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ALTERNATING FIELD DEMAGNETIZATION STUDY ON LOWER SINIAN SANDSTONES IN XIUNING [HSIUNING] DISTRICT, ANHUI [ANHWEI] PROVINCE *

Liu Ch'un and Feng Hao
刘 椿 馮 浩
(Academia Sinica, Institute of Geology; Peking University, Department of Geophysics)

ABSTRACT

This paper presents the results of magnetic stability testing, by alternating current demagnetization, of some orientated Lower Sinian sandstone samples from the Xiuning formation in Xiuning 休宁 District, Anhui Province. The results show that the natural remanent magnetization of the formation is stable, and its mean direction is determined as $D_r = 311°$ and $i_r = 76°$. Thus the position of the paleomagnetic north pole in this era is inferred to be 90°E and 45°N, and the paleolatitude of the sampling site was 63°. The paper confirms the importance of the alternating current demagnetization test for paleomagnetic research. Finally, some views are expressed on the study of the local climatic conditions during the Early Sinian period.

I. Introduction

In China, exposures of the Sinian strata are very wide-spread; indeed China leads the world in this respect. Study of the natural remanent magnetism of the Sinian rocks is of great importance for research on the characteristics and distribution of the geomagnetic field and the position of the earth's pole during this era; also on the movements of the continental blocks with respect to each other, and related questions of stratigraphy.

We have previously ** measured the remanent magnetism of some Sinian beds in China and have, by a qualitative method, tested their magnetic stability. In order to proceed with the testing of rock sample magnetic stability by laboratory methods, we have experimented with the alternating field demagnetization of orientated samples of the Xiuning sandstones, of Lower Sinian age, from Xiuning District in Anhui Province. The purpose of this paper is to describe these experiments and their results.

It is an established fact that all rocks containing a ferromagnetic fraction have a natural remanent magnetism. The natural remanent magnetism has originated by different mechanisms in different rocks; nevertheless the direction of the magnetization which they acquire in the process of their formation always corresponds to the geomagnetic field at the time in question.

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* The gist of this paper has been previously published in "Synopses of Papers, First Structural Conference, Chinese Geological Society" (1965).

** Ref. [1]. All the references are missing from the original text. [Translator.]

The records of geomagnetic observations over the last few hundred years indicate that:

- In the long-term mean, the geomagnetic field is a central dipole field, directed along the earth's axis;

- In the long-term mean, the points where the axis of the dipole passes through the earth's surface --- the magnetic poles --- more or less coincide with the earth's geographic poles.

The remanent magnetization acquired by the rocks in the process of their formation is called the original natural remanent magnetization; in general it is relatively stable. Remanent magnetization acquired by the rocks after their formation is called secondary remanent magnetization, and it is relatively unstable; by laboratory processing (alternating current or direct current demagnetization, heat treatment, low-temperature demagnetization) we can usually remove this secondary magnetism, or show that it is not present.

Igneous rocks and sedimentary rocks, after their formation, remain directly exposed to the action of the geomagnetic field. Consequently the above-said natural remanent magnetization must be regarded as including, in general, two components, the original magnetization and the secondary magnetization; sometimes there is an additional temporary magnetization. The original remanent magnetization of igneous rocks is one that must have been acquired when magma, cooling from a high temperature in the earth's magnetic field, passed through the Curie point; it is a thermoremanent magnetization. The original remanent magnetization of sedimentary rocks was acquired when igneous rock particles ablated by erosion or weathering are, during their redeposition, turned so that the magnetic particles in them, like tiny magnets, are oriented in the direction of the geomagnetic field at the time in question. The other remanent magnetization components, namely the secondary magnetization and the temporary magnetization, are classed as isothermal remanent magnetizations. Experimental work has made it clear that the coercive force for the thermoremanent residual magnetization is much higher than for the isothermal remanent magnetization, and also that for the original remanent magnetization of the majority of sedimentary rocks the coercive force is very high. On the basis of these important findings we can, by applying to rock samples at room temperature an alternating magnetic field of several hundred oersteds peak intensity, "clean" them of their secondary and temporary remanent magnetization, and leave in them only the original remanent magnetization --- or we may employ this demagnetization procedure to test the rocks for the stability of their remanent magnetization.

