Geophys. J. R. astr. Soc. (1985) 80, 555–559

Letter to the editors

On 'The relationship between the magnitude and direction of the geomagnetic field during the late Tertiary in Eastern Iceland' by N. Roberts and J. Shaw

L. Kristjánsson *Science Institute, University of Iceland, Dunhaga 3, 107 Reykjavík, Iceland*

Accepted 1984 September 7. Received 1984 August 14; in original form 1984 May 2

In palaeomagnetic research, empirical criteria for sample selection and experimental procedure are generally derived from limited pilot studies, and may not apply universally. It is therefore necessary to employ various consistency checks, including repeat measurements, measurements on duplicate specimens from several samples, measurements on different samples from the same geological unit, comparisons between different methods, and/or measurements on units of closely similar ages. Such consistency checks require particular care in palaeointensity determination, for instance because heating of specimens is involved and because systematic errors in results may persist between petrologically similar specimens from the same sample.

In the extensive literature on the palaeomagnetism of Icelandic basalts, insufficient attention has been given to the determination of absolute palaeofield intensities. In recent papers, Shaw, Dagley & Mussett (1982) and Roberts & Shaw (1984) report detailed work on this important property of the field. I wish to comment on the latter paper, primarily in regard to the above-mentioned consistency checks.

In the paper of Shaw *et al.* (1982), the only consistency checks reported dealt with repeated measurements on three samples (their table 1). In two of these, intensities changed by respectively 25 and 50 per cent, indicating that the thermal remanence values acquired in the laboratory are either poorly repeatable or seriously non-linear with respect to the applied field during heating.

The paper by Roberts & Shaw (1984) includes no repeat measurements, but duplicate measurements are reported on samples from 10 units (out of 114; two units are common to their tables 1 and 3). All their duplicate results are listed in Table 1; in some cases it is possible that the samples were collected quite close together. It is evident from the table that the variation of palaeointensity values between samples reaches much larger proportions than the 10 per cent 'standard error' estimated by Roberts & Shaw.

In averaging results from duplicate samples, the authors then use a weighting procedure which is based on the assumption that systematic between-sample variations are not large compared to the random variations or uncertainties derived from individual specimen measurements. As the assumption fails in many of the measurements listed in Table 1, this procedure has some irrational consequences. For instance, intensities from samples R1A-1 and R1A-2 are 221 ± 10 and 67½ ± 1½ μT respectively. Their mean is given as 68½ ± 1½ μT, which in effect ignores R1A-1 and clearly underestimates the systematic errors present.

Table 1. Duplicate palaeofield intensity determinations (Roberts & Shaw 1984), rounded off to the nearest ½ μT.

Unit no.	Palaeointensity, μT	Unit no.	Palaeointensity, μT
C8S	6, 8	L19S	11½, 16
L3	42, 87½	L33D	94, 190
L5S, L5	28, 38	L33E	44, 46
L6, L6S	40, 50, 53, 74, 76	L33F	71, 111
L8A	23, 43	R1A	67½, 221

Samples N6-1 and N10A-1, where the quoted uncertainty exceeds 90 per cent, should have been rejected from further analysis.

Table 1 of Roberts & Shaw (1984) reproduces many intensity values already given in table 2 of Shaw *et al.* (1982), but intensity values from 14 units in profiles P to V which seem equivalent to the others in quality, are not reproduced for unexplained reasons. Many numerical discrepancies also occur between these tables, e.g. in flows U12 (palaeointensity values of 91 and 130 μT respectively), V10 (199 and 80 μT) and V16 (30½ and 23½ μT). The lava V2 is taken to be normally magnetized by Roberts & Shaw (1984) but it had reverse polarity according to Shaw *et al.* (1982). Samples from two other lavas (P26 and V9; probably also B10/B10S) yield internally discordant directions (Watkins & Walker 1977; Kristjánsson 1982, p. 99) so that their sample palaeointensity values cannot be correlated with their directional properties.

Roberts & Shaw (1984) state that in one lava (L6S, see Table 1) they obtain intensities which are divergent from those of Lawley (1970). In fact, Roberts & Shaw (1984) have measured samples from seven other flows identical to flows studied by Lawley, obtaining divergent results in most of them, cf. Table 2. It should be noted that the within-flow agreement in Lawley's samples (her tables 1 and 2) is much better than that of Roberts & Shaw (1984).

The work of Roberts & Shaw (1984) also overlaps with that of Smith (1967) in two lava flows, namely N7A and M30. In the former unit, both obtain the same palaeointensity value of 44 μT. In the latter, however, Smith obtains 21 μT while Roberts & Shaw obtain 47½ μT.

Table 2. Results by Lawley (1970) and Roberts & Shaw (1984) on intensities in the same transitional lava flows.

Lawley (table 2)				Roberts & Shaw (tables 1 and 3)		
Unit no.	No. of samples	Palaeointensity, μT		Unit no.	No. of samples	Palaeointensity, μT
B7	2	4.2	...	B7S	1	16.9
B10	3	5.6	...	B10S	1	8.7
B10A	3	5.1	...	B10T	1	10.9
C13B	1	7.4	...	C13U	1	9.9
C23	5	8.4	...	C23S	1	7.3
L4	5	8.7	...	L4S	1	4.3
L5	3	12.2	...	L5, L5S	2	see Table 1
L6	4	10.6	...	L6, L6S	5	see Table 1

Note: Samples were collected by two expeditions; hence the differences in numbering of flows and flow units.

Yet another check, not made use of by Roberts & Shaw (1984) employs 'flow units' which commonly occur within the lava pile of Iceland. Judging from field evidence as well as from experience in recent Icelandic eruptions, these thin pahoehoe lava units have in many cases been emplaced in rapid succession (½–50 yr between units).

