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PALEOINTENSITY OF THE EARTH'S MAGNETIC FIELD AND K-AR DATING OF THE LOUCHADIERE VOLCANIC FLOW (CENTRAL FRANCE): NEW EVIDENCE FOR THE LASCHAMP EXCURSION

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Abstract. We report paleointensity results of the Earth's magnetic field from a Late Pleistocene lava flow (Louchadière, Central France), which recorded an intermediate geomagnetic field direction (5 sites, mean declination=114.1°, inclination=58.2°, k=130, $\alpha 95=6.7°$). New K-Ar age determinations confirm that this flow is contemporaneous with the Laschamp and Olby flows, and that this excursion occurred around 45ka ago. Using the Thellier double heating method, reliable paleointensities have been obtained for ten samples from three different sites, providing an average field strength of 12.9 μT (±3.3). This low value and previous results of the Laschamp excursion from France and Iceland confirm that the Earth's magnetic field was in an intermediate state during the Laschamp excursion.

Introduction

Analyses of the magnetic polarity time scale indicate that reversals are essentially Poisson-distributed in time [McFadden and Merrill, 1984], first suggested by Cox [1968]. This implies that many additional short-lived polarity subchrons (or excursions) might exist in the geological record. The Brunhes chron is an apparent long period of normal polarity in which several excursions or short polarity episodes have been reported [Champion et al., 1988]. Interest in upper Pleistocene excursions stems from the fact that they should be more easily identified at different sites around the world, providing an opportunity for studying the global morphology of the geomagnetic field during such magnetic disturbances. In addition, geomagnetic excursions can be valuable for stratigraphic correlations.

The Laschamp excursion was the first event identified in the Brunhes period [Bonhommet and Babkine, 1967], originally discovered in two volcanic flows of Laschamp and Olby (Chaîne des Puys, Central France). Because these two lava flows recorded a field direction that is nearly reversed, a full polarity reversal was considered, and numerous detailed paleomagnetic and radiometric studies were conducted on these two volcanic units. Recently, a paleointensity study has shown that the strength of the Earth's magnetic field during the Laschamp feature was about 8μT [Roperch et al., 1988], suggesting that the field was in an intermediate state and that the Laschamp should be more properly classified as a geomagnetic excursion. Other transitional directions were also found in the same volcanic province, notably the one recorded at several sites of the Louchadière flow [Bonhommet, 1972]. Thermoluminescence dating (TL) on plagioclases performed by Guérin [1983], on samples from two sites (BO and BP) of the Louchadière flow provided similar ages (33.8 ± 2.7 and 36.4 ± 3.1 ka) to those obtained by the same method on samples from the Laschamp flow (35 ± 3.0 and 33.5 ± 5.0 ka) [Gillot et al., 1979].

In this paper, we report a more detailed paleomagnetic investigation and paleointensity data from the Louchadière flow. New K-Ar age determinations show that this volcanic unit is contemporaneous with the Laschamp excursion.

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Sampling and Paleomagnetic method

A total of 41 cores were drilled at five sites within the Louchadière flow (BP: Beauloup, BO: le Bouchet, FOU: Fougères, BEAU: Beauregard and CHAU: Chausselles), separated by at least several kilometers (Figure 1). Two sites (BP and CHAU) were situated in a less-oxidized part of the flow, while the other three comprised more oxidized rock and scoria. Small areas at two sites (FOU and BEAU) were clearly affected by lightning, showing significant deviations of the magnetic compass. Paleomagnetic measurements and progressive demagnetizations by alternating fields (AF) were performed with Schonstedt equipment. Paleointensity determinations were done by the original version of the Thellier and Thellier [1959] stepwise double heating method, where the laboratory field was applied during both heating and cooling cycles and the field direction was reversed between two heatings at each temperature step. Heatings were conducted in vacuum (10^{-2} Torr). Samples with minimum secondary remanences (Figure 2a) and which showed a single, high Curie point above 500°C and relatively reversible thermomagnetic curves were selected for paleointensity experiments.

Paleomagnetic results

Directions

Progressive AF demagnetization of the natural remanent magnetizations (NRM) indicated two kinds of overprints: (1) a viscous component (VRM) in the direction of the present day field and (2) a secondary component with shallow inclinations and scattered declinations for samples at the edges of the areas affected by lightning. However, several samples have NRM directions close to the characteristic direction (Figure 2a). Samples carrying a viscous component have NRM intensities typically between 1 to 5 Am^{-1} and are mostly from sites CHAU and BP. Samples affected by lightning have much higher NRM intensities (up to 30Am^{-1}). Samples for which the strong magnetic overprint was not completely removed during AF demagnetization were omitted in calculating the characteristic mean site directions.

