Source of the 1755 Lisbon Earthquake: A Phenomenological Reconstruction Based on Historical Records and Tsunami Simulation

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The Great Lisbon earthquake (GLE) (November 1, 1755) with an estimated moment magnitude (Mw) of 8.7 (e.g., Johnston, 1996), struck Portugal, Spain, and northern Morocco, with tremors felt across most of northwestern Europe. This is the only major earthquake to have occurred far from a major subduction zone in the last ˜350 years. The earthquake triggered a devastating trans-oceanic tsunami that swept the nearby Atlantic coast with run-up heights of 5–15 meters. In the Caribbean Islands, run-up heights of 1–5 meters were also reported (Gutscher, 2004). The mechanism behind its generation has been extensively studied and several conflicting sources have been proposed, but none have satisfactorily explained the historical data.

Here, we investigate three aspects of the historical evidence: tsunami height and arrival times, macroseismic impacts, and aftershock distribution, to gain a better understanding of the fault responsible for generating this earthquake. To achieve this, we performed tsunami simulations and compared the obtained run-up heights and arrival times with those reported in historical documents collected at 9 locations. Next, using the back-projection approach, we invert the simulated tsunami travel time to estimate the source area. Finally, we analyze the distribution of macroseismic impacts and calculate the Coulomb stress changes from each source fault to the Lower Tagus Valley region, where most of the aftershocks of the GLE are believed to have occurred.

To simulate a tsunami, we used the tsunami simulation code JAGURS (Baba et al., 2015). Bathymetry grids for the simulation were obtained from the General Bathymetric Chart of the Oceans (GEBCO, 2023) with flat resolutions of one arc minute. The time step for calculations was set at 0.5 s to satisfy the Courant-Friedrichs-Lewy stability condition, and the tsunami was simulated for 15 h after the earthquake ensuring that the maximum tsunami height would be obtained, and that the tsunami could travel across the oceans. Manning's roughness coefficient and rigidity were assumed at 0.025 $m^{-1/3}s$ and 34.3 GPa, respectively. We reexamine four contemporary potential source faults that have been suggested by previous studies: the Gorringe Bank Fault (Johnston, 1996); the composite source that encompasses the Marques de Pombal Thrust Fault and Guadalquivir Bank (Zitellini et al., 2001); the Gulf of Cádiz Fault (Gutscher et al., 2006) and the Horseshoe Abyssal Plain Thrust (HAPT) fault (Barkan et al., 2009).

The results show that the four modeled earthquake sources were able to somewhat reproduce the historical records. The primary source located at Horseshoe Abyssal Plain Thrust yielded the best correlations between simulations and historical records of run-up heights. The result of seismic intensity analysis shows high intensities (Modified Mercalli Intensity IX –X) around the Lisbon and Algarve regions. Among all the analyzed epicentral locations, the one closest to Lisbon is approximately 220 km southwest of its end. This suggests that additional factors could have played a role in favoring this shift to longer distances, thus requiring further investigations. Finally, results of the static Coulomb stress changes from each analyzed source to the location of the Lower Tagus Valley (LTV) fault show that LTV may have experienced more than a 0.1 MPa stress increase towards the failure from the HAPT Fault.

In summary, our integrated results suggest that the 1755 GLE likely involved cascading triggering, with the primary source located at the HAPT Fault. These results provide a new perspective toward a coherent interpretation of the fault source of the 1755 GLE. However, we acknowledge that several outstanding challenges remain to be overcome, due mainly to our inability to reliably assess the accuracy of historical data.

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Keywords: Run-up heights, Tsunami simulation, back-projection approach, Seismic intensity, Coulomb stress changes, Cascading triggering.

