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Palaeointensity Measurements on Postglacial Lavas From Iceland

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Abstract. Palaeointensities were determined mainly with the Thellier method (in some cases additionally with the Wilson and the Van Zijl method) on 17 postglacial lava flows from Iceland with ages between 196 and 10,500 years B.P. The mean pole position of all lava flows, at 257. 3° E, 89.1° N, agrees well with the actual pole of rotation. Within the limits of error, the palaeointensities confirm also for Iceland the general trend observed for Europe and Japan of a decreasing palaeofield intensity since the maximum at about 2,000–3,000 years B.P. The field minimum at about 6,000 years B.P. could not be tested as no flows of about that age span have been available. Another maximum at about 9,000 years B.P. and earlier minimum at about 11,000 years B.P. fit also in the palaeointensity secular variation curve determined by Bucha (1967) for Czechoslovakia.

Key words: Iceland – Postglacial lavas – Palaeomagnetism – Palaeointensities – Secular variation.

1. Introduction

The palaeointensity of the geomagnetic field can be determined from lavas, baked rocks and soils by comparing the properties of natural remanence acquired in the unknown palaeofield with an artifical remanence obtained by heating and cooling in a field of known intensity. Various methods have been developed (Thellier and Thellier, 1959; Wilson, 1961; Van Zijl et al., 1962), which have been tested both theoretically and experimentally by various authors in recent years (Coe and Grommé, 1973; Schweitzer, 1975; Dunlop and Waddington, 1975; Kono and Ueno, 1977). Details and advantages of the different methods cannot be discussed here.

This paper reports on palaeointensity measurements made on postglacial lavas from Iceland with the view of contributing to the knowledge of the secular variation in Iceland in the last 10,000 years.

2. Sampling

Sampling was carried out in 1973 in connection with a ground magnetic survey in NE Iceland by Becker (1978). Figure 1 shows the 17 sites at which a minimum of B oriented cores were drilled. Accurate descriptions of the sampling sites are given by Schweitzer (1975). About one half of the samples were oriented by means of a sun compass, otherwise a magnetic compass was used (see Table 1). Whenever possible, samples were taken from various points across a profile from the top to the bottom of the lava flows. However, systematic studies of the variation of palaeointensity across a lava flow have not been made. The ages of the lavas flows (see Table 1) are either known directly as an historical event (H) or have been determined by means of C 14 method on baked peat (C) or by tephrochronology (T) (Brynjolfsson, 1957; Thorarinsson, 1967; Thorarinsson et al., 1973).

3. Palaeomagnetic Measurements

Test specimens from all 17 sites were subjected to AF and thermal demagnetization (1,200 Oe, 550° C). In all cases only a minor component of a secondary viscous remanence was found, which could be erased with AF fields of about 100 Oe or by thermal cleaning at 100° C. Table 1 shows the analysis of the directions of stable remanence. The corresponding pole positions are plotted in Fig. 2 together with the ages. The mean pole position at 257.3° E, 89.1° N ($N=17$, $R=16.58$, $k=37{,}9$, $\alpha_{95}=5.8°$) is in good agreement with the actual pole of rotation. The dashed line shows the migration of the virtual geomagnetic pole determined by Brynjolfsson (1957) from lavas of the last thousand years indicating a very rapid secular variation. Our data are too sparse for the evaluation of a similar curve for earlier periods.

4. Rock Magnetic Investigations

All past experiments on palaeointensity determination have shown that the nature and properties of the ferrimagnetic carriers of remanence strongly influence the applicability of the various methods to a given set of samples. A vital requirement is that the ore fraction is essentially free from hydrothermal or low temperature oxidation which tends to alter the primary fresh titano-

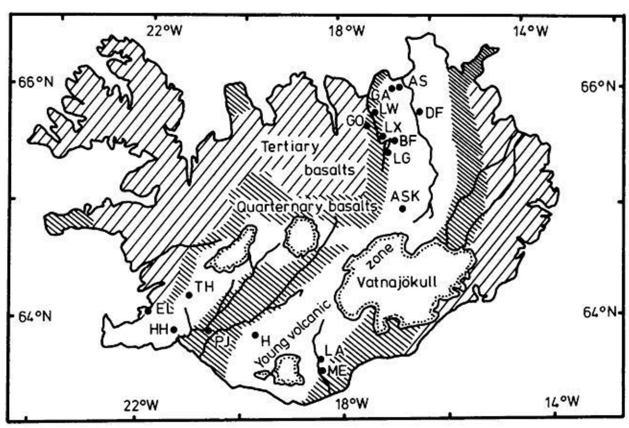

Fig. 1. Sketch map of Iceland showing the sampling sites

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Table 1. Palaeomagnetic data of postglacial lavas from Iceland

