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The Laschamp excursion*

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The reversely magnetized lavas at Laschamp and Olby (Chaîne des Puys, Auvergne, France) are commonly believed to document the most recent geomagnetic field excursion in the present Brunhes normal epoch. However, complete or partial self-reversal of natural remanent magnetization (n.r.m.) is observed in many Olby samples and to a lesser extent in the Laschamp rocks during thermal laboratory experiments. Magnetic and optical examination suggests that the self-reversal mechanism is caused by a negative magnetostatic coupling between titanomagnetite phases of widely varying degrees of oxidation. To check independently whether field reversal or self-reversal caused the reversed n.r.m. directions, a contemporaneous loess section at Steinheim (southern Germany) has been studied magnetostratigraphically. No reversed polarities have been detected in this section or in other loess profiles from Czechoslovakia and northern China.

INTRODUCTION

Reversed directions of natural remanent magnetization (n.r.m.), observed in two lava flows at Olby and Laschamp in the Auvergne, France (Bonhommet & Babkine 1967), have been taken as a document of the most recent geomagnetic field excursion and accordingly named the 'Laschamp event' (Bonhommet 1970). The possibility that self-reversal of n.r.m. occurs in the volcanics was ruled out by Whitney *et al.* (1971). Radiometric measurements gave age estimates for the lavas between 8000 years (radiocarbon minimum age of trees in overlying ashes (Pelletier *et al.* 1959)) and less than 20000 years (K–Ar estimate (Bonhommet & Zähringer 1969), which have recently been revised. Thermoluminescence dating (Gillot *et al.* 1979; Guérin & Valladas 1980), U–Th dating (Condomines 1978) and improved K–Ar dating (Hall & York 1978; Gillot *et al.* 1979) give a probable age for the extrusion of the reversed Olby and Laschamp lavas in the range 35000–45000 years. The Olby lavas apparently give slightly greater ages than the Laschamp rocks implying a duration of a few thousand years for the Laschamp event, if it existed as a single uninterrupted excursion.

The record of a very young polarity event in the Brunhes normal epoch would be very valuable for understanding the regional or global character of field reversals. Because of the synchronous occurrence of such an excursion over the whole globe such an isochron would also be important for stratigraphic correlation of otherwise undatable, but continuously deposited, Pleistocene loess or lake sediments. Heller & Petersen (1982) have summarized the palaeomagnetic investigations devoted to the search of the Laschamp event in various sedimentary environments. The results are inconclusive, or the age falls outside the time limits given by the new radiometric data.

Bonhommet & Babkine (1967) suggested as an alternative that the reversed Laschamp and

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Olby directions might be due to a self-reversal mechanism. In fact the n.r.m. of a considerable proportion of samples we have collected at Olby and Laschamp shows complete or partial self-reversal characteristics during laboratory heating experiments (Heller 1980; Heller & Petersen 1982).

Additional evidence for or against the 'Laschamp event' may be found in contemporaneous late Pleistocene sediments. Unfortunately deep sea sediments of that age are not yet consolidated and recent lake sediments rarely date back far enough. Loess sections in eastern Europe (Bucha & Horacek 1973; Fink & Kukla 1977) and northern China (An *et al.* 1977; Wang *et al.* 1980; Liu *et al.* 1981) have proved to be reliable recorders of late Pleistocene geomagnetic field variations. Therefore new magnetostratigraphic data from a loess section at Steinheim (southern Germany) that covers the last 60000 years, and a compilation of the available palaeomagnetic loess data may provide further evidence on the reality of the 'Laschamp event'.

THE OLBY–LASCHAMP VOLCANICS

The n.r.m. of the Olby basalt and the Laschamp trachyandesite always contains a strong viscous proportion due to the presence of very fine-grained (superparamagnetic) titanomagnetite (Nordemann *et al.* 1979). Alternating field (a.f.) cleaning easily removes the unstable component and gives cleaned mean directions (table 1) at four sites in the volcanics similar to those obtained by Bonhommet & Babkine (1967) and Gillot *et al.* (1979). All samples originating from the Laschamp flow are reversely magnetized, but nearly half of the Olby samples are normally magnetized (figure 1). Owing to a number of intermediate n.r.m. directions the dispersion about the Olby mean value is large.

