PALAEOMAGNETISM OF SOME RECENT VOLCANIC ROCKS FROM TRISTAN DA CUNHA (lat. 37°S., long. 13°W.)

By D. J. BLUNDELL*

THE eruption in October 1961 of a small volcano close to the Settlement on Tristan da Cunha has aroused considerable interest in the geology of the island. A Royal Society Expedition under the leadership of Dr. I. G. Gass made an immediate survey of Tristan da Cunha and a preliminary report of their findings has been presented to the Royal Geographical Society (Gass, 1963). In this report Dr. Gass points out that: ". . . Tristan is formed of interbedded layers of basaltic lava and pyroclastic material of the same composition, derived largely from a central conduit. . . . Dykes are numerous and usually radiate from the centre of the island; . . . Superimposed on the flanks of the primary volcano are over thirty secondary, or parasitic, volcanic centres. All but two of these centres were formed by explosive activity which built up cinder cones varying in height from 50 to 600 feet [15–180 m.]. . . . There are only two parasitic centres of entirely effusive origin: Stony Hill on the south side of the island and the new volcano. . . . radiometric ages determined at the Department of Geodesy and Geophysics, Cambridge, using the potassium/argon method, . . . indicate an age of less than 1 million years for the rocks of Tristan da Cunha. . . . Dr. K. M. Creer of the Department of Physics, King's College, Newcastle-on-Tyne, who undertook the palaeomagnetic investigations on Tristan material, has found that all the rocks are orientated in the present magnetic meridian."

During a brief visit to the island in 1960 two Falkland Islands Dependencies Survey geologists, Dr. D. C. Goldring and Mr. G. J. Hobbs, made a collection of orientated rock samples suitable for palaeomagnetic studies. They reported that the top 15 ft. (5 m.) or so of all the sea cliffs in the neighbourhood of the Settlement are heavily weathered and that spheroidal weathering is prominent along stream sections. They chose three localities where they were able to sample fresh unweathered rock and these are shown in Fig. 1. Locality TR.1 is at the mouth of Hottentot Burn. Samples of lava were collected from the base of the cliff at approximately 10 yd. (9 m.) intervals. The lavas are dark grey fine-grained basalts containing feldspar phenocrysts and are highly vesicular. Locality TR.2 is a small quarry and the samples came from a vertical dyke 5 ft. (1·7 m.) wide, striking 280° east of true north. At locality TR.3 the rock samples were collected at approximately 10 yd. (9 m.) intervals from the base of the cliff about 200 yd. (180 m.) east of the Canning Factory and were all taken from one lava flow. This locality has since been engulfed by the lava flow from the new volcano and is therefore no longer exposed.

Magnetic measurements have been carried out on 0·75 in. (2 cm.) cylindrical specimens cut from ten samples following the routine which has already been described in detail (Blundell, 1962, p. 6–8). Natural remanent magnetism (N.R.M.) measurements were made with a spinning magnetometer. These were followed by a.c. demagnetization and susceptibility measurements.

RESULTS OF MAGNETIC MEASUREMENTS

The results of the measurements of the N.R.M. are given in Table I. All the samples except TR.3.3 are normally magnetized. The mean direction of the N.R.M. of the normally magnetized samples has a declination of 2° east of true north and an inclination of 39° **UP**, and the circle of confidence about it for 95 per cent probability has a radius of 13°. This direction can be compared with the Earth's present field direction at Tristan da Cunha which is 26° west, 53° **UP** and with the theoretical axial dipole field direction at this latitude, which is due north, 56° **UP**. A.c. demagnetization tests were made on one specimen from every sample (except TR.3.1 and TR.3.3) and the results are given in Table II. The grouping of magnetic directions is closest after demagnetization from a field of 100 oersted and it is presumed that in this state the soft or unstable component has been largely removed, whilst the

