Web links to the author's journal account have been redacted from the decision letters as indicated to maintain confidentiality.

This manuscript has been previously considered at another Nature Research journal. This document only contains reviewer comments and rebuttal letters for versions considered at Communications Earth & Environment. Mentions of the other journal have been redacted.

16th Apr 21

Dear Dr Martínez-Loriente,

Your manuscript titled "Unveiling the source and causes of the 1755 Lisbon earthquake and tsunami" has now been seen by 3 reviewers, whose comments are appended below. You will see that they find your work of some potential interest. However, they have raised quite substantial concerns that must be addressed. In light of these comments, we cannot accept the manuscript for publication, but would be interested in considering a revised version that fully addresses these serious concerns. In particular, please ensure that the revised manuscript meets the following editorial thresholds:

Provide a robust compelling case that a crustal-scale thrust fault on the Horseshoe Abyssal Plain could have caused the 1755 Lisbon earthquake

Ensure that your interpretations and conclusions are fully supported by the data and modelling in your study and tone down or caveat these where appropriate including, for example, adapting the title as suggested by Reviewer #1

Clearly explain the assumptions, values and data sources you select and use to inform your modelling and interpretations and ensure these are justified in the context of existing relevant literature

We hope you will find the reviewers' comments useful as you decide how to proceed. Should additional work allow you to address these criticisms, we would be happy to look at a substantially revised manuscript.

However, please bear in mind that we will be reluctant to approach the reviewers again in the absence of substantial revisions.

If the revision process takes significantly longer than three months, we will be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We understand that due to the current global situation, the time required for revision may be longer than usual. We would appreciate it if you could keep us informed about an estimated timescale for resubmission, to facilitate our planning. Of course, if you are unable to estimate, we are happy to accommodate necessary extensions nevertheless.

We are committed to providing a fair and constructive peer-review process. Please do not hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter) and any completed checklist:

[link redacted]

** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

Please do not hesitate to contact me if you have any questions or would like to discuss the required revisions further. Thank you for the opportunity to review your work.

Best regards,

Luca Dal Zilio,
Editorial Board Member
Communications Earth & Environment

Joe Aslin
Associate Editor
Communications Earth & Environment

EDITORIAL POLICIES AND FORMAT

If you decide to resubmit your paper, please ensure that your manuscript complies with our editorial policies and complete and upload the checklist below as a Related Manuscript file type with the revised article:

Editorial Policy Policy requirements

For your information, you can find some guidance regarding format requirements summarized on the following checklist:(https://www.nature.com/documents/commsj-phys-style-formatting-checklist-article.pdf) and formatting guide (https://www.nature.com/documents/commsj-phys-style-formatting-guide-accept.pdf).

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

Dear Editor and Authors,
The manuscript presents good contributions for the advancement in the knowledge of the mechanisms of generation of earthquakes in the studied region, as well as the tectonic configurations that generated the earthquake that caused the tsunami of 1755.

The 1755's tsunami source problem is complex and the today solutions showed are not unanimous recognizied by all scientifc community.

We recognize the importance and the contribution of the manuscript but this title is superstimated. This manuscript offers us only more one possibility, and needs the analysis and acceptance of scientific community. Please, review the title expressing the contribution and not the solution to this problem.

The manuscript tests its model with historical observations in the southern portion of the Iberian peninsula and northern Africa, in addition to the USA, the Caribbean and the South Atlantic, where it obtains good results. However, the great current challenge for the identification of the source of the earthquake that caused the 1755 tsunami is to determine a source that validates the models with the historical observations mentioned above and also in the northern portion of the Iberian peninsula, the British Isles and Ireland.

In some parts of the text there are statements that do not have scientific references to confirm them, making them just speculations or opinions of the authors (eg. Lines 36, 38 and 112).
The affirmation "Additionally, the tsunami simulation fits better than any other proposed source the historical reports from the 1755 Lisbon event, particularly the observed wave-heights." Is not true. Others papers show for some historical reports better fits.

The figures presents the results in an understandable and visually well made way. The supplementary material supports the understanding of the reading of the manuscript.

In this way it is suggested: that:
- Comparisons of the results are made with more historical data from the northern portion of the Iberian Peninsula, the British Isles and Ireland.
- The affirmations statements are supported by references.
- The parts of the manuscript should be reordered in order to give a good flow in the reading of the text. The item "Regional implications" appears before the general conclusions of the manuscript. The methodological item appears at the end of the text.
- The conclusions are highlighted in the text, as they appear in the form "The HAT as a source of the 1755 Lisbon Earthquake and Tsunami."

Reviewer #2 (Remarks to the Author):

Dear Editor,

Martinez-Loriente et alii present a smart manuscript mixing and blending together seismological, geological, marine, and rheological evidence to re-intepret the source of the great 1755 earthquake and tsunami, which hit Lisbon and large part of the Iberian peninsula (i.e. the coasts). I suggest publication of this manuscript after some important reviews:

(1) The most important review to deal with, in my opinion, is to respond to the follwing question: how does this work advance, in general, the science of tsunamis and related earthquakes? I see

some regional implications at the end of the manuscript, but I do not see a clear general take-home message. I deem this work has surely the potential of expressing a more general message on tsunamis and the generating earthquakes. This message should be clearly expressed in the abstract and discussed at the end of the manuscript. How about a comparison with other case histories so to generalize the presented findings? A manuscript on Nature (family) should, in my opinion, always explain how the results advance the science.

(2) One of the keys and novelties of this works consists of the fact that, based on geological-rheological analyses, "modest-length thrust faults such as the HAT could potentially account for large earthquakes". Comparison-contrast with similar settings-cases elsewhere would greatly support this result. Is the result/hypothesis of modest-length thrusts generating large earthquakes common elsewhere? If yes, what are the causes? Rheological causes as in the case proposed in this work?

(3) Concerning the tsunami modeling, I think that results and comparison with previous works should be better analyzed, presented, and discussed. Tables 2 and 3 should be, in my opinion, (spatially) graphed to show the trend and minor-major differences with previous works. Is there a statistical way to quantify the deltas between observed and modelled data for this work and previous ones? The best fit should be properly quantified and assessed. Some statistical processing on the results from the models compared with observed data and previous models would greatly support results by Martinez-Loriente et alii.

(4) In places, I see big discrepancies in the run-up data between observed and modelled cases. Could these discrepancies be justified through local submarine landslides? The same applies to the arrival time data. I see that the authors have proposed this hypothesis (landslide) at the end of the manuscript. I suggest the authors to better constrain this hypothesis through the use of the above-proposed (spatial) graphs.

(5) I am not sure whether the 1755 earthquake has been the most destructive known earthquake in European history. The 1908 Messina Straits earthquake and the 1693 SE Sicily earthquake were also very big with associated tsunamis.

I hope that these suggestione will be useful

Rome, April 2021
Andrea Billi

Reviewer #3 (Remarks to the Author):

Martinez-Loriente et al. (the manuscript) address a recurrent scientific subject: the characteristics of the source of the 1755 Cadiz Gulf earthquake and tsunami. This is a challenging task, given the offshore location, the length of time elapsed, and the apparently contradictory information. The authors draw on geophysical and seismological data to propose that the rupture of the NE-SW trending Horseshoe Abyssal Thrust (HAT) in response to the Nubia-Iberia convergence was the culprit. In favour of their proposed model the authors argue that their modeling of tsunami heights

and traveltimes improves significantly the fit to coeval reports. They solve the paradox of accounting for a mega-earthquake without the presence of faults with the corresponding length by invoking nucleation in the upper mantle and propagation through serpintinized basement rocks that outcrop in the Cadiz Gulf, a mechanism that they support with thomographic evidence.
Forgetting for a minute the 1755 earthquake, the proposed mechanism has at least the merit of explaining the M7.8 1969 Cape St Vincent earthquake, with hypocentral depth of 37 km (Buforn et al., 2020) and no apparent surface rupture, and other intermediate-depth instrumental earthquakes of lesser magnitude occurring in the Horseshoe Abyssal Plain. The scientific merit of the model is therefore undeniable.
And yet… I cannot help feeling that the authors just missed the opportunity to make a qualitative improvement of our understanding of this elusive historical earthquake, given the power of the tools under their command. My view is that the interpretation sails too close to orthodox thinking, and some interesting clues are missed, as is often the case when that approach is taken.
For example, the authors open by stating that the 1755 earthquake has magnitude Mw ~8.5 (line 12). This is understandable because such a figure is widely cited in the literature, but the reference given for this value ((Johnston, 1996) is 25 years old, and doesn't benefit from robust techniques for estimating the magnitude of historical earthquakes that in the meantime have become standard (e.g. Bakun and Wentworth, 1997). But since the authors cite synthetic peak ground accelerations derived from intensities by Buforn et al. (2020) to support their choice of strike and focal mechanism (I will ignore for tphe sake of the argument that this is debatable given the distance to the coast) I would expect them to notice a remarkable feature of those PGA values: except for the coastal regions of southern and western Portugal, they tend to be lower than the values estimated for the M7.8 1969 earthquake at the same locations (Figure 10 of the cited reference). Since the relative difference in epicentral distance is small at ~1000 km from the epicenters, there is certainly something there to be learned about the relative magnitudes of the two earthquakes. To be fair, the authors of the cited reference missed that implication too (but they were not trying to publish in ComsEEnv!). Another missed cue is the fact that the magnitude estimate adopted by the authors (and by many others) was published in Johnston (1996), the same paper (and the same method) that estimated a magnitude for the New Madrid 1812 earthquake which was subsequently downgraded by approximately 1 magnitude unit, while the 1755 magnitude estimate remained unchallenged (the authors may also want to have a look at Fonseca (2000), where the magnitude of this earthquake is discussed).
The authors may find that I am focusing too much on the magnitude issue. This is to some extent justified by the fact that the bulk of the manuscript hinges on the seismic and tsunami source geometry, hence magnitude. And said magnitude is also a key parameter in the tsunami modeling. But the point that I am trying to make is broader: unveiling the mysteries of an earthquake that has eluded the seismological community for decades requires ingenuity, alongside powerful tools.
Another example: had the authors chosen not to follow the well-trodden path of modeling the tsunami source as a classical tectonic rupture, their attention might have been drawn to one of the pieces of the tsunami puzzle which is systematically ignored: the possible role of the Cadiz Gulf accretionary prism (Medialdea et al., 2004) in the tsunamigenic process. With the exception of Gutscher et al. (2006) who claimed a subduction-type rupture at its base to explain the 1755 earthquake and tsunami, I am not aware of any attempt to model the effect of the deformation of this sedimentary body (maybe as a partial rupture branching from the HAT, or just a catastrophic landslide?), configuring a tsunami earthquake, i.e., an earthquake with much larger tsunami magnitude than moment magnitude. This is the kind of "out-of-the-box" thinking that, in my view, has the potential to remove the veil that still covers the 1755 earthquake, after so many "orthodox" attempts. I fear that the main shortcoming of the manuscript was its lack of this type of ingenuity.

This judgement may seem too harsh in view of the amount of information put forward in the manuscript. The problem here is one of novelty. No doubt the tsunami modelling is new and produces some improvement to the fit. But upper mantle seismogenesis in the region was documented and discussed before by Stich et al. (2007) and Geissler et al. (2010), among others. Likewise, the tomographic results that led to the identification of the tectonic domains of the Cadiz Gulf and in so doing highlighted the importance of the HAT – in my opinion the most important step so far towards understanding the large earthquakes of the Cadiz gulf – where previously published by Martinez-Loriente et al. (2014). The application of the two-state mechanism of serpentinite rheology to explain the intermediate-depth seismicity of the region is original, but the concept was used before to explain nucleation and propagation of earthquakes elsewhere (Reinen et al., 1991). So, the key issue to be addressed is, in my view: are the tsunami modeling results robust and illuminating enough to warrant publication in ComsEEnv? This task involves critical assessment of coeval sources, and the authors did themselves a disservice by repeating "hype" about the 1755 earthquake: that it killed 100000 people (line 40), off by one order of magnitude if reliable coeval sources such as Mendonca (1758) are taken in account; that it released 15 times more energy than the M7.8 1969 earthquake judging from tsunami wave-heights (line 116), when the differences could equally well be explained by near-source bathymetry and scattering since the sources were not co-located (effects that the authors invoke later to illustrate the merits of their model, in lines 192-199). Comparison of data fits from tables 2 and 3 in the Supplement is not easy, and a quantitative metric would help. I felt uncomfortable with the strong "correlation" between data that did not fit the model well and data that were labelled "not credible" (Supplement, line 52). To be sure, the authors are entitled to grade the reliability of the input data and to weigh them accordingly, but it should be done with objective and verifiable criteria.
The discussion of the tsunami source model passed the impression that the best contender was the model of Barkan et al. (2009), who focused their attention on transatlantic data since the near-source effects, in association with source uncertainty, make regional observations very unreliable. This the authors downrate on the grounds that the strike used in the modelling "does not correspond to any known structure in [the] area" (line 233). However, the manuscript's Figure 1 shows that the frontal slope of the Gulf of Cadiz accretionary prism, on the eastern side of the Tagus Abyssal Plain (Medialdea et al., 2004), displays the orientation blindly selected by Barkan et al. (2009). In my view, in such conditions the tsunami earthquake hypothesis warrants investigation, if nothing else to dismiss it as a possible explanation.
In short: the authors state that "[A] number of candidate sources have been proposed [for the 1755 earthquake and tsunami], although none of them explains satisfactorily the inferred seismic moment of the event, as well as the arrival-times and, particularly, the run-up heights of the tsunami referred to in the historical reports" (lines 45-48)". Yet, the approach described in the manuscript was quite conservative, hitting the problem with improved tools but on old premises. The improvements are predictably quantitative, but they left me wanting more. I got the impression that the authors are tantalizingly close to a "Eureka moment", and I urge them to look critically at the vast literature in the topic, instead of accepting established ideas at face value. I will be looking forward to review an improved version of the manuscript, if the authors choose to go that way.
Lisbon, April 5, 2021
Joao Fonseca

References used in this review (not included in the manuscript only):

Bakun, H.W. and C.M. Wentworth (1997). Estimating earthquake location and magnitude from seismic intensity data, Bull. Seism. Soc. Am. 87 (6), 1502–1521.

Fonseca, J.F.B.D. (2020). A Reassessment of the Magnitude of the 1755 Lisbon Earthquake, Bulletin of the Seismological Society of America, 110 (1): 1–17. https://doi.org/10.1785/0120190198

Martinez-Loriente, S., V. Sallares, E. Gracia, Bartolome, J.J. Dañobeitia and N. Zittelini (2014), Seismic and gravity constraints on the nature of the basement in the Africa-Eurasia plate boundary: New insights for the geodynamic evolution of the SW Iberian margin, J. Geophys. Res., 119.

Medialdea, T., R. Vegas, L. Somoza, J.T. Vasquez, A. Maldonado, V. Rio, A. Maestro, D. Cordoba and M.C. Puga (2004), Structure and evolution of the "Olistostrome" complex of the Gibraltar Arc in the Gulf of Cadiz (eastern Central Atlantic): evidence from two long seismic cross-sections, Marine Geology, 209, p. 173-198.

