Remanent Magnetism of Poorly Sorted Deposits from the Minoan Eruption of Santorini

J. V. WRIGHT *Department of Geology, Imperial College, London, SW7 2BP, England*

ABSTRACT

Thick, poorly sorted ash deposits produced during the Minoan eruption have differing palaeomagnetic histories. Included clasts from deposits produced in the second phase of the eruption have random NRM and cleaned directions and were emplaced as cold mudflows. Clasts from ignimbrite flow units erupted in the third phase have significant directions and their palaeomagnetic pole is consistent with today's geomagnetic pole. These deposits acquired a TRM on deposition and were emplaced as hot pumice flows.

INTRODUCTION

The Minoan eruption (1470 B.C.) of Santorini is one of the largest known to have occurred in post-glacial times. The eruption produced vast quantities of ash and pumice and the present day caldera, some 83 km^2 in area. Evidence from deep-sea sediment cores collected in the eastern Mediterranean show that the eruption produced at least 28 km^3 of tephra (WATKINS *et al.*, 1978).

The eruption can be divided into three main phases (WATKINS *et al.*, 1978) and during the second and third, large volumes of poorly sorted, largely structureless ash deposits were produced. The deposits are dominantly fine ash but contain larger pumice and lithic clasts. There has been some debate about the origin of these deposits. PICHLER and KUSSMAUL (1972) and GÜNTER and PICHLER (1973) regarded them all as ignimbrite, that is the deposits of hot pumice flows. BOND and SPARKS (1976) however believed that the deposits of the second phase were mudflows while those of the third were ignimbrite.

In this paper the results of a study of the remanent magnetism of these deposits is reported as a successful means of discriminating between mudflow and ignimbrite. Similar studies have in the past been made on some Japanese pyroclastic deposits by ARAMAKI and AKIMOTO (1957).

FIELD RELATIONS

In the caldera wall and on the steep inner slopes of the volcano a great thickness of white, unsorted and unstratified ash deposits overlie the plinian pumice fall of phase 1 and base surges of phase 2. The greatest thickness (approximately 40 m) is seen in Thera quarry, just south of Thera. Blocks of pumice up to 50 cm and lithics, some over 100 cm, occur in a fine white ash matrix (Fig. 1). The deposit is composed of several flow units and fine grained basal layers are found. No evidence of grading of either lithic or pumice clasts has been found. The lack of grading of large lithic blocks and the steep slopes (> 20°) to which the deposits adhere suggest that these flows had a high yield strength (BOND and SPARKS, 1976) and were mudflows. Included clay fragments show no evidence of baking suggesting they are mudflow deposits rather than ignimbrite.

On the gentle outer slopes (< 5°) of the volcano ash deposits of a different kind occur and form cliffs up to 60 m high on the coast. These deposits are pink, poorly sorted and generally structureless. In detail however they are composed of a large number of flow units; superposition of many flow units may give the deposit a stratified appearance. In contrast to the deposits exposed in the caldera wall, the largest pumice rarely exceeds 10 cm and the largest lithic 5 cm (Fig. 2). Most flow units have a well defined basal layer. A wide variety of grading of both pumice and lithic clasts is observed within individual flow units and is typical of ignimbrite (SPARKS *et al.*, 1973; SPARKS, 1976). Flow units at many places are interbedded with coarse, well sorted and crudely bedded lithic rich flood breccias. Lithic enriched fumarole pipes often extend upwards from these into overlying flow units, and are thought to result from steam generated in contact with such wet sediments. This is evidence that these ash deposits were formed from hot flows and are ignimbrite. Although the ignimbrite is totally nonwelded such features indicate that flow units were emplaced at temperatures well above 100°C (BOND and SPARKS, 1976).

