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A NEW STUDY OF THE REVERSAL OF THE EARTH'S MAGNETIC FIELD RECORDED IN THE JURASSIC BASALTS OF LESOTHO: PRELIMINARY REPORT.

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INTRODUCTION

The Earth's magnetic field is known from direct measurements carried out over the last few centuries. With a good approximation, the geomagnetic field may be described as the field due to a magnet (with two opposed poles, North and South) which would be placed at the centre of the Earth and inclined about 11°with respect to the Earth's rotation axis. Of course, such a magnet does not exist. The temperatures within the Earth's mantle and core are so high that no magnetized mineral can exist at such depths. The geomagnetic field is due in fact to electric currents within the outer liquid core.

Beyond the historical period, the magnetization of rocks may allow us to determine the direction and sometimes also the intensity of the past geomagnetic field. When a rock forms, it acquires a magnetization which is directed as the Earth's magnetic field at that time. This magnetization persists whatever the subsequent changes in the geomagnetic field. It is called a remanent magnetization. We may think of a volcanic or sedimentary rock as carrying a large number of microscopic magnetic needles which have been statistically oriented in the direction of the past geomagnetic field. The blocking of these microscopic magnetic moments occurs when the lava flow cools or when the sedimentary particles are deposited. The remanence acquired when the rock forms is called a primary remanence. For sediments, it is a detritic remanent magnetization (DRM) resulting from the mechanical blocking of the grains as the interstitial water progressively disappears. The primary remanence of volcanic rocks is a thermoremanent magnetization (TRM), which results from a blocking of the magnetic moments at a temperature at which magnetic particles are already blocked in the solidified lava flow. More generally, any material which is heated and then allowed to cool down in the presence of a magnetic field acquires such a TRM. Secondary magnetization, acquired later during the aging of the rock, are also often present. As a result, the natural remanent magnetization (NRM) of rocks is complex and physical techniques have to be used in the laboratory to eliminate selectively secondary remanences. Studying the remanent magnetization of rocks in order to describe the behaviour of the geomagnetic field over geological times is the main objective of paleomagnetism.

At the beginning of this century, the first paleomagnetic study carried out on volcanic lava flows of Cenozoic age found in the Massif Central (France) provided astonishing results. Some lava flows exhibit a remanent magnetization whose direction is the same as that of the present geomagnetic field. Such rocks are said to be normally magnetized. However, other lava flows were found to carry a remanent magnetization just opposite to the direction of the normal field: they are called reversely magnetized rocks. Over the last 20 years, it has become apparent that rocks of the same age all have the same magnetic polarity, either normal or reversed. This implies that the Earth's magnetic field reverses as a whole from time to time, the North magnetic pole taking the place of the South magnetic pole and vice-versa. Such geomagnetic reversals are among the most intriguing characteristics of the Earth's magnetic field.

GENERAL CHARACTERISTICS OF GEOMAGNETIC REVERSALS

Reversals of the Earth's magnetic field are, geologically speaking, common phenomena. A few hundreds of reversals occurred over the last 200 million years. Length of polarity intervals between two successive reversals is highly variable, from say 10,000 years to several tens of millions of years. It seems that the average length has progressively decreased since Cretaceous time, a trend which has not yet been fully explained.

Even more intriguing is the behaviour of the geomagnetic field as it reverses. What happens then? Does the dipole moment of the Earth simply rotate by 180°? Or is the morphology of the reversing field (often called transitional field) entirely different from that of the stable dipole field? We know that the second hypothesis is probably true. Rather than having only two geomagnetic poles, North and South, diametrically opposed on the Earth's surface, the transitional field has probably more poles (and even "lines of poles" along which the field is vertical). Similarly, instead of having a single magnetic equator (along which the field is horizontal) as for the dipole field, the transitional field has several such magnetic equators. Such a field is quite complex. Recent data, obtained both from volcanic and from sedimentary records of polarity reversals, suggest that the transitional field is not even symmetrical about the Earth's rotation axis. However, it has not yet been possible to fully describe the morphology of transitional fields due to a lack of simultaneous recording of the same reversal at various locations on the Earth's surface.