1	2	3	4	5	6	7	8	9	10	11	
Locality	Age	Method	Orientation	*N*	*H*(Oe)	*D*	*I*	α_{95}	*k*	°N	°E
AS I	10,500	T	mc	31	100	349.4	72.5	1.45	302	80.4	232.5
AS II	10,500	T	mc	16	100	7.9	70.2	2.76	161	77.6	174.5
BF	2,000	T	mc	11	100	31.3	77.4	3.25	169	77.3	91.1
DF	6,000	T	mc	11	100	42.0	76.6	2.06	419	72.6	92.4
EL	4,630	C	mc	12	100	332.9	72.5	2.48	266	75.5	278.1
GA I	10,500	T	mc	7	100	33.9	77.5	5.15	106	76.4	90.7
GA II	10,500	T	mc	6	100	353.7	68.8	4.40	169	75.8	212.6
GO	8,000	T	mc	16	100	339.0	71.0	1.37	653	75.6	252.3
HH I	1,500–2,000	T	mc	15	100	0.9	78.2	1.82	396	86.7	27.3
HH II	1,000	T	sc	13	100	14.4	74.1	3.74	108	82.4	133.4
LA	196	H	sc	12	100	311.1	73.5	2.70	219	66.9	300.2
LG	3,800	T	sc	8	100	334.4	72.6	3.71	183	75.8	266.4
LW	2,000	T	sc	16	100	346.5	79.8	2.39	214	83.3	334.5
LX	2,000	T	sc	16	100	356.7	78.7	2.78	159	87.1	352.3
ME	2,000	T	sc/mc	15	100	348.0	76.8	6.50	32	84.6	307.4
PJ	8,100	C	sc/mc	9	100	20.5	75.2	2.36	391	80.6	112.0
TH	9,100	C	sc	12	100	30.2	84.8	3.19	138	72.4	38.4
Mean pole position				17				5.80	38	89.1	257.3

1 Locality, 2: Age in years, 3: Age determination method (*T*: tephrochronology, *C*: C 14 method, *H*: historic event); 4: Orientation method (*mc*: magnetic compass, *sc*: sun compass). 5: Number of specimens, 6: *AF* demagnetizing field, 7· Declination, 8: Inclination, 9: Radius of cone of 95% confidence, 10: Precision parameter, 11 Pole position

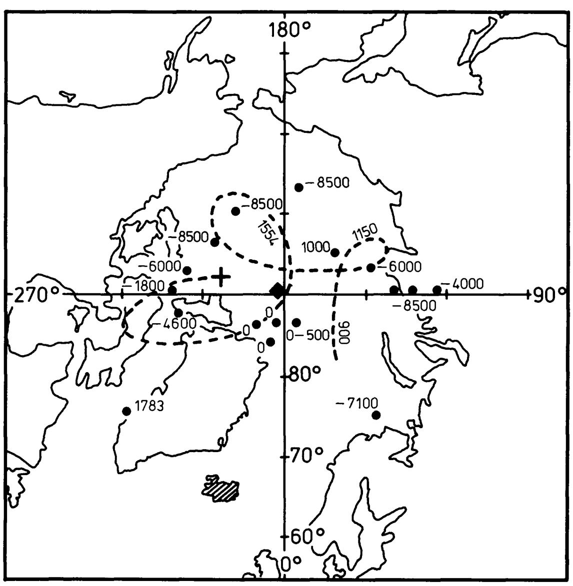

Fig. 2. Virtual geomagnetic pole positions (VGP) of postglacial lavas from Iceland with ages of extrusion. *Square*. mean pole position. *Cross*. geomagnetic pole of the reference field for 1965. *Dashed curve*. migration of the VGP during the last 1,000 years in Iceland after Brynjolfsson (1957)

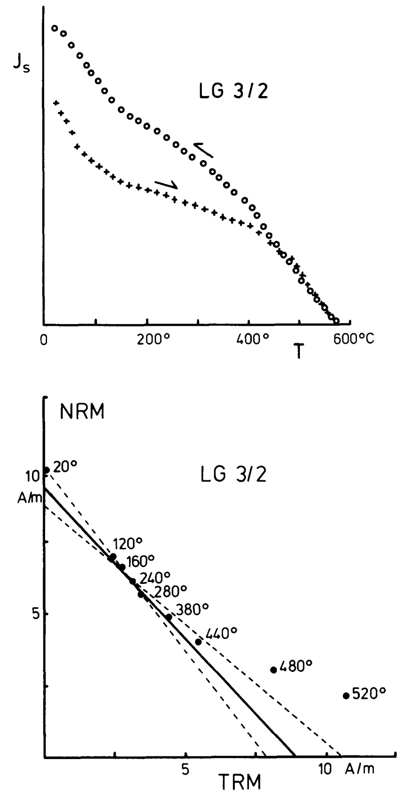

Fig. 3a and b. Older Laxá-lava (age: 3,800 years). **a** J_s/T-curve showing two Curie-temperatures (100° and 560° C). **b** Palaeointensity determination with the Thellier method. For explanation see text

