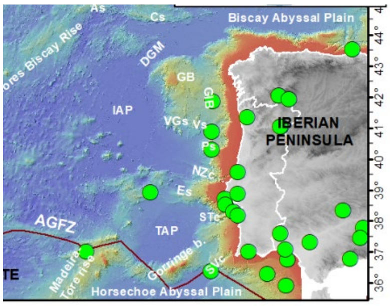
Answer to RV1:

COMMENTS BY MARTINEZ-LORIENTE	ANSWER, CHANGES IN MANUSCRIPT BY FERNANDEZ-VIEJO ET AL
L45-47: If the "W-E thrusts" refers to the Gorringe Bank, change it to "NE-SW thrusts"	We agree. Corrected.
L59: The Africa-Europe plate boundary continues east of the Strait of Gibraltar. I suggest to rephrase the expression	We have revised the sentence to highlight the diverse characteristics along the entire plate boundary. It is important to note that the boundary extends east of Gibraltar, signifying its complex nature throughout.
L62: Add space "theWIM"	Ok. Corrected.
L62: what is the "WIM abyssal plain"? If it exists, locate it in figure 1.	It refers to the oceanic seafloor of the margin, where anomalies are used for kinematic reconstructions. We have rephrased and put the Iberian Abyssal plain as the name to refer to this extended area
L63: Add "." after ")"	Ok. Corrected.
L70: Ramos et al., 2016 focused on the Algarve basin, southern Portugal… nothing related to structural domains along the WIM.	We agree, it was a mistake. Corrected.
L78-80: Sallarès et al., 2013 and Martínez-loriente et al., 2014 presented geophysical evidence suggesting that the Gorringe Bank and the neighbouring abyssal plains are composed mainly of exhumed mantle rocks and presented a new model for the opening of the North Atlantic. I suggest including these references.	We have avoided to explain in the introduction the southernmost area of the Iberian margin, due to the fact that its seismicity cannot be considered intraplate, but related to the plate boundary. Therefore, we do not include most of the works from this area. In any case, those references have been used later when appropriate in the discussion
L87-114: I highly recommend adding a map with the domains referenced in this section, and the delimitation of the different segments of the WIM. It is very difficult to follow the (messy) description of the authors. Therefore, I also suggest rewriting the section	Yes, we have rewritten the section that was exposed in an unclear way. We have also corrected the corresponding figures and references.
L90-92 & Fig 2: "The OCT extends between 12º10'W and 12º30'W in the IAP (Whitsmarsh et al., 1990) and it would extend Nº10 for 130 km until Extremadura Spur (…)" It is very difficult to correctly locate the COT with the map coordinates. I highly recommend adding more subdivisions between coordinates. How can readers locate longitude 12º10'W if all the information they have is the location of longitudes 12ºW and 16ºW?	We agree, we have modified the coordinate axes of the figures, which now have intervals every 0.5 degrees.
L91: 10ºN, Sure?	It is indeed a mistake. It should read N70ºE.
L94: "The exhumed mantle domain has been drilled at a serpentinite ridge (Boillot et al.,	The location of the OPD drilling is now included in Figure 2 and figure description.

1988b)" Where?	
L95-98. Add reference.	Done, it is from Amigo-Marx, 2022
L100: DGM? It is not located on the map and the abbreviation is not described	We have added the location and name of this area (from Granado et al., 2021)
L102: "The GB is 15-20 km thick"... and? Made of?...	Certainly. Apologies for the inadvertent deletion in the previous sentence. The revised version has been corrected to address the issue.
L107: What is "THD" y "dZ"? where are these maps?	THD = Total horizontal Derivative; dZ = Vertical derivative; In both cases referring to maps obtained by Granado et al, 2021. This has been better phrased in the new version as it was misleading and those maps are not shown in this manuscript but only referred to. Corrected
L111-114: Let's see, if the WIM is divided into 3 segments, and the authors say that there is a segment further south than what they call "South WIM", wouldn't it be more logical to call it Central WIM or something similar?	Yes, it makes more sense to rename the segments in this way. We have done it now in the manuscript, taking the whole margin as divided in three distinct segments. This study only deals with the North and Central segments as the seismicity in the third southernmost segment is too close to the plate boundary to be considered intraplate
L116-120: when? it should be specified to which period the authors refer	A sentence has been added to specify the period where Iberia functioned as an independent plate according to some authors.
L135-136: when? At present? At the beginning? Has it been constant over time?	Well, the authors refer those numbers "since the Miocene", which implies up to now but they do not say if it has been constant or not over time, which is also quite difficult to prove with that methodology only.
L138-142: I suggest the authors include some arrows in figure 1 that indicate the kinematics along the plate boundary.	Done
L142: Again, Ramos et al. only investigate a small portion of the SW Iberian Margin, the Algarve basin south of Portugal. There are many other works that propose the reactivation of thrusts throughout SW Iberia at a regional level, such as Martinez-Loriente et al. 2013 (but there are many others). Ramos's work is very local and their conclusions quite debatable.	We have added a cite for this sentence.
L144: The Gloria Fault is the source of one of the largest earthquakes occurred in the North Atlantic, 1941 Mw 8.3-8.4 (e.g., Baptista et al., 2016)	Yes, this paragraph was incomplete. We have made the necessary revisions by rephrasing it and incorporating additional references to ensure its accuracy and comprehensiveness.
L146-152: In this section the authors mix nanostrain/yr and mm/yr... for non-experts, it is difficult to compare the different geodetic velocities.	We have added the nomenclature of nanostrain in mm/yr in parenthesis for clarity (1 mm/yr/1000 km → 1 nanostrain/yr) By definition, strain is a relative change in distance, divided by the distance over which the change occurs, for example, 1 mm change in 1 km long line corresponds to a strain change of 1 part in 10^6 or 1 microstrain. It relates to a different concept than a simple displacement of 1mm/yr, which means a velocity

	(distance over time). Therefore, it is not mixing, just giving the units that were used in the references and their significance.
L179: Why have you included historical seismicity but not the instrumental seismicity available prior to 2003? What's the point of including the first and ignoring the second? I would like to know what these 10 historical earthquakes are, and if there is any relevant aspect, that it be recorded in the figures, text, in a table (somehow).	The fact of taking data from 2003 is not arbitrary. Between 2001 and 2003 the IGN network changed and data became more reliable, according to an increased number of stations and also to the fact that stations passed to have three components instead just one. Chasing a higher quality of the data was the main purpose of this decision. On historical earthquakes, they really do not contribute to the results of this study apart from the fact that they do exist in the area. They could be introduced in the figures if reviewer think is a significant aid, but we honestly have the idea that they will only increase the density of the images and not contribute to clarity or evidences. They are the green dots portrayed below 
L182: "The 9 focal mechanisms considered in this work have been obtained from the CMT Catalogue". Figure 2 includes 14 focal mechanisms (not 9 as mentioned by the authors)	Yes, we gathered 14, but only 9 of them are in the marine area. We have rephrased that to make it clear.…
L185: "(ii) geological structures mapped in the continental platform (Somoza et al., 2021)". Why only those included in the continental shelf?	The sentence was misleading, because we have included other structures interpreted in the non-continental area of the margin. We rephrased.
L195: "Further up towards the MAR, there is some isolated events.". Could this lack of seismicity be associated with the distance to the onshore stations?	This issue does not stem from a problem with the level of detection or sensitivity. Instead, it is characterized by a gradual decrease in detection as distance increases. Notably, events are detected towards the south, even when they occur at the same or greater distance from the monitoring stations. Additionally, the stations successfully capture seismic activity from the abundant mid-oceanic ridge, which is further away from the study area. Hence, based on these observations, the answer is no
L196: "The orientation of these bands is about N80ºW". In my opinion, the southern alignment has a clear E-W orientation and it is related to the Estremadura Spur and the Tore Seamount (it is not located on figure 1).	The determination of the overall orientation relies on the solutions derived from the density map. While it is indeed noted in the subsequent text that events in the proximal margin adhere to the Spur, the width of this cluster raises doubts regarding the direction of the band's lineation. In any case, this deviation is only 10 º from the E-W direction that the reviewer perceives. We have now included the Tore seamount in Figure 1.

L202: “This density band of events is oriented N75ºW from the coast until 17.5ºW”. I disagree with the interpretation of this alignment. There is an E-W alignment from the coast until 12ºN related to the Galicia Bank and a second cluster of seismicity to the northwest related to another ridge/ relief (without name in Figure 1). Between both clusters of seismicity there is a gap of more than 100 km without seismicity, so there is no evidence to indicate a relationship between them.	Yes, we do acknowledge the paragraph in the discussion section that highlights this fact. However, as mentioned earlier, when constructing the density map, the overall trend of both separate clusters is considered, which guides the determination of these directions based on specific criteria. While it is possible to subdivide the clusters into slightly different trends, the global perspective provided by the density map solution aims to fit all the events into the most reliable and cohesive solution as a whole. The gap of seismicity in the northern lineation is evident, while still the density map shows both clusters follow the direction explained in the text Additionally, we have taken your suggestion into account and have included the Coruña Seamount in Figure 1.
L211: “The number of events is larger at the transition between hyperextended crust and exhumed mantle” As it is not indicated in figure 3, I do not know what the authors consider to be the hyperextended crust and the exhumed mantle domains. According to my consideration (which coincides with that of Granados et al., where the profiles come from), there is exactly 1 earthquake in this segment (Profile 1). Therefore, I think the authors' statement is wrong.	The location of that unique earthquake is in the transition between exhumed mantle and oceanic domains. We corrected the statement. The majority of the events in this cluster are situated below the necking and the hyperthinned domains (brown in the figure) towards the exhumed mantle (green) domain. According to the domain map we can say that the number of events is larger at the transition between the necking and the hyperthinned domains.
L211: “There is an arguably but noticeable 50 km wide gap in event distribution west of the Galicia Bank”. Why this gap is “arguably”? In 150 km there are exactly 2 earthquakes.	Yes, we have rephrased according to your feedback. It is evident.
L2014-2015: “especially within the transition between the hyperextended and exhumed mantle domains”. Same as in the comment of Line 211.	Refer to the answer of previous comment. Figures have been modified to include the limits of passive margin domains and a legend with colours to differentiate them.
L215-216: “A particular set of south-dipping earthquakes can be observed in profile 5”. This is highly debatable. The seismicity could be vertically aligned, or even dip to the southwest but with a lower dip than that interpreted in figure 3 by the authors.	We appreciate your observation. Upon reviewing profile 5a, specifically the first panel below the Galicia margin, it appears evident that the events deepen towards the south, forming an inclined wedge. The base of this wedge has a lesser dip than initially indicated, as you pointed out correctly. In contrast, the second panel below the Extremadura spur does indeed exhibit vertical alignments. We acknowledge that this distinction may not have been clear initially, and therefore, we have taken steps to address this concern. We have rephrased the relevant text and included profile 5a and profile 5b in both the figures and the accompanying text to provide further clarification.
L218: “Some of the focal mechanism in this area…”. There is a lot of distance between the few focal mechanisms shown in figure 2 and this seismicity. By the way, why are some focal mechanisms represented in red and others in blue? It is not indicated in the legend or in the figure caption	The red ones correspond to data from IGN, the blue ones to the ones obtained through CTM. Added the clarification in the figure
L219-221: As I mentioned before, I see this seismicity aligned E-W from the coast up to 14 or 15ºN (? = it is difficult for me to be precise with the low coordinate discretization of	The partitions of the axis of the figures have been incremented for better understanding. Again, N80W is 10 degrees shorter than E-W direction; we have chosen that number based on the density map solutions.

figure 2)	
228-230. In this case, I agree that there is an amount of seismicity in the transition between hyperextended crust and exhumed mantle, but I disagree with “a lack of them in the oceanic crust until the western termination…” the seismicity decreases, but there are 15 or 20 earthquakes.	We have rephrased, as “lack” implies too absolute and it is not true. Changed
L231: It would be interesting to know which segment of profile 5 of Figure 2 is represented in Figure 3, since it would allow to locate on the map these possible vertical seismicity alignments.	Yes, we have added the locations of both profile 5a and profile 5 b within the long line in a wider legend
L234-235: “… the highest magnitude earthquakes in this area occur in the subcrustal mantle and below two seamounts…” What??? In profile 4 the seismicity is projected (100 km). If we look at the map (figure 2), these 2 earthquakes that the authors refer to are located far from these two seamounts or volcanic edifices.	Yes, that is right. Maybe the projection of event gives a misleading picture. However, the location of the events and their magnitude suggest some relation to the volcanic nature of the topographic highs,
235-236: “The referred vertical alignment would be consistent with a volcanic origin for those particular events.” Are the authors referring to the vertical alignment mentioned in the previous paragraph (231-233)? If so, it is difficult for me to understand the relationship that the authors see between this seismicity of the Estremadura spurn that is seen in the southern part of profile 5 with these two earthquakes that are seen in profile 4 and that the authors say are related to two volcanic edifices (which actually aren't)?	We have reprased
L254-256: Geissler et al. 2010 already showed that in SW Iberia the majority of seismicity occurred between 40-60 km depth, and with strike-slip or inverse focal mechanism solutions. Bartolomé et al. (2012) associated the strike-slip seismicity with the Lineament North and Lineament South strike-slip faults. Martínez-Loriente et al. (2021) associated the deep inverse seismicity as well as the largest seismic events occurred in the region with the HAT.	We include the reference with the hypocentral depths of those events in the area adding to the text of this paragraph.
L256: “?” Delete it	Done
279: “Seismicity almost abruptly stops around the area of undisputed oceanic crust. Nonetheless, there is still a few events westward toward the MAR, and they follow the N80ºW direction too.”. In the north, the seismicity stops just before the COB (around 12ºW), more than 50 km before the oceanic crust. In the south, seismicity does not stop at any point and continues from one domain to another	In figure 4d according to the domain map seismicity occurs in the oceanic crust north and south. Undisputed oceanic crust is marked by anomaly M3 which according to most authors is a real oceanic magnetic anomaly, unlike anomaly J which is disputed. In any case, we have rephrased slightly the paragraph as in the vertical profiles, looks like a more abrupt change than in the map.