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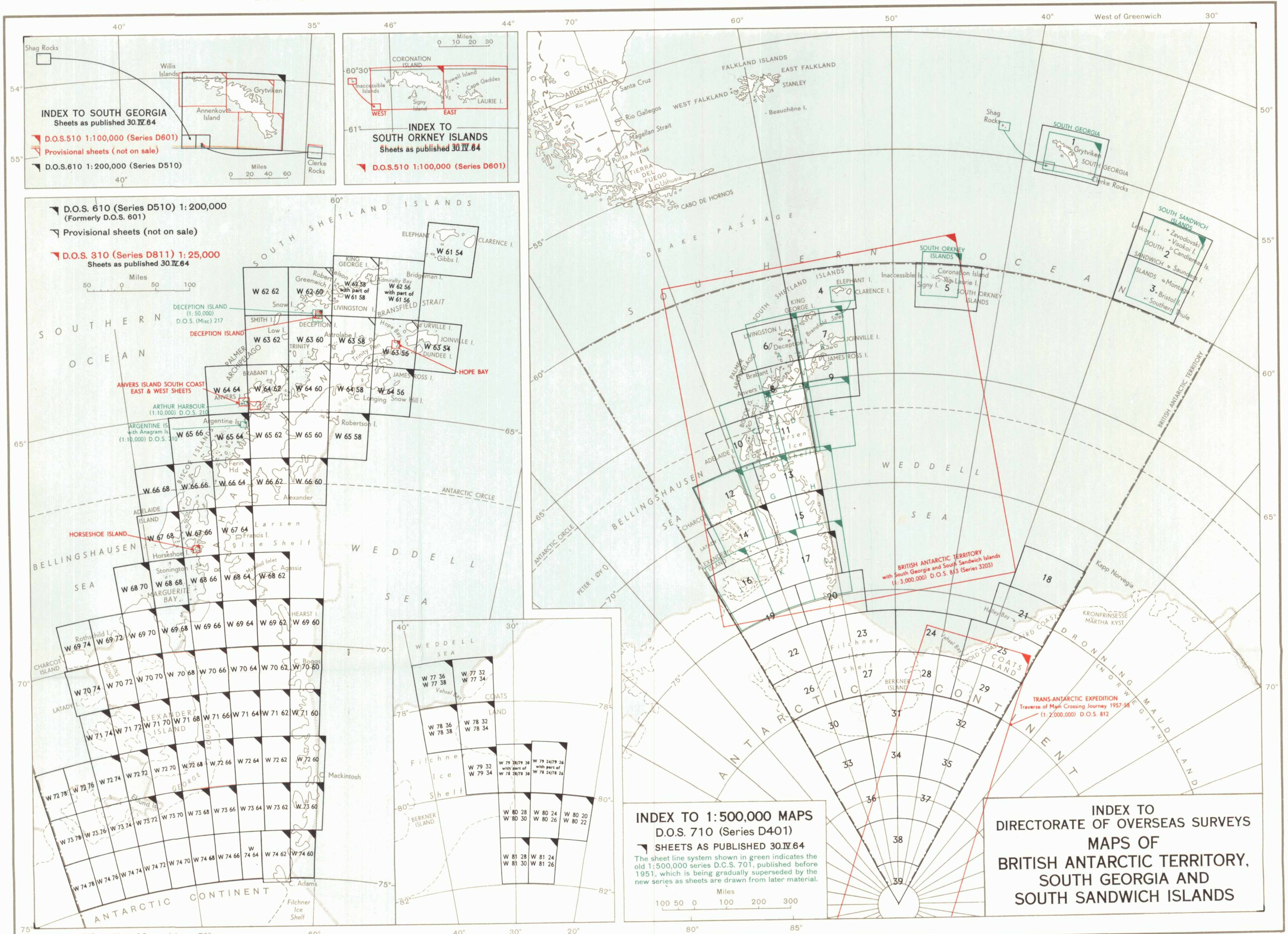