The smallest scatter of n.r.m. directions is obtained by continuous thermal demagnetization at elevated temperature. The samples are measured in zero field at temperatures higher than room temperature by using a high-temperature vector magnetometer (Heiniger & Heller 1976). Near the maximum blocking temperatures (200–550 °C (table 1)) well grouped reversed n.r.m. directions are measured in nearly all Olby and Laschamp samples. Subsequent cooling and measuring at room temperature changes the n.r.m. polarity of most Olby samples at site 1 (table 1), but leaves the reversed polarization in most samples from Laschamp and Olby sites 2 and 3. The different polarities are caused by a variable extent of titanomagnetite oxidation.

The variable degree of titanomagnetite oxidation has been demonstrated by the analysis of J_s–T curves and optical examination (Heller & Petersen 1982). Three distinct Curie temperatures around 180, 320 and 520 °C indicate differently oxidized titanomagnetite in the rocks investigated. Inflexions in the heating curves of a.f.-cleaned n.r.m. intensity (Heller & Petersen 1982) occur at even more different temperature levels. They have been taken as evidence that the degree of oxidation varies strongly from sample to sample. Optically homogeneous, but also variably exsolved (by low-temperature and high-temperature oxidation) titanomagnetite has been observed with the microscope. High-temperature oxidation occurs preferentially, but not exclusively, in the Laschamp trachyandesite, whereas both low-temperature and high-temperature oxidation has affected the Olby basalt titanomagnetites. Low-temperature and high-temperature oxidation features are sometimes visible within a single rock specimen and even within single titanomagnetite grains. Therefore titanomagnetite and titanomaghaemite phases with Curie temperatures ranging between 180 and 550 °C are expected to coexist in these volcanics, leading to a complicated magnetization history.

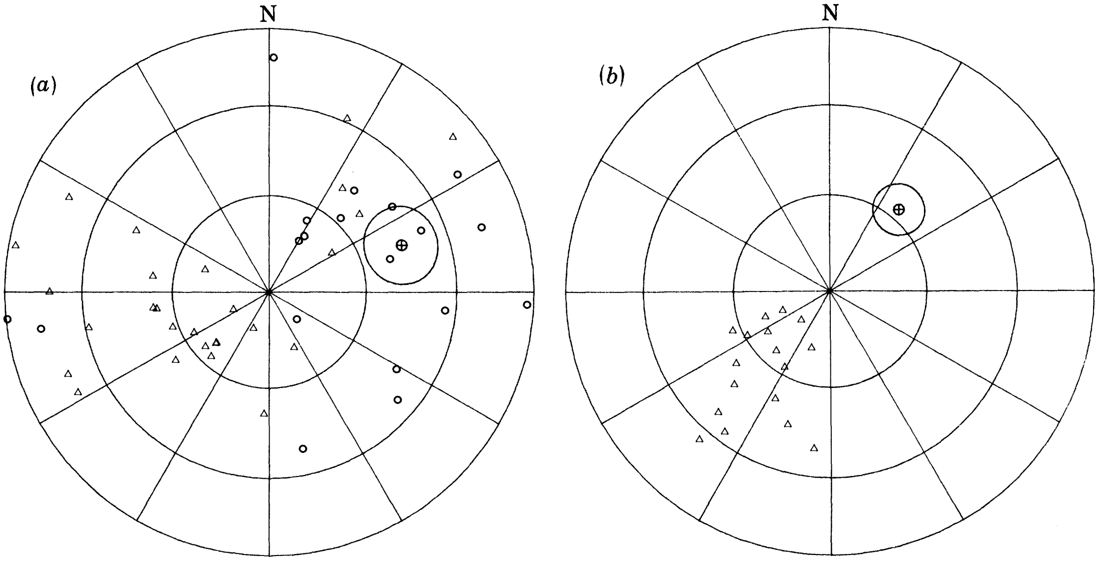

Figure 1. Stereographic projection of a.f.-cleaned n.r.m. directions from the Olby (*a*) and the Laschamp (*b*) flows. Circles, lower hemisphere; triangles, upper hemisphere. Mean direction always on lower hemisphere. Number of samples plotted: (*a*), 46; (*b*), 17.