L290: in figure 2 it does not include the AGFZ, so I cannot get a visual idea of what the distance is between it and the southern alignment.	Right. We have make the reference to Figure 1 which includes the AGZF now.
L310: "GAP"? Describe the abbreviation	GAP in seismology is the maximum angle separating two adjacent seismic stations, both measured from the epicenter of an earthquake
L343-346: There are a lot of scientific publications showing strike-slip faults with MCS data. I can include 10 or 15 references only in the SW of Iberia. I know that the authors have access to seismic profiles acquired in the WIM. If they don't see the strike-slip faults, could it be that these structures don't really exist?	With that paragraph we only want to point out that a pure strike slip fault as with any vertical structure would be impossible to discern in near vertical incidence seismic profiles unless the blocks in contact show different types of basement or geological history, and even less in oceanic domains with only one type of rock. If they have a mixed component of transpression or transtension they may be identified in seismic lines, but again, if the sediments on top show any dislocations at the resolution level of the seismic wave. We are not aware or have seen in any of the profile such a structure in this margin. Therefore, although we do not have evidences, we cannot conclude that they do not exist. It is logical that the may be seen in SW Iberia close to the plate boundary where actual deformation is taking place quickly and constantly. Within the central and northern parts of the margin, it may be quite difficult to identify any structure if its activity is low or spaced in time. We are still in a passive quiet margin. Seismicity would be the first indication of activity and incipient formation of these structures. Therefore, what we meant in the text is that seismicity implies some strain and deformation is going on, so maybe some incipient strike slip structures are being formed, as focal mechanisms suggest that the release of stress is taking place along that type of discontinuities.
L408: "NE-SW thrust systems extending 300 km along the WIM accommodate the arc-orthogonal convergence (Gutscher et al., 2012)". What are these fault systems??? Specify them and add references. Gutscher et al., investigated the possible subduction under the Gibraltar Arc, nothing related to the WIM or any "thrust system" there.	We have rewritten and clarified this paragraphs
L409: "and younger thrust faults are nucleating along the west Portuguese passive margin or in the Tagus Abyssal plain". Which ones? Specify them and add references where the existence of these structures can be verified. The work of Duarte et al. (2013) does not count as a reference since they only presented a theory without a single real data to support it.	We have added the pertinent references
L416-428: I am surprised that the authors do not consider the Gorringe Bank and/or the HAT as possible structures hosting this possible subduction initiation. It would be much easier to explain (and in fact has already	We have added those references, but we do not deal with the southernmost part of the WIM. We wanted to focus on the NOT plate boundary seismicity and how these events can relate to the different theories in the literature. We do not postulate or support a subduction start here or there, we just

been proposed) than is suggested here.	want to express that the WIM seismicity within the central and northern parts of the margin does not support a subduction interface forming along the WIM north of the actual plate boundary.
Figure 2A - the legend does not fit the map - green and blue lines. - P-2 is missing (or I don't see it); P-3 is indicated 2 times; P-1 is wrongly indicated according to Fig 3 and the text… -. I highly recommend adding more subdivisions between coordinates. - I suggest to indicate in figure 2 the two segments of profile 5 shown in figure 3.	The mistakes have been corrected and subdivisions in geographical coordinates increased; also indicated the profiles 5a and 5b now
Figure 3 -Figure caption: It is not clear to which profile they refer in each case. This occurs for two reasons: 1) wrong nomenclature in Figure 2 (mentioned above); 2) mixes two nomenclatures "profile" and "a, b, c….", the latter not used in the figure 3. - Figure caption: "Profile 1) Depth profile of seismicity along alignment North (Galicia) b) Profile along alignment south c)". According to Figure 2, these profiles are located to the south of both alignments. - A complete legend is missing. For example, it is not indicated what the dark brown corresponds to, the two blues of the oceanic crust, the small red and purple dots. -I also recommend indicating the extension of each segment (hyperextended, exhumed mantle...) in each profile since much reference is made to it in the text. -Profile 4: there are 2 earthquakes in the water.	Mistakes have been corrected and improved following the reviewers notes. We have added the legend and extension of rift domains along the profiles -
L268 & Figure 4a: - If the Moho is the crust-mantle boundary and there is the ZECM (zone of Exhumed Continental Mantle) along the WIM, how can Figure 4 show the depth of the Moho in this zone if there is no Moho?	Well, the Moho is the discontinuity (at present time) that separates crust from lithospheric mantle. It does exist beneath all kind of domains and oceanic crust except beneath mid oceanic ridges where lithospheric mantle is being erupted at the surface. And it is defined by a change in seismic velocity, observed in refraction/wide angle reflection profiles, normally from values of 6.8-6.9 to 8.0-8.3 in continental crust, and values from 7.5-7.8 to over 8.0 in zones where peridotites or hydrated, exhumed mantle, serpentinites, are present. Although in the MCS data it is not observed a reflectivity that can be Moho, in all the refraction/WAR lines crossing the central and north Iberian margin, Moho has been interpreted based on PmP reflections, In some cases beneath the interpreted exhumed mantle Vp shows a high gradient to reach the velocities of mantle and Moho is not a first order discontinuity. (Afilhado et al 2008, Dean et al, 2000) If this is what the reviewer is referring too, this fact does not mean that Moho does not exist. Lithospheric mantle is interpreted

	generally when Vp reach 8.0km/s or higher. So, the map of crustal thickness reflect this velocity change, independently that the Moho appears as a first order discontinuity or as a change in velocity gradient .
Figure 5c: - By what name are the N-S thrusts represented in the central part of the WIM and in the SWIM known? and the long marine strike-slip fault at the latitude of Lisbon?	The image has been taken from a publication where those names are not present, it was just to illustrate the possible way to start a subduction along structures that may or may not be present.

Response to Reviewer 2

We appreciate the time and effort invested on reviewing the work and thank you for the suggestions, comments and the editing. We have now made the pertinent changes included in the revised version. Most of them were accepted, except from paragraphs were other changes were included following the suggestions and comments of a previous revision.

The question aside from the text that the reviewer posts is if there would be a “radial” rather than linear pattern in the seismicity that seems to coincide with the pattern of a magnetic anomaly in the area (fig 4c).

The answer is: possibly. Although at large distance the striped NW-SE pattern seems quite clear, it is also acknowledgeable that in closer inspection the striped trend gets diffuse, adding difficulty on the interpretation and grouping events in smaller clusters. The magnetic anomaly that the reviewer refers to, results of the structural disposition of the basement rocks, the variscan formations that can be seen on land. Our understanding is that probably the pattern of seismicity presents more complication than the simplistic NW-SE bands we talk about, something that it is intrinsic to the study of this type of moderate, low seismicity in intraplate “quiet” settings. Therefore, any minor structure slightly moving, added to the uncertainty location, will give events that may be clustered in specific smaller scale structural features such as the one the magnetic anomaly evidences.

Regarding the text edits and comments in the manuscript, we proceed to deal with all of them individually.

Line 152 comment on “the map shows in this area”. It is an unfortunate phrasing. We have changed the text to serve the meaning we wanted to give to this sentence.

Line 198 “however the separation in two bands is not that simple”. Well, this is a poorly expressed explanation. Please refer to the introduction of this document. We have rephrased.

Line 218 “inverse fault” changed to reverse fault.

Line 226 “which relates to an unknown error”. This refers to the fact that the depth location of seismicity has always a higher error than in the XY coordinates. This is due to the method for getting the events depth, which uses as input a preliminary velocity model. In turn, this velocity model and its variations affect very much the depth of solutions and the more geologically restricted the better. In this area, where there is an abundant set of deep seismic reflection and refraction data, the local velocity model is as good as it can be, but it also has its own depth-velocity errors.

Line 232 “wihin it”. To the north of it.

Line 235 “the referred vertical alignment would be consistent with a volcanic origin for those particular events”. The reviewer says (rightly) that there is not vertical alignment in this location. The reviewer number one also pointed out this contradiction. We have amended those paragraphs, but still noting that some vertical alignments may have to do with volcanism as the area shows an abundance of these edifices in close areas, preferring this interpretation to a structural cause, due to the mantle depth of most of the events.

Line 275 “main N-S disposition of the magnetic anomalies”. The reviewer points out the circular pattern in the magnetic anomaly, which seems to cluster also the events. And yes, the reviewer is right about that, we have partially answered or commented this fact at the beginning of the document and also in the text. The phrase refers more to the N-S alignment of the oceanic magnetic anomalies, which are parallel to the ridge. Of course, in the continental platform and margin, the complexity of the magnetic anomalies has to do with the continental basement. The seismicity seems to cluster around several structural features within the margin but we did not find a clear relation to known structures or outcropping features in the sea floor.

Line 299 “the text highlights the limitations of seismotectonic interpretations due to inconclusive mapping of structures in the sea floor of the WIM”. We have rewritten this paragraph and tried not to repeat the things, moving them to section 2.

Line 227 “may have been bouncing from its perpendicular to extension direction”. This means that the Iberian Peninsula, specifically its N-S Margin along Spain and Portugal, which now is parallel to the ridge, may have been oblique to the ridge extension direction in several periods while the Atlantic opening took place. This means the micro Iberian plate included some type of rotation adding complexity to the margin structure. The presence of the triple point to the north also supports the evidences of rotational movement of Iberia while extension along the ridge maintained its direction.

The revised manuscript with the changes is uploaded in the system for its reassessment.

Thank you, sincerely,

The Authors

Offshore seismicity clusters in the West Iberian Margin illustrated by two decades of events.

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Abstract. An analysis of two decades (2003-2022) of seismicity recorded by the Spanish and Portuguese seismic networks along the West Iberian passive margin has resulted in a better understanding of the distribution of moderate seismic activity in this intraplate submarine area. The study provides a precise trend of specific alignments inferred from the density maps of seismicity, giving an accurate depiction of event distribution along two wide stripes that extend for 700 km ~~long~~ through the ocean floor in a WNW-ESE direction. These bands are parallel to the Africa-Eurasia plate boundary but are distinctly separated from its related seismicity by approximately 300 km and 700 km, respectively. This is a sufficient distance to be considered as intraplate activity. When trying to relate this seismicity to structural and geophysical features, a conclusive picture doesn't emerge. The earthquakes occur indiscriminately across thinned continental, hyperextended, and exhumed mantle rift domains. They fade out in the proximity of undisputed oceanic crust, but some events extend beyond. The hypocentral depths signal a considerable amount of events nucleating in the upper mantle. The focal mechanisms, although scarce, are predominantly strike-slip. Considering these observations, hypothesis ranging from subduction initiation, development of strained corridors or local structures of the margin, ~~have been~~are discussed in order to explain this relatively anomalous seismicity. However, some of them ~~do not portray~~lack convincing arguments, while others are too ~~unspecific~~vague. None of them are flawless, suggesting that several factors may be at play. Despite being one of the most probed passive margins in the world, the present geodynamic~~al~~ status of the West Iberian Margin manifested in its modern seismicity remains unknown. Interpreting this data within a global tectonic plate framework, together with the potential addition of seafloor seismometers, may provide the key to understanding this activity along one of the most archetypical margins of the Atlantic Ocean.

1 Introduction

1.1 Physiographic aspects and brief geological history of the West Iberian Margin

The West Iberian Margin (WIM) is an 850 km long passive margin parallel to the N-S trending rectilinear coast of western Iberia that resulted from a tectonic evolution marked by a multiphase rifting history (Pinheiro et al., 1996; Péron-Pinvidic et al., 2007; Tucholke et al., 2007; Alves et al., 2009; Pereira et al., 2016; Granado et al., 2021). Currently, the dynamics of the margin are influenced by two significant plate limits. To the west lies the mid-Atlantic ridge (MAR) constructive plate boundary. Meanwhile, to the south, the margin is impacted by the complex NW Africa-SW Eurasia plate limit, known as the Azores-Gibraltar Fault Zone (AGFZ) (Fig. 1). To the north, the West Iberian Margin (WIM) adjoins the E-W trending southern Biscay passive margin, which ~~locates~~ is located to the south of the extinct Bay of Biscay ridge.

Along the WIM, the 30-85 km wide continental platform is noticeably intersected by deep E-W/NE-SW trending canyons, namely Nazaré (NZc), Setubal (STc), and San Vicente (SVc) (Fig. 1). Northwards of NZc, 200 km from the coast and separated from the platform by the Galicia Interior Sedimentary Basin (GIB), the Galicia Bank (GB) stands out, which is an elevated area with a relief of over 3,500 m, along with other minor topographic seamounts. Westwards of the GB, the Iberian Abyssal Plain (IAP) emerges as an expansive and flat ocean floor that reaches a depth of 5,300 m. As we move towards the MAR, the surface becomes considerably rough, indicative of oceanic crust. To the west of the IAP, the prominent Kings T~~h~~rough (KT) is a 450 km long and WNW-ESE trending scar in the oceanic floor (Fig. 1) (Srivastava and Roest, 1992), which consists of a central depression flanked by ridges. It is proposed that this feature formed from 56 to 25 Myr during ~~the~~ Mesozoic rifting along the crest of a hotspot, resulting in an aseismic ridge, which represented the plate boundary between Iberia and Eurasia. This boundary shifted and was active along the Bay of Biscay between 49-36 Myr, extending eastwards along the Pyrenees (Roest and Srivastava, 1991) and finally moved to its present location along the AGFZ at Chron 13 (Macchiavelli et al., 2017). Between NZc and STc, the Extremadura Spur (Es) separates the IAP from the Tagus Abyssal Plain (TAP), a 200 km wide flat area and situated at 5,000 m depth. The TAP is limited to the west by the Madeira Tore Rise and to the southeast by the Gorringe Bank, one of the principal seismogenic sources in the region. The presence of ~~these reliefs~~areas of relief has been associated with N-S normal faults and NE_SW~~W-E~~ thrusts (Boillot et al., 1988a, Pinheiro et al., 1996; ~~Alvarez~~Álvarez-~~Marron~~Marrón, et al., 1997, Vazquez et al., 2008; Duarte et al., 2013; Sallarès et al., 2013; Martinez-Loriente et al., 2013), which in turn can be related to ~~the~~ margin reactivation during the Mesozoic and the Paleogene (e.g., Jiménez-Munt y Negredo, 2013). Furthermore, the Extremadura Spur and related reliefs are connected to extensive Late Cretaceous alkaline magmatic occurrences (Pereira et al., 2016; Escada et al., 2022).

The mid-Atlantic ridge (MAR), a constructive plate boundary situated about 1,500 km west of the WIM, separates the North American plate from the Eurasian plate. With a slow-spreading rate, it accretes at a rate of 24-26 mm/y at 43ºN (Somoza et al., 2019). Unlike other areas of the North Atlantic, the MAR is remarkably devoid of significant transform faults, spanning over 1400 km without any such faults between 40.6ºN and 43.6ºN and between 43.6ºN and 47.6ºN, except for short ones with negligible displacement. This unique characteristic of the ridge in this section of the North Atlantic contrasts with its displacement by relevant transform faults both to the south and north of the WIM (fig.1).

The AGFZ plate boundary that limits the WIM southwards is structurally much more complex. The Southwest Iberian Margin (SWIM) faults (Zitellini et al., 2009; Martínez-Loriente et al., 2013) connects the Gloria Fault with the eastern part of the Africa-Europe plate boundary (Fig. 1). To the East of the Strait of Gibraltar, the plate boundary is defined by a right-lateral transpressive shear one (Morel and Meghaoui, 1996). And in a ~~The AGFZ is sometimes described as a diffuse convergent plate boundary to the East of Gibraltar due to the ample area of deformation. But a~~ recent seismic study ~~interprets~~ Gomez de la Peña et al., 2002 interpret long and active faults accommodating most of the deformation in the Western ~~Mediterranean (Gomez de la Peña et al., 2022)~~

~~The~~Mediterranean. The kinematic evolution of the Iberian margin during the Atlantic opening ~~along theWIM abyssal plain~~ is well determined by magnetic anomalies after the Cretaceous normal polarity superchron (Roest and Srivastava, 1991). However, the early rift to drift seafloor evolution from 200 Myr to 83 Myr, remains controversial, mainly due to the dual assignment of the J anomaly either to a real isochron (e.g., Barnett-Moore et al., 1996) or to a polygenic magmatic event right before oceanic inception (e.g., Nirrengarten et al., 2017).

1.2 Crustal structure and domains of the WIM

The WIM fits into the category of a non-volcanic passive margin with a narrow platform (Lymer and Reston, 2022). It developed conjugate to the Newfoundland margin during the Mesozoic rifting (Péron-Pinvidic and Manatschal, 2009). Its crustal structure, although debated in ~~minor aspects~~detail, is formed by a series of structural domains from East to West (e.g., Péron-Pinvidic and Manatschal, 2009; ~~Ramos et al., 2016;~~ Druet et al., 2019; Merino et al., 2021) and includes a Variscan basement (Schulmann et al., 2022). The segmentations observed within the WIM resulted from the northward migration of extension and successive late Jurassic to early Cretaceous extensional phases (e.g., Malod and Mauffret, 1990; Péron-Pinvidic et al., 2007; Tucholke et al., 2007; Merino et al., 2021).

Following the onset of breakup within the Pangea supercontinent 200 Myr ago, the pre-Jurassic template of the North Atlantic was subjected to three main phases of rifting that took place from Late Triassic to Early Jurassic, Late Jurassic to Early

Cretaceous, and during the Mid Cretaceous. The different rifting stages led to a system of tilted blocks limited by westward-dipping extensional detachment faults (Lymer and Reston, 2022), which show a N-S orientation in the North and variable trends in the South. At the end of rift-related deformation, during the Late Cretaceous, the WIM experienced continental break-up (Soares et al., 2012; Welford and King, 2021), leading to irregular regions of exhumed and serpentinized mantle (Afilhado et al., 2008; Merino et al., 2021; Grevemeyer et al., 2022). The onset of seafloor spreading occurred at least in two pulses, ~~a~~the first one at the end of the Jurassic between the Grand Banks and the TAP, and a second one during the early Cretaceous between the IAP and the Grand Banks, following the temporal northward opening of the Atlantic Ocean.

As a consequence of the later Alpine orogeny that formed the actual reliefs on land, there was an important compressive deformation, which produced the reactivation of some extensional faults as thrusts, or as transpressive strike slip faults (e.g., Pereira et al., 2011; Martínez-Loriente et al., 2013; Ramos et al., 2016; Terrinha et al., 2019). The Cenozoic deformation abruptly terminates against the Ocean-Continent transition (OCT).

