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Incorporation of seawater into mid-ocean ridge lava flows during emplacement

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Abstract

Evidence for the interaction between seawater and lava during emplacement on the deep seafloor can be observed in solidified flows at a variety of scales including rapid quenching of their outer crusts and the formation of lava pillars through the body of the flow. Recently, an additional interaction, incorporation of heated seawater (vapor) into the body of a flow, has been proposed. Large voids and vesicles beneath the surface crusts of mid-ocean ridge crest lobate and sheet lava flows and lava drips found within those cavities have been cited as evidence for this interaction. The voids resulting from this interaction contribute to the high porosity of the shallow ocean crust and play an important role in crustal permeability and hydrothermal circulation at mid-ocean ridges, and thus it is important to understand their origin. We analyze lava samples from the fast-spreading East Pacific Rise and intermediate-spreading Galapagos Spreading Center to characterize this process, identify the source of the vapor, and investigate the implications this would have on submarine lava flow dynamics. We find that lava samples that have interacted with a vapor have a zone of increased vesicularity on the underside of the lava crust and a coating of precipitate minerals (*i.e.*, crystal fringe) that are distinct in form and composition from those crystallized from the melt. We use thermochemical modeling to simulate the reaction between the lava and a vapor and find that only with seawater can we reproduce the phase assemblage we observe within the crystal fringes present in the samples. Model results suggest that large-scale contamination of the lava by mass exchange with the vapor is unlikely, but we observe local enrichment of the lava in Cl resulting from the incorporation of a brine phase separated from the seawater. We suggest that high eruption rates are necessary for seawater incorporation to occur, but the mechanism by which seawater enters the flow has yet to be resolved. A persistent vapor phase may be important in inhibiting the collapse of lava flow roofs during natural waxing and waning of lava levels during emplacement allowing lava pathways to be maintained during long lived eruptions. In addition, we illustrate the potential for a persistent vapor layer to increase local flow rates within submarine flows by up to a factor of three, thereby influencing how lava is distributed across the ridge crest.

Keywords: submarine; lava; Mid-ocean ridge; seawater; vapor; thermochemical modeling

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1. Introduction

The volcanic layer 2A at mid-ocean ridges (MORs) is constructed from a series of overlapping lava flows that comprise the upper few hundred meters of oceanic crust. The physical properties of the shallow crust (*e.g.*, porosity and permeability) place important controls on hydrothermal fluid pathways, and as a result influence macro- and micro-biological habitat both at the seafloor and in the subsurface. The chemical characteristics of lavas collected from MOR axial seafloor provide an important record of magmagenesis and mantle processes beneath the ridge crest. In order to understand the broad scale chemical and physical properties of the upper ocean crust, it is necessary to understand the generation of its component parts—individual lava flows. Our knowledge of volcanic processes in the deep ocean is based almost entirely on examination of the solidified products of past eruptions. Although analogous volcanic phenomenon can be actively observed in terrestrial settings, there are significant differences between these environments that impact the mode and processes inherent to seafloor volcanic eruptions.

One important way in which MOR eruptions are different from their subaerial counterparts is their eruption into cold (0–2 °C) seawater at greater than 200 bars of hydrostatic pressure. The extent to which this difference in environmental conditions is reflected in the dynamics of eruptions is not known, because no deep-sea eruptions have been directly observed, and only one has been indirectly measured during emplacement [1]. However, evidence for the interaction between seawater and lava during emplacement can be observed in solidified flows at a variety of scales. At the scale of an entire flow, interaction with cold seawater is responsible for rapidly quenching the outer surface of the lava more effectively than air does [2]. Thick, glassy lava crusts, slower cooling and crystallization of the flow interiors, unique lava forms (*e.g.*, pillows), and lava flow inflation all reflect this process [3–5]. At a more local scale, heated seawater and/or hydrothermal fluids produce hollow conduits (*i.e.*, lava pillars) that

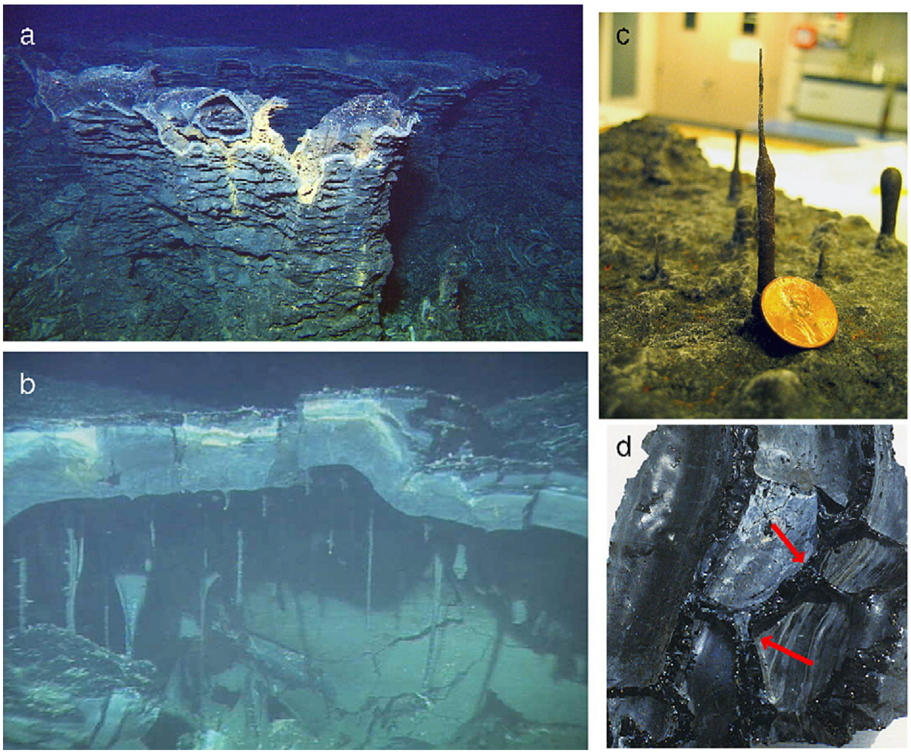

Fig. 1. a) A large lava pillar in the axial summit trough of the East Pacific Rise at 9°50′ N. The lava pillar is ~2 m tall. The body of the flow has drained away leaving a series of sub-horizontal selvages along the sides of the pillar. b) Image of a vapor cavity within a lobate flow at the EPR near 9°43′ N. Lava crust is approximately 4 cm thick and lava drips are 3–10 cm in length. c) Image of a delicate lava drip on the interior of a lava crust sample collected from the Galapagos Spreading Center. d) Underside of lava crust collected at the EPR near 9° 50′ N showing septa between trapped vesicles that join in triple-junction topology (arrows). Septa, at their widest, are ~1 cm across.