Table 1. Site mean directions obtained by different cleaning techniques

(A.f., alternating fields up to 60 mT; t.h. (200–550 °C), n.r.m. measured in the temperature range indicated; t.h. (20 °C), n.r.m. measured after cooling in zero field. Polarity column indicates the percentage of normal and reversed samples. *N*, number of samples; dec., inc., α_{95}, mean directions and confidence circle.)

locality	demagnetization	polarity +	polarity −	*N*	dec. deg	inc. deg	α_{95}
Laschamp	a.f.	—	100	17	220.4	−56.7	8.1
	t.h. (500–550 °C)	—	100	13	256.5	−61.5	5.7
	t.h. (20 °C)	—	100	6	229.6	−55.4	9.8
Olby (Site 1)	a.f.	40	60	37	252.3	−49.1	12.9
	t.h. (200–500 °C)	3	97	29	227.4	−62.7	9.2
	t.h. (20 °C)	56	44	25	53.4	+49.9	14.3
Olby (Sites 2+3)	a.f.	44	56	9	243.0	−13.5	36.2
	t.h. (250–500 °C)	—	100	18	244.7	−67.2	9.9
	t.h. (20 °C)	7	93	14	260.4	−68.4	17.2

Complete self-reversal of n.r.m. is observed during thermal cycling above room temperature in two Olby samples (figures 2 and 3). Before being heated, the samples were partly demagnetized by alternating fields to remove secondary viscous components. In the first heating cycle up to 269 °C, sample Olby 1FA (figure 2) starts with a normal n.r.m. direction which changes to reversed polarity at around 200 °C. During the subsequent cooling cycle a normal direction is again obtained below 160 °C. The apparently different temperatures of the polarity change during thermal cycling are due to temperature hysteresis of the relatively large, 2.5 cm, samples used. Repeated heating and cooling to a slightly increased maximum temperature (304 °C) shows that the self-reversal mechanism is reversible.

Sample Olby 1PA (figure 3) indicates that peculiar intensity changes occur during the self-reversal process. The directional behaviour during the first heating and cooling is quite similar to that of the former sample, but complete reversal is just achieved at room temperature. The intensity during heating to 240 °C drops initially, increases until about 120 °C and decreases normally at higher temperatures. Upon cooling the magnetization rises again until about 80 °C and then decreases sharply. An intensity increase with further decrease in temperature, which is clearly seen in figure 2, is not observed in this sample. The final heating cycle reverses the polarity again and this remains negative up to more than 500 °C. At temperatures above 530 °C the polarity reverts to normal. Since the intensity at this stage is close to the noise level of the measuring device, the evidence for a high-temperature normal polarity is not very well documented, but indicative trends are found quite often (Heller & Petersen 1982). Other samples exhibit only partial self-reversal, characterized by a decrease in n.r.m. intensity upon cooling, but incomplete polarity reversal at temperatures below 200 °C. The reversal to normal polarity at temperatures above 500 °C is often not observed. The polarity of the Laschamp samples usually stays negative until the remanence signal disappears.