Published works investigating the Mesozoic rift domains in the WIM distinguish two sectors. In the northern sector, the continental hyperextended crust stretches for more than 300 km and the exhumed mantle domain extends westwards of the GB (Druet et al., 2019). In the southern sector, contrastingly, the hyperextended crust extends for 200 km before reaching the same transition (Pedrera et al., 2017). The OCT extends between 12º10'W and 12º30'W in the IAP (Whitsmarsh et al., 1990) and it ~~would~~ is interpreted to extend Nº10 for 130 km until Extremadura Spur. According to Grevemeyer et al. (2022), the OCT ~~would~~ runs between 12.5ºW and 13ºW ~~and~~ in the TAP, while Merino et al. (2021) ~~locate~~locates the OCT between 13-13.5ºW.

Crustal thickness based on refraction profiles north of the Extremadura Spur, report thicknesses that shallow from almost 30 km close to the coast to 15 km in the ocean side with a quick thinning happening in 50 km extension (Dean et al, 2000). Based on seismic-derived gravity modelling, Amigo Marx et al. (2022), differentiate an 18 km thick proximal domain, a <18 km thick extended domain, and a < 7km thick hyperextended domain. The exhumed mantle domain has been drilled at a serpentinite ridge (Boillot et al., 1988b). Westwards of the Extremadura Spur, a thin lower crust has been interpreted beneath a dense upper crust. The thickness of the crust decreases quickly towards the West, while it does so gradually towards the North, creating two distinct domains. The first one is located near the continent and characterized by a thin and light crust, while the second one is further away and has a denser and thicker crust (Amigo-Marx et al., 2022).

Using seismic, wells and gravity data, Granado et al. (2021) modelled a more complex 3D crustal scale structure of the WIM~~.~~ with two necking domains along the GIB and the ~~DGM~~Deep Galicia basin in the west of the Galicia Bank, suggesting two rift directions. The GIB encompasses localized regions of significantly thinned crust that are segmented by NE-SW trending transfer zones and it has been interpreted as a failed rift (Murillas et al., 1990; King et al., 2020). The GB is a 15-20 km thick block of continental crust with relatively low thinning (Péron-Pinvidic and Manatschal, 2010; King et al., 2020). ~~The North has a narrower exhumed mantle domain than the southern WIM.~~ The outer necking zone merges southwards with the eastern one following a NW-SE orientation. ~~The southern sector has a narrow continental domain, with a broader exhumed mantle domain.~~

The limit between the North and ~~South~~ Central WIM~~,~~ follows the NW-SE orientation that is observed by Granado et al., 2021 in ~~the~~ their Bouguer gradient anomaly maps THD~~-~~ (total horizontal derivative) and dZ (vertical derivative). According to these authors, ~~Granado et al. (2021)~~ it relates to the Variscan fabric onshore, suggesting unrecognized transfer structures to explain the transition. A similar transfer zone SW of the GB was suggested earlier (Pinheiro et al., 1992; Whitsmarsh et al., 1993) based on the analysis of magnetic anomalies and named as the Figueira Fracture zone, which would represent an original fracture zone born at the time of initiation of seafloor spreading.

So, within the general ~~dichotomy North WIM-South WIM~~variations of the WIM, we can consider in our study area two of the three WIM segments from north to south: the Galicia margin that includes the GB and IAP, as the northern segment, and the ~~southern segment~~central segment, that includes the Extremadura Spur and the TAP. The seismicity related to the third and southernmost segment of the WIM, the so-called Southwest Iberian Margin is out of the scope of this study, as it is considered related to the AGFZ plate boundary (Buforn et al., 1988).

1.2 Stress state, ~~seismicity~~seismicity, and kinematics in the WIM

Seismicity is the expression of active stresses within plates, and these forces are intimately linked to kinematics. The so-called Iberian plate takes its name from periods where effectively, the Iberian Peninsula and part of its margins acted as an independent minor tectonic plate between the surrounding and larger European and African plates, for instance from Late Eocene (Chron 18,42 Ma) to early Miocene time (chron 6c, 24 ma)~~–~~ ~~(e.g., ~~(Roest and Srivastava, 1991). At earlier periods, Iberia was attached to Africa, having a plate boundary running in the northern part through the Bay of Biscay and the actual Pyrenees, and subsequently, moved in solidarity with Europe. The presence of thick post-orogenic and post-tectonic units offshore sealing the Biscay accretionary wedge (Álvarez-~~Marron~~Marrón et al., 1997; Fernández-Viejo et al., 2012) among other things confirm that Iberia is now part of the Eurasian plate without discussion. Nevertheless, Iberian kinematics have been for a long time a cause of study and controversy. The M sequence of magnetic anomalies along the Newfoundland margin and WIM forms one of the primary constraints for plate kinematic reconstructions characterising the motion of Iberia during the Mesozoic (Vissers and Mejer, 2012; Sibuet et al., 2004, Barnett-Moore et al., 2016 and references therein). However, the validity of these anomalies has been questioned (Bronner et al., 2011). The difficulty in distinguishing different crustal types only adds uncertainty (Granado et al., 2021, and references therein). The seafloor spreading history of the western and northern margins of Iberia has been described involving successive jumps of the plate boundary between Iberia, Europe, and Africa from north (Bay of Biscay axis, and KT) to south (AGFZ) (Roest and Srivastava, 1991; Macciavelli et al., 2017).

Complexity in kinematics is normally inversely proportional to the size of the plate. Therefore, numerous models of Iberia ~~whereabouts~~ kinematics have been published in the last decades, the most modern ones approaching the problem through deformable plate tectonic models (King and Welford, 2022). These have provided insight into the kinematic role of continental blocks and their interplay with large and micro-tectonic plates during the formation of the north Atlantic rifted margins (e.g., Nirrengarten et al., 2018; Peace et al., 2019; King and Welford, 2022).

Macchiavelli et al. (2017) indicates a spreading rate of 23 mm/yr north of 40ºW latitude and 20.5 mm year south of 38 ºW and 2 mm/yr of N-S convergence between Iberia and Africa since the Miocene. The earlier partitioning of convergence between north and south became totally accommodated by the southern boundary from early Miocene onwards. The total convergence oscillates between 3-6 mm/y (Fernandes et al., 2003; Nocquet, 2012; Serpelloni, et al., 2004). It is characterized around the Azores archipelago by an NNE-SW extension that passes to the East to a dextral strike-slip border along the Gloria fault. Along the Gulf of Cádiz, the boundary becomes ~~an~~ obliquely convergent~~ boundary,~~ N45ºW (Ribeiro et al., 1996; Stich et al., 2006; Pedrera et al., 2011) with a velocity of 4.5 mm/year (Nocquet and Calais, 2004; Stitch et al., 2006), that accommodates intense deformation along shear zones (Terrinha et al., 2009), and through the reactivation of thrusts in the SWIM (Martinez-Loriente et al., 2013; Ramos et al., 2016). A neotectonic model across the southern plate boundary indicates that friction coefficients between 0.06 and 0.1 are the best solutions and that the maximum slip rates predicted outside the ridge occur along the Gloria fault~~.,~~ Although~~–~~ the western segment of the Gloria fault ~~which~~ is almost devoid of seismicity (Jimenez-Munt and Negredo, 2003), which could indicate an expression of fault locking or slow creeping (Hensen et al, 2019), the central and eastern segments have a record of high magnitude earthquakes, the M8.4 event of 1941 or the M7.1 event in 1931.The deformation here is attributed to a wide zone area (Lay, 2019) or to the existence of hydrated mantle permitting water circulation along fractures down to 12 km below~~–~~ the sea floor (Batista et al. 2016, 2017)

Geodetic velocities (Garate et al., 2015, Palano et al., 2015) also reveal an important deformation in the southern sector of Iberia, while in the interior of the Iberian Peninsula the crustal deformation is locally accommodated, with rates of less than 15 nanostrain/yr (15 mm/yr/1000 km). The stations situated in central and northern Portugal are displaced to the north around 1 mm/yr (Palano et al., 2015). Along the NW margin, the geodetic~~al~~ data provide evidence of E-W contraction, with rates of

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55 nanostrain/yr (55 mm/yr/1000 km). In the WIM, there is movements to the NW reaching 3 mm/year. In the active stress map of the Iberia, the transition from a compressive to an extensi~~ve~~onal regime occurs ~~just~~ around the Lisboa-Nazaré latitude (Fig. 1). A peculiarity worthy of ~~to~~ note is the large amount of compression that ~~the map shows~~exists in this area and the radical change to extension north of this transition.

Within the global picture, the present-day NNW-SSE compressional stress, has been practically constant since the Miocene (Andeweg et al., 1999; de Vicente et al., 2008 and references therein), and oriented at high angles to both north and west coasts of Iberia, being subparallel to the tensile stresses induced by the lateral density variations along these Iberian margins (Andeweg et al., 1999).

These complex systems of forces and movements outlined above ~~is~~ are the engine producing ~~the~~ intraplate earthquakes in the WIM. Seismicity in the southernmost WIM is overwhelmingly clustered, as expected on both plate ~~boundarues~~boundaries, along the AGFZ, with significantly complex patterns, and along the MAR. However, within mainland Western Iberia and along adjacent offshore domains, away from both boundaries, seismicity has been repeatedly classified as diffuse. There is a general consensus ~~on noting~~ that the magnitude~~,~~ and the number of events are difficult to reconcile with a typical intraplate location (Custodio et al., 2015; Kruger et al., 2020; Veludo et al., 2017; Duarte et al., 2013; Ribeiro, 2002).

~~The seismicity at the WIM hasn't been directly approached in published studies, and the~~The absence of Ocean Bottom Seismometers within the central and northern WIM, except for some local studies in neighbouring areas, (Kruger et al., 2020) has discouraged an in depth ~~profound~~ study of~~n~~ their characteristics. In an extended study including mainland Portugal, Custodio et al. (2015) indicated that the marine earthquakes ~~do~~ collapse into well-defined clusters while cumulative seismic moment and epicentre density decrease from South to North. The analysis of some focal mechanisms ~~corroborates~~ confirms that Portugal is under horizontal pressure in the NNW-SSE direction, with a great proportion of strike-slip solution and some reverse oblique mechanisms onshore (Borges et al., 2001).

2 Gathering seismicity in the WIM

The data gathered for this study belong to the permanent seismic networks of Portugal and Spain. In the Portuguese network, operated by the Instituto Português do Mar e da Atmosfera (IPMA) there is a network of 50 land stations, 5 in the Madeira archipelago and another 35 in the Azores. The Spanish network, operated by the Instituto Geográfico Nacional de España (IGN), maintains 60 stations on land and 56 in the Canary Islands. We have retrieved data from the available catalogues since January 2003 until December 2022 in the area between 38ºN and 45ºN and 8ºW and 20º W, ~~o~~for earthquakes showing magnitudes > 2.5.

In total, 278 events were collected from the IPMA network and 649 from the IGN network. Integrating both catalogues, and selecting, in case of coincidence, those with the lesser error in location, we ~~elaborated~~ compiled a final working catalogue of 708 events. From these, we established several requisites of quality required to be included in this study (RMS < 1, Smax < 25, Smin < 25 and Err < 75), resulting in 606 events, 352 from the Spanish network and 254 from the Portuguese network. (Table 1).

Likewise, we have included the existing historical seismicity data in the IGN catalogues and ~~collected in~~included the work of Ferrao et al. (2016), which contains information on 10 historical events that occurred within the study area. The 9 focal mechanisms considered in this work from events occurring in the marine domain have been obtained from 14 focal mechanisms included in the CMT Catalogue (Dziewonski et al., 1981; Ekström et al., 2012) and from the IGN Seismic Moment Tensor Database (Rueda and Mezcua, 2005).

We should be aware of some of the data limitations and reliability. The seismotectonic interpretations in continental margins under the sea present an added difficulty due to the inconclusive mapping of structures in the sea floor. Despite being well probed, the WIM contains many highs, roughness, and bathymetric heterogeneities that make it difficult to map tectonic features, specifically faults that could act as seismogenic sources. The structural variability observed along the margin added uncertainty in the data processing when introducing velocity models in the location programs of the events. Additionally, crustal depths in the margin vary, but a considerable number of events show hypocentres below the interpreted Moho depth. The acquisition mode poses the second limitation as the land stations are located to the east, leading to a biased location error. This results in uncertainty in some locations and the lack of full azimuth to relocate with confidence. To minimize the impact of these shortcomings, only the events that comply with the requirements were considered reliable and retrieved:

a) Magnitude should be over > 2.5.

b) Events with location uncertainty of < 25 km in plant with average values < 10 km, and 75 km in depth. It is precisely this last parameter the one that poses the main problem, although the average error estimated has been of 4.9 km.

c) The average GAP (maximum angle separating two seismic stations, measured from the epicentre of an earthquake) < 183, for all the events used in this study being the ones with higher GAP discarded for this purpose.

The information collected was integrated through a geographic information system with (i) bathymetric information provided by the European Marine Observation and Data Network (EMODnet Bathymetry Consortium, 2020), (ii) geological structures mapped in the margin ~~continental platform~~ (Somoza et al., 2021), (iii) gravity and magnetic data (Granado et al., 2021, GeoMapAPP-Ryan et al., 2009), and (iv) data from crustal Moho Depth (Granado et al., 2021; Whitmarsh, 1990; GeoMapApp - Ryan et al., 2009). The ArcMap v.10.3.1 (ESRI) program was used.

3 Results, ~~clusters~~clusters, and trends

3.1 Distribution, ~~magnitudes~~magnitudes, and focal mechanisms of the events in the WIM

Figure 2 displays the concentration of activity over the last 20 years, which extends from the coast to 19~~8~~ºW. The figure shows the distribution of events collected and processed, represented on a marine bathymetric chart (Fig. 2a), along with a density map of events (Fig. 2b) that has been calculated.

According to those results, events are more abundant at the coast, blending in with the onshore, more dispersed seismicity. Going~~–~~ seawards, we start to recognise a subtle clustering, which seems to define two separated diffuse bands that extend up to 18ºW longitude and become narrower with distance. Further ~~up~~ towards the MAR, there ~~is~~ are some isolated events. The orientation of these bands is about N80ºW. Although these blurred alignments have been inferred before (Custodio et al., 2015) the discrimination of events made in this study ~~permits to get rid~~allows removal of badly located earthquakes that add to fuzziness ~~giving place to~~resulting in a sharper image of these two seismic alignments. However, the separation in two bands is not that simple. The density maps in figure 2b also show that the northern band is composed of two distinct clusters that while following the same rough NW-SE trend, they are separated for more than 100 km band space were seismicity is very scarce.

Figure 3 represents the depth distribution of events, superimposed ~~to~~ on crustal ~~domain~~ cross-sections representative of the latitudes of the alignments ~~(Granado et al., 2021)~~. The bands observed are named in this study as the Galicia ~~(N)~~ for the Northern segment of the WIM and the Lisbon ~~one~~band ~~(S)~~ for the Central segment of the WIM. Specifically, they can be described by particular characteristics:

a)~~.~~ **Events offshore Galicia, Northern WIM ~~(North)~~**. This density band of events is oriented N75ºW from the coast until 17.5ºW. It spreads over 670 km and ends in the proximity of the bottom topographic expression of the Azores-Biscay rise (Fig. 2a). It seems there is a clustered seismicity in two main spots along the band with a ~~middle~~ gap in the middle over 100 km extension.

Offshore in this sector during the studied period, we registered a total of 165 events over 2.5, (8 events/yr), and 21 over 4, (1/yr). Most of them are over 20 km depth, and progressively shallower to the west. The depths of events include mantle depths below the geophysical inferred Moho depth, which~~–~~ rises from 22 km ~~in~~at the coast up to 11 km oceanwards, at the end of the lineation. The β-value is 0.87.

In profile 1 (Fig.~~–~~ 3), which represents the crustal cross-section type for the Galicia Margin, there is an abundance of events in the thickest crustal areas, corresponding to the GB or to the proximal domain. The number of events is larger at the transition between ~~hyperextended crust and exhumed mantle~~the westernmost necking and hyperthinned domains interpreted by Granado et al. (2021). There is ~~an arguably but~~ noticeable ~~50 km wide~~ gap in event distribution west of the Galicia Bank, followed by a second cluster in the distal margin, which coincides with an area of topographic roughness in the ocean bottom.

