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Zooming in on crystal mush: recent advances in volcano tomography

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The lack of direct seismological evidence for large molten magma chambers is considered to be one of the most important arguments in support of the mush paradigm. However, most published melt fraction estimates based on interpretation of seismological data are associated with large uncertainties because of two limitations: i) inherent limits to resolution of seismic tomography and, ii) trade-offs in the constitutive relationships that tie seismic properties to melt fraction. Low-velocity volumes associated with magma storage are particularly difficult to image with conventional travel-time tomography due to limited resolution and wavefront healing, resulting in blurred images and a high velocity bias. We tackle these limitation by applying full waveform inversion to active source seismic data collected over the Kolumbo submarine volcano (Greece). We recover a previously undetected Vp anomaly of –50% beneath the volcano and interpret this as a shallow magmatic intrusion. Extension of this approach to the wider Santorini volcanic system is ongoing. Concurrently, we are tackling the second limitation, which is the result of the dependence of elastic properties on the microgeometry of the melt. Seismological melt estimates rely on the assumption that the melt pore space can be represented by simple geometrical shapes, usually ellipsoids, with a given aspect ratio. Since the aspect ratio is poorly constrained, this results in a trade-off between melt fraction and melt geometry. We have adapted a method for the homogenisation of the elastic properties of multi-phase composites and applied it to calculating the elastic properties of partially molten rocks starting from the melt microstructure determined by X-ray CT scanning. The microgeometry of the mush can be inferred from the study of glomerocrysts: crystal mush inclusions with quenched interstitial melt that are carried to the surface by erupted lava. After the sample is digitized and segmented into its constitutive phases (crystals, melt, vesicles), the average elastic properties are determined by numerical homogenisation which consists of numerically simulating the deformation of the sample under load and predicting its elastic response. The results are compared to a semi analytical solution for ellipsoidal inclusions. We apply this approach to a plutonic nodule from St Kitts and show that the melt microstructure leads to an elastic response equivalent to that of ellipsoidal melt inclusions with an aspect ratio of 0.1 (oblate spheroids). This equivalent aspect ratio is used to refine melt estimates for Montserrat, Santorini and Kolumbo volcano.