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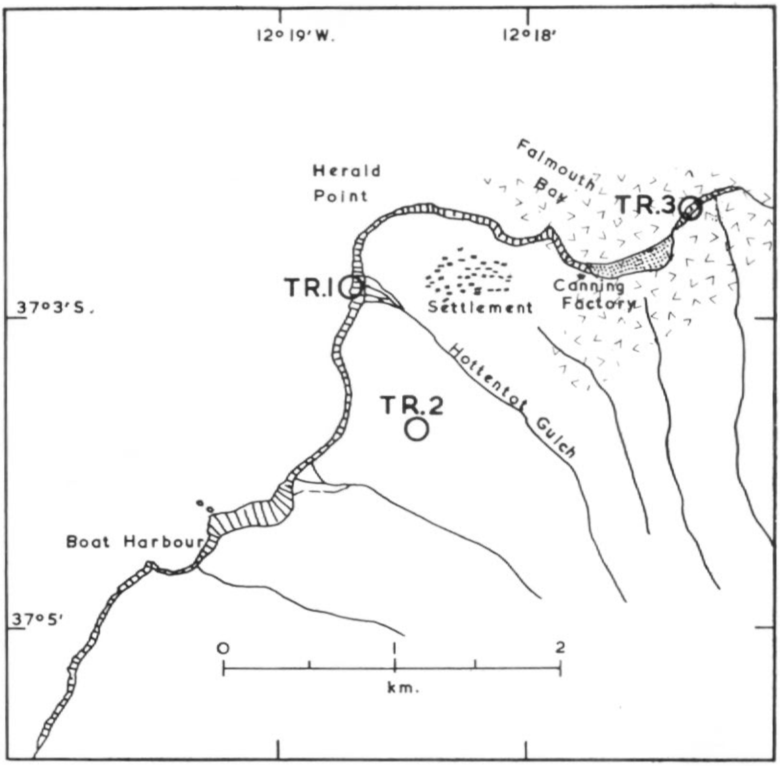

Fig. 1. Sketch map showing palaeomagnetic sample localities on Tristan da Cunha. The area with a V-pattern represents the approximate extent of the 1961 eruption.

TABLE I. N.R.M. OF SAMPLES FROM TRISTAN DA CUNHA

(Mean values for two specimens per sample, except TR.3.1 where only one specimen was obtained which disintegrated immediately after measurement of N.R.M.)

Locality	*Sample Number*	*Intensity of N.R.M.* J (e.m.u./cm.^{3})	*Initial Susceptibility* χ (e.m.u./cm.^{3})	$Q_N = J/0\cdot 5\chi$	*Direction of N.R.M.*	
					Declination ϕ	*Inclination* I
Mouth of Hottentot Burn (lava)	TR.1.1	0·0025	0·0053	0·9	350°	31° **UP**
	TR.1.2	0·0064	0·0053	2·5	352°	32° **UP**
	TR.1.3	0·0056	0·0058	1·9	013°	21° **UP**
	TR.1.4	0·0084	0·0053	3·2	350°	45° **UP**
Quarry (dyke)	TR.2.1	0·0034	0·0030	2·3	350°	30° **UP**
	TR.2.2	0·0050	0·0037	2·7	046°	40° **UP**
Cliff east of Cannery (lava)	TR.3.1	—	—	—	051°	46° **UP**
	TR.3.2	0·0013	0·0053	0·5	352°	39° **UP**
	TR.3.3	0·0037	0·0020	3·7	143°	74° **DOWN**
	TR.3.4	0·0042	0·0013	6·5	341°	53° **UP**

TABLE II. A.C. DEMAGNETIZATION

(Demagnetization of one specimen per sample, excluding TR.3.1 and TR.3.3)

Maximum Field of a.c. Demagnetization (oersted)	*Number of Specimens* N	*Resultant* R	*Precision Parameter* k	*Circle of 95 per cent Confidence, Radius* α	*Mean Direction of N.R.M.* ϕ	I	*Mean* J/J_0
0	8	7·646	20	13	357°	39° **UP**	1·00
100	8	7·825	40	9	359°	46° **UP**	0·64
200	8	7·319	10	18	349°	43° **UP**	0·43

more stable component of the N.R.M. has not been affected appreciably by the demagnetization. Hence the mean direction of N.R.M. after demagnetization from a field of 100 oersted should provide the best estimate of the direction of the field prevailing when the N.R.M. was acquired. This value for the N.R.M. direction lies no further from the theoretical dipole field than does the Earth's present field direction and is therefore compatible with the geological evidence that the volcanic rocks are of recent origin.