Mendonça, J. J. M. (1758), História Universal Dos Terramotos Que Tem Havido No Mundo de Que Há Notícia Desde a Sua Criação Até Ao Século Presente. Lisboa: Oficina de António Vicente Silva, in Portuguese.

Reinen, L.A., Weeks, J.D and Tullis, E. (1991). The frictional behavior of serpentinite: Implications for aseismic creep on shallow crustal faults, Geophys. Res. Lett., https://doi.org/10.1029/91GL02367

Unveiling the source and causes of the 1755 Lisbon earthquake and tsunami

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Abstract

The Africa-Eurasia plate convergence zone off SW Iberia has been the site of great earthquakes and tsunamis, including the Mw ~8.5, 1755 Lisbon Earthquake, the largest and most destructive known event in western Europe. Despite the considerable amount of work, the source and causes of this event remain unclear and disputed. Here we combine geophysical data and tsunami modelling to propose a new, reliable source and mechanism of the 1755 and other major regional events. Our results show that a crustal-scale thrust-fault located at the Horseshoe Abyssal Plain is the most likely source candidate. It coincides with the location and focal mechanism of the largest regional events, and the combination of the inferred dimensions and fault-rock properties can account for the 1755 earthquake's magnitude. Moreover, the tsunami simulation fits historical data better than any other source. It reproduces tsunami energy propagation patterns, explains arrival-times, and improves predicted run-up heights by 50%. The occurrence of deep seismicity and of earthquakes that appear to be anomalously large for the regional fault lengths is naturally explained by upper mantle peridotite/serpentinite rheology. Therefore, the seismic potential of the major regional faults must be re-analysed for proper geohazard assessment.

The present-day Eurasia-Africa plate boundary off SW Iberia is dominated by a NW-SE trending convergence (3.8-5.6 mm/yr)[1] (Fig. 1). The plate boundary is diffuse[2] and deformation is accommodated by thrust and strike-slip faults[3,4]. It is one of the most seismically active regions in Western Europe, showing a constant background of seismic activity with low to moderate magnitude events of up to M_w~6.0[5-8], mostly concentrating at upper mantle depths[6-8]. Besides the background seismicity, this area has also experienced large magnitude events in historical and instrumental times, such as the 1755 Lisbon (estimated $M_w \geq 8.5$)[9] and the 1969 Horseshoe (M_w7.9)[10] ones.

The 1755 Great Lisbon earthquake has the largest documented felt area of any shallow earthquake in history. The ground motion was felt in Greenland, Norway, Great Britain, Madeira or Morocco[6] and it was the most destructive known earthquake in European history. The associated tsunami, with run-up heights reported to reach 5 to 15 m[11], devastated the coasts of SW Iberia and NW Morocco. The event killed close to 100,000 people[12] combining the effects of ground-shaking, the ensuing fires and the tsunami waves, which were reported to hit as far as England, Newfoundland, the Caribbean and Brazil[11]. The source and the generating mechanism of the Lisbon earthquake have been the subject of numerous studies and the matter of a continuous debate during the last decades[5-21]. A number of candidate sources have been proposed[13-20], although none of them explains satisfactorily the inferred seismic moment of the event, as well as the arrival-times and, particularly, the run-up heights of the tsunami referred to in historical reports.

Based on a tomography model of controlled-source seismic data in the area, Martínez-Loriente et al.[22] identified the presence of the Horseshoe Abyssal plain Thrust (HAT), a deep thrust-fault located in the Horseshoe Abyssal Plain (HAP). The HAT has been shown to separate two regional geological domains of different nature and origin. In this work, we show that the HAT has the dimensions, geometry, and fault-rock bulk properties required to explain the deep regional seismicity and that it has the potential to generate earthquakes as large as the 1755 Lisbon one. Additionally, we have carried out tsunami simulations to show that the HAT source can generate transatlantic tsunamis with characteristics compatible with those referred in historical records of the 1755 event. Finally, we discuss the regional implications linked with the presence of this deep thrust and the bulk-rock properties in terms of seismic and tsunami hazard assessment.

Crustal domains and tectonic setting

The SW Iberian margin has undergone a complex geodynamic history spanning from the Mesozoic extension to the Neogene-to-present-day convergence. Martínez-Loriente et al.[22] used P-wave seismic tomography models obtained along two regional controlled-source wide-angle seismic (WAS) profiles (profiles P1 and P2 in Fig.1), to evidence the presence of three different oceanic domains in the area originated in three different opening systems (inset on Figure1). First, the Seine Abyssal Plain (SAP) domain, which is made of oceanic crust generated during the first stages of seafloor spreading in the NE Central Atlantic (Early Jurassic). Second, the Gulf of Cadiz (GC) domain, formed by Jurassic-age oceanic crust generated at the Alpine-Tethys oblique-spreading system between Iberia and Africa (i.e. the Western Tethys)[23]. Third, the Gorringe Bank (GB) domain, composed of unroofed mantle rocks with little synchronous magmatism. These rocks, which constitute the basement of the Gorringe Bank, southern Tagus and northern Horseshoe abyssal plains, were exhumed during the first stages of North Atlantic opening (Lower Cretaceous)[24]. The present-day plate configuration was established ~20 Ma ago, when the plate boundary between Africa and

Eurasia shifted from north to south Iberia[25]. The Neogene NW-SE convergence resulted on the emplacement of large allochthonous masses during the Tortonian[26], and caused the reactivation of major Mesozoic extensional faults[3].

The deformation resulting from the present-day NW-SE convergence (3.8-5.6 mm/yr)[1] is mainly accommodated by two types of active faults. The first includes regional NE-SW trending thrusts, such as the HAT[22], Gorringe Bank (GBF)[9,24] or Marquês de Pombal (MPF)[16,17] faults, whereas the second comprises large WNW-ESE trending dextral strike-slip faults (i.e., the SWIM faults)[17], such as the so-called Lineaments North and South[3,28,29] (LN and LS, respectively) (Fig. 1). According to Martínez-Loriente et al.[22], the SAP and GC oceanic basement domains are separated by the LS strike-slip fault, while the GC and GB domains are limited by the HAT. This means that the HAT separates exhumed mantle rocks (NW) from oceanic crust (SE) (Figs. 1 and 2).

Origin of deep seismicity offshore SW Iberia

The seismic activity in the study area mostly concentrates north of the LS, between the Gorringe and Guadalquivir banks (Fig. 1). Regional micro-seismicity recorded by temporal networks of ocean bottom seismometers[6-8] has allowed identifying three main seismicity clusters located in the GB, HAP and Sao Vicente Canyon (SVC)[8] that display a combination of thrust and strike-slip focal mechanisms. These events, which concentrate at upper mantle depths (i.e. between 30-60 km depth), appear to be associated with inverted rift structures identified at the transition zones between the different rheological domains that localize regional stresses and hence seismic strain.

Previous works on the 1755 earthquake have proposed a number of candidate sources for this event, such as the GB[9], MPF[13,14,16,17], the subduction beneath Gibraltar[18], the SWIM strike-slip faults[20], Horseshoe Fault (HF) [16], São Vicente fault (SVF) [16] or some composite systems[14,16]. However, due to either their limited surface areas, their locations and geometry, or both, they do not seem to be able to account for the large seismic moment, the overall reach and energy pattern of the tsunami, as well as the historical recorded amplitudes and arrival times. Among all the proposed candidates, the only tsunami simulation considering far-field observations favours a source location in the HAP area[19].

Almost all existing studies of the 1755 event rely on the comparison with two of the largest recent earthquakes occurred in SW Iberia, the first on February 28th 1969 (M_w 7.9)[10,30] and the second on February 12th 2007 (M_w 6.0)[5,31] (Fig. 1, Supplementary Table 1). Both earthquakes share the focal mechanism and a deep hypocentre suggesting that they might be generated by the same fault system. The M_w 7.9 1969 earthquake generated a small tsunami with centimetric wave-heights on the SW Portuguese coasts. For comparison, several meter wave-heights were reported in the same area after the 1755 earthquake, indicating that the energy released by this event was about 15 times larger than that of the 1969 one[11]. The analysis of peak ground accelerations estimated from reported intensities of the 1755 earthquake supports a NE-SW oriented reverse dip-slip mechanism[30]. This would be similar to that of the December 17th 2009 earthquake ($M_w = 5.5$; Supplementary Table 1)[30] associated with the MPF, located at the mouth of the SVC where the HAT changes its orientation in depth and would be linked to the MPF (Figs. 1, 2, Supplementary S1).

As stated above, recent work shows evidence for the presence of a deep structure in the HAP[22] between the SAP and GB domains with the location and geometry required to be the source of these large earthquakes. This structure was interpreted as a NE-SW trending, NW-verging blind-deep thrust located in the middle of the HAP (Figs. 1, 2). Although the HAT was initially interpreted to extend to the SVC, the reanalysing of available geophysical data, in combination with recent seismological studies[5-8,30,31], suggest that it rather spans from the MPF to the LS (~200 km). Its location and geometry makes it a likely source candidate for part of the deep seismicity recorded by OBS networks in the area (Figs. 1, 2).

Earthquakes result from stick-slip frictional instability, and its frictional behaviour is commonly described by a rate- and state-variable constitutive law[32]. At steady-state, the frictional response depends on a slip velocity-dependent “friction parameter”. Depending on the sign of this parameter, the material is either velocity-strengthening (i.e. earthquakes cannot nucleate and any earthquake propagating there will tend stop rapidly), or velocity weakening (i.e. earthquakes can nucleate and propagate there). This parameter depends on rock lithology, temperature (T) and pressure (P). For example, granite is velocity-weakening below 300º C and velocity-strengthening above, due to the onset of plasticity of quartz, the most ductile mineral in granite. In oceanic basalt, frictional stability is controlled by feldspar transition, which occurs at ~450º C[31]. This temperature is typically assumed to mark the downdip limit of interplate seismicity in subduction zones.

According to the interpretation of the local controlled-source seismic-tomography models[22], the HAT separates serpentinized peridotite basement at the northwest (GB domain) from oceanic lithosphere at the southeast (GC domain), so the deep frictional stability, which concentrates at upper mantle depths, should be controlled by the rheological transition of olivine, which occurs at ~600º C[33]. Oceanic plate cooling models indicate that this isotherm is located at 50-55 km depth in a ~140 Myr old lithosphere[34], in agreement with the location of the deepest earthquakes in the area[6] (Fig. 2). This pre-eminence of deep seismicity strongly supports that it is controlled by peridotite/ serpentinite rheology. The high peridotite rigidity (~70 GPa) and the potential large stress-drop, combined with the large downdip extension of the seismogenic layer (>60 km for a 45º thrust), makes that modest-length thrust faults such as the HAT could potentially account for large earthquakes[5]. Therefore, if we assume a focal depth of 50-60 km on peridotite rock (which has a rigidity of ~70 GPa) and an upward propagation over lower rigidity rocks such as serpentinite (for an average rigidity of ~50 GPa), a dip angle of 45º, and a realistic slip-to-length ratio of $8.5 \cdot 10^{-5}$, a M_w 8.5-8.7 earthquake like the one that destroyed Lisbon in 1755, requires a fault length of just 160-225 km (Fig. 3).

In this rupture scenario, seismic rupture at shallower levels should be controlled by serpentinite, which is more ductile than peridotite. Experimental results show that, at crustal P,T conditions, serpentinite is velocity-strengthening at plate tectonic rates but it is unstable at higher velocities. This means that while serpentinized regions are not a likely site of earthquake nucleation, seismic rupture of deeper earthquakes could propagate through them[35]. This two-state mechanical behaviour of serpentinite could explain two apparently contradictory observations: the lack of shallow earthquakes in the region[6-8]; and the occurrence of large, occasionally devastating tsunamis requiring shallow slip and substantial seafloor deformation[36].

The HAT as a source of the 1755 Lisbon Earthquake and Tsunami.

Although multichannel seismic data and TOPAS sub-bottom profiles across the HAT (Fig. 1) do not provide clear evidence of the thrust reaching the seafloor, the OBS records[22] show a deep seismic-phase consistent with a reflection at a NW-verging structure reaching at least 25-30 km-depth, which is interpreted to extend to at least 60 km-depth based on seismological data[5-8,29]. Such a structure can totalize ~16.700 km^2 of surface area (Figs. 1, 2, Supplementary S1). The controlled-source seismic tomography model shows that the dip of the blind-thrust changes with depth, from 20-30º from the surface to 25-30 km depth, to 40º-45º deeper than this level, as indicated by focal mechanism solutions of deep seismicity on this area[5-8,29] (Figs. 2 and Supplementary S1).

We have used this fault plane as a source for tsunami simulations (Methods), in order to verify if such a feature is compatible with the reported characteristics of the largest tsunamigenic earthquakes in the area, and in particular with those of the 1755 Lisbon one (Fig.4). To test it, the simulated travel times, amplitudes and tsunami propagation resulting from the HAT source are compared with the available historical records of the 1755 event[11,19,37] and with previous works[13,18,19] (Supplementary Tables 2 and 3).

The modelled tsunami propagation fits better than any other proposed candidate with the information included in the available historical chronicles (Fig. 4, Supplementary Tables 2 and 3). The HAT source scenario reproduces the wave arrivals to all locations reported to be hit by the 1755 tsunami including the distant ones such as the United Kingdom, Newfoundland, Barbados or Brazilian coasts. Additionally, it correctly predicts the zones protected from the tsunami impact, such as Vigo in West Iberia or cities like Boston, Baltimore, and New York in the eastern U.S. coast. The bathymetric roughness has a significant effect on tsunami propagation, dispersing, amplifying or diminishing the tsunami waves[38]. For instance, and according to our simulation, Vigo was protected from the tsunami by the *rías* (i.e. sea-inlet or estuary), southern Florida by the Bahamas Banks, and the Madeira Tore-Rise acted as scatter for tsunami energy protecting U.S. East coast. In contrast, the Madeira island scattered the energy towards the Caribbean, whereas the Great Meteor seamount scattered it towards Brazil.

Comparing arrival-times and tsunami amplitude in particular localities is problematic due to the inaccuracy and incompatibility of some arrival times in historical reports. For instance, they indicate a 50 min difference in the arrival time between Lisbon and Porto Novo, which are just 50 km apart, 35 min difference between Penzance and Newly, which are 2 km apart, or 30 min difference between Porto Santo and Madeira Islands, which are 50 km apart. Likewise, they indicate a maximum wave height of ~15 m in Lisbon, Cadiz, Tangiers and Azores, which is hard to believe. Historical observations contain information on estimated run-up heights (i.e. maximum height of the inundation), but tsunami simulations provide maximum wave-height (Hmax) before reaching the coast. Therefore, we are comparing different features. To overcome this issue, we have normalized (HmaxN) our results to 1 m below seafloor according to the Green's Law[39] (Methods). Almost all previous works[11,13,18,19] assumed a run-up of 15 m in Cadiz, although the French scientist Louis Godin, who was in Cadiz when the tsunami hit the city, reported a wave-height of 5 m [37]. Shallow water estuaries are highly affected by non-linear propagation effects, which can induce significant modelling errors. Therefore, we included in our comparison Oerias and Vila Real de San Antonio instead of Lisbon and Huelva (respectively), which are affected by estuaries.

