Exploring a Relationship Between Earthquakes Location and the Temperature Evolution of a Sedimentary Basin in the Atlantic

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Abstract

The analysis of 8 earthquakes located in the Gorringe Bank and adjacent regions, including the northern part of the Horseshoe Basin and the region to the east, from -12oW to -9o W longitude and 35.8o N to 36.8oN latitude is carried out using temperature variations obtained from geoid height values in the region. Earthquakes occurred in 2005, 2007 and 2008. Considering distinct types of crust/materials in the region that have been identified in other studies conducted by different teams, it was possible to verify that the earthquakes occurred near the boundary of distinct types of crust/ materials or in the Gorringe Bank. The temperature evolution (geoid height variation) is not uniform in the region. Comparing data obtained in 2008 with data from 1996 it is possible to identify cooling and warming regions separated by points with constant values. The earthquakes studied occurred in the warming regions near the border with areas that are being cooled. Earthquakes located in the western part of the region are related with the cooling process of the Gorringe Bank, an elongated chain of underwater mountains with NE-SW direction presenting a negative gravity anomaly and a high value of geoid height. The external parts of this region have been losing heat while the internal part of the mountains shows an increase in geoid height values. This fact can be related to natural cooling due to natural sinks but also with possible sources of heat inside the mountains. The epicenters of the earthquakes are located near the lateral borders of the mountains in the warming regions, close to one point of nearly zero changes. Two earthquakes are located close to the points with the highest geoid height value in the latitude of the occurrence. The heat transferred from the cooled to the warmed regions can originate pressure gradients of thermal origin whose value can increase causing rupture of the materials and earthquakes. This process related with the cooling of the region may be increased by fluid movement.

Keywords: *Geoid heights; Temperature evolution; pressure thermal gradients; earthquakes; sedimentary basins*

1. Introduction

Geomagnetic anomalies registered by “Permanent Magnetic Observatories” in the Iberian Peninsula and Canary Islands were used [1] to deduce a water temperature increase in Mainland Portugal and parts of the Atlantic Ocean, including the Gorringe Bank and adjacent regions, at the end of February 1969. Average seismic velocity values obtained using the “first seismic wave arrival time registered on February 28, 1969” at three seismic observatories located near the Atlantic coast in Mainland Portugal, at three different latitudes, indicate higher temperature values at lower latitude [1]. Seismic Bulletins published by IPMA (Portuguese Institute of Sea and Atmosphere) shows that since February 1969 until now several earthquakes has been registered in the region, some of them with high magnitude values.

The effects of heating/cooling near the contact zone of different materials were studied [2] using thermal and mechanical properties of two materials (A and B) with initial equal volume and temperature, placed in physical contact. Due to different values of density, specific heat, thermal expansion (contraction) coefficient and thermal conductivity, the temperature increase will be different in each material but presents the same value in the contact zone originating temperature gradient values with different signals in the perpendicular direction to the contact zone [2]. Pressure variation near the contact zone will be different in the two materials originating pressure gradients of thermal origin. The model described was applied [3] to peridotites and gabbro. The results show a horizontal compression exerted by gabbro on peridotites. Near the contact zone there is a decrease in thermal stress in the vertical direction in gabbro relative to peridotites. Thermal stresses are higher on peridotites than in gabbro [3]. Heating/cooling processes in the region can develop compression and deformation phenomena and may eventually cause rupture of materials.

The present work uses the location of 8 earthquakes, with magnitude values between 3.6 and 5.9, The present work uses the location of 8 earthquakes, with magnitude values between 3.6 and 5.9, recorded in years 2005, 2007 and 2008, to identify heating/cooling processes in the region using geoid height values obtained online, with GEM84, GEM96 and EGM2008 models, using GeographicLib utility, disponible by SourceForge.[4].

2. The region on study

Located in the southwestern part of the North Atlantic Ocean in a magma-poor continent transition zone, the region under study is characterized by an upper serpentinized mantle [5]. The serpentinization was recognized under continental crust in the northeastern part of the region [6] and in the Gorringe Bank, in the western part, where exhumed mantle was detected [7][8][9]. Different tectonic processes in the past originated a complex structure in the region where different types of crust were identified [6][10] including old oceanic crust from the Western Tethys, thin and thick continental crust and oceanic Atlantic crust. The heat flow density values obtained in the region [11][12] are relatively higher than was expected. The lower values were found in the

oceanic Atlantic crust (southern border of the studied region) with no evidence of serpentinized mantle [5]. Thermal conductivity values show different types of material near the contact zones of crustal types [6].

