Unifying Europe: the enhanced use of (crypto)tephra layers for synchronising palaeoenvironmental records

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Tephra layers in sedimentary archives can provide valuable isochrons for independently dating sequences of palaeoenvironmental change. In combination with high-resolution chronologies (e.g. annual layer counting) and detailed multi-proxy data sets tephra layers further enable the alignment of different archives in order to test the pacing of regional climate change and respective environment responses.

Past studies in Europe were commonly restricted to visible tephra layers and hence limited the proxy data comparison to relatively small geographical areas. The recent advances of tephra methodological and micro-analytical techniques, however, allow for detection and chemical fingerprinting of tephra levels with low glass shard concentrations (cryptotephra). Consequently, cryptotephra studies have massively increased the number of tephra findings and extended the area of palaeoenvironmental sites that can use common tephras for detailed data comparison.

A first case study derives from a 900 km long W-E transect archive alignment of terrestrial Lateglacial sequences across central Europe (Lake Meerfelder Maar, Hämelsee, Rehwiese and Trzechowskie palaeolakes). Here, high-resolution (decadal) lake depositional, hydrological (biomarker δD) and vegetation data from annual laminated lake sediments were aligned by the Eifel Laacher See Tephra (LST, 12.9 ka) to test the spatiotemporal relationships of environmental responses at the onset of the Younger Dryas cooling (e.g., Wulf et al., 2013; Słowiński et al., 2017; Jones et al., 2018; Collins et al., 2018). Furthermore, the finding of the Icelandic 12.1 ka Vedde Ash (VA) in Lake Meerfelder Maar (Lane et al., 2013) allowed for a first direct alignment of hydrological data from central Europe with the Greenland oxygen isotope record (Rach et al., 2014; Collins et al., 2018).

The results of these data comparisons reveal complex patterns of lead- and lag phase relationships of hydrological and vegetation changes in response to Greenland cooling (Rach et al., 2014; Collins et al., 2018) related to a reorganization of atmospheric circulation patterns over Europe at the onset of the Younger Dryas cold period. The ERC-funded project *STEEPclim* ('Spatiotemporal evolution of the hydrological cycle throughout the European continent during past abrupt climate changes') aims to reconstruct hydrological and vegetation changes

via detailed biomarker analyses on further 10+ Lateglacial lacustrine sequences from across the entire European continent. Hence as part of this project, detailed cryptotephra studies of varved sequences from southern Germany (Steißlinger See) and Italy (Lago Grande di Monticchio) have been initiated. One major goal is to identify the Laacher See Tephra, the Vedde Ash, and other Lateglacial tephras of Italian provenance in these sequences to enable proxy data alignment into the Mediterranean region. The search for ultra-distal cryptotephras (LST, VA) in the tephra-dominated sediments of Lago Grande di Monticchio, however, encounters new methodological challenges and limitations, some of which are presented here.

The results of proxy data alignment of Central European Lateglacial sequences demonstrate the immense value of tephras when applied as isochrones delivering an unprecedented picture of the anatomy of abrupt climatic change. The recent successful identification of Icelandic cryptotephra in Romanian lakes (Kearney et al., 2018) in combination with an improving Eastern Mediterranean (crypto)tephrostratigraphy suggest that there is also great potential to extend proxy-data comparison not only spatially into the Eurasian region but also to examine lead-lag-phase relationships during older climatic transitions.

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