The 1755 Great Lisbon Earthquake, 270 years later: A unique event in a cryptic plate boundary

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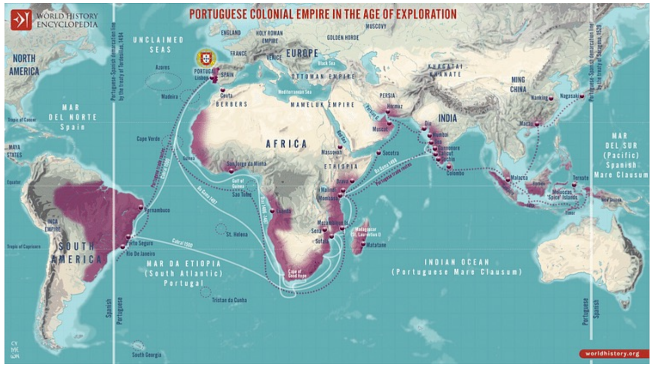
Part I

The birth of modern Seismology

Lisbon in 1755: A city of oppulence

Portugal in the age of explorations



15th century (Ceuta 1415) – 20th century (Macau 1999)
(Greatest extent in 1820)

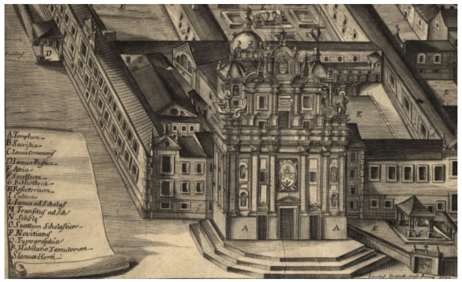
Economic and cultural richness

Lisbon, 1752

Architectural splendor

“Águas Livres” aqueduct (1731-1799)

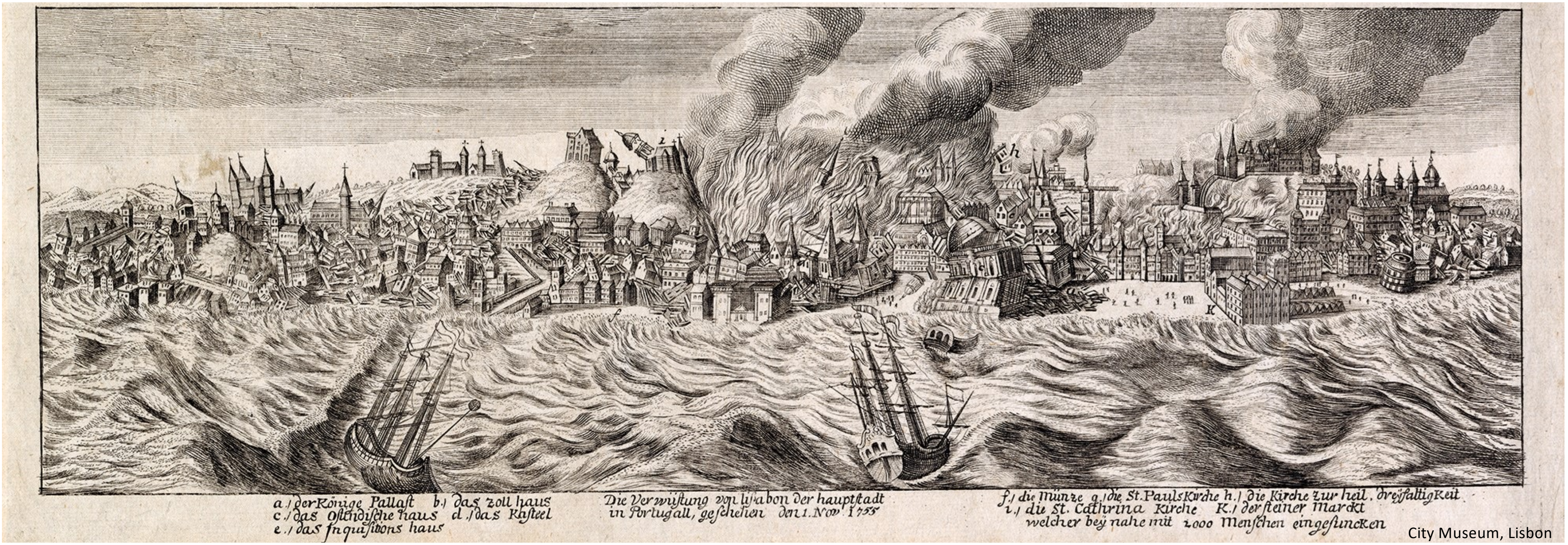
Counter-reform deeply religious culture



The university forbade “… any conclusions contrary to the Aristotelian system … such as those of Descartes, Newton, …” (1746)

Execution of criminals convicted by the Inquisition, 18th century, City Museum, Lisbon

November 1st, 1755: The great Lisbon earthquake



City Museum, Lisbon

<u>Ground shaking</u>

All Saints day, many in houses and churches.
~9h40, 7-15 min, 2-3 moments of shaking
“>1/3 of houses remain habitable”
“1/10 of houses are levelled to the ground"
(Moreira de Mendonça)

<u>Fires</u>

House stoves, church candles.
Many wood buildings.
Deadly for many under rubble.
People rush to the riverside.

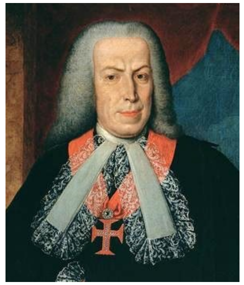
<u>Tsunami</u>

Inundates downtown, ships in the river.
“Water level rises for 5 min, then falls, repeats for 3x.”
Sea level returns to normal at ~14h

<u>+ Many aftershocks…</u> (~11h, 10 years…)

Emergency Management

Marquês do Pombal
(1699-1782)
(PM: 1756-1777)



- "First" earthquake disaster in which the state takes the responsibility of organizing the emergency response.

