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Phantom creation and analysis: Improving X-Ray microtomography scanning of soft sediment cores containing volcanic ash

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Abstract. We present a series of soft sediment geological phantoms constructed to simulate volcanic ash deposits preserved within sediment cores. This study aimed to systematically discern which sediment components are most effectively detected and therefore characterised by X-ray microCT (μ CT). Samples with low or overlapping attenuation contrast but distinct morphologies such as coarse grained ($>125 \mu\text{m}$) ash within fine mud ($<4 \mu\text{m}$) can be manually separated using analysis software, while samples with high attenuation contrast display distinct horizons that are easily segmented using attenuation thresholds. We anticipate that this work will have broader applications within Earth Science to optimise the exploration of sediment with μ CT analysis.

1. Introduction

Volcanic ash deposits, which are widely used as age-markers in soft sediment records, are prone to post-depositional displacement within sedimentary environments. These sediment cores are routinely investigated by linear and surface analyses, which only provide one and two dimensional data, respectively. With X-ray μ CT a much needed third dimension is revealed to aid the detection of microstructures that may be linked to post-depositional processes. Geological samples, however, mainly consist of similarly attenuating silicates which makes analysis using X-ray μ CT challenging. To allow effective segmentation, histograms either with distinct peaks or with enough dilation to allow phase separation need to be generated. Ongoing work aims to characterise and quantify the three-dimensional structures of volcanic ash found in core samples of sedimentary sequences. However, the detection and discernment of the presence of volcanic ash in a sample remains a particular problem.

This study aims to systematically discern which combinations of volcanic ash and sediment best respond to X-ray μ CT analysis. This response is measured by observing which samples show the greatest amount of attenuation contrast and therefore can be effectively segmented and the three-dimensional structures quantified. Constraining the attenuation contrast of particular combinations of ash and sediment will give clearer limitation boundaries to samples of similar composition. Previous work in this area [1] relied on additional information, such as optical analysis, to determine thresholds to separate sediment from volcanic ash rich regions.

Geochemical composition and grain-size of the volcanic ash are the key variables within these phantom samples. The success of the analyses is quantified by the level of grayscale contrast between the ash and host sediment and the ease of segmentation. The work herein informs further work where candidate specimens will be selected based on the potential for successful μ CT analysis and segmentation.



