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Simultaneous Effusive and Strombolian Eruptions along Mid-Ocean Ridges

D. Clague

Monterey Bay Aquarium Research Institute, Moss Landing, CA, 95039, USA, clague@mbari.org

Mid-ocean ridges are commonly thought to erupt effusively, with flow morphology ranging progressively from pillows to lobate and sheet flows mainly determined by increasing eruption rate. Employing a new sampling strategy, we have discovered that pyroclasts are produced during most mid-ocean ridge eruptions, regardless of water depth. Pyroclasts have now been recovered from the Gorda and Juan de Fuca Ridges in the northeast Pacific, the northern and southern East Pacific Rise, and the Fiji Back-arc Basin. Pyroclasts were sampled using sediment push cores and a small suction sampler that "vacuums" the surface of flows. Finding pyroclasts at all young lava flow we have sampled leads us to propose that production of pyroclasts during strombolian activity is a ubiquitous feature of mid-ocean ridge eruptions over a wide depth range, including depths exceeding the critical point of seawater. At such pressures, steam cannot form to disrupt the molten lava.

Pyroclasts are small glass fragments of Pele's hair, limu o Pele (bubble-wall fragments), folded and twisted ribbons, tube pumice, and dense angular fragments. Many of these particles contain up to about 10% elongate stretched vesicles resembling those commonly trapped in viscous rhyolitic glass, except these are in fluid basaltic melts. The limu o Pele range in size up to more than a cm across and in thickness from a few microns to nearly 1 mm; many are contorted and folded, and sometimes tack-welded to themselves. Pele's hairs up to 2 cm long are as thin as 1-2 microns in diameter. Many are bent or coiled, and some have tack-welded into intricate shapes.

Such pyroclasts form during strombolian eruptions driven by discharge and bursting of gas slugs that disrupt the molten surface of the lava at the top of a dike or within lava ponds over the vents. Many of the limu o Pele fragments preserve a curved surface

that can be used to estimate 2-8 cm diameter gas bubbles that produced the fragments. These gas bubbles appear to decrease in size with increasing eruption depth. Sampling on and around 5 historic-aged flows along the Juan de Fuca and Gorda Ridges reveals that the abundance of pyroclasts correlates with the inferred eruption rate; eruptions that form pillow ridges and sheet flows produce rare and abundant pyroclasts, respectively. The correlation of eruptive style and abundance of pyroclasts supports the idea that larger gas discharge increases both pyroclastic activity and effusion rate. We infer that mid-ocean ridge magmas are more gas rich than generally thought and that rise of this coalesced gas phase helps accelerate magmas towards the sea floor and eruption.

These pyroclasts are widely distributed following their formation, most likely by entrainment in rising plumes of seawater heated by the flows. Once carried aloft, the glass particles are dispersed by currents. A grid of 130 pushcores on the southern Gorda Ridge showed that pyroclasts from a single eruption traveled about 3 km in all directions, with particle size and abundance decreasing away from the inferred vents. Pyroclasts from submarine strombolian eruptions, rather than forming thick deposits close to their vents, are widely dispersed and form extensive thin blankets.