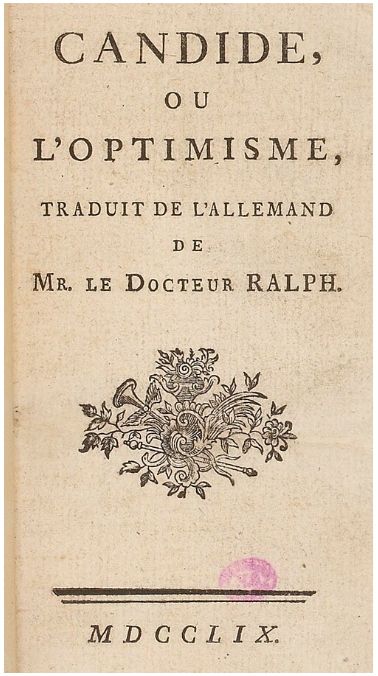
- "Take care of the living, bury the dead."
- Search & rescue.
- Military help from out of Lisbon.
- Centralized food distribution.
- Strong law enforcement.
- Prevent people from leaving the city.
- Temporary shelter.
- Rebuilding of Lisbon.

Theological & Philosophical

Divine punishment

João Glama Ströberle (1756)
Museu Nacional de Arte Antiga, Lisbon

A benevolent God?



CANDIDE,
OU
L'OPTIMISME,
TRADUIT DE L'ALLEMAND
DE
MR. LE DOCTEUR RALPH.

MDCCLIX.

Voltaire (1759)

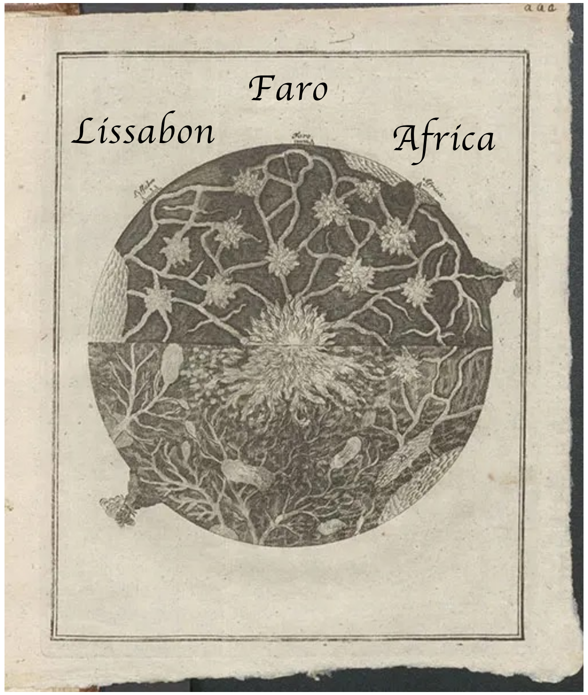
A natural disaster, but with human responsibility.

"If the residents of this large city had been more evenly dispersed and less densely housed, the losses would have been fewer or perhaps none at all"

Rousseau to Voltaire (1756)

Scientific

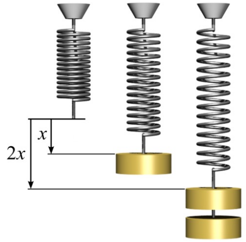
The inner Earth



Ruhlen (1756), Linda Hall Library

Elasticity (Hooke, 1676)

$$F = -kx$$



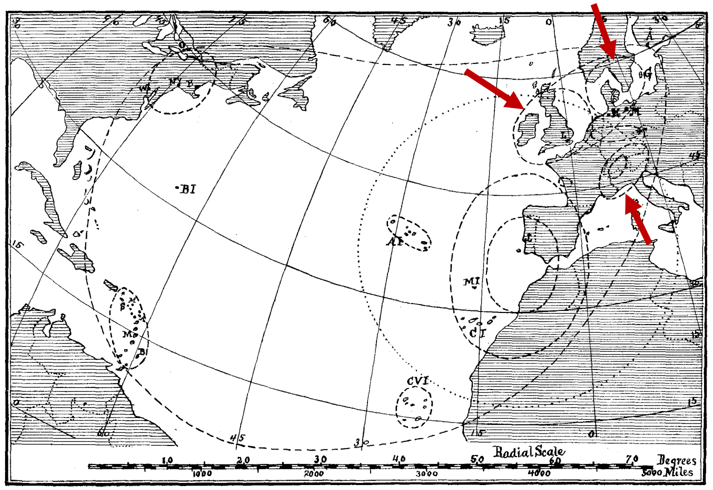
Sound & Acoustics

Mersenne 1640: Measured speed of sound
Newton 1687: Motion through resisting mediums

1D Wave equation (D'Alembert, 1747)

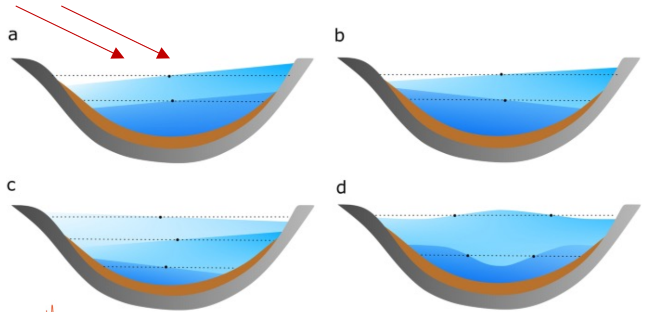
$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$$

The "motion of the Earth" reaches far from the source (Kant, 1756 a,b,c)



The Lisbon Earthquake of 1755

Reid, BSSA 1914



Seiches (Bueno et al, EFM 2020)

“Conjectures concerning the cause, and observations upon the phaenomena, of earthquakes; particularly of that great earthquake of the first of November 1755, which proved so fatal to the city of Lisbon, and whose effects were felt as far as Africa, and more or less throughout almost all Europe”

John Michell (Philosophical Transactions, 1760)

John Michell (1724-1793)
“Father of Seismology & Magnetometry”

Seismic waves

“… earthquakes have their origin underground…”
“… the cause (…) is subterraneous fires…”

Seismically active regions.