Another puzzling point is that the dynamics of reversals might be different from one transition to another one. Some records of transition suggest a steady change in direction from one polarity to the other. Other records indicate a more complex behaviour simulating a pseudo-oscillatory process.

Similarly, the rate of change of the transitional field is poorly known. We do know however that a field reversal is very rapid, geologically speaking: a few thousand years to 10,000 years. A recent suggestion is that the changes of the transitional field are jerky and, sometimes, extremely rapid. Angular charges in direction of several tens of degrees might then occur within no more than a few years.

It is now generally agreed that the intensity of the Earth's magnetic field decreases as the field reverses. Thus, an extensive paleomagnetic study of a Miocene reversal recorded in the Steens Mountain (Oregon) showed that transitional fields are on the average 5 times weaker than normal fields and may sometimes be 10 times weaker. It should be noted however that relatively high field intensities have been reported from a single polarity transition found in Iceland. However, this finding needs to be confirmed.

PREVIOUS WORK ON THE LESOTHO GEOMAGNETIC REVERSAL

In the early 1960's when the Lesotho lavas were first studied by van Ziji (1961) the phenomenon of geomagnetic field reversal was not well established. The thesis went some way to verifying their existence. Propitiously a sedimentary lens was found interbedded within the lavas and a number of normally magnetized dykes cut through the lava pile. The transitional palaeomagnetic direction within the baked sedimentary lens matches that within overlying lava. Also, a normal field direction is recorded by an otherwise reversely magnetized lava in the region where it has been baked by the dyke. These findings strongly suggest that all the magnetizations are readings of the ancient geomagnetic field and that the reversed directions are not attributable to a process of self-reversal. There can be very little doubt that the Lesotho basalts record a geomagnetic field reversal; notably reversals are the aspect of geomagnetic field behaviour that we can now be most certain of (e.g., Merril and McElhinny, 1985).

The Jurassic Lesotho lavas overlay a sedimentary formation called the Clarens formation and this was the level at which van Zihl (1961) began his sampling in each of the two sections he studied. Three thousand feet of lavas were sampled at Bushman's Pass near Nazareth and four thousand feet at Sani Pass. The sampling equipment used was quite bulky, requiring a small generator to be taken into the field. In consequence cores could only be drilled at outcrops close to the road. A total of 151 cores, each being one inch in diameter and averaging 3 feet in length were collected. No account of the number of lava flows sampled was made. Data were simply plotted against elevation above bottom contact.

There is a good degree of compatibility between the records provided by each section. The first 500 feet of lavas were recognized as being reversely magnetized. Then over a thickness of 700 fee (Bushman's Pass) to 900 feet (Sani Pass) the change from a reversed to normal field polarity is indicated. Lavas in the upper parts of the section are normally magnetized.

The manner in which the field direction changed to indicate the new polarity cannot be considered well defined. The suggestion of a hiatus in an otherwise steady change is of interest.

An attempt was made to define the variation in the field intensity during the reversal. A straightforward comparison was made of the natural remanent magnetization (NRM) intensity with a thermoremanent magnetization induced in the laboratory. Both were damagnetized by alternating fields to 219 oersteds. It was hoped that the partial demagnetization would remove all the secondary components from the NRM but no checks were made to ensure whether the specimen had ungerone magnetic or chemical alteration during the laboratory heating. The suggestion of a substantial decrease in intensity during reversal is well accepted. But the suggestions of a slight increase in the intensity prior to the reversal, and similarly immediately afterwards are to be regarded as tentative.

THE PRESENT STUDY

Over 20 years from the original work on the Lesotho lavas we have decided to make a new investigation. We are from three laboratories in Europe which have for some years been involved in international research on geomagnetic reversals and their detailed study. N. Roberts is from the University of Liverpool, Great Britain, where much work has been done over the last 20 years on geomagnetic records from Iceland, North America, and the British Isles. M. Prévot, previously at the laboratoire de Géomagnétisme at St. Maur, Paris in France and now at the Centre Géologique et Géophysique, Montpellier, has for a long time been concerned with the subject and undertook the study of the most detailed known transition record at Steens Mountain, Oregon (USA). J. Thompson is currently at St. Maur, Paris working on transitions from Iceland and the Kerguelen Islands.

