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Editorial

The ELSA - Stacks (Eifel-Laminated-Sediment-Archive): An introduction

The west Eifel volcanic field in Germany spans an area of ~ 1000 km^2 and contains more than 250 scoria cones of Tertiary and Quaternary age, as well as 7 extant and 61 dry maar lakes with the latter having filled up with sediments (Büchel and Lorenz, 1982). Coring of the extant maar lakes produced the first paleoclimate records from central Europe that revealed varve chronologies for the Holocene and late glacial (e.g. Negendank et al., 1990; Zolitschka, 1998; Brauer et al., 2001) and are today well established archives for annual-resolution studies of the climate and environment of the last 15 000 years (e.g. Litt and Stebich, 1999; Kubitz, 2000; Lücke et al., 2003; and many others).

Most of the 61 infilled lakes have been cored as part of the ELSA Project (Eifel Laminated Sediment Archive) during the last 18 years to extend the Holocene paleoclimate time series back into the mid Pleistocene. Unfortunately, no single of these dry maar sediment sequence extends from the present back over the entire Last Glacial Cycle or even longer. One core (representing the time for filling of a maar basin) usually spans only several ten thousand years (Schaber and Sirocko, 2005) and thus cores have to be stacked together to obtain long time series. After drilling of the infilled lakes we cored the Holocene maar lakes of Ulmen, Schalkenmehren and Holzmaar to arrive at a continuous stacked record from modern times back into the Pleistocene, all analysed with the same analytical approaches.

Each of the ELSA records is dated independently using ^{137}Cs, ^{210}Pb, ^{14}C, varve counting, magnetostratigraphy, luminescence techniques and argon/argon dating (Sirocko et al., 2013). Doubt on the credibility of some of the ^{14}C datings came from the almost 300 dates obtained for the core UM2 from Ulmen, which was intended to serve for a wiggle match dating. Instead, strong problems from reworking of older sediments and a strong hard water effect from eolian dust carbonate dissolution and mantel CO_2 exhalation became obvious (Sirocko et al., 2013) in particular when dating older sediments with low organic carbon content or Holocene sediments of different grain sizes (Rothacker et al., 2013). However also luminescence dating did not always provide consistent chronologies (Degering and Krbetschek, 2007; Schmidt et al., 2011).

All cores were then analysed in a next step for pollen with a time resolution of about 1000 years by Frank Dreher to further improve/corroborate core correlation between different maars and distinguish the principle major vegetation zones. Layer counting on petrographic thin sections provided floating varve chronologies for MIS1 and MIS5 (Sirocko et al., 2005; Rein et al., 2007; Fritz, 2011). The petrographic thin sections used for varve counting were also analysed with an automated quartz grain size detection algorithm called RADIUS (Seelos and Sirocko, 2005) which led to the development of the ELSA Dust Stack (Seelos et al., 2009; Dietrich and Seelos, 2010; Dietrich and Sirocko, 2011). The time series of greyscale and dust content over the last 130 000 years have been tuned to the Greenland ice time scale NGRIP Community Members (2004), because the lake sediment colour changes (caused by organic carbon content variability) reflect the Greenland interstadial succession nicely in the cores from Oberwinkler and Dehner Maar, Jungferweiher and Auel (Sirocko et al., 2005, 2013).

The most important chronological marker for the MIS5 sediment cores was the petrographically and geochemically-distinct Dümpelmaar Tephra (DMT). The DMT was Ar/Ar dated by van den Bogaard and Schmincke (1990) to 116 000 $\pm$ 11 000 BP near the eruption site at Herchenberg in the East Eifel volcanic field. The DMT tephra was correlated with ash layers in the sediment cores from Jungferweiher, Hoher List and Eigelbach maars geochemically (Lenaz et al., 2010; Sirocko et al., 2013). The above Ar/Ar age from the site of eruption was consistent with luminescence datings measured by the late Matthias Krbetschek for the cores from Jungferweiher and Hoher List. The ice core greyscale tuning for these cores by Katja Schaber was also consistent when using the C24 cool event (McManus et al., 1994) as well visible anchor point in the greyscale curve of HL2 (Sirocko et al., 2005). The continuation of the chronology from the C24 into the MIS5e section of core HL2 was done by the varve counting from Bert Rein (Rein et al., 2007). C24 and DMT are thus the two anchor points for the MIS5 chronology of all ELSA cores. Within the error bars of the consistent results from Ar/Ar dating and luminescenc dating, ice core and marine tuning, and varve dating the age for the DMT in the ELSA record is 106 000 BP.