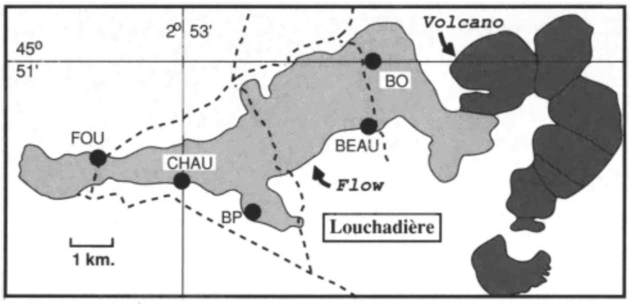

Fig. 1. Location map and sampling sites (BO, BEAU, FOU, BP and CHAU) of the Louchadière flow, Chaîne des Puys, France.

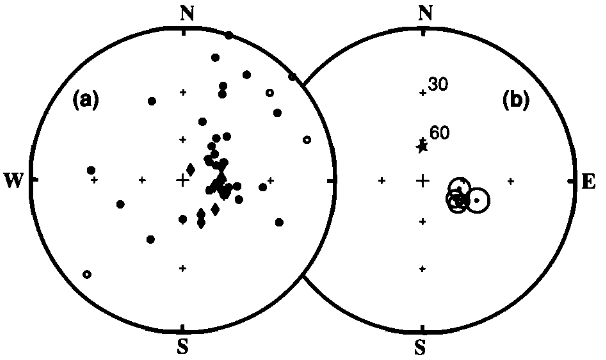

Fig. 2. a) Stereographic projections of NRM directions of all samples collected from the Louchadière flow. Solid symbols (open symbols) are on the lower (upper) hemisphere. Diamonds are the directions of the samples selected for the paleointensity determinations. b) Mean direction per sites and α_{95} confidence cones, after af and thermal cleaning. The star represents the direction of the axial dipole field.

TABLE 1. Site mean directions

Sites	n/N	D(°)	I(°)	k	α95	Lat	Long
Fou	6/10	119.0	62.8	130	5.9	15.0	43.4
Beau	8/11	123.1	59.3	84	6.1	9.9	43.5
Chau	5/6	102.3	62.3	107	7.4	22.8	53.0
BP	6/8	109.8	48.6	75	7.8	8.5	58.8
BO	6/6	117.0	57.2	237	4.4	10.9	48 7
Mean	5	114.1	58.2	130	6.7	13.2	49.8

n/N: number of samples used in the mean calculation/measured samples; D, I: mean declination and inclination per site; k: precision parameter estimate, α95: 95% confidence cone about the mean; Lat, Long: latitude and longitude of the virtual geomagnetic pole.

The average direction of the characteristic magnetization at each site is reported in Table 1 and shown in Figure 2b. The mean direction of the flow (D= 114.1°, I= 58.2°) shows a large departure (42°) from the axial dipole field and a low VGP latitude (13.2°).

Paleointensity

Eleven samples from three sites (FOU, BEAU and BO) were used for paleointensity experiments. They were selected on the basis of having minimum overprint (Figure 2a), high Curie points, and good reversibility between heating and cooling in thermomagnetic tests. Strong field thermomagnetic experiments on samples from sites BP and CHAU indicated low Curie temperatures due to the relatively low oxidation state of the Ti-rich titanomagnetites. Because this type of mineralogy often lead to mineralogical changes during heating, no samples from these two sites were selected. During the Thellier experiment, the samples were treated in various applied fields: 10, 15 and 20 µT. Numerous partial thermoremanent magnetization (TRM) checks were performed in order to test the stability of TRM acquisition during the heating [Prévot et al., 1985].

Among the eleven selected samples, only one did not provide a paleointensity result due to a drastic decrease in the capacity of TRM acquisition at temperatures above 410°C. Table 2 summarizes the paleointensity results. From each site, one example of an NRM-TRM diagram and evolution of the NRM vector during the heating are shown in Figure 3. Although cores with large overprints were avoided, samples selected for paleointensity measurements were not completely free from small secondary VRM components. However, these secondary magnetizations were commonly removed at temperature between 200 and 350°C. With the exception of sample Beau-06a which is from a core that broke during drilling, the NRM directions, in the temperature interval used for paleointensity determinations, are similar to those determined by AF demagnetization.

At least 9 to 10 steps, and a large fraction of the NRM, were used to determine the paleointensity. The quality factor q and the standard error for single sample determinations were calculated following the statistical method developed by Coe et al. [1978]. The weighted average paleointensity of the flow was obtained using the weighting factor proposed by Prévot et al. [1985]. The maximum error that CRM acquisition might have caused, in percent of the laboratory field, is indicated by the index R (Table 2), as defined by Coe et al. [1984]. For our data, this index is typically less than 10%.

