Site 2)

Sampling	4 lithic fragments
Directions	dispersed
Main type	~Type IV (emplacement temperature close to ambient temperature)

(Site 3)

Sampling	1 lithic fragment and matrix sample

Note: D = declination in degrees east of north; I = inclination in degrees above the horizontal; K = precision parameter; and α_{95} = cone of 95% confidence, around mean direction (Fisher, 1953).

Alchichica explosion crater

This crater is located close to Los Humeros caldera at about 19.42°N and 97.40°W and is locally known as Axalapasco de Alchichica (terms meaning sand pot and place of salt water respectively). The crater is of oval shape with semi-axes of about 2.3 km and 1.8 km, and the interior lake is almost circular with a ~1.5 km diameter and minimum depth of about 72 m. Samples were collected at three sites on the easterly inner slope rim. Five samples of clasts were collected at the base of the rim, which give initial NRM directions with some dispersion around a mean direction with an inclination about 15° less steeper than the site dipolar direction (Fig. 4).

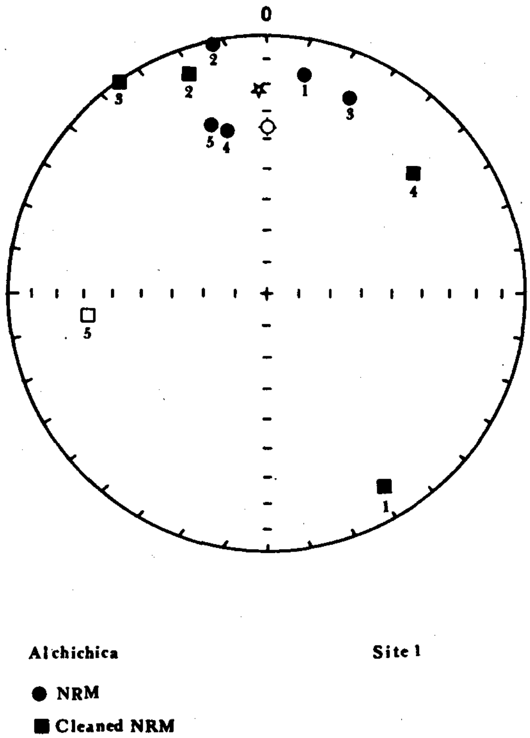


Fig. 4. Initial (dots) and demagnetized (squares) NRM direction for site 1 of Alchichica. Numbers indicate the sample identification. The open star indicates the mean direction before demagnetization. The site of dipolar direction is given by ⌖. Demagnetized directions after the 450°C step.

Thermal demagnetization indicated that the NRM is composed of at least two components, sometimes with opposite polarities (Fig. 5). The overlap of blocking temperature spectra of the magnetic components does not permit to estimate the maximum unblocking temperature of the first component, which is higher than 100°C