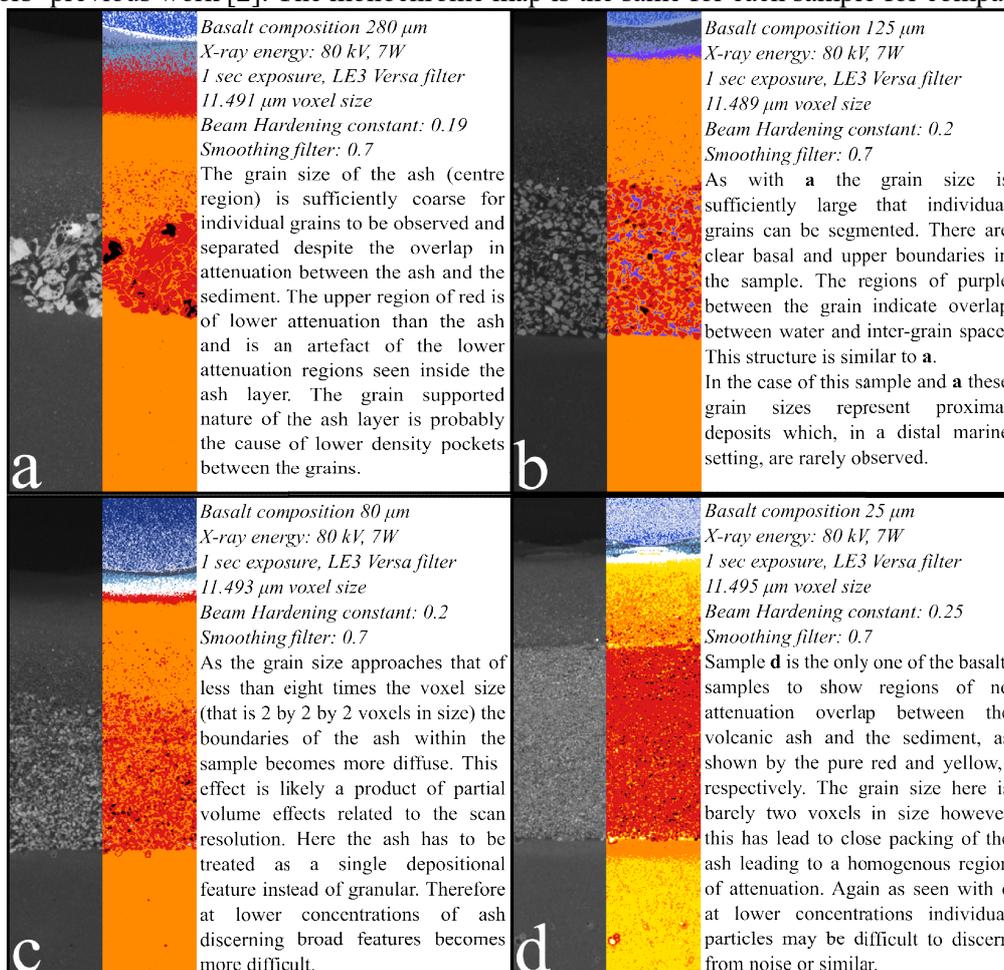
2. Samples and methodology

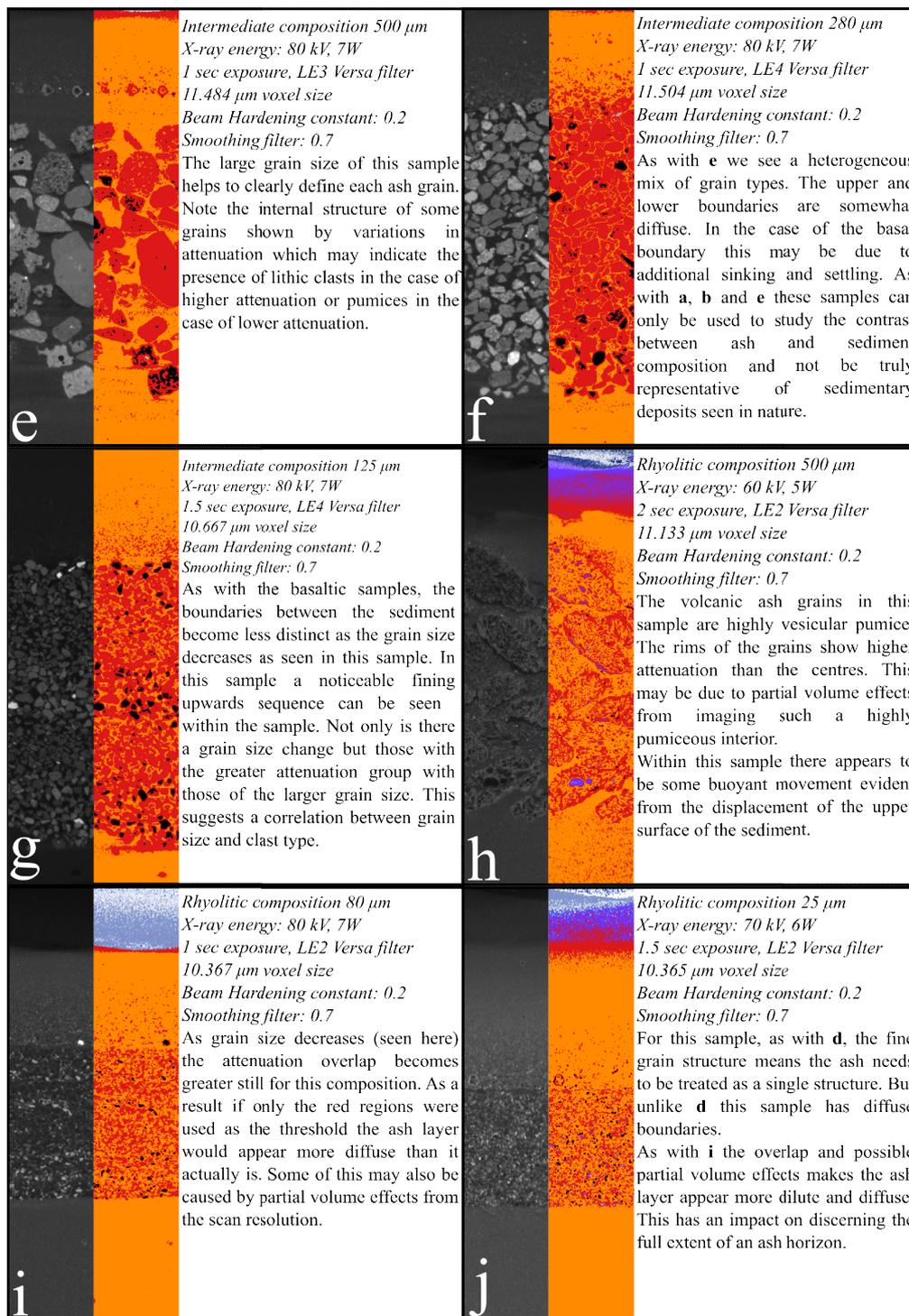
This study uses marine mud from the Marion Dufresne cruise MD123, core MD01-2444. The sediment is continentally derived and drilled approximately 100 km west of the Beja District, Portugal. The volcanic ashes used are derived from proximal deposits on mainland Iceland. Together the sediment and ash types represent compositions found in North Atlantic marine core sequences. Three igneous rock types were selected for their contrasting chemical composition; basaltic, intermediate and rhyolitic (relatively; low, medium and high silica, respectively). The volcanic ashes were sieved into 5 size ranges, 500, 280, 125, 80 and 25 μm . The phantoms were produced by gravity settling through water within 9 mm diameter polypropylene transparent drinking straws. The layers were formed with the volcanic ash sandwiched between two layers of marine mud.