The other stratigraphically important section was for MIS3. Engels et al. (2008) used the tuned and ^{14}C dated core from Oberwinkler Maar to show by analysis of the chironomids that the lake water temperature during the early MIS3 in the Oberwinkler Maar was almost as warm as it is today; a finding in accord with the pollen record from Dehner Maar (Sirocko 2009, Sirocko et al., 2013), which revealed the presence of abundant thermophilous trees during the time of high chironomid abundance in early MIS3.

Other micropaleontological studies included the analysis of Holocene cladocera (Kattel and Sirocko, 2011) and plant macrofossils (Herbig and Sirocko, 2012) with the latter used to find both ^{14}C datable material and corroborate the pollen results, in particular for the MIS3 pollen, because the finding of the thermophilous pollen in the early MIS3 were quite unexpected.

The latest publications on the ELSA sediments involved organic biomarker analyses, which have demonstrated the potential of these techniques for reconstruction of Holocene past water temperature (Anhäuser et al., 2014), and in particular for quantifying the fire proxies of human impact during Roman times, the Migration Period and Medieval times into the lake systems and the landscape (Bandowe et al., 2014).

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Drilling and coring of the maar lakes and dry maar structures continued from 1998 to 2014 and cores from 50 of the 68 Eifel maar structures are now archived in the ELSA core repository. The deep drilling in the dry maar structures was undertaken by Stölben Bohr (http://www.stoelben-gmbh.de/) using "Seilkern" technology (similar to ICDP, but not from a barge), whilst the extant lake drilling was undertaken by Klaus Schwibus using Niederreiter piston core equipment (http://www.uwitec.at/) from a barge. 10 of the 68 maars cannot be drilled/cored because they are protected and/or inaccessible. The core repository at Mainz now hosts 2700 meters of sediment from more than 50 extant and dry maars spanning the last 220 000 years continuously, and with floating chronologies for individual maar lake sequences extending back to 550 000 BP (Sirocko et al., 2013; Förster and Sirocko, 2016–this volume).

The most important core of the ELSA Project was retrieved from the dry maar of Auel only in the terminal drilling phase of 2013, and the first results from this drilling are presented in this special volume of Global and Planetary Change. The 123 m long AU2 core contained the Laacher See Tephra at 13.8 m depth and has several ^{14}C ages on Ranuncalacea seeds in the MIS2 section, and a MIS3 organic carbon time-series of 100 year resolution provided by Michael Zech, which demonstrated that all Greenland interstadials are contained in the Auel maar record (Fig. 1). Accordingly, core AU2 was tuned with high precision to the ice core chronology of Svensson et al. (2008) on the b2k time scale (Fig. 1).

The Auel maar sediments show four distinct tephra layers of up to several cm-thickness in the MIS3 section that are also found in all other nearby ELSA cores and allow a secure inter maar core to core correlation, with ages from the Greenland ice core chronology. The dates from tuning the Auel carbon record are consistent with the varve counted chronology by Marieke Röhner for Dehner Maar cores; this floating varve chronology extend from the Laacher See Tephra back to 30 000 b2k. The synthesis from the AU2 tuning and the DE3 varve counting are the main results for the MIS3 chronology of all ELSA cores presented in the paper of Sirocko et al. (2016–this volume).

1. The ELSA Stacks

After the consistent multiproxy dating of Auel and Dehner Maar we were in a position to synthesize the best of the ELSA records into a continuous stack covering the last 60 000 years. The sediments for the stacks are from the varve counted freeze core SMf2 (Fritz, 2011) from Schalkenmehrener Maar lake that span the last 700 years back to the flood layer of 1342 AD (Glaser, 2008). This well visible 2-10 cm thick layer with abundant organic debris is used as the tie point to the varve counted pollen time series from Lake Holzmaar. Holzmaar is one of the classical German varve sequences (Zolitschka, 1998); it was recored by the ELSA project to extent our records from the older dry maars up to the very modern times with consistent analytical methods. The ELSA varve counting of the Holzmaar core was undertaken by Marieke Röhner, who arrived at the same age as the earlier work by Zolitschka (1998). Holzmaar can be well correlated to older Pleistocene records because it shows the Laacher See Tephra (LST) at 12 880 BP in its lower part. The LST tephra layers is also visible in the records from the Auel and Dehner maars, but here in the uppermost sections. The sections below contain the entire MIS2 and MIS3. Both maars have erupted around 60 000 BP near the MIS4/3 boundary, which is the oldest time of the records presented in the ELSA stacks 2016 presented in this volume of Global and Planetary Change.

