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STATISTICS OF REMANENT MAGNETIZATION INTENSITIES OF SOME CENOZOIC EXTRUSIVE IGNEOUS ROCKS FROM JALISCO STATE, MEXICO

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RESUMEN

El relevamiento de ocho unidades volcánicas de la Era Cenozoica del estado de Jalisco, México, ha demostrado que las intensidades de magnetización remanente de las rocas, tienen una distribución de función de densidad que se aproxima a la distribución logarítmica normal. Las intensidades medias calculadas en base a los distintos lazos parecen guardar relación con la polaridad.

La intensidad logarítmica media de todos los lazos, se presenta en comparación con otros datos de la Era Cenozoica.

RÉSUMÉ

Les intensités de magnétisation rémanente de roches de huit unités volcaniques de l'âge Cénozoíque relevées dans l'Etat de Jalisco, Mexique, ont une distribution de fonction de densité que s'approche à la distribution logarithmique normale. Les moyennes d'intensité calculées en base aux logarithmes des différents liens paraissent avoir une relation avec la polarité. La moyenne d'intensité logarithmique de tous les liens est comparée avec d'autres dates de l'âge Cénozoíque.

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ABSTRACT

The remanent magnetization intensities of eight extrusive igneous units of Cenozoic age from Jalisco State, Mexico, are found to have a distribution which approximates to a logarithmic gaussian distribution. The sample population (104) is better represented by statistical parameters derived from the logarithmic gaussian distribution than from the normal distribution. The log-normal average intensities of the different sites appear to correlate with magnetic polarity. Finally, the log-normal average intensity determined using all sites is compared with other Cenozoic data.

INTRODUCTION

During the last few decades, palaeomagnetic studies have succesfully been used for a wide range of applications (see e.g. Aitchison y Brown, 1957; Irving, 1964; McElhinny, 1973). The basic ground of palaeomagnetism is the study of the magnetization contained in the rocks which is currently known as natural remanent magnetization (NRM). Palaeomagnetic studies on volcanic rocks have shown that in a single unit, while the NRM directions of different samples are relatively well grouped, the intensities can be quite different from one sample to another and sometimes from specimen to specimen within a same sample. Most studies have been restricted to the directions, however the intensity is important for different investigations: to determine palaeointensities, to interprete magnetic anomalies, to correlate different rock units, etc., and even to better study the directions using analytical techniques such as magnetic cleaning and stability indices, vectorial analysis, vector diagrams, least-square analysis, etc.

Despite the interest and use of the NRM intensity, only a few attempts have been made to investigate this property. Tarlin (1966) and Irving *et al.* (1966) studied the statistical distribution of NRM intensities and suggested that the theoretical distribution which best fits the data is the logarithmic gaussian or log-normal distribution. The results reported here support their considerations and by using log-normal statistics suggest a possible correlation between NRM intensities and magnetic polarity.

In recent works, Urrutia (1976) and Urrutia and Pal (1977) presented the results of a palaeomagnetic study of Cenozoic lava flows from the Atotonilco-Arandas area of the State of Jalisco, Mexico. These earlier palaeomagnetic investigations were chiefly concerned with the analysis of the directions of natural and "stable" remanent magnetizations and their interpretation in terms of the tectonic implications. In the present paper the statistics of NRM intensities of these rocks is discussed

