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Auto-granulation of particle surfaces during Surtseyan eruptions

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Surtseyan eruptions are shallow emergent subaqueous volcanic eruptions leading to the formation of tuff cones. In contrast to the environment of subaerial eruptions, seawater is a dense cooling medium, with high heat capacity and thermal conductivity. Accordingly, magma fragmentation mechanisms, cooling, vesiculation, aggregation, recycling and particle dispersal are strongly affected. Several fragmentation mechanisms have been proposed for Surtseyan eruptions, such as magmatic fragmentation, molten-fuel coolant interactions, steam-driven explosions and non-explosive thermal granulation or turbulent shedding. Recent studies proposed that Surtseyan eruptions cannot be explained by any single fragmentation mechanism, but rather by a feedback between these fragmentation processes. Aggregation of ash particles is a common process during water-influenced eruptions and "coated lapilli" have been described as a dominant constituent of Surtseyan deposits. Ash-generation (by fragmentation) and aggregation are important influences on volcanic hazard, because they increase and decrease areas affected by ash dispersal, respectively.

We analysed "ash-encased" pyroclastic particles (lapilli size) from the Surtseyan eruptions of Capelinhos (1957-1958) and Hunga Tonga- Hunga Ha'apai (2014-2015) volcanoes using X-ray micro-computed tomography in order to shed light on the fragmentation and aggregation processes. The cores of the "ash-encased" lapilli consist of scoria with variable vesicularity, vesicle-size distribution, vesicle shape and crystallinity. They are partially to completely surrounded by a rim of fine ash, frequently filling the external vesicles. The interface between scoria cores and the ash rim are characterized by abundant cracks, sometimes organised in clusters. The cracks occur in lapilli with highly variable textures. In the ash rims and at the contact to the core, we observed matching fracture planes, vesicle concavities and crystal fragments, forming jigsaw-fit textures.

Our observations of the ash rims around these scoria particles leads us to conclude that they have formed in-situ during brittle auto-granulation of the lapilli margins. That is, these are not "coated" particles, sensu stricto. The clear jigsaw-fit packing of neighbouring particles in three dimensions, show that they were formed in-situ by fracturing the scoria core. The presence of jigsaw textures in subaqueous settings has been already reported in several studies on hyaloclastites and peperites and is generally attributed to in-situ thermal granulation during non-explosive water-magma interaction. By analogy, we propose that after magma fragmentation, the margins of lapilli-sized clasts experienced thermal cracking and granulation due to quenching in seawater. This is the first documentation of in situ auto-granulation by thermal stress for the microscale production of ash particles in a volcanic eruption. Thermal granulation is an important secondary fragmentation process in Surtseyan eruptions.

Our results show that these "ash-encased" particles are not the result of ash aggregation, but demonstrate new-ash formation. In future, understanding the conditions that alter the relative balance between in-plume aggregation (decreasing free ash) and the subaqueous production of ash by auto-granulation (possibly increasing free ash) will be a key for better assessment of potential hazard of ash particles in the atmosphere impacting on populations and air traffic.