Förster and Sirocko (2016–this volume) developed a new and efficient method for quantifying the petrographic composition of the tephra layers by microscopic inspection of the sand fraction. 10 typical

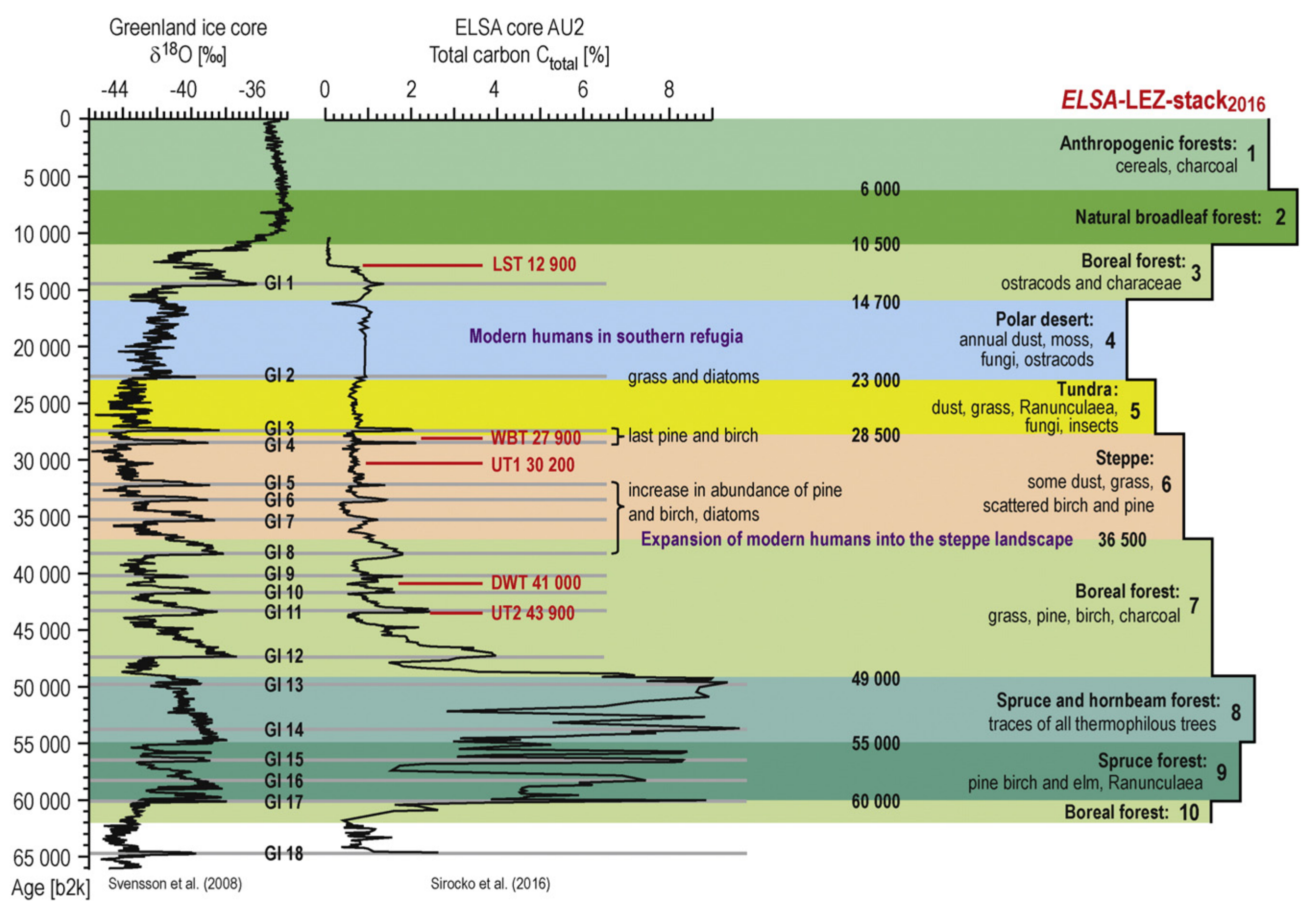

Fig. 1. Greenland ice isotope and Eifel Maar lake sediment total carbon record of the last 60 000 years. Included are the main marker tephra of the ELSA-Tephra-Stack$_{2016}$ and the vegetation zones of the ELSA-Landscape Evolution Zone Stack$_{2016}$.