Overall, our results fit better than any previous modelled source the reported observations (Supplementary Tables 2 and 3). The improvement is remarkable (of over 50%) for the wave-heights, whereas the arrival times, which suffer from evident inconsistencies, are comparable or slightly better on average. The HAT modelling results show lower deviations in the estimated wave-heights from historical reports in all the reported cases except Tangier, where the available information is not credible[11,19]. Regarding the arrival times, the HAT simulation obtains good results in the far field, with average differences of less than 20%, and acceptable results in the near field, where we obtain values within the reported time range, except in localities with incompatible values for the differential arrival times (i.e., Lisbon, Safi, Madeira and Azores). Note that only one of the previous works proposed a source capable of generating a transatlantic tsunami and considered near- and far-field historical observations. Their results favour a tsunami generated by a NNW–SSE-trending fault located in the centre of the HAP[19], so at the same location as the HAT but with a different strike direction. However, the proposed orientation was chosen *ad hoc* for the purposes of the modelling but it does not correspond to any known structure in this area. In summary, the HAT can explain the location and focal mechanism of the largest instrumental events having occurred in the area, and has the dimensions and the inferred fault-rock bulk properties at focal depths to account for such a giant earthquake. Additionally, the tsunami simulation fits better than any other proposed source the historical reports from the 1755 Lisbon event, particularly the observed wave-heights.

Regional implications

Our work has relevant implications at regional level in the fields of active tectonics, petrophysics, seismology and for the seismic and tsunami hazard assessment. We show that the deep regional seismicity is controlled by peridotite/serpentinite rheology, allowing modest-length thrust faults to generate anomalously large earthquakes (Fig. 3). This suggests that there is a number of active thrusts in the area[3,4,17] similar to the HAT that might also have the potential of generating greater earthquakes than previously thought. One example is the GBF, a 155 km-long, NW-verging thrust fault located in between the Tagus and the Horseshoe abyssal plains that thrust two exhumed mantle blocs[24] (Fig. 1). Therefore, the earthquake and tsunami hazard associated to these structures must be re-evaluated in light of the new findings.

Methods

Tsunami modelling.

To evaluate the seismic and tsunamigenic potential of the HAT and estimate if this structure would generate great earthquakes (Mw≥8.5) and transatlantic tsunamis, we first specify fault parameters and physical properties, considering that:

$$M_w = \frac{2}{3} \times \log_{10}(M_0) - 6.07$$

$$M_0 = \mu \times A \times \dot{D}$$

where M_w is seismic magnitude, M_0 is seismic moment, μ is rigidity, A is fault area, and $\dot{D}$ is slip rate. M_0 is 7.16×10^{21}Nm for M_w =8.5. A is 16.730 km^2 (Fig. Supplementary S1), and μ is 50 GPa. This is an average value assuming that the earthquake nucleated in fresh peridotite at ~50 km depth (~70 GPa) and propagated along the fault plane up to shallower levels where serpentinite and basalts predominate (~30 GPa)[5]. Therefore, the slip value derived from the scaling relations that is required to generate a large earthquake (M_w=8.5) is 8.5 m. We carried out a succession of tsunami simulations using the HAT fault plane (Fig. Supplementary S1) with a rake of 90º, the parameters described above, and varying the slip from 7 to 20 m. Our results show that a slip of 15 m is required to generate a transatlantic tsunami that affects all localities that reported the 1755 event. This value is similar to that assumed in previous works[9,18,17] (Fig. 3b). Tsunami simulations, for the equivalent of twelve hours of propagation, were performed using the finite-volume Tsunami-HySEA software[40]. Tsunami-HySEA is a GPU-optimised code that solves non-linear shallow water equations in spherical or Cartesian coordinate system[40]. The computational grid has a spatial resolution of 2 arcmin and covers all the Atlantic from Newfoundland to Brazil, considering open boundary conditions. The initial seawater elevation is considered equal to the vertical displacement of the sea bottom, computed as a Volterra's formulation of the elastic dislocation theory applied to a source buried in an elastic half-space, using the Okada's fault deformation model[41]. The rupture is considered instantaneous and the initial velocity field is zero. Results of tsunami modelling were processed to obtain regional tsunami wave propagation patterns and maximum wave height (Hmax) profiles at selected coastal points. Hmax were extracted at approximately 50 m depth. They are subsequently extrapolated at the 1 m depth using the Green's law approximation for 1D shoaling as the 4th root of the 50 m, that is by applying a multiplicative amplification factor of ~ 2.66. Arrival times at the coast were calculated with the TTT software (http://www.geoware-online.com/tsunami.html), using the 2 arcmin digital bathymetry (SRTM15, https://topex.ucsd.edu/WWW_html/srtm15_plus.html), 64 Huygens nodes, and a set of source points on a rectangle obtained from the projection of the fault on the Earth's surface.

The leading wave of a tsunami is considered to be a shallow water gravity wave, where the ocean depth is negligible compared to the wavelength. In deep waters, the propagation velocity is approximately proportional to $\sqrt{g \times h}$, where g is the acceleration of gravity and h is the water depth in meters. In deep waters, the tsunami wave travels at a velocity of ~800 km/h, while at water depth of 1000 m, the velocity drops to 360 km/h. In shallow continental shelf the wave propagation speed drops dramatically. Under these conditions, an excellent bathymetric grid is required for accurately modelling amplitudes and tsunami arrival times. Due to the enormous dimensions of our tsunami scenario and the unavailability of high-resolution bathymetry for all coastal areas, we used a grid size of 2 arcmin for the simulations.

When comparing modelled results with historical information, it should be considered that some reported observations are incompatible in many cases for any single source, so they are not credible, such as Lisbon, Porto Novo, Penzance or Madeira. In addition, some delays can be due to poorly constrained shallow shelf bathymetry and to the potential effects of landslides (i.e. multiple tsunami sources). Additionally, an increase of 2-3 m should be considered due to the high tide at the time of the tsunami[19,37,42,43].

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Author Contributions:

All authors contributed to the original idea. S.M-L led the writing of the paper, conducted the tsunami simulations and made the figures. V.S. contributed to the text and wrote part of the codes of magnitude estimation. E.G. contributed to the text and with funding.

Competing Interests statement

The authors declare no competing interests.

References

1. DeMets, C., Gordon, R. G. & Argus, D. F. Geologically current plate motions, *Geophys. J. Int.* 181, 1–80, doi:10.1111/j.1365-246X.2009.04491.x (2010).

2. Sartori, R., Torelli, L., Zitellini, N., Peis, D. & Lodolo, E. Eastern segment of the Azores-Gibraltar line (central-eastern Atlantic): An oceanic plate boundary with diffuse compressional deformation. *Geology*, 22, 555–558 (1994).

3. Martínez-Loriente, S. et al. Active deformation in old oceanic lithosphere and significance for earthquake hazard: Seismic imaging of the Coral Patch Ridge area and neighboring abyssal plains (SW Iberian Margin). *Geochem. Geophys. Geosyst*. 14, 2206–2231, doi: 10.1002/ggge.20173 (2013).

4. Martínez-Loriente, S. et al. Morphostructure, tectono-sedimentary evolution and seismic potential of the Horseshoe Fault, SW Iberian Margin. *Basin Res*. 30: 382-400. doi:10.1111/bre.12225 (2018).

5. Stich, D., Mancilla, F.D.L., Pondrelli, S., & Morales, J. Source analysis of the February 12th 2007, Mw 6.0 Horseshoe earthquake: implications for the 1755 Lisbon earthquake. *Geophys. Res. Lett*. 34 (L12308). ttp://dx.doi.org/10.1029/2007GL030012 (2007).

6. Geissler, W. H. et al. Focal mechanisms for sub-crustal earthquakes in the Gulf of Cadiz from dense OBS deployment, *Geophys. Res. Lett.* 37, L18309, doi:10.1029/2010GL044289 (2010).

7. Grevemeyer, I., Matias, L., & Silva, S. Mantle earthquakes beneath the South Iberia continental margin and Gulf of Cadiz – constraints from an onshore-offshore seismological network. *J. Geodyn.* 99:39–50. http://dx.doi.org/10.1016/j.jog.2016.06.001 (2016)

8. Silva, S. et al. Micro-seismicity in the Gulf of Cadiz: Is there a link between micro-seismicity, high magnitude earthquakes and active faults?. *Tectonophysics*, 717, 226-241, https://doi.org/10.1016/j.tecto.2017.07.026 (2017).

9. Johnston, A. Seismic moment assessment of earthquakes in stable continental regions — III New Madrid 1811–1812, Charleston 1886 and Lisbon 1755. *Geophys. J. Int*. 126, 314–344 (1996).

10. Fukao, Y. Thrust faulting at a lithospheric plate boundary, The Portugal earthquake of 1969. *Earth Planet Sci. Lett.* 18, 205–216 (1973).

11. Baptista, M. A. et al. The 1755 Lisbon earthquake; evaluation of the tsunami parameters. *J. Geodyn*. 25, 143–157 (1998a).

12. Chester, D.K. The 1755 Lisbon earthquake. *Prog. Phys. Geogr*. 25, 363–383 (2001).

13. Baptista, M. A. et al. Constraints on the source of the 1755 Lisbon tsunami inferred from numerical modelling of historical data on the source of the 1755 Lisbon tsunami. *J. Geodyn*. 25, 159–174 (1998b).

14. Zitellini, N. et al. Source of the 1755 Lisbon earthquake and tsunami investigated. *EOS Trans. Am. Geophys. Union*, 82, 285 (2001).

15. Baptista, M .A., Miranda, J. M., Chierici, F., & Zitellini, N. New study of the 1755 earthquake source based on multi-channel seismic survey data and tsunami modeling. *Nat. Hazards Earth Sci. Syst*. 3, 333–340 (2003).

16. Gràcia, E., Danõbeitia, J. J., Vergés, J. & PARSIFAL Team. Mapping active faults offshore Portugal (36°N–38°N): implications for seismic hazard assessment along the southwest Iberian margin. *Geology*. 31, 83–86 (2003a)

17. Terrinha, P. et al. Tsunamigenic–seismogenic structures, neotectonics, sedimentary processes and slope instability on the southwest Portuguese Margin. *Mar. Geol*. 195, 55–73 (2003).

18. Gutscher, M.-A., Baptista, M.A., & Miranda, J.M. The Gibraltar Arc seismogenic zone: Part 2. Constraints on a shallow east dipping fault plane source for the 1755 Lisbon earthquake provided by tsunami modeling and seismic intensity. *Tectonophysics.* 426, 153–166 (2006).

19. Barkan, R., ten Brink,U. S., & Lin, J. Far field tsunami simulations of the 1755 Lisbon earthquake: Implications for tsunami hazard to the U.S. East Coast and the Caribbean. *Marine Geology*, 264, 109-122, doi: 10.1016/j.margeo.2008.10.010 (2009).

20. Zitellini, N. et al. The quest for the Africa-Eurasia plate boundary west of the Strait of Gibraltar. *Earth Planet. Sci. Lett*., 280, 13–50, doi:10.1016/j.epsl.2008.12.005 (2009).

21. Gràcia, E. et al. Holocene earthquake record offshore Portugal (SW Iberia): Testing turbidite paleoseismology in a slow convergence margin. *Quat. Sci. Rev.*, 29, 1156–1172, https://doi.org/10.1016/j.quascirev.2010.01.010 (2010).

22. Martinez-Loriente, S. et al. Seismic and gravity constraints on the nature of the basement in the Africa-Eurasia plate boundary: New insights for the geodynamic evolution of the SW Iberian margin. *J. Geophys. Res. Solid Earth*, 119, 127–149 (2014).

23. Sallarès, V. et al. Seismic evidence for the presence of Jurassic oceanic crust in the central Gulf of Cadiz (SW Iberia margin), *Earth Planet. Sci. Lett*., 311, 112–123, doi:10.1016/j.epsl.2011.09.003 (2011).

24. Sallarès, V. et al. Seismic evidence of exhumed mantle rock basement at the Gorringe Bank and the adjacent Horseshoe and Tagus abyssal plains (SW Iberia), *Earth Planet. Sci. Lett.*, 365, 120–131, doi:10.1016/j.epsl.2013.01.021 (2013).

25. Srivastava, S. P. et al. Iberian plate kinematics: A jumping plate boundary between Eurasia and Africa. *Nature*, 344, 756–759 (1990).

26. Gràcia, E. et al. Crustal architecture and tectonic evolution of the Gulf of Cadiz (SW Iberian margin) at the convergence of the Eurasian and African plates, *Tectonics*, 22, 1033, doi:10.1029/2001TC901045, 4 (2003b).

27. Duarte, J., Schellart, W., & Rosas, F. The future of Earth's oceans: Consequences of subduction initiation in the Atlantic and implications for supercontinent formation. Geological Magazine, 155(1), 45-58. doi:10.1017/S0016756816000716 (2018).

28. Terrinha, P. et al. Morphotectonics and strain partitioning at the Iberia–Africa plate boundary from multibeam and seismic reflection data. *Mar. Geol*. 267, 156–174 (2009).

29. Bartolome, R. et al. Evidence for active strike-slip faulting along the Eurasia-Africa convergence zone: Implications for seismic hazard in the SW Iberian Margin. *Geology.* 40(6), 495–498, doi:10.1130/G33107.1 (2012).

30. Buforn, E. et al. Re-evaluation of Seismic Intensities and Relocation of 1969 Saint Vincent Cape Seismic Sequence: A Comparison with the 1755 Lisbon Earthquake. *Pure Appl. Geophys*. 177, 1781–1800, https://doi.org/10.1007/s00024-019-02336-8 (2020).

31. Lozano, L. et al. A new 3-D P-wave velocity model for the Gulf of Cadiz and adjacent areas derived from controlled-source seismic data: application to nonlinear probabilistic relocation of moderate earthquakes. *Geophysical Journal International*. 221 (1), 1–19, https://doi.org/10.1093/gji/ggz562 (2020).

32. Scholz, C. Earthquakes and friction laws. *Nature,* 391, 37–42 (1998).

33. Boettcher, M. S., Hirth, G., & Evans, B. Olivine friction at the base of oceanic seismogenic zones, *J. Geophys. Res*., 112, B01205, doi:10.1029/2006JB004301 (2007).

34. McKenzie, D., Jackson, J. & Priestley, K. Thermal structure of oceanic and continental lithosphere, *Earth and Planetary Science Letters*, 233, 337-349, https://doi.org/10.1016/j.epsl.2005.02.005 (2005).

35. Reinen, L.A. Seismic and aseismic slip indicators in serpentinite gouge. *Geology*, 28 (2): 135–138 (2000).

36. Omira, R., Baptista, M. A. & Miranda, J. M. Evaluating Tsunami Impact on the Gulf of Cadiz Coast (Northeast Atlantic). *Pure Appl. Geophys*. 168, 1033–1043 https://doi.org/10.1007/s00024-010-0217-7 (2011).

37. Martínez-Solares, J. M. Los efectos en España del terremoto de Lisboa (1 de noviembre de 1755), Dirección General del Instituto Geográfico Nacional, 756 pp, ISBN: 84-95.172-26-7 (2001).

38. Satake, K. Tsunamis. *Treatise on Geophys*. Second Ed. 4, 477–504. https://doi.org/10.1016/B978-0-444-53802-4.00086-5 (2015).