II. Demagnetization Apparatus and Procedure

Our laboratory's demagnetizing apparatus was designed and built by ourselves. The solenoid producing the demagnetizing field was wound with no.17 copper wire, 20 layers in all, and 2000 turns. Its external diameter was 12 cm, length 13.5 cm, self-inductance 0.4 henries. When the solenoid was fed with alternating current from the city power supply, at 220 V and 50 cycles/sec., the magnetic field (peak value) at the center of the solenoid axis was 175 oersteds/ampere. The field on the solenoid axis decreased rapidly with distance from the center; at 30 cm distance it had fallen off to 2-5% of the value at the center. At still further distances the decrease became relatively slow. Calculated for 1.5 m distance, the magnetic field of the solenoid could be taken as negligible (Fig. 1).

In order to eliminate the asymmetric magnetic effect of the higher harmonics in the city power supply (chiefly the harmonic of 100 cycles/sec) we connected in series with the solenoid circuit a 20 microfarad condenser, resonating at 50 cycles and acting as a filter for the higher harmonics.

In the demagnetizing procedure, the rock samples have to be enclosed in a region with no [external] magnetic field. This amagnetic region was provided by two square coils, neutralizing the horizontal and vertical components of the geomagnetic field. In order to suppress the inductive effect of the solenoid's alternating current on the neutralizing coils, each of them had a choke of 10 henries inductance connected in series with it. The direct current for the coils was supplied from batteries.

Our demagnetizing procedure was as follows. The samples were fixed in the sample holders and were placed at the center of the neutralizing coils. The solenoid producing the alternating magnetic field was mounted on a carriage that could be moved horizontally along rails. For each demagnetization, the solenoid was first pushed to the center of the two coils and the sample was accurately positioned in the center of the solenoid; some pre-selected value of alternating current was passed through the solenoid winding, and then, very smoothly and slowly, the solenoid was moved along the rails away from the sample to a distance in excess of 1.5 m, whereupon the current was switched off. In carrying out this work, it is desirable to demagnetize the cube-shaped test-pieces separately in the direction of each of their three sets of edges, and in both senses for each direction. After completing the demagnetization the test-pieces were removed to the astatic magnetometer to measure their residual magnetism.

In using the astatic magnetometer to determine a given component of a sample's residual magnetization, we measured the said component four times (Fig. 2), in order to eliminate the effect of the other components on the measured component. Thus when measuring the x-component we first let the positive x-axis point in the direction of the magnetic system, with the z-axis pointing downwards; for the next measurement the sample was rotated 180° around the z-axis, leaving the negative x-axis turned in the direction of the magnetic system; again the sample was turned 180° around the x-axis, to make the z-axis point upward; then the sample was once more rotated 180° around the z-axis and the final measurement was made with the positive x-axis in the direction of the magnetic system.

III. Demagnetization Results and Discussion

The samples used in the present alternating field demagnetization experiments were all from our collection of specimens from the Xiuning series of sandstones, Lower Sinian in age, collected at Lantian 兰田, Zhangchuan 张川, Qiaochuan 巧川 and Jixi Coal Hill 绩溪煤炭山 in Xiuning District * in the south of Anhui Province. The specimens, twelve in number, were cut up to form forty test-cubes measuring 3 × 3 × 3 cm and 4 × 4 × 4 cm.

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* Xiuning (City) is at 29°45'N 118°10'E. Jixi is at 30°05'N 118°35'E. This is a metal mining district. [Translator.]

The Lantian samples were subjected to chemical analysis and found to contain $FeO + Fe_2O_3$ 4.56-5.94%, TiO_2 0.56%, SiO_2 64.75-70.67%, Al_2O_3 14.12-15.56% and other compounds. When they were examined under a polarizing microscope, the iron mineral was found to constitute 3-5% of the total mineral content: it was mainly magnetite and ilmenite.

