Earth and Planetary Science Letters 387 (2014) 184–197

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Dynamics of the earth magnetic field in the 10–75 kyr period comprising the Laschamp and Mono Lake excursions: New results from the French Chaîne des Puys in a global perspective

Carlo Laj, Hervé Guillou, Catherine Kissel *

Laboratoire des Sciences du Climat et de l'Environnement/IPSL, CEA/CNRS/UVSQ, Avenue de la Terrasse, 91198 Gif-sur-Yvette Cedex, France

ARTICLE INFO

Article history:
Received 25 July 2013
Received in revised form 12 November 2013
Accepted 13 November 2013
Available online 10 December 2013
Editor: J. Lynch-Stieglitz

Keywords:
geomagnetic excursions
earth magnetic field intensity
K/Ar dating
$^{40}Ar/^{39}Ar$ dating
volcanic records

ABSTRACT

We report here on a new paleomagnetic (directions and intensities) and coupled K/Ar and $^{40}Ar/^{39}Ar$ analysis of 35 different flows, emplaced in the Chaîne des Puys during the 75 to 10 kyr interval, which contains the Mono Lake and Laschamp excursions. There is a remarkable agreement between the new set of absolute volcanic intensities and published sedimentary (GLOPIS-75) and cosmogenic (^{10}Be and ^{36}Cl) records. The Laschamp and Mono Lake excursions are clearly revealed by a very significant intensity drop at 41.2 ± 1.6 ka and 34.2 ± 1.2 ka respectively. The duration of the Laschamp excursion is ~1500 yr and about 640 yr when the drop of paleointensity or the directional change are considered respectively. The intensity drop at the Mono Lake is twice as short. In the ~7 ka interval separating the two excursions, the field intensity recovers to almost non-transitional values. The rate of decrease of the field intensity during these excursions attains 18 nT/yr for the Laschamp and even greater value (33 nT/yr) for the Mono Lake. This figure is, for the Laschamp excursion, similar to the present field intensity decrease in the last two centuries so that one may wonder whether such a high rate of change may be characteristic of an impending geomagnetic event (reversal or excursion). We suggest that the name Auckland excursion should be used for the present-day called Mono Lake.

1. Introduction

Documenting precise characteristics such as frequency, amplitude and duration of both directional and intensity changes during geomagnetic excursions, is essential to understand their origin and consequently to acquire a deeper knowledge of the mechanisms of the Earth's dynamo. Acquisition of volcanic excursion records coupled with high precision age determinations, and estimation of the duration and timing of excursion with high chronological precision are two of the major directions for further research in the field (Roberts, 2008).

The French Chaîne des Puys (French Massif Central) offers a good opportunity to provide at least partial answers to these two points. Since the discovery of the Laschamp excursion by Bonhommet and Babkine (1967) in lava flows and scoria near the village of Laschamp and at Olby, this volcanic chain has been the object of several paleomagnetic and dating studies. There is now a wide agreement that self-reversal, initially suggested as a potential explanation for the reverse magnetization of the Laschamp and Olby flows (Heller, 1980; Heller and Petersen, 1982a, 1982b), cannot account for the reversed magnetization observed in these lavas, which, therefore, can be considered as reliable recorders of the geomagnetic field (Whitney et al., 1971; Krasa et al., 2005; Roperch et al., 1988; Singer et al., 2009; Plenier et al., 2007).

On the other hand, controversies exist in the ages assigned to the different flows of the Chaîne des Puys, not only limited to early determinations (Bonhommet and Babkine, 1967; Bonhommet and Zähringer, 1969; Hall and York, 1978; Huxtable et al., 1978; Condomines, 1978; Gillot et al., 1979; Chauvin et al., 1989; Guérin and Valladas, 1980; Guérin, 1982), but also in recent surveys (Guillou et al., 2004; Plenier et al., 2007; Singer et al., 2009).

Guillou et al. (2004) applied coupled unspiked K–Ar and $^{40}Ar/^{39}Ar$ dating techniques on samples from the two type-localities for the Laschamp excursion, at Laschamp itself and Olby, and obtained an age 40.4 ± 2.0 ka, where the 2σ uncertainty includes both analytical and systematic (^{40}K decay constant) errors.

Using only the unspiked K/Ar technique, Plenier et al. (2007) reported ages from several lava flows including an age of 37.0 ± 0.7 ka (1σ) for the Olby flow, which is inconsistent with that of Guillou et al. (2004). On the basis of this age and the ages 41.9 ± 1.4 ka (1σ) and 33.4 ± 0.7 ka (1σ) obtained from normally and transitionally magnetized lavas from other flows in the Chaîne des Puys, Plenier et al. (2007) concluded that the Laschamp excursion began at about 39.6 ka and lasted about 6 ka until 33.3 ka, in sharp contrast with previous results from sedimentary (Laj et al. 2000, 2004) and from ice cores, where the Laschamp and the Mono Lake excursions are recorded as sharp and short increases in ^{10}Be

* Corresponding author.