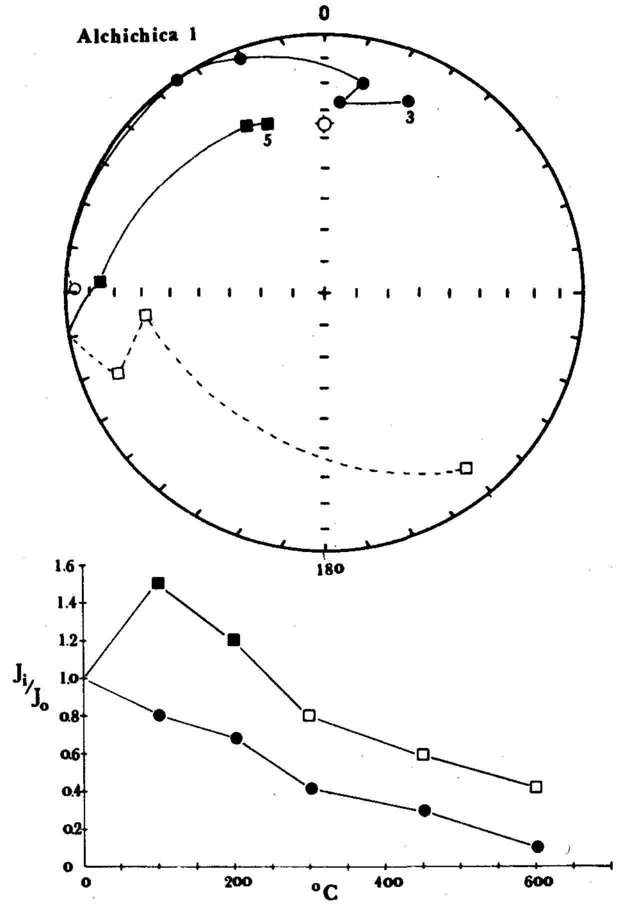


Fig. 5. Thermal demagnetization of two samples of site 1. Open symbols are negative inclinations and closed symbols are positive inclinations.

and lower than 300°C. The results correspond to type II deposits. Site 2 is located about half way towards the top of the rim and consists of four samples of clasts. Initial NRM directions form a scattered distribution (Fig. 6). With thermal demagnetization, two samples were very stable (samples 1 and 4) and two samples showed indication of a high blocking temperature component (Figs. 6 and 7). The results

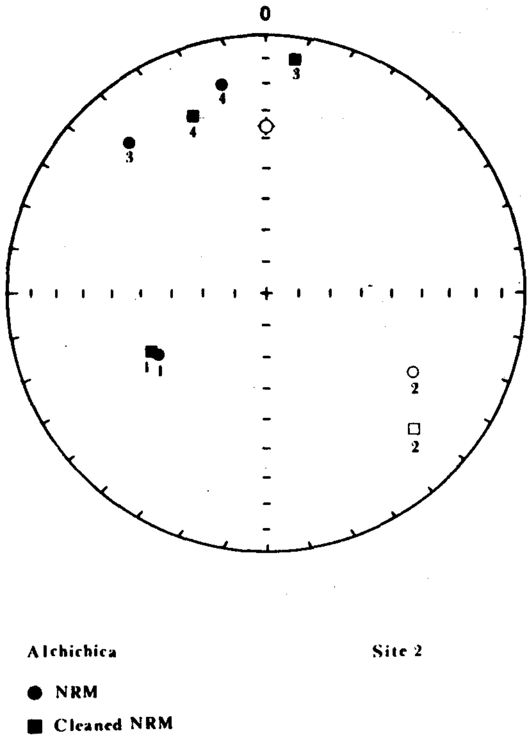
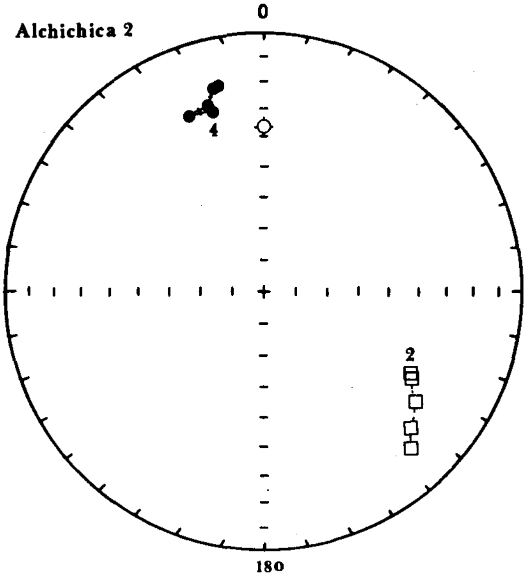


Fig. 6. Initial (dots) and demagnetized (squares) NRM directions for site 2 of Alchichica. Numbers indicate the sample identification. Demagnetized directions after the 450ºC step. The site dipolar direction is given by -ɸ-.

suggest a deposit emplaced at ambient temperature. Finally, four samples were collected from a site intermediate between sites 1 and 2, but only one clast sample and one matrix sample were usable for measurement. The directions before and after thermal demagnetization diverge, and neither agree with expected directions for the site (Fig. 8). No conclusions are obtained. Results are summarized in Table 1.