39. Witting, J. M. (1981). A note on Green's law. Journal of Geophysical Research, 86(C3), 1995-1999.

40. De la Asunción, M., et al. Efficient GPU implementation of a two waves TVD-WAF method for the two-dimensional one layer shallow water system on structured meshes. Comput. Fluids, 80, 441–452. https://doi.org/10.1016/j.compfluid.2012.01.012 (2013).

41. Okada, Y. Surface deformation due to shear and tensile faults in a half-space. Bull. Seismol. Soc. Am. 75, 1135–1154 (1985).

42. Lee, H.S., Shimoyama, T., & Popinet, S. Impacts of tides on tsunami propagation due to potential Nankai Trough earthquakes in the Seto Inland Sea, Japan. *J. Geophys. Res. Oceans*. 120, 6865–6883. doi:10.1002/2015JC010995 (2015).

43. Androsov A., Behrens J., & Danilov S. Tsunami Modelling with Unstructured Grids. Interaction between Tides and Tsunami Waves. In: Krause E., Shokin Y., Resch M., Kröner D., Shokina N. (eds) Computational Science and High Performance Computing IV. Notes on Numerical Fluid Mechanics and Multidisciplinary Design, vol

115. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-17770-5_15 (2011).

44. IGN Seismic Catalogue, Available at: https://www.ign.es/web/ign/portal/sis-catalogo-terremotos.

Figure captions

Fig. 1. Tectonic map offshore SW Iberia. Bathymetric map of the SW Iberian margin with the location of the main active tectonic structures[4]. The thick brown line is the wide-angle seismic profile P1[22] along which the schematic cross section of Fig. 2 has been drawn. The stars indicate the largest instrumental earthquakes that have occurred in the region (i.e., 1969[9], 2007[10], 2009[31]; Supplementary Table 1). White and grey circles show epicentral locations of regional earthquakes with Mw> 3 for the period 1960-2020[44]. Left inset: Global map including the major tectonic plates and boundaries. The red rectangle corresponds to the area depicted in this figure. Right inset: Map of the SW Iberian Margin Geological Domains[22]. AGFZ: Azores-Gibraltar Fault Zone; AP: Abyssal plain; GBF: Gorringe Bank Fault; HAT: Horseshoe Abyssal plain Thrust; HF: Horseshoe Fault; LN: Lineament North; LS: Lineament South; MPF: Marquês de Pombal Fault; SVF: São Vicente Fault.

Fig. 2. The Horseshoe Abyssal plain Thrust (HAT) 3D scheme. 3D regional tectonic and stratigraphic cross-section along profile P1 (located in Fig. 1) showing the geometry of the HAT and the projection in depth of the 1969 M_w7.9[10,30] and 2007 M_w6.0[5,31] earthquakes (Supplementary Table 1). Serpentinization degree is indicated as gradation of colour.

Fig. 3. Moment magnitude (M_w). **a)** Calculated earthquake magnitude (M_w) as a function of fault length and rigidity (μ) according to the regional configuration and bulk-rock properties in the SW Iberian margin and tsunami results. White line highlights that assuming a μ ~ 50 GPa, the generation of a M_w 8.7 earthquake (star) requires a fault length of ~180 km. Slip (15 m), focal depth (50 km) and fault dip (35º) were assumed as constant. **b)** Calculated earthquake magnitude (M_w) as a function of fault length and seismogenic depth according to the Horseshoe Abyssal plain Thrust (HAT) geometry, properties and tsunami modelling results. The star locates the M_w value of an earthquake capable of generating a tsunami compatible with that of the 1755 event. White lines highlight the sesimogenic zone between 40 and 60 km depth. Rigidity (μ = 50 GPa), slip (15 m) and fault dip (35º) were assumed as constant. See text for further explanations.

Fig. 4. The HAT tsunami simulation. a) Tsunami simulation for the Horseshoe Abyssal plain Thrust (HAT) over a regional bathymetric map showing maximum wave-heights and tsunami travel-time (30 min intervals) and illustrating the effects of bathymetric roughness in tsunami energy propagation. **b)** Close-up of the HAT tsunami simulation showing maximum wave-heights and tsunami-travel times (10 min intervals) highlighting the most affected areas along the SW Iberian and NW Moroccan margins. White numbers refer to localities listed (Id) in Supplementary Tables 2 and 3. Yellow circles label locations of run-up and time arrival reports in Supplementary Tables 2 and, 3. Red circles indicate locations with no historical reports.

Comments to the revision (COMMSENV-21-0159-T)

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#REV 1

The manuscript presents good contributions for the advancement in the knowledge of the mechanisms of generation of earthquakes in the studied region, as well as the tectonic configurations that generated the earthquake that caused the tsunami of 1755.

We thank Reviewer 1 for his/her constructive review. His/Her suggestions have allowed us further verify that the HAT is a very likely source candidate because it also fits historical observations in additional control localities along the coast of Ireland, Great Britain and Spain (N and SE). In addition, we have followed his/her recommendations by modifying the title and reordering the manuscript, including some new sections and subsections.

The 1755's tsunami source problem is complex and the today solutions showed are not unanimous recognized by all scientifc community.

We recognize the importance and the contribution of the manuscript but this title is superstimated. This manuscript offers us only more one possibility, and needs the analysis and acceptance of scientific community. Please, review the title expressing the contribution and not the solution to this problem.

The manuscript tests its model with historical observations in the southern portion of the Iberian peninsula and northern Africa, in addition to the USA, the Caribbean and the South Atlantic, where it obtains good results. However, the great current challenge for the identification of the source of the earthquake that caused the 1755 tsunami is to determine a source that validates the models with the historical observations mentioned above and also in the northern portion of the Iberian peninsula, the British Isles and Ireland.

In some parts of the text there are statements that do not have scientific references to confirm them, making them just speculations or opinions of the authors (eg. Lines 36, 38 and 112).

The affirmation "Additionally, the tsunami simulation fits better than any other proposed source the historical reports from the 1755 Lisbon event, particularly the observed wave-heights." Is not true. Others papers show for some historical reports better fits.

The figures presents the results in an understandable and visually well made way. The supplementary material supports the understanding of the reading of the manuscript.

In this way it is suggested: that:

- Comparisons of the results are made with more historical data from the northern portion of the Iberian Peninsula, the British Isles and Ireland.

The list of localities selected to make the comparison between our results and previous tsunami simulations for other tectonic sources included in the first version of the ms. (tables 2 and 3), was based on previous reviews of historical data (Baptista et al., 1998a; Martínez-Solares, 2001; Barkan et al., 2009). For instance, Baptista et al 1998a presented a compilation of almost all available historical data from the countries affected by the tsunami. Their review is based on a careful analysis of a large amount of documentation written between 1755 and 1759, but they discarded the documents that described the tsunami effects and arrival time in a qualitative way.

Barkan et al. added localities along the western Atlantic coast, where there was tsunami report but no run-up report (NRR in table 2), and localities populated in 1755 but without tsunami impact report (NR in table 2) to Baptista's compilation.

Following the reviewer's recommendation, we have reviewed other publications where historical information on the tsunami impact had been analysed (e.g., Lyell, 1830; Dawson and Stewart, 2007; Oliveira 2008; Allgeyer et al., 2012; Gupta and Gahalaut, 2013; Martinez-Solares, 2001). As Baptista et al. stated, all information available on the tsunami impact along Ireland, Grain Britain or North Spain are qualitative descriptions without actual ranges of values. However, we have included this information (Table Tr1) on tables 2 and 3 to show that the HAT modelled tsunami has also a relevant impact at these localities. Below we include some examples of the information found in these reports:

- "At Kinsale, in Ireland, a body of water rushed into the harbour, whirled round several vessels, and poured into the market place" (Lyell, 1830)

- "Several locations of impact are reported, such as in the county of Cork (Ireland), the Bristol Channel, and the region of Penzance in Cornwall (REID 1914, 1918)" (Allgeyer et al., 2012).

- "Even in SW England, contemporary observations by Borlase (1755; 1758) describe the arrival of the tsunami in Mounts Bay, Cornwall: 'the first and second refluxes were not so violent as the 3rd and 4th (tsunami waves) at which time the sea was as rapid as that of a mill-stream descending to an undershot wheel and the rebounds of the sea continued in their full-fury for fully 2 hours ... alternatively rising and falling, each retreat and advance nearly of the space of 10 minutes until 5 and a half hours after it began" (Dawson and Stewart, 2007).

- "In distances larger than 1,000 km, the seismic waves caused floods originated by seiches, the movement of the waters of the lakes, rivers and harbours, in a rhythmic way. This was observed in Switzerland, England, Scotland, Finland and Sweden. In Scotland, 2,000 km away, the waters of Lake Lamond oscillated with amplitudes of more than 60 cm during more than one and half hours. In the Dal river, north of Stockholm, 3,000 km away, these oscillations were also felt. No other earthquake in the history caused rhythmic perturbations in the water at such large distances in a certain predominant direction of propagation (to the north). It is important to refer that only very large magnitude events, such as the Alaska 1964 Mw9.2, have caused phenomena of the same type denoting important energy at very short frequencies (<0.02 Hz)." (Oliveira, 2008).

- "The coasts of France, Great Britain, Ireland, Belgium and Holland also experienced tsunamis. Cornwall on the southern coast of England was hit by a three meter tsunami. Located on the west coast of Ireland, Galway was also hit by a tsunami and the 'Spanish Arc' section of the city wall was destroyed" (Gupta and Gahalaut, 2013).

In addition, Martínez-Solares (2001) in a monograph on the effects of the 1755 earthquake and tsunami includes a map (map 20, page 750) and a table (table 16, page 52) with information on all the Spanish towns affected by the tsunami.

Table Tr1. Summary of the HAT tsunami impact on Irish, British and Spanish (N and SE) localities where historical information on 1755 tsunami is available.

Id	Locality	Historical record		This work	
		Run-up (m)	T (min)	$\widehat{H_m}$ (m)	T (min)
1	Bilbao	NRR	-	0.48	144.6
2	Santander	NRR	-	0.45	133.9
3	Vibeiro (Lugo)	NRR	-	0.95	109.7
5	Baiona	NRR	-	1.14	76.7
14	Marbella	NRR	-	1.28	87.9
22	Galway	NRR	-	0.30	300.1
23	Kinsale	NRR	-	0.5	251.9

24	Cork	NRR	-	0.62	279.7
25	Cardiff	NRR	-	0.18	467.0
26	Bristol	NRR	-	0.17	512.4
27	Hartland	NRR	-	0.94	349.2
28	Widemouth Bay	NRR	-	0.93	341.8
29	Mount’s Bay	NRR	-	0.61	269.2

According to Tables 2 and 3 and the new figures 5 and 6 where we show that the maximum wave height of the HAT tsunami simulation fits 80% better with historical reports and matches arrival-times as well as previous simulations with other sources, we disagree with the reviewer on the fact that "other papers show for some historical reports betters fits". To our knowledge, there are no other published simulations aside from those included in our comparisons.

- The affirmations statements are supported by references.

We agree. We have added references to the sentences indicated by the reviewer. In addition, as suggested by the reviewer, we have changed the title trying to express a contribution to the scientific question investigated. Now it reads as: “Unveiling the potential source and underlying causes of the 1755 Lisbon earthquake and tsunami”.

- The parts of the manuscript should be reordered in order to give a good flow in the reading of the text. The item "Regional implications" appears before the general conclusions of the manuscript. The methodological item appears at the end of the text.

Initially, we submitted the manuscript to [redacted] and it followed the guidelines set by the journal, including the Methods section at the end of the text. In this new version we have adapted the text to the Communications Earth and Environment guidelines, reordering the manuscript as follows: Abstract (reduced to 150 words); Introduction; Crustal domains and tectonic setting; Results and Discussion; and Methods. The Results and Discussion section includes the following subsections: Origin of deep seismicity offshore SW Iberia; Simulation of the tsunami caused by a HAT-like source; and Regional and global implications.

- The conclusions are highlighted in the text, as they appear in the form "The HAT as a source of the 1755 Lisbon Earthquake and Tsunami."

We have modified the title of the section indicated by the reviewer to: “Simulation of the tsunami caused by a HAT-like source”. Moreover, we have moved the last paragraph of this section to the “Regional and global implications” one, to avoid confusion and improve the flow of the text.

 # REV 2

Dear Editor,

Martinez-Loriente et al present a smart manuscript mixing and blending together seismological, geological, marine, and rheological evidence to re-interpret the source of the great 1755 earthquake and tsunami, which hit Lisbon and large part of the Iberian Peninsula (i.e. the coasts). I suggest publication of this manuscript after some important reviews:

We thank the Reviewer 2 for his constructive suggestions that have helped to greatly improve the manuscript. The comparison between the different tsunami simulations and the historical reports, as well as the fit improvement achieved by the HAT source, is now much clearer. In addition, we have expanded the "Regional and global implications" section emphasizing the occurrence of grate intraplate earthquakes and associated tsunamis and the role of the serpentinite in the seismogenesis process that explains the occurrence of deep seismicity and large earthquakes off SW Iberia.

(1) The most important review to deal with, in my opinion, is to respond to the following question: how does this work advance, in general, the science of tsunamis and related earthquakes? I see some regional implications at the end of the manuscript, but I do not see a clear general take-home message. I deem this work has surely the potential of expressing a more general message on tsunamis and the generating earthquakes. This message should be clearly expressed in the abstract and discussed at the end of the manuscript. How about a comparison with other case histories so to generalize the presented findings? A manuscript on Nature (family) should, in my opinion, always explain how the results advance the science.

We thank the reviewer for this important observation. We agree that this was not well explained in the previous version of the ms so we have tried to make our overarching point clearer in the new version. A common assumption by the scientific community is that great earthquakes (Mw>8.5) are restricted to subduction zones, but the occurrence of earthquakes such as the 1755 Lisbon one frontally challenges this widely accepted premise. The question is that large and giant earthquakes can also occur in intraplate settings, and a few recent cases can be cited to illustrate this fact. The best recent examples are probably the two large earthquakes (Mw8.6 and Mw8.2) that occurred in the Wharton Basin (Indian Ocean) in April 2012 (Hill et al., 2015). The events generated a small tsunami with centimetric wave-heights but, interestingly, they nucleated at upper mantle depths associated with modest-length faults.

This has been the largest intraplate earthquake sequence that has been instrumentally recorded (Yue et al., 2012). The events initiated ~400 km to the SW of northern Sumatra, Indonesia, on the oceanic side of the Sunda megathrust, within the Wharton Basin and west of the Investigator Fracture Zone. The WNW-trending faults experienced large slip and stress drops. Most slip concentrated within the upper mantle, reaching at least 60 km depth. Therefore, the event had a large magnitude despite the modest length faults because the large slip occurred in high-rigidity upper mantle rocks (Hill et al., 2015).

Therefore, the occurrence of great earthquakes in intraplate settings and the possible associated tsunami exist and should be considered in geohazard assessments worldwide. Following the reviewer's suggestion, we have incorporated this key message and the corresponding discussion in the abstract and in the "Regional and global implications" section as well.