STATISTICS OF NATURAL REMANENT MAGNETIZATION

Table 1 shows some details of the sample collection analyzed (i.e. number of sites, number of samples and specimens, lithology, opaque mineralogy and magnetic polarity). A detailed description of the rock units and sampled sites is given by Urrutia (1976). For this study, intensities measured from each specimen were given equal weight in the analysis, i.e. irrespective of number of samples, stability, suspected lightning effects, etc. This approach however permits to estimate certain effects of these factors by testing the internal agreement of the data and by comparing the final results. The first statistical analysis (current analysis) was made assuming a normal distribution. The results are summarized in table 2. For each site, conventional normal parameters such as range, arithmetic mean and standard deviation were computed. In addition, 95% confidence intervals for the mean and variance were estimated. The confidence intervals and levels are measures of the precision and reliability of a given statistical parameter. The greater the precision, the smaller the confidence interval and the greater the reliability, the higher the confidence level. A 95% confidence level was selected as this level value is currently used in palaeomagnetic directional statistics (Irving, 1964). The intensity values were then plotted as histograms and a true probability normal density function was calculated. The fit of the observed to the calculated hyppothetical distribution was poor in all cases (e.g. Fig. 1b). The same result was obtained from the analysis with all the data (Fig. 1a). In particular it can be observed from these figures

(Fig. 1a and b) that the arithmetic means are poor estimations of the distributions and do not constitute representative parameters of the sample populations.

Then, the analysis was made assuming a log-normal distribution. The degree of agreement was found to be good in site VIII (N = 22), in other cases the number of determinations available was considered small for a correct statistical analysis. Although all these sample populations are described with a best fit by a log-normal distribution. The distribution of all data is also best described by a log-normal distribution. Figure 2 shows the histograms for the site VIII (Fig. 2b) and for all sites (Fig. 2a). The best fitting log-normal curve was also plotted. It can be noticed the good agreement found for site VIII and that the log-normal means represent best representative estimations of these sample populations (compare these results with those of Figs. 1a and b).

Following the positive results of the graphical scrutiny, the degree of log-normality was then tested with the chi-square test of goodness of fit (x^2 test). The results of this test are given in table 3. An alternative test of log-normality is by means of cumulative percentage graphs. In this, the data are plotted using logarithmic probability paper, where the cumulative percentage of the logarithm of the variable are plotted on the horizontal scale and the intensities are on the vertical scale. For this test the data are grouped in a cumulative frequency form which is easy to produce. On this graphs log-normal distributions plot as straight lines and departures from this pattern indicate the degree of goodness of fit to the log-normal distribution. On the other hand, when more than one sample population is present within the population being analyzed, breaks in slope of the straight lines occur. This last property is particularly useful in the analysis of magnetic properties of rocks, e.g. where samples are collected from sites with poor-known field relationships, units affected by local phenomena, lighting effects, weathering, etc. Examples of this analysis are given in Figs. 3a and b. The graph for all sites (Fig. 3b) indicates the presence of more than one population within the sample collection, in agreement with the chi-square test (Table 3).

In Table 4 the average and standard deviation calculated from the arithmetic values are shown. It is suggested that these parameters are better estimations than those calculated from the arithmetic values (see Figs. 1 and 2).

The log-normal averages of each site were plotted in order to investigate their relations. Figure 4 shows the result obtained. From this figure a possible correlation between log-normal average intensity and polarity arises (site VIII is the only one with reverse polarity). This result can be explained in terms of a viscous remanent magnetization (VRM). This kind of secondary magnetization is acquired by exposition for long periods to a magnetic field at temperatures below the Curie point (ussuallly at room temperatures). The present polarity of the Earths's magnetic field (EMF) is taken as normal (that is the inclination of the magnetic vector is downward in the northern hemisphere) and this polarity was attained by the EMF about 700 000 years ago. The VRM acquisition processes are such that the effects of the EMF during this period (Brunhes geomagnetic normal epoch) create a VRM of normal polarity (diminishing or destroying VRM previously acquired). The NRM is the vector resultant of the various remanent components, therefore the effect of VRM component is to increase the magnitudes of normal NRM and to decrease those of reverse NRM.