The figures also show that there is a non-negligible percentage of events inside the uppermost mantle, especially within the transition between the ~~hyperextended~~ westernmost necking and ~~exhumed mantle~~hyperthinned domains. In a N-S crustal profile within the Galicia Bank cluster, a~~A~~ particular set of south-dipping earthquakes can be observed ~~in~~ (profile 5a~~, (~~Fig.~~–~~ 3). This is interpreted as the expression of the thrusts~~,~~ resulting from the limited Alpine convergence and incipient subduction in the Bay of Biscay the led to the partial closure of the Bay.~~ of Biscay~~ (~~Alvarez~~Álvarez-Marr~~o~~ón et al., 1997; Ayarza et al., 2004; Fernández-Viejo et al., 2012). Some of the focal mechanism in this area give a component of ~~in~~reverse fault, which would agree with this interpretation.

b) ~~.~~ **Events offshore Lisbon, Central WIM ~~(South)~~**. This second band runs ~~along~~ for 670 km between the coast of Portugal and 16.8ºW. We can ~~subdivide~~ define two ~~subclusters~~subtrends, the first one oriented N80ºW from the coast until 12.5ºW. 320 km away~~part~~, a small bend occurs ~~adopting a position~~to an orientation N75ºE along a further 160 km until 16.8W. ~~This band presents more events than the Galicia one~~In the Central WIM, seismicity is much more abundant that in the Northern WIM, although magnitudes are similar. In this sector, for the 20-year period analysed, we ~~got~~ recognised a total of 295 events with magnitude over 2.5, (15 events/yr.), 20 over 4-4.9, (1/yr.) and 3 over 5, (2 in the last decade). Most of them are concentrated in the first 30 km of depth, being progressively more superficial~~, as crust thickness diminishes oceanwards~~. The β-value is 0.96.

The focal mechanisms of the events further away than~~far away events than~~ 14ºW, present a significant component of strike slip. The depth ~~of the events, which relates to an unknown error~~solutions reveal earthquakes nucleating below~~, is more than~~ the Moho depth, which in this area decreases from 23 km in the coast to 12 km oceanwards, at the end of the lineation.

Again, in the depth distribution profiles (Fig. 3, profile 2) it seems that there ~~is~~are more events up to the transition between hyperextended crust and exhumed mantle and ~~a lack of them~~less number of events beneath the ~~in the~~ oceanic crust until the western termination of the profiles where there is an increase in the amount of seismicity and at greater depths, in the oceanic domain. This decrease cannot be considered such an evident gap as in the northern WIM at the same longitudes.

There is a puzzling vertical alignment (Fig. 3, profile 5b) below the Extremadura Spur, indicating some type of structure northwards and probably a second one ~~within~~ to the north of it. There may be a manifestation of a splay fault delimiting this topographic high. Both vertical alignments occur within the exhumed mantle section.

A detail worthy of ~~to~~ note is that the highest magnitude earthquakes in this area occur in the subcrustal mantle ~~and below two seamounts~~ (Fig. 3, profile 4). The northernmost event locates ~10 km westwards of a seamount~~-~~ that may be ~~correspond~~ related to volcanism, ~~to a volcanic edifices~~ as there ~~is~~are some volcanic edifices in the surface (Escada et al., 2022). ~~The referred vertical alignment would be consistent with a volcanic origin for those particular events.~~

Although the graphics show how the depth of the earthquakes is ~~accordingly~~ in general, diminishing towards the ocean along the whole WIM, there is a considerable amount of earthquakes nucleating in the uppermost mantle, and especially in the transition areas to exhumed mantle domain and towards the oceanic crust at the end of the alignments. This suggest that seismicity occurs in the whole margin ~~crust~~, down to lithospheric levels. Within the ~~Lisbon (S) alignment~~Central WIM, the hypocenters are slightly deeper than in the ~~Galicia (N) alignment~~Northern WIM clusters, even when crustal depths are similar in both areas. The dispersion of events is greater at around longitude 14ºW, maybe indicating the presence of some type of seismic boundary or discontinuity in the N-S direction that traverses the whole WIM. Profiles 3 and 4 in figure 3, show the

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distribution at depth within the oceanic domains of the margin revealing the separation of ~~the both~~both bands. ~~Also~~Also, they illustrate how hypocenters get shallower towards the west. In general, earthquakes along both alignments seem to cluster around marine reliefs, of either tectonic origin (GB~~alicia Bank~~) or with volcanic additions (ES~~xtremadura Spur~~).

Earthquakes located below the Moho may indicate a strong, seismogenic upper mantle that can sustain large stresses, later released during brittle rupture. This type of "ductile earthquakes" have been proposed for Wyoming lithospheric mantle (Prieto et al., 2017), or in Newport-Inglewood fault attributed to a system of seismic asperities in ductile fault zones. Once a ductile mylonitic structure has developed a shear zone, subsequent cataclastic deformation is consistently localized in a narrow zone (Takahashi et al., 2017). The role of temperature in the rheology of the oceanic lower crust and lithospheric mantle is not well understood. Earthquakes occur throughout the oceanic crust and upper mantle, the later with olivine-dominated rheology. The brittle ductile transition is associated with a threshold temperature of about 600ºC, which represents a transition from velocity weakening to velocity strengthening, consistent with the focal depth of earthquakes in the oceanic lithosphere elsewhere (Boettcher et al., 2007).

~~-~~In the area of study, but in the most southern segment of the WIM,

Geissler et al., (2012) provided evidence that most of the earthquakes within the Gulf of Cadiz have hypocentral depths between 40 and 55 km.. ~~In the SWIM,~~ And~~–~~ Grevemeyer et al. (2016) also in the SWIM, provide evidence for earthquakes rupturing at 30-50 km depth, hypothesizing that they are caused by the proximity to the AGFZ plate boundary and by an elastic behaviour at the continent-ocean transition zone, which is further supported by low heat flow and the amount of regional stresses caused by the Africa and Eurasia~~?~~ collision. Being and old passive margin, shortening and deformation of such a rigid lithosphere, may cause intense deformation at mantle depths. Mantle nucleation of events may additionally be encouraged by the presence of fluids or fluid migration in the mantle, either by reducing the effective normal stress or promoting strain localization along the shear zones. The velocity gradients observed on the edges of rift domains would make them preferred sites for reactivation due to inherited strength contrasts down to mantle depths.

Regarding t~~T~~he focal mechanisms in the study area, corresponding to events of magnitude 4.1 to 5.9 (Table 2), indicate mostly strike-slip movement.

3.2 WIM seismicity and geophysical data

The superposition of seismicity onto different types of geophysical data can be used to infer relationships that may give hints of~~to~~ the seismicity sources. In the absence of confidently mapped submarine faults in the area, figure 4 depicts the event distribution obtained in this study overlaid to a different set of geophysical data for assessment. In the first case, the events are overlaid onto the Moho depth map. As expected, depth of events follows crustal thickness decrease seawards. However, as many events seem to nucleate in the uppermost mantle, we must infer that the crust and the upper mantle in the WIM must be strong, and that neither the Moho discontinuity nor the transition upper-lower crust are the rheological fundamental boundaries concerning seismicity.

When the seismicity is overlaid on the calculated gravity (Fig.~~–~~ 4b), the main relation ~~arise~~arises from the fact that seismicity indeed does align where the basement is uplifted (i.e. Galicia Bank or Extremadura Spur), and therefore, follows the gravimetric expression of thickened crustal blocks, something that could be expected given that ~~gradients of velocity~~velocity gradients have a notable influence on crustal strength. Regarding the magnetic map (Fig.~~–~~ 4c), it is difficult to establish a relationship, ~~attending~~ due to the main N-S disposition of the oceanic magnetic anomalies. The complexity in the magnetic imprint of the~~e~~ continental margin reveals some relation of several events to particular magnetic structures. Finally, figure 4d shows the seismicity overlaid onto the WIM rift domains map, which shows that seismicity does not nucleate preferentially in any domain. Although events are somewhat more abundant in the proximal domain, they do appear on exhumed mantle and hyper-thinned crust, indicating that the weakness of the domains is adequate for producing earthquakes anywhere. Seismicity almost abruptly stops around the area of undisputed oceanic crust marked by anomaly M3 (figure 4c). Nonetheless, there is still a few events westward toward the MAR, and they follow the N80ºW direction too.

Moreover, it also shows that the ~~south alignment~~Central WIM seismicity happens south of the ~~boundary between Northern and southern WIM, if we consider this boundary the~~ location of the change in width of the exhumed domain, therefore ignoring rift domains transitions altogether.

4 Causes of the intraplate seismicity along the West Iberian margin

The concentration of seismicity at the northern and western coasts is explained in general terms as the internal deformation being the prime mode to accommodate strain induced by the convergence between Africa and Eurasia and the impossibility of propagating west of the ~~Iberian peninsula~~Iberian Peninsula due to the Atlantic ridge push.

Prior~~eviously~~ to discussing the possible sources of the WIM seismicity, a summary of the characteristics of the studied events that are reliable and therefore treated as strong constraints are:

a) Seismic events are concentrated along two distinct WNW-ESE trends parallel to the active AGFZ Eurasia-Africa plate boundary. The interval distance between bands is similar, around 300 km (Fig.~~–~~ ~~2~~1).

b) Magnitude is low to moderate, and hypocentral depths include the whole crust and upper mantle.

c) The bands do not follow inherited tectonic trends. The events cut different rift domains and are prone to cluster along transitional areas and topographic highs. There is not an evident link to ~~gravity or~~ magnetic anomalies.

d) They do show an association with topographical highs, especially with the western border of the Galicia Bank and the northern part of the Extremadura Spur.

e) The few focal mechanism available indicate overwhelmingly strike slip types.

~~A note on reliability of observations and data limitations~~

~~The text highlights the limitations of seismotectonic interpretations due to the inconclusive mapping of structures in the sea floor of the WIM. Despite being well probed, the margin contains many highs, roughness, and bathymetric heterogeneities that make it difficult to map tectonic features, specifically faults that could act as seismogenic sources. The structural variability observed along the margin added uncertainty in the data processing when introducing velocity models in the location programs of the events. Additionally, crustal depths in the margin vary, but a considerable number of events show hypocentres below the interpreted Moho depth.~~

~~The acquisition mode poses the second limitation as the land stations are located to the east, leading to a biased location error. This results in uncertainty in some locations and the lack of full azimuth to relocate with confidence. To minimize the impact of these shortcomings, only the events that comply with the requirements were considered reliable and retrieved:~~

~~a) Magnitude should be over > 2.5.~~

~~b) Events with location uncertainty of < 25 km in plant with average values < 10 km, and 75 km in depth. It is precisely this last parameter the one that poses the main problem, although the average error estimated has been of 4.9 km.~~

~~c) The average GAP < 183, for all the events used in this study being the ones with higher GAP discarded for this purpose.~~

Based on the aforementioned observations, we ~~may have a walk through~~review ~~the~~ various hypotheses that have been proposed to explain seismic activity in the WIM plus a few new ideas. We can evaluate the validity of these hypotheses against the data collected over the past two decades.

4.1 Intraplate seismicity generated by unmapped faults. Strike-slip corridors, shear zones, transform faults.

Some causes for local clusters of events within the WIM have been put forward in the literature: for instance, Vazquez et al. (2008) indicated that the GB resulted from the reactivation of two major faults, forming an ample shear zone. Borges et al. (2001) related the central WIM seismicity to strike-slip movements in certain structures. Recently, Somoza et al. (2021)

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~~indicated~~ speculates that to the north of Nazaré fault, seismicity responds to a reactivation and inversion of thrusts situated in the ocean seamount, that even connect to faults in the continent. The Nazaré fault would be ~~prolongated~~ extended ~~up~~ to the MAR, linking with the Kurchatov transform fault (Fig. 1). However, there is not enough data to support this interpretation.

In any case, local clusters do not explain the overall distribution in the WIM. We have observed also local clusters such as the southward directed cluster in the GB related to the arrested subduction in the Bay of Biscay (~~figure~~Fig. 3, profile 5a) or the vertical alignment ~~beneath some volcanic edifices~~ along the Extremadura Spur that may relate to either some magmatic activity or to an splay fault quasy vertical~~-~~ (Fig~~ure~~. 3, profile 5b).

For the bigger picture and an inclusive theory for the WIM seismicity, one of the recurring hypothesis indicated by some authors was the presence of shear corridors, (Custodio et al., 2015; Whitsmarsh et al., 1990) due to the particular stress state of the margin and the Iberian Peninsula.

Their oblivious indifference to structures of the crust or rheological boundaries of the rifted margin, all support the view that the events we are studying respond to the actual stress state, drawing the incipient silhouette of rectilinear lithospheric fractures or zones of strain parallel to the south and north of well-formed transform faults, one of them a plate boundary. These events may~~-~~ signal the formation of fracture zones that mimic oceanic transform faults. ~~Contrastingly~~In contrast ~~,~~ to the ones formed during the ocean opening, these ones are forming in the opposite direction, from land to sea. These faults may correspond to delayed accommodation structures of the extension and opening of the Atlantic in these latitudes, where oblique extension and the jump of plate boundaries (Srivastava et al., 1990), might have impeded the formation of classic oceanic transform faults at the time.

This process would be framed within the peripatetic behaviours of the Iberian microplate. The topic of oblique spreading along the WIM has not been ~~deeply studied~~approached in depth. However, there is some evidence that the opening of the Atlantic, and especially during the Bay of Biscay rift, Iberia, may have been "bouncing" from its perpendicular to the extension direction. Favouring this option is the fact that oblique spreading is very common in slow spreading ridges, as lithosphere is relatively cold and crustal growth is decelerated (Peyve, 2009). Another argument in agreement with this hypothesis is that mid-ocean ridges with oblique spreading are not dissected by transform faults. Shallow tectonics dictates their segmentation rather than mantle convection.

~~In the other hand, the presence of these heterogeneities stand out from the rift domains map, where the width of domains changes at the Lisbon lineation and north of the Galicia lineation (Fig. 3).~~

~~Published interpretation relying on the study of seismic profiles that cross the WIM seismicity bands, do not show evident crustal strike-slip structures. However, it is important to note that sub-vertical strike slip faults that promote horizontal displacements are difficult to image in near-vertical reflection data, and have a limited expression on the floor surface, even more if they are relatively recent.~~

The claim for these NW-SE oriented transform corridors to facilitate extension along the MAR, working as "pseudo transform faults" (Fig. 5a), reinforces the need to accommodate differential stresses from South to North along the WIM, which have resulted from the rotations and subtle drift of the Iberian plate during the past 30 Myr, together with the current NW-SE oriented compression. In this case, the seismicity alignments may correspond to those shallow accommodation zones, similar to shear zones that act as nascent oceanic transform faults, without dissecting the ridge (yet).

This compartmentalization of a passive margin into strike slip narrow belts between the MAR and a deformable plate interior, is more consistent with soft plate ~~idealizations~~ concepts than with perfectly rigid plates and narrow boundaries (Storti et al., 2007), which takes us to the next hypothesis to try to fit this seismicity into the plate tectonics theory.

4.2 A d~~D~~iffuse and ~1000 km wide plate boundary

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Plate rigidity and narrow plate boundaries are central assumptions of the original plate tectonics theory. But in the last decades evidence~~s~~ ~~have~~ has been piling up to suggest that in many cases, plate boundaries can be very wide and plates may not be as rigid as assumed (Ribeiro, 2002). The diffuse plate boundary hypothesis tries~~y~~ to reconcile observations related to intraplate activity by proposing that large plates may be composed of a few smaller subplates and crustal blocks, so more rigid portions are in relative motion with each other separated by diffuse boundaries with clustered deformation (Gordon, 1998). The diffuse plate boundaries are much broader than traditional boundaries such as mid-ocean ridges, trenches and/or oceanic transform faults (Zatman et al., 2000).

In this way, the passive interior of tectonic plates can be dissected by strike slip deformation belts propagating towards MAR segments that separate adjacent, partially coupled lithospheric slivers with differential translations, and deformation rates. These internal differential displacements are then accommodated by distributed deformation within the plate interior, so that localized deformation is ultimately dissipated into a non-rigid plate.

Applying this model to WIM is challenging because

published studies proposing soft plate deformation and the formation of weakened zones involve the spatial extension of transform faults through oceanic fracture zones, possibly weakened by serpentinization, that are used to transfer deformation from mid ocean ridges towards neighbouring plate interiors. In the WIM case, as pointed out earlier, the ~~Galicia (N) and Lisbon (S) lineation~~seismicity bands are discontinuous, do not intersect the MAR and specifically stop ~~in the vicinity of the oceanic crust~~before reaching the MAR, so a full lithospheric detachment is not occurring. ~~Therefore~~Therefore, it is more likely that these lineations may be inherited from the rifting period, or from post rift accommodation and thermal subsidence rather than to the sea floor spreading stage of the Atlantic.