The region studied includes, from West to East, the Gorringe Bank, the northern part of the Horseshoe Basin and the region to the east, from -12ºW to -9ºW longitude and 35.8ºN to 36.8ºN latitude.

3. Data

The values of the geoid height in the region are not constant in space or time, showing different values at the same location in the years 1984, 1996, and 2008 [13]. However, it is possible to identify points where the values remain constantly separating increasing from decreasing values. They are points without changes in density and/or temperature values.

Earthquakes used in the present work are located in specific regions named SB-1, SB-2 and SB-3. Table 1 shows dates of occurrence and geographical coordinates of the earthquake's sources. The magnitude and the type of crust are also included in the table. Because geoid height variations from 1984 to 2008 are different in the southern and northern parts of the Gorringe Bank, a subdivision was made. Maximum values of geoid height in region SB-3' were obtained in 1984 and in SB-3b maximum geoid height values were obtained in 2008.

Tab. 1. Earthquakes location , date of occurrence and magnitude

Date	Latitude N	Longitude W	Region	Magnitude	Crustal type
29.08.2005	36.692	-11.177	SB-3b	4.6	Gorringe region-Northern part
19.10.2005	36.704	-9.794	SB-2	3.6	Continental crust over serpentinized mantle
26.05.2005	36.368	-11.465	SB-3b	4.2	Gorringe region-Eastern side
19.07.2005	36.176	-11.606	SB-3a	4.6	Gorringe region-Southern part
01.07.2007	36.568	-11.986	SB-3b	4.9	Gorringe region-Western side
12.02.2007	35.933	-10.495	SB-1	5.9	Gorringe region/oceanic crust from Western Tethys
11.01.2008	36.480	-9.944	SB-2	4.7	Continental crust over serpentinized mantle
10.05.2008	35.970	-10.801	SB-1	4.1	Gorringe region/ oceanic crust from Western Tethys

SB-1 earthquakes are in lower latitudes of the Horseshoe Basin, near the contact zone between crust formed by exhumed mantle materials associated with the Gorringe Bank and old oceanic crust remaining from Western Tethys Ocean. The highest geoid height values were found in 1984 showing a pronounced decrease in 1996 and a small increase in some parts in 2008. "Fig. 1" shows the evolution of geoid height values near the source of an earthquake with magnitude 5.9 registered in 12.02.2007 at latitude 35.933º N. The geoid height values in 2008 (in blue) are higher than those obtained in 1996 (in red), indicating warming of the region. The crossing point of values in 1996 and 2008 is located at -10.25 W. The earthquake occurred at -10.495 W. The region was strongly warmed in 1984.

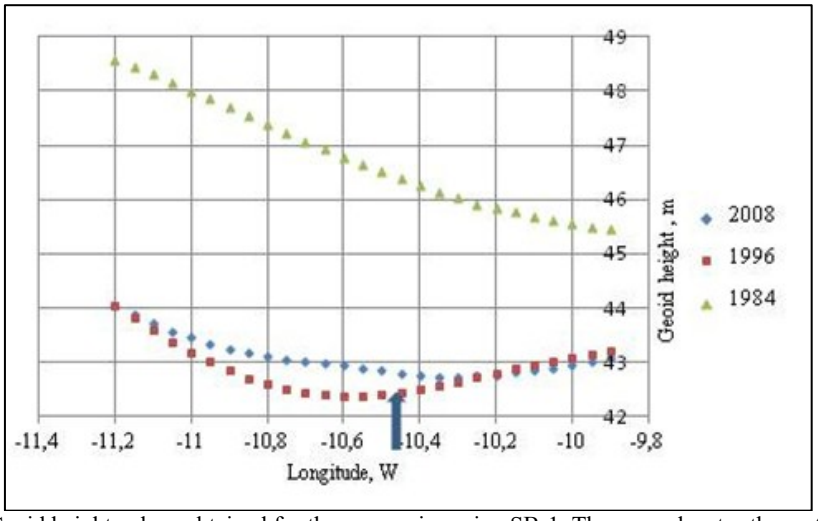

Fig. 1. Geoid height values obtained for three years in region SB-1. The arrow locates the earthquake