On the other hand, the differences observed for the normal sites (Fig. 4) can be due to several factors: differences in the amount and type of magnetic minerals (Table 1), differences in magnetic properties (susceptibility, remanence carriers, etc.), ambiental factors at the time of lava extrusion (oxygen fugacity, temperature of magma, water, deuteric alterations, etc.), low-temperature alterations, and many others, including that the lava units can be of different ages and therefore the EMF at the time of remanence acquisition was different. This last possibility seem to be supported by the cumulative percentage graph (Fig. 3b) and the palaeopole position pattern derived by Urrutia (1976) from the direction results. It is considered that more information is needed before a conclusion can be given.

In order to compare the results with other studies (Tarling, 1966).

Table 2. **Statistics of** remnant **magnetization** intensities (after Urrutia, 1976).

Site	N	range R	arithmetic mean $\bar{J}_a$	standard deviation S_J	95% confidence intervals for the mean and variance: population mean $-r_{\bar{J}}$	population mean $+r_{\bar{J}}$	population variance $-r_{\sigma^2}$	population variance $+r_{\sigma^2}$
I	16	0.406×10^{-4}	0.357×10^{-4}	0.100×10^{-3}	-0.952×10^{-5}	0.816×10^{-4}	0.132×10^{-5}	0.291×10^{-6}
II	16	0.967×10^{-5}	0.253×10^{-4}	0.291×10^{-4}	0.120×10^{-4}	0.388×10^{-4}	0.117×10^{-6}	0.194×10^{-7}
III	11	0.185×10^{-6}	0.204×10^{-5}	0.149×10^{-5}	0.117×10^{-5}	0.291×10^{-5}	0.388×10^{-9}	0.583×10^{-10}
IV	9	0.219×10^{-4}	0.422×10^{-4}	0.311×10^{-4}	0.214×10^{-4}	0.622×10^{-4}	0.214×10^{-6}	0.253×10^{-7}
V	11	0.210×10^{-4}	0.387×10^{-4}	0.598×10^{-4}	0.524×10^{-5}	0.719×10^{-4}	0.602×10^{-6}	0.952×10^{-7}
VI	6	0.589×10^{-6}	0.167×10^{-5}	0.328×10^{-6}	0.136×10^{-5}	0.194×10^{-5}	0.388×10^{-10}	$0 \quad \times 10^{-11}$
VII	13	0.192×10^{-3}	0.111×10^{-3}	0.985×10^{-4}	0.602×10^{-4}	0.161×10^{-3}	0.148×10^{-5}	0.272×10^{-6}
VIII	22	0.200×10^{-4}	0.115×10^{-4}	0.113×10^{-4}	0.719×10^{-5}	0.159×10^{-4}	0.144×10^{-7}	0.408×10^{-8}

Table 1. Paleomagnetic data of Jalisco, Mexico.

Site	N° of samples	N° of specimens	Rock type	Magnet.miner-als.appr.wt(%)	Polar-ity
I	10	16	olivine poor basalt	magnetite(7)	N
II	8	16	olivine poor basalt	magnetite(7)	N
III	8	11	basaltic andesite	magnetite(4) hematite (2)	N
IV	8	9	basaltic andesite	magnetite(5)	N
V	8	11	basaltic andesite	magnetite(6)	N
VI	4	6	basaltic andesite	magnetite(4) hematite (4)	N
VII	9	13	olivine andesite	magnetite(7)	R
VIII	10	22	olivine poor basalt	magnetite(6)	N

the log-normal average of all sites was corrected to its palaeo-equatorial value. This is given by

$$J_{eq} = J_{NRM}(1 + 3 \sin^2 \lambda)^{-1/2}$$

where J_{NRM} is the NRM intensity and λ is the palaeolatitude derived from the palaeodirectional results (Urrutia, 1976). The result seems to be consistent with results from marginal (Fiji) and continental collections, and in agreement with the geological field evidences. The marginal and continental results display the lower values respect to oceanic collections (Table 5, note the change of units of the NRM intensities).