fragments of the Eifel country rock (e.g. grey Devonian sandstone - red sandstone from the Bunter) and characteristic volcanic minerals (e.g. pyroxene, sanidine and leucite) are used to characterize the tephra compositions in all ELSA sediment records and connect them with the mineralogy of the tuff rings around the 68 Eifel maars. Förster and Sirocko (2016–this volume) describe for the first time four distinct tephra from the MIS 3 lake sediments, which can be reliably correlated between all cores and sites because these four eruptions form tephra isochrons apparently across the entire Eifel region. The tephra at 27 900 b2k resembles the composition of the Wartgesberg (WBT), whilst a tephra at 30 200 b2k is from an unknown eruption site. Deeper in the sequence is tephra from Dreiser Weiher (DWT), dated at 41 000 b2k, and easily identified as it contains abundant pyroxenes and sanidine. This is a unique mineral composition characteristic of the primitive DWT, which is known for its large olivine bombs from the upper mantle. The sanidines in the same layers as the olivines and pyroxenes are thus apparently xenoliths from an older crustal magma chamber and were transported by the rising mantle magma to the surface.

The eruption site of another thick maar tephra dated at 43 900 BP has not been located yet, but is likely to be sourced from Meerfelder Maar, the formation of which was dated to this time by Schaber and Sirocko (2005). The four MIS 3 marker tephra (Förster and Sirocko, 2016–this volume) have been used to transfer the dated and tuned age model of core AU2 from the dry maar of Auel to all other ELSA cores using the Greenland ice chronology.

The next paper of this volume by Sirocko et al. summarizes the above stratigraphic results and combines them with the core DE3 pollen analysis of Frank Dreher, and plant macro-fossil analyses of core AU2 by Hannes Knapp; the photographs of the plant macro-fossils where taken by Christel Adams. Michael Zech provided the important Auel organic carbon curve. The tuning of the AU2 carbon record to the Greenland ice chronology (Fig. 1) and thus refining the age model was done by Johannes Albert and Heiko Brunck. Uli Hambach, Daniel Veres and Stephan Dietrich placed the resultant ELSA vegetation stack in the context of other European MIS3 paleoenvironmental records. Saskia Rudert used the correlation program $ELSA_{interactive}$ (Seelge, in preparation) to plot the down core data on a consistent time scale. All the above results were used to define Landscape Evolution Zones (LEZ) for the Eifel area. The definition of the "Landscape Evolution Zones" appeared necessary, because the classical pollen zones for central Europe conventionally start in the late glacial, which inhibits, however, the continuation of the pollen zone nomenclature back into the Pleistocene. The other advantage of the LEZ approach is that LEZs take into account also dust, flood events, human induced landscape change and volcanic activity. Accordingly, the ELSA-LEZ-$Stack_{2016}$ departs from the established nomenclature, but provides all data needed for an integrated synthesis of the climatic and environmental evolution of the Eifel landscape and the central European environment during the late Pleistocene and Holocene.

The most important finding from the application of the new landscape classification was the observation that pollen and plant macrofossils indicative of thermophilous taxa were encountered in all cores that span early MIS3 during GI12-14 (Fig. 1). The pollen-inferred vegetation assemblage at this time was dominated by up to 60% of spruce, whilst containing all the typical Holocene interglacial taxa. This finding contrasts with aboreal pollen-free spectra from northern Germany (e.g. Behre and Lade, 1986), but is in accord with the observation of spruce-dominated forests in Switzerland at this time (e.g. Welten, 1982). The unexpected occurence of up to 20% of thermophilous taxa in the early MIS 3 is possibly to be explained by nearby MIS4 tree refugia in the warm and sunny Rhine and Mosel valleys where today the northernmost vines of Europe are cultivated and the summers are up to 2°C warmer than in the Eifel only 30 km distant.

This early MIS3 spruce forest converted rapidly after 49 000 b2k into a boreal forest with abundant grass and charcoal indicating more cold and arid conditions. This taiga further changed to a steppe at 36 500 b2k as indicated by the lower content of wood remains and in particular charcoal. Striking for this environmental change is also the abundant occurrence of coenococcum fungi. This major landscape change coincided with the time when modern humans spread rapidly into central Europe hunting wild horses, bison and the mammouth, which must have found favourable conditions in the grass steppe with scattered pine and birch. Increases in tree cover occurred during the interstadials (D-O events) when also diatom blooms occurred in the Eifel maar lakes. Diatoms were analysed in high resolution for core DE3 by Simone Illig, and appear to be the most suited indicator to quantify the speed of the environmental changes during the onset of the interstadial warm phases.