Before demagnetization, the directions of the natural remanent magnetization of the samples were as shown in Figure 3. The intensities were $\sim 10^{-7}$—10^{-6} CGSM.

The demagnetizing field (peak value) was increased in 30 oersted steps from zero to 600-800 oersteds; for a few of the samples it was increased to a peak value of 1000 oersteds.

From the results of the demagnetization it appears that practically speaking the samples may be divided into two types. In one type the magnitude and direction of the natural remanent magnetization changes little in the demagnetizing process; the magnetization of these samples can be regarded as very stable. Figure 4 shows the change in the intensity of the natural remanent magnetization versus the demagnetizing field peak intensity, for two typical samples, nos. 19-1 and 24-3. Here it is seen that in the demagnetizing process, from zero field to 150 oersteds peak value, the remanent magnetization moderately decreases in intensity, making it clear that the samples did have a secondary remanent magnetization, although its value is not great; numerically it amounts only to 10-20% of the natural remanent magnetization. After the peak magnetizing field passes 150 oersteds, the ratio I_r/I_{ro} remains higher than 80%, and the demagnetization curves run almost perfectly parallel to the horizontal axis. After the demagnetization, the direction of the samples' natural remanent magnetization on the whole exhibits no marked change, so that now it may well represent the original direction of magnetization. Belonging to this type there were five samples in all. One of them (no.18-2) had a very feeble remanent magnetization, with a fairly large relative error of measurement. Nevertheless, during the demagnetization process the variations of both the intensity and the direction of its remanent magnetization, to either side of the mean value, were inside the range of measurement error. For this reason we concluded that the magnetization of this sample was stable (Fig. 5).

The second type has an unstable magnetization. In samples of this type, the intensity and direction of the remanent magnetization exhibited, in the process of demagnetization, a continuous change, the value of I_r/I_{ro} monotonically falling with [every] increase of the demagnetizing field. By the time the demagnetizing field's peak value reached 400 oersteds, the ratio I_r/I_{ro} had fallen to 50%, and showed no tendency to stop falling even when the demagnetizing field was raised to 800-1000 oersteds peak value. The samples belonging to this type were from seven rock specimens taken at Jixi and at Zhangchuan and Qiaochuan in Xiuning District. The Jixi Coal Hill sample no. 10 is a typical example (Fig. 6). We examined thin sections of it under the polarizing microscope and discovered that the iron mineral in it mostly had the external form of magnetite, but under direct illumination it showed a brown color and was in a semi-transparent state. This generally indicates that the original magnetite has been converted to a secondary limonite. With the ferromagnetic fraction in the rocks undergoing this change, the direction of remanent magnetization could have ceased to represent the geomagnetic field direction at the time the rocks were formed. Consequently no attention was paid to these samples in determining the paleomagnetic pole position.

The results of the demagnetization thus made it clear that we had, as samples with quite stable magnetization, just the five from Lantian. (Because of the limited precision of our instrumentation there is not much point in detailing the directions of remanent magnetization of the samples before and after demagnetization. So far, under the conditions of our experiments, all that we have really effected with the alternating current demagnetization is just a testing of the magnetic stability of the samples, not a proper magnetic cleaning in the sense generally understood.)

After demagnetization, the directions of remanent magnetization in the five stable samples were determined. Figure 7 shows the Fisher statistical means of the measurements of the direction of remanent magnetization made on each of the twenty-four test-pieces that were cut from the said samples. Their mean direction is: declination D = 311°, inclination i = 76°. The position of the (northern) terrestrial pole at the time in question was 90°E 45°N (Fig. 8); angle of confidence $\alpha = 15°$. The place of origin of the samples was at paleolatitude 90° - p = 63°N [p being the polar distance, Table 1].

