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Lake dwellers occupation gap in Lake Geneva (France–Switzerland) possibly explained by an earthquake–mass movement–tsunami event during Early Bronze Age

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ABSTRACT

High-resolution seismic and sediment core data from the 'Grand Lac' basin of Lake Geneva reveal traces of repeated slope instabilities with one main slide-evolved mass-flow (minimum volume 0.13 km^3) that originated from the northern lateral slope of the lake near the city of Lausanne. Radiocarbon dating of organic remains sampled from the top of the main deposit gives an age interval of 1865–1608 BC. This date coincides with the age interval for a mass movement event described in the 'Petit Lac' basin of Lake Geneva (1872–1622 BC). Because multiple mass movements took place at the same time in different parts of the lake, we consider the most likely trigger mechanism to be a strong earthquake (Mw 6) that occurred in the period between 1872 and 1608 BC. Based on numerical simulations, we show the major deposit near Lausanne would have generated a tsunami with local wave heights of up to 6 m. The combined effects of the earthquake and the following tsunami provide a possible explanation for a gap in lake dwellers occupation along the shores of Lake Geneva revealed by dendrochronological dating of two palafitte archaeological sites.

1. Introduction

In the Neolithic and Bronze age, raised stilt house (or palafitte or lake dwelling) settlements were common around peri-Alpine lakes. Since 2011, a representative selection of 111 prehistoric lake dwellings has been inscribed on UNESCO's World Heritage list in six countries bordering the Alps: France, Germany, Austria, Italy, Slovenia and Switzerland (http://whc.unesco.org/en/list/1363/). Such house remains, present on the shores of Lake Geneva as underwater fields of wooden piles, can be accurately dated with dendrochronology to obtain the exact year of tree cutting. The occurrence of continuous series of dated piles defines the (minimum) lake dweller occupation interval of lake shores. In Lake Geneva, pile data show a 21 years-long period of continuous tree cutting and house building at Preverenges, ending in 1758 BC, followed by the building of new pile houses starting in 1730 BC, 3 km away in Morges/Les Roseaux (Fig. 1; Corboud and Pugin, 2008). However in Preverenges, new pile houses building started only 129 years later in 1625 BC. This 28 years interval without dated piles is interpreted as a human occupation gap. Such human occupation gaps are generally explained by an increase in lake-level, soil depletion or social and cultural changes (Magny, 2004; Corboud, 2012; Magny et al., 2012; Swierczynski et al., 2013).

For several of the peri-Alpine lakes occupied by palafitte settlements, large-scale subaqueous mass movement events, transporting large amounts of sediment from lateral slopes to the deep basins, have been reconstructed based on sedimentological and geophysical evidence (Chapron et al., 1999; Arnaud et al., 2002; Schnellmann et al., 2006; Strasser and Anselmetti, 2008; Smith et al., 2013; Strasser et al., 2013; Wilhelm et al., 2013). These mass

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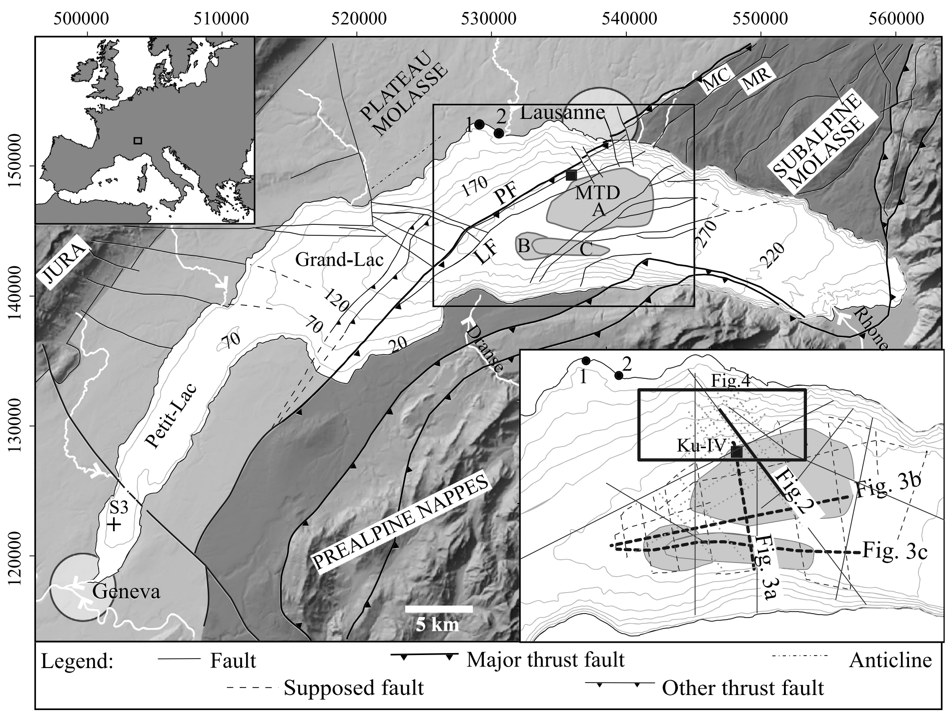