The paleointensity results range from 11 to 15 µT, with only one determination, (22 µT, sample BO-01), out of this range. BO-01 has the lowest quality factor of all our specimens, so its contribution to the weighted mean is least important. The unweighted mean intensity of the flow is 13.9 µT, and the weighted mean [Prévot et al., 1985] considered to be the best estimate of the paleointensity of the Louchadière flow is 12.9 µT. This result is one third to one quarter the strength of the present day field. The virtual dipole moment (VDM) associated to this flow is 2.2 10^{22} Am^2, which is considerably less than the average VDM obtained for the last 10 ka [McElhinny and Senanayake, 1982] or the last 5 m.y.[McFadden and McElhinny, 1982], which is about 8.7 10^{22} Am^2.

Dating

K-Ar radiometric age determination from samples from site BP provides an age (42 ± 4 ka, Table 3) slightly older than those determined by thermoluminescence [Guérin, 1983]. A ^{40}Ar-^{39}Ar incremental heating experiment yielded a poorly-constrained plateau age of 39±28 ka. The age determined by K-Ar is also very similar to new measurements on the Laschamp and Olby flows (Table 3). A good inter-laboratory consistency between these new K-Ar data and those obtained for Laschamp and Olby samples [Gillot et al., 1979; Hall and York, 1978] is observed. Significant age differences seem to occur between results obtained by TL and K-Ar methods, rather than between three different volcanic units.

Discussion

Another volcanic unit in the Chaîne des Puys, the Royat lava, recorded a magnetic direction (D=284.7°; I=68.2°) which deviates significantly from normal secular variation.

TABLE 2. Paleointensity results

Samples	D(°)	I(°)	N	H_{lab}	J_{NRM}	ΔT	f	g	q	r	R%	Fe±sFe
Beau-02a	145.0	60.0	10	10	4.4	370-530	0.700	0.868	36.4	0.998	18.6	11.0±0.2
Beau-06a	104.0	86.0	10	15	3.8	200-500	0.672	0.854	8.4	0.981	3.4	13.5±0.9
Bo-01a	110.5	57.5	9	20	1.4	350-515	0.419	0.860	7.7	0.992	11.5	22.4±1.0
Bo-02a	111.5	54.5	15	10	1.5	250-550	0.891	0.908	30.3	0.995	1.9	15.1±0.4
Bo-03a	117.0	64.0	11	15	2.0	250-520	0.697	0.860	12.1	0.989	2.6	15.5±0.8
Bo-250a	123.0	53.0	11	10	2.2	350-540	0.701	0.879	28.9	0.998	10.3	11.2±0.3
Bo-252a	126.5	58.0	10	10	1.2	300-510	0.533	0.860	14.9	0.996	7.9	12.1±0.4
Fou-03a	108.0	59.5	10	20	2.2	350-525	0.704	0.883	61.8	0.999	3.2	12.3±0.1
Fou-04a	113.0	63.0	10	10	1.9	300-510	0.724	0.873	36.0	0.998	3.6	12.7±0.2
Fou-05a	110.0	60.5	10	10	4.2	200-500	0.914	0.863	19.0	0.993	3.5	13.3±0.5

Mean: Fe ± s.d.= 13.9 μT± 3.3 <Fe> = 12.9 μT VDM = 2.2 x10^{22}Am^2

D, I: magnetic declination and inclination of the NRM left in the ΔT temperature interval; N: number of temperature steps in the ΔT interval; H_{lab}: laboratory field (in μT); J_{NRM}: initial intensity of magnetization in Am^{-1}; ΔT: interval of temperature used to calculate the paleointensity; f, g, q: NRM fraction used, gap factor and quality factor respectively [Coe et al., 1978]; r: linear correlation coefficient; R%: maximun percentage of CRM; Fe: paleointensity estimate for individual specimen in μT; sFe: standard error; Fe±s.d.: unweighted average paleointensity of the Louchadière lava flow plus or minus its standard deviation; <Fe> : weighted mean in μT.

TABLE 3. K-Ar Ages

Lava Flow	%K	$^{40}Ar^*$ (x10^{-13} mole/g)	%$^{40}Ar^*$	Age±1σ (ka)
Laschamp	1.857	1.578	2.8	49.0±6.7
Olby	1.733	1.148	1.8	38.2±6.3
Louchadière	1.677	1.213	3.0	41.7±3.9

Decay and abundance constants used in age calculations: λ_ε=0.581x10^{-10} yr^{-1}, λ_β=4.962x10^{-10}yr^{-1}, $^{40}K/K$=1.167x10^{-4} mole/mole, $^{40}Ar^*$: Radiogenic ^{40}Ar

Paleointensity determinations, performed by the Thellier method on sediments baked by the Royat flow [Barbetti and Flude, 1979], suggest a low field close to 15 μT. The Royat flow has been dated by TL at around 40-46 ka [Guérin, 1983]. Thus the Royat flow may have been erupted at the time of the Laschamp excursion.

