***Supplementary Material***

**Characteristics and deposit stratigraphy of submarine-erupted silicic ash, Havre volcano, Kermadec Arc, New Zealand.**

**Arran. P. Murch, James. D.L. White\* and Rebecca. J. Carey**

**\*Correspondence:** James D.L. White: james.white@otago.ac.nz

**1. Supplementary Data**

**1.1. Seafloor sampling methods**

Samples were collected from the seafloor at Havre volcano using remote operated vehicle (ROV) Jason and employing a range of techniques. Coherent pumice and dense rock could be sampling using a robotic manipulator. The manipulator however, cannot collect fine-grained clastic deposits, or weak aggregates. To collect such samples, three other devices were employed; push cores, scoops, and vacuum sampling.

A push core is a 3.5” diameter plastic tube with a handle at one end and open at the other; a core catcher supplemented with stretch-nylon fabric is mounted on the inside near the opening. This tube is designed to be inserted into sediment until either full or until the tube can be inserted no further, then retrieved with the sampled sediment in the tube. For many Havre samples, unfortunately, the tube was either inserted repeatedly and/or rotated to improve penetration. The rotation and multiple plunging during sampling via push cores generally destroyed any deposit layering present. Only two cores returned samples with preserved stratigraphy.

A scoop is a frame holding two layers of netting, one fine (200 µm) and one coarse (1 mm), on a metal rod. The scoop is dragged through the sediment and then placed into a sample box mounted on Jason. ‘Scooping’ generally destroys any deposit layering present, but one sample did preserve layering in a sediment clump.

Vacuum sampling uses a pump to draw seawater and sediment into a tube that exits into one of several water-filled sampling canisters where particles are collected; the excess water is released through two filters; a >1 mm mesh and a 1000-200 µm fabric filter. Vacuum sampling disaggregates sampled material, destroying any fabric or layering present. The vacuum sampler was effective in deposits with particles up to 3 cm in diameter.

**1.2. Site-specific information on sampling of the Ash with Lapilli Unit.**

Sampling from the tops of giant pumice clasts at sites HVR132 and HVR163 exposed the most complex stratigraphy, showing four layers in the AL Unit with similar features and thicknesses at both locations (Fig. 2e-f.). At these locations, 2.5 km apart on the caldera floor, the basal layer directly on top of the giant pumice is about 4 cm thick, relatively coarse-grained (coarse ash) and light in colour. Overlying this layer is a 2 cm thick highly cohesive layer with ~ 5 vol.% of coarser dark particles. Above this layer is an approximately 2 cm thick, coarser-grained coarse ash layer, comprising dominantly dark coloured grains with rare light-coloured grains (Fig. 2e, 2f). The top layer is approximately 4 cm thick and appears light grey at HVR132. Like the second layer, the top layer is highly cohesive and very fine-grained. In both locations the upper surface of the top layer appears light brown.

Sampling of HVR196, proximal to Dome OP to the southeast, from on top of a GP clast exposed two layers in the AL Unit (Fig. 2c.). Directly overlying the GP is a ~2 cm thick layer of white fine lapilli and coarse ash in a grey matrix of finer ash. Overlying this is a 1-2 cm thick grey fine-grained cohesive layer, the upper surface of which appears light brown. The two layers observed here have similarities with the basal and top layers observed in HVR132 and HVR163, with the significant difference that in HVR196 there is only a single cohesive fine-grained layer.

Samples taken from the tops of GP clasts at HVR229, HVR232, and HVR272, all on the northwest caldera rim, exposed only a single layer (Fig. 2d.). At HVR229 the layer is 1.5 cm thick, while at HVR232 and HVR272 the layer is approximately 3 cm thick. The layer is a cohesive light grey extremely to very fine ash deposit, the upper surface of which appears light brown. The single layer observed at HVR229, HVR232, and HVR272 has similar characteristics to the top layer observed in HVR132 and HVR163.

In addition to the four layers present in HVR132 and HVR163 another deposit was observed on the seafloor overlying Lava G and at location HVR070 ~150 m to the northwest of Lava G (Fig. 2e-f.). It consists of highly elongate tube-pumice ash and lapilli and at HVR070 was approximately 0.5 m thick. At both locations the deposit of highly elongate tube-pumice ash and lapilli is overlain by a cohesive fine-grained layer, with no other layers observed.

In pushcore HVR159 similar layer stratigraphy, thicknesses and characteristics to those in vertical exposures through the AL Unit at HVR132 and HVR163 are observed (Fig. 2a-b and 3.). The basal fine to coarse ash layer, the 2.5 cm thick dark layer, and the cohesive upper layer are all consistent with seafloor observations.