Volcanoes are seismically active regions.

Earth motion:
1) “Tremulous” (shaking), near-field.
2) “Propagated by waves”, far-field.

theſe extraordinary motions. The cauſe I mean is ſubterraneous fires. Theſe fires, if a large quantity of water ſhould be let out upon them ſuddenly, may produce a vapour, whoſe quantity and elaſtic force may be fully ſufficient for that purpoſe. The principal facts, from which I would prove, that theſe fires are the real cauſe of earthquakes, are as follow.

6. *Firſt*, The ſame places are ſubject to returns of earthquakes, not only at ſmall intervals for ſome time after any conſiderable one has happened, but alſo at greater intervals of ſome ages.

9. *Secondly*, Thoſe places that are in the neighbourhood of burning mountains, are always ſubject to frequent earthquakes; and the eruptions of thoſe mountains, when violent, are generally attended with them.

11. *Thirdly*, The motion of the earth in earthquakes is partly tremulous, and partly propagated by waves, which ſucceed one another ſometimes at larger and ſometimes at ſmaller diſtances; and this latter motion is generally propagated much farther than the former.

15. *Fourthly*, It is obſerved in places, which are ſubject to frequent earthquakes, that they generally come to one and the ſame place, from the ſame point of the compaſs. I may add alſo, that the velocity, with which they proceed, (as far as one can collect it from the accounts of them) is the ſame; but the velocity of the earthquakes of different countries is very different.

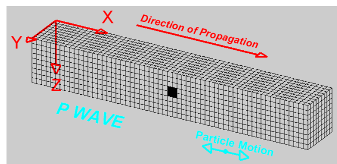
21. *Fifthly*, The great Liſbon earthquake has been ſucceeded by ſeveral local ones ſince, the extent of which has been much leſs.

weight of the ſuperincumbent matter, this compreſſion muſt be propagated on account of the elaſticity of the earth, in the ſame manner as a pulſe is propagated through the air; and again the materials immediately over the cavity, reſtoring themſelves beyond their natural bounds, a dilatation will ſucceed to the compreſſion; and theſe two following each other alternately, for ſome time, a vibratory motion will be produced at the ſurface of the earth. If theſe alter-

Source, ray direction.
Seismic velocity.

Aftershocks.

“… this compression must be propagated on account of the elasticity of the Earth, …



“Conjectures concerning the cause, and observations upon the phaenomena, of earthquakes; particularly of that great earthquake of the first of November 1755, which proved so fatal to the city of Lisbon, and whose effects were felt as far as Africa, and more or less throughout almost all Europe”

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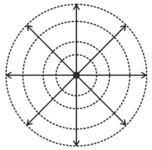
Earthquake location

1. Incoming directions

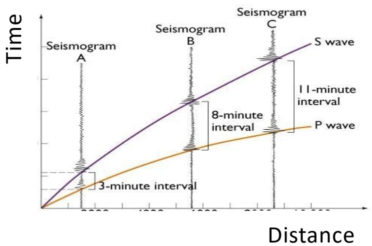


91. *Firſt*, The different directions, in which it arrives at ſeveral diſtant places: if lines be drawn in theſe directions, the place of their common interſection muſt be nearly the place ſought: but this is liable to great difficulties; for there muſt neceſſarily be great uncertainty in obſervations, which cannot, at beſt,

2. Arrival times

92. *Secondly*, We may form ſome judgment concerning the place of the origin of a particular earthquake, from the time of its arrival at different places; but this alſo is liable to great difficulties. In both theſe methods, however, we may come to a much greater degree of exactneſs, by taking a medium amongſt a variety of accounts, as they are related by different obſervers. But,

3. $t_{tsunami} - t_{seismic}$



93. *Thirdly*, We may come to the greateſt degree of exactneſs in thoſe caſes, where earthquakes have their ſource from under the ocean; for, in theſe inſtances, the proportional diſtance of different places from that ſource may be very nearly aſcertained, by the interval between the earthquake and the ſucceeding wave: and this is the more to be depended on, as people are much leſs likely to be miſtaken in determining the time between two events, which follow one another at a ſmall interval, than in obſerving the preciſe time of the happening of ſome ſingle event.

	d	t_{seis}	t_{tsu}
	Half deg.	Min.	Min.
Liſbon *	2	3	12
Oporto *	3	5	
Ayamonte	6		53
Cadiz	9	12	82
Madrid	9	11	
Gibraltar	11	18	
Madeira	19	25	152
Mountſbay	20		267
Plymouth	21		360
Portſmouth	23	29	
Kingſale	23		290
Swanſea	24		530
The Hague	30	32	
Lochneſs	33	66	
Antigua	98		565
Barbadoes	101		485

Earthquake location:
“... I compute, at a distance of about a degree of a great circle from Lisbon, and a degree and a half from Oporto”,

the height of fifty or ſixty feet. The true reaſon of this diſproportion, ſeems to be the difference in the depth of the water; for, in every inſtance in the above table, the time will be found to be proportionably ſhorter or longer, as the water through which the wave paſſed was * deeper or ſhallower. Thus the