Along the southern Biscay margin, the Ventaniella seismicity line (Fernandez-Viejo et al., 2014; López-Fernández et al., 2018) shows a similar NW-SE trend and includes earthquakes of similar magnitude, distribution and focal mechanism as the Galicia (N) and Lisbon (S) lineation identified in the WIM. ~~Contrastingly~~By contrast, it appears in a continental margin whose direction is perpendicular to the orientation of the WIM~~ direction~~ (the Bay of Biscay margin). If the three seismicity bands are expressions of shear corridors inside an exceptionally wide plate boundary, this hypothesis would deserve ~~its~~ credit, and the fact that they appear in two completely perpendicular trending passive margins, even crossing oceanic and continental parts of the Iberian plate, would ~~agree with~~support it.

Asti et al. (2022) proposed a 400 km wide, diffuse Iberia-Eurasia plate boundary transecting Iberia that would have been active during the Mesozoic, and extended from the Iberian Rift system to the Armorican shelf, which was associated with the contemporaneous opening of the North Atlantic and Bay of Biscay. The deforming domain between these two boundaries was a fuzzy region, where the exact locations of different tectonic structures and rift basins is still debated. If a similar diffuse plate boundary ~~may~~ exists today, it would be almost double in width and would encompass the entire Peninsula except for its northeastern third (Pyrenees and related foreland basin).

One advantage of the diffuse plate boundary theory (Fig. 5b) is that some of the inconsistencies between the deformations inferred from plate kinematic models and geological observations (which are extraordinarily abundant in Iberian kinematics-see~~;~~ Barnett-Moore et al., (2016), and references therein) may be then reconciled. The same amount of total displacement is partitioned between a series of subparallel strike slip corridors, each of them accommodating a portion of the total displacement between the stable parts of the African and European plates. This would significantly broaden the range of geodynamical models in a region with such ~~as~~ slow lithospheric deformation. If deformation between Africa and-Eurasia is distributed inside Iberia, these internal corridors of deformation can accommodate the convergence of both macroplates, while assisting synchronically the E-W Atlantic extension.

Nevertheless, if a great part of Iberia belongs to a “diffuse plate boundary”, we still need to explain why the corridors are produced at those particular separation of about 300 km. Does that separation depends on the width of the subplates related to the “rigid microplate”? Does it depend on the velocity rate of the ridge? This needs further investigations out of the scope of this study, but it points to some kind of relationship to be able to form measurable strike-slip corridors between areas with contrasting crustal lithospheric thickness, plate width and undergoing different stress fields. In any case, a complete radical hypothesis has been advanced in the literature, which approaches the dynamics of the WIM ~~in~~ from a very different perspective: the closing of the Atlantic Basin.

4.3 **Subduction initiation and oceanic dynamics that may be, or have been, at play in the WIM**

Several authors have suggested the possibility of a developing subduction zone in the SWIM, which could explain the moderate seismicity and the large magnitude of the 1755 Lisbon earthquake in an intraplate setting (Vilanova et al., 2003; Martinez-Loriente et al., 2021). Ribeiro et al. (1996) proposed that ~~the WIM is the site of~~ an incipient northward propagating subduction zone may be nucleating at the Gorringe Bank (figure 5c). The ongoing terminal stage of collision between Africa and Eurasia produces compressive stresses along the SWIM, which could trigger passive margin reactivation. Gutscher et al., (2012) show evidences of subduction towards the East in the Gibraltar arc and in the West within the southern Iberian margin NE-SW thrust systems extending 300 km along the SWIM accommodate the ~~arc-orthogonal~~ convergence ~~(Gutscher et al., 2012)~~ ~~and~~ while younger thrust faults are nucleating along the ~~west Portuguese passive margin~~SWIM (Zitellini et al., 2009; Terrinha et al., 2019; Martínez-Loriente et al., 2013; 2021) or in the Tagus Abyssal plain (Neves et al., 2009). Duarte et al, (2013) ~~suggest~~ speculate that these structures may be indicative of the onset of margin tectonic inversion and the nucleation of a new subduction, which develops due to the westward propagation of the Gibraltar Arc and related subduction (Gutscher et al., 2012.

However, focusing on the central and northern WIM, away from the complexity of the plate boundary, the buoyancy of old and cold oceanic lithosphere makes the spontaneous initiation of subduction in a passive margins difficult, and significant weakening mechanisms are required to fail in subduction (e.g., Stern and Gerya, 2018). The Azores, Madeira plume, or the peridotite ridge in the Galicia margin may serve as potential weakening mechanisms. A 100 my old oceanic crust ~~that~~ would need a significant compressive stress to fail (Zhong et al., 2019), which is not observed at the WIM.

Thermo-mechanical models suggest that magma-poor margins with hyperextended and exhumed mantle domains are favourable sites for subduction initiation, as the serpentinized mantle facilitates strain localization and the progressive development of a major shear zone that ultimately links up with a zone of high strain the continental lower crust along the necking zone (Auzemery et al., 2021). Shearing then propagates into the mantle or initiate a subduction plate boundary. The exhumation and hydration of the mantle in the footwall of major detachments induces weak decollement layers (Brun and Beslier, 1996) prone to tectonic reactivation, which would diminish the required ~~–~~ compressive stress to initiate subduction (Hirt et al., 2013). However, the seismicity observed as we have seen it is not restricted to the exhumed mantle domains– and the focal mechanisms either suggest an inverse fault. Subduction could be easier in the southern WIM as a relevant transform fault, the Gloria fault, puts in contact two different lithospheric age crusts making for additional stresses and weakened lithosphere. Although the initiation of subduction by passive margin collapse is extremely unrealistic, i.e. (Stern and Gerya., 2018), the westward migration and propagation of the Gibraltar Arc along the SWIM may be responsible for induced subduction initiation (Duarte et al., 2013).– – ~~The majority of focal mechanisms along the WIM events outside of the plate boundary are strike-slip, which does not support the lithospheric collapse in a subduction interface propagating northwards along the WIM.~~ Although some type of underthrusting ~~cannot be ruled out~~and convergence is evidenced in the south (Gutscher et al, 2012, Martinez-Loriente et al., 2021), ~~–~~ seismicity distribution and focal mechanisms, which are predominantly strike-slip, do~~es~~ not support ~~unequivocally – the presence of a subduction zone~~the northward propagation of a subduction interface.

4.4 **Oceanic complexity, inheritance, formation of strained corridors in the Atlantic ocean**

Within the other big oceanic basin of the Earth, in the Pacific, crustal studies evidence complex tectonic settings. In triple junctions, triangular microplates without any bounding continental margins grow, as exemplified by the Galapagos microplate. Researchers have found strong evidence that indeed, one ~~of~~ such microplate~~s~~ grew to become the Pacific plate~~, for instance~~ (Boschman and Hinsberger, 2016). Schouten et al. (2008), studying distributed deformation at oceanic triple junction showed that lithospheric plates undergo significant internal deformation as their boundaries rapidly evolve, as exemplified by the triple

Comentado [p1]: **Gutscher et al., 2002** (Evidence for active subduction beneath Gibraltar), **y Medialdea et al., 2004** (Structure and evolution of the "Olistostrome" complex of the **Gibraltar Arc** in the Gulf of Cádiz (eastern Central Atlantic): evidence from two long seismic cross …), hay que revisar que muestran NE-SW thrust systems in the SWIM. Revisar también Terrinha et al. 2019

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Con formato: Fuente: Times New Roman junction (RRR) Cocos-Nazca. The Cocos Nazca rift tip does not meet the East P~~p~~acific R~~r~~ise. Instead, two secondary rifts form the link. The active incipient rift is just the latest of a sequence of southeast trending fractures that progressively stepped sideways during the last 5 Myr, successively accommodating minor N-S extension of the generated oceanic crust (Smith, 2011).

The roughness of the abyssal plain around the King´s T~~h~~rough may represent the incipient and ~~left alone~~abandoned rotation of a potential mini Galapagos-like microplate. The current scars ~~related~~ associated to the triple junction on the King~~´~~s T~~h~~rough area with seafloor expression relate to inherited lithospheric fractures, which developed during the evolution of the triple point and the plate boundary migration. However, even when considering the inheritance of such lithospheric discontinuities, the seismicity in the WIM does not appear connected to it in particular, more than following the general NNW-SSE trend. And as figure 2 shows, seismicity is mainly within the continental rifted crust and not so abundant within the oceanic domains.

Palano et al. (2015) propose a current large-scale clockwise rotation that makes Iberia ~~to~~ act as a microplate with a southern limit in the AGFZ Nubia-Eurasia convergent zone. Somoza et al. (2021) indicate that the main weakened zones along ~~the~~ N and NW Iberia are the old inherited limits between the oceanic domains of Eurasia and Iberia (King´s Trough, Azores-Biscay rise, Jean-Charcot Seamount). They question the clockwise rotation in the oceanic domain, which would be dominated by the stress derived from the ridge propagation in the segment between Azores and King´s Trough, with a— N120º propagation direction. They also suggest a left-lateral shear zone resulting from the northward movement of the continental Iberia and the SE movement of oceanic Iberia along the OCT.

According to the possible hypothesis above mentioned, the one that presents less problems in this study is that the pre-existing Mesozoic rift structure, together with the oblique oceanic spreading, when the plate boundary was shifting southwards towards the AGFZ, may have left weakened areas along the WIM. These inherited zones may be prone to reactivation and release seismicity under the ~~actual~~ prevailing stress regime. Inherited features revealed by the seismicity are for instance, the old proto-subduction interface in the north of Galicia Bank (figure 3, profile 5) or the associated volcanic edifices around the Extremadura Spur. On the contrary, ~~rhe~~the remarkable reduction of exhumed domains towards the central parts seem not to have any expression in the current seismicity distribution.

5 Conclusions

Analysis of two decades of seismicity data recorded by the Spanish and Portuguese seismic networks along the West Iberian passive margin (WIM), covering an area between 38º and 45ºN latitude, shows that two NNW-SSE bands concentrate 98% of the intraplate activity. The northern band is located offshore Galicia, while the southern band is in offshore Lisbon. The observed seismicity is higher than expected for a passive margin, and coincides with the area where the mid-Atlantic ridge lacks conspicuous transform faults. Focal mechanisms indicate strike-slip deformation, and hypocentral depths suggest crustal and upper mantle sources.

Various hypotheses have been proposed to explain this seismicity, including the formation of shear corridors/transform faults, a diffuse plate boundary, initiation of subduction, and other less understood mechanisms associated with weakened zones inherited from the Mesozoic rifting, complex ocean opening, and/or triple point migration in the Iberia microplate. Based on the parameters obtained in this study, a conservative approach to explain the WIM seismicity would be the presence of strained shear corridors that nucleate preferentially on topographical heterogeneities of the seafloor. These corridors form in response to the accommodation of two perpendicular sources of stress: the E-W extension associated with the MAR, and the N-S compression from the Azores-Gibraltar Fracture Zone. The drastic crustal thickness variations from east to west and the nucleation of small events along multiple faults that make up the block morphology of the Mesozoic rifted margin conform the occurrence of areas prone to strain release. The presence of sub-Moho earthquakes also indicates that the upper mantle in the WIM acts as a high-strength layer, particularly beneath the hyperextended and exhumed mantle transition areas.

Several plate-scale processes may be acting simultaneously to produce the observed seismicity, such as the possible initiation of convergence-related deformation in the SWIM or the inherited compartmentalization of the lithosphere in the northern part of the margin due to triple junction migration. Further study of seismicity in the WIM and neighbouring oceanic areas, together with the arrival of seafloor stations, may provide further insights to better understand this marine intraplate clustered activity.

Data and resources

Seismicity data used in this study were collected from the IGN Spanish seismic network at www.ign.es (last accessed December 2022) and from IPMA Portuguese seismic network at www.ipma.pt/en/ (last accessed December 2022). Gravity, magnetic and crustal data were obtained from GeoMapApp at https://www.geomapapp.org/ (last accessed January 2023).

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References

Álvarez-Marrón, J., Rubio, E., and Torne, M.: Subduction-related structures in the North Iberian Margin, J. Geophys. Res. 102, 22497-22511, doi:10.1029/97JB01425,1997.

Ayarza, P., Mrtinez-Catalán, J.R., ~~Alvarez~~Álvarez-~~Marron~~Marrón, J., Zeyen, H., and Juhlin, C.: Geophysical constraints on the deep structure of a limited ocean-continent subduction zone at the North iberian margin. Tectonics, 23 TC101, doi:1.1029/2002TC001487, 2004.

Afilhado, A., Matias, L., Shiobara, H.,Hirn, A., Mendes-Victor, L., and Shimamura, H.: From unthinned continent to ocean: The deep structure of the West Iberia passive continental margin at 38N, Tectonophysics,,458, 9-50, doi:10.1016/j.tecto.2008.03.002, 2008

Alves, T., Moita, C., Cunha, T., Ullnaess, M., Myklebust, R., Monteiro, J.H., and Manuppella, G.: Diachronous evolution of Late Jurassic-Cretaceous continental rifting in the northwest Atlantic (west Iberian margin). Tectonics, 28, TC4003, doi:10.1029/2008TC002337, 2009

Amigo Marx, B., Fernandez, O., Olaiz, A., Poblet, J., and Zamora, G.: On the influence of Variscan inheritance on rifting of the Western Iberian margin, Terra Nova, 34, 424-432, doi:10.1111/ter.12595, 2022.

Andeweg, B., De Vicente, G., Cloetingh, S.A.P.L., Giner, J., and Muñoz-Martin, A.: Local stress fields and intraplate deformation of Iberia: variations in spatial and temporal interplay of regional stress sources, Tectonophysics, 305, 153-164, doi:10.1016/S0040-1951(99)00004-9, 1999.

Asti, R., Saspiturry, N., and Angrand, P.: The Mesozoic Iberia-Eurasia diffuse plate boundary: A wide domain of distributed transtensional deformation progressively focusing along the North Pyrenean Zone, Earth. Sci. Rev., 230, 104040, doi:10.1016/j.earscirev.2022.104040, 2022.

Auzemery, A., Willingshofer, E. Sokoutis, D. Brun, J.P., and Cloetingh, S.A.: Passive margin inversion controlled by stability of the mantle lithosphere, Tectonophysics, 817, 229042, doi:10.1016/j.tecto.2021.229042, 2021.

Barnett-Moore, N., M. Hosseinpour, and Maus, S.: Assessing discrepancies between previous plate kinematic models of Mesozoic Iberia and their constraints, Tectonics, 35, 1843-1862, doi:10.1002/2015TC004019, 2016.

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

Boillot, G., Girardeau, J., and Kornprobst, J.: Rifting of the Galicia margin: crustal thinning and emplacement of mantle rocks on the seafloor. In Boillot, G., Winterer, E.L., et al., Proc. ODP, Sci. Results, 103: College Station, TX (Ocean Drilling Program), 741-756, doi:10.2973/odp.proc.sr.103.179.1988, 1988a

Boillot, G., Keith W. Dunham, Philip A. Meyers, and Eileen, S.H.: Proceedings of the Ocean Drilling Program: Scientific Results, Ocean Drill. Program, College Station, Texas, 1-858, 1988b

Borges, J.F., Fitas, A.J.S., Bezzeghoud, M., and Teves-Costa , P.: Seismotectonics of Portugal and its adjacent Atlantic Area, Tectonophysics. 337, 373-387, doi:10.1016/S0040-1951(00)00291-2, 2001.

Boschman, L.M., and van Hinsbergen , D.J.J.: On the enigmatic birth of the Pacific Plate within the Panthalassa Ocean, Sci. Adv. 2(7) e1600022, doi:10.1126/sciadv.1600022, 2016.

Bronner, A., Sauter, D., Manatschal, G., Péron-Pinvidic, G. and Munschy, M.: Magmatic breakup as an explanation for magnetic anomalies at magma-poor rifted margins, Nature Geosci. 4, 549-553, doi:10.1038/ngeo1201, 2011.

Brun, J.P., and Beslier, M.O.: Mantle exhumation at passive margins, Earth. Planet. Sci. Lett., 142, 161-173, doi:10.1016/0012-821X(96)00080-5, 1996.

