Physics of the Earth and Planetary Interiors 262 (2017) 101–115

Contents lists available at ScienceDirect

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi

# Paleomagnetism and $^{40}Ar/^{39}Ar$ geochronology of the Plio-Pleistocene Boring Volcanic Field: Implications for the geomagnetic polarity time scale and paleosecular variation

Jonathan T. Hagstrum *, Robert J. Fleck, Russell C. Evarts, Andrew T. Calvert

U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, USA

ARTICLE INFO

Article history:
Received 2 May 2016
Received in revised form 14 July 2016
Accepted 30 July 2016
Available online 24 November 2016

Keywords:
Paleosecular variation
Paleomagnetism
Geochronology
Geomagnetic field
Lavas

ABSTRACT

Paleomagnetic directions and $^{40}Ar/^{39}Ar$ ages have been determined for samples of lava flows from the same outcrops, where possible, for 84 eruptive units ranging in age from 3200 ka to 60 ka within the Boring Volcanic Field (BVF) of the Pacific Northwest, USA. This study expands upon our previous results for the BVF, and compares the combined results with the current geomagnetic polarity time scale (GPTS). Lava flows with transitional directions were found within the BVF at the Matuyama-Brunhes and Jaramillo-Matuyama polarity boundaries, and replicate ages corresponding to these and other boundaries have been newly ascertained. Although the BVF data generally agree with GPTS chronozone boundaries, they indicate that onset of the Gauss-Matuyama transition and Olduvai subchron occurred significantly earlier than given in the current time scale calibration. Additional comparisons show that the BVF results are consistent with recent statistical models of geomagnetic paleosecular variation.

Published by Elsevier B.V.

## 1. Introduction

The Boring Volcanic Field (BVF) in western Oregon and Washington, USA, (Fig. 1) has recently been the subject of U.S. Geological Survey (USGS) investigations that included detailed geologic mapping, petrographic and geochemical analyses, and $^{40}Ar/^{39}Ar$ geochronologic and paleomagnetic studies (e.g., Evarts et al., 2009; Fleck et al., 2014). A systematic determination of the BVF's eruptive history was undertaken to assess its anomalous neotectonic setting west of the Cascade arc (e.g., Hildreth, 2007), as well as the magnitude of its concomitant volcanic hazards within the greater Portland and Vancouver metropolitan area. The BVF consists of more than eighty monogenetic volcanic centers, each of which produced relatively small volumes of basalt to low-$SiO_2$ andesite (Evarts et al., 2009). The duration of most eruptive events was likely no more than a few years to decades. The BVF represents a westward extension of Cascade volcanism across the Portland Basin (Hildreth, 2007), and its eastern boundary is arbitrarily placed at longitude 122°W (Allen, 1975; eastern edge of Fig. 1). In the southern and eastern part of the BVF, Boring lavas overlie low-K tholeiite flows (Evarts et al., 2009) that apparently issued from vents near the axis of the High-Cascade volcanic arc (Conrey et al., 2004).

This paper follows on that of Fleck et al. (2014) in which >140 $^{40}Ar/^{39}Ar$ determinations were reported for lava flows and intrusions from within the BVF having ages between ~3200 ka and ~60 ka (Table 1; Fig. 2). Paleomagnetic data were also included from an equivalent number of localities (>160) coincident with, or within the same unit proximal to, the geochronologic sampling sites. To improve age control, duplicate $^{40}Ar/^{39}Ar$ determinations were made for this study on sixteen samples (Table 2), whose ages were near or at chronozone boundaries of the geomagnetic polarity time scale (GPTS; Ogg, 2012; Singer, 2014).

This large data set provides the opportunity to compare these results to recent compilations of the GPTS, and the timing of reversals and excursions of the geomagnetic field during the Late Pliocene and Pleistocene epochs will be the main subject of this paper. Rapidly cooled lava flows can be particularly useful in documenting the ancient geomagnetic field because they provide geologically instantaneous records of the paleofield's characteristics. Moreover, the BVF data set captures transitional fields at two polarity boundaries allowing precise determinations for the timing of these reversals. Also, our data permit us to more tightly bracket the timing of other field reversals and subchrons within this time period. In addition, we have compared the Boring lavas paleomagnetic data with current statistical models of geomagnetic paleosecular variation and previously published data sets (e.g., Constable and Parker, 1988; Tauxe and Kent, 2004; Johnson et al., 2008).

---

* Corresponding author.
*E-mail address:* jhag@usgs.gov (J.T. Hagstrum).

http://dx.doi.org/10.1016/j.pepi.2016.07.008
0031-9201/Published by Elsevier B.V.