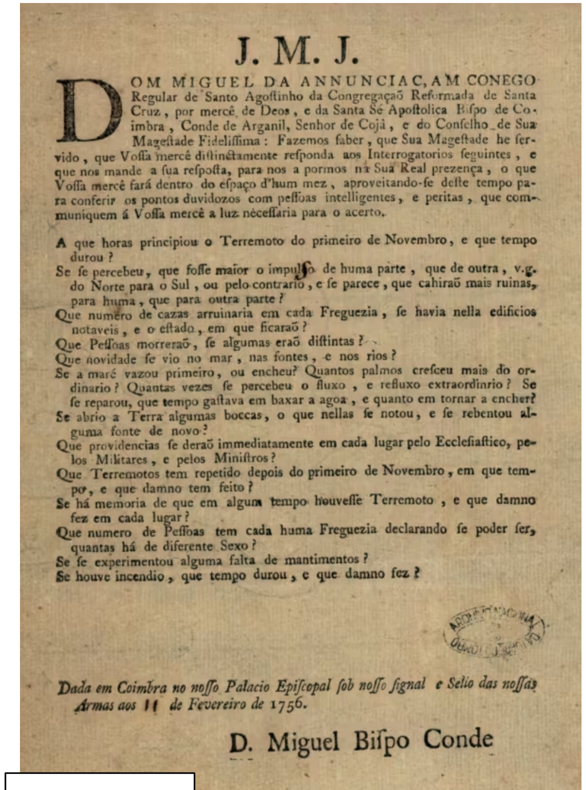
Tsunami speed depends on water depth.

100. If we would inquire into the depth, at which the cauſe lies, that occaſions any particular earthquake, I know of no method of determining it, which does not require obſervations not yet to be had; but if ſuch could be procured, and they were made with ſufficient accuracy, I think ſome kind of gueſs might be formed concerning it: for,

“... [as to] the depth (...) I know of no method of determining it, ...” 😰

“Macroseismic” questionnaire

“… has a <u>truly scientific character</u>,
quite unusual for the time”
Montessus de Balore (early 20th century)



J. M. J.

DOM MIGUEL DA ANNUNCIAC,AM CONEGO Regular de Santo Agoftinho da Congregaçaõ Reformada de Santa Cruz, por mercê de Deos, e da Santa Sé Apoftolica Bifpo de Coimbra, Conde de Arganil, Senhor de Cojà, e do Confelho de Sua Mageftade Fideliffima: Fazemos faber, que Sua Mageftade he fervido, que Voffa mercê diftinctamente refponda aos Interrogatorios feguintes, e que nos mande a fua refpofta, para nos a pormos na Sua Real prezença, o que Voffa mercê fará dentro do efpaço d'hum mez, aproveitando-fe defte tempo para conferir os pontos duvidozos com peffoas intelligentes, e peritas, que communiquem á Voffa mercê a luz neceffaria para o acerto.

A que horas principiou o Terremoto do primeiro de Novembro, e que tempo durou?
Se fe percebeu, que foffe maior o impulfo de huma parte, que de outra, v.g. do Norte para o Sul, ou pelo contrario, e fe parece, que cahiraõ mais ruinas, para huma, que para outra parte?
Que numero de cazas arruinaria em cada Freguezia, fe havia nella edificios notaveis, e o eftado, em que ficaraõ?
Que Peffoas morreraõ, fe algumas eraõ diftintas?
Que novidade fe vio no mar, nas fontes, e nos rios?
Se a maré vazou primeiro, ou encheu? Quantos palmos crefceu mais do ordinario? Quantas vezes fe percebeu o fluxo, e refluxo extraordinrio? Se fe reparou, que tempo gaftava em baxar a agoa, e quanto em tornar a encher?
Se abrio a Terra algumas boccas, o que nellas fe notou, e fe rebentou alguma fonte de novo?
Que providencias fe deraõ immediatamente em cada lugar pelo Ecclefiaftico, pelos Militares, e pelos Miniftros?
Que Terremotos tem repetido depois do primeiro de Novembro, em que tempo, e que damno tem feito?
Se há memoria de que em algum tempo houveffe Terremoto, e que damno fez em cada lugar?
Que numero de Peffoas tem cada huma Freguezia declarando fe poder fer, quantas há de diferente Sexo?
Se fe experimentou alguma falta de mantimentos?
Se houve incendio, que tempo durou, e que damno fez?

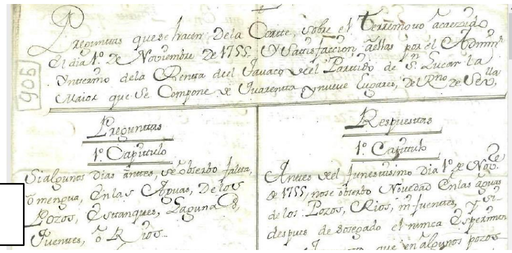
Dada em Coimbra no noffo Palacio Epifcopal fob noffo fignal e Selio das noffas Armas aos 11 de Fevereiro de 1756.

D. Miguel Bifpo Conde

Portugal

1. At what time did the earthquake begin on November 1st, and how long did it last? **[Time, duration of shaking]**
2. Did you perceive the shock to be greater from one direction to the other? E.g., from north to south, or on the contrary, did more buildings seem to fall to one side or the other? **[Directionality]**
3. How many buildings were ruined in each parish, if any notable buildings were among them, and in what state did they remain? **[Damage]**
4. How many people died, and were any of them distinguished? **[Fatalities]**
5. What unusual phenomena were observed in the sea, springs, and rivers? **[Hydrological effects]**
6. Did the sea rise or fall first, how many hands did it rise above normal, how many times did you notice the extraordinary rise or fall, and did you note how long it took for the water to fall and rise? **[Tsunami polarity, amplitude, period, nr of waves]**
7. Did the earth open up in some places, what was noticed there, and did any new springs burst forth? **[Surface “rupture”]**
8. What measures were immediately taken in each place by the clergy, the military, and the ministers? **[Emergency response]**
9. What earthquakes have repeated since the first of November, at what time, and what damage have they done? **[Aftershocks]**
10. Have there been any other earthquake in living memory and what damage did they cause in each place? **[Background seismicity]**
11. How many people are there in each parish, stating, if possible, how many of each gender? **[Demography]**
12. Has there been shortage of food? **[Supplies]**
13. If fire broke out, how long did it last and what damage did it cause? **[Fire duration and damage]**

