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The ELSA-Flood-Stack: A reconstruction from the laminated sediments of Eifel maar structures during the last 60 000 years

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ABSTRACT

This study reconstructs the main flood phases in central Europe from event layers in sediment cores from Holocene Eifel maar lakes and Pleistocene dry maar structures. These reconstructions are combined with recent gauge time-series to cover the entire precipitation extremes of the last 60 000 years. In general, Eifel maar sediments are perfectly suited for the preservation of event layers since the deep water in the maar lakes is seasonal anoxic and therefore, bioturbation is low. However, the preservation of annual lamination is only preserved in Holzmaar and Ulmener Maar; the other cores are dated by ^{14}C, magnetostratigraphy, tephra markers and ice core tuning. The cores were drilled in the Eifel region of central western Germany, which represents a climatic homogenous region from Belgium to Poland and all across Central Europe.

A total of 233 flood layers over 7.5 mm were detected in all analysed cores. The stratigraphic classification of the flood events follows the newly defined Landscape Evolution Zones (LEZ). The strongest events in the Holocene have occurred during LEZ 1 (0–6000 b2k) in the years 658, 2800 and 4100 b2k. Flood layers in the LEZ 2 (6000–10 500 b2k) are not as frequent as during the LEZ 1, nevertheless, the floods cluster between 6000 and 6500 b2k. Twenty flood layers are found in the LEZ 3 (10 500–14 700 b2k); 11 in LEZ 4 (14 700–21 000 b2k); 15 in LEZ 5 (21 000–28 500 b2k); 34 in LEZ 6 (28 500–36 500 b2k); 8 in LEZ 7 (36 500–49 000 b2k); zero in LEZ 8 (49 000–55 000 b2k) and LEZ 9 (55 000–60 000 b2k). The maximum flood phases during the Pleistocene are at 11 500–17 500 (late glacial and Younger Dryas), 23 000–24 000 (before Greenland Interstadial (GI) 2), 29 000–35 000 (especially between GI 5 and 4) and 44 000–44 500 b2k (transition from GI 12 to 11).

The variations in flood dynamics are climatically driven and mainly associated with climate transitions and colder periods, combined with light vegetation. It turns out that low vegetation coverage related to both Greenland Stadial phases and anthropogenic impacts since late Holocene is the main cause for the development of flood layers in maar sediments. The precipitation itself, plays only a secondary role. This interpretation is based on the current climate understanding of cold phases and several studies of fluvial erosion related to vegetation coverage.

1. Introduction

The weather of the next decades will most likely undergo an intensification of weather extremes. Prognostic models have highlighted an intensification of prolonged summer droughts and precipitation maxima combined with a higher risk of flash floods in creeks and rivers (IPCC report 2014 and 2007; Jacob et al., 2007). Lacustrine sediments are very sensitive to natural and anthropogenic environmental changes. Thus, lake sediments are excellent climate archives and have been used for reconstructions of vegetation, water temperature, environment, volcanic activity, climate and quite recently, for precipitation and flood events (e.g. Wessels, 1998; Macklin et al., 2006; Moreno et al., 2008; Zielhofer et al., 2008; Storen et al., 2010; Wilhelm et al., 2012a, 2012b, Swierczynski et al., 2013; Wirth et al., 2013; Kämpf et al., 2014).

Lakes that are used for the Holocene reconstructions are numerous in the landscape of central Europe. However, lakes that have the potential to reconstruct the climate conditions between 10 000 and 60 000 b2k in central Germany are restricted to Eifel maar structures. The Eifel region is characterized by a climatic homogenous area from Belgium to Poland and all across Central Europe (Wernli and Pfahl, 2009). Other suitable locations are in central France (Ampel et al., 2008; Wohlfarth et al., 2008) or southern Italy (Brauer et al., 2000, 2001), and thus in regions with another climate forcing. River sediments are a complicated and incomplete archive, due to the fact that flood event layers are separated by erosion from the normal sedimentation (Brakenridge et al., 1988; Macklin, 1999; Thorndycraft et al., 2005). Small basins, like maars, with long water residence time and anoxic bottom water are better suited to preserve a complete flood archive, if they are fed by small creeks. The suspension layers can be distinguished from

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background sedimentation and seismites macroscopically or in thin sections (Marco et al., 1996; Moreno et al., 2008). Further sedimentological (e.g. grain size analysis) and geochemical (e.g. μ-XRF analysis) studies help to differentiate between flood layers, turbidites and slumps (Sturm et al., 1995; Mulder et al., 2003; Wirth et al., 2011). Accordingly, the Eifel maar lakes are the only location in central Europe that allows one to generate a long time series with event resolution (Sirocko et al., 2013).

The maar lakes and the dry maar structures of the Eifel region have been systematically cored since 1998 by the ELSA Project (Eifel Laminated Sediment Archive; http://www.elsa.geowissenschaften.uni-mainz.de) of the Institute for Geoscience, Johannes Gutenberg University Mainz, Germany. In this study, the maar structures of Holzmaar, Ulmener Maar, Schalkenmehrener Maar and Aueler Maar are used to reconstruct the flood history of the last 60 000 years. In contrast, studies on the average precipitation are better done in the closed/semiclosed basins of Gemündener Maar or Dehner Maar, where terraces document past lake levels (Sirocko et al., 2013). So far, the flood history of the last 60 000 years is increasingly studied in the Holocene, the time before 10 000 years is still completely unknown.

