Earthquake-triggered Zurich moraine-dam breakthrough and subsequent lake outburst (~13’850 cal yr. B.P.)

Strasser, M., *Schindler, C. & Anselmetti, F.S.

Geological Institute, Department of Earth Science, ETH Zurich, Switzerland
*Oetwil a.S., Switzerland

Many lakes impounded by moraines are a threat to people and infrastructure in mountain regions throughout the world, because dams may fail suddenly, producing destructive floods with peak discharges far in excess of normal flows (e.g Huggel et al., 2004). Especially during periods of atmospheric warming, hazard potential might increase due to accelerating rates of glacier retreat and enhanced susceptibility for moraine-dam failures, both by melting ice cores and by increasing the amount of water flowing over the moraines (Clague & Evans, 2000). Such events also may be triggered by earthquake shaking that initiates the moraine-dam breakthrough. In order to asses the hazard potential of future events, the geologic record of major lake outbursts that occurred after the glacier retreat during Late Pleistocene warming needs to be studied. The here presented study investigates the sedimentary record of Lake Zurich, Central Switzerland, in order track and to reconstruct an earthquake-triggered Late Glacial failure of the Zurich moraine-dam and the subsequent lake outburst.

Lake Zurich occupies a perialpine, glacigenic oversteepened trough in the northern Plateau of Switzerland. At its northern end the lake is bordered by a prominent terminal moraine that was deposited during overall glacier retreat after the Last Glacial Maximum (Zürcher Stadium; Hantke 1967). Based on geomorphological and sedimentological data from various studies around and downstream Lake Zurich, it was postulated that the Zurich moraine-dam collapsed in early Late Glacial times and the subsequent catastrophic lake drainage resulted in a sudden lake level drop of ~ 14 m (Schindler 1971, 2004). The here presented study aims (i) to track this outburst in the sedimentary record of Lake Zurich; (ii) to quantitatively reconstruct the discharge of this catastrophic drainage; (iv) to precisely date the event, and (v) to discuss possible cause and trigger mechanisms.

Imaging the subsurface of Lake Zurich by a dense grid of high-resolution 3.5 kHz reflection seismic profiles and coring the Late Glacial lacustrine record reveal distinct depositional and erosional features within one stratigraphic event horizon, which is interpreted to be related to the postulated Late Glacial outburst event. This event horizon is characterized by basinwide mass movement deposits and coincides with a major reorganization in the sedimentary system expressed by a prominent lithologic change. Furthermore, sedimentary structures observed over the entire flat upper Lake Zurich basin between Männedorf/Stäfa and Richterswil/Wädenswil indicate that sediment was transported in a flowing water body. The low-amplitude, high-wave length bedforms only can be formed if the outburst produced enough discharge to bring the sediment in this water depth (~32 m at the time of deposition) into suspension (i.e. settling velocity of grains has to be smaller then the shear velocity of the flowing water;

Allen, 1997). By combining the reconstructed total volume drained during the outburst event (~2 km^3) and by grain size measurements of the bedforms, the required critical flow velocities can be back-calculated allowing for quantitatively reconstructing the maximal duration and minimal water discharge of the Lake Zurich outburst.

Preliminary results suggest that the observed sedimentary structures only can be explained if the duration of the discharge event lasted not longer than ~13 days. This reveals a minimum estimate of peak discharge through the opened gateways in the Zurich moraine-dam of ~1750 m^3/s (As comparison: peak discharge measured in Swiss rivers during the flood in August 2005 reached ~1000 m^3/s (Bundesamt für Wasser und Geologie, 2005)). The results thus confirm and quantify the hypothesis that the Zurich moraine-dam breakthrough resulted in a catastrophic drainage and sudden lake level drop in Lake Zurich (Schindler, 1971; 2004).

The event is dated (^{14}C AMS technique on terrestrial samples from sedimentary cores) to 13700-13990 cal yr. B.P. and thus occurred during the Bölling stage, a time period that represents the onset of mid-European climatic amelioration after the end of the last glacial stage. Ice and/or permafrost thawing in the core of the moraine and increasing amount of water discharge from rapidly melting alpine glaciers likely resulted in unfavorable conditions susceptible for moraine-dam failures. Regional paleoseismic investigations show that the timing of the outburst event also coincides with a major North Alpine Earthquake (Mw > 6.5; Strasser et al., 2006). We therefore conclude that the 'thawing' and weakened Zurich moraine eventually collapsed, triggered either by earthquake shaking or by secondary earthquake effects such as subaquatic landslide-generated tsunami or rockslide-generated impact waves, which overtopped the moraine-dam and initiated failure and subsequent drainage.

REFERENCES

Allen, P.A., (1997). Earth surface processe. Blackwell Science, Oxford, 404 pp.
Clague, J.J. & Evans, S.G., (2000). A review of catastrophic drainage of moraine-dammed lakes in British Columbia. Quaternary Science Reviews, 19(17-18): 1763-1783.
Hantke, R., (1967). Geologische Karte des Kantons Zürich und seiner Nachbargebiete. Mitteilungen aus dem Geologischen Institut der Eidg. Technischen Hochschule und der Univ. Zürich, Neu Folge; 82.
Huggel, C., Haeberli, W., Kaab, A., Bieri, D. & Richardson, S., (2004). An assessment procedure for glacial hazards in the Swiss Alps. Canadian Geotechnical Journal, 41(6): 1068-1083.
Schindler, C., (1971). Geologie von Zürich und ihre Beziehung zu Seespiegelschwankungen. Vierteljahresschrift der Naturforschendengesellschaft in Zürich, 116(2): 285-315.
Schindler, C., (2004). Zum Quartär des Linthgebietes zwischen Luchsingen , dem Walensee und dem Züricher Obersee. Beiträge zur Geologischen Karte der Schweiz, Lieferung 169. Landesgeologie, BWG.
Strasser, M., Anselmetti Flavio, S., Fäh, D., Giardini, D. & Schnellmann, M., (2006). Magnitudes and source areas of large prehistoric northern Alpine earthquakes revealed by slope failures in lakes. Geology, in press.