DISCUSSION

It should be mentioned that much more studies are to be required before a statistical distribution can be derived for NRM intensities (e.g. results reported in literature sometimes do not follow a log-normal distribution). In particular, studies on theoretical models of NRM intensity acquisition and on models of generation of the log-normal distribution of NRM intensities seem to be required. The study of intensity distribution is of considerable value for the comprehension of magnetic properties and their relations to other factors, i.e. lithology, environments, age, etc. (Tarling, 1966) and also in other palaeomagnetic aspects such as palaeointensity investigations. Detailed analysis of intensity distribution can be used as a criterion of selection of suitable rocks for palaeointensity determinations. The comprehension of intensity distribution can be useful in the investigation of the natural remanent magnetization present in different rocks. Present anomalous data may be due to mixtures of two or more different log-normal distributions. Combined with detailed field and laboratory work the analysis of log-normal distribution and cumulative percentage graphs will possibly permit a better estimation of the palaeodirections. For example, anomalous directions appear to correlate with intensities far from the log-normal average, situation possibly related to remanence acquisition or subsequent history or that these intensities belong to different sample populations, etc.

Table 3. Comparison of observed distributions with a log-normal distribution.

	N	x^2	P
Site VIII	22	0.7	$\simeq 0.87$
All sites	104	33.93	< 0.01

N, number of samples; x^2 chi-square test of the observed distribution against the best fitting log-normal distribution; P, probability that the difference between the observed and the hypothetical log-normal distribution could have arisen by chance.

Table 4. Arithmetic and log averages of intensities

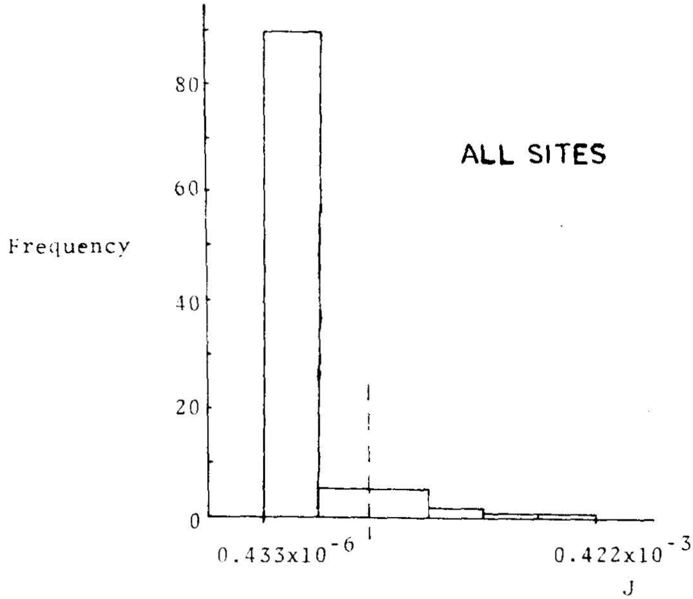
Site	Nc	$\bar{J}_a$	$\bar{J}_1$	$\bar{J}_e$	S
I	16	0.357×10^{-4}	0.993×10^{-5}	0.854×10^{-5}	0.530
II	16	0.253×10^{-4}	0.125×10^{-4}	0.967×10^{-5}	0.536
III	11	0.204×10^{-5}	0.178×10^{-5}	0.149×10^{-5}	0.266
IV	9	0.422×10^{-4}	0.280×10^{-4}	0.231×10^{-4}	0.467
V	11	0.387×10^{-4}	0.125×10^{-4}	0.117×10^{-4}	0.731
VI	6	0.167×10^{-5}	0.165×10^{-5}	0.145×10^{-5}	0.087
VII	13	0.111×10^{-3}	0.857×10^{-4}	0.781×10^{-4}	0.443
VIII	22	0.115×10^{-4}	0.396×10^{-6}	0.348×10^{-6}	0.406
All sites	104	0.136×10^{-3}	0.972×10^{-5}	0.882×10^{-5}	0.681

Ne, number of specimens; $\bar{J}_a$, arithmetic average intensity (emu/cm^3); $\bar{J}_1$, logarithmic average intensity (emu/cm^3); $\bar{J}_e$, mean log intensity corrected to palaeo-equator (emu/cm^3); S, logarithm standard deviation.