The key objectives of this study are: (1) to develop a high resolution long time flood frequency record for central Europe; (2) to analyse the relationship between flood activity and a) climate, b) precipitation and c) vegetation; and (3) to study the last 60 000 years with respect to the interlacing of flood layers and predominant climatic and anthropogenic development.

2. Coring sites

Four sediment cores (from three Holocene maar lakes and one Pleistocene dry maar structure) are used to reconstruct the flood activity in the Eifel for the last 60 000 years (Fig. 1).

2.1. Schalkenmehrener Maar

Lake Schalkenmehrener Maar is part of the Dauner Maare. It has a diameter of 528 m, an average depth of 14.5 m and a maximum depth of 21 m (Scharf and Oehms, 1992). With a lake surface of 219 000 m^2, it is one of the larger maar lakes of the Eifel. It has no large inflow or outflow stream. However, it is connected to a flanking dry maar, which is filled with sediment and peat since the middle Holocene (Straka, 1975) and drained since Roman times (Sirocko, 2009). Accordingly, Schalkenmehren is well suited to monitor the post-Roman landscape evolution. The freeze core SM_{f2} (Fig. 1) was used for the flood event reconstruction depicting the last 1000 years; in particular the medieval landscape history.

2.2. Holzmaar

The most investigated maar of the Eifel is the Holzmaar. The stratigraphy for this maar includes annual varve counting, which was constrained using ^{14}C-dating (Brauer, 1994; Hajdas et al., 1995; Zolitschka, 1998, and Brauer et al., 1999a, 1999b). Holzmaar has a diameter of 272 m and a maximum depth of 20 m (Scharf and Oehms, 1992). It also has the smallest water volume of all maar lakes in the Eifel. The Sammetbach flows from the west into the maar. Just a few metres further south it flows out again. The small size of the maar and the direct inflow by the Sammetbach cause a relative high sedimentation rate (10 m Holocene). Persistent low deep water oxygenation led to the formation of countable varves throughout the entire Holocene (Sirocko et al., in this volume).

2.3. Ulmener Maar

The Ulmener Maar is slightly smaller than the Holzmaar with a diameter of 265 m (Scharf and Oehms, 1992). It is the smallest and youngest maar in the Eifel (about 11 000 b2k). However, it is also one of the deepest with a maximum depth of 39 m (Scharf and Oehms, 1992). The Ulmener Maar has the largest catchment area of the three analysed Holocene maars. Up to the pre-Roman times flood sediments were flushed from the Dellbach into the maar. Nowadays, the Dellbach flows west of the maar and had no contact to it since the founding of the city Ulmen. Consequently, the Ulmener Maar can only be applied to reconstruct the pre-Roman flood history. Flood layers in the core UM2 have partly whitish colours, which correspond well to silt and clay sediments of Devonian age (Eckfeld and Reudelsterz layers) in the western catchment area of the maar. Pollen and botanical macroremains reveal that the region around the maar is anthropogenically modified since 5700 b2k (3700 BC) (Sirocko, 2009). Nevertheless, the Ulmener Maar is certainly the best suited for the early Holocene flood reconstruction and has a higher sedimentation rate than that of Holzmaar.

2.4. Auel dry maar

The silted up basin Auel is one of the largest dry maar structures of the Eifel with a diameter of 1325 m. The modern Tiefer Bach flows through the maar centre and leaves the dry maar again at the opposite side. This river has a large catchment area of 12.187 km^2 and a total length of 9.4 km (Water management administration Rhineland-

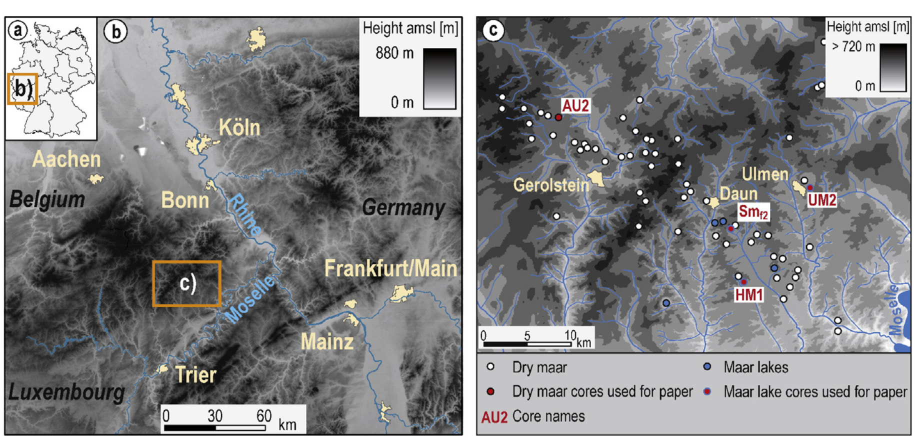

Fig. 1. a) Outline map of Germany. b) Digital terrain model West Germany with the drainage system c) Digital terrain model of the Eifel with the maar locations after Büchel (1993), the drainage system and the core positions: SM_{f2} (Gauß-Krüger-Koordinatensystem Zone 2 (GK-System) 2,561,310/5,559,585); HM1 (GK-System 2,562,900/5,554,030); UM2 (GK-System 2,570,165/5,564,270) and AU2 (GK-System 2,542,455/5,572,017). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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