(2) One of the keys and novelties of this works consists of the fact that, based on geological-rheological analyses, "modest-length thrust faults such as the HAT could potentially account for large earthquakes". Comparison-contrast with similar settings-cases elsewhere would greatly support this result. Is the result/hypothesis of modest-length thrusts generating large earthquakes common elsewhere? If yes, what are the causes? Rheological causes as in the case proposed in this work?

We agree with the reviewer, and we have incorporated the Wharton Basin example described above into the "Regional and Global implications" section of the ms.

(3) Concerning the tsunami modeling, I think that results and comparison with previous works should be better analyzed, presented, and discussed. Tables 2 and 3 should be, in my opinion, (spatially) graphed to show the trend and minor-major differences with previous works. Is there a statistical way to quantify the deltas between observed and modelled data for this work and previous ones? The best fit should be properly quantified and assessed. Some statistical processing on the results from the models compared with observed data and previous models would greatly support results by Martinez-Loriente et alii.

We agree with the reviewer's suggestion. In order to facilitate the comparison, we have graphed our results together with previous works and historical reports (Figs. R1a and R2a, and new Figs. 5a and 6a in the ms.). In addition, we have calculated the relative variation of the maximum wave-height (ΔH_m) and the arrival time (Δt_a) between the historical values reported (H_m^{obs} and t_a^{obs}) and every simulation (H_m^{calc} and t_a^{calc}) at all the referred locations (Figs. R1b and R2b, and new Figs. 5b and 6b in the ms.).

$$\Delta H_m = \frac{|H_m^{obs} - H_m^{calc}|}{H_m^{obs}} \quad (1)$$

and

$$\Delta t_a = \frac{|t_a^{obs} - t_a^{calc}|}{t_a^{obs}} \quad (2)$$

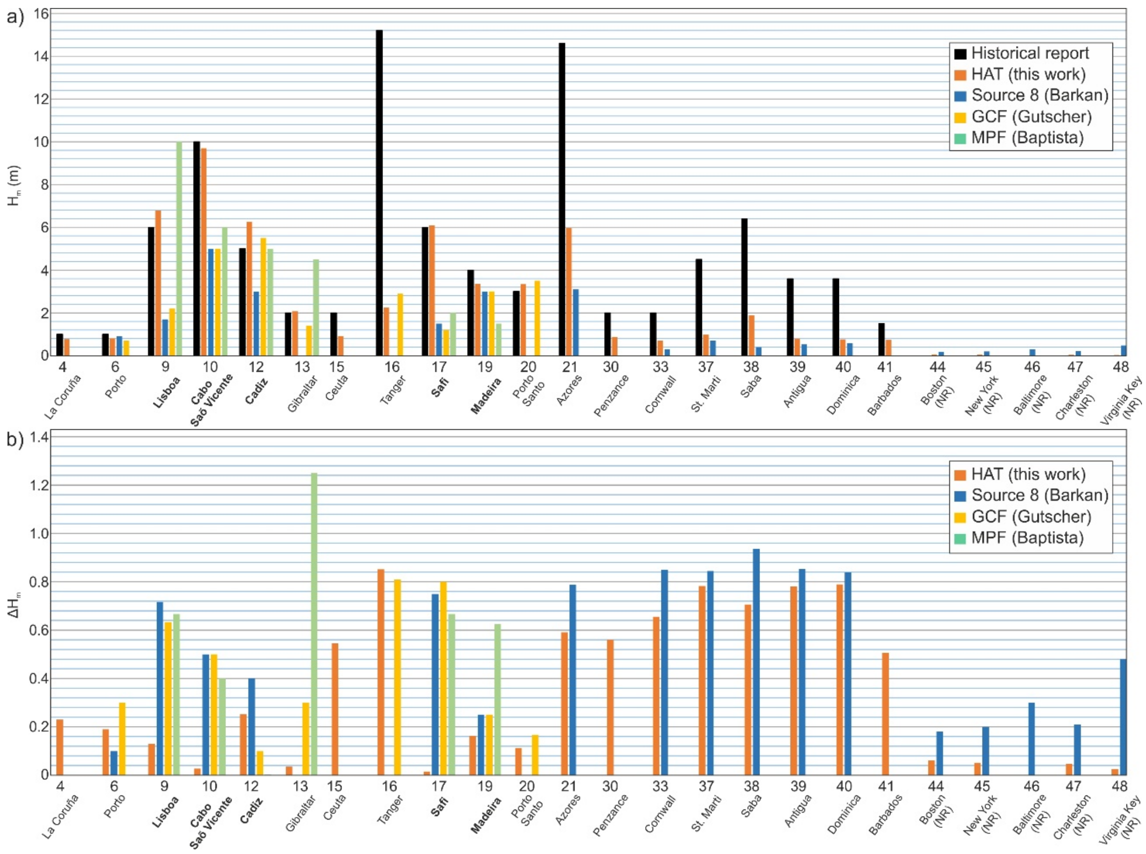

Figure R1. Comparative between the wave height of the tsunami simulations and the run-up of the 1755 tsunami historical reports. a) Graph showing the run-up of the 1755 Lisbon tsunami specified on historical reports (H_m^{obs}, in black), and the maximum wave height (H_m^{calc}) obtained from the tsunami simulations of different tectonic structures: the Horseshoe Abyssal plain Thrust (HAT, in orange), the Source 8 (from Barkan et al. (2009), in blue), the Gulf of Cadiz Fault (GCF from Gutscher et al. (2006), in yellow), and the Marques de Pombal Fault (MPF from Baptista et al. (1998b), in green) (see table 2). b) Graph showing the relative variation (ΔH_m) at different locations between the reported run-up (H_m^{obs}) and the H_m^{calc} specified in a) for each tsunami simulation. In bold are labelled locations with information available for comparison from the four tsunami simulations.

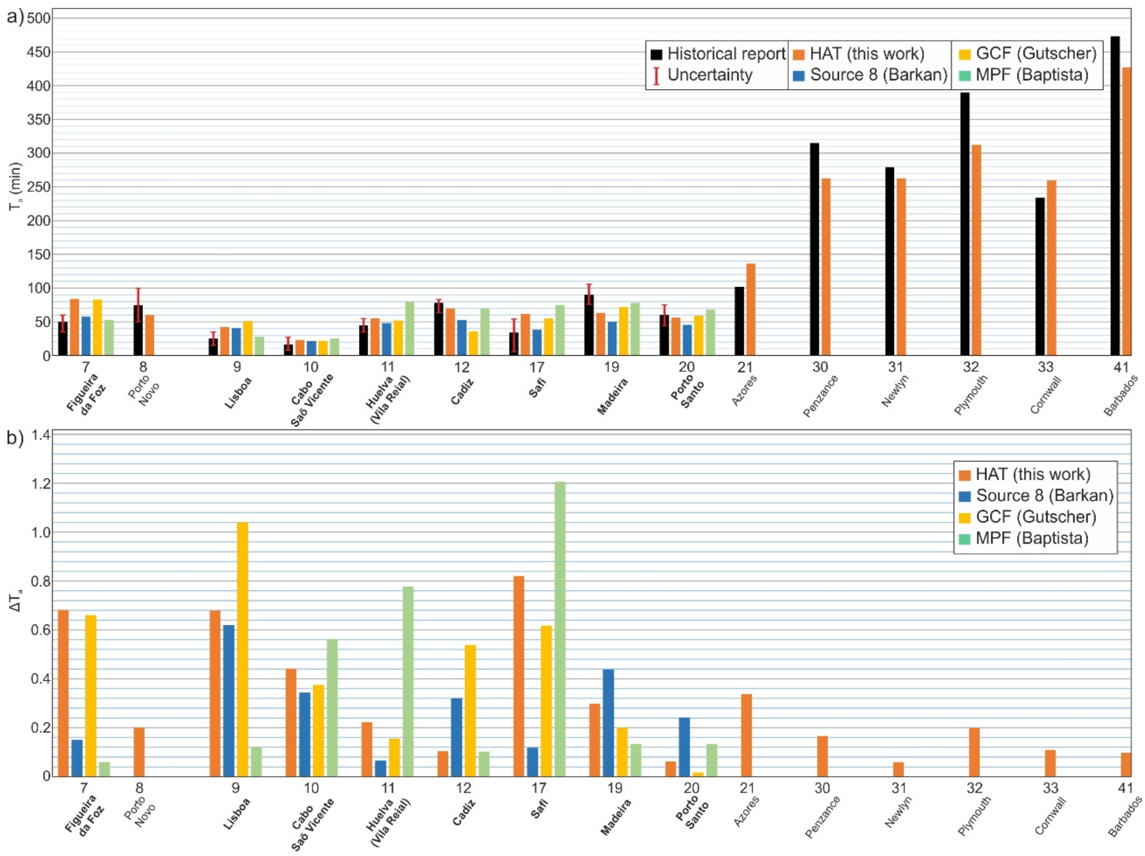

Figure R2. Comparison between estimated arrival times of the 1755 tsunami at different locations according to historical reports and those obtained by tsunami simulations. a) Graph showing the arrival time (t_a^{obs}) and uncertainty of the 1755 Lisbon tsunami specified on historical reports (black and red error bar, respectively) and the arrival time obtained from the tsunami simulations (t_a^{calc}) of different tectonic structures (HAT in orange, Source 8 in blue, GCF in yellow and MPF in green). b) Relative variation (Δt_a) at different locations between the t_a^{obs} reported and the t_a^{calc}obtained from tsunami simulations specified in a). In bold are labelled locations with information available for comparison from the four tsunami simulations.

When analysing the H_m in the localities with available data from the four simulations (i.e., Lisbon, Cabo Saõ Vicente, Cadiz, Safi and Madeira), it is observed that the HAT tsunami simulation obtains a better fit in all locations except for Cadiz (Fig. R1). In fact, in these "check-locations", the rms between the HAT simulation and the historical report is 0.7, while for the Source 8 is 3.7, for the GCF is 3.5 and for the MPF is 3.3, implying a fit improvement of ~80 % (Table 2). In the comparison between the only two sources of the four compared capable of generating transatlantic tsunamis, the HAT always obtains a better fit than Source 8, both in the far- and near-fields (except in Porto where the difference is minimal). Note that to enable the comparison of results in Figure R1b, the wave heights have approached to zero in the locations where no impact of the 1755 tsunami was reported (identified with "NR" in table 2 and in figure R1).

In the comparison between the historical tsunami arrival time in the “check-locations” (i.e., Figueira de Foz, Lisboa, Cabo Saõ Vicente, Huelva, Cadiz, Safi, Madeira, and Porto Santo) and those obtained in the four simulations, we only get a better fit in Cadiz. Note that in 6 of the 8 check-locations, the HAT results are within or close to the reported time range (Figure R2). It is obvious that the fit of the HAT source is poorer in the arrival time than in the wave height. However, the rms between the simulated results and the historical reports is similar for all four sources (i.e., HAT rms= 19.9 min; Source 8 rms= 18.5 min; GCF rms= 23.4 min; and MPF rms= 20.2 min) (Table 3). Morevover, it must be taken into account that some of the reported values are incompatible between them for a single source.

As suggested by Reviewer 1, we have added to Tables 2 and 3 the locations along the coast of Ireland, Great Britain and Spain (N and SE) that reported tsunami impact qualitatively (i.e., without specifying the run-up or arrival time) (see Table Tr1 of this rebuttal letter). The modelled HAT source tsunami arrives at all these localities, showing that the dispersion of the tsunami energy is in agreement with historical reports.

This new information, figures, tables and the corresponding discussion have been incorporated into the new version of the manuscript. We have therefore enriched the analysis as well as the comparison of the tsunami modelling results with previous works and historical reports as suggested by the reviewer.

(4) In places, I see big discrepancies in the run-up data between observed and modelled cases. Could these discrepancies be justified through local submarine landslides? The same applies to the arrival time data. I see that the authors have proposed this hypothesis (landslide) at the end of the manuscript. I suggest the authors to better constrain this hypothesis through the use of the above-proposed (spatial) graphs.

Discrepancies in the run-up and arrival time values between the observed and modelled results could be a consequence of different factors. First, historical observations contain information on estimated run-up heights (i.e. maximum height of the inundation), but tsunami simulations provide maximum wave-height (H_m) before reaching the coast. Therefore, we are comparing different features. Second, and as stated above, it should be taken into account that in many cases the reported observations are incompatible between them for any single source, so they are not credible. Some outstanding examples are Lisbon, Tangier, Azores or Madeira, as it has already been pointed out in previous works (Baptista et al., 1998b; Gutscher et al., 2006 and Barkan et al., 2009). Third, some delays could be due to the poorly constrained shallow shelf bathymetry in the modelling. Four, and as indicated by the reviewer, it could reflect the effect of local landslides (i.e. multiple tsunami sources). However, there is some previous work supporting that the turbidite related to the Lisbon earthquake, which has a modest estimated volume (1.3 km^3), is unlikely to have contributed significantly to the 1755 tsunami (Gràcia et al., 2010). Five, the increase in wave height caused by a high tide at the time of the tsunami is also a potential enhancing factor that is not taken into consideration by the models.

Almost all this information was already included in the first version of the manuscript. However, in the new version we tried to clarify the different points and especially point 4, specifying that the turbidite generated by the earthquake is too thin to have contributed significantly to the tsunami.

(5) I am not sure whether the 1755 earthquake has been the most destructive known earthquake in European history. The 1908 Messina Straits earthquake and the 1693 SE Sicily earthquake were also very big with associated tsunamis.

The catastrophic dimensions of the 1755 event had an immediate repercussion all over 18th century Europe. The fact that damage could be evaluated, *in situ*, lead to the publication of several types of reports, descriptions, philosophical and religious explanations. In the philosophical field, this event had a strong impact on the anti-optimism movement by thinkers such as Kant and Voltaire (e.g., 'Poeme sur la desastre de Lisbonne' (1756), 'Candide ou l'optimisme' (1759)), generating a philosophical debate that surpassed that of any other previous event.

Nevertheless, we have followed the reviewer's suggestion and changed the sentence. Now it reads as "one of the most destructive known earthquakes in European history".

I hope that these suggestions will be useful

Rome, April 2021
Andrea Billi

REV 3

Martinez-Loriente et al. (the manuscript) address a recurrent scientific subject: the characteristics of the source of the 1755 Cadiz Gulf earthquake and tsunami. This is a challenging task, given the offshore location, the length of time elapsed, and the apparently contradictory information. The authors draw on geophysical and seismological data to propose that the rupture of the NE-SW trending Horseshoe Abyssal Thrust (HAT) in response to the Nubia-Iberia convergence was the culprit. In favour of their proposed model the authors argue that their modeling of tsunami heights and traveltimes improves significantly the fit to coeval reports. They solve the paradox of accounting for a mega-earthquake without the presence of faults with the corresponding length by invoking nucleation in the upper mantle and propagation through serpintinized basement rocks that outcrop in the Cadiz Gulf, a mechanism that they support with thomographic evidence.

Forgetting for a minute the 1755 earthquake, the proposed mechanism has at least the merit of explaining the M7.8 1969 Cape St Vincent earthquake, with hypocentral depth of 37 km (Buforn et al., 2020) and no apparent surface rupture, and other intermediate-depth instrumental earthquakes of lesser magnitude occurring in the Horseshoe Abyssal Plain. The scientific merit of the model is therefore undeniable.