IV. Summary

To summarize the above four sections of the paper, our conclusions from the work are as follows. The alternating field demagnetization procedure is a comparatively reliable laboratory method for testing the stability of remanent magnetism in rocks and if applicable to rock samples collected in the field it has definite importance for paleomagnetic studies. From the paleomagnetic data obtained, it appears that at the time when the Xiuning strata of the Early Sinian were deposited, the Xiuning zone of Anhui Province was at high latitudes. We may conclude that this region should show signs of a sub-arctic climate at the time in question. The slanting incidence of the solar radiation would keep the atmospheric temperatures from rising very high, and the annual means would be predominantly determined by the cold season.

The findings are basically in agreement with our earlier paleomagnetic results (Liu Ch'un and Liu Haishan) for some South China Sinian strata, obtained in 1963 with different apparatus (Table 2, Fig. 8).

The work was completed under the guidance of Professor Wang Zichang 王子昌 who also reviewed and amended this paper once it was written. In the course of the work we also had the assistance of Li Pu 李普 and Chen Yangyen 陈养炎. To them the author expresses his cordial thanks.

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TABLE 1. Paleomagnetic data for Xiuning series of Lower Sinian, from Xiuning District, Anhui Province

Stratigraphic name	Place of origin of samples		Direction of remanent magnetization		Ancient north pole position		Angle of confidence α	δ_φ	δ_m	Ancient polar distance of sampling site p
	Longitude λ	Latitude φ	Declination D_r	Inclination i_r	Longitude λ	Latitude φ				
Xiuning series	118°08'E	29°55'N	311°	76°	90°E	45°N	15°	28°	26°	27°

TABLE 2. Paleomagnetic data for rocks of Xiuning and Lianto series, South China, of Early Sinian age. (Liu Ch'un and Liu Haishan, 1963.)

Stratigraphic name	Place of origin of samples		Direction of remanent magnetization		Ancient north pole position		Angle of confidence α	δ_φ	δ_m	Ancient polar distance of sampling site p
	Longitude λ	Latitude φ	Declination D_r	Inclination i_r	Longitude λ	Latitude φ				
Xiuning series	118°08'E	29°55'N	313°	80°	98°E	42°N	13°	24°	25°	20°
Xiuning series	118°36'E	30°04'N	292°	82°	100°E	35°N	10°	19°	21°	17°
Lianto series	111°07'E	30°52'N	300°	83°	95°E	37°N				14°

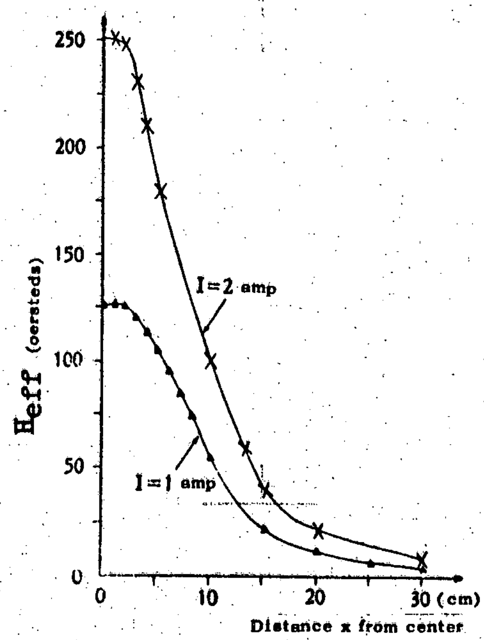


Fig. 1. Distribution of magnetic field along the solenoid axis.

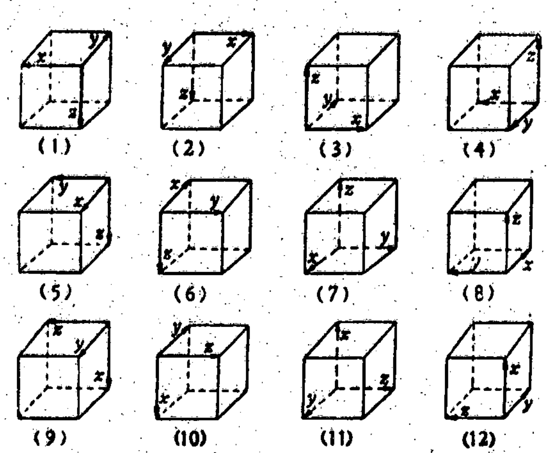


Fig. 2. Sequence of measurements of components of I_n with astatic magnetometer.
(1)-(4) Sequence of x-component measurements;
(5)-(8) Sequence of y-component measurements;
(9)-(12) Sequence of z-component measurements.