SB-2 earthquakes are located in thin continental crust located over a serpentinized mantle near the northeastern border of the Gorringe Bank and adjacent regions. Latitude values are higher than those of SB-1 and longitudes are in the interval from -10.0 to -9.8 º W. The earthquake whose location is shown in "Fig. 2" occurred on October 19, 2025, at latitude 36.704ºN. The geoid height line in 2008 is higher (+ 0.41 m) than that obtained in 1996. The region would be warming in 2025, after having undergone significant cooling from 1984 to 1996 and did not reach a value like that of 1984.

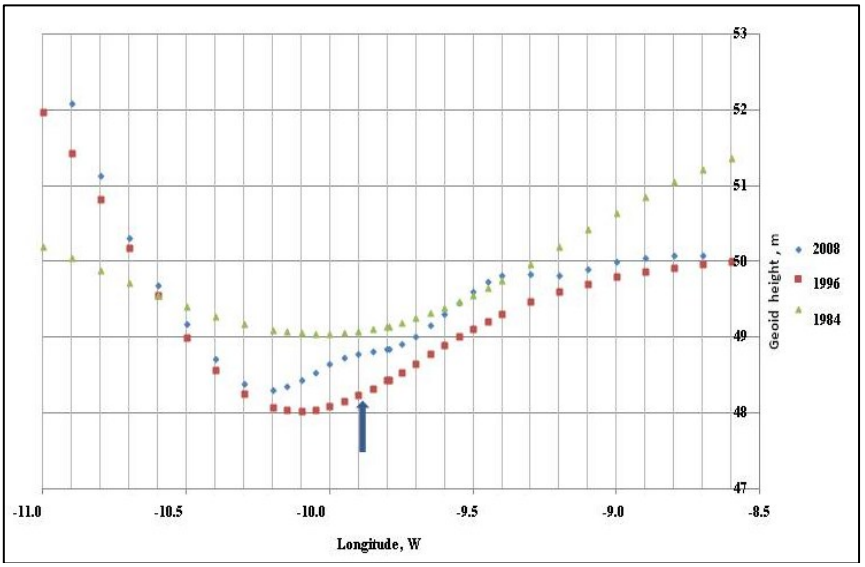

Fig. 2. Geoid height values obtained for three years in region SB-2. The arrow locates the earthquake

Region SB-3 is the Gorringe Bank, an elongate chain of underwater mountains with cylindrical shape suffering cooling from materials in the eastern and western sides. Using the results obtained in engineering problems [14] it is expected an increase of geoid height near the middle longitude of the cylinder and values decreasing in lateral borders. Looking at the values obtained from southern latitude to high latitude values in the region, it is possible to deduce the existence of internal sources of heat that seem to have been more active in 1984 in the southern part of the bank while in the northern part the high geoid values were obtained in 2008. "Fig 3" shows data related with two earthquakes of magnitude 4.6. On the left side an earthquake registered on August 29, 2005, at 36.692 º N latitude and on the right side an earthquake registered on July 19, 2005, at 36.176 º N latitude. On both sides the epicenter is at the location where the height of the geoid reaches its maximum value in 1996 and later in 2008 but the geoid height in 1984 has the maximum value in the lower latitude and a low value at the higher latitude. In 2005 the region was heating up in both cases. The earthquake on the left side occurred at -11.177 º W, immediately before the region of maximum value (-11.20 º W in 2008 and -11.25º W in 1996). The separation between the heating zone and the cooling zone is at longitude -10.60 º W (Eastern side) and -11.65 º W (Western side).