0012-821X/$ – see front matter
http://dx.doi.org/10.1016/j.epsl.2013.11.031

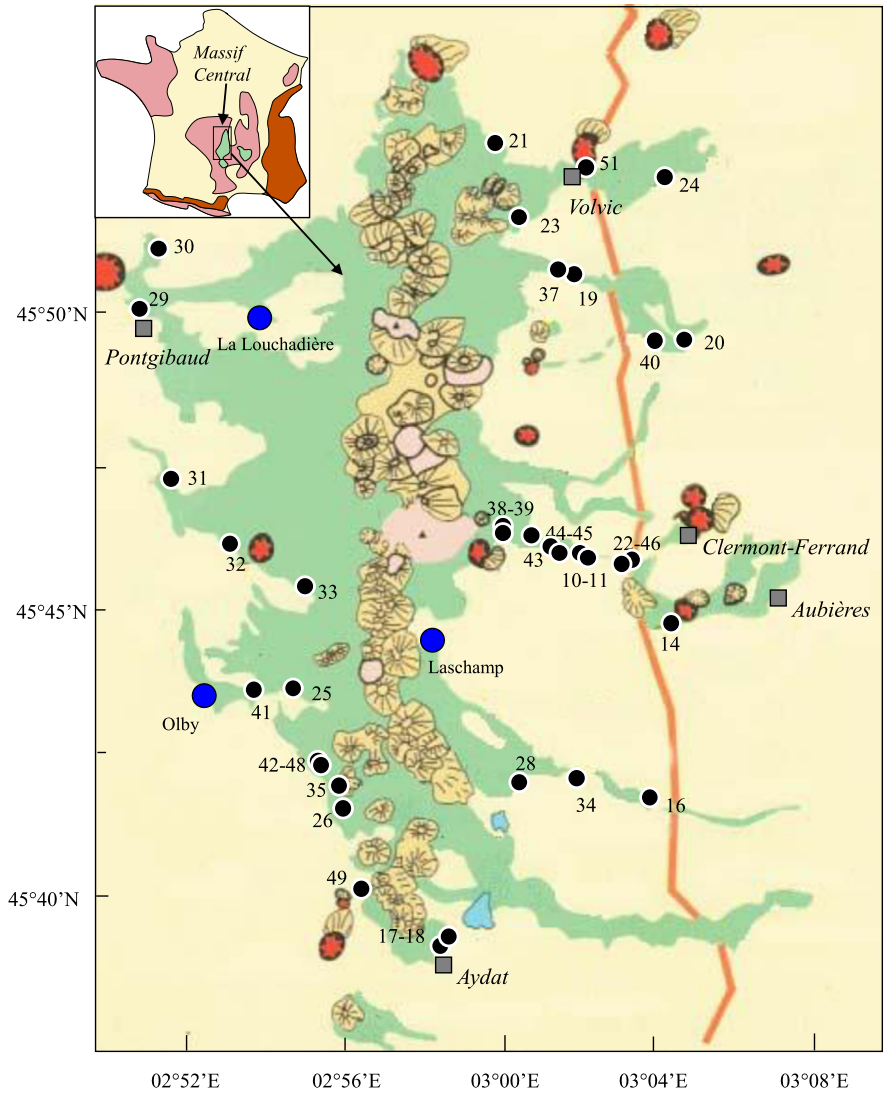

Fig. 1. Schematic map of the Chaîne des Puys in the French Massif central. The blue dots correspond to the first lavas on which the Laschamp excursion has been identified. The black dots are the localities of the lava flows we sampled. The N–S alignment of explosive craters of different nature is shown in the middle of the map. Green is for the volcanic products from these craters. Yellow is for substratum and alluvions. In the schematic geological map reported in the inlet, pink is for crystalline rocks, brown for recent mountain chains and yellow for sedimentary basins. The volcanic regions are reported in green. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and ^{36}Cl production (Wagner et al., 2000; Muscheler et al., 2004; Raisbeck et al., 2007).

Singer et al. (2009), using the same analytical techniques as Guillou et al. (2004), reported results from a third type locality for the Laschamp excursion, the Louchadière flow (Chauvin et al., 1989), and proposed an age of 40.7 ± 1 ka (2σ), virtually identical to the Guillou et al. (2004) value.

Singer et al. (2009) also questioned the reliability of both the K–Ar ages and the long ~6000 yr duration for the Laschamp excursion proposed by Plenier et al. (2007), on the basis that the K–Ar technique alone does not allow to check some crucial basic assumptions related to the K–Ar clock (Dalrymple and Lanphere, 1969; McDougall and Harrison, 1988). In particular, even small deviations in isotopic composition of the initial argon from atmospheric composition, as well as unidentified argon loss, can result in significant errors in the apparent age of very young lava flows containing only very small amounts of radiogenic argon (^{40}Ar*), such as those from the Chaîne des Puys. This stresses the importance of coupled K–Ar and ^{40}Ar/^{39}Ar dating, because the latter allows to check the basic assumptions of the K–Ar clock and consequently objectively validates the radiometric ages.

In this paper we report on a new extensive paleomagnetic and radiometric dating study of several flows in the Chaîne des Puys, some of which are investigated here for the first time, with the objective of precisely characterize the behavior in direction and intensity of the geomagnetic field. The results allow a first comparison of volcanic data with sedimentary and cosmogenic isotopes continuous records, during a time interval when the geomagnetic field has undergone large variations.

2. Sampling

Sampling was conducted at 35 different sites distributed between the towns of Volvic in the North, Aydat in the South, Pontgibaud in the West and Aubières in the East on the basis of the old dating reported in Boivin et al. (2004) and taking advantage of newly exposed outcrops (Fig. 1). In the north, the three superimposed lava units originating from the Puy de la Nugère have been sampled (the old trachybasalts at MC24 and MC51 and the youngest trachyandesite well-known "Pierre de Volvic" at MC23). Close to Montmeyre, where previous ages have been reported for older surrounding rocks, we sampled site MC33 from an undated