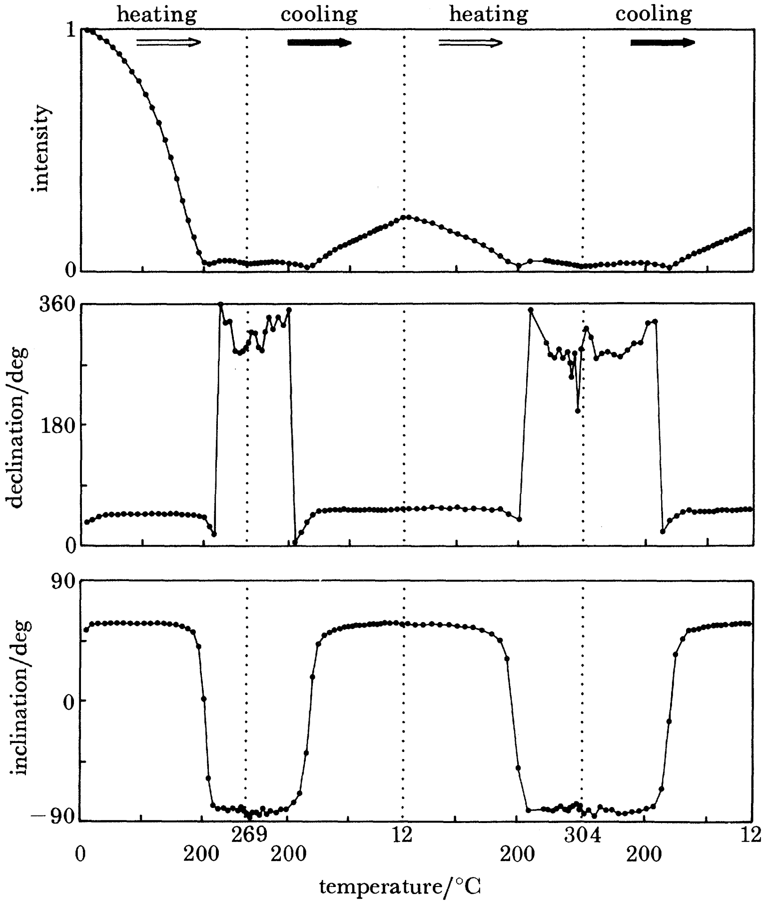

Figure 2. Repeated heating and cooling cycles of a low-temperature oxidized Olby (Olby 1 FA) sample showing complete self-reversal below 180 °C. A.f. = 12.5 mT; M_0 = 1.93 A m^{-1}.

Reversely magnetized rocks generally represent the polarity of the Earth's magnetic field during their formation. However, self-reversal of n.r.m. or laboratory-induced t.r.m. has been reported in a number of continental or oceanic basalts (Heller & Petersen 1982). It may be due either to a polarity change of spontaneous magnetization in a single magnetic phase at a certain temperature (Néel's (1955) N-type ferrimagnets) or to a negative coupling by magnetostatic or exchange interaction between two phases.

The titanomagnetites of the Olby and Laschamp flows have been oxidized under different conditions and to a highly variable extent. J_s–T curves and optical studies demonstrate the presence of at least two magnetic phases in low-temperature oxidized titanomagnetite. This evidence and the sharp onset of the n.r.m. reversal process during thermal treatment below 200 °C suggest that the observed self-reversal is caused by interaction of two magnetic phases