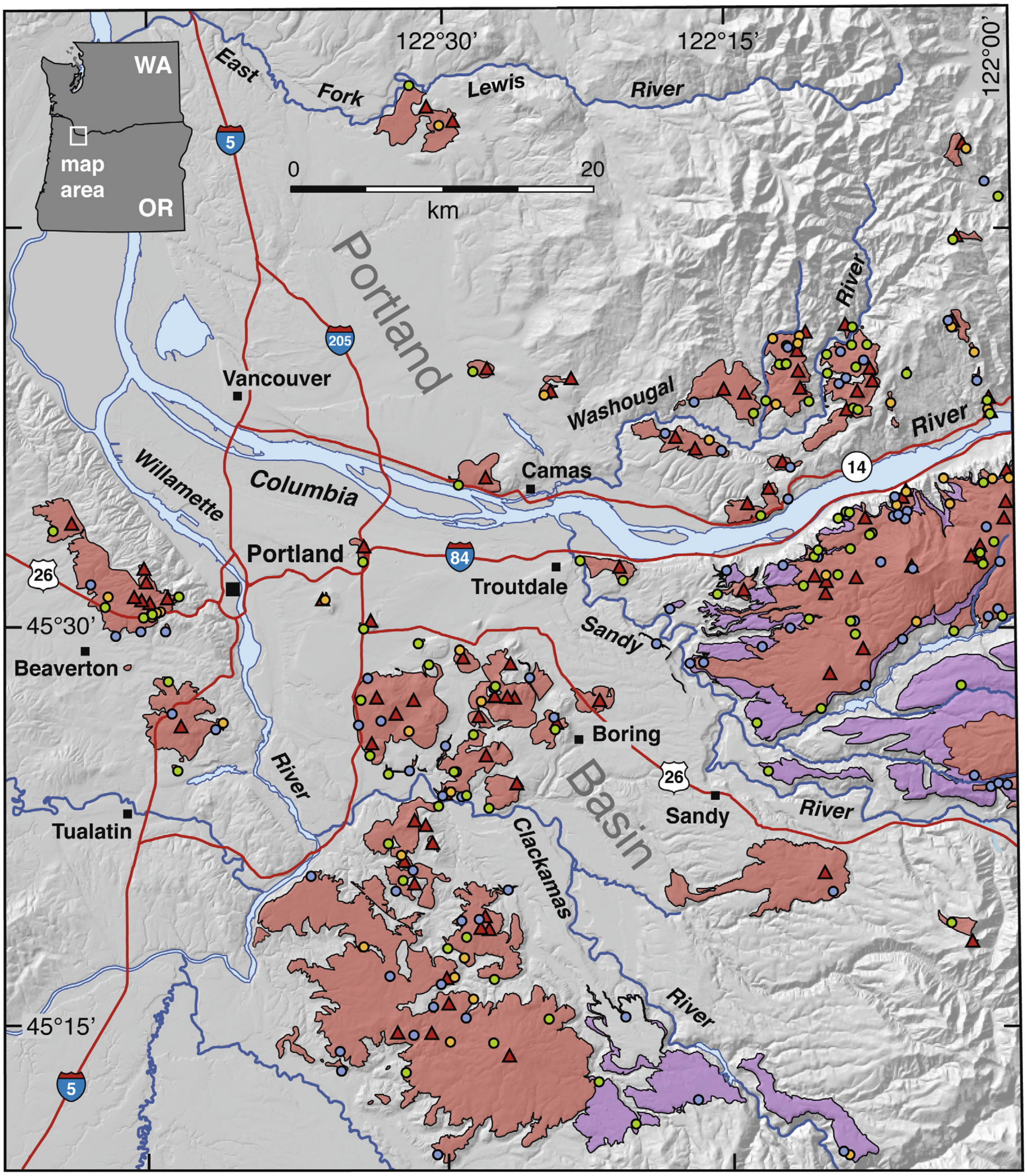

**Fig. 1.** Map showing Boring volcanic rocks in pinkish-orange color, low-potassium tholeiite flows originating in the Cascade arc to the east in purple, as well as major geographic and cultural features of the region. Symbols: green circles, locations of $^{40}$Ar/$^{39}$Ar and paleomagnetic sampling sites; orange circles, $^{40}$Ar/$^{39}$Ar sampling sites; blue circles, paleomagnetic sampling sites; and red triangles, mapped volcanic vents.

## 2. Methods

### 2.1. Paleomagnetism

Oriented samples of Boring lavas and shallow intrusions were collected primarily from artificial (e.g., road, quarry) and stream cut exposures in order to obtain the freshest possible rock. At most sites eight paleomagnetic core samples were drilled and were oriented and marked, prior to removal, using an orienting tool consisting of magnetic and solar compasses and clinometer. Hand samples oriented with a magnetic compass, to be later drilled in the laboratory, were also collected at remote and inaccessible sites to determine a rock unit's polarity.

In the laboratory, usually three 2.2-cm-long specimens were cut from each core sample, and natural remanent magnetizations (NRMs) of specimens from all samples were measured using a three-axis 2G superconducting magnetometer within a magnetically shielded room. The lowermost specimen of the drill core (i.e., least-weathered) was subjected primarily to progressive alternating-field (AF) demagnetization to determine the stability and structure of the specimen's natural remanent magnetization (NRM). Initially a Schonstedt GSD-5 tumbling AF demagnetizer was used, and later AF demagnetizations were accomplished with an automated system sample handling system (Kirschvink et al., 2008). Thermal demagnetizations were done on a smaller number of representative samples, using an ASC TD-48 oven, with a