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MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

General Introduction

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I. GENERAL INTRODUCTION

CONTENTS

The results of this survey are presented in five papers which follow this introductory paper. Experimental methods, statistical treatment, conventions and abbreviations used in the work as a whole are described here. A list of references to published work in English on South American geology and also of South American palaeomagnetic data is appended.

1. Introduction

The palaeomagnetic survey of the geological column in South America was begun in 1956 and since then, with the help of universities, national, state and provincial geological institutes, and of the geophysical branches of petroleum and mining companies, the work has continued.

Some results have been published, in British, Argentinian and Brazilian journals, but most of the data obtained have not yet been properly described, although some of the palaeomagnetic poles presented here have been used in review articles. A list of previously published data and of reviews of South American palaeomagnetic data is given in the references.

The data presented in these five papers have been derived from: (i) northeast Brazil where the strata are mainly flat lying, but where difficult problems arise because of remagnetization produced during weathering in the hot and wet climate; (ii) from the pre-Cordillera of northwest Argentina, where the strata are well exposed owing to the block-faulted structure, yet where the folding is not too steep to have caused severe remagnetization problems; (iii) from the Chaco plain in Bolivia, where the tectonics have not resulted in appreciable secondary magnetization and from the altiplano where considerable inaccuracies arise in restoring the strata to their original horizontal positions and where remagnetization probably due to burial has occurred, (iv) in the central Cordillera of Peru where remagnetization after folding has been so extensive that it has proved impossible to isolate the stable remanence by thermal demagnetization, yet where the information about the palaeomagnetic pole throughout geological time obtained from other areas has allowed the stable direction to be inferred by extrapolation and hence the magnetic age to be deduced; and (v) from the Venezuelan and Colombian Cordilleras where problems similar to those mentioned for the Peruvian Cordillera were encountered.

2. Conventions and symbols

2.1. *Projections of magnetic vectors and pole positions*

Stereographic projections of magnetic vectors are used throughout: the advantages presented by the property of this projection that small circles on the sphere project as circles is thought to outweigh the concentration of representative points near the centre of the projection.

Solid symbols and continuous lines have been used to represent vectors and great circles projected from the lower hemisphere and open symbols and broken lines have been used to represent those projected from the upper hemisphere. Small circles are invariably shown as continuous lines.

On the other hand, pole positions are plotted on maps constructed on equal area nets, so that circles of confidence surrounding pole positions appear as ovals.

2.2. *Statistical treatment*

Statistical methods described by Fisher (1953) have been used throughout, although instead of Fisher's precision factor (k), the circular standard deviation, c.s.d., δ ($\delta = 81/k^{\frac{1}{2}}$ degrees) is used to describe the width of populations of vectors. The accuracy of the mean is similarly described by the circular standard error, c.s.e. (δ_m) rather than the 95 % circle of confidence, α. The former, $\delta_m = 81/[K(N-1)]^{\frac{1}{2}}$ degrees whereas $\alpha = 140/[K(N-1)]^{\frac{1}{2}}$. The probability that the true mean lies within the c.s.e. of the calculated mean is 63 % as compared with 67 % for a Gaussian distribution of distances on a plane. It is common practice when dealing with Gaussian statistics to accept a level of significance given by twice the standard error. This criterion will be adopted here, two vectors being regarded as significantly different if separated by an angle greater than twice the c.s.e. (which is approximately equal to α_{95}).

3. Measurements

N.r.m. measurements were made on an astatic magnetometer (Creer 1955; Collinson *et al.* 1957) by the off-centre method (Blackett 1952). Thermal demagnetization was carried out by heating in air in a furnace described by Chamalaun (1963) and by Stephenson (1966).

Each hand sample was cut into disks and these were measured under the magnetometer. Sample-mean directions of r.m. were then calculated. It is clearly stated in the captions to the figures or in the tables whether disk directions or sample mean directions have been used as statistical units.

4. On the use of sample-mean vectors or disk vectors as statistical units

It is generally accepted that the use of sample-mean directions as unit vectors in computing the reliability of formation-mean directions and of the corresponding formation-mean palaeomagnetic poles is preferable to the use of disk directions as units. Usually, when the latter are used as unit vectors, the standard errors obtained about the mean are very small about a few degrees, especially if many disks are taken from a thin stratigraphical thickness, e.g. from a given lava flow.