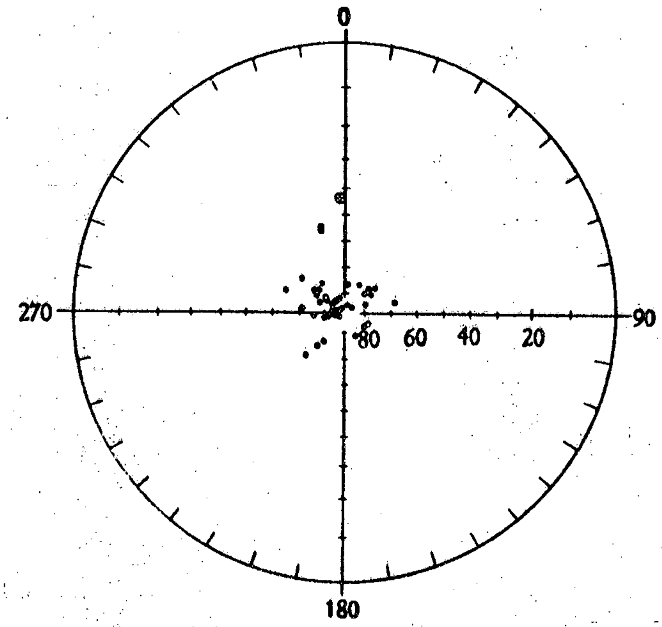


Fig. 3. Directions of remanent magnetization of samples from the Xiuning sandstones before demagnetization.

- ● Direction of remanent magnetization of each sample;
- ⊕ Present direction of the geomagnetic field at the place of origin of the samples.

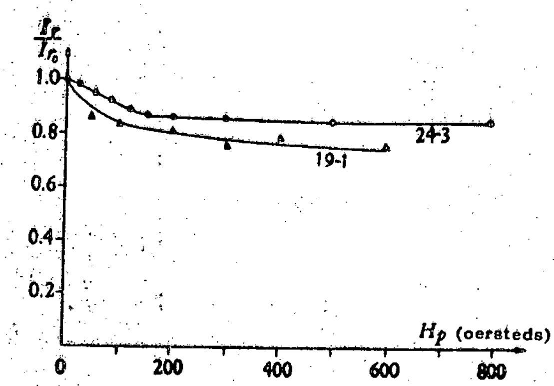
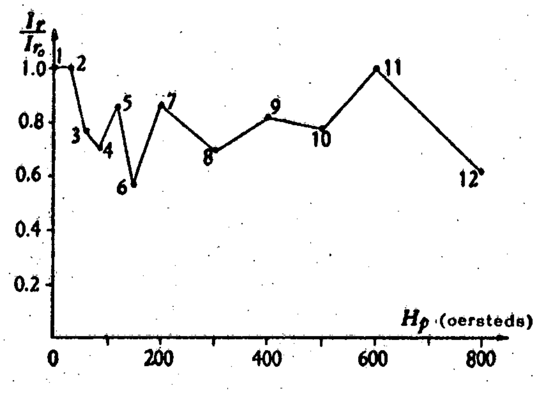
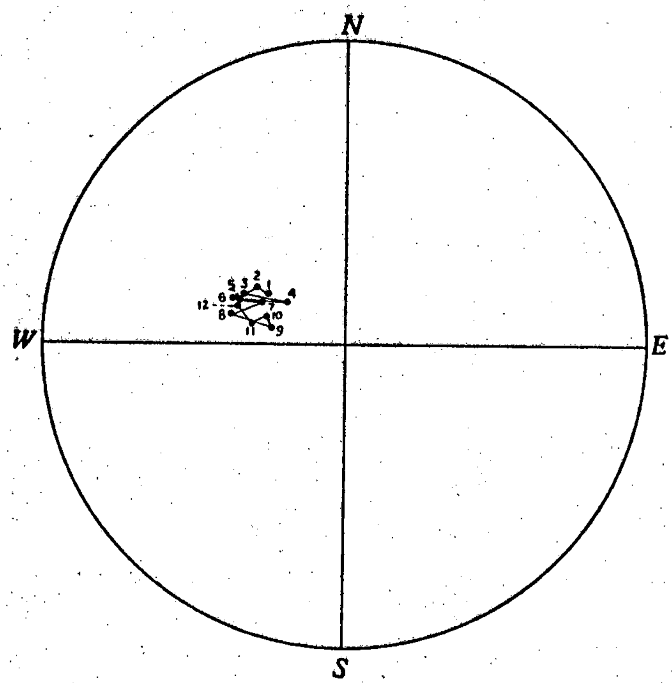