The global or regional extent of the Laschamp excursion is not, well defined. The only excursion recorded in lavas correlated with Laschamp is in Iceland (D=258.0°, I=-15.0°) [Kristjansson and Gudmundsson, 1980]. Paleointensity determinations by the Thellier method have been performed by two groups and provide paleofields as low as 4.3 μT [Marshall et al., 1988] and 4.2 μT [Levi et al., 1989]. K-Ar radiometric age determinations show that these flows were erupted around 40-50 ka and suggest contemporaneity with the Laschamp excursion [Levi et al., 1989]. (A reversed direction recorded in welded tuffs in Japan [Tanaka and Tachibana, 1981], was originally dated at around 30 ka, and was first correlated with the Laschamp excursion. New dating of the tuff gives an age around 0.7 Ma, showing that the reversed direction was probably acquired during the

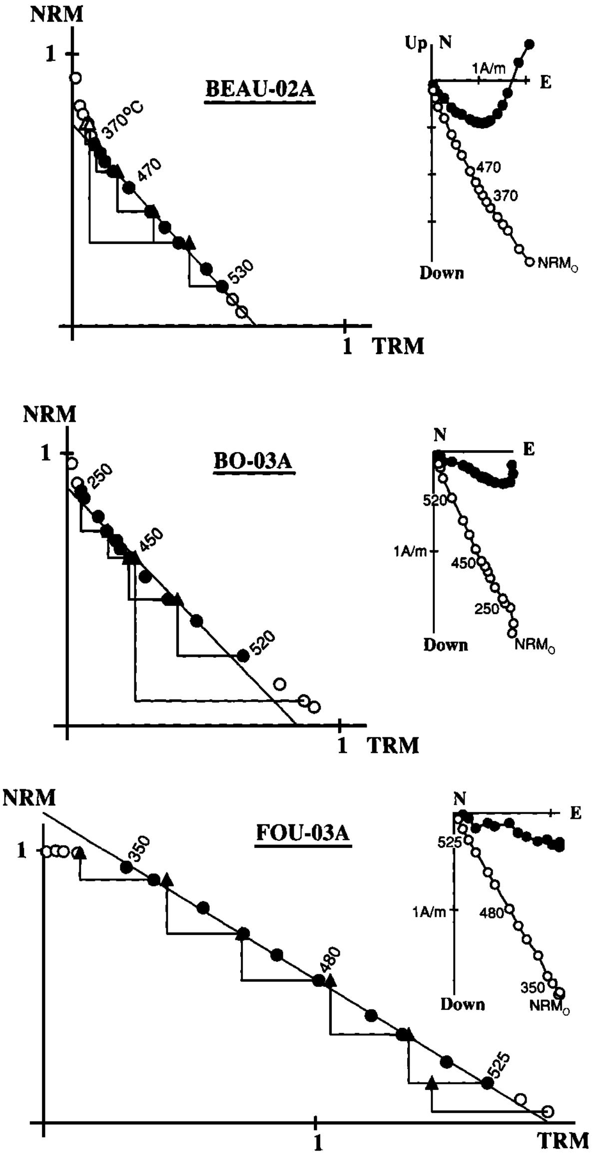

Fig. 3. Examples of reliable paleointensity determinations (NRM-TRM diagrams), for 3 samples from the sites BEAU, BO, and FOU. Black dots are used to calculate the slope; triangles represent PTRM checks; the associated orthogonal vector plots of the thermal demagnetization of the NRM are shown in geographical (in situ) coordinates on the right of each NRM-TRM plot. Temperature steps are indicated in °C.

Matuyama period [Tanaka, 1988, personnal communication]). A very well defined intermediate direction (D= 101.1°, I= -36.1°) was recently measured at 63 sites of 8 distinct lava flows of the Albuquerque Volcanos (New Mexico, USA) [Geissman et al., 1989]. Preliminary K-Ar age determinations suggest latest Pleistocene (i.e. 20 to 100 ka) as the time of the extrusion. More precise age determinations are required prior to more exact correlation with proposed Late Pleistocene excursions.

Three models have been applied to explain geomagnetic excursions: (1) a dramatic change in direction of the dipole field; (2) a large increase in strength of non-dipole sources; and (3) a decrease in strength of the main dipole field causing non-dipole domination over larger portions of the globe. The last hypothesis was recently used in order to interpret directions and low paleointensities obtained on the Laschamp and Olby flows [Roperch et al., 1988]. The low paleointensity value observed at Louchadière reinforces this interpretation. For example, a dipole only one fourth of the present value with non-dipole fields of the same order as present non-dipole field values can produce regional intermediate directions. We may speculate that such a decrease in the dipole field might have been a first step in an attempted and finally aborted polarity reversal.

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