magma fragmentation in the conduit. Rapid magma ascent is also consistent with the absence of microlite crystallization in the Macauley magmas[2]. The high BNDs therefore do not support the low-to-intermediate magma discharge rates that would be consistent with bleb detachment[2]. Rather, the Macauley data seem to preserve evidence of an explosive style, consistent with recognized styles of submarine pumice eruptions[11]. ❐

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Additional information

Supplementary information accompanies this paper on www.nature.com/naturegeoscience.

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Authors' reply — Shea *et al.* raise three issues pertaining to our work[1]. First, they argue that our pyroclasts were potentially from different eruptions or magma types with different degassing histories. However, we do not require the Tangaroan pyroclasts to be from a single eruption; indeed, we propose that this style can apply to magmas of diverse compositions for eruptions at submarine volcanoes worldwide. At Macauley Volcano, glass chemistries for Tangaroan dredged pyroclasts are dacitic[1] and the clasts lack microlites, indicating a common history without significant degassing[2]. Furthermore, we do not claim that all dredged pyroclasts are Tangaroan in origin[3]. Some high-density microlite-bearing clasts, for example, have contrasting textures interpreted to reflect dome-forming eruptions[3].

Second, Shea *et al.* argue that our stacked density data provide a misleading representation of the density distributions for individual eruption events. However, as discussed in ref. 3, irrespective of whether the data are derived from individual stratigraphic levels, single or multiple eruption sequences or dredge hauls, the pyroclast density characteristics from the four volcanoes we have studied are consistent within and distinctive between the volcanoes and eruptive settings. We chose only one representative Tangaroan clast for detailed discussion, but descriptions and analyses of more clasts are presented elsewhere[4]. The stacking of density data presented in Fig. 1 from Shea *et al.* is misleading. The Taupo eruption density bimodality (Fig. 1a) is caused by data from differing eruption styles, recognisable from textural characteristics. The high-density mode represents microlite-rich, degassed clasts from phreatoplinian (Unit 4) and sub-lacustrine effusive (Unit 7) phases, whereas their low-density mode is caused by microlite-poor, highly explosive plinian eruptions[5]. In contrast, the Tangaroan-style pyroclasts we have studied span both density modes. Individual fragments are linked by the density values and textures across the gradient clasts[1].

Third, Shea *et al.* compare our data to selected data from pyroclasts with differing magma compositions and crystal contents (Fig. 1c). They assert that the Tangaroan discharge rate was equally high and the activity explosive. This comparison is misplaced because explosively erupted magmas with similar compositions to ours show higher bubble number density (BND) values. For example, the Mount St Helens eruption in Washington in 1980 generated clasts with BND values of 8.2×10^8 cm^{-3} (ref. 6) and the Mount Mazama eruption in Oregon around 7,700 years ago generated clasts with BND values of 6.0×10^9 cm^{-3} (ref. 7). In contrast to Shea *et al.*, we conclude that BND values from natural pyroclasts are often higher than those obtained through experiments[8] or numerical simulations[9]. The equations[9] on which Shea *et al.* construct their comparative argument are based on a single, homogenous nucleation event that produces bubbles with a narrow size range. Such conditions are more easily replicated in experimental simulations. Natural pyroclasts, however, may result from multiple nucleation events or continuous nucleation before fragmentation (for example, ref. 10 and references therein).

Comparison between the denser, quenched rims of the Tangaroan clasts from Macauley Volcano and subaerially erupted pyroclasts with similar chemistries and crystal contents taken from Raoul Volcano (also part of the Kermadec Arc in the southwest Pacific Ocean) shows that the BND values of the Tangaroan clast rims are significantly lower than the BND values of 2.6×10^9 to 1.9×10^{10} cm^{-3} measured for the Raoul clasts that were erupted in explosive events[4]. We therefore conclude that when relevant data are compared on an equal basis, our proposal for the Tangaroan eruption style remains fully justified and open to further application. ❐

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