# 2. Supplementary Figures and Table

# 2.1. All Seafloor samples of the Ash with Lapilli Unit

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sample Name | Collection method | Latitude | Longitude | Elevation (mbsl) |
| HVR\_002 | Push core | -31.12351646 | -179.0064123 | 943.75 |
| HVR\_004 | Push core | -31.12293853 | -179.0058133 | 946.2 |
| HVR\_005 | Push core | -31.12292781 | -179.0058175 | 945.97 |
| HVR\_017 | Push core | -31.12603462 | -179.0272806 | 991.31 |
| HVR\_018 | Push core | -31.12603282 | -179.0272831 | 991.31 |
| HVR\_019 | Scoop | -31.1260315 | -179.0272828 | 991.4 |
| HVR\_024 | Push core | -31.1257272 | -179.0309827 | 980.03 |
| HVR\_027 | Push core | -31.12560255 | -179.0352229 | 996.51 |
| HVR\_031 | Push core | -31.12635316 | -179.0385246 | 889.32 |
| HVR\_039 | Push core | -31.1041308 | -179.0379003 | 1508.09 |
| HVR\_040 | Push core | -31.1041279 | -179.0379014 | 1508.06 |
| HVR\_042 | Push core | -31.1084433 | -179.0409833 | 1483.3 |
| HVR\_047 | Push core | -31.1107206 | -179.0433318 | 1466.58 |
| HVR\_050 | Scoop | -31.1137272 | -179.0435333 | 1428.89 |
| HVR\_054 | Push core | -31.1178165 | -179.0419366 | 1341.08 |
| HVR\_058 | Push core | -31.1210883 | -179.0486191 | 958.78 |
| HVR\_059 | Push core | -31.1210809 | -179.0486013 | 955.82 |
| HVR\_060 | Scoop | -31.1210684 | -179.048606 | 954.83 |
| HVR\_062 | Slurper | -31.1210966 | -179.0485574 | 950.71 |
| HVR\_065 | Push core | -31.1208973 | -179.0480273 | 949.74 |
| HVR\_067 | Scoop | -31.1207194 | -179.0488246 | 964.24 |
| HVR\_070 | Scoop | -31.1210727 | -179.0485561 | 951.5 |
| HVR\_072 | Push core | -31.1211274 | -179.0478345 | 955.5 |
| HVR\_077 | Push core | -31.1210878 | -179.0475806 | 949.14 |
| HVR\_084 | Slurper | -31.12090091 | -179.0458161 | 960 |
| HVR\_091 | Push core | -31.1252021 | -179.0409089 | 975.24 |
| HVR\_098 | Push core | -31.12533665 | -179.0348949 | 989 |
| HVR\_100 | Push core | -31.12531064 | -179.0347642 | 988.24 |
| HVR\_105 | Scoop | -31.12713113 | -179.0321702 | 962.85 |
| HVR\_107 | Slurper | -31.1271539 | -179.0318084 | 962.74 |
| HVR\_108 | Push core | -31.12715151 | -179.0318096 | 963.14 |
| HVR\_120 | Scoop | -31.13262652 | -179.0126988 | 756.25 |
| HVR\_122 | Push core | -31.13334664 | -179.0121838 | 716.98 |
| HVR\_123 | Push core | -31.13721682 | -179.0171635 | 873.09 |
| HVR\_124 | Push core | -31.13722351 | -179.0171929 | 874.38 |
| HVR\_127 | Scoop | -31.1384347 | -179.0131238 | 960.79 |
| HVR\_131 | Scoop | -31.1342714 | -179.0119343 | 695.75 |
| HVR\_132 | Slurper | -31.1026467 | -179.0286233 | 1512.51 |
| HVR\_134 | Push core | -31.1046489 | -179.0364448 | 1508.61 |
| HVR\_135 | Slurper | -31.1039916 | -179.0385242 | 1502.44 |
| HVR\_136 | Push core | -31.1027492 | -179.0432429 | 1488.05 |
| HVR\_149 | Slurper | -31.1155468 | -179.0472319 | 1202.97 |
| HVR\_158 | Push core | -31.1197975 | -179.0549 | 953.04 |
| HVR\_159 | Push core | -31.1197974 | -179.0549 | 953.04 |
| HVR\_160 | Push core | -31.1197974 | -179.0549 | 953.04 |
| HVR\_161 | Push core | -31.1197974 | -179.0549001 | 953.04 |
| HVR\_162 | Slurper | -31.0993213 | -179.0485662 | 1517.87 |
| HVR\_163 | Push core | -31.0993402 | -179.0485556 | 1518.04 |
| HVR\_166 | Scoop | -31.1028952 | -179.0473228 | 1508.99 |