Extra. Did any damage occur in the 1755 earthquake, and if so, what was it, and has it been repaired? **[Reconstruction]**



906

Preguntas

1° Capitulo

Respuestas

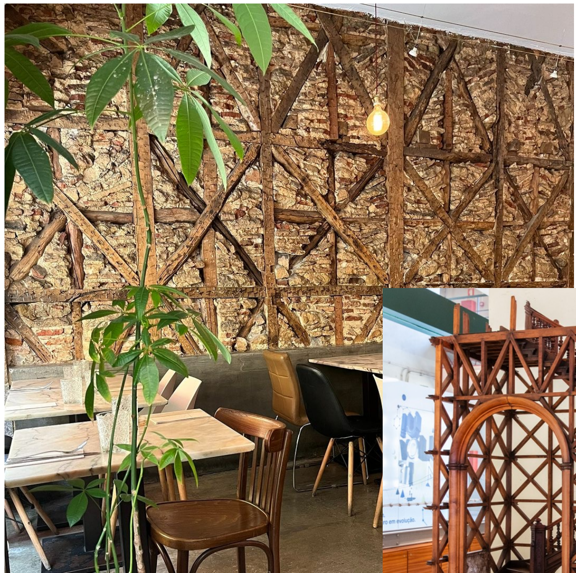
1° Capitulo

Spain

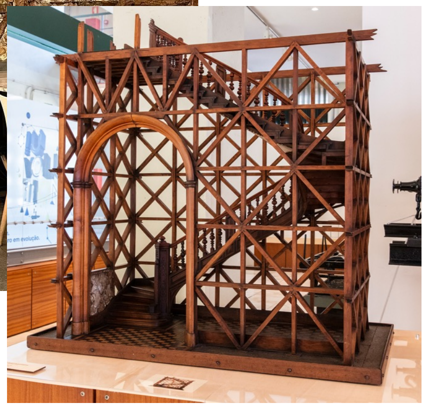
Currently archived at Torre do Tombo.
(Lost for the Algarve and Lower Tagus Valley.)