And yet… I cannot help feeling that the authors just missed the opportunity to make a qualitative improvement of our understanding of this elusive historical earthquake, given the power of the tools under their command. My view is that the interpretation sails too close to orthodox thinking, and some interesting clues are missed, as is often the case when that approach is taken.

We appreciate the comments of the reviewer who have helped us to critically revise our arguments and working hypothesis. This has allowed us to improve the manuscript and to be more precise and not overstating the effects of the event. We disagree with the reviewer's repeated suggestion to consider the GCF as the source of the Lisbon earthquake. In the previous works of Gutscher et al. (2006) and Barkan et al. (2009) it is shown that this structure is not capable of generating an earthquake and subsequent tsunami like the one that destroyed Lisbon in 1755. Additionally, there is compelling evidence mainly from seismic reflection data that the accretionary wedge is inactive and sealed by a thick layer of undeformed sediments.

For example, the authors open by stating that the 1755 earthquake has magnitude Mw ~8.5 (line 12). This is understandable because such a figure is widely cited in the literature, but the reference given for this value ((Johnston, 1996) is 25 years old, and doesn't benefit from robust techniques for estimating the magnitude of historical earthquakes that in the meantime have become standard (e.g. Bakun and Wentworth, 1997).

There are several works that propose different Mw through different approaches. For instance, Martínez-Solares and Arroyo (2004) proposed a Mw = 8.5 ± 0.3; Baptista et al. (1998b) a Mw = 8.5; Johnston (1996) a Mw = 8.7 ± 0.39; Martins and Mendes Victor (1990) a Mw = 8.5; Abe (1979) a Mw = 8.5; Lopez-Arroyo and Udias (1972) a Mw = 8.9, and other authors in older papers arrive at estimates that vary from 8.3 to 9.0 (Martínez-Solares, 2001).

Due to the restriction on the number of references that can be included in the manuscript, in the original version of the manuscript we decided to include a single reference widely recognized by the scientific community and one of the first to use "modern" seismological methods. However, we think that it is a better option to indicate that the Mw8.5+ and include the corresponding references (e.i., Lopez-Arroyo and Udias,1972; Abe, 1979; Martins and Mendes Victor, 1990; Johnston, 1996; Baptista et al., 1998b; Martínez-Solares, 2001; Martínez-Solares and Arroyo, 2004)

But since the authors cite synthetic peak ground accelerations derived from intensities by Buforn et al. (2020) to support their choice of strike and focal mechanism (I will ignore for tphe sake of the argument that this is debatable given the distance to the coast) I would expect them to notice a remarkable feature of those PGA values: except for the coastal regions of southern and western Portugal, they tend to be lower than the values estimated for the M7.8 1969 earthquake at the same locations (Figure 10 of the cited reference). Since the relative difference in epicentral distance is small at ~1000 km from the epicenters, there is certainly something there to be learned about the relative magnitudes of the two earthquakes. To be fair, the authors of the cited reference missed that implication too (but they were not trying to publish in ComsEEnv!).

We use the analysis of the peak ground accelerations derived from intensities by Buforn et al. (2020) just to support a NE-SW oriented reverse dip-slip mechanism, which would be similar to the 2009 earthquake associated with the MPF, and would back up the prolongation of the HAT towards the MPF.

As stated in our answer to Editor, we fundament our choice for the proposed location, depth, strike and focal mechanism of the source on the following observations:

1) Controlled-source tomographic evidence for the presence of a deep dipping reflector in the middle of the Horseshoe Abyssal Plain (i.e., the HAT). According to this models, this reflector separates serpentinized peridotite basement at the northwest from oceanic lithosphere at the southeast (Martinez-Loriente et al., 2014).
2) Regional micro-seismicity recorded by temporal networks of ocean bottom seismometers that show seismicity concentrating in three main clusters located in this area at upper-mantle deeps (between 30-60 km depth) (Geissler et al., 2010; Grevemeyer et al., 2016; Silva et al., 2017);
3) Seismological data analysis the two largest recent earthquakes occurred in SW Iberia. Both occurred at upper mantle depths in the middle of the Horseshoe Abyssal Plain (Fukao, 1973; Stich et al., 2007; Buforn et al., 2020; Lozano et al., 2020), and share location, source mechanism, and hypocentral depth with the proposed HAT thrust;
4) The two-state mechanical behaviour of serpentinite, which could explain both the occurrence of deep seismicity and of earthquakes that appear to be anomalously large for the regional fault lengths;
5) The HAT tsunami simulations, which fit better data from historical reports than previous simulations performed with other source candidates, particularly for the maximum observed wave-heights.

There are several works (e.g., Martinez-Solares et al., 1979; Levret, 1991; Stich et al., 2007) that propose that the mechanism and strike of the structure responsible for the 1755 earthquake could well be similar to the one that originated the seismic events of 1969 (Mw 7.9) and 2007 (Mw 6.0), which share the location, focal mechanism and a deep hypocentre. It sounds like a good working hypothesis if we apply Occam's razor: it allows explaining a large number of observations with a limited number of assumptions.

Another missed cue is the fact that the magnitude estimate adopted by the authors (and by many others) was published in Johnston (1996), the same paper (and the same method) that estimated a magnitude for the New Madrid 1812 earthquake which was subsequently downgraded by approximately 1 magnitude unit, while the 1755 magnitude estimate remained unchallenged (the authors may also want to have a look at Fonseca (2000), where the magnitude of this earthquake is discussed).

The authors may find that I am focusing too much on the magnitude issue. This is to some extent justified by the fact that the bulk of the manuscript hinges on the seismic and tsunami source geometry, hence magnitude. And said magnitude is also a key parameter in the tsunami modeling. But the point that I am trying to make is broader: unveiling the mysteries of an earthquake that has eluded the seismological community for decades requires ingenuity, alongside powerful tools.

As stated before, there are many works supporting a Mw>8.5 for the 1755 Lisbon earthquake. There is consensus in the scientific community on the larger magnitude of the 1755 earthquake as compared to the Mw7.8-8.0 1969 event. Baptista et al. (1998b) states that in order to generate the tsunami observed, the 1755 earthquake needed to liberate 30 times more energy than the 1969 event, whereas Abe (1979) had obtained a value of 15 times larger. The intensity maps of both events do not leave any doubt about the higher intensity of the 1755 earthquake as compared to the 1969 one (Grandin et al., 2007). The 1755 event was felt all over the North Atlantic coasts, producing a remarkable agitation of lakes, rivers and harbours in a rhythmic way as far as Great Britain, Switzerland, Finland and Sweden (Lyell, 2009; Oliveira 2008), and generated considerable transoceanic tsunami waves crossing the whole Atlantic Ocean (Gupta and Gahalaut, 2013). Oliveira (2008) noted that "No other earthquake in the history caused rhythmic perturbations in the water at such large distances in a certain predominant direction of propagation (to the north). It is important to refer that only very large magnitude events, such as the Alaska 1964 Mw9.2, have caused phenomena of the same type denoting important energy at very short frequencies (<0.02 Hz)". The 1969 event generated a tsunami of < 1 m, much smaller than that of the 1755 (Abe, 1979; Gutscher et al., 2006; Buforn et al., 2020). In our opinion, the evidences pointing to a giant event, incomparably larger than that of 1969, are overwhelming.

Another example: had the authors chosen not to follow the well-trodden path of modeling the tsunami source as a classical tectonic rupture, their attention might have been drawn to one of the pieces of the tsunami puzzle which is systematically ignored: the possible role of the Cadiz Gulf accretionary prism (Medialdea et al., 2004) in the tsunamigenic process. With the exception of Gutscher et al. (2006) who claimed a subduction-type rupture at its base to explain the 1755 earthquake and tsunami, I am not aware of any attempt to model the effect of the deformation of this sedimentary body (maybe as a partial rupture branching from the HAT, or just a catastrophic landslide?), configuring a tsunami earthquake, i.e., an earthquake with much larger tsunami magnitude than moment magnitude. This is the kind of "out-of-the-box" thinking that, in my view, has the potential to remove the veil that still covers the 1755 earthquake, after so many "orthodox" attempts. I fear that the main shortcoming of the manuscript was its lack of this type of ingenuity.

Aside from the evidences indicated in our previous answer that point to a very large magnitude event (i.e. the very distant shaking), there is also clear evidence from seismic reflection data that the Gulf of Cadiz Imbricated Wedge (GCIW) is sealed by a 300-400 m-thick undeformed sedimentary cover, ruling out any recent activity. The typical deformation associated with active accretionary prisms, as those described in many subduction zones, is absent here. This is clearly visible in the seismic profile (Figure 5) published by Martínez-Loriente et al. (2018) and in the works of Iribarren et al. (2007) and Zitellini et al. (2009). Additionally, there is no megathrust-type activity that could be attributed to active subduction there.

There are two works that performed the tsunami modelling of this structure, which is referred to as the "Gulf of Cadiz Fault" (GCF) in both works. Gutscher et al. (2006) concluded that the structure alone could not explain the historical observations, and therefore proposed a composite rupture together with the Marques de Pombal Fault. Figures R1 and R2 of this rebuttal letter and tables T1 and T2, show that the HAT tsunami modelling fits better reported wave heights and arrival times than these structures. In addition, Barkan et al. (2009) investigated constraints on the epicentre of the 1755 Lisbon earthquake from far field numerical tsunami simulations. They generated 16 tsunami simulations using the same tectonic source at 16 different locations and compared the fit of each simulation to the historical record. Sources 8 and 5 located in the middle of the Horseshoe Abyssal Plain, are those providing the best results. The GCF corresponds to Source 1, which obtained one of the worst fits among all the modelled sources, both on terms of wave heights and arrival times (Figures 5, 7 and 17 in Barkan et al.).

Regarding a possible catastrophic landslide suggested by the reviewer, if it had occurred, there would be a sedimentary record of it. However, offshore core sampling performed in the area show no evidence of a major catastrophic event such as that proposed related to the Lisbon earthquake, but just a turbidite with a modest volume (1.3 km^3), which is very unlikely to have contributed significantly to the tsunami (Gràcia et al., 2010).

This judgement may seem too harsh in view of the amount of information put forward in the manuscript. The problem here is one of novelty. No doubt the tsunami modelling is new and produces some improvement to the fit. But upper mantle seismogenesis in the region was documented and discussed before by Stich et al. (2007) and Geissler et al. (2010), among others. Likewise, the tomographic results that led to the identification of the tectonic domains of the Cadiz Gulf and in so doing highlighted the importance of the HAT – in my opinion the most important step so far towards understanding the large earthquakes of the Cadiz gulf – where previously published by Martinez-Loriente et al. (2014). The application of the two-state mechanism of serpentinite rheology to explain the intermediate-depth seismicity of the region is original, but the concept was used before to explain nucleation and propagation of earthquakes elsewhere (Reinen et al., 1991).

So, the key issue to be addressed is, in my view: are the tsunami modeling results robust and illuminating enough to warrant publication in ComsEEnv? This task involves critical assessment of coeval sources, and the authors did themselves a disservice by repeating "hype" about the 1755 earthquake: that it killed 100000 people (line 40), off by one order of magnitude if reliable coeval sources such as Mendonca (1758) are taken in account; that it released 15 times more energy than the M7.8 1969 earthquake judging from tsunami wave-heights (line 116), when the differences could equally well be explained by near-source bathymetry and scattering since the sources were not co-located (effects that the authors invoke later to illustrate the merits of their model, in lines 192-199).

We have come a long way and it has been necessary to piece together many isolated bits of information along with key new observations and models to support this hypothesis. As noted by the reviewer, it is not easy to make a fully compelling case when we are treating with a 250 years old event, so it is necessary to accumulate evidence from many different complementary sources. This is what we have done.

First, Sallarès et al. (2013) used tomographic and gravity modelling results to reveal that the basement underlying the Horseshoe and Tagus abyssal plains is made of exhumed mantle rocks. Then, also used the controlled-source tomography models to construct the first map of basement domains off SW Iberia, and to show that the HAT is a first-order boundary between basement domains (Martinez-Loriente et al., 2014). At that time, we did not have enough scientific evidence to propose this structure as the source of the major seismic events in the region. Subsequently, recordings of temporal networks of ocean bottom seismometers showed that seismicity in this area concentrates at upper-mantle depths, in a location that is consistent with the HAT location (Silva et al., 2017 and Grevemeyer et al., 2016). Then, after relating deep regional seismicity and the occurrence of large earthquakes with the presence of a thrust fault within serpentinite rocks, we built a conceptual model that could explain the largest number of observations with all bits of information. The last remaining 'acid test' was to perform the tsunami modelling; and the result is that the HAT source simulation fits the historical observations, both in the near- and far-fields, better than any other known tectonic source in the region taken into account the notable error bars associated with this type of -often incompatible and even contradictory- observations.

As indicated above, we have made an exhaustive review of the available historical information and of most relevant previous works. We agree with the reviewer that the 100,000 victims attributed to the earthquake is probably an exaggeration, as it is the tsunami height exceeding 15 m reported at some locations. It is necessary to clarify that we refer to the total number of victims in all countries, including those due to the ground-shaking, the triggered fires and the ensuing tsunami. Some studies that have analysed historical information conclude that it is very difficult to quantify the real number victims of the 1755 event, but they agree that the number is overestimated. For instance, Martínez-Solares and Arroyo (2004) stated that the victims in Portugal probably did not exceed 12.000 due to all causes, of which only 10.000 would correspond to Lisbon. They conclude that total victims could be between 15 and 20 thousand people overall. Therefore, we have changed the sentence and now reads as: "The event is thought to have caused near 20,000 victims combining the effects of ground-shaking, the related fires and ensuring tsunami, (...) ".

Regarding the comparison of magnitudes between the events of 1755 and 1969, we explained before that we do not question the higher energy released by the 1755 earthquake compared to that of 1969 according to sesimological and historical information. If we accept that the source of both seismic events was the same, the possible effects of near-source bathymetry and scattering suggested by the reviewer are invalidated, since they would have had the same effect for both tsunamis, which is clearly not the case.

Comparison of data fits from tables 2 and 3 in the Supplement is not easy, and a quantitative metric would help. I felt uncomfortable with the strong "correlation" between data that did not fit the model well and data that were labelled "not credible" (Supplement, line 52). To be sure, the authors are entitled to grade the reliability of the input data and to weigh them accordingly, but it should be done with objective and verifiable criteria.

We agree with the reviewer. As we explain in our answer to Reviewers 1 and 2, we have incorporated two new figures (Figures R1 and R2 of this rebuttal letter) to clarify the comparison between the HAT tsunami simulation results with previous simulations and with historical reports. In addition, we have also calculated the variation rate between all simulations and the historical reports, showing that the HAT model improves substantially the fit of the wave height, while the fit of arrival times is similar. It is also key to note that the only two of the compared sources capable of generating transatlantic tsunamis are the HAT and Source 8 –which, by the way, is perpendicular to all known tectonic structures and to plate convergence! -. Therefore, the comparison between the four sources is only carried out in near-source localities where previous studies have specified the results obtained. Moreover, we have added to Tables 1 and 2 new localities along the coast of Ireland, Grain Britain and Spain (N and SE) to show that the HAT tsunami also impacts these locations as qualitative inferred from historical reports. Finally, we have revised the historical data qualified as "not credible", and ensured that they were qualified in the same way by previous works based on reasonable arguments. For instance: a) the arrival time in Safi is between 26 and 34 min (±20), resulting in a wide range of 6 to 54 minutes; b) Penzance and Newlyn are 2 km apart, but there is 35 min difference in the tsunami arrival time; c) tsunami run-up at some localities as Angra (14.6 m), Tanger (15.2 m), Cadiz (15 m) or Lisboa (15 m) are considered as "not credible" in all previous works because they are overestimated and there is no evidence, as has occurred with the number of victims of the 1755 event.

