The morphology and effusion rate of deep submarine silicic lava flows and domes emplaced during the Havre 2012 eruption, Kermadec Arc, New Zealand

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1. Introduction
The eruption of Havre 2012 was the largest deep submarine silicic eruption in the modern history (Carey et al. 2014). The eruption was first detected by an airline passenger who saw extensive rafts of floating pumice on the ocean. The later investigation identified the onset of pumice dispersion on the 18th July 2012, which was accompanied by a subaerial plume and hotspot on the NASA MODIS satellite imagery. In addition, significant seismicity at the Havre caldera was measured during this time. Three months after the event, R/V Tangaroa of NIWA (National Institute of Water and Atmospheric Research, New Zealand) visited the Havre volcano and mapped the area using a EM120 multibeam system. This survey detected several new features along the caldera rim which did not exist in 2002. However, the resolution of the map did not permit the identification of the types of volcanic features present.
2. MESH Cruise
In 2014, the Mapping Exploration & Sampling at Havre (MESH) cruise was conducted to visit the seafloor and performed a geological field study of the 2012 eruption deposits. The R/V Roger Revelle (Scripps Institution for Oceanography, UCSD) and two unmanned vehicles, Sentry AUV (Autonomous Underwater Vehicle), and Jason ROV (Remotely Operated Vehicle) of WHOI (Woods Hole Oceanographic Institute) facilitated the voyage. The Sentry AUV mapped the full area of the 5-km wide Havre caldera with high-resolution bathymetry (1-m grid). The ROV Jason conducted traverses along the eruption products discovered by the Sentry high-resolution map, conducting sampling for the rocks and sediments at the seafloor.
3. Results and Discussions
The MESH cruise identified six lava flows (A~D,F,G), eight lava domes (H,I,K~P), two units of ash and lapilli deposits (AL,ABL), two debris avalanche deposit (MF1,2), and an extensively emplaced giant pumice deposit (GP) as the products of the 2012 eruption (Fig. 1). Most of the effusive products which this research focuses on have porphyritic textures with the phenocrysts of plagioclase, and pyroxene. Their whole rock composition ranges from 68~72% SiO2 and inferred that the Havre 2012 magma was rhyodacitic.
The series of lava consists of both lava flows (length of 0.6~1.2 km) and lava domes (height of 70~250 m). Their vents were distributed along the fissures at the southern rim of the caldera which strongly infers structural control for magma ascent. The western part of the fissure is dominated by lava flows (A~G) which immediately descended the 30° slope of the caldera wall. They have clear levee structure with 70~150 m thickness, compression ridges for 10~30 m intervals, and talus with >20 degrees. The fissures from the middle to east formed small lava domes (H~P), although the easternmost one (O-P complex) is exceptionally large (1.1 x 0.8 km elliptical base with 250 m height). The total volume of these effusive products was 0.24 km^3.
The chronology of the lava effusion has been investigated using the stratigraphical relationship to the GP unit, which was dispersed on 18th July. This enables constraints on the lava effusion rate between the 18th July to 19th August (NIWA voyage). The maximum volume of the lava post-dating GP (0.19 km^3 for A, F~P) draws the maximum effusion rate of 25 m^3/s for 90-days average. This values comparable to other well-constrained subaerial silicic lavas, such as 50 m^3/s for 20-days at

Cordon-Caulle 2011 eruption (Bertin et al. 2015), or 66 m^3/s for 14-days at Chaiten 2008 eruption (Pallister et al. 2013).

4. Conclusion

The Havre 2012 eruption produced 0.24 km^3 of rhyodacite lava flows and domes. The largest lava dome grew to the height of 250m and the longest lava flow advanced 1.2km from its vent despite the deep submarine environment. These investigations have calculated submarine silicic lava effusion rates (25 m^3/s) for the first time.

Keywords: Submarine volcano, Submarine caldera, Lava flow morphology, Effusion rate, Rhyolitic magma