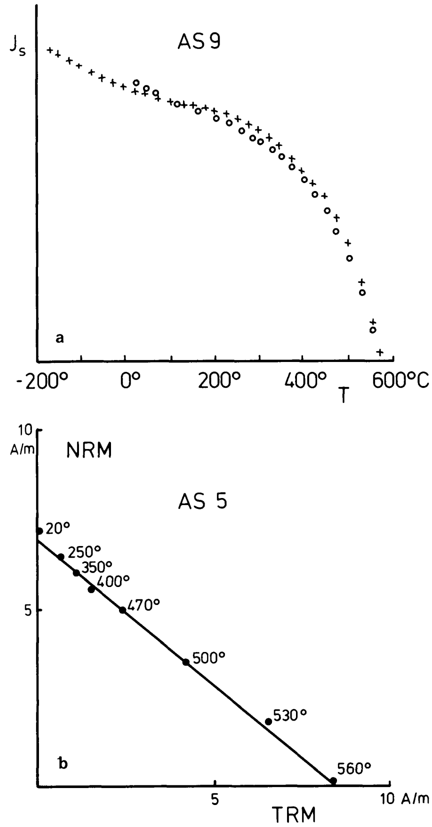

Fig. 4a and b. Lava from Asbyrgi (age: 10,500 years). **a** J_s/T-curve showing a single Curie temperature at 560° C. *Crosses*. heating curve; *circles* cooling curve. **b** Palaeointensity determination with the Thellier method. For explanation see text

magnetites into cation deficient titanomaghemites with other physical parameters.

Ore microscopic studies showed that all lavas possess a primary titanomagnetite phase coexisting with hemoilmenite, both in the form of unexsolved skeletal crystals. They can in general be attributed to classes II and III of high temperature oxidation according to Ade-Hall et al. (1968). Only slight indications of low temperature oxidation could be detected microscopically. In a few cases the ore grains were too small to allow a detailed optical investigation.

Most thermomagnetic (J_s/T) curves are more or less irreversible after heating to temperatures higher than about 400° C and show two Curie temperatures (Fig. 3a). Only the lavas of the shield volcano Theistareikjabunga (As, GA: $T_c = 560°$ C) and from Burfellsrhaun (BF: $T_c = 550°$ C) show a single Curie temperature and more or less reversible J_s/T-curves (Fig. 4a).

5. Palaeointensity Measurements and Results

Details of the equipment used and of the various methods are given by Schweitzer (1975) where it was shown that for those rocks with two Curie temperatures reliable palaeointensity data could be obtained with the Thellier method. An example is shown in Fig. 3b. The decay of partial natural remanence during thermal demagnetization in a zero magnetic field is plotted versus the increase of an artificial partial thermoremanent magnetization in a field of known intensity. The slope, $m = -F/H$ of the best fitting

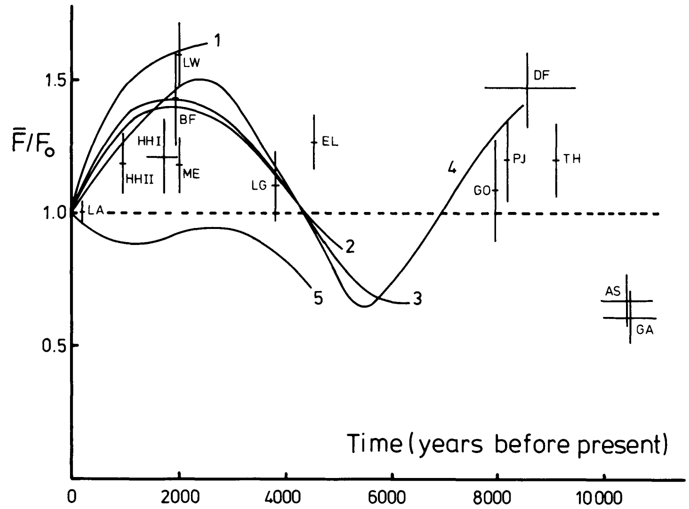

Fig. 5. Normalized secular variation of palaeointensity during the last 10,000 years for France (1), USSR ('), Japan (3), Czechoslovakia (4) and India (5). For references see text. Normalized palaeointensities of postglacial lavas from Iceland. *Vertical* and *horizontal bars* indicate inaccuracies with respect to intensity and age

line in a temperature interval with no viscous remanence, represents the ratio between the intensities of the palaeofield F and the laboratory field H. The dashed lines represent the greatest and smallest slope of best fitting lines on the 95% confidence level based on a Student test. This means that the true slope corresponding to the true palaeointensity should be between the dashed lines with 95% probability. The error of the measured palaeointensity is defined accordingly (see Table 2).

