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Archeomagnetism of Piton de la Fournaise: Bearing on volcanic activity at La Réunion Island and geomagnetic secular variation in Southern Indian Ocean

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ABSTRACT

Historical and other recent lavas from Piton de la Fournaise (La Réunion Island) are studied using the large sample archeomagnetic method which provides here paleodirections of the Earth Magnetic Field with confidence cones between 0.9 and 2.5°, thus offering a precise record of the geomagnetic field and potential dating constraints. Ages of the lavas are known thanks to historical chronicles (from 1708) or ^{14}C dating and their analysis give information about the directional secular variation (SV) in a region where observatory measurements are scarce and not available before the end of the 19th century. For the past 250 yr we find a high value of inclination (−50 to −55°) with respect to the geographic latitude (21°S), connected with a very restricted directional SV. Conversely, the older volcanic units present a larger SV with magnetic inclinations of between −31° and −46°, and declinations from 16°W to 10°E. These results, which are in reasonable agreement with instrumental measurements made on ships in the vicinity of La Réunion, allow us to infer that undated lavas of the northern part of the caldera emanated from eruptions during the second half of the 1700s. Other volcanic products (e.g. Mare Longue flow, Piton Chisny cone and flows and Pointe Langevin), despite their fresh morphology, are necessarily older than about 1500 AD. Further knowledge of the path of the SV in the more distant past, and therefore further archeomagnetic dating, is hampered by the lack of a precise chronology through radiometric or other similar methods. Available models of the geomagnetic field during the last millennium, which suffer from the scarcity of data in the Southern Hemisphere, are discussed in the light of our results.

1. Introduction

Archeomagnetism can be defined as a branch of Paleomagnetism devoted to recent variations of the Earth Magnetic Field (EMF) recorded in baked artifacts whose ages are known thanks to archeological dating (Evans and Hoye, 2005; Gallet et al., 2002; Hagstrum and Blinmann, 2010; Thellier, 1981). By extension, Archeomagnetism also includes volcanic materials resulting from eruptions dated by human history (Genevey et al., 2002; Hoye, 1981; Tanguy et al., 2003). Archeomagnetic variations of the EMF are obviously smaller in amplitude than those over geological timescales and thus require highly precise determinations. Following Thellier's work, we developed at the St. Maur laboratory, a particular methodology involving the collection of large samples (0.5 to 1 kg each) and their measurement using an inductometer specially designed for the size of the samples (LeGoff et al., 2006). This large sample method (LSM) was successfully applied to Italian volcanoes, showing that most of the "historically dated" lavas prior to the 1700s were in fact older by centuries and sometimes more than a millennium (Tanguy et al., 2009), simply because the historical accounts were not precise enough for identification of the lavas themselves.

On La Réunion Island where the shield volcano Piton de la Fournaise erupts frequently (Peltier et al., 2009), it was interesting to seek whether experience gained in Italy might lead to good results, for two purposes. Firstly, there are only a few instrumental measurements of the EMF prior to the end of the 19th century in this region of the Southern Hemisphere, and secondly, the lack of age determination for many of the morphologically recent lavas makes it impossible to reconstruct a comprehensive eruptive history before the 1900s. Here, we present preliminary data on the directional secular variation (SV) obtained from 18 volcanic units ascribed to the last 2000 yr on the basis of historical evidence or ^{14}C dating. In addition, magnetic directional data are provided on some undated lava flows whose well-preserved morphology implies ages within the same range.

Comparisons with available instrumental measurements and field models are also discussed. For instance, the reliability of field modeling over a millennial scale, such as those constructed by Korte

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et al. (2009) (using archeomagnetic, volcanic and sedimentary data), clearly suffers from the poor distribution of data available in the Southern Hemisphere. The new data presented here contribute to filling this gap to further understand the behavior of the Earth's magnetic field.

2. Piton de la Fournaise shield volcano and archeomagnetic sampling

La Réunion Island (21.07°S, 55.32°E) is roughly elliptical in shape (70×50 km) and represents the emerged part of a large hotspot volcano which culminates at Piton des Neiges (3070 m), a deeply eroded ancestor edifice (Lénat et al., 2009). The Piton de la Fournaise (PDLF) active volcano developed in the SE part of the island (21.23°S, 55.71°E) with a current elevation of 2632 m on the northern rim of a double summit caldera named the Bory and Dolomieu craters (Bachèlery, 1981; Michon et al., 2007; Staudacher et al., 2009). Because it was superimposed on the SE slope of its ancestor, PDLF underwent several flank collapses, the last of which formed the Enclos Fouqué, a horseshoe-shaped depression that opens eastward on the Indian Ocean (Fig. 1). The Enclos Fouqué is delimited by steep walls called the Rempart de Bois Blanc to the North and the Rempart du Tremblet to the South. In recent times, PDLF has produced numerous eruptions, usually every few months or years (Lacroix, 1936; Lénat, 1989; Peltier et al., 2009). The eruptions are largely effusive and consist of basaltic fire fountains and lava flows, most of which are channeled within the Grand Brûlé, i.e. the lower reaches of the Enclos Fouqué. Lava flows of different eruptive episodes are largely superimposed and become indistinguishable after a matter of decades. Some eruptions, however, may be qualified "eccentric" (Lacroix, 1936) as they occur outside the Enclos Fouqué, although their mechanism is not different from that of other lateral eruptions. They sometimes built cinder cones such as the Puys Ramond, Piton Chisny, Petit Cratère or Piton Taïpoul. Other eccentric lava flows have outpoured through fissures without forming cinder cones, on the NE flank in 1708, 1977 and 1998 and on the SE flank in 1776, 1800 and 1986. These eruptions are well recorded because of the destruction or unique features which resulted close to inhabited areas. The 1708 lava flow overwhelmed the village of Sainte Rose (Quai La Rose at the time). The 1977 flow partly devastated Piton Sainte Rose, another village of the NE coast. The 1776 lavas formed a prominent delta known as Pointe de la Table on the SE shore. This delta was enlarged further by the 1986 flows which originated in the same area.