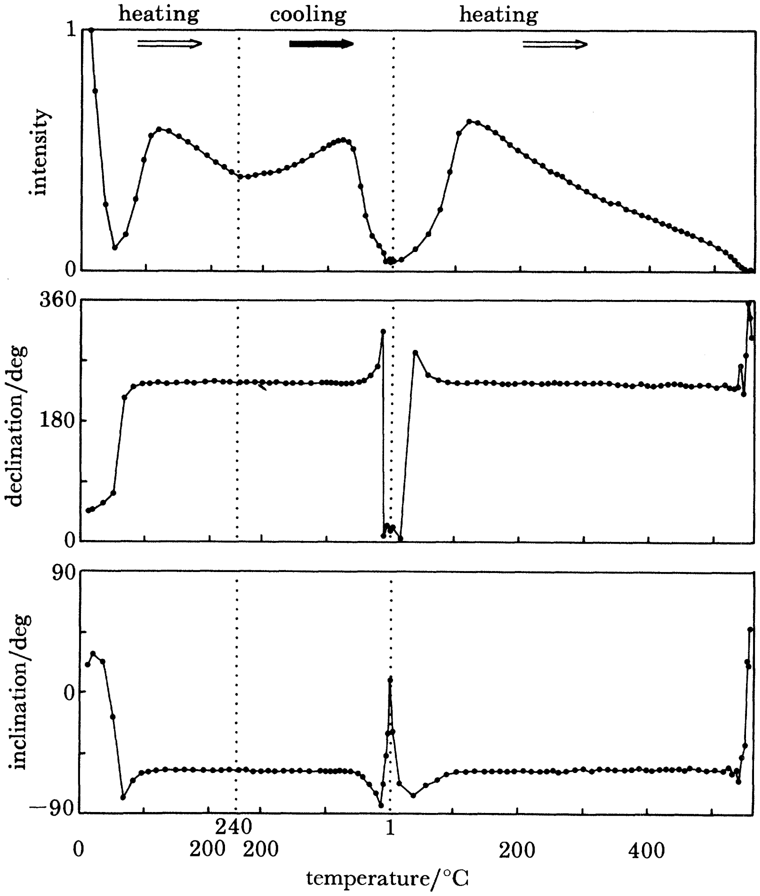

FIGURE 3. Thermal behaviour of a.f.-cleaned n.r.m. of an Olby sample (Olby 1 PA) containing both low-temperature and high-temperature oxidized titanomagnetite. A.f. = 7.5 mT; M_0 = 1.22 A m^{-1}.

coupled magnetostatically (Heller & Petersen 1982). The phases are (*a*) unoxidized titanomagnetite with T_c below 180 °C and (*b*) secondary titanomaghaemite with T_c less than 400 °C. If the reversely magnetized titanomaghaemite formed below the Curie point of the primary titanomagnetite, then the geomagnetic field was in a normal polarity state at the time of emplacement of the volcanics.

In the rocks oxidized at high temperature, evidence for or against field reversal or self-reversal is less clear. The original magnetic mineral has been largely replaced by secondary minerals, and a normal magnetization direction residing in the remnants of a high-temperature oxidized (titano-)magnetite may be hardly or not at all detectable at high temperature in our laboratory experiments (figure 3). Self-reversal is clearly documented by the heating experiments in many samples from Olby and Laschamp. However, the time and extent of titanomagnetite oxidation cannot be estimated exactly, and it is not certain that self-reversal has actually taken place during the formation of the volcanics. The remanent magnetism of appropriate sediment sections may give further clues about the reality of the 'Laschamp event'.

Loess deposits in Europe and northern China

Loess is typically a yellow, calcareous, porous silt of aeolian origin. It has been deposited in the periglacial realm in various parts of the world during the Pleistocene. The loess stratigraphic record has been closely correlated (Kukla 1975; Liu *et al.* 1981) with deep-sea sediments (Shackleton & Opdyke 1973) on the basis of palaeoclimatic indications and palaeomagnetic and oxygen isotope measurements. However, magnetization processes and magnetic properties have not yet been studied thoroughly. Maghaemite, iron hydroxides and magnetite have been identified as the most common magnetic minerals in Czechoslovakian (Bucha & Horacek 1973) and Polish (Tucholka 1976) loess. The problems of secondary, especially viscous, remagnetization and also of accurate age dating remain to be solved. Nevertheless certain loess sections in