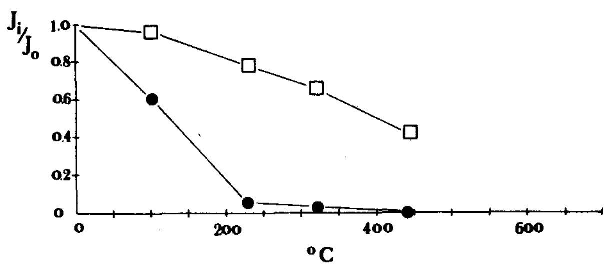


Fig. 7. Thermal demagnetization of two samples of site 2. Open symbols are negative inclinations and closed symbols are positive inclinations.

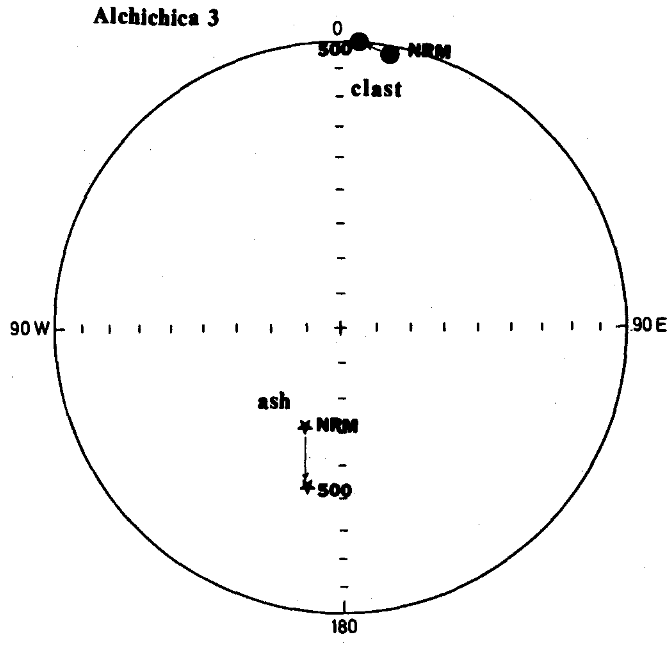


Fig. 8, Initial and demagnetized directions of site 3. Demagnetized directions after the 500°C step.

Measurements of anisotropy of magnetic susceptibility of clasts give directions of principal axes with scattered distributions and degree of anisotropy (k_1/K_3) ranging from 1.082 (8.2%) to 1.116 (11.6%). Measurements of two matrix samples give well developed foliation planes with minimum susceptibility axes normal to the horizontal and degress of anisotropy of 1.068 (6.8%) and 1.069 (6.9%). Well developed horizontal foliation planes have been observed in ash (air or water) deposits of the May 1980 eruption of Mount St. Helens, U. S. A. (Steele, 1981).

DISCUSSION

The classification scheme of Fig. 1 may help in analysing the palaeomagnetic results of pyroclastic deposits. Palaeomagnetic measurements in clasts can easily distinguish between hot and cold emplacement modes (Aramaki and Akimoto, 1957; Chadwick, 1971; Kent *et al.*, 1981). Estimation of the emplacement temperature presents more difficulties, which may be overcome by detailed demagnetization, analytical analysis of results (vector substraction, least-squares analysis) and rock magnetic measurements.

This procedure works best in young fresh deposits, and further work is required for older less-well preserved pyroclastic deposits. Also, incorporation of tests to detect alterations occurring during laboratory heating, such as those used in palaeointensity determination methods (e.g. Urrutia Fucugauchi, 1980), may reduce uncertainties in unblocking temperature estimates.

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