JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 93, NO. B4, PAGES 3480–3496, APRIL 10, 1988

Basement Heating by a Cooling Lava: Paleomagnetic Constraints

HARALDUR AUDUNSSON AND SHAUL LEVI

College of Oceanography, Oregon State University, Corvallis

Paleomagnetism can provide quantitative, empirical data on basement heating by cooling lava flows, thereby constraining theoretical models of heat transport processes. We used paleomagnetism to study heating in a Frenchman Springs (FS) lava by the overlying cooling Roza flow. The flows belong to the Miocene Columbia River Basalt (CRB) group, and they recorded very different primary paleomagnetic directions: FS has normal polarity, and Roza is transitional. The solid base of Roza typically rests on a few meters of the brecciated and vesicular top of FS, which is otherwise solid. Thermal demagnetization of FS specimens was usually successful at separating the overprinting due to Roza from the primary FS direction and for establishing limits on the unblocking temperatures of the overprinting. The unblocking temperatures agree well between sites separated by up to 70 km, irrespective of Roza thickness at the sites, which vary from 35–62 m. In specimens from 0.3 to 1 m below the contact, the overprinting was unblocked in the laboratory between 600 and 300 °C and close to 200 °C at 4-m depth. No overprinting was apparent below 6 m. The influence of longer heating times in the field on the unblocking temperatures was estimated by viscous remanence acquisition at elevated temperatures. The results suggest typical reductions of the unblocking temperatures by a few tens of degrees. Our observations imply much less heating of the basement than predicted by simple conductive thermal models. Accounting for the low conductivity breccia in the contact zone results in a better agreement with the experimental temperature profile, but unrealistically low conductivities are needed to sufficiently reduce the absolute temperature. The observed heating is effectively explained by postulating a wet basement at the time of Roza extrusion, as well as groundwater, to maintain a low-temperature isotherm (~100 °C) a few meters below the contact. The presence of water during the time of Roza extrusion and some other CRB flows has been suggested by field observations.

INTRODUCTION

We conducted a paleomagnetic study to determine basement heating by an overlying, cooling lava flow, each with a distinct primary paleomagnetic direction. Knowledge of basement heating will lead to a better understanding of dominant heat transfer mechanisms and thermal evolution of the cooling lava. These data are necessary to relate paleomagnetic measurements to the time of remanence acquisition, so that thick lava flows with sufficiently protracted cooling histories might be used to study high-resolution geomagnetic fluctuations, including normal secular variation and polarity transitions [*Furlong and Shive*, 1983; *Audunsson and Levi*, 1984; *Nyblade et al.*, 1987].

A lava flow crystallizes and cools both through its upper surface and base, thereby heating the underlying basement. A simple solidification and cooling model, assuming heat transfer by conduction only and with constant thermal conductivity and heat capacity, predicts substantial basement heating of up to 300 °C to a depth of half the thickness of the cooling upper flow, giving a high estimate for the cooling time of the flow and the extent of basement heating.

Structural and textural studies of thick Columbia River Basalt (CRB) flows have led *Long and Wood* [1986] to conclude that extensive flooding or extremely high rainfall are required to explain the multiple intraflow alternations of entablature and colonnade structures, which suggest rapid cooling of parts of the interior of these flows. In contrast, relatively simple thermal models were successful in describing the thermal evolution of Alae lava lake in Hawaii [*Peck et al.*, 1977]. However, the cooling of lavas can be very complex, and simple thermal models may be insufficient to explain their thermal evolution, recently shown by paleomagnetic measurements of thick consecutive lava flows [*Nyblade et al.*, 1987].

When a rock with primary thermal remanent magnetization (TRM) is reheated and allowed to cool in a nonzero magnetic field, the primary TRM may be replaced by a total or partial TRM (PTRM) and a high-temperature viscous remanent magnetization (VRM) parallel to the new secondary field. In cases where physical and chemical changes of the magnetic minerals can be ignored, the proportions of the primary and secondary remanences in the rock are determined principally by heating temperature, spectrum of the blocking temperatures, relative intensities of the external fields, and the time the rock spent at and near the maximum temperature. If the rock is heated above its highest blocking temperature, it will be totally remagnetized, but if the maximum heating temperature is within the blocking spectrum, it will usually be only partially remagnetized.

Néel [1949] showed explicitly that for an assemblage of identical noninteracting single-domain (SD) particles cooling from above their Curie temperature (T_c), the magnetic moments are blocked in a narrow temperature range, the blocking temperature, T_b, determined by composition-dependent magnetic properties, grain volumes and shapes, and the associated magnetic anisotropies. The magnitude of the external field and time spent at elevated temperatures will also influence T_b. Thus, blocking temperatures of a PTRM produced in an external field, H_{ex}, and time interval Δt will be different from the unblocking temperatures, T_{ub}, of that PTRM, determined from laboratory thermal demagnetization

Paper number 7B3015.
0148-0227/88/007B-3015$05.00