The last pine and birch trees disappeared at the end of GI3, which marks the transition to tundra after 26 500 b2k and then polar desert after 23 000 b2k in central Europe. The Aurignacien humans hunted according to the results from Auel and Dehner Maar in a steppe, the Gravettien humans in a tundra (Sirocko 2009). These humans migrated apparently into their southern refugia when the polar deserts spread in central Europa during the last glacial maximum.

The final paper of this volume is by Heiko Brunck, Johannes Albert and Frank Sirocko, who classified characteristic layers of flood sediment in the maar sediment records from Schalkenmehren, Holzmaar and Auel and developed a stack of flood events. Flood layers cannot be differentiated visually from distal turbidites and slumps, but show a characteristic grain size distribution when studied on petrographic thin sections. Flood layers are not grain size graded from a coarse base layer to a fine top layer, but show an inhomogenous grain size gradient with several maxima representing the discharge pulses during the days/weeks of a flood event. They are however topped with a fine sediment layer when finally all suspension settle to the lake bottom, which makes them sometimes difficult to distinguish from distal turbidites and slumps.

The unique sediment record from the dry Auel maar allowed the identification of the flood layers already visibly, because the maar basin of Auel was fed by a small river with a large catchment and has thus the highest sedimentation rate of all Eifel maar lakes (2 mm/year mean). In addition, the maar basin is small enough such that the pulses of fluvial runoff could spread over the entire lake bottom and leave layers of cm-thickness with a discontinuous grading, which distinguishes them from turbidites and slumps. The multiple grain size changes within one flood layer are sometimes even visible to the unaided eye (see flood layer photograph in Brunck et al., 2016–this volume).

The time series of Auel maar flood events is sourced from a creek flowing into the former maar lake and thus represents the local precipitation extremes. However, a comparison of modern gauge data shows that the small flood events in the Eifel creeks correlate on a statistical basis with todays flood events in central Europe largest river the Rhine (Pfahl et al., 2009). Thus, the local flood event history contained in Auel is likely representative of the flood history of most of central Europe. Accordingly, the time series of the individual Auel flood events is not presented as a table of dated flood events, but integrated into a normalized index of flood events per millennia to show only the times of maximum flood activity. The same procedure was done for the Holocene records from Schalkenmehren and Holzmaar, which are stacked with the Auel time series to the ELSA-Flood-$Stack_{2016}$ (Brunck et al., 2016–this volume).

The structure of this flood stack over the last 60 000 years indicates that the flood events were associated with times of reduced vegetation cover such as the Younger Dryas, some of the Heinrich Events but also some "normal" interstadials. Consequently, the flood events most likely document the erodability of the soils to the first order, and climate events only to the second order. In addition, the flood layers are difficult to distinguish for summer rain events and winter snow melt events. Accordingly, the climatological interpretation of the flood stack is at the moment not unambiguous, but first pilot studies have shown that pollen and diatom analysis of the individual layers have a high potential to determine the season of the flood layers.

The three papers highlighted in this special issue of Global and Planetary Change represent an important milestone for the ELSA Project, because we are now able to integrate the most important proxies for the most promising maar lake sediment records into one set of stacks that are directly comparable to the Greenland ice core record.

The ELSA stacks will soon be extended back to 130 000 BP, then to 220 000 BP and finally to 550 000 BP, which is the oldest time dated in the ELSA core from the dry maar of Hausten (Sirocko et al., 2013). The subsequent stacks will include an ELSA Organic Stack, an update of the ELSA Greyscale and Dust Stacks, as well as a comparison of the ELSA-LEZ with the central European loess records.

It is the intention of the ELSA Project to bring the Eifel maar records to their full potential as one of the major paleoclimate geoarchives from central Europe. Accordingly, the repository is open to the entire scientific community and can provide samples/data for any new collaborations necessary to understand the volcanism, climate, weather, environment and human land use in the unique Eifel landscape of central Europe.

The data published in the three papers of this volume are accessible in the supplements of each paper, the PANGEA and NOAA data archives, and also on the web page of the ELSA Project (http://www.klimaundsedimente.geowissenschaften.uni-mainz.de).

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