MAGNETISM OF SAMPLE TR.3.3

When just one sample from a collection has a reversed N.R.M. the obvious explanation is that it was marked incorrectly when it was collected. However, the marking of this particular sample is quite explicit and there does not appear to have been any mistake. During the a.c. demagnetization of specimen TR.3.3A (though not with TR.3.3B) the intensity *increased* to begin with and this is best explained as the result of removing a soft normal magnetism from the harder reversed N.R.M. This behaviour has been observed before with genuine reversely magnetized rocks, but it does not occur with any other specimen in this collection from Tristan da Cunha. Thus there appears to be sufficient justification to look further for some explanation of the reversed N.R.M. of sample TR.3.3 before disregarding the result. Several possibilities present themselves:

i. Reversal of the Earth's magnetic field. This seems most unlikely since the rock is almost certainly less than 1 million years old and it has been established in other parts of the world (Cox and Doell, 1960, p. 733–39) that no reversal of the Earth's field has occurred during this time. A reversal of the field would have affected all the samples from the same flow similarly, and this is not observed.

ii. The effect of lightning. This can produce local anomalous magnetization, but usually the N.R.M. is of high intensity which is almost completely demagnetized in a.c. fields of about 200 oersted (Cox, 1961). This, therefore, also seems an unlikely explanation.

iii. Rotation during emplacement. It is just possible that sample TR.3.3 came from a part of the lava flow which had cooled below the Curie Point and had therefore acquired a thermo-remanent magnetism (T.R.M.) before the lava finally came to rest. For example, by imagining the flow of a lava with a solid crust around a highly viscous interior to have the character of a caterpillar track rolling forward (Fig. 2), it is possible to understand how a rotation of 180° could come about. To explain the reversed magnetism it is necessary to suppose the mechanical rotation

Fig. 2. Diagram to illustrate rotation of the solidified crust of a lava during flow.

to be about an east–west axis which in this case is quite possible since the flow from the central vent would at this locality probably be to the north. Such an explanation is of course entirely speculative and since the exposure is now lost there seems no chance of testing it.

iv. Self-reversal. A small number of rocks have been found to acquire a T.R.M. in the reverse sense to the direction of the ambient field. This behaviour is generally thought to be the consequence of a particular combination of magnetic moments that can result from a close interrelation of several magnetic minerals. It is quite possible that a rock which was originally reversely magnetized in this manner might in time lose the self-reversing character but retain a reversed N.R.M. This rock might be expected to show some mineralogical character that would differentiate it from one with a normal magnetism, such as has been observed in some basaltic lavas from Mull (Ade-Hall and Wilson, 1963).

In looking for some evidence of self-reversal in sample TR.3.3 a number of comparisons have been made with the normally magnetized sample TR.3.4 of their various magnetic and mineralogical properties. Specimens from the two samples were demagnetized in alternating fields up to 800 oersted, with the result, shown in Fig. 3, that no distinction could be made between them, the directions of N.R.M. remaining substantially constant throughout (Fig. 4). One specimen from each sample was thermally demagnetized in the non-magnetic furnace built by Dr. R. L. Wilson, University of Liverpool (Wilson, 1962), and the results of this test are shown in Figs. 5 and 6. No variations in directions of N.R.M. were observed and on cooling to room temperature after the demagnetization both specimens gained a normal T.R.M. The intensities of the specimens differed during demagnetization only in the temperature range 20–100° C, presumably due to sample TR.3.3 having a slightly greater proportion of "soft" N.R.M. Although on average the specimens cut from the two samples had the same intensity, the specimen of TR.3.3 prepared for the heating experiment had a larger N.R.M. than the equivalent one from TR.3.4. The thermal demagnetization curves shown in Fig. 5 give the impression that two magnetic minerals may be present in both specimens, with Curie Points at about 300° and 580° C. To check this, Dr. Wilson measured the Curie Points of the two samples by heating a small quantity of powdered rock in a strong field. Fig. 7 shows the results of these measurements. No difference between the samples can be