Engineering & City Planning

“Gaiola Pombalina” & anti-fire walls



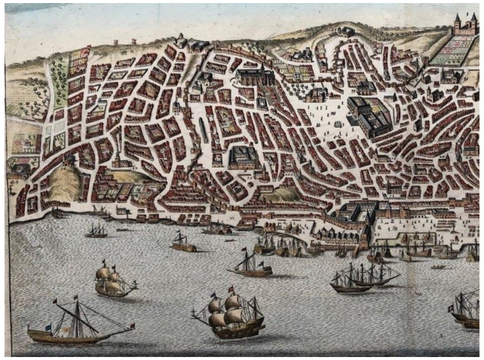
Café do Rio, Praça do Comércio



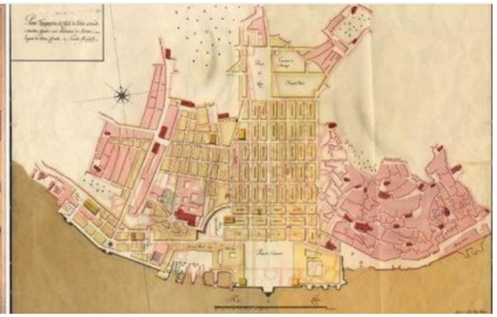
Museu do Técnico

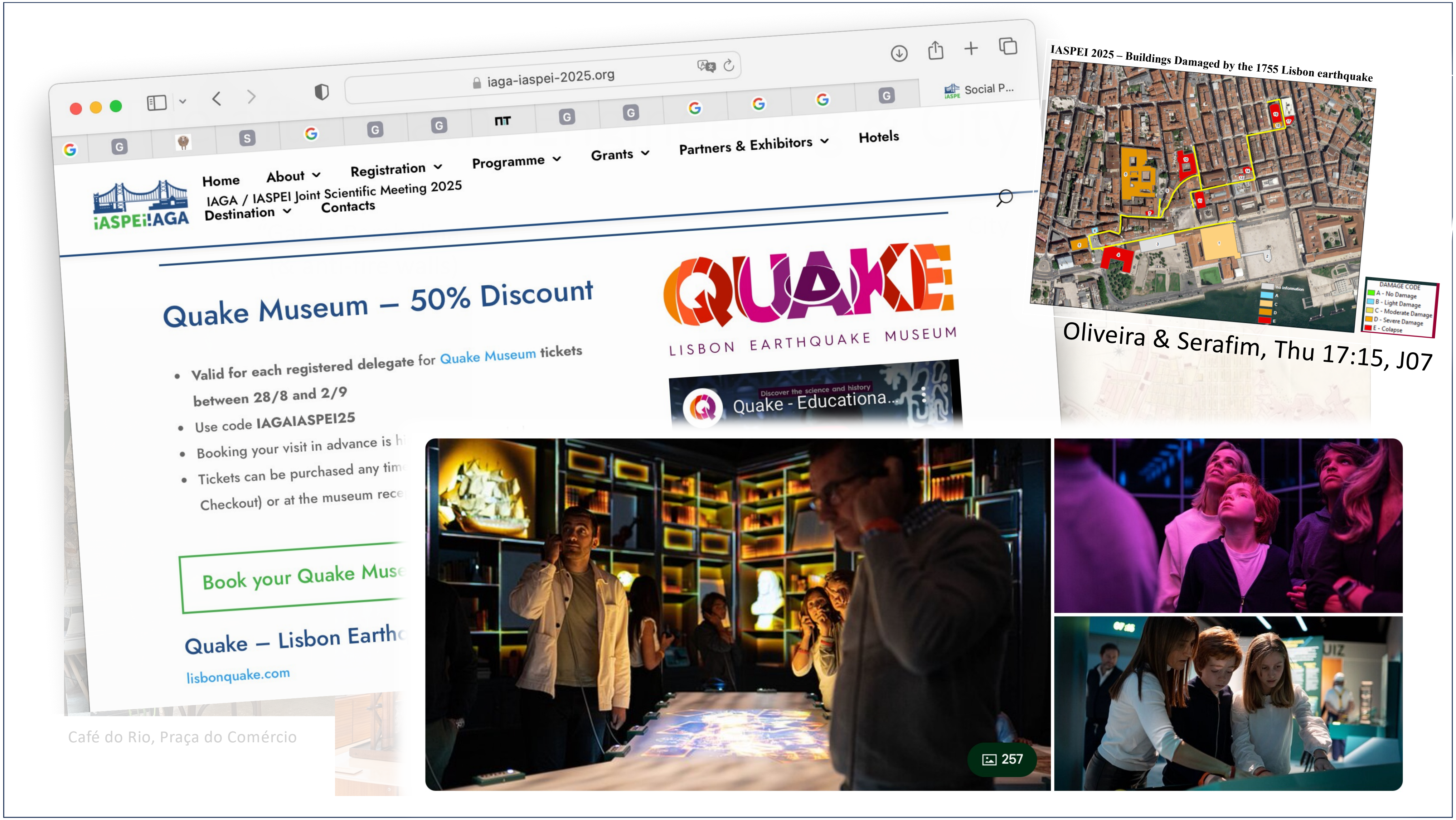
City Planning

Before



After

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257
IASPEI 2025 – Buildings Damaged by the 1755 Lisbon earthquake
DAMAGE CODE
A - No Damage
B - Light Damage
C - Moderate Damage
D - Severe Damage
E - Colapse
Oliveira & Serafim, Thu 17:15, J07
Café do Rio, Praça do Comércio

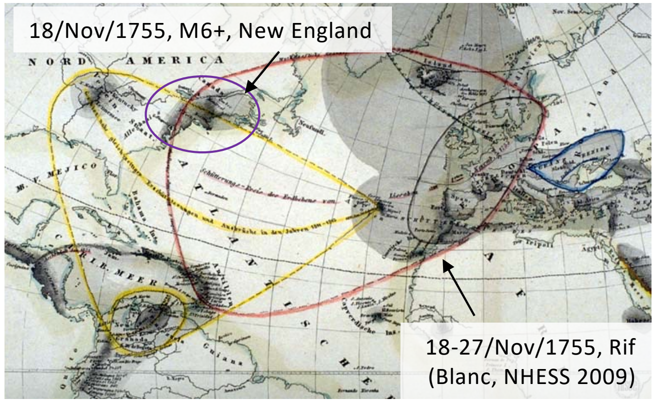
Part II

The quest for the source

Seismic Intensities

- Revision needed.
- Complex very far and near fields.

Felt area (1849-52)



NISEE

AHEAD (Aug/2025)

Date		Epicentral area	Info
1755-02-26		Serbia	
1755-08-01	06:40		
1755-08-07		Vallee De La Loire	
1755-08-24	03	Mora.TO	
1755-08-28		Friuli	
1755-10-01		Niederurnen, Naefels/GL	
1755-10-15		CLUSE DE CHAMBERY (CHAMBERY)	
1755-11-01		Ponza	
1755-11-01	09:30	Lisboa	
1755-11-01	17	Acquapendente	
1755-11-02	04	La Brevine	
1755-11-02	14:30	Aesch	
1755-11-04	01	W. Cabo San Vicente	
1755-11-10		W. Cabo San Vicente	
1755-11-15	02	Sangüesa.NA	
1755-11-16	08:30	Torrecampo.CO	
1755-11-27	11	Mar de Alborán	
1755-12-09		Donauwörth	
1755-12-09	13:45	Brig-Naters	
1755-12-20		Le Locle	
1755-12-21	03	Brig-Naters	
1755-12-26	16	Düren	
1755-12-26	23:56	Hautes-Fagnes	
1755-12-27		Düren	
1755-12-27	03	[Düren]	
1755-12-27	03	CONFLENT (PRADES)	
1755-12-27	04:15	CONFLENT (PRADES)	
1755-12-27	09	Stolberg-Vicht	
1755-12-27	13:30	Brig-Naters	
1755-12-30		Brig-Naters	