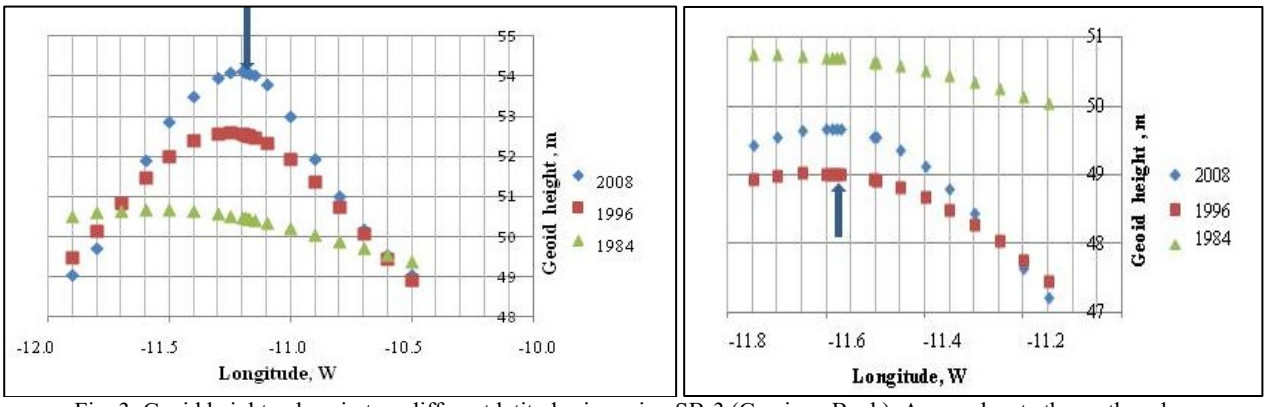

Fig. 3. Geoid height values in two different latitudes in region SB-3 (Gorringe Bank). Arrows locate the earthquake

SB-3b earthquakes are located near the borders of the Gorringe Bank in the Eastern or Western side. "Fig 4" shows the location of two earthquakes. On the left side the earthquake located on the eastern border of Gorringe at latitude 36.368 º N with magnitude 4.2 and on the right side an earthquake located on the western border, at latitude 36.568 º N with magnitude 4.9.

The earthquakes occurred on May 26, 2005, and July 1, 2007, which means that geoid height values were rising. It is possible to see also that in the eastern side of Gorringe (left side of the figure) the increase from 1996 to 2008 values is higher than the increase in the western side.

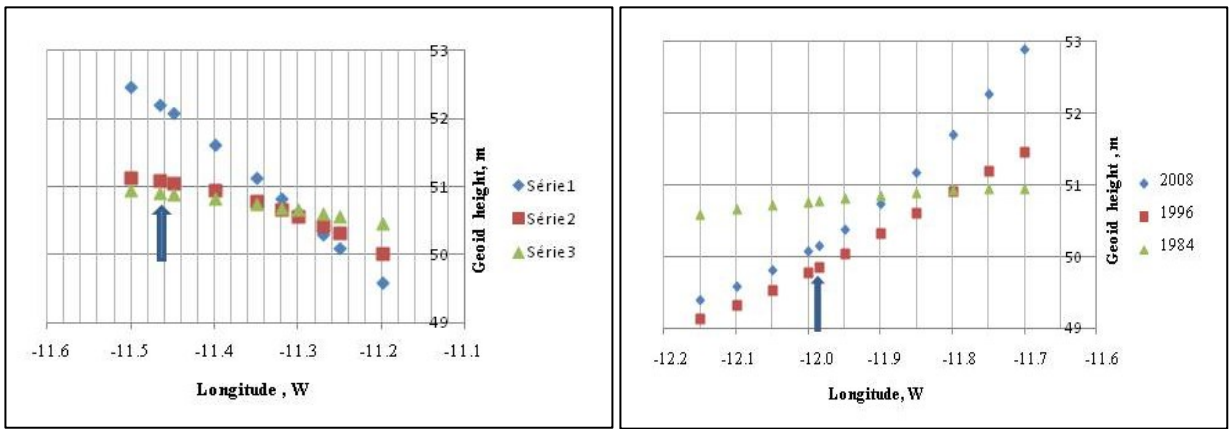

Fig. 4. Geoid height values in two different latitudes in region SB-3b Arrows locate the earthquakes

4. Conclusion

In all sub regions studied the Geoid Height value was rising up when the earthquake occurred. This means temperature increasing compared to neighbour regions. It is possible to see in "Fig. 1, 2 and 4" points without changes in geoid height values. The model described in [3] and [2] can be used in this region to increase deformation, causing possible rupture of materials. The location of earthquakes near the contact zones of different materials can favour the process. The increase of geoid height values in the Gorringe Bank can be explained as a consequence of cooling of lateral parts due to contact with cooling water and sediments of the Horseshoe Basin.