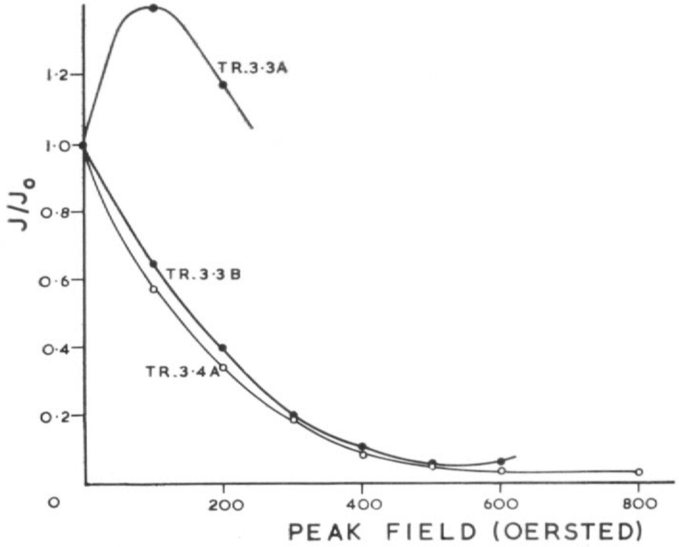

Fig. 3. Variation of relative intensity of N.R.M. (J/J_0) due to a.c. demagnetization.

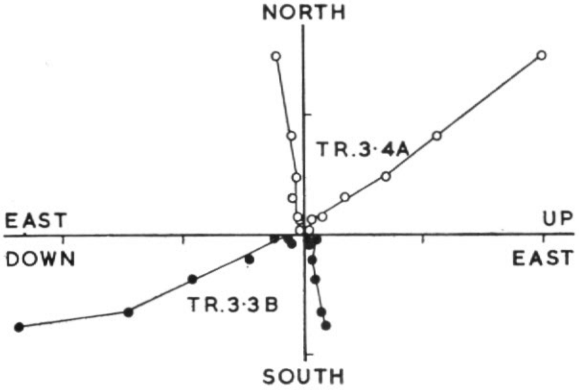

Fig. 4. Graphs showing variations during a.c. demagnetization of the component values of N.R.M. plotted in the horizontal and meridional planes (arbitrary units). The points are plotted at intervals of 100 oersted and correspond to those in Fig. 3.

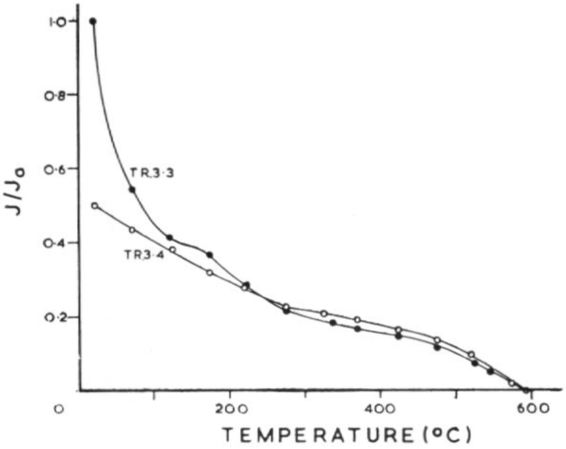

Fig. 5. Variation of relative intensity of N.R.M. (J/J_0) with increasing temperature.

