A 2500 year paleoseismic record of the Húsavík-Flatey Fault inferred from the sediments of Botnsvatn Lake (North Iceland)

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The Mid-Atlantic-Ridge formed by the divergent movement of the North American and Eurasian plates is offset towards east in Iceland, which results in a dextral transform zone just north of the island. The strain accommodated along this dextral transform zone is released mainly by the Húsavík-Flatey Fault (HFF) and Grímsey Oblique Rift (GOR) (Fig. 1a, inset) in magnitude 6-7 earthquakes. However, historical accounts of past major earthquakes are inaccurate and incomplete and primarily provide information for only the last 300 years. The GOR does not allow paleoseismological trenching since it is completely offshore, but a ~20 km-long southeastern part of the HFF is onshore. Still, the number of sites that are favorable for paleoseismic trenching is limited. We have therefore carried out lacustrine paleoseismological investigations in Botnsvatn Lake, which is located in a pull-apart basin of the HFF (Fig. 1a), that may provide crucial information about the past seismic activity of the HFF. We collected five sediment cores from the lake to investigate possible sedimentary traces of past earthquakes of the HFF.

Figure 1. (a) Topography around Botnsvatn Lake and main strands of the Húsavík-Flatey Fault. The inset (modified from Metzger et al. (2013)): NA, North American Plate; EU, Eurasian Plate; RR, Reykjanes Ridge; KR, Kolbeinsey Ridge; GOR, Grímsey Oblique Rift; HFF, Húsavík-Flatey Fault. Blue star stands for the location of Botnsvatn Lake. (b) Bathymetric and slope maps in/around the lake. Maximum water depth reaches up to 19 m, and southwest-facing slopes are as steep as 50 degrees.
We carried out a bathymetric survey in Botnsvatn Lake (125 m a.s.l.) in August 2012 and it revealed that the lake has one basin with maximum water depth of 19 m (Fig. 1b). We collected five sediment cores in February 2013, which were 10-30 m apart from each other, from the deepest part of the basin, namely; 2F, 2E, 2D, 2C, and 2B (138, 401, 225, 267 and 182 cm-long, respectively). The sediment chronology was constructed by tephrochemical analyses on 125 tephra layers and four radiocarbon dates along the longest core (i.e., 2E). Accordingly, the bottom of 2E was dated to 430 BC. All cores were logged at 1 mm increments by Geotek-MSCL for magnetic susceptibility (MS) and gamma-ray density profiles. High-resolution radiographic images of all cores were obtained by ITRAX micro-XRF and SCOPIX scanners. Along 2F and 2E, micro-XRF scanning was done as well at 0.5 mm increments. In addition to these non-destructive logging and scanning methods, grain-size distribution and organic matter content measurements were done at 2 cm increments along 2E. In this way, a high-resolution multi-proxy dataset was obtained, which allowed us making detailed sedimentological interpretations.

The most commonly observed sedimentary consequences of earthquakes in lake sediments are soft-sediment deformations (SSD) and mass-wasting deposits (MWD) (e.g., Beck, 2009; Moernaut et al., 2014). In Botnsvatn Lake, we do not observe any distinct evidences of SSDs and/or MWDs corresponding to the historical earthquakes in the region, which were in 1872, 1755, 1577 and 1260 (Thorgeirsson et al., 2013). However, around the dates of these four historical earthquakes, we observe angular particles with diameters around 1-2 mm that are dispersed within the fine-grained background sedimentation. These particles are seen as black spots in the radiographic images, and result in slightly higher magnetic susceptibility values. Fig. 2 illustrates the radiographic images and magnetic susceptibility profiles along the stratigraphical horizon between the 1614 Veidivötn-Bárdarbunga and ca. 1500 Grímsvötn tephras. The episode around mid-1500s, in which angular particles (black or dark gray spots) are concentrated, is also associated with higher magnetic susceptibility values compared to the background sedimentation. This sedimentary event is probably related to the 1577 historical earthquake in North Iceland. We observe similar sedimentary events that can be temporally correlated to the historical earthquakes in 1872, 1755 and 1260 as well.

![Figure 2. Radiographic images of Botnsvatn cores (2F-2B) overlapped by magnetic susceptibility profiles (red curves). The angular particles with diameters around 1-2 mm (black or dark gray spots) are interpreted to be the ice-rafted debris (IRD) due to the 1577 earthquake, which is seen between the 1614 Veidivötn-Bárdarbunga and ca. 1500 Grímsvötn tephras.](image-url)
The most probable mechanism that can explain the existence of coarse angular particles within clayey/silty background sediments is ice-rafting. As it can be seen in Fig. 1b, the slopes adjacent to the north-/south-eastern parts of the lake are as steep as 50 degrees, which makes them highly susceptible to earthquake-triggered snow avalanches. Particularly in winter, when the lake and adjacent slopes are covered with ice and snow, an earthquake can easily trigger snow avalanches, which are associated with debris ripped from the slopes. The snow-debris mixture slides over the ice cover of the lake and during the following summer, when the ice cover starts to melt and float on the lake, the debris accumulated on the ice cover is deposited into the silty/clayey sediments of the lake. On the other hand, earthquakes occurring in summer might cause rock falls and weaken the top soil on the steep slopes. In this way, the slopes become highly sensitive to extra overloading due to snow accumulation in the subsequent winter, which may result in snow avalanches as well.

We detected a total of eleven earthquake-triggered IRDs during the last 1800 years of the Botnsvatn record, four of which are temporally correlated to the known historical earthquakes. On the other hand, the IRDs become highly frequent (40-50 years apart) during the period between 1800 BP and 2400 BP, which corresponds to significantly warmer climatic conditions compared to the rest of the record. Hence we believe that the oldest 600 years of the Botnsvatn record probably contains non-seismic origin IRDs, which prevents revealing paleoseismic information. According to the last 1800 years of the record, the recurrence interval of the earthquake-triggered IRDs is 140±35 years.

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References