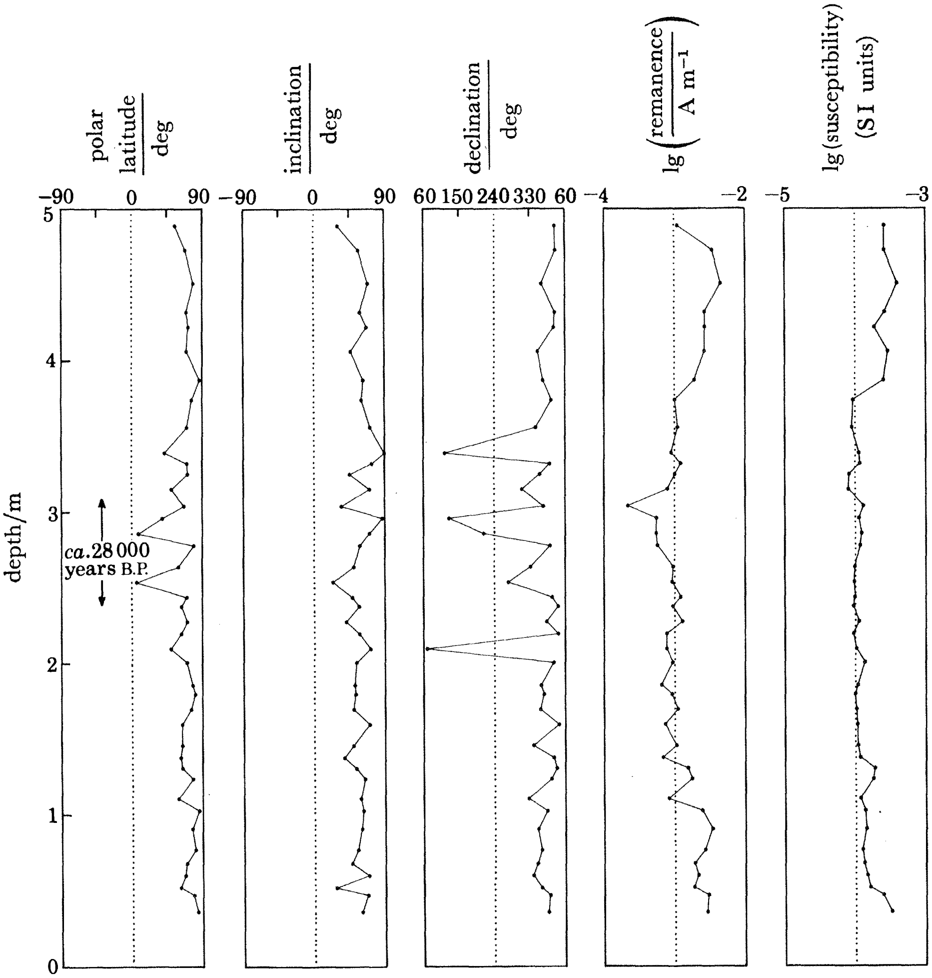

FIGURE 4. Magnetostratigraphic section (17.5 mT) at Steinheim (southern Germany). No clearly reversed n.r.m. polarity is indicated. Number of samples: 42.

Czechoslovakia (Cerveny Kopec (Kukla 1975; Fink & Kukla 1977), Kutna Hora (Bucha & Horacek 1973)) and in northern China (Lochuan (An *et al.* 1977; Liu *et al.* 1981)) have provided a reasonably continuous record of geomagnetic field variations during the Brunhes epoch and earlier. Loess sediments covering the time span of the 'Laschamp event' may therefore be used to investigate the existence of this excursion.

A loess section at Steinheim near Memmingen (southern Germany) has been sampled across a thickness of *ca.* 5 m. It consists of yellow to grey loess silt. A wet soil horizon in the middle of the profile is equivalent to the Stillfried B soil complex in Austria (H. Jerz, personal communication 1981) for which radiocarbon dating gives an age of 28340 ± 220 years (Kukla 1975). At a depth of 6 m from the top a gravel horizon documents the Riss/Würm interglacial (Jerz & Wagner 1978). Thus the sampled section covers probably the last 60000 years.

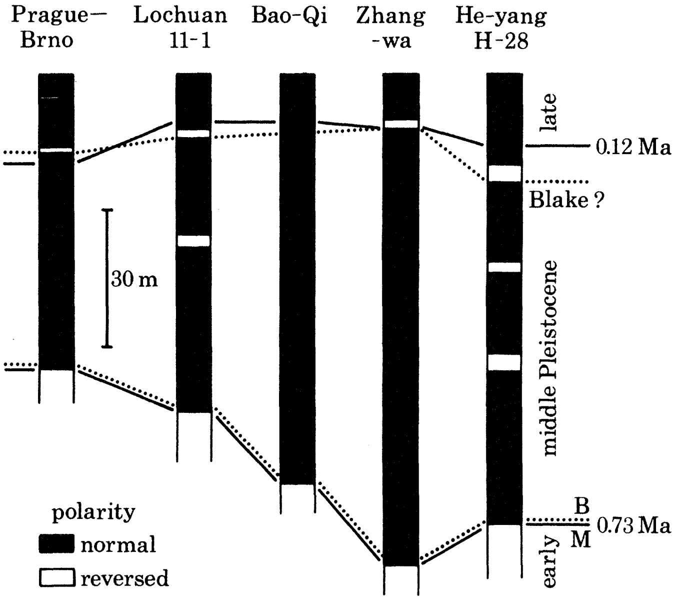

FIGURE 5. Magnetostratigraphy of Brunhes age loess sections in Czechoslovakia (Prague–Brno) and northern China (Lochuan and He-Yang bore holes; Bao-Qi and Zhang-wa outcrops). Chinese sections redrawn from Wang *et al.* (1980).