Table 5. Comparison with other sample collection given by Tarling (1966)

		N	$\bar{J}_e$ (x10^{-3}gauss)
Late Cenozoic			
Oceanic	Hawaii	159	0.666
	Samoa	102	0.313
	Tahiti	53	0.604
	Bora Bora	36	0.765
	Heard Island	24	0.466
	Iceland	75	0.135
Marginal	New Hebrides	35	0.692
	Jalisco Volcanics	104	-0.354
	Fiji	28	-0.129
Continental	Newer Volcanics,Victoria	75	-0.113
	Czechoslovakia	54	-0.201
Other Cenozoic data			
	Mohole EM7	23	0.638
	Tristan da Cunha	10	0.747
	Older Volcanics,Victoria	42	-0.048

N, number of observations; $\bar{J}_e$, mean log intensity (x10^{-3}gauss) corrected to paleo-equator.



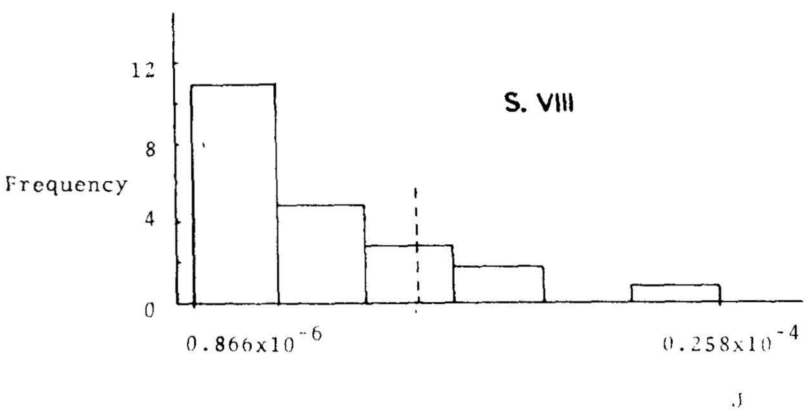


Figure 1. Histograms of intensity of magnetization. Data assuming a normal distribution. Intensities are plotted on the horizontal scale and frequency on the vertical scale. (a) Data for all sites analyzed and (b) for site VIII. See text. Arithmetic means are included.