The Lesotho lavas recording the transition here probably cover a large extent of the country, but the more complete of the two records studied by van Zijl was found to be in the Maseru area where the lavas are quite easily accessed from the road leading to Bushman's Pass. We therefore decided to concentrate our efforts for sampling in this area.

Two main sections have been sampled in detail between 2105 m and 2300 m: along the road, where a recent widening scheme has left suitably fresh outcrops; and up a small stream roughly parallel to the road, whose bend affords equally good opportunities for sampling.

METHODS AND EQUIPMENT

A brief preliminary geological survey was undertaken with the collaboration of Dr. G. Prasad, with the aim of ascertaining the chief characteristics of the flows, the best criteria for identifying flow boundaries, and obtaining some information on the zones of sedimentary rock known to occur near the base of the lavas, whose presence would indicate a hiatus in the extrusion sequence and consequently a gap in the record. The sediments were found to outcrop discontinuously through the area, but possibly different "lenses" could have been deposited at approximately the same time.

The upper contact of sediments with the overlying basalts is generally baked, and so may be expected to record the same geomagnetic field as the lava above.

The lavas themselves vary in thickness, grain size, and in the character of their contacts but allow some general points to be made. The flow base is nearly always characterized by large vertically elongated vesicles frequently containing calcite. This zone may be as much as 1 m thick but is often only 30 cm to 50 cm. The central zone is much more uniform showing a regular probably quite coarse grained matrix with sometimes green mineral inclusions. This zone gradually gives way to another where smaller more spherical vesicles appear in a scoriaceous area, often more altered, and often showing a red band close to the contact with the overlying flow. Ropy flow surfaces were observed at several places.

Mountaineous areas in many parts of the world are subject to lightining strikes which cause an isothermal remanent magnetization (IRM) to be superimposed on the natural remanence carried by the rock. Such secondary magnetization may be removed with the aid of alternating fields for the purposes of directional studies but generally render the samples unusable for intensity work. An IRM due to lightning strikes is usually strong and may be detected with the use of a magnetic gradiometer with audio output.

In undertaking our sampling programme it was essential to define the approximate upper and lower limits of the transitional zone within the Lesotho Basalts. For this, a number of oriented hand samples were taken from flows near the base and summit of the Bushman's Pass section and their NRM directions determined with the aid of a small fluxgate probe. We were thus able to estimate the polarity of these lava flows, assuming that the initial TRM formed the major component of the NRM measured by the fluxgate.

SAMPLING STRATEGY

Three sections were sampled in April/May 1986. The largest, consisting of 31 identified volcanic units and including two thin (40 cm) baked sedimentary layers, follows the bed of a stream draining the western side of Thaba Tseka hill (Latitude = 29°24'50''S; Longitude = 27°50'43''E). This section is thought to include the totality of the transitional record, several reversely magnetized flows below, and a number of normally magnetized flows at the top. A second section roughly parallel to the first follows the road up to the top of Bushman's Pass. This section consists of 20 units, including a sedimentary layer very similar to the second one found in the first section and outcropping at the same altitude. A third section extends our sampling downwards into the reversed zone through some 15 volcanic units.

Core samples were taken with the aid of a watercooled diamond-bit drill, averaging 8 cm in length and of 2.5 cm in diameter. These were oriented before removal with the aid of magnetic bearings, and using bearings on the sun or on topographical points for checks on possible variations in local declination of the magnetic field. This orientation will allow the magnetization direction of the samples measured in the laboratory to be calculated with respect to geographic North and the horizontal plane at the site.

CONCLUSION

The elucidation of the details of a geomagnetic field reversal which occured about 200 million years ago is our aim. Portable field equipment has allowed us to sample at the most suitable locations and to take sufficient samples that we shall be able to accurately define the paleomagnetic field direction recorded by particular lavas. We shall use rigorous methods to establish where possible the paleomagnetic field intensity.

The recording in Lesotho is likely to be one of most detailed that we have. Individually, such records can be important. However, we realize that it represents the recording at only one particular site of a global phenomenon. Its main importance will be in adding to the already existing records.

Eventually a general behaviour might be recognized amongst the records. This is likely to assist in the development of ideas as to the mechanism by which the Earth's magnetic field is generated and maintained. This still remains one of the most important problems in geophysics.

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