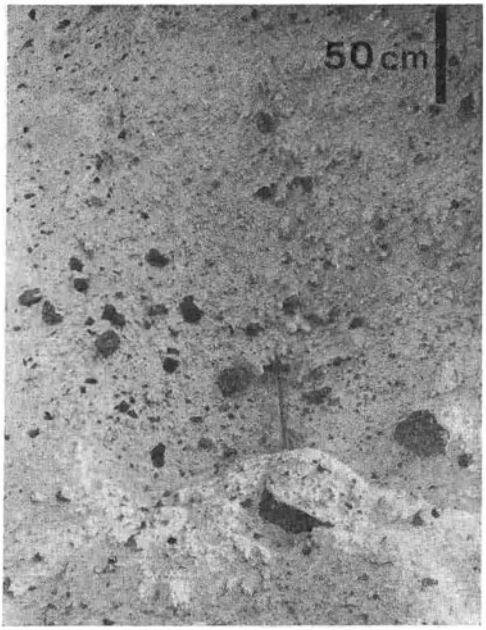

FIG. 1 - Unsorted and structureless deposits of the Minoan eruption in the caldera wall at Thera quarry. Large lithic and pumice clasts occur in a fine white ash matrix.

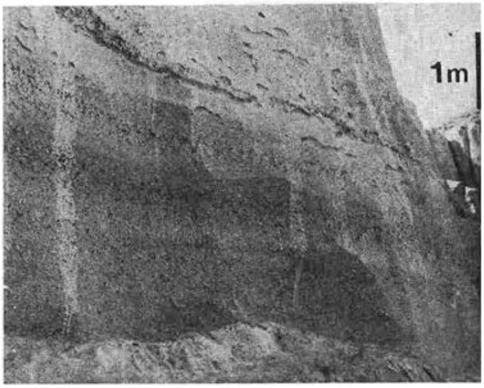

FIG. 2 - Flow units of the Minoan ignimbrite on the coast north of Monolithos. Note that there is a lack of large lithic clasts and some flow units show a reverse grading of lithic clasts.

PALAEOMAGNETIC STUDY AND RESULTS

Several oriented hand samples of included lithic clasts were collected from the poorly sorted deposits at Thera quarry and two ignimbrite flow units from different sites on the east coast. From each sample specimens 2.5 cm × 2.5 cm were cored and cut. From all the samples collected at Thera quarry at least two specimens were obtained to check internal consistency. However, large clasts are rare in the ignimbrite and from two samples only one specimen could be obtained. The natural remanent magnetism (NRM) of all specimens was then measured on a « Digico » spinner magnetometer. Pilot specimens were

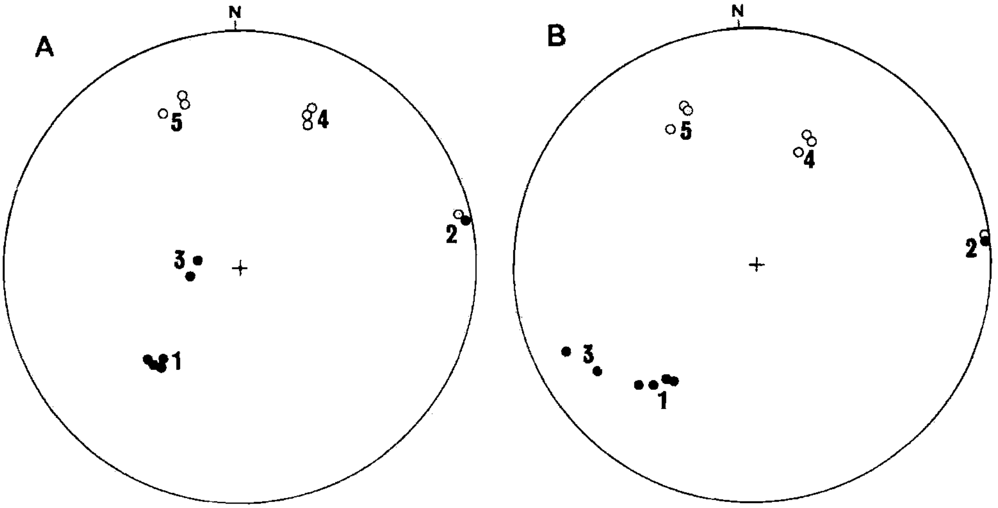

FIG. 3 - Palaeomagnetic results from the poorly sorted deposits found in the caldera wall at Thera quarry. Stereographic projection of A: NRM directions and B: AF cleaned directions at 500 Oe (peak). Closed circles are downward inclinations; open circles are upward inclinations; numbers are sample numbers.