Buforn E, Udías A, Colombás MA: Seismicity, source mechanisms and seismotectonics of the Azores-Gibraltar plate boundary, Tectonophysics, 152, 89-118, 1988.

Custódio, S., Dias, N. A., Carrilho, F., Góngora, E., Rio, I., Marreiros, C., Morais, I., Alves, P. and Matias, L.: Earthquakes in western Iberia: Improving the understanding of lithospheric deformation in a slowly deforming region, Geophys. J. Int. 203(1), 127-145, doi:10.1093/gji/ggv285, 2015.

Dean, S.M., Minshull, T.A., Whitmarsh, R.B., Louden, K.E.: Deep structure of the ocean-continent transition in the southern Iberia abyssal Plain from seismic refraction profiles: The IAM-9 transect at 40º20´N, Journal of Geophysical Res., 105: 5859-5885, 2000.

De Vicente, G., Cloetingh, S., Muñoz-Martín, A., Olaiz, A., Stich, D., Vegas, R., Galindo-Zaldívar, J., and Fernández-Lozano, J.: Inversion of moment tensor focal mechanisms for active stresses around the microcontinent Iberia: Tectonic implications, Tectonics, 27. TC1009, doi:org/10.1029/2006TC002093, 2008.

Druet, M., Muñoz-Martín, A., Granja-Bruña, J.L., Carbó-Gorosabel, A., Llanes, P., Catalán, M., Maestro, A., Bohoyo, F., and Martín-Dávila , J.: Bouguer anomalies of the NW Iberian continental margin and the adjacent abyssal plains, J. Map. Geogr. Libr., 15, 635-641, doi:10.1080/17445647.2019.1644214, 2019.

Duarte, J.C., Rosas, F.M., Terrinha, P., Schellart, W., Boutelier, D., Gutscher, M.A. and Ribeiro , A.: Are subduction zones invading the Atlantic? Evidence form the southwest Iberia Margin, Geology, 41, 839-842, doi:10.1130(G34100.1, 2013

Dziewonski, A.M., T.A. Chou, and Woodhouse, J.H.: Determination of earthquake source parameters from waveform data for studies of global and regional seismicity, J. Geophys. Res., 86, 2825-2852, doi:10.1029/JB086iB04p02825,1981.

EMODnet Bathymetry Consortium (2020). EMODnet Digital Bathymetry (DTM 2020), doi:10.12770/bb6a87dd-e579-4036-abe1-e649cea9881a, 2020.

Ekström, G., M. Nettles, and Dziewonski, A. M.: The global CMT project 2004-2010: Centroid-moment tensors for 13,017 earthquakes, Phys. Earth Planet. Inter., 200-201, 1-9, doi:10.1016/j.pepi.2012.04.002, 2012.

Escada, C., Represas, P., Santos, F., Pereira, R., Mata, J., and Rosas, F.M.: New evidence of Late Cretaceous magmatism on the offshore central West Iberian margin (Extremadura Spur) from potential field data, Tectonophysics, 832, 229354, doi:10.1016/j.tecto.2022.229354, 2022.

Fernandes, R. M. S., Ambrosius, B. A. C., Noomen, R., Bastos, L., Wortel, M. J. R., Spakman, W., and Govers, R.: The relative motion between Africa and Eurasia as derived from ITRF2000 and GPS data, Geophys. Res. Lett., 30, 1828, doi:10.1029/2003GL017089, 2003.

Fernández-Viejo, G., López-Fernández, C., Domínguez-Cuesta, M.J., and Cadenas, P.: How much confidence can be conferred on tectonic maps of continental shelves? The Cantabrian-Fault case, Sci. Rep., 4, 3661, doi:10.1038/srep03661, 2014.

Fernandez-Viejo, G., Pulgar, J.A., Gallastegui, J. and Quintana, L.: The fossil accretionary wedge of the Bay of Biscay: critical wedge analysis on depth-migrated seismic sections and geodynamical implications, J Geol., 120, 1-18. doi:10.1086/664789, 2012.

Ferrão, C., Bezzeghoud, M., Caldeira, B., and Borges, J.F.: The Seismicity of Portugal and Its Adjacent Atlantic Region from 1300 to 2014: Maximum Observed Intensity (MOI) Map, Seismol. Res. Lett., 87, 743-750, doi:10.1785/0220150217, 2016.

Garate, J., Martin-Davila, J., Khazaradze, G., Echeverria, A., Asensio, E., Gil, A.J., de Lacy, M.C., Armenteros, J.A., Ruiz, A.M., Gallastegui, J., ~~Alvarez~~Álvarez-Lobato, F., Ayala, C., Rodríguez-Caderot, G., Galindo-Zaldívar, J., Rimi, A. and Harnafi, M.: Topo-Iberia project: CGPS crustal velocity field in the Iberian Peninsula and Morocco, GPS Solut., 19, 287-295,. doi:10.1007/s10291-014-0387-3, 2015.

Geissler, W.H., Matias, L., Stich, D., Carrilho, F., Jokat, W., Monna, S., Ibenbrahim, A., Mancilla, F., Gutscher, M.A., Sallares, V., and Zitellini, N: Focal mechanisms for sub-crustal earthquakes in the Gulf of Cadiz from s dense OBS deployment, Geophys. Res. Lett., 37, L18309, doi: 10.1029/2010GL044289, 2010.

Gomez de la Peña, L., Ranero, C.R., Gràcia, E., Booth-Rea, G., Azañón, J.M., Tinivella, U., and Yelles-Chaouche, A.: Evidence for a developing plate boundary in the western Mediterranean, Nat. Commun., 13, 4786. doi:10.1038/s41467-022-31895-z, 2022.

Gonzalez, A. Cordoba, D. and Vales, D.: Seismic crustal structure of Galicia continental margin, NW Iberian Peninsula, Geophys Res Lett., 26, 1061-1064, 1999.

Gordon R.G.: The plate tectonic approximation: Plate nonrigidity, diffuse plate boundaries, and global plate reconstructions, Ann. Rev. Earth Planet. Sci., 26, 615-642, 1998

Granado, C., Muñoz-Martín, A., Olaiz, A.J., Fernández, O., and Druet, M.: 3D crustal-scale structure of the West Iberia margin: a novel approach to integrated structural characterization of passive margins, Mar. Geophys. Res., 42, 10, doi:10.1007/s11001-021-09432-2, 2021.

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

Grevemeyer, I., Ranero, C.R., Papenberg, C., Sallares, V., Bartolomé, R., Prada, M., Batista, L., Neres, M.: The continent-to-ocean transition in the Iberia Abyssal Plain, Geology, 50, 615-619, 2022.

Gutscher, M.A., Dominguez, S., Westbrook, G.K., Le Roy, P., Rosas, F., Duarte, J.C., Terrinha, P., Miranda, J.M., Graindorge, D., Gailler, A., Sallares, V., and Bartolome R.: The Gibraltar subduction: a decade of new geophysical data. Tectonophysics, 574, 72-91, doi:10.1016/j.tecto.2012.08.038, 2012.

Hirt, G., and Guillot, S.: Rheology and tectonic significance of serpentine, Elements, 9, 107-113, doi:10.2113/gselements.9.2.107, 2013.

Jimenez-Munt, I., and Negredo, A.: Neotectonic modeling of the western part of the Africa-Eurasia plate boundary: from the Mid-atlantic ridge to Algeria, Earth Planet. Sci. Lett., 205, 257-271, doi:10.1016/S0012-821X(02)01045-2, 2003.

King, M.T., Welford, J.K., and Peace, A.L.: Investigating the role of the Galicia Bank on the formation of the North West Iberian margin using deformable plate tectonic models, Tectonophysics, 789, 228537, doi:10.1016/j.tecto.2020.228537, 2020.

King, M.T., and Welford, J.K.: Advances in deformable plate tectonic models: 2. Reconstructing the southern North Atlantic back through time, G-cubed, 23, e2022GC010373, doi:10.1029/2022GC010373, 2022.

Krüger, F., Dahm, T., and Hannemann, K.: Mapping of Eastern North Atlantic Ocean seismicity from Po/So observations at a mid-aperture seismological broad-band deep sea array, Geophys. J. Int., 221, 1055-1080. doi:10.1093/gji/ggaa054, 2020.

Laske, G., Masters., G., Ma, Z. and Pasyanos, M.: Update on CRUST1.0 - A 1-degree Global Model of Earth's Crust, Geophys. Res. Abstr. 15 EGU2013-2658. https://ui.adsabs.harvard.edu/abs/2013EGUGA..15.2658L, 2013.

Con formato: Inglés (Estados Unidos)

Con formato: Inglés (Estados Unidos)

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Código de campo cambiado

Con formato: Inglés (Reino Unido)

Con formato: Inglés (Reino Unido)

López-Fernández, C., Fernández-Viejo, G., Olona, J., and Llana-Fúnez, S.: Intraplate seismicity in Northwest Iberia along the trace of the Ventaniella fault: a case for fault intersection at depth, Bull. Seism. Soc. Am., 108, 604-618, doi:10.1785/0120170215, 2018.

Lymer, G., and Reston, T.J.: The West Iberian margin: past and current research concepts and future challenges. Continental rifted margins 2. Case examples. Eds: Wiley and Sons, 256 p., 2022

Macchiavelli, C., Vergés, J., Schettino, A., Fernàndez, M., Turco, E., Casciello, E., Torne, M., Pierantoni, P.P. and Tunini, L.: A new southern North Atlantic isochron map: Insights into the drift of the Iberian Peninsula since the Late Cretaceous, J. Geophys. Res. B, 122, 9603-9626, doi:10.1002/2017JB014769, 2017

Malod, J.A. and Mauffret, M.: Iberian plate motions during the Mesozoic, Tectonophysics, 184, 261-278, The Geological Society of London, London, 1990.

Martínez-Loriente, S., Gracia, E., Bartolome, R., Sallarès, V., Connors, C., Perea, H., Lo Iacono, C., Klaeschen, D., Terrinha, P., Danobeitia, J.J. and Zitellini, N.: 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), G-cubed, 14, 2206-2231, 2013.

Martinez-Loriente, S., Sallares, V., and Gracia, E.:The Horseshoe abyssal plain thrust could be the source of the 1755 Lisbon earthquake and tsunami. Commun. Earth. Environ., 2, 145, doi:10.1038/s43247-021-00216-5, 2021.

Merino, I., Ranero, C.R., Prada, M., Sallares, V., and Grevemeyer, I.: The Rift and Continent-Ocean Transition Structure under the Tagus Abyssal Plain West of the Iberia, J Geophys Res B Solid Earth Planets, 126, e2021JB022629. doi:10.1029/2021JB022629, 2021.

Meyer, B., Saltus, R. and Chulliat, A.: EMAG2v3: Earth Magnetic Anomaly Grid (2-arc-minute resolution). Version 3. NOAA National Centers for Environmental Information, doi:10.7289/V5H70CVX, Accessed [December 2023]., 2017

Murillas, J., Mougenot, D., Boulot, G., Comas, M.C., Banda, E. and Mauffret, A.: Structure and evolution of the Galicia Interior Basin (Atlantic western Iberian continental margin), Tectonophysics 184 297-319, doi:10.1016/0040-1951(90)90445-E, 1990.

Neves, M.C., Terrinha, P. , Alfilhado, A., Moulin, M., Matias, L., Rosas, F. (2009). Response of a muti-domain continetal margin to compression: Study from seismic reflection-refraction and numerical modelling in the Tagus Abyssal plain. Tectonophysics, 468 (1-4), 113-130, https://doi.org/10.1016/j.tecto.2008.05.008.

Nirrengarten, M., Manatschal, G., Tugend, J., Kusznir, N.J. and Sauter, D.: Nature and origin of the J-magnetic anomaly offshore Iberia-Newfoundland: implications for plate reconstructions, Terra Nova, 29, 20-28, doi:10.1111/ter.12240, 2017.

Nirrengarten, M., Manatschal, G., Tugend, J., Kusznir, N. J. and Sauter, D.: Kinematic Evolution of the Southern North Atlantic: Implications for the Formation of Hyperextended Rift Systems, Tectonics, 37, 89-118, doi:10.1002/2017TC004495, 2018.

Nocquet, J.M.: Present-day kinematics of the Mediterranean: A comprehensive overview of GPS results, Tectonophysics, 579, 220-242, doi:10.1016/j.tecto.2012.03.037, 2012.

Nocquet, J.M., and Calais, E.: Geodetic measurements of crustal deformation in the western Mediterranean and Europe, Pure Appl. Geophys., 161, 661-681. doi:10.1007/s00024-003-2468-z, 2004.

Palano, M., Gonzalez, P.J., and Fernandez, J.: The diffuse plate boundary of Nubia and Iberia in the western Mediterranean: crustal deformation evidence for viscous coupling and fragmented lithosphere, Earth Planet. Sci. Lett., 430, 439-447, doi:10.1016/j.epsl.2015.08.040, 2015.

Peace, A.L., Welford, J.K., Ball, P.J., and Nirrengarten, M.: Deformable plate tectonic models of the southern North Atlantic, J. Geodyn., 128, 11-37, doi:10.1016/j.jog.2019.05.005, 2019.

Pedrera, A., Ruiz-Constán, A., Galindo-Zaldívar, J., Chalouan, A., Sanz de Galdeano, C., Marín-echado, C., Ruano, P., Benmakhlouf, M. Akil, M., López-Garrido, A.C., Chabli, A., Ahmamou, M., and González-Castillo ,L.: Is there an active

Con formato: Portugués (Portugal)

Con formato: Inglés (Canadá)

Con formato: Inglés (Canadá)

Con formato: Inglés (Canadá)

subduction beneath the Gibraltar orogenic arc. Constraints from Pliocene to Present-day stress field, J. Geodyn., 52, 83-96, doi:10.1016/j.jog.2010.12.003, 2011.

Pedrera, A., García-Senz, J., Ayala, C., Ruiz-Constán, A., Rodriguez-Fernández, L. R., Robador, A. and González Menéndez, L.: Reconstruction of the exhumed mantle across the North Iberian Margin by crustal-scale 3-D gravity inversion and geological cross section, Tectonics, 413, 150-154, doi:10.1002/2017TC004716, 2017.

Péron-Pinvidic, G., Manatschal, G., Minshull, T.A. and Sawyer, D.S.: Tectonosedimentary evolution of the deep Iberia-Newfoundland margins: evidence for a complex breakup history, Tectonics, 26, TC2011, doi:10.1029/2006TC0019070, 2007.

Péron-Pinvidic, G., Manatschal, G.:. The final rifting evolution at deep magma-poor passive margins from Iberia-Newfoundland: a new point of view, Int. J. Earth Sci., 98, 1581-1597, doi:10.1007/s00531-008-0337-9, 2009.

Pereira, R., Alves, T. and Cartwright , J.: Post rift compression of the SW Iberian margin (eastern North Atlantic): a case for prolonged inversion in the ocean-continent transition zone. J. Geol. Soc., 168, 1249-1263, doi:10.1144/0016-76492010-151, 2011.

Pereira, R., Alves, T. and Mata, J.: Alternating crustal architecture in West Iberia: a review of its significance in the context of NE Atlantic rifting, J. Geol. Soc., 174, 522-540, doi:10.1144/jgs2016-050, 2016.

Pinheiro, L.M., Whitmarsh, R.B. and Miles, P. R.: The ocean-continent boundary off the western continental margin of Iberia-II. Crustal structure in the Tagus Abyssal Plain, Geophys. J. Int., 109, 106-124, doi:10.1111/j.1365-246X.1992.tb00082.x, 1992.

Pinheiro, L.M., Wilson, R.C.L., Pena dos Reis, R., Whitmarsh, R. B., and Ribeiro, A.: The western Iberia margin: A geophysical and geological overview, Proc. Ocean Drill. Prog. Sci. Results, 149 3.1996

Ramos, A., Fernández, O., Terrinha, P. and Muñoz, J.A.: Extension and inversion structures in the Tethys-Atlantic linkage zone, Algarve Basin, Portugal, Int. J. Earth Sci., 105, 1663-1679, doi:10.1007/s00531-015-1280-1, 2016

Ribeiro, A., Cabral, J., Baptista, R. and Matias, L.: Stress pattern in Portugal mainland and the adjacent Atlantic region, West Iberia, Tectonics, 15, 641-659, doi:10.1029/95TC03683, 1996.