Fig. 1. Shaded digital elevation model (Swiss Federal Office of Topography) of the region surrounding Lake Geneva with the main rivers, cities as well as tectonic units and faults (in black) after the Swiss tectonic map (1:500 000) and Dupuy (2006). PF: Paudeze Fault; LF: Lutrive Fault; MC: Molasse à charbon; MR: Molasse rouge. General bathymetry (m) is given by grey contour lines. The areal extent of mass transport deposits within the lake sediments (MTDs A, B, and C; this study) is indicated in grey. Black dots refer to archaeological palafitte sites (1: Morges VD–Les Roseaux, 2: Preverenges, after Corboud and Pugin, 2008). Black square (Ku-IV) and cross (S3) locate sediment core and drilling, respectively. The inset map locates seismic reflection airgun (black), watergun (doted) and pinger (dashed) lines with references to profiles of Figs. 2 and 3 (bold lines) and multibeam bathymetry data (black rectangle) with reference to Fig. 4. Coordinates are in meters (Swiss Grid).

movements have the potential to produce tsunamis with heights reaching several metres, which constitute a considerable natural hazard along the shores of these lakes (Kremer et al., 2012). A common trigger mechanism for slope instabilities in this environment is earthquake shaking, which often leads to widespread mass transport, producing coeval deposits in different parts of a lake or even in more than one lake (Schnellmann et al., 2002; Strasser et al., 2006, 2013). Current research shows that initial sublacustrine mass movements (slides, slumps…) often produce complex mass transport deposits (Mulder and Cochonat, 1996; Schnellmann et al., 2006 and references therein) including mass wasting and mass-flow deposits in the same bed.

Here, we propose an alternative explanation for the observed occupation gap of the palafitte settlements on Lake Geneva, involving the combined effects of a large earthquake that triggered mass movements and a tsunami in the lake. As evidence, we present new seismic reflection, sedimentological, palynological data and new ^{14}C dates along with results of tsunami wave numerical modelling.

2. Geological setting

Lake Geneva is the largest freshwater basin in Western Europe with a water volume of 89 km^3 extending over an area of 580.1 km^2. It is divided into two sub-basins; the 'Grand Lac', the lake's main part with a maximum water depth of 309 m and the 'Petit Lac' at its western end with a maximum water depth of 70 m (Fig. 1). Lake Geneva is situated in the Alpine foreland between the Alps and the Jura mountain ranges and was carved during Quaternary glaciations mostly into the Tertiary Molasse.

The Molasse bedrock comprises two tectonic units: the relatively undeformed, south–east dipping Plateau Molasse and a complex assemblage of imbricated thrust slices, the Subalpine Molasse (Gorin et al., 1993; Sommaruga et al., 2012). In the region of Lake Geneva, these two units are divided by the 'Paudeze Fault' (PF) zone (Fig. 1), which is a major thrust fault with a vertical throw of 1 km in the vicinity of the city of Lausanne and a southwest–northeast trend (Weidmann, 1998). This fault zone runs through the city of Lausanne, across the lake and reappears on the southern shore (Dupuy, 2006; Scheidhauer et al., 2005; Weidmann, 1998). Towards the east, a second fault system, called 'Lutrive Fault' (LF), separates two subunits of the Subalpine Molasse: the 'Molasse à charbon' (MC) and the 'Molasse rouge' (MR).

Quaternary sediments in Lake Geneva have a maximum thickness of 400 m (Dupuy, 2006; Vernet et al., 1974). They consist mainly of moraines, pro- and peri-glacial units and lacustrine deposits. The geometry of the lacustrine infill is complex and varies greatly depending on its location and age (Girardclos et al., 2005; Loizeau, 1991). In areas exposed to deep current erosion (Girardclos et al., 2003), such as the junction between the two sub-basins and the Versoix area, Holocene lacustrine sediment thickness is close to zero, whereas in the Rhone delta area it reaches 400 m (Dupuy, 2006). Holocene background hemipelagic sediments are often 5–10 m thick but mixing and deposition together with clastic sediments, brought by lateral rivers such as Dranse, Aubonne, Versoix, Promenthouse, and Venoge, generally increase lacustrine sediment thickness to 20–75 m near deltas (Baster et al., 2003; Dupuy, 2006; Fiore, 2007; Fiore et al., 2011). Analogously, the sediment accumulation rate for the past 50 years varies between 0.01 and 1.96 $g\,cm^{-2}\,yr^{-1}$, thus reflecting the locally highly variable sediment input (Corella et al., in press; Loizeau et al., 2012).

From historical and instrumental data, six earthquakes with Mw > 4.5 occurred in the Prealps, south east of the lake, in the period between 1500 and 2009 in Lake Geneva region (Table A1, Fig. A1; Fäh et al., 2011). In the same period, the area north of Lake Geneva was seismically less active, with only low-magnitude