The μCT scans were performed using an Xradia Zeiss 520 Versa X-ray microscope at Swansea University's AIM (Advanced Imaging of Materials) facility. Data was reconstructed using Zeiss' proprietary XMReconstructor software (Filtered Back-Projection) along with any pre-processing Beam Hardening removal and Smoothing (see Results for settings). For all scans the centre of the sample was 86.7212 mm from the 0.4 x objective lens and 35.8028 mm from the X-ray source.

3. Results

The figures below were generated in the software package Avizo 9 (FEI 2015, Oregon, USA). The multi-coloured map for each image was generated by assigning primary colours red, yellow and blue to volcanic ash, sediment and other materials (air, straw and water) respectively, with the overlaps in attenuation being the secondary colours in between. Further exploration of this method can be found in the authors' previous work [2]. The monochrome map is the same for each sample for comparison.





4. Discussion

The aim of this work was to systematically study the attenuation contrast between volcanic ash of varying compositions and sizes with a host material, in this case marine mud. As SiO₂ increases within the volcanic ash the contrast between the ash and sediment becomes more overlapped. This variation appears to be independent of grain size but partially dependant on grain type (contrast the pumice of **h** with the glassy shards of **i**). The attenuation contrast between the ash and sediment is relative and so both the composition of the ash and sediment must be assessed for suitability. Exact quantification of

this limit may not be possible and merely provides a priori information about the samples post-scanning. However, using effective atomic numbers and the attenuation contrasts seen in this study a semi-quantitative process of selecting suitable samples may be a viable option moving forward. Part of the aim of this study is to quantify these detection limits.

Coarser grained ash is easiest to detect in the cores regardless of composition. Although the ash may not be able to be separated using grayscale thresholds, it can be separated with manual “tagging” (user selection within analysis software). Such grain sizes are rare to encounter in distal marine deposits but common in lakes near the eruption centre. The cut off for size contributing to ease of segmentation varies with composition. Comparing figures **d** and **j**, which have the same grain size but different chemistry; **d** has regions of attenuation exclusively marked as volcanic ash (red), while in **j** the ash attenuation overlaps with that of the sediment, making it difficult to separate. For 25 μm grain sizes single ash particles may only be represented by ~ 8 voxels and therefore, at this resolution the ash can only be visualised as a bulk layer because the individual particles cannot be separated. These issues may be mitigated by increasing the scan resolution to produce batch or mosaic scans, which would also reduce partial volume effects such as those seen in figure **h** and the poor definition of individual grains seen in figure **j**. However the benefit of such increased scan times would have to be weighed against the likelihood of improved results. The machine maximum pre-set of 3201 projections were chosen for all scans however the authors acknowledge that this was beyond the point that additional spatial detail could be discerned and increased scan time. Similar images could result from fewer projections. Optical or physical magnification needs to be employed to improve resolution.

Additionally, samples **h**, **e**, **f** and **g** reveal interactions between coarse-grained ash deposits and the host sediment. These observations are particularly promising for future investigations of depositional processes in sedimentary environments using X-ray μCT . Whether these interactions within these phantoms are representative of natural sedimentary systems is as yet unknown.

5. Conclusions

The results of this study points to the necessity of pre-scanning knowledge of volcanic ash and sediment density/effective atomic number to determine the potential gains from μCT analysis of a sample. However, the additional information gained from the understanding of 3D structures outweighs the additional pre-scanning data acquisition.

Further work of this nature is essential and we recommend exploring different volcanic ash compositions and sediment types to better represent the diversity of sedimentary environments. These may include marine or lake muds of differing attenuation, coarser grained sediments, peat and ice. We anticipate that this work will have broader applications for other Earth Scientists in the exploration of soft sediment with μCT analysis.

Acknowledgements

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