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Earthquake's location, date of occurrence and magnitude were obtained in the webpage of IPMA/ Seismicity/Seismic Bulletins.

Geoid Height values were obtained online using the GeoidEval utility provided by SourceForge.

References

1. M.R. Duque, "Investigating a Temperature Increase Before and During a Magnitude 8 Earthquake Affecting the Portuguese Territory", Inżynieria Mineralna 3, 2, 27-31 (2025).
2. M.R. Duque, "Problems associated with the contrast between thermal and mechanical properties of materials", Brazilian Journal of Development 9, 3362-3370 (2023).
3. M.R. Duque, "Density Variations, Thermodynamic Properties and Earthquakes in the Horseshoe Basin", Advances in Meteorology and Geophysics 2023", edited by M.G. Pereira, R. Oliveira, P. Navarro and L. Bugalho (UTAD, Universidade de Évora, IPMA, I.P: 2023), p.p. 105-110.
4. Online Geoid Calculations using GeoidEval Utility. Last access April 8, 2026. https://geographiclib.sourceforge.io/cgi-bin/GeoidEval.
5. J. Kim Welford, "Magma-poor continent–ocean transition zones of the southern North Atlantic: a wide-angle seismic synthesis of a new frontier", Solid Earth 15, 683–710 (2024).
6. R. Correia, M. Prada, V. Sallarès, A. L. Cameselle, L.M. Pinheiro, I. Grevemeyer and C. R. Ranero, "Deep crustal structure and seismogenic potential of the Southwest Iberian Margin: insights from seismic and gravimetric data", Geophys. J. Int. 242, 1-20 (2025).
7. J. M. Auzende, J.L. Olivet, J. Charvet, A. L. Lann, X.L. Pichon, J. H. Monteiro, A. Nicolas and A. Ribeiro, "Sampling and observation of oceanic mantle and crust on Gorringe Bank", Nature 273 (5657), 45-49 (1978).
8. J. Girardeau, G. Cornen, P. Agrinier, M. O. Beslier, G. Dubuisson, B. Le Gall, C. Monnier, L.M. Pinheiro, A. Ribeiro and H. Whitechurch, "Preliminary results of nautile dives on the Gorringe Bank (West Portugal)", Comptes Rendus de l'Academie des Sciences Series IIA Earth and Planetary Science 4(326), 247-254 (1998).
9. V. Sallarès, S. Martinez-Loriente, M. Prada, E. Gràcia, C. Ranero, M.-A.-Gutscher, R. Bartolome, A. Gailler, J. J. Dañobeitia and N. Zitellini, "Seismic evidence of exhumed mantle rock basement at the Gorringe Bank and the adjacent Horseshoe and Tagus abyssal plains (SW Iberia)", Earth and Planetary Science Letters 365, 120-131 (2013).
10. S. Martinez-Loriente, V. Sallarès, E. Gràcia, R. Bartolomé, J. J. Dañobeitia and N. Zitellini, "Seismic and gravity constraints on the nature of the basement in the Africa-Eurasia plate boundary: New insights for the geodynamic evolution of the SW Iberian margin", J. Geophys. Res. Solid Earth 119 (1), 127-149 (2014).
11. I. Grevemeyer, N. Kaul and A. Kopf, "Heat flow anomalies in the Gulf of Cadiz and off Cape SanVincente, Portugal", *Marine and Petroleum Geology* 26, 795-804 (2009).
12. E. V. Verzhbitsky and V. G. Zolotarev, "Heat flow and the Eurasian-African plate boundary in the eastern part of the Azores-Gibraltar fracture zone", Journal of Geodynamics 11, 267-273 (1989).
13. M.R. Duque, "The Deep South Portuguese Margin: An Attempt to Account for Heat Flow Density Variation in this Region", International Journal of Terrestrial Heat Flow and Applied Geothermics 5, 14-19 (2022).
14. Y. A. Çengel and A. J. Ghajar, Heat and Mass Transfer. Fundamentals and Applications (McGraw-Hill, New York, 2011), pp. 232-235.