Giant Lake Geneva tsunami in AD 563

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Supplementary Methods – Numerical simulations

Simulations were carried out by numerically solving the shallow water equations in two dimensions. In our model, surface water waves were generated by kinematically displacing the lake bottom by a volume of 0.25 km$^3$ between the Rhone delta and the deepest part of the lake. The displacement velocity, computed on the basis of a simple empirical relationship$^6$ between the total distance travelled (23 km) and the slope (0.5°), is estimated to have been 46 km/hr, implying a total slide duration of 30 minutes. We assumed this velocity was constant throughout the event, and thus ignored periods of acceleration and deceleration that could be expected within the initial and final phases. We have not accounted for how the subaerial rockfall actually initiated failure of the delta, or the transformation of the subsequent subaqueous landslide into a mass flow, for which we have no observational data. We also didn’t include erosion, sediment transport or sedimentation or any other interaction between the slide mass and the water column that may introduce momentum dissipation, something that would reduce wave heights compared to the results presented. The entire modern lake border was assumed to be a no flow (closed) boundary. Thus, we do not compute run-up distances relative to the lake shore but focus on initial wave heights and initial arrival times which are less dependent on the nature of the boundary conditions. Though we present results based on our best estimate of parameters, it is important to recognize that our results are still strongly dependent of several key variables that are uncertain, particularly the slide volume, and the slide velocity. The slide volume used in simulations is a minimum of that actually measured and could potentially be even larger, that would generate even larger wave heights. The slide velocity could potentially be smaller than our used estimate, for example due to interaction with the water column resulting in loss of momentum. Reducing the slide velocity from 46 km/hr to 23 km/hr decreased the maximum wave height observed in Geneva from 8 m to 3 m. Maximum wave heights and arrival times measured in Geneva do not depend strongly on either the position or the shape of the slide mass.
Supplementary Figure 1: Lake Geneva location map and bathymetry. a, Shaded relief map (Swiss Federal Office of Topography) of the region surrounding Lake Geneva with the location of major settlements. Water depth within the lake is indicated with grey contour lines. The thickness of the 563 AD turbidite is shown with a colour shaded scale. Seismic reflection survey is indicated with dark grey lines. The solid black line represents the location of seismic profile in Supplementary Figure 3, the black squares are locations of sediment cores, and the dashed line shows the position of the bathymetric profile in b. True slope angles are shown in the inset.
**Supplementary Figure 2: Summary of the chain of events in 563 AD.** Sketch of the geological and limnogeological process describing the main phases of the 563 AD event similar to the scenario that has been previously proposed\(^1\), from the aerial rockfall in the Rhone valley (1) to the sublacustrine Rhone delta collapse, followed by turbiditic and debris flow propagation with wave generation (2), ending with water wave passing over the old city walls of Burgundian Geneva (3).
Supplementary Figure 3: Seismic profile. High resolution seismic reflection (3.5 kHz) profile shows the turbidite as a lens-shaped unit (H) with chaotic facies. The position and length of the sediment cores are marked with vertical bars. The black part of the cores is described in Supplementary Figure 4. True slope angles are shown in the inset. Though our study focuses on the largest and most recent mass movement deposit (outlined in black, unit H), we note that there are at least seven more mass movement units (A-G) deeper in the basin that are recognized on the basis of their chaotic to transparent seismic signals and overall lens shape (outlined in green).
Supplementary Figure 4: Sedimentary and geophysical description of the turbidite.

Sedimentary logs in various parts of the lake basin documenting the structure, grain-size, magnetic susceptibility and density of the large turbidite. The positions of three samples analysed for 14C dating are indicated with stars on Ku-V.
**Supplementary Figure 5: Age model of the turbidite in core KuV.**

Calibrated age intervals are indicated with 95% probability (2σ). The age-depth model is based on linear interpolation between neighbouring levels using the clam code\(^2\) for the open source statistical 'R'. The white envelope shows the 95% confidence interval, giving an extrapolated age of 381 to 612 cal AD for the turbidite.
Supplementary Figure 5: Age model of the turbidite in core KuV.
Calibrated age intervals are indicated with 95% probability (2σ). The age-depth model is based on linear interpolation between neighbouring levels using the clam code2 for the open source statistical 'R'. The white envelope shows the 95% confidence interval, giving an extrapolated age of 381 to 612 cal AD for the turbidite.

Supplementary Figure 6: Possible inundated zone in Geneva for an 8 m wave. Aerial photographs (SITG Geneva) of Geneva showing regions that would have been submerged by an 8 m tsunami. Inundated regions were estimated taking account of the first arrival wave height (at the lake shore) and the current topography. a, 6th century reconstruction of the city of Geneva with Burgundian buildings, walls and bridge (in white) and the past lake border3,4,5 (thick black line). b, location of the Burgundian city within modern Geneva showing possible zone of inundation.
**Supplementary Table: Radiocarbon ages.** Radiocarbon ages obtained for organic material (leaves and wood). Calibration was performed with the 'calibrate' function of the clam code\(^2\) for the open-source statistical software 'R' using the northern hemisphere terrestrial IntCal09 calibration data\(^7\).

<table>
<thead>
<tr>
<th>Sediment core depth (cm)</th>
<th>Sample No.</th>
<th>Conventional Radiocarbon Age (^{14}\text{C} \text{ yr BP})</th>
<th>2 Sigma calibration (yr BP)</th>
<th>2 Sigma calibration (yr AD)</th>
<th>Dated Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>581.2</td>
<td>ETH-41102</td>
<td>1330 ± 35</td>
<td>1179 to 1212 or 1225 to 1304</td>
<td>646 to 725 or 738 to 771</td>
<td>Leaves</td>
</tr>
<tr>
<td>626.5</td>
<td>ETH-41883</td>
<td>1540 ± 40</td>
<td>1351 to 1523 or 416 to 613</td>
<td>256 to 340 or 314 to 424</td>
<td>Leaves</td>
</tr>
<tr>
<td>637.3</td>
<td>ETH-41103</td>
<td>1685 ± 35</td>
<td>1526 to 1636 or 1646 to 1694</td>
<td>256 to 340 or 314 to 424</td>
<td>Wood</td>
</tr>
</tbody>
</table>
Supplementary References

1. Fort, M. et al., Geomorphic impacts of large and rapid mass movements: a review. Geomorphologie-Relief Processus Environnement 1, 47-63 (2009).