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The pumice raft-forming 2012 Havre submarine eruption was effusive

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ABSTRACT

A long-standing conceptual model for deep submarine eruptions is that high hydrostatic pressure hinders degassing and acceleration, and suppresses magma fragmentation. The 2012 submarine rhyolite eruption of Havre volcano in the Kermadec arc provided constraints on critical parameters to quantitatively test these concepts. This eruption produced a >1 km^3 raft of floating pumice and a 0.1 km^3 field of giant (>1 m) pumice clasts distributed down-current from the vent. We address the mechanism of creating these clasts using a model for magma ascent in a conduit. We use water ingestion experiments to address why some clasts float and others sink. We show that at the eruption depth of 900 m, the melt retained enough dissolved water, and hence had a low enough viscosity, that strain-rates were too low to cause brittle fragmentation in the conduit, despite mass discharge rates similar to Plinian eruptions on land. There was still, however, enough exsolved vapor at the vent depth to make the magma buoyant relative to seawater. Buoyant magma was thus extruded into the ocean where it rose, quenched, and fragmented to produce clasts up to several meters in diameter. We show that these large clasts would have floated to the sea surface within minutes, where air could enter pore space, and the fate of clasts is then controlled by the ability to trap gas within their pore space. We show that clasts from the raft retain enough gas to remain afloat whereas fragments from giant pumice collected from the seafloor ingest more water and sink. The pumice raft and the giant pumice seafloor deposit were thus produced during a clast-generating effusive submarine eruption, where fragmentation occurred above the vent, and the subsequent fate of clasts was controlled by their ability to ingest water.

1. Introduction

Submarine volcanic eruptions may be fundamentally different from those on land owing to the high hydrostatic pressure provided by the ocean, which inhibits degassing and hence magma acceleration and fragmentation. The records of such eruptions are few and our understanding is limited by the challenge in directly witnessing eruption processes and sampling and characterizing the deposits from those eruptions. Indeed, overcoming this biased understanding of volcanic eruptions was highlighted by a National Academies report (National Academies, 2017): "What processes govern the occurrence and dynamics of submarine explosive eruptions"?

Silicic magmas that erupt more than a few hundred meters below sea-level give rise to eruption styles distinct from those on land owing to the contrasting properties of the ambient fluid (water vs air) into which the magmas erupt (Cashman and Fiske, 1991). For example, clasts that erupt at the seafloor are initially buoyant, but ingest water into pore space as they cool (e.g., Whitham and Sparks, 1986); hence fragmented magma can either rise to the surface to form rafts, or feed submarine density currents if the clasts become waterlogged (Allen and McPhie, 2009).

One distinctive facies of both modern and ancient clastic deposits from submarine silicic eruptions is voluminous deposits of

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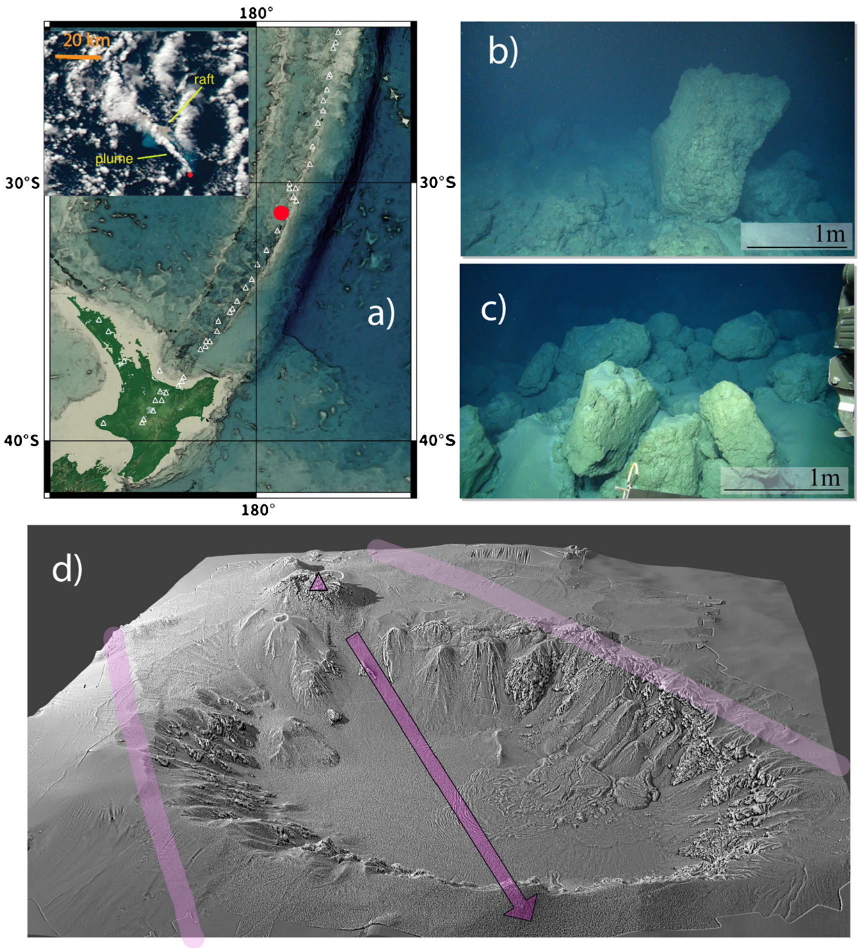