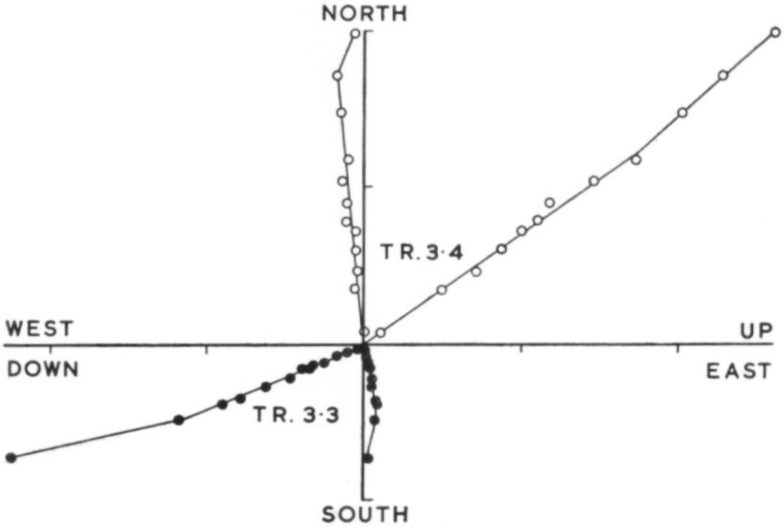

Fig. 6. Graphs showing variations during thermal demagnetization of the component values of N.R.M. plotted in the horizontal and meridional planes (arbitrary units). The points are plotted at intervals of 50° C and correspond to those in Fig. 5.

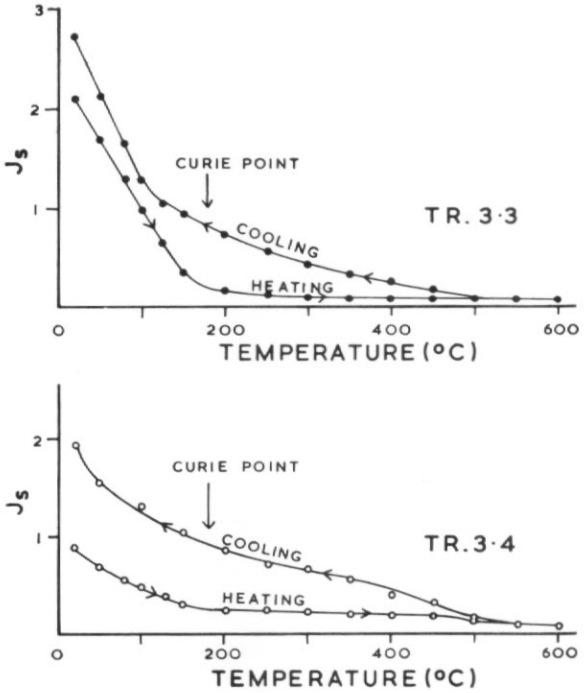

Fig. 7. Variation of intensity of saturation magnetization (J_s) with temperature.

distinguished, yet the curves showing a single Curie Point near 200° C seem incompatible with the result of thermally demagnetizing the N.R.M. Two explanations are likely: first, that during thermal demagnetization chemical changes occur to alter the magnetic minerals carrying the N.R.M., and secondly, that the N.R.M. is carried by only a small fraction of the material which can acquire an induced magnetism in a strong field.

Dr. Wilson has also examined polished surfaces of the two samples under the microscope and was unable to discern any difference between them. He was able to state that both samples contain "well-preserved subhedral crystals of homogeneous magnetite that are pale brown in colour. No exsolved ilmenite is visible in the magnetite grains and only a very small number of ilmenite grains are present in the rock. No alteration of the transparent minerals is seen. Most of the magnetite grains have diameters estimated to lie between 15μ and 25μ, but a few grains are present which are much larger."

The conclusion to be drawn from all these tests is that no evidence can be found to distinguish sample TR.3.3 from the normally magnetized samples and that, if the reversed N.R.M. is real, perhaps an explanation such as given in (iii) is nearer to the truth. With just one sample the reality of the reversed N.R.M. must in any case be suspect and to test further would seem to be unfruitful. Nevertheless, the experiments that have been made show up the complicated nature of the N.R.M. and further work is needed to examine just what proportion of the magnetic minerals in the rock carry the remanent magnetism.

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I should like to thank Dr. D. C. Goldring and Mr. G. J. Hobbs for making the collection of rock samples in the first place and the British Antarctic Survey for making the rocks available to me. As I hope is clear from the text, I am most grateful to Dr. R. L. Wilson for his hospitality in allowing me to use his non-magnetic furnace, and for his assistance in making Curie Point measurements and in examining polished surfaces of the samples.

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