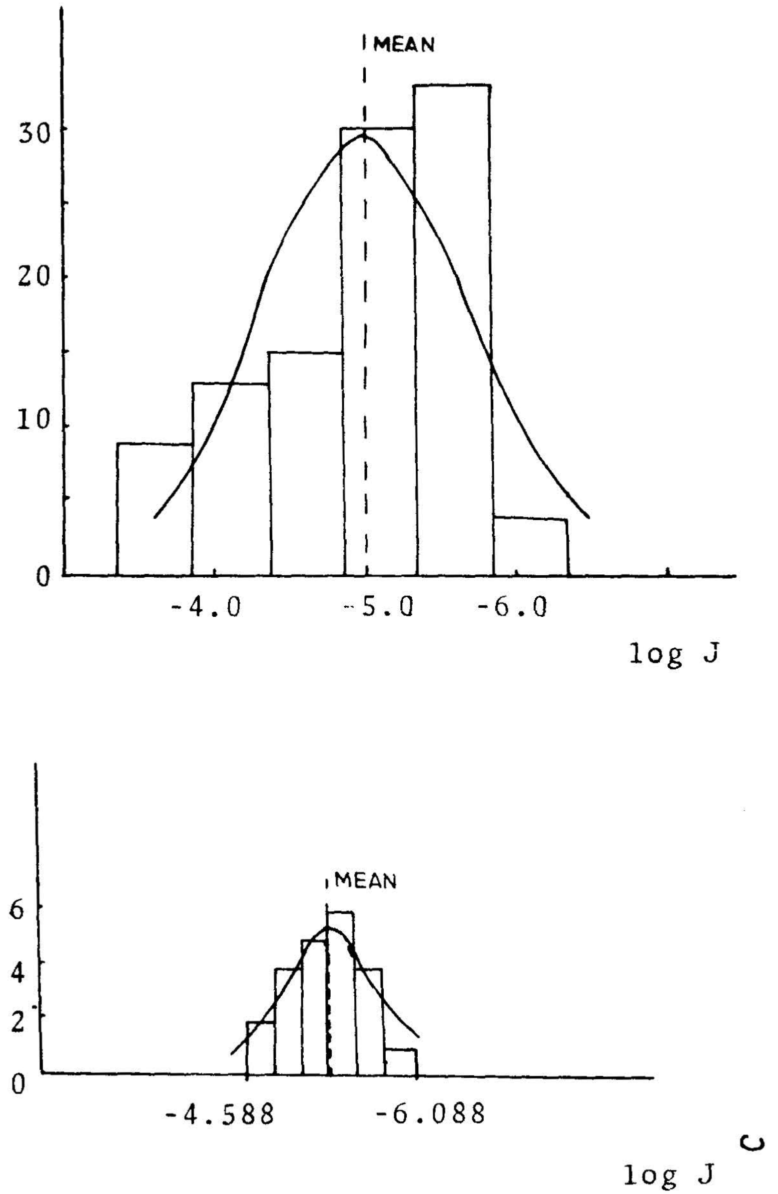
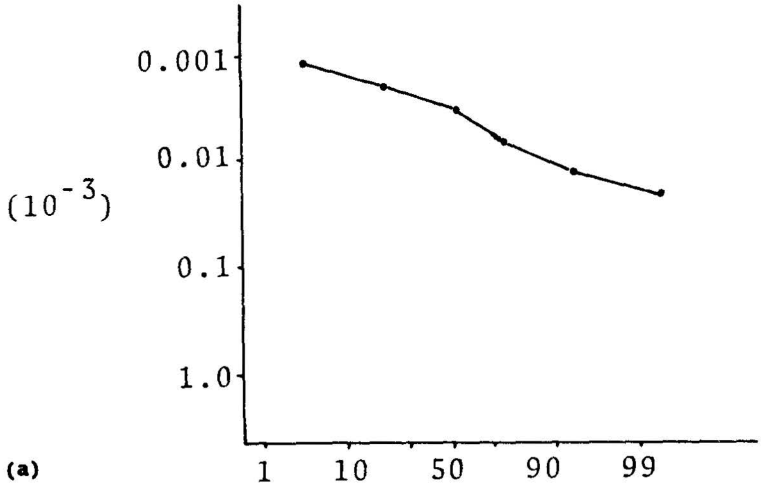
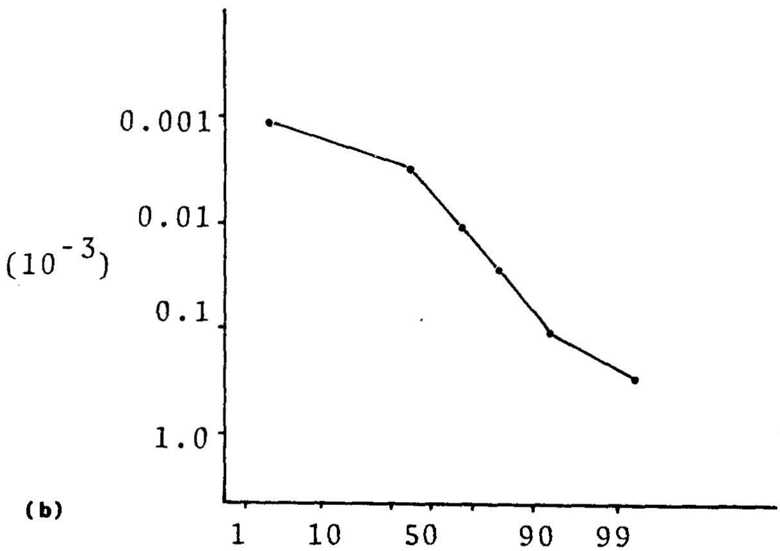