Fig. 1. (a) Location of the Havre volcano (red circle) in the Kermadec arc. Inset shows the raft and plume on 19 July, 01:26 UTC. Inset scale bar is 20 km long. Plume and raft show the transport direction to the northwest. Example seafloor giant pumice clasts showing curviplanar surfaces (b) and typical deposit (c). (d) Shaded relief map showing the vent location (triangle) at a depth of 900 m; arrow shows the dispersal axis of seafloor giant pumice (the same as the transport direction in a), and the light purple lines bound the region containing those clasts. Caldera is 4.5 by 5 km in size. Viewing direction is looking south. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

giant (>1 m) pumice clasts (e.g., Kato, 1987; Kano et al., 1996; Kano, 2003; Allen and McPhie, 2009; Allen et al., 2010; Jutzeler et al., 2014). These clasts often have one or more quenched margins with curviplanar joints perpendicular to the cooling surface that suggest they quenched in water (e.g., Wilson and Walker, 1985; Allen et al., 2010; von Lichtan et al., 2016; Fig. 1). Otherwise, submarine pumice vesicularities are similar to those produced in subaerial Plinian eruptions (e.g., Barker et al., 2012) and hence it has been proposed that fragmentation mechanisms are also similar for large (>1 km^3) submarine equivalents (e.g., Allen and McPhie, 2009; Shea et al., 2013). There are, however, textural differences: pumice clasts from deep submarine eruptions tend to have smaller bubble number densities, lack very small vesicles (<10 µm), and display a narrower range of modal vesicle sizes (Rotella et al., 2015). Clasts have also been proposed to form from buoyant bubbly magma as it exits the vent by “viscous detachment or by the development of cooling joints” (Rotella et al., 2013), an eruption style that would not fit neatly into either the “effusive” or “explosive” categories used to describe subaerial eruptions. Pumice clasts can also form by spallation from a pumiceous carapace on effusive domes (e.g., Cas and Wright, 1987; Kano, 2003; Allen et al., 2010).

In July 2012, approximately 1.2 km^3 of rhyolite pumice clasts erupted at a water depth of 900 m from the submarine Havre volcano in the Kermadec volcanic arc (Carey et al., 2014; Fig. 1). The majority of the pumiceous material formed a raft of floating clasts that was widely dispersed in the western Pacific Ocean (Jutzeler et al., 2014; Carey et al., 2018). A second clastic product of this eruption is a 0.1 km^3 deposit of giant pumice clasts on the seafloor around the inferred vent. An outstanding question is whether these seafloor giant pumice clasts and raft pumice originated from the same eruptive phase. Though not conclusive, the vesicularities, composition, microtextures (e.g., bubble number densities, crystallinity, microlite mineralogy), and macrotextures (e.g., banding), are similar as is their primary axis of dispersal (Carey et al., 2018). If the raft and seafloor pumice did originate from the same eruptive episode, their different fate, i.e., whether they floated or sank, thus requires seafloor giant pumice to ingest water more effectively than clasts that were transported into the raft.

Here we use a model for magma ascent, constrained by estimates of the eruption rate for the pumice raft and a variety of measurements on erupted materials, to show that buoyant magma reached the seafloor prior to fragmenting. We then investigate how pumice clasts from the raft and seafloor ingest water as they cool and find that seafloor pumice ingest water more efficiently by trapping very little gas. We thus infer that vesicular coherent magma extruded into the ocean. The magma quenched and fragmented non-explosively to form the pumice clasts that then either remained afloat because they retained enough gas or, if they waterlogged, settled to the seafloor.