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# Revealing the three-dimensional geometry of tephra horizons found within soft sediment deposits

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Traditionally, the stratigraphic position of tephra horizons within sedimentary deposits is identified by visual inspection in the case of macro-deposits (e.g. by distinct changes in colour or grain-size), or through quantified shard concentration profiles with respect to low concentration deposits (cryptotephras). Within core samples, the one-dimensional approach of shard concentration profiles often masks any potential displacement or post-depositional processes that may have impacted the tephra deposit. We present a new perspective to tephra analysis and apply X-Ray Computed MicroTomography (XR$\mu$CT) to obtain 3D visualisations of Icelandic tephra horizons preserved within North Atlantic marine sedimentary sequences. Geological samples present challenges for XR$\mu$CT scanning as X-ray attenuation is controlled by density and effective atomic number. Like many geological samples, the samples of this study are made up of complex silicates with similar atomic numbers and so have similar attenuation properties. Therefore, contrast between sediment and tephra can be very low. Initial experimentation on simulated tephra deposits in the laboratory provided the basis for devising a series of parameters and recommendations for scanning to maximise the quality of data attained from scans before post-processing and analysis. The most successful scans were obtained when the tephra properties (grain-size and composition) showed a marked contrast to the host material (e.g. coarse-grained tephra $>125$ $\mu$m in fine mud or basaltic tephra in calcareous sediment). These optimised scan parameters were applied to real core examples and 3D visualisations of macro-deposits revealed tephra lined worm casts; down-going injection-like structures; tephra sinking into the basal sediment; evidence of graded bedding; and most significantly for those using tephra horizons as stratigraphic markers (such as used in tephrochronology), discontinuous and fragmented deposition. Such complex sedimentary features were not apparent in the one-dimensional visual descriptions.

We also apply the XR$\mu$CT technique to investigate the three-dimensional structures associated with cryptotephra deposits where tephra concentrations may be anywhere between 1 - 400,000 shards per 0.5 g dry weight (in the case of one sample studied). At this concentration there is no visible macroscopic horizon of tephra in the sample. Our scans, with an isotropic voxel size of $\sim$26 $\mu$m (giving an effective resolution of $\sim$50-80 $\mu m^3$), detected low concentration deposits that broadly agree with the shard concentration profile derived by conventional microscopy work. These data also provide new insight into the sedimentary structures and indicate the discontinuous nature of cryptotephra deposits where "cross-bedding" features between tephra-rich and poor regions are visible. The unprecedented three-dimensional insight into the structure of cryptotephra deposits has considerable potential as a routine first step in a workflow for constructing a tephrostratigraphical framework in sediment cores.