4 earthquakes in Aug/1755

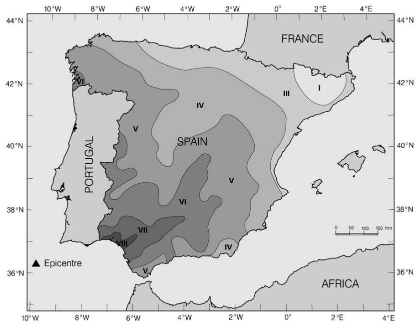
2 earthquakes in Oct/1755

10 earthquakes in Nov/1755

13 earthquakes in Dec/1755

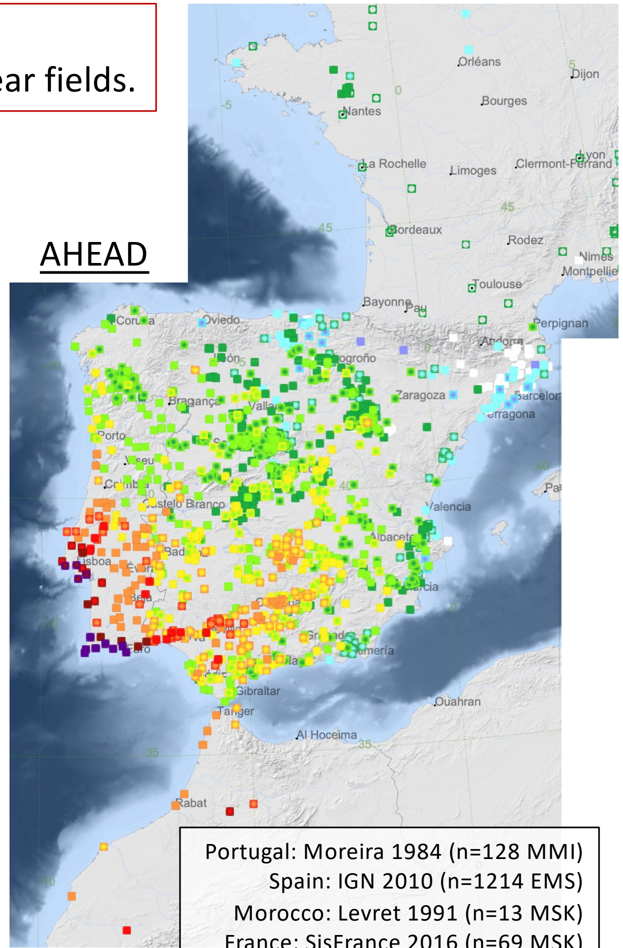
Intensities

Pereira de Sousa (1932)
(n=500+ Rossi-Forel)

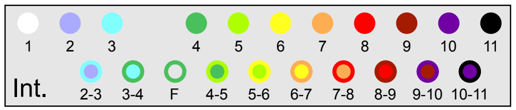


Martinez Solares & Lopez Arroyo (2004)

AHEAD



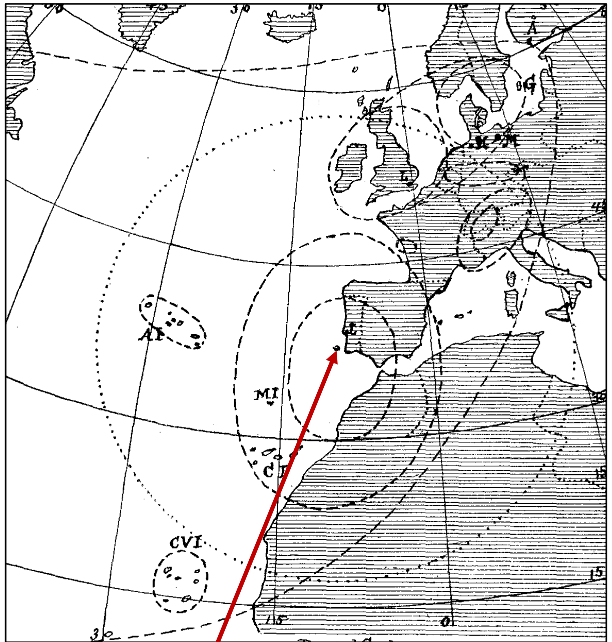
Portugal: Moreira 1984 (n=128 MMI)
Spain: IGN 2010 (n=1214 EMS)
Morocco: Levret 1991 (n=13 MSK)
France: SisFrance 2016 (n=69 MSK)



“Somewhere” in the SWIM plate boundary.

Macroseismic location

Reid (1914)



“… only for convenience”

Machado (1966)

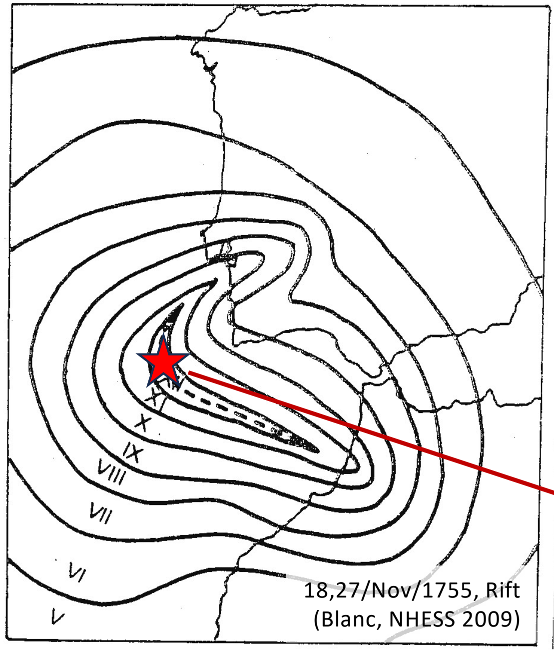
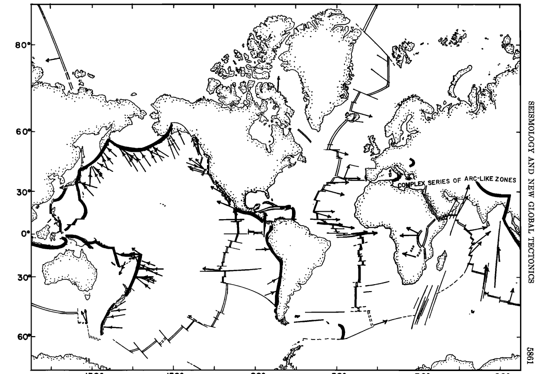
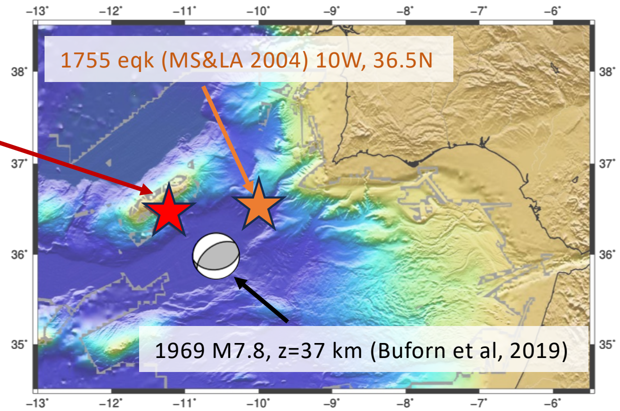


Plate tectonics (1960s)



Isacks, JGR 1968

1969 M7.8 earthquake

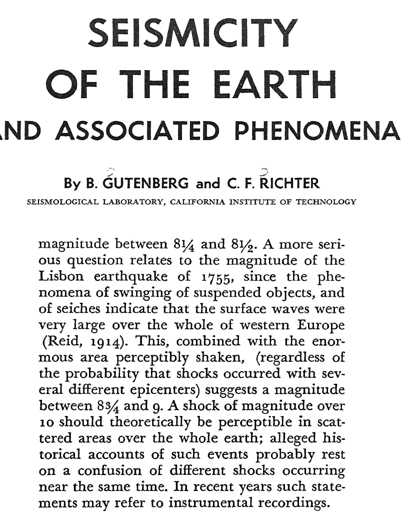


Magnitude

Strong trade-off: location vs magnitude.