The discussion of the tsunami source model passed the impression that the best contender was the model of Barkan et al. (2009), who focused their attention on transatlantic data since the near-source effects, in association with source uncertainty, make regional observations very unreliable. This the authors downrate on the grounds that the strike used in the modelling "does not correspond to any known structure in [the] area" (line 233). However, the manuscript's Figure 1 shows that the frontal slope of the Gulf of Cadiz accretionary prism, on the eastern side of the Tagus Abyssal Plain (Medialdea et al., 2004), displays the orientation blindly selected by Barkan et al. (2009). In my view, in such conditions the tsunami earthquake hypothesis warrants investigation, if nothing else to dismiss it as a possible explanation.

As stated before, Barkan et al. (2009) performed a set of 16 tsunami simulations using the same source at 16 different locations. Sources 8 and 5, both located at the Horseshoe Abyssal Plain, get the best fit with historical record. However, the proposed orientation was chosen *ad hoc* for the purposes of the modelling but it does not correspond to any known structure in this area. As stated above, Barkan et al. (2009) also modelled the GCF (Source 1) as suggested by the reviewer, obtaining one of the worst fits with the historical record, as shown in Figures 5, 7 and 17 of Barkan's paper. Gutscher et al. (2006) concluded after the GCF tsunami simulation that this structure alone could not explain the historical observations. According to these previous works, the GCF does not seem a good candidate as a source of the 1755 Lisbon earthquake.

In short: the authors state that "[A] number of candidate sources have been proposed [for the 1755 earthquake and tsunami], although none of them explains satisfactorily the inferred seismic moment of the event, as well as the arrival-times and, particularly, the run-up heights of the tsunami referred to in the historical reports" (lines 45-48)". Yet, the approach described in the manuscript was quite conservative, hitting the problem with improved tools but on old premises. The improvements are predictably quantitative, but they left me wanting more. I got the impression that the authors are tantalizingly close to a "Eureka moment", and I urge them to look critically at the vast literature in the topic, instead of accepting established ideas at face value. I will be looking forward to review an improved version of the manuscript, if the authors choose to go that way.

Lisbon, April 5, 2021

Joao Fonseca

References

Abe K. (1979) Size of great earthquakes of 1837-1974 inferred from tsunami data. J. Geophys. Res. B4(84), 1561-1568.

Allgeyer, S., Daubord, C., Hébert, H. et al. Could a 1755-Like Tsunami Reach the French Atlantic Coastline? Constraints from Twentieth Century Observations and Numerical Modeling. Pure Appl. Geophys. 170, 1415–1431 (2013). https://doi.org/10.1007/s00024-012-0513-5

Bakun, W. H., and C. M. Wentworth (1997). Estimating earthquake location and magnitude from seismic intensity data, Bull. Seismol. Soc. Am. 87, no. 6, 1502–1521.

Baptista, M. A. et al. The 1755 Lisbon earthquake; evaluation of the tsunami parameters. J. Geodyn. 25, 143–157 (1998a).

Baptista, M. A. et al. Constraints on the source of the 1755 Lisbon tsunami inferred from numerical modelling of historical data on the source of the 1755 Lisbon tsunami. J. Geodyn. 25, 159–174 (1998b).

Barkan, R., ten Brink,U. S., & Lin, J. Far field tsunami simulations of the 1755 Lisbon earthquake: Implications for tsunami hazard to the U.S. East Coast and the Caribbean. Marine Geology, 264, 109-122, doi: 10.1016/j.margeo.2008.10.010 (2009).

Buforn, E. et al. Re-evaluation of Seismic Intensities and Relocation of 1969 Saint Vincent Cape Seismic Sequence: A Comparison with the 1755 Lisbon Earthquake. Pure Appl. Geophys. 177, 1781–1800, https://doi.org/10.1007/s00024-019-02336-8 (2020).

Dawson A, and Stewart I. Tsunami geoscience. Progress in Physical Geography: Earth and Environment. 2007; 31(6): 575-590. doi:10.1177/0309133307087083

Duarte, J., Schellart, W., & Rosas, F. The future of Earth's oceans: Consequences of subduction initiation in the Atlantic and implications for supercontinent formation. Geological Magazine, 155(1), 45-58. doi:10.1017/S0016756816000716 (2018).

Geissler, W. H. et al. Focal mechanisms for sub-crustal earthquakes in the Gulf of Cadiz from dense OBS deployment, Geophys. Res. Lett. 37, L18309, doi:10.1029/2010GL044289 (2010).

Gràcia, E. et al. Holocene earthquake record offshore Portugal (SW Iberia): Testing turbidite paleoseismology in a slow convergence margin. Quat. Sci. Rev., 29, 1156–1172, https://doi.org/10.1016/j.quascirev.2010.01.010 (2010).

Grandin, R., Borges, J.F., Bezzeghoud, M., Caldeira, B., Carrilho, F., 2007. Simulations of strong ground motion in SW Iberia for the 1969 February 28 (Ms=8.0) and the 1755 November 1 (M~ 8.5) earthquakes — I. Velocity model. II. Strong ground motion simulations. Geophys. J. Int. 171 (2), 807–822 (16).

Grevemeyer, I., Matias, L., & Silva, S. Mantle earthquakes beneath the South Iberia continental margin and Gulf of Cadiz – constraints from an onshore-offshore seismological network. J. Geodyn. 99:39–50. http://dx.doi.org/10.1016/j.jog.2016.06.001 (2016)

Gupta, H., and Gahalaut, V. Three Great Tsunamis: Lisbon (1755), Sumatra-Andaman (2004) and Japan (2011). Springer Netherlands. https://doi.org/10.1007/978-94-007-6576-4 (2013)

Gutscher, M.-A., Baptista, M.A., & Miranda, J.M. The Gibraltar Arc seismogenic zone: Part 2. Constraints on a shallow east dipping fault plane source for the 1755 Lisbon earthquake provided by tsunami modeling and seismic intensity. Tectonophysics. 426, 153–166 (2006).

Fukao, Y. Thrust faulting at a lithospheric plate boundary, The Portugal earthquake of 1969. Earth Planet Sci. Lett. 18, 205–216 (1973).

Hill, E. M., et al., The 2012 Mw8.6 Wharton Basin sequence: A cascade of great earthquakes generated by near-orthogonal, young, oceanic mantle faults, J. Geophys. Res. Solid Earth, 120, 3723–3747, doi:10.1002/2014JB011703 (2015)

Iribarren, L., J. Vergés, F. Camurri, J. Fullea, and M. Fernàndez (2007), The structure of the Atlantic-Mediterranean transition zone from the Alboran Sea to the Horseshoe Abyssal Plain (Iberia–Africa plate boundary), Mar. Geol., 243, 97–119.

Johnston, A. Seismic moment assessment of earthquakes in stable continental regions — III New Madrid 1811–1812, Charleston 1886 and Lisbon 1755. Geophys. J. Int. 126, 314–344 (1996).

Levret, A. The effects of the November 1, 1755 “Lisbon’’ earthquake in Morocco. Tectonophysics 193, 83–94 (1991).

Lopez-Arroyo, A. and Udias, A., 1972. Aftershock sequence and focal parameters of the February 28, 1969 earthquake of the Azores- Gibraltar fracture zone, Bull. seism. Soc. Am., 62, 699-720.

Lozano, L. et al. A new 3-D P-wave velocity model for the Gulf of Cadiz and adjacent areas derived from controlled-source seismic data: application to nonlinear probabilistic relocation of moderate earthquakes. Geophysical

Journal International. 221 (1), 1–19, https://doi.org/10.1093/gji/ggz562 (2020).

Lyell, C. 1830. Principles of Geology, vol 1, chapter25, p. 439. London. 1830-1833.

Martinez-Loriente, S. et al. Seismic and gravity constraints on the nature of the basement in the Africa-Eurasia plate boundary: New insights for the geodynamic evolution of the SW Iberian margin. J. Geophys. Res. Solid Earth, 119, 127–149 (2014).

Martínez-Loriente, S. et al. Morphostructure, tectono-sedimentary evolution and seismic potential of the Horseshoe Fault, SW Iberian Margin. Basin Res. 30: 382-400. doi:10.1111/bre.12225 (2018).

Martínez-Solares, J.M., and López-Arroyo, A. The great historical 1755 earthquake. Effects and damage in Spain. Journal of Seismology, 8, 275–294 (2004)

Martínez-Solares, J. M. Los efectos en España del terremoto de Lisboa (1 de noviembre de 1755), Dirección General del Instituto Geográfico Nacional, 756 pp, ISBN: 84-95.172-26-7 (2001).

Martinez-Solares, J.M., Lopez, A., Mezcua, J. Isoseismal map of the 1755 Lisbon earthquake obtained from Spanish data. Tectonophysics 53, 301–313 (1979)

Martins I. and Mendes Victor L. A. Contribuiçao para o estudo da sismicidade de Portugal Continental. Pub. No. 18, Instituto Geofisico do Infante D. Luis. Universidade de Lisboa, Lisboa, Portugal, 67 p (1990)

Oliveira, C. S. (2008). Review of the 1755 Lisbon earthquake based on recent analyses of historical observations, in Historical Seismology. Modern Approaches in Solid Earth Sciences, J. Fréchet, M. Meghraoui, and M. Stucchi (Editors), Vol. 2, Springer, Dordrecht, The Netherlands.

Sallarès, V. et al. Seismic evidence of exhumed mantle rock basement at the Gorringe Bank and the adjacent Horseshoe and Tagus abyssal plains (SW Iberia), Earth Planet. Sci. Lett., 365, 120–131, doi:10.1016/j.epsl.2013.01.021 (2013).

Silva, S. et al. Micro-seismicity in the Gulf of Cadiz: Is there a link between micro-seismicity, high magnitude earthquakes and active faults?. Tectonophysics, 717, 226-241, https://doi.org/10.1016/j.tecto.2017.07.026 (2017).

Stich, D., Mancilla, F.D.L., Pondrelli, S., & Morales, J. Source analysis of the February 12th 2007, Mw 6.0 Horseshoe earthquake: implications for the

1755 Lisbon earthquake. Geophys. Res. Lett. 34 (L12308). ttp://dx.doi.org/10.1029/2007GL030012 (2007).

Yue, H., Lay, T. & Koper, K. En échelon and orthogonal fault ruptures of the 11 April 2012 great intraplate earthquakes. *Nature* 490, 245–249 (2012). https://doi.org/10.1038/nature11492

Zitellini, N., et al. (2009), The quest for the Africa-Eurasia plate boundary west of the Strait of Gibraltar, Earth Planet. Sci. Lett., 280, 13–50, doi:10.1016/j.epsl.2008.12.005.

8th Jun 21

Dear Dr Martínez-Loriente,

Your manuscript titled "Unveiling the potential source and underlying causes of the 1755 Lisbon earthquake and tsunami" has now been seen by our reviewers, whose comments appear below. In light of their advice I am delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment under the open access CC BY license (Creative Commons Attribution v4.0 International License) provided you critically discuss the uncertainties associated with previous magnitude estimates for the 1755 earthquake and remove or substantially tone down your statements on the implications for intraplate earthquakes, as highlighted by Reviewer #3.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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Best regards,

Luca Dal Zilio, PhD
Editorial Board Member
Communications Earth & Environment
orcid.org/0000-0002-5642-0894

Joe Aslin
Associate Editor
Communications Earth & Environment

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

All of my suggestions were incorporated into this manuscript, as well as the recommendations of the other reviewers. The final product presented has a scientific basis and a very good writing style. My opinion is for the publication of this work.

Reviewer #2 (Remarks to the Author):

Dear Editor,
the manuscript by a Martinez-Loriente et al. on the 1755 Lisbon earthquake and tsunami has significantly improved and I consider it suitable for publication on Communications Earth & Environment.
Sincerely
Andrea Billi

Reviewer #3 (Remarks to the Author):

1) To the question "where your concerns addressed by the authors?" the only honest answer I can give is "no".
2) The main criticism in my review concerned the unquestioned adoption of previous magnitude estimates for the 1755 earthquake. The authors are not seismologists and it is only normal that they rely on the literature, but for such a key parameter I felt that it was incumbent upon the authors to demonstrate the robustness of the adopted value, otherwise they might build a big edifice on weak foundations. In the revised manuscript, the authors cite a list of publications with magnitude estimates on which they base their choice, but at close inspection those sources are at best reworkings of the estimate of Johnston (1996), and some are not even estimates (they just cite one another until the trail is lost). This critical stance on the commonly accepted magnitude of the 1755 earthquake is admittedly a minority view (although a published one, see Fonseca, 2000), and it would not be fair to penalize the authors for staying with the mainstream. Still, I believe that a more critical attitude would be adequate.
3) In the review, I argued that "the tsunami earthquake hypothesis warrants investigation, if nothing else to dismiss it as a possible explanation". The authors go a great length to rebut "the reviewer's repeated suggestion" that the Gulf of Cadiz Fault may have caused the earthquake, but this suggestion was not made in my review (actually, I do not subscribe to that view). What was raised was the possibility that deformation of the accrecionary prism induced by the proposed rupture in the HAT might have played a role in tsunami generation. This was rebutted on the grounds of negative evidence that I found insufficient, and some of it from a location ~100 km further west.
4) I pointed out in my review that several aspects of the manuscript which are very relevant for the understanding of the seismotectonics of SW Iberia (identification of the tectonic domains of the Cadiz gulf, two-state mechanism of serpentinite as an explanation for upper mantle seismogenesis, etc) where already published by the authors elsewhere, leaving as the original contribution of the manuscript the refinement of the tsunami modeling. Given that "research papers published by [COMMSENV] represent significant advances that bring new insight", I feared that this original contribution would not be sufficient. The revised manuscript does not show a significant change in this respect. The model improves the fit to run-up heights but fails to improve significantly the arrival time reports, and it generally gives the impression that the uncertainty propagating from the input data to the models precludes a fine discrimination between contending results.
Some changes introduced in the revised manuscript raise additional concerns. The authors say that the study area is located in a diffuse plate boundary (line 29) but go on to say that the HAT is located in an intraplate setting (line 59). Later they say that the 1755 earthquake shows that "great destructive tsunamigenic earthquakes can also occur in intraplate settings" (line 266). It does not seem adequate to me to describe this tectonic setting as intraplate, since there is oblique converge of two major tectonic plates. The pairing of the 1755 earthquake (thrusting on a convergent plate margin) with the Wharton Bay earthquakes of 2012 (strike slip on intraplate faults) to argue the global relevance of the results seems forced to me. The statement that "the occurrence of great earthquakes in intraplate settings and the possible associated tsunami should be considered in geohazard assessments worldwide" is too vague to be useful, in my view. Especially because the study area is not an intraplate setting. The manuscript documents a mechanism to account for upper mantle seismicity, and such result may be relevant to model seismic rupture more adequately where the required conditions of extensive serpentinization are identified, but the blanket conclusion doesn't seem warranted. Hazard assessment is based on earthquake catalogs, and intraplate

earthquakes are not ignored where past seismicity shows them. Concerning the study area, the SHARE hazard model, for example, adopts Mmax values of 8.5 to 8.8, which cover these large earthquakes.