In fact whether (i) disks, (ii) samples or (iii) suitable stratigraphic units (such as a bed of sedimentary rock or a lava flow) should be used as the statistical unit when the object is to define the reliability of a mean direction of magnetization of a rock formation and of its palaeomagnetic pole, depends very much on the particular circumstances. As far as extrusive igneous rocks are concerned, it is fairly safe to make the generalization that the best statistical unit is the mean direction of magnetization of a lava flow because each thin lava flow has memorized the geomagnetic field direction and intensity at a given point in geological time (that this may have been partly obliterated by subsequent partial remagnetization is another question). In such cases the standard deviation may be representative of the palaeosecular variation if sufficient flows are included in the population.

With sediments, however, it is not possible to make any general rule. We may distinguish the following cases:

(*a*) Strongly magnetized flat lying sediments in which the error of measurement of each disk is small, as is the bedding correction. Whether the sediments have chemical or depositional magnetization, there will be larger differences in direction from sample to sample than from disk to disk. Hence sample-mean directions should be given unit weight.

(*b*) Strongly magnetized sediments from tectonically disturbed regions in which the largest source of error is that involved in restoring the beds to the palaeo-horizontal. Here sample-mean directions should be chosen as units. The scatter of directions within each sample should be small. Many localities should be sampled.

(*c*) Weakly magnetized flat lying sediments: the largest error involved is likely to be the experimental error with which the direction of remanence of each disk can be measured. This may exceed the scatter due to palaeo-secular variation for which the c.s.d. is about 10 to 20°. It may arise from inhomogeneities of magnetization or instrumental noise. In these cases directions of disks should be given unit weight. Up to six disks have been cut from each sample and measured.

(*d*) Weakly magnetized sediments from tectonically disturbed regions: each case has to be considered on its own merits. If the circular standard deviation of the distribution with disk directions as units is about the same as that with sample-mean directions as units, then the smaller circular standard error (or 95 % radius of confidence) will be obtained in the former case. Whether this is more realistic than the larger value obtained using sample means as units may be judged by comparing results from different formations in the same continent.

In the papers which follow, the statistical parameters have sometimes been calculated using specimens (disks) and then whole hand samples as statistical units. Usually, however, the latter procedure has been adopted in the computation of palaeomagnetic poles.

5. Palaeomagnetic poles and virtual geomagnetic poles

These two terms are defined as follows. A virtual geomagnetic pole is given by the latitude and longitude of the poles of a hypothetical geocentric dipole which would produce a field parallel to the magnetic vector measured at the site in question. It may be computed for the mean direction of remanence for a whole sedimentary formation, for a lava flow or for a hand-sample.

A palaeomagnetic pole corresponds to an ancient geographic pole and must be computed from a series of virtual geomagnetic poles which represent a sufficiently long interval of geological time to average out the palaeosecular variations of the geomagnetic field. Only palaeomagnetic poles should be used in the construction of polar wandering curves.

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In this work, the c.s.d. and c.s.e. for each palaeomagnetic or virtual geomagnetic pole for a rock formation is obtained by treating the virtual pole of the direction of remanence of each hand-sample collected from that formation as a statistical unit.

6. Description of rock samples

The remanent intensity of a rock formation depends very much on the colour. This was realized early on in the study of palaeomagnetism and led to the selection of red-beds (the adjective red being used in a very broad sense) for such work. The relation between colour and magnetic properties has remained over the years very much a subjective matter, partly because of the lack of precision with which the colour of sedimentary rocks can be described. Therefore, in these papers, the colours of the rocks collected have been described in terms of the colour code described in the G.S.A. colour chart (1963), in the hope that the descriptions may later prove of use to help predict the potentialities of rock formations for palaeomagnetic study.

7. Abbreviations and symbols

A list of abbreviations used in the papers is given below:

Ꞓ	Cambrian	n.r.m.	natural remanent magnetization
O	Ordovician	r.m.	remanent magnetization
D	Devonian	c.s.d.	(symbol δ) circular standard deviation
C	Carboniferous		
P	Permian	c.s.e.	(symbol δ_m) circular standard error
Ꞩ	Triassic	D	declination
K	Cretaceous	I	inclination
T	Tertiary	M	intensity of remanence in μG
a.d.f.	axial dipole field	α_{95}	radius of 95 % circle of confidence
p.f.	present field		

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