Ribeiro, A.: Soft Plate and Impact Tectonics, Springer Verlag, Heidelberg, 1-324, 2002.

Roest, W.R. and Srivastava ,S.P.: Kinematics of the plate boundaries between Eurasia, Iberia and Africa in the North-Atlantic from the Late Cretaceous to the present, Geology, 19, 613-616, doi:10.1130/0091-7613, 1991.

Rueda, J. and Mezcua, J.: Near-real-time Seismic Moment-tensor Determination in Spain, Seismol. Res. Lett., 276, 455-465. doi:10.1785/gssrl.76.4.455, 2005.

Ryan, W.B.F., Carbotte, S.M., Coplan, J., O'Hara, S., Melkonian, A., Arko, R., Weissel, R.A., Ferrini, V., Goodwillie, A., Nitsche, F., Bonczkowski, J. and Zemsky, R.: Global Multi-Resolution Topography (GMRT) synthesis data set, Geochem. Geophys. Geosyst., 10, Q03014, doi:10.1029/2008GC002332, 2009.

Sallarès, V., Martínez-Loriente, S., Prada, M., Gràcia, E., Ranero, C., Gutscher, M.A., Bartolome, R., Gailler, A., Dañobeitia, J.J. and Zitellini, N.: Seismic evidence of exhumed mantle rock basement at the Gorringe Bank and the adjacent Horseshoe and Tagus abyssal plains (SW Iberia), Earth. Planet. Sci., 365, 120-131, doi:10.1016/j.epsl.2013.01.021, 2013.

Sandwell, D.T., Müller, R.D., Smith, W.H.F., Garcia, E. and Francis, R.: New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure, Science 346, 6205, 65-67, doi:10.1126/science.1258213, 2014.

Schouten, H., Smith, D.K., Montési, L.G.J., Zhu, W. and Klein, E.M.: Cracking of lithosphere north of the Galapagos triple junction, Geology, 36, 339-342, doi:10.1130/G24431A.1, 2008.

Schulmann, K., Edel, J.B., Martínez Catalán, J.R., Mazur, S., Guy, A., Lardeaux, J.M., Ayarza, P., Palomeras, I.: Tectonic evolution and global crustal architecture of the European Variscan belt constrained by geophysical data, Earth. Sci. Rev., 234, 104195, doi:10.1016/j.earscirev.2022.104195, 2022.

Serpelloni, E., Vannucci, G., Pondrelli, S., Argnani, A., Casula, G., Anzidei, M., Baldi, P. and Gasperini, P.: Kinematics of the Western Africa-Eurasia plate boundary from focal mechanisms and GPS data, Geophys. J. Int., 169, 1180-1200, doi:10.1111/j.1365-246X.2007.03367.x, 2004.

Sibuet, J., Srivastava, S.P. and Spakman, W.: Pyrenean orogeny and plate kinematics, J. Geophys. Res., 109, B08104, doi:10.1029/2003JB002514, 2004.

Smith, D.K.: Grid(s) of multibeam bathymetry at Galapagos Triple Junction, Palisades, New York: Integr. Earth Data Appl. Doi:10.1594/IEDA/100005, 2011.

Srivastava, S.P., Schouten, H., Roest, W.R., Klitgord, K., Kovacs, L.C., Verhoef, J., and Macnab, R.: Iberian plate kinematics: a jumping plate boundary between Eurasia and Africa, Nature, 344, 756-759, 1990.

Stich, D., Serpelloni, E., Mancilla, F.L., and Morales, J. Morales: Kinematics of the Iberia-Maghreb plate contact from seismic moment tensors and GPS observations, Tectonophysics, 426, 295-317, doi:10.1016/j.tecto.2006.08.004, 2006.

Soares, D.M., Alves, T.A, and Terrinha, P.: The breakup sequence and associated lithospheric breakup surface: Their significance in the context of rifted continental margins (West Iberia and Newfoundland margins, North Atlantic). Earth. Planet. Sci. Lett., 355-356, 311-326, 2012.

Somoza, L., Medialdea, T., González, F. J., León, R., Palomino, D., Rengel, J., Fernández-Salas, L.M. and Vázquez, J.: Morphostructure of the Galicia continental Margin and Adjacent Deep Ocean Floor: From Hyperextended Rifted to Convergent Margin Styles. Mar. Geology. 407, 299-315, doi:10.1016/j.margeo.2018.11.011, 2019.

Somoza, L., Medialdea, T., González, F. J., Machancoses, S., Candón, J. A., Cid, C., Calado, A., Afonso, A., Pinto Ribeiro, L., Blasco, I., Albuquerque, M., Asensio-Ramos, M., Bettencourt, R., De Ignacio, C., López-Pamo, E., Ramos, B., Rincón-Tomás, B., Santofimia, E., Souto, M., Tojeira, I., Viegas, C. and Madureira, P.: High-Resolution Multibeam Bathymetry of the Northern Mid-Atlantic Ridge at 45-46°N: the Moytirra Hydrothermal Field, J. Maps, 17, 184-196. doi:10.1080/17445647.2021.1898485, 2021.

Stern, R.J., and Gerya, T.: Subduction initiation in nature and models: A review. Tectonophysics, 746, 173-198, doi:10.1016/j.tecto.2017.10.014, 2018.

Srivastava, S.P. and Roest, W.R.: King's Trough: reactivated pseudo-fault of a propagating rift, Geophys. J. Int., 108, 143-150, doi:10.1111/j.1365-246X.1992.tb00845.x, 1992.

Storti, F., Soto Marin, R., Rossetti, R. and Casas Sainz, A.M.: Evolution of experimental thrust wedges accreted from along-strike tapered, silicone-floored multilayers, J. Geol. Soc., 164, 73-85, doi:10.1144/0016-76492005-186, 2007.

Takahashi, M., van den Ende, M.P.A., Niemeijer, A.R. and Spiers, C.J.: Shear localization in a mature mylonitic rock analog during fast slip, Geochem. Geophys. Geosyst,. 18, 513-530, doi:10.1002/2016GC006687, 2007.

Terrinha, P., Matias, L., Vicente, J., Duarte, J., Luís, J., Pinheiro, L., Lourenço, N., Diez, S., Rosas, F., Magalhães, V., Valadares, V., Zitellini, N., Roque, C., and Mendes Víctor, L.: Morphotectonics and Strain Partitioning at the Iberia-Africa Plate Boundary from Multibeam and Seismic Reflection Data, Mar. Geology, 267, 156-174, doi:10.1016/j.margeo.2009.09.012, 2009.

Terrinha, P., Ramos, A., Neres, M., Valadares, V. Duarte, J. et al.: The alpine orogeny in the West and Southwest Iberia margins. In Terrinha, P. et al. (2019). The Alpine Orogeny in the West and Southwest Iberia Margins. In: Quesada, C., Oliveira, J. (eds) The Geology of Iberia: A Geodynamic Approach. Regional Geology Reviews. Springer, Cham. 487-505, doi:10.1007/978-3-030-11295-0_11 , 2019

Tucholke, B.E., Sawyer, D. and Sibuet, J. C.: Breakup of the Newfoundland-Iberia rift, In: G. D. Karner, G. Manatschal and L. M. Pinheiro (Eds.), Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup, Geol. Soc. London Spec. Publ., 282, 9-46, 2007.

Vázquez, J.T., Medialdea, T., Ercilla, G., Somoza, L., Estrada, F., Fernández-Puga, M.C., Gallart, J., Gràcia, E., Maestro, A., and Sayago, M.: Cenozoic deformational structures on the Galicia Bank Region (NW Iberian continental margin), Mar. Geology, 249, 128-149, 2008.

Veludo, I., Dias, N. A., Fonseca, P. E., Matias, L., Carrilho, F., Haberland, C. and Villaseñor, A.: Crustal seismic structure beneath Portugal and southern Galicia (Western Iberia) and the role of Variscan inheritance, Tectonophysics, 717, 645-664, doi:10.1016/j.tecto.2017.08.018, 2017.

Vilanova, S.P., Nunes, C.F., and Fonseca, J.F.B.D.: Lisbon 1755: A Case of Triggered Onshore Rupture? Bull. Seismol. Soc. Am., 93, 2056-2068, doi:10.1785/0120020245, 2003.

Vilanova, S.P., Nemser, E.S., Besana-Ostman, G.M., Bezzeghoud, M., Borges, J.F., Brum da Silveira, A., Cabral, J., Carvalho, J., Cunha, P.P., Dias, R.P., Madeira, J., Lopes, F.C., Oliveira, C.S., Perea, H., García-Mayordomo, J., Wong, I., Arvidsson, R., and Fonseca, J.F.B.D.: Incorporating Descriptive Metadata into Seismic Source Zone Models for Seismic-Hazard Assessment: A Case Study of the Azores-West Iberian Region, Bull. Seismol. Soc. Am., 104, 1212-1229, doi:10.1785/0120130210, 2014.

Vissers, R., and P.T. Meijer: Mesozoic rotation of Iberia: Subduction in the Pyrenees?, Earth Sci. Rev., 110, 93-110, doi:10.1016/j.earscirev.2011.11.001, 2012.

Whitsmarsh, R.B., Miles, P.R., and Mauffret, A.: The ocean-continent boundary off the western continental margin of Iberia-I. Crustal structure at 40°30'N. Geophys. J. Int., 103, 509-531, doi:10.1111/j.1365-246X.1990.tb01788.x, 1990.

Whitsmarsh, R.B., Pinheiro, L.M., Miles, P.R., Recq, M., and Sibuet, J.C.: Thin crust at the Western Iberia Ocean-Continent Transition and ophiolites. Tectonics, 12, 1230-1239, doi:10.1029/93TC00059 , 1993.

Zatman, S.: On steady rate coupling between an elastic upper crust and a viscous interior, Geophys. Res. Lett., 27, 2421-2424, doi:10.1029/2000GL011592 , 2000.

Zitellini, N., Gracia, E., Matias, L., Terrinha, P., Abreu, M.A., Dealteris, G., Henriet, J.P., Dañobeitia, J.J., Masson, D.G., Mulder, T., Ramella, R., Somoza, L., and S. Diez: 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.

Zhong, T., Gordon, R. G., and C. Wang: Oblique seafloor spreading across intermediate and superfast spreading centers, Earth Planet. Sci. Lett., 495, 146-156, doi:10.1016/j.epsl.2018.05.001, 2019.

FIGURES

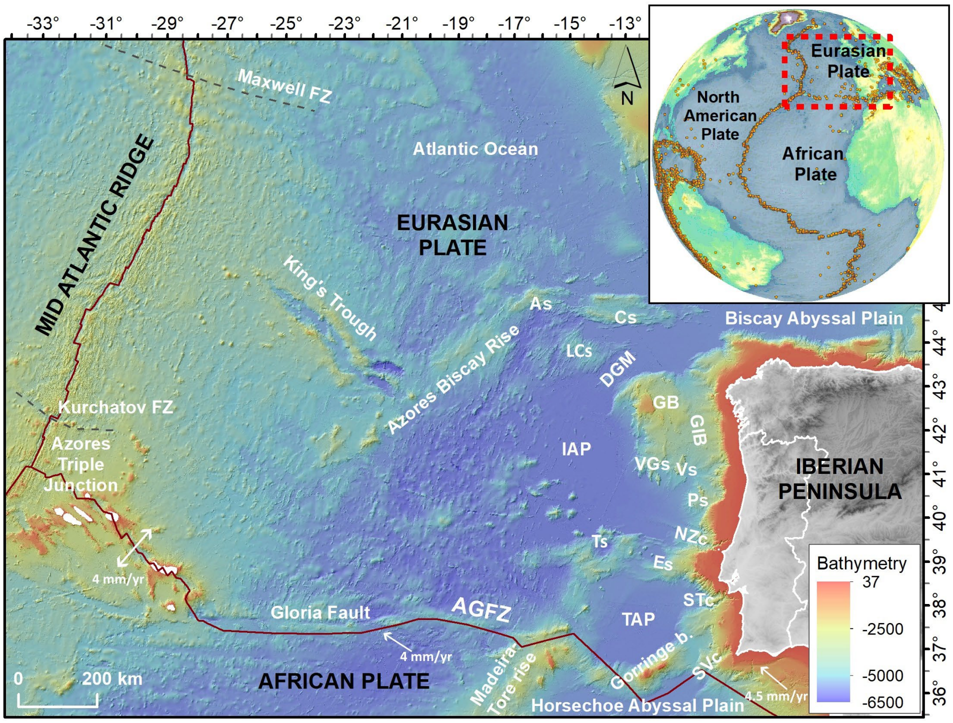
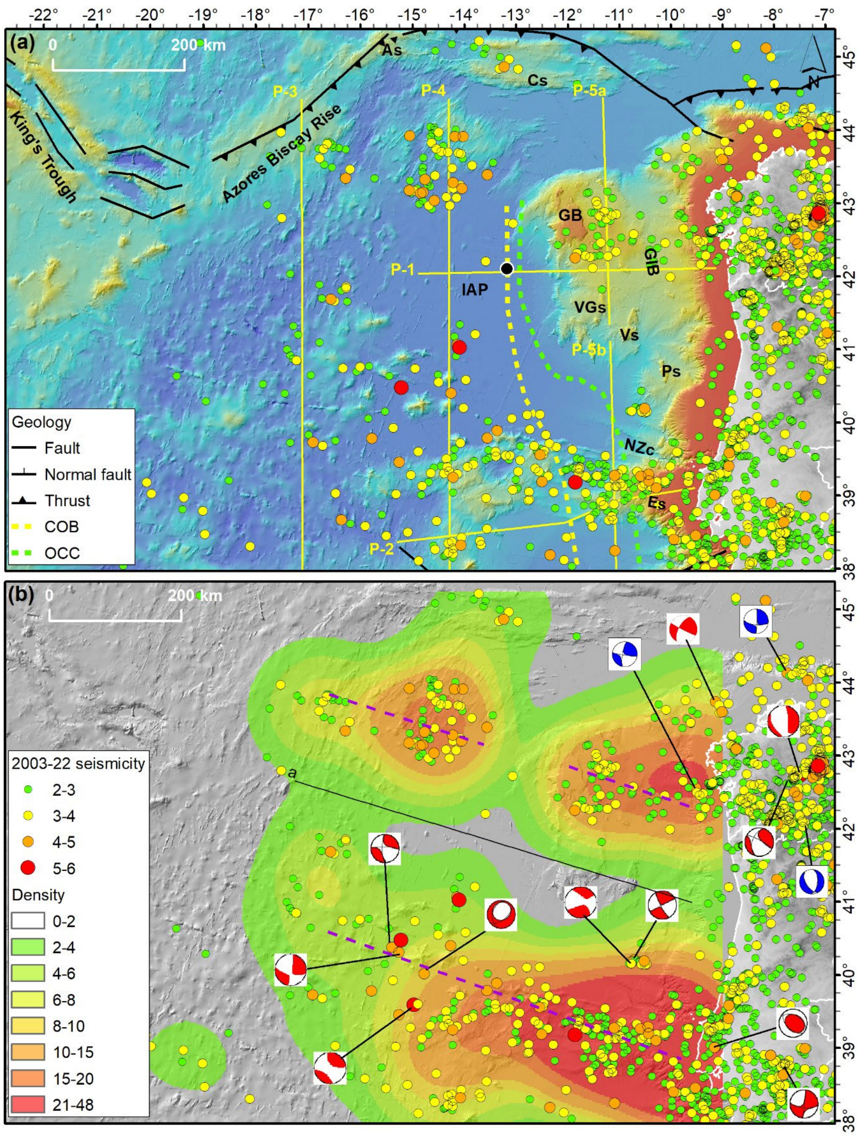


Figure 1.: ~~Figure 1:~~ Study area. The WIM and its main physiographic features including their West (mid Atlantic ridge (MAR) , Eurasia- America) and South (Azores-Gibraltar fault zone AGFZ, Eurasia-Africa) plate boundaries. GB: Galicia Bank, IAP: Iberian Abyssal Plain, GIB: Galician interior Basin, VGs: Vasco de Gama seamount, Vs: Vigo seamount, Ps: Porto seamount, NZc: Nazare canyon, Es: Extremadura Spur, STc: Setubal canyon, TAP: Tagus abyssal plane, SVc: San Vicente canyon, FZ: fracture Zone (Kurtachov). Cs: Charcot seamount, As: Atlantic seamount.