Several examples of these are included in table 1 of Roberts & Shaw (1984). Corresponding remanence direction data have been published by Watkins & Walker (1977), and

Table 3. Magnetic pole positions (Watkins & Walker 1977) and palaeofield intensities (Roberts & Shaw 1984) from series of lava flow units having tightly grouped directions of primary remanence.

Unit no.	VGP coordinates Lat.	Long.	Palaeointensity, μT
L12	+62	169	45
A	+66	175	
B	+62	183	13
C	+60	183	
L33B	−73	284	39
C	−69	283	
D	−61	283	111 (average)
E	−72	274	46 (average)
F	−62	241	82 (average)
G	−62	245	41
H	−64	241	149
I	−79	263	110
N9	+54	9	8
A	+55	10	8
R33	+38	332	*
A	+36	345	
B	+44	349	62
C	+38	353	51
D	+39	347	30 (*)
E	+53	350	
S17A	+86	332	*
B	+73	12	58 ($R<1.98$*)
C	+87	150	
D	+88	40	56
E	+85	84	
T9A	−76	200	
B	−72	192	
C	−76	203	
D	−78	252	*
E	−80	233	118
F	−77	239	114
G	−68	197	

* Results from units R33 (12½ μT), S17A (56 μT), and T9D (63 μT), were obtained by Shaw *et al.* (1982) but are not reproduced by Roberts & Shaw (1984). Unit R33D gave an intensity of 34 μT in Shaw *et al.* (1982), and S17B gave 65 μT.

generally happen to show very good within-unit directional agreement (vector sum $R > 1.99$ for $N = 2$).

In some of the flow-unit series where Roberts & Shaw have obtained palaeointensity results, there is a tight clustering of directions for several successive units. The only acceptable interpretation is that these represent spot readings within an interval (of probably 200 yr or less) during which the field direction was stationary.

Table 3 lists the relevant data for six such flow-unit series. We see that the intensity values are in close agreement in three cases (N9, S17, T9) out of six; in three other cases, notably the long series at L33 (where the circular standard deviation of the poles listed is 10°), major variations in field strength are apparent.

Such variations, if confirmed, would provide unexpected constraints upon models of the generation of the geomagnetic field. If the strength of the field can change locally by a factor of 3 or more while its direction is essentially constant, then it becomes difficult to represent the main field in terms of several partially independent or mobile current sources, as has been suggested in some studies.

Another constraint on geomagnetic dynamo models would be provided by the high intensity values occasionally obtained by Shaw *et al.* (1984). These reach up to four times the present strength of the field in Iceland.

An alternative possibility is that the palaeointensity method of Roberts & Shaw (1984) only yields reliable results under certain favourable conditions of sample petrology, which are yet to be fully delineated for Icelandic Tertiary basalts. Roberts & Shaw (1984, p. 642) indeed state that it is necessary to investigate a greater number of samples from a lava before conclusions can be drawn.

Considering the evidence presented above, I wish to advocate the stronger view that Roberts & Shaw should have carried out some additional testing of their experimental procedures before the results and analyses of their 1984 paper were committed to print.

Conflicts with results from previous work on these lavas (Smith 1967; Lawley 1970; Shaw *et al.* 1982) should also have been resolved or explained more fully. These conflicts are not likely to be due to sampling errors in the field, as all the lava sites in question were permanently marked (Watkins & Walker 1977).

References

Kristjánsson, L., 1982. Palaeomagnetic research on Icelandic rocks – a bibliographical review 1951–1981, *Jökull*, 32, 91–105.

Lawley, E. A., 1970. The intensity of the geomagnetic field in Iceland during Neogene polarity transitions and systematic deviations, *Earth planet. Sci. Lett.*, **10**, 145–149.

Roberts, N. & Shaw, J., 1984. The relationship between the magnitude and direction of the geomagnetic field during the Late Tertiary in Eastern Iceland, *Geophys. J. R. astr. Soc.*, 76, 637–651.

Shaw, J., Dagley, P. & Mussett, A. E., 1982. The magnitude of the palaeomagnetic field in Iceland between 2 and 6 Myr ago, *Geophys. J. R. astr. Soc.*, 68, 211–218.

Smith, P. J., 1967. The intensity of the Tertiary geomagnetic field, *Geophys. J. R. astr. Soc.*, **12**, 239–258.

Watkins, N. D. & Walker, G. P. L., 1977. Magnetostratigraphy of Eastern Iceland, *Am. J. Sci.*, 277, 513–584.

Reply

We agree that there are some inconsistencies between results obtained from the same flow unit. The experimental data did not allow us to decide which, if any, of the results was in error and so we published them all, weighting the results according to the inverse of their variance. The mean value for flow A01R001 in our table 1 is miscalculated and should be 70.0 μT.

We carried out a statistical analysis of the data and stated clearly that 'Caution would need to be exercised if the results were to be used for more detailed investigations'. We would not wish to compare individual flow units unless we had a set of consistent results from each unit.

A statistical analysis of field magnitude results is not influenced by the same factors as are pseudo-field magnitude results as derived from NRM data only, especially if we give importance to the oxidation polarity relationship which would clearly bias NRM intensities and therefore pseudo-field magnitude results but should not influence field magnitude determinations.

Both field magnitude and pseudo-field magnitude data add to our understanding of geomagnetic field behaviour. The fact that they sometimes provide slightly different pictures is very interesting and we are preparing a full analysis of the Eastern Iceland field magnitude data that may help to resolve these differences.

N. ROBERTS
Sub-Department of Geophysics,
University of Liverpool,
Oliver Lodge Laboratory,
PO Box 147,
Liverpool L69 3BX

J. SHAW
Department of Geology,
University College,
PO Box 78,
Cardiff CF1 1XL