Gutenberg and Richter (1949)
M 8.75 – 9

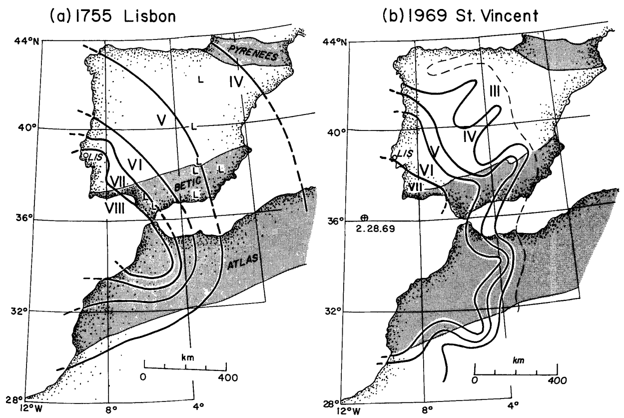
"… swinging of suspended objects, and of seiches, indicate that the surface waves were very large over the whole of western Europe (Reid 1914)" + perceptibility radius of 2500 km


SEISMICITY OF THE EARTH AND ASSOCIATED PHENOMENA

By B. GUTENBERG and C. F. RICHTER
SEISMOLOGICAL LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY

magnitude between 8¼ and 8½. A more serious question relates to the magnitude of the Lisbon earthquake of 1755, since the phenomena of swinging of suspended objects, and of seiches indicate that the surface waves were very large over the whole of western Europe (Reid, 1914). This, combined with the enormous area perceptibly shaken, (regardless of the probability that shocks occurred with several different epicenters) suggests a magnitude between 8¾ and 9. A shock of magnitude over 10 should theoretically be perceptible in scattered areas over the whole earth; alleged historical accounts of such events probably rest on a confusion of different shocks occurring near the same time. In recent years such statements may refer to instrumental recordings.

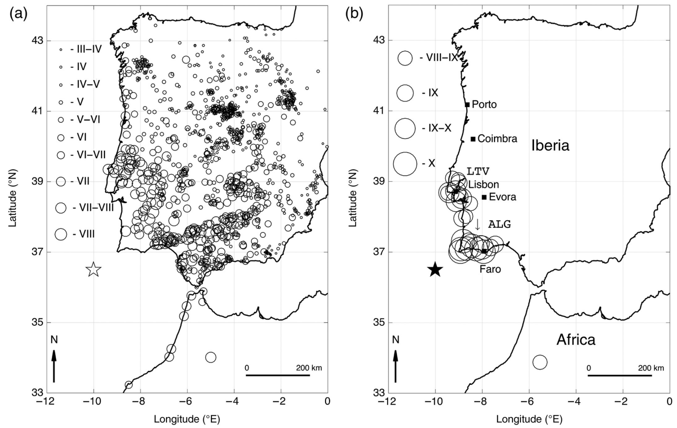
Johnston (GJI 1996)
M 8.7 ± 0.39
(Machado 1966 epicenter)



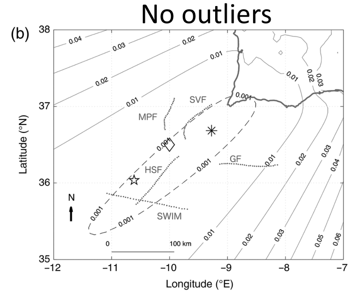
Martinez Solares & Lopez Arroyo (JS 2004)
M 8.5 ± 0.33

Fonseca (BSSA 2020)
(partial) M 7.7 ± 0.5

No outliers
Outliers



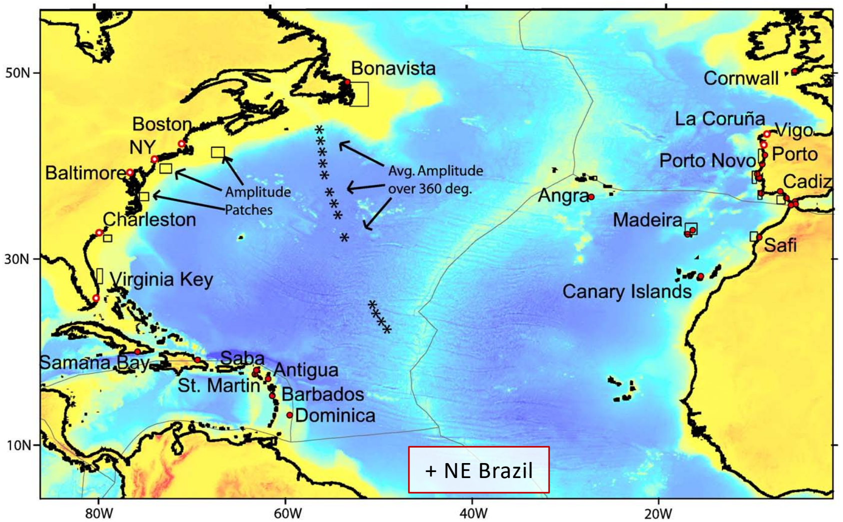
No outliers



Trans-Atlantic tsunami