Lisbon, May 25, 2021
Joao Fonseca

REVIEW of manuscript COMMSENV-21-0159-T

Comments on the rebuttal

By J. Fonseca

Review 1: My view is that the interpretation sails too close to orthodox thinking, and some interesting clues are missed…

Rebuttal: We disagree with the reviewer's repeated suggestion to consider the GCF as the source of the Lisbon earthquake. In the previous works of Gutscher et al. (2006) and Barkan et al. (2009) it is shown that this structure is not capable of generating an earthquake and subsequent tsunami like the one that destroyed Lisbon in 1755. Additionally, there is compelling evidence mainly from seismic reflection data that the accretionary wedge is inactive and sealed by a thick layer of undeformed sediments.

Comment: at no point in the review was it suggested that the GCF is a credible source for the 1755 earthquake (a view that I do not subscribe, see for instance Fonseca, 2005). In fact, the epicentral location proposed in the manuscript (Horseshoe Abyssal Thrust, HAT) seems to me the most credible in the face of the available evidence, so this is a moot point. What was mentioned in the review was the possibility that the accrecionary wedge might be deformed in response to a nearby strong earthquake “as a partial rupture branching from the HAT, or just a catastrophic landslide”. Negative evidence of the type mentioned by the authors is not compelling, in my view: for example, Crutchley et al. (2011) describe gravitational deformation of this sedimentary body.

Review 1: For example, the authors open by stating that the 1755 earthquake has magnitude Mw ~8.5 (line 12). This is understandable because such a figure is widely cited in the literature, but the reference given for this value ((Johnston, 1996) is 25 years old, and doesn’t benefit from robust techniques for estimating the magnitude of historical earthquakes that in the meantime have become standard (e.g. Bakun and Wentworth, 1997).

Rebuttal: There are several works that propose different Mw through different approaches. For instance, Martínez-Solares and Arroyo (2004) proposed a Mw = 8.5 ± 0.3; Baptista et al. (1998b) a Mw = 8.5; Johnston (1996) a Mw= 8.7 ± 0.39; Martins and Mendes Victor (1990) a Mw = 8.5; Abe

(1979) a Mw = 8.5; Lopez-Arroyo and Udias (1972) a Mw = 8.9, and other authors in older papers arrive at estimates that vary from 8.3 to 9.0 (Martínez-Solares, 2001).

Comment: In my view the authors failed to rebut the criticism, instead they reinforce it. Martinez-Solares and Arroyo (2004) repeat the steps of Johnston (1996) with the same method, just enlarging the database. Baptista et al. (1998b) do not perform any estimate, they just cite Martins and Mendes-Victor (1990). Martins and Mendes-Victor (1990) do not include any estimate, they just cite an unspecified catalog of Iberian isoseismals as source. Lopez-Arroyo and Udias (1972) do not perform any estimate of the magnitude, mentioning only that "estimates of [the] magnitude were as high as 8.9" (this was indeed common in the early days). Martinez-Solares (2001) give the same estimate that was later published in Martinez-Solares and Arroyo (2004), using the method of Johnston (1996). With the exception of Fonseca (2000), I am not aware of any estimates of the magnitude of the 1755 earthquake with methods developed after Johnston (1996).

Abe (1979) estimate a tsunami magnitude Mt=8.6, stating that "if we tentatively adopt Mt=8.6, the [1755] Lisbon earthquake is 15 times larger, in both the seismic moment and the energy released, than the 1969 Portugal earthquake (…). The present result is admittedly subject to large uncertainty". In particular, the concept of tsunami earthquake would challenge this estimate. In fact, Abe (1989) proposes that discrepancies between M_t and M_w can be used to identify tsunami earthquakes.

Review 1: I am not aware of any attempt to model the effect of the deformation of this sedimentary body (maybe as a partial rupture branching from the HAT, or just a catastrophic landslide?), configuring a tsunami earthquake, i.e., an earthquake with much larger tsunami magnitude than moment magnitude.

Rebuttal: (…) there is also clear evidence from seismic reflection data that the Gulf of Cadiz Imbricated Wedge (GCIW) is sealed by a 300-400 m-thick undeformed sedimentary cover, ruling out any recent activity. The typical deformation associated with active accretionary prisms, as those described in many subduction zones, is absent here. This is clearly visible in the seismic profile (Figure 5) published

by Martínez-Loriente et al. (2018) and in the works of Iribarren et al. (2007) and Zitellini et al. (2009). Additionally, there is no megathrust-type activity that could be attributed to active subduction there.
(…)
Regarding a possible catastrophic landslide suggested by the reviewer, if it had occurred, there would be a sedimentary record of it. However, offshore core sampling performed in the area show no evidence of a major catastrophic event such as that proposed related to the Lisbon earthquake, but just a turbidite with a modest volume (1.3 km3), which is very unlikely to have contributed significantly to the tsunami (Gràcia et al., 2010).

Comment: Gracia et al. (2010) sampled a different zone, ~100 km further to the west, and their results should not, in my view, be used as negative evidence of a catastrophic landslide in the Gulf of Cadiz Imbricated Wedge (GCIW). The cited papers converge in that the GCIW is not cut by active faults. I have no problem with the conclusion that "the typical deformation associated with active accretionary prisms, as those described in many subduction zones, is absent here". The absence of an active subduction zone is also a moot point. The possibility that I raised in the review is different: it concerns the gravitational deformation that strong shaking (caused by the rupture of the HAT source proposed in the manuscript) might induce in this sedimentary body. On a seismically chaotic body like this (Iribarren et al. (2007) such deformation may be difficult to identify in seismic reflection profiles.

Comments to the revision (COMMSENV-21-0159A)

Received 8th June 2021 and sent 21th June 2021

Reviewer #3 (Remarks to the Author):

1) To the question "where your concerns addressed by the authors?" the only honest answer I can give is "no".

In the first review of the manuscript, we addressed the reviewer's concern about the scarce bibliography that supported the assertion that the Lisbon earthquake reached a Mw $\geq$ 8.5. We added a total of 6 references to support this statement.

In addition, we followed the reviewer's suggestion and reviewed the historical reports looking for objective, well-grounded evidence of the actual consequences of the 1755 earthquake and tsunami. We rewrote the related section of the manuscript trying not to overstating the effects of the event. The numbers we give represent in fact a lower bound of the actual impact.

We did not follow the rest of his suggestions because, as we argue in detail in our response, we do not agree with them.

2) The main criticism in my review concerned the unquestioned adoption of previous magnitude estimates for the 1755 earthquake. The authors are not seismologists and it is only normal that they rely on the literature, but for such a key parameter I felt that it was incumbent upon the authors to demonstrate the robustness of the adopted value, otherwise they might build a big edifice on weak foundations. In the revised manuscript, the authors cite a list of publications with magnitude estimates on which they base their choice, but at close inspection those sources are at best reworkings of the estimate of Johnston (1996), and some are not even estimates (they just cite one another until the trail is lost). This critical stance on the commonly accepted magnitude of the 1755 earthquake is admittedly a minority view (although a published one, see Fonseca, 2000), and it would not be fair to penalize the authors for staying with the mainstream. Still, I believe that a more critical attitude would be adequate.

We continue to disagree with the reviewer. In our opinion, there is a large body of evidence, particularly the effects of the earthquake at very long distances (notable trans-Atlantic tsunami, significant shaking perceived in Central and Northern Europe, etc), pointing towards a very large released energy, comparable to recent M8.5+ events. However, following the Editor's suggestion, in the new version of the manuscript we incorporate the following clarification in the "Introduction section":

"Given such evidence, the scientific community widely supports an estimated Mw≥ 8.5 for the Lisbon earthquake, although recent work has also suggested a lower magnitude (Fonseca et al., 2020)".

3) In the review, I argued that "the tsunami earthquake hypothesis warrants investigation, if nothing else to dismiss it as a possible explanation". The authors go a great length to rebut "the reviewer's repeated suggestion" that the Gulf of Cadiz Fault may have caused the earthquake, but this suggestion was not made in my review (actually, I do not subscribe to that view). What was raised was the possibility that deformation of the accrecionary prism induced by the proposed rupture in the HAT might have played a role in tsunami generation. This was rebutted on the grounds of negative evidence that I found insufficient, and some of it from a location ~100 km further west.

We provide two main arguments based on observational evidence to rule out this hypothesis:

a) The Gulf of Cadiz Imbricated Wedge (GCIW) is sealed by a 300-400 m-thick undeformed sedimentary cover, ruling out any recent activity (eg., Iribarren et al., 2007, Zitellini et al., 2009; Martínez-Loriente et al., 2018).

b) If a catastrophic landslide has occurred as suggested by the reviewer, there would be a sedimentary record of it. However, offshore core sampling performed in the area show no evidence of a major catastrophic event such as that proposed related to the Lisbon earthquake, but just a turbidite with a modest volume (1.3 km^3), which is very unlikely to have contributed significantly to the tsunami (Gràcia et al., 2010).

In our opinion, these arguments are sufficient and conclusive to rule out the hypothesis suggested by the reviewer.

4) I pointed out in my review that several aspects of the manuscript which are very relevant for the understanding of the seismotectonics of SW Iberia (identification of the tectonic domains of the Cadiz gulf, two-state mechanism of serpentinite as an explanation for upper mantle seismogenesis, etc) where already published by the authors elsewhere, leaving as the original contribution of the manuscript the refinement of the tsunami modeling. Given that "research papers published by [COMMSENV] represent significant advances that bring new insight", I feared that this original

contribution would not be sufficient. The revised manuscript does not show a significant change in this respect. The model improves the fit to run-up heights but fails to improve significantly the arrival time reports, and it generally gives the impression that the uncertainty propagating from the input data to the models precludes a fine discrimination between contending results.

We disagree with the reviewer about the lack of originality of this work. As we explained in the first review, we have come a long way and it has been necessary to piece together many isolated bits of information along with key new observations and models to support the hypothesis proposed in this work. In our opinion, this work is not only relevant at regional level, but also on a global scale, since we propose a plausible mechanism that explains the occurrence of a great and destructive earthquake caused by a modest-length fault outside an active subduction zone.

Some changes introduced in the revised manuscript raise additional concerns. The authors say that the study area is located in a diffuse plate boundary (line 29) but go on to say that the HAT is located in an intraplate setting (line 59). Later they say that the 1755 earthquake shows that "great destructive tsunamigenic earthquakes can also occur in intraplate settings" (line 266). It does not seem adequate to me to describe this tectonic setting as intraplate, since there is oblique converge of two major tectonic plates. The pairing of the 1755 earthquake (thrusting on a convergent plate margin) with the Wharton Bay earthquakes of 2012 (strike slip on intraplate faults) to argue the global relevance of the results seems forced to me. The statement that "the occurrence of great earthquakes in intraplate settings and the possible associated tsunami should be considered in geohazard assessments worldwide" is too vague to be useful, in my view. Especially because the study area is not an intraplate setting. The manuscript documents a mechanism to account for upper mantle seismicity, and such result may be relevant to model seismic rupture more adequately where the required conditions of extensive serpentinization are identified, but the blanket conclusion doesn't seem warranted. Hazard assessment is based on earthquake catalogs, and intraplate earthquakes are not ignored where past seismicity shows them. Concerning the study area, the SHARE hazard model, for example, adopts Mmax values of 8.5 to 8.8, which cover these large earthquakes.

We think that there has been a misunderstanding due to the terminology used, as the reviewer is not a tectonic expert but a seismologist.

In tectonics, a plate boundary *sensu stricto* is defined by a fault that accommodates ~90% of the deformation between plates as occurs in well-developed subduction zones or oceanic ridges. The seismicity associated with this type of limit is called "inter-plate seismicity". The seismicity occurring out of this setting, is called “intra-plate seismicity”.

The plate boundary off SW Iberia is a young embryonic boundary that began to form few million years ago. Zitellini et al. (2009) showed that here the plate boundary is diffuse and deformation is accommodated along a 600 km-long deformation band by a series of thrust and strike-slip faults. This regional tectonic configuration is widely accepted by the scientific community and explains why we refer to the seismicity associated with the HAT as intraplate seismicity.

However, we understand that other readers may be as confused as the reviewer. Therefore, we have modified the sentences indicated by the reviewer as follows:

(old line 29): “The plate boundary is diffuse[2] and deformation is accommodated along a 600 km-long deformation band[2] by a series of thrust and strike-slip faults[3,4]”

(old line 59): “These data also allowed identifying the presence of the Horseshoe Abyssal plain Thrust (HAT), a deep thrust-fault located in the Horseshoe Abyssal Plain (HAP), away from any well-established subduction zone”.

(old line 266): “Globally, the MW8.5+ Lisbon earthquake is a “case study” evidencing that great destructive tsunamigenic earthquakes can also occur in intraplate settings (i.e., away from a well-defined plate boundary), challenging the widely extended idea in the scientific community that these events are restricted to subduction zones”

Finally, the paring of the 1755 earthquake with the 2012 Wharton Bay earthquakes, is not only convenient as a recent example of a great earthquake in outside a subduction zone, but it is also an excellent example of a Mw 8.5 earthquake caused by a modest-length fault due to the very large slip in high-rigidity upper mantle rocks, which is the mechanism that we propose for the Lisbon earthquake. Reviewer 2, who suggested us a comparison with other case histories to generalize the presented findings, agrees with the proposed example.

Lisbon, May 25, 2021

Joao Fonseca

ATTACHED FILE; Reviewer 3:

1) Regarding the suggested active deformation associated with the GCIW the reviewer argues that “Negative evidence of the type mentioned by the authors is not compelling, in my view: for example, Crutchley et al. (2011) describe gravitational deformation of this sedimentary body.”

The deformation described by Crutchley et al. (2011) is restricted to a pull-a-part basin associated with a strike-slip fault, not related with the mechanism proposed by the reviewer "the accretionary wedge might be deformed in response to a nearby strong earthquake “as a partial rupture branching from the HAT, or just a catastrophic landslide”.

2) Discrepancies on the magnitude of the 1755 earthquake

As we explained before, we have added the reference to the reviewer work that suggests a lower magnitude event (Fonseca 2020)

3) Regarding the possible catastrophic landslide associated with the 1755 earthquake, the reviewer state “Gracia et al. (2010) sampled a different zone, ~100 km further to the west, and their results should not, in my view, be used as negative evidence of a catastrophic landslide in the Gulf of Cadiz Imbricated Wedge (GCIW).”

Gràcia et al carried out a regional study based on turbidite paleoseimology. To conduct this study, they analysed various core samples, including two in the Horseshoe Abyssal Plain, literally over the HAT (not 100 km further west). In this work, they also related a turbidite with a modest volume (1.3 km^3) with the 1755 event, which is very unlikely to have contributed significantly to the tsunami, and there is no evidence of a catastrophic landslide as suggested by the reviewer.