Lavas with only one Curie temperature around 550° C and more or less reversible J_s/T-curves produced similar palaeointensity values for different methods (Schweitzer, 1975). An example of a palaeointensity determination with the Thellier method on a lava from Asbyrgi is shown in Fig. 4b.

In Table 2 all palaeoinsity data are listed. Information is also given on the ages and some rock magnetic properties. For details see legend of Table 2.

A plot of the palaeointensities versus age is shown in Fig. 5 together with other intensity variations obtained for France (1), USSR (2), Japan (3), Czechoslovakia (4), and India (5) compliled by Bucha (1967), Kinoshita (1970), Kitazawa (1970). The data from Iceland are in general agreement with the results obtained for Europe and Japan for the last 4,000 years. For the presumed intensity minimum between 4,000 and 8,000 years B.P. no additional data could be provided. Icelandic rocks with ages between 8,000 and 10,000 years seem to confirm the maximum obtained by Bucha (1967) for Czechoslovakia. The older lavas (AS, GA) indicate another intensity minimum following the maximum at about 9,000 years B.P.

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Table 2. Palaeointensity data of postglacial lavas from Iceland

Number	Age	T_c(°C)	T_c(°C)	ΔJ_s	Class	Method	H(Oe)	ΔT, ΔH	F(Oe)	ΔF(Oe)	$\bar{F}$(Oe)	$\bar{F}/F_o$
AS 4	10,500		560	−5		MWI	0.42	100–560° C	0.36		0.33	0.65
AS 5						MTH	0.42	100–530° C	0.35			
AS 6		−100	550	−3	III/IV	MVZ	0.50	200–1,200 Oe	0.32			
AS 9		−20	550	0	III/IV	MVZ	0.50	100–1,200 Oe	0.34			
BF 8	2,000		550	+1	III	MTH	0.50	20–440° C	0.74	0.09	0.72	1.41
BF 5						MTH	0.50	50–440° C	0.70	0.08		
DF 35	8,000–	200	520	+12	II	MTH	0.50	20–380° C	0.81	0.18	0.76	1.49
DF 37	10,000					MTH	0.50	20–390° C	0.70	0.14		
EL 1	4,630	170	510	+12	II	MTH	0.50	20–440° C	0.72		0.66	1.29
EL 3						MTH	0.50	20–345° C	0.60	0.08		
GA 8	10,500		555	−6	III/IV	MTH	0.50	20–520° C	0.31	0.06	0.32	0.63
GA 21			560	−9		MTH	0.50	20–550° C	0.33			
GO 2	8,000	200	490	+25	–	MTH	0.50	20–340° C	0.54	0.15	0.56	1.10
GO 15						MTH	0.50	50–390° C	0.58	0.19		
HH 2	1,500–	200	540		III	MTH	0.50	20–390° C	0.63	0.12	0.63	1.24
HH 7	2,000					MTH	0.50	20–440° C	0.62	0.14		
HH 20	1,000	180	515	+15	II/III	MTH	0.50	50–440° C	0.61	0.09	0.61	1.20
LA 4	196	170	510	+25	II	MTH	0.50	50–440° C	0.49	0.02	0.49	0.96
LG 3	3,800	100	560	+35	–	MTH	0.50	50–440° C	0.54	0.09	0.52	1.02
LG 6						MTH	0.50	50–440° C	0.49	0.10		
LW 7	2,000	200	560	−1	II	MTH	0.50	20–440° C	0.81	0.20	0.82	1.61
LX 7						MTH	0.50	20–440° C	0.83	0.13		
ME 2	2,000		300	+8	I/II	MTH	0.50	20–380° C	0.61	0.06	0.61	1.20
PJ1	8,100	200	410	+9	II/III	MTH	0.50	20–440°C	0.75	0.20	0.69	1.35
PJ 3						MTH	0.50	20–390° C	0.62	0.12		
TH 1	9,100	200	560	+33	III	MTH	0.50	20–440° C	0.56	0.10	0.56	1.10

1: Locality; 2: Age in years; 3: Lower Curie temperature; 4: Upper Curie temperature; 5: Relative change of saturation magnetization at 20° C before and after heating to 600° C in percent; 6: Class of high temperature oxidation after Ade-Hall et al. (1968); 7: Palaeointensity method (*MWI*: Wilson; *MTH*: Thellier; *MVZ*: Van Zijl); 8: Field intensity for the generation of artificial partial thermoremanent magnetization; 9: Best temperature or *AF*-field interval respectively for palaeointensity determination; 10: Palaeointensity, 11. Standard deviation, 12: Mean palaeointensity; 13: Mean normalized palaeointensity with respect to the present field intensity in Iceland

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