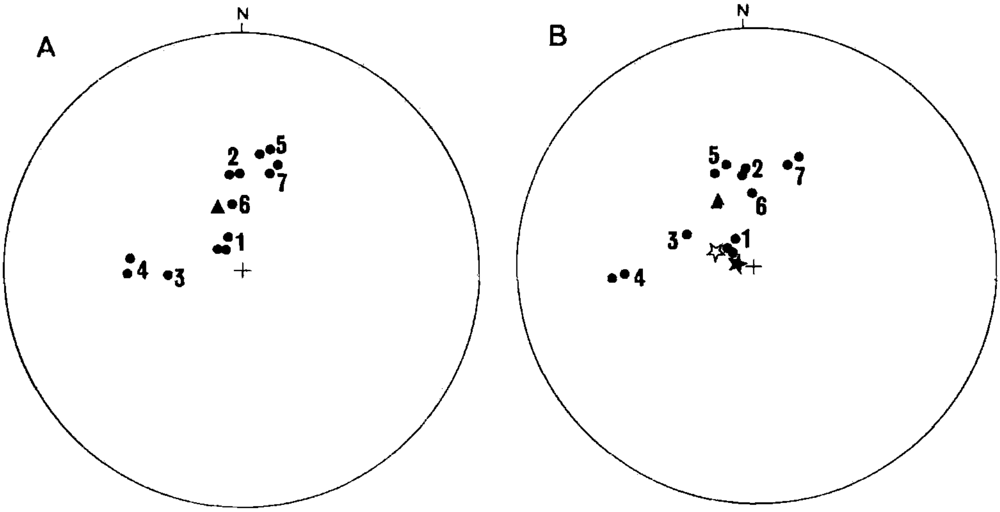

FIG. 4 - Palaeomagnetic results from two flow units of the Minoan ignimbrite. Flow unit 1: samples 1-5, flow unit 2: samples 6 and 7. Closed triangles are the means. Open star is the palaeomagnetic north pole position; closed star is the Earth's present geomagnetic north pole. Other details as in Fig. 3.

TABLE 1 - Summary of palaeomagnetic results

Deposit	*Total NRM*						*A.F. cleaned at 500 Oe (peak)*						
	N	*R*	*K*	*α 95*	*D*	*I*	*R*	*K*	*α 95*	*D*	*I*	*Palaeomagnetic north pole*	
Mudflows	5	—	1.0	>90	—	—	—	0.9	>90	—	—	—	—
Ignimbrite	7	6.1	6.6	25.1	341.4	58.6	6.2	7.2	24.0	335.3	55.3	59W	70N

N = number of samples; *R* = resultant of N unit vectors; *K* = (*N* − 1)/(*N* − *R*), the best estimate of Fisher's dispersion parameter; α 95 = semi-angle of the cone of 95 % confidence; *D* and *I* = mean declanation and inclination of remanent magnetism.

selected for partial demagnetization using an alternating field demagnetizer and from these results bulk cleaning was carried out at 500 Oe (peack).

Initial NRM directions and AF cleaned directions of the poorly sorted deposits from Thera quarry are scattered (Fig. 3a and b). AF cleaning does not improve the precision and the results have no statistical significance (Table 1). However, samples are internally consistent and show good stability of direction.

The samples from ignimbrite flow units have well grouped NRM and AF cleaned directions (Fig. 4a and b). Samples are internally consistent and show good stability of direction. AF demagnetization does improve precision and indicates the removal of some randomly orientated components. The mean directions obtained from the seven samples of the ignimbrite are statistically significant (Table 1) and the palaeomagnetic pole indicated is consistent with the Earth's present geomagnetic pole.

CONCLUSIONS

Palaeomagnetic results indicate that flow units of the ignimbrite acquired a stable remanent magnetism on deposition. The most reasonable explanation is that this is a thermal remanent magnetism (TRM) and the flows were emplaced hot above the blocking temperatures of the included clasts (by comparison with other palaeomagnetic studies these can be taken as about 500°C). In contrast, this reasoning suggests that the deposits of the second phase of the eruption were cold and clasts contain original NRM directions now randomly orientated. Hence they are thought to be mudflow deposits. These conclusions therefore agree with the field observations and conclusions of BOND and SPARKS (1976).

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