Fig. 4. Changing intensity of remanent magnetization during demagnetization, versus peak value of demagnetizing field, for samples nos. 24-3 and 19-1. (Samples belong to the magnetically stable type.)



(a)



(b)

Fig. 5. Relative intensity and direction of remanent magnetization of sample no. 18-2 during demagnetization, for 12 successive peak values of the demagnetizing field. (Sample belongs to the magnetically stable type.)

(a) shows variation of intensity;
(b) shows variation of direction.

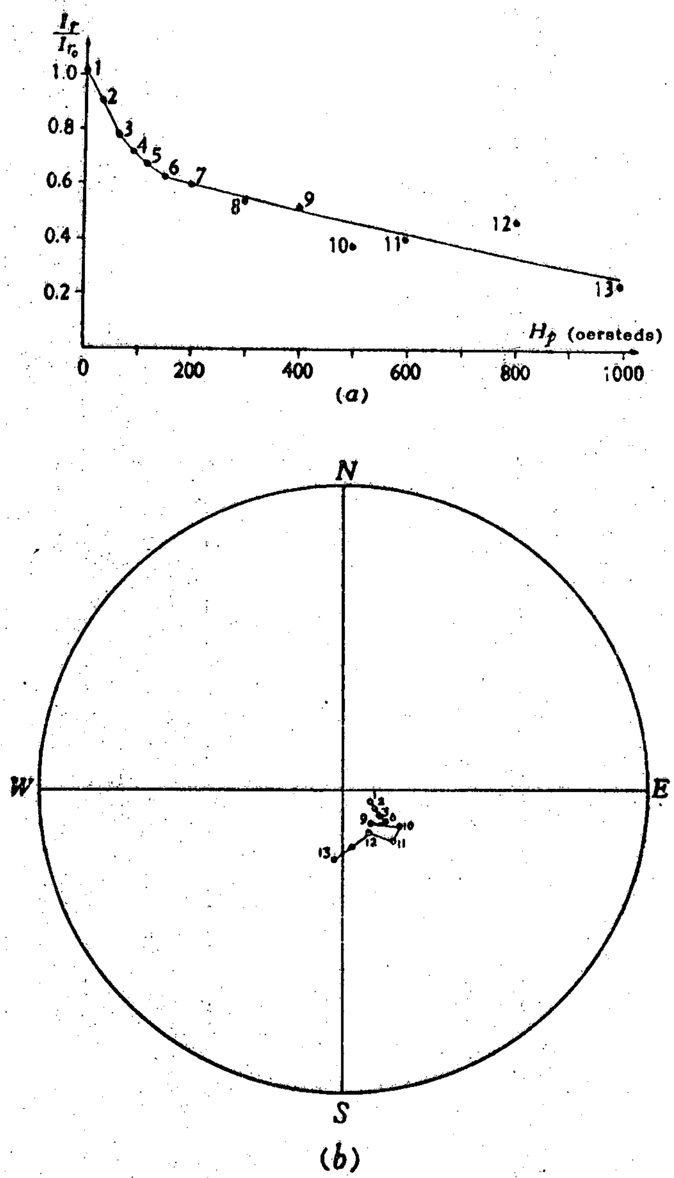


Fig. 6. Relative intensity and direction of remanent magnetization of sample no. 10 during demagnetization, for 13 successive peak values of the demagnetizing field. (Sample belongs to the magnetically unstable type.)