Violent explosive eruptions at PDLF are rather scarce and consist of phreatomagmatic activity producing spatter lavas and ash layers that may include carbonized wood suitable for ^{14}C dating, as occurred about 1900 yr ago at the Commerson crater (#17, on Fig. 1) (Bachèlery, 1981). Carbonized wood was also found, though rarely, beneath eccentric lava flows or pyroclastic cones. Minor explosions are mentioned episodically over the past several centuries, sometimes

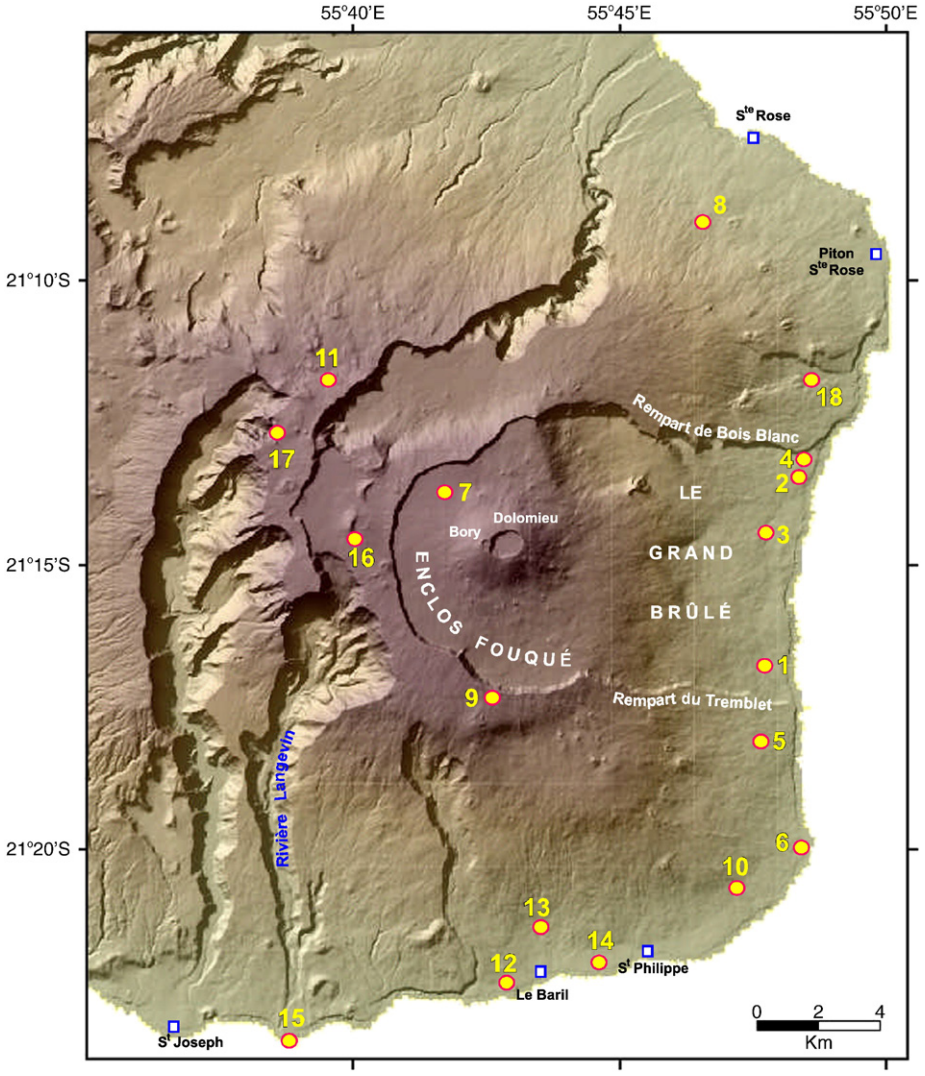

Fig. 1. Map of Piton de la Fournaise (PDLF) showing our archeomagnetic sampling sites. Numbers are those reported in Table 3.