| HVR\_175 | Push core | -31.111973 | -179.049469 | 1307.08 |
| HVR\_177 | Scoop | -31.1122013 | -179.0496967 | 1305.25 |
| HVR\_180 | Slurper | -31.113082 | -179.0521233 | 1175.49 |
| HVR\_181 | Push core | -31.1132288 | -179.0520365 | 1164.19 |
| HVR\_182 | Push core | -31.1133125 | -179.0520516 | 1164.28 |
| HVR\_184 | Scoop | -31.1320453 | -179.0174859 | 841.01 |
| HVR\_189 | Scoop | -31.1312349 | -179.0157533 | 773.4 |
| HVR\_191 | Push core | -31.1341666 | -179.0052509 | 1014.73 |
| HVR\_196 | Slurper | -31.1302687 | -179.0093419 | 891.44 |
| HVR\_198 | Scoop | -31.1298142 | -179.0098406 | 876.7 |
| HVR\_211 | Slurper | -31.1038993 | -179.0564021 | 1248.53 |
| HVR\_216 | Push core | -31.1049398 | -179.0586857 | 1087.19 |
| HVR\_218 | Push core | -31.1049965 | -179.0588461 | 1073.5 |
| HVR\_222 | Scoop | -31.105507 | -179.0591968 | 1050.36 |
| HVR\_225 | Slurper | -31.1023386 | -179.0618335 | 980.08 |
| HVR\_229 | Push core | -31.0898893 | -179.0637765 | 778.02 |
| HVR\_230 | Slurper | -31.0898833 | -179.0636951 | 776.73 |
| HVR\_231 | Scoop | -31.0877823 | -179.0605 | 826.41 |
| HVR\_232 | Slurper | -31.0886693 | -179.0566434 | 870.59 |
| HVR\_234 | Push core | -31.0891555 | -179.0555675 | 918.7 |
| HVR\_236 | Slurper | -31.0956966 | -179.0491457 | 1503.38 |
| HVR\_241 | Push core | -31.11174188 | -179.0224751 | 1437.13 |
| HVR\_242 | Push core | -31.11174387 | -179.0224731 | 1437.01 |
| HVR\_247 | Scoop | -31.11415966 | -179.0211225 | 1316.09 |
| HVR\_248 | Scoop | -31.11416041 | -179.0211545 | 1314.43 |
| HVR\_250 | Slurper | -31.11408712 | -179.0212729 | 1318.48 |
| HVR\_253 | Slurper | -31.12820036 | -179.0138054 | 639.37 |
| HVR\_255 | Push core | -31.124133 | -179.0121098 | 870.26 |
| HVR\_256 | Push core | -31.12046865 | -179.0106356 | 966.6 |
| HVR\_257 | Slurper | -31.12234163 | -179.0142893 | 845.19 |
| HVR\_258 | Scoop | -31.1223514 | -179.0143004 | 845.27 |
| HVR\_259 | Push core | -31.12320148 | -179.0144741 | 838.7 |
| HVR\_260 | Slurper | -31.1232224 | -179.0144683 | 838.44 |
| HVR\_263 | Scoop | -31.0857721 | -179.0400252 | 854.95 |
| HVR\_265 | Scoop | -31.0851193 | -179.0403185 | 803.18 |
| HVR\_266 | Scoop | -31.0851461 | -179.0404921 | 801.65 |
| HVR\_268 | Slurper | -31.0850596 | -179.0416054 | 805.55 |
| HVR\_272 | Slurper | -31.0842763 | -179.0398383 | 800.65 |
| HVR\_275 | Slurper | -31.0843817 | -179.0368396 | 862.46 |
| HVR\_277 | Push core | -31.0866801 | -179.0354297 | 939.84 |
| HVR\_279 | Scoop | -31.0862869 | -179.0342809 | 899.19 |
| HVR\_283 | Slurper | -31.0974662 | -179.0116619 | 962.7 |
| HVR\_285 | Scoop | -31.0973702 | -179.0119117 | 969.22 |

**Supplementary Table. 1.** The name, sampling method, location, and depth of all samples of the AL Unit taken during the 2015 Havre cruise.

**2.2. Supplementary Figures**

**Supplementary Fig. 1.** Detailed views of sampling at site HVR132 and HVR163 exposing several layers within the seafloor AL Unit at Havre.

**Supplementary Fig. 2.** Picture of push core HVR159 taken prior to subsampling. (a) A view of the upper part of the push core showing 3 layers with sharp contact between each. The uppermost layer is composed of extremely fine ash. The middle layer is composed of coarse dark ash. The lowest observable layer is composed of coarse ash and is rich in elongate particles (b).