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Geology
Fault
Normal fault
Thrust
COB
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39°
38°

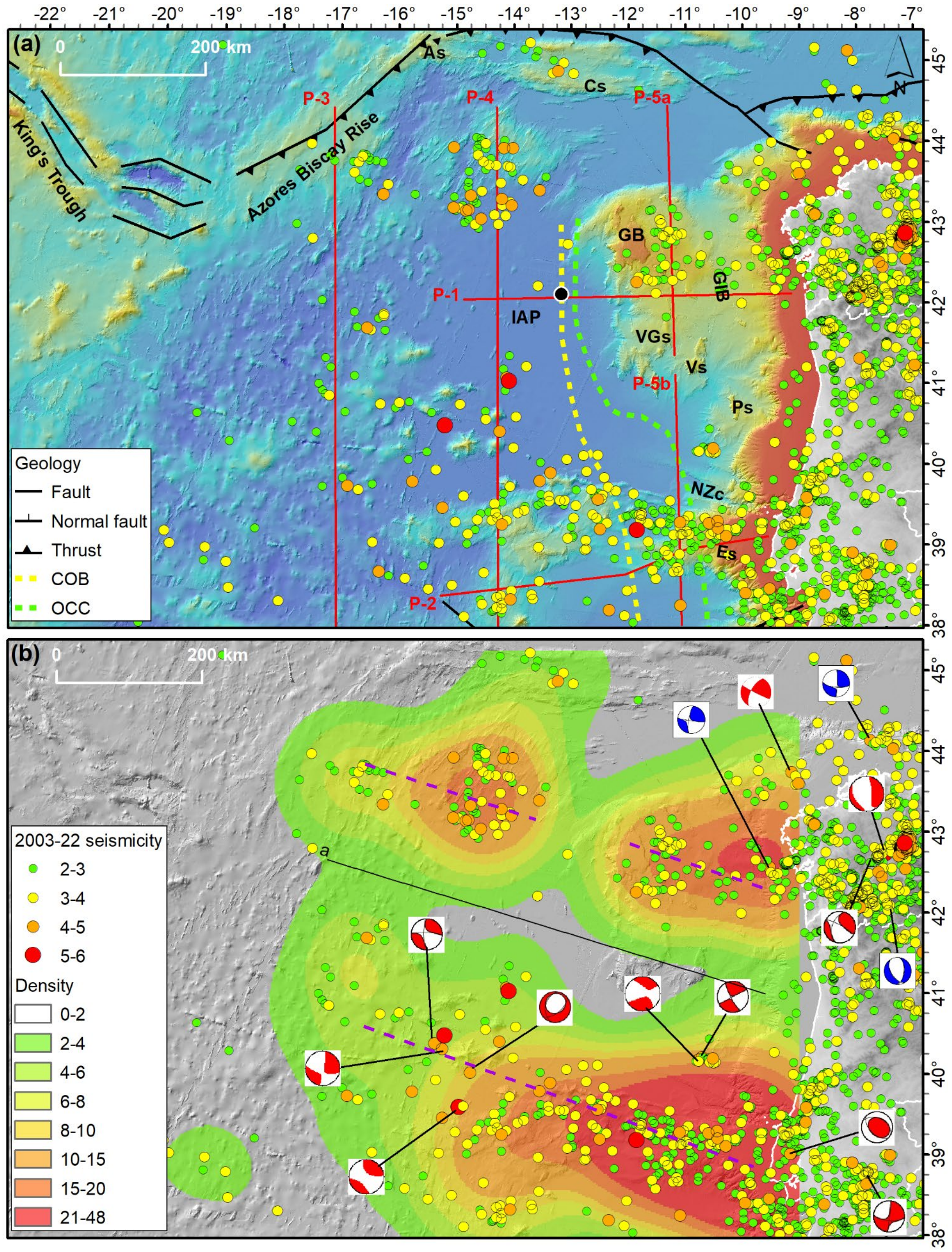
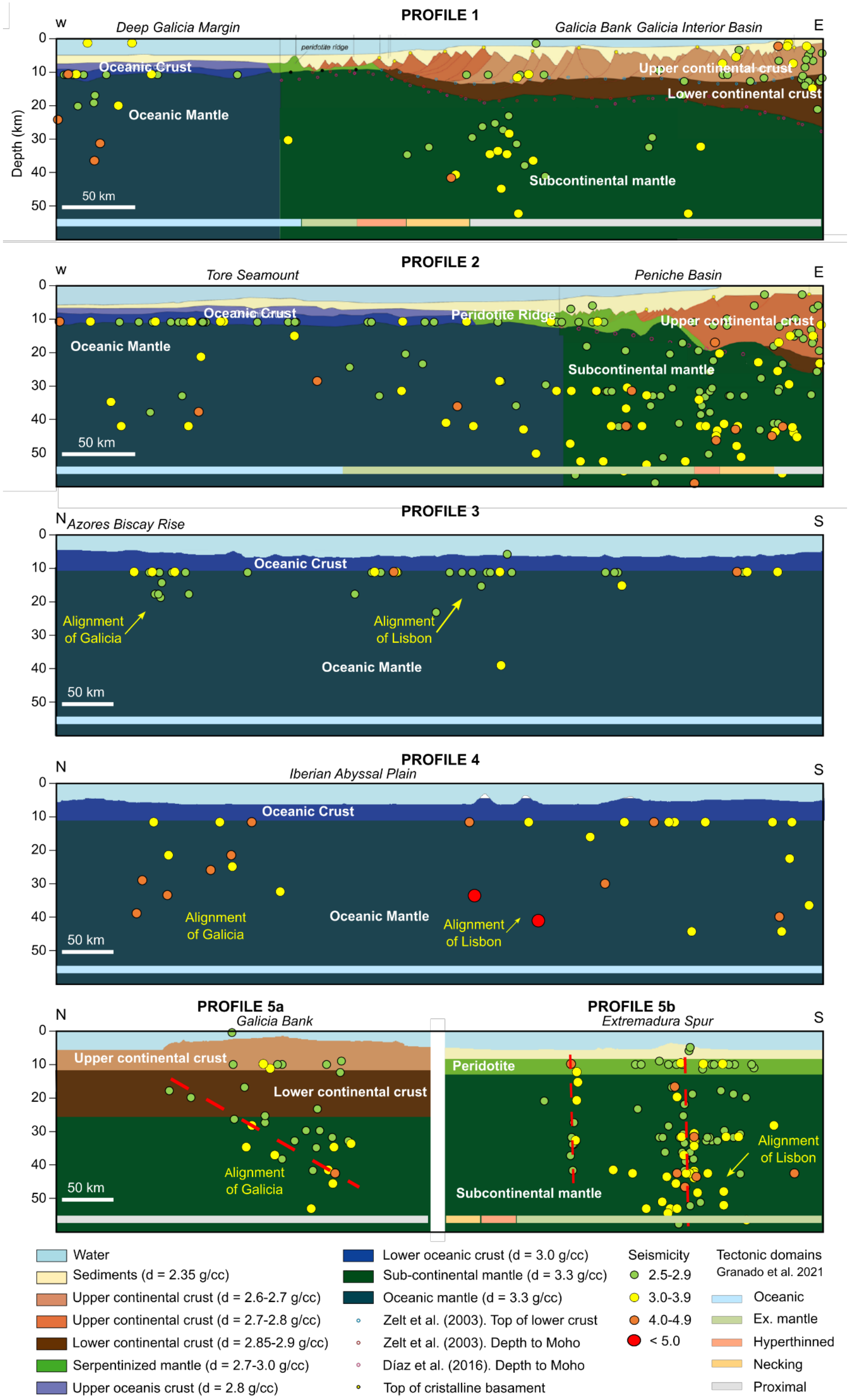


Figure 2. a) Seismicity studied in this work showing the events according to magnitude. b) Density map of events studied in this work highlighting the alignments in purple discontinuous lines 1) Galicia, north and 2), Lisbon, south (see text) some focal mechanisms are shown. Seismicity catalogue in the WIM in the period 2003-2022 (magnitude > 2.5, RMS < 1, Smaj < 25, Smin < 25 and Err < 75), according to the parameters described in the methodology section. Topographic base from EMODnet Bathymetry Consortium (2020). Focal mechanism from CMT (blue) Catalog and IGN (red) Seismic Moment Tensor Database.

P1 to P5 white solid lines show the position of the profiles shown in figure 4. Red circle is the 637-drill location cited in Boillot et al. (1988a)

Con formato: Color de fuente: Automático



PROFILE 1
W
Deep Galicia Margin
Galicia Bank
Galicia Interior Basin
E
Depth (km)
Oceanic Crust
Oceanic Mantle
Upper continental crust
Lower continental crust
Subcontinental mantle
50 km
PROFILE 2
W
Tore Seamount
Peniche Basin
E
Oceanic Crust
Peridotite Ridge
Upper continental crust
Oceanic Mantle
Subcontinental mantle
50 km
PROFILE 3
N
Azores Biscay Rise
S
Oceanic Crust
Alignment of Galicia
Alignment of Lisbon
Oceanic Mantle
50 km
PROFILE 4
N
Iberian Abyssal Plain
S
Oceanic Crust
Alignment of Galicia
Oceanic Mantle
Alignment of Lisbon
50 km
PROFILE 5a
Galicia Bank
PROFILE 5b
Extremadura Spur
N
S
Upper continental crust
Lower continental crust
Alignment of Galicia
Peridotite
Subcontinental mantle
Alignment of Lisbon
50 km
Water
Sediments (d = 2.35 g/cc)
Upper continental crust (d = 2.6-2.7 g/cc)
Upper continental crust (d = 2.7-2.8 g/cc)
Lower continental crust (d = 2.85-2.9 g/cc)
Serpentinized mantle (d = 2.7-3.0 g/cc)
Upper oceanis crust (d = 2.8 g/cc)
Lower oceanic crust (d = 3.0 g/cc)
Sub-continental mantle (d = 3.3 g/cc)
Oceanic mantle (d = 3.3 g/cc)
Zelt et al. (2003). Top of lower crust
Zelt et al. (2003). Depth to Moho
Díaz et al. (2016). Depth to Moho
Top of cristalline basement
Seismicity
2.5-2.9
3.0-3.9
4.0-4.9
< 5.0
Tectonic domains
Granado et al. 2021
Oceanic
Ex. mantle
Hyperthinned
Necking
Proximal

Figure 3. Representation of cross-sections of seismicity at depth overlaid on crustal cross-sections modified from ~~Granado~~ Amigo Marx et al. (~~2021~~2022), showing the crustal domains. The ~~location of the profiles is shown in figure 2a and the~~ seismicity included in each profile comprises 100 km band along that direction. ~~Profile 1) Depth profile of seismicity along alignment North (Galicia) b) Profile along alignment south c), d) North south cross-sections along different longitudes, oceanic domain, and e) close up in cross -section of the seismicity clusters around Galicia Bank and Extremadura Spur.~~

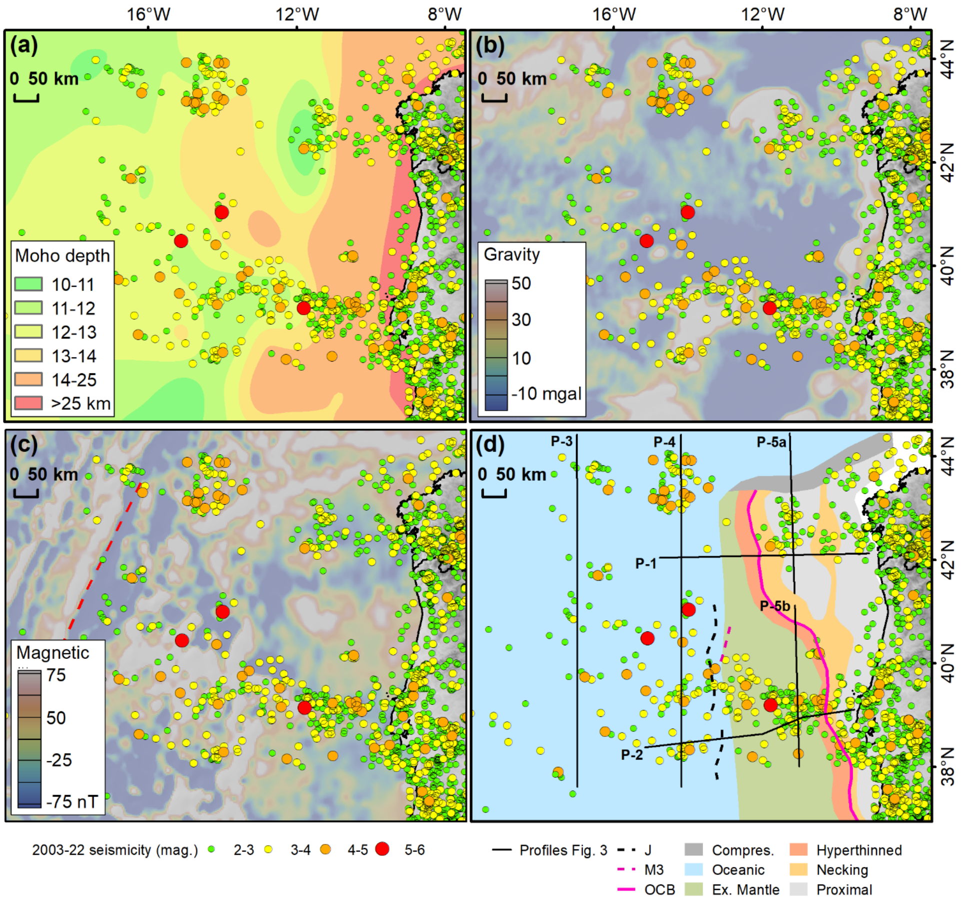


Figure 4. Map of the WIM seismicity located in this study overlaid on: a) crustal depth of the WIM (Laske et al., 2013); b) gravity map (Sandwell et al., 2014); c) magnetic map (Meyer et al., 2017); d) rift domains of the WIM (Granado et al., 2021).

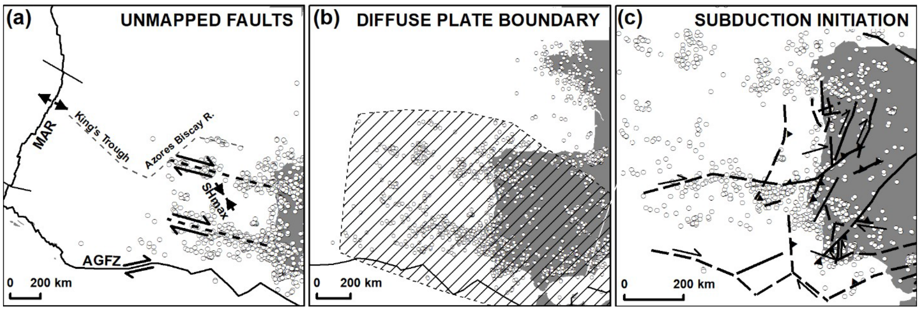


Figure 5. Schematic cartoons to illustrate the different hypothesis on the origin of seismicity of the WIM. a) shear corridors, inverse transform faults b) diffuse plate boundary c) initiation of subduction.

TABLES

Table 1. Synthesis of the statistical parameters of the seismicity catalogue prepared from the data of the IGN and IPMA seismic networks.

	RMS	Smaj	Smin	Err	GAP
Minimum	0.10	1.5	0.8	0.1	4
Maximum	0.99	24.8	22.9	74	335
Average	0.57	9.48	5.56	4.98	182.44
Standar deviation	0.21	5.59	4.09	11.46	87.29

Table 2. Focal mechanisms collected for the study area from CMT Catalog and IGN Seismic Moment Tensor Database.

LONGITUDE	LATITUDE	DEPTH (km)	Mw	DATE	DATABASE
-14.4400	39.4800	32	5.9	24/01/1983	CMT
-09.1204	43.7570	27	4.3	23/04/2006	IGN
-14.2965	39.9127	3	4.3	18/08/2007	IGN
-10.6200	40.1800	19	4.8	04/09/2018	CMT
-10.5665	40.2162	29	4.9	04/09/2018	IGN
-14.7700	40.1800	12	4.7	01/11/2018	CMT
-14.9012	40.2458	25	4.7	01/11/2018	IGN
-07.7683	44.1478	21	4.2	29/10/2021	IGN
-09.4919	42.5781	12	4.1	27/01/2022	IGN

Tabla con formato