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Large volcanic eruptions and the PETM: Geochemistry from the Fur Formation, Denmark

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The opening of the North Atlantic Ocean during the early Cenozoic was accompanied by substantial volcanism that resulted in the deposition of numerous ash layers over much of northern Europe. This volcanism was contemporaneous with the extreme greenhouse climate of the Palaeocene-Eocene Thermal Maximum (PETM), and is therefore of particular interest for volcanism-climate interactions. The island of Fur, northern Denmark, contains abundant outcrops of volcanic ash layers deposited in a shallow marine environment. Over 179 distinct ash horizons (those greater than $\sim$1 cm are numbered #-39 to #+140) are found within the $\sim$60 m thick Fur Formation. The ash layers are predominantly black and composed of volcanic glass particles ranging from silt to sand in size. Each bed is normally graded and lacks any evidence of significant reworking. There were no volcanoes in the vicinity of Fur during this time, and the outcrops are $>$700 km from the break-up axis, indicating that at least some of the ash layers were formed during very large eruptions and transported a long way from the source volcanoes. A few thick grey ash layers (e.g. #-33 and #+19) are believed to have originated from volcanoes in East Greenland. Here we present geochemical data from two key sections within the Fur Formation, a beach section at Stolleklint where ashes #-34 to #-31 are exposed, and a quarry section at Jenshøj that covers ashes #+17 to #+35. The #-33 and #+19 ashes are both prominent marker horizons around 15-20 cm thick. The Stolleklint section is clay rich while the quarry section is dominated by diatomite. At Stolleklint, bulk rock total organic carbon (TOC) δ^{13}C values throughout a 1.5 m section are relatively steady at -30.7 to -31.7 ‰ typical of the carbon isotope excursion values of the PETM at Fur. Just above ash layer #-33, δ^{13}C = -27.9 ‰ characteristic of post-PETM values. The bulk rock TOC is high, 1.5 to 4 wt. %. The post-PETM quarry section is much poorer in organic material (0-0.5 wt. % TOC). Values of δ^{13}C are more varied than at Stolleklint, scatter around -28.0 ‰ in the lower 0.5 m. A small negative δ^{13}C excursion occurs just above the thick #+19 ash layer, followed by a slow recovery to less negative values up section. This suggests a possible causal relation between the ash deposition and the carbon isotope record, as diminished primary productivity is typified by negative δ^{13}C TOC values. These results indicate that North-Atlantic volcanism had significant repercussions and could have played a role in the termination of the PETM.