(a) variation of intensity;

(b) variation of direction.

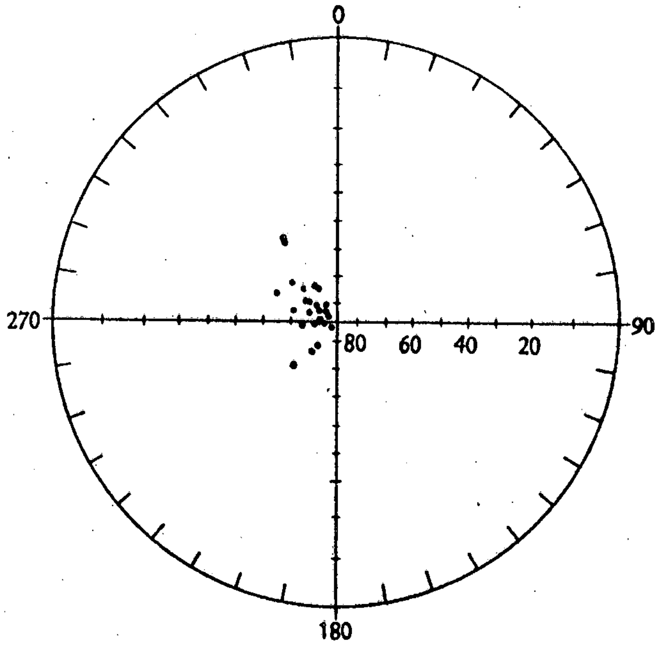


Fig. 7. Distribution of directions of I_n, after demagnetization, for Xiuning series (sandstones) from Lantian in Xiuning District of Anhui Province.

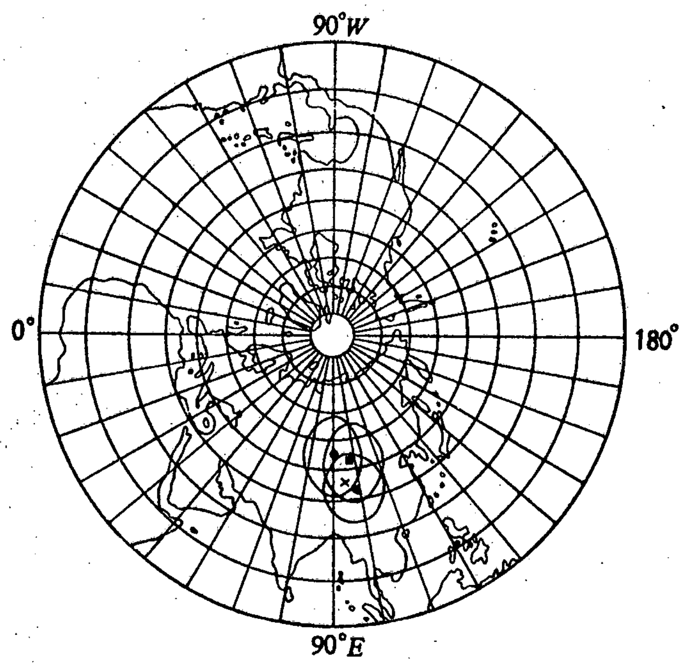


Fig. 8. Position of the north terrestrial pole in the Early Sinian of South China.

● - North pole position at time of deposition of the Xiuning series;

■,▲ - North pole position at time of deposition of the Xiuning series according to findings of Liu Ch'un and Liu Haishan (1963) at Xiuning and Jixi respectively;

× - North pole position at time of deposition of the Lianto 蓮沱 series, according to Liu Ch'un and Liu Haishan (1963).

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