Figure 2. Histograms of logarithms of intensity of magnetization. Logarithms of intensity are plotted on the horizontal scale and frequency on the vertical scale. The continuous lines represent the best fitting normal curve derived from a theoretical distribution. The log-normal means are included. (a) Data for all sites and (b) for site VIII. See text.



(a)



(b)

Figure 3. Graphs of cumulative percentage of the logarithms of the intensity on a probability scale. Logarithm cumulative percentage of the intensities plotted on the horizontal scale and intensities on the vertical scale. (a) Data for site VIII and (b) data for all sites analyzed. See text.

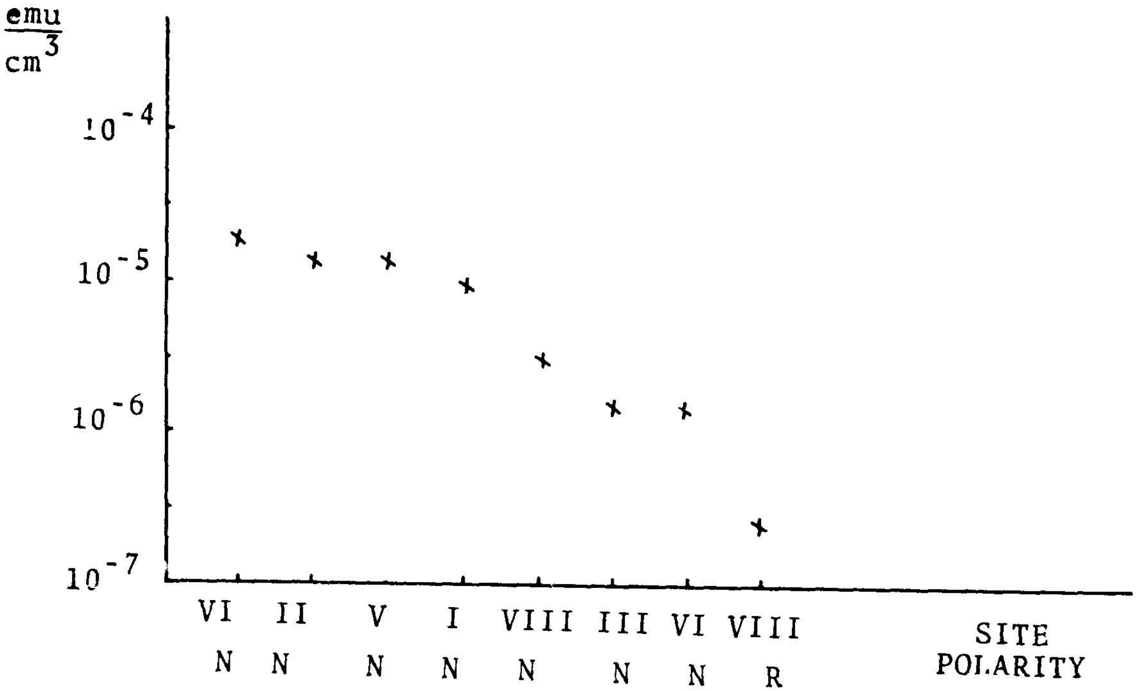


Figure 4. Comparision between log-normal means of intensity and magnetic polarity of the volcanic units studied. Polarity (unit-site) on the horizontal scale and log-normal means (units emu/cm^3) on the vertical scale. N, normal polarity and R, reverse polarity.

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