JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 97, NO. B4, PAGES 4349–4360, APRIL 10, 1992

# Magnetic Property Zonation in a Thick Lava Flow

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In this study, grain size and composition-dependent magnetic properties of titanomagnetite minerals are used as indicators of intraflow structures and magmatic evolution in an extensive and thick (30–60 m) basaltic lava flow. Similar zonation occurs in this flow at three localities separated by tens of kilometers. The magnetic properties subdivide the flow to three zones. The upper layer, representing the top 1/3 of the lava (≤ 20 m), has higher magnetic stability due to smaller and more deuterically oxidized titanomagnetite grains, approaching pure magnetite. The central layer in the underlying 2/3 of the flow (≤ 35 m) has larger, magnetically less stable, and less oxidized grains with relatively uniform magnetic properties. The basal layer, the bottom 1/10 of the flow (≤ 5 m), has near primary, least oxidized titanomagnetites ($Ulv_{68}Mag_{32}$). The upper intraflow boundary of the magnetic properties appears to coincide with the transition from entablature (above) to colonnade (below), distinguishing between regions of faster and slower cooling. Microprobe data indicate that the intraflow oxidation state ($Fe^{3+}/Fe^{2+}$) of the initially precipitated primary titanomagnetites increases with falling equilibrium temperature from the flow margins to a maximum near the center, the position of lowest equilibrium temperature. In contrast, Curie temperature measurements indicate that titanomagnetite oxidation increases with height in the flow. Modification of the initially symmetric equilibrium titanomagnetite compositions was caused by subsolidus high-temperature oxidation possibly due to hydrogen loss produced by dissociation of magmatic water, as well as unknown contributions of circulating air and percolating water from above. The titanomagnetites of the basal layer of the flow remain essentially unaltered.

## INTRODUCTION

### *Background*

To improve the resolution of paleomagnetic results from thermal remanent magnetization (TRM) in igneous rocks would require a more fundamental understanding of the origin and evolution of the magnetic particles, which directly reflects on remanence blocking and its stability.

In basaltic rock, the magnetic properties are due primarily to iron-titanium oxide minerals, precipitating from cooling magmas. In thick lavas a range in magmatic conditions and extended thermal histories influence the composition and oxidation trends, microscopic structures, and grain sizes of the magnetic minerals, thus controlling their magnetic behavior. Conversely, spatial variations of the magnetic properties can be useful for delineating structures and revealing aspects of magmatic and thermal evolution of volcanic bodies [*Watkins and Haggerty*, 1967].

The iron-titanium oxides are usually a late stage crystallization phase in basaltic melts at low pressure [e.g., *Hill and Roeder*, 1974]. Particle sizes of the iron-titanium oxides are related to the cooling rate of the magma, and their composition depends, in large part, on the availability of oxygen. In a quenched melt, iron-titanium oxides may comprise only a minor fraction of the crystalline rock, or be absent altogether. For slower-cooling igneous units the iron-titanium oxide grains may be larger and exhibit compositional evolution, i.e., exsolution lamellae and high-temperature oxidation [e.g., *O'Reilly*, 1984]. The composition of associations of some iron-titanium oxide phases can be used to infer the absolute temperature and oxygen fugacity at their lowest equilibrium temperature [e.g., *Buddington and Lindsley*, 1964; *Anderson and Lindsley*, 1988].

Magmatic bodies with sufficiently protracted cooling histories, such as intrusions and thick lavas, may preserve continuous records of geomagnetic secular variation. Correct interpretation of these data requires knowledge of the sequence of remanence blocking in the unit and an absolute time scale. The relative timing of blocking would be further complicated by spatial variation of the parameters that control remanence blocking within the magmatic body.

We measured profiles of different magnetic properties in a single basalt flow at several sites. The flow thickness varies from 30 to 62 m, corresponding to 10 to 50 years for the flow to have cooled everywhere to below 600°C [e.g., *Audunsson*, 1989]. Because the lava is relatively fresh, it retains much of its primary magmatic zonation. The flow has strongly layered magnetic properties, consistent with the inferred cooling history and correlated with intraflow structures as well as conditions during the initial formation of the magnetic grains.

### *Geological Setting*

Our data are from the tholeiitic Roza Member of the middle Miocene Columbia River Basalt (CRB) Group in northwestern United States. The Roza is one of the most voluminous and extensive CRB units with estimated area and volume of 40,000 $km^2$ and 1500 $km^3$, respectively [*Swanson et al.*, 1975]. The Roza flooded across the topographically low Pasco Basin in south central Washington State from source-dikes in the southeast part of the state. The lava ponded in the Pasco Basin with thicknesses exceeding 60 m, approximately 150 km from its source.

In the Pasco Basin we sampled the Roza flow in two vertical drill cores, DC2 and DC12, 11 km apart, where the flow is 62 and 54 m thick, respectively [*Reidel and Fecht*, 1981], core recovery was nearly 100%, and the Roza appears to be a single cooling

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Paper number 91JB01508.
0148-0227/92 /91JB-01508$05.00