After small initial direction changes the remanence vector is directionally quite stable during a.f. demagnetization. Medium destructive fields are attained between 10 and 17.5 mT and the cleaned mean direction parallels the present field ($D = 7.5$, $I = 61.1$, $\alpha_{95} = 6.2$, $N = 42$). The magnetization is either depositional or chemical in origin and assumed to be contemporaneous with the deposition of the sediments. There are, however, no means of evaluating the eventual presence of a later chemical or hard viscous overprint. The intensities of remanence and susceptibility depend on the stratigraphic position (figure 4); bottom and top portions of the section are more strongly magnetized than the middle part. Since the total iron content is more or less constant throughout the section (Jerz & Wagner 1978), the intensity variations may be caused by different degrees of oxidation of the magnetic minerals as a result of climatic changes during deposition. The n.r.m. inclinations (figure 4) are always positive and the declinations usually point towards north. Deviating declinations that give corresponding virtual geomagnetic pole positions at lower, but still positive, latitudes are found at two levels in the middle of the section. These abrupt directional changes of apparently very short duration (corresponding to less than 2000 years) probably reflect mechanical disturbance (such as solifluction) rather than geomagnetic field variation.

Extensive magnetostratigraphic investigations have been carried out in the loess sections of Czechoslovakia. The results for the last 700000 years have been summarized in the Prague–Brno section (figure 5). The Brunhes/Matuyama boundary has been clearly identified at many places and the Brno magnetohorizon (which has southerly declination but positive inclination) has been correlated (Kukla & Koci 1972) with the Blake event (Smith & Foster 1969). The most recent reversal near the top of the Prague–Brno section has been observed in the same stratigraphic horizon of two closely neighbouring sections at Kutna Hora (C.S.S.R.), but not in any other section (Bucha & Horacek 1973). This horizon (age *ca.* 15000 years) may be considered as another example of local perturbation, but not of a field excursion.

The four Chinese loess sections (figure 5) located in the loess plateau to the west of Peking also document the Brunhes/Matuyama boundary, which is equivalent to the geological stage boundary from early to middle Pleistocene. According to the Chinese investigators the Blake event has been identified in three of the sections plotted. The other Brunhes 'excursions' shown in figure 5 are based on reversed directions of isolated single specimens. Their significance remains dubious until more detailed and elaborate work has been done.

CONCLUSIONS

The 'Laschamp event' has not been positively identified in any of the loess sections, and it has not been found in any other sediment sections. If it is a real record of the geomagnetic field it must represent features of only local or possibly regional character. Our rock magnetic studies indicate, however, that it may in fact not be a record of reversed geomagnetic polarity at all. Although laboratory experiments cannot reproduce original geological conditions, they raise the strong suspicion that the 'Laschamp event' may result from a magnetomineralogical self-reversal.

Professor T. S. Liu has provided information and translation of the Chinese palaeomagnetic research on loess. Helpful criticisms and suggestions by Professor W. Lowrie improved the manuscript.

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Discussion

C. LAJ (*Centre des Faibles Radioactivités, Gif-sur-Yvette, France*). I wish to give some information about the work that has been done at the Centre des Faibles Radioactivités by G. Guérin with the use of thermoluminescence dating.

His work has shown that all the lava flows that possess an abnormal or reverse magnetization belong to the time interval 29000–42000 years B.P. Even though most of the lava flows from the Chaîne des Puys have been dated, no lava flow with direct magnetization has been found belonging to this period. Moreover, the abnormal flows belonging to this period show a variety of petrological compositions. These facts seem to me to be in contradiction with the hypothesis of self reversal. These results are currently in the press in *Modern Geology*.

F. HELLER. Bonhommet (1972) reported magnetization directions from 50 Quaternary lavas in the Chaîne des Puys. Nine of these flows have anomalous or reversed polarization. They have been dated by various authors including the recent work of Guérin. The exact age of almost all the other flows with 'direct' magnetization is not known at present. Moreover, the flows of Ceyssat and Royat, which have been erupted at around 35000 and 42000 years respectively (Guérin, in the press), have divergent magnetization directions being partly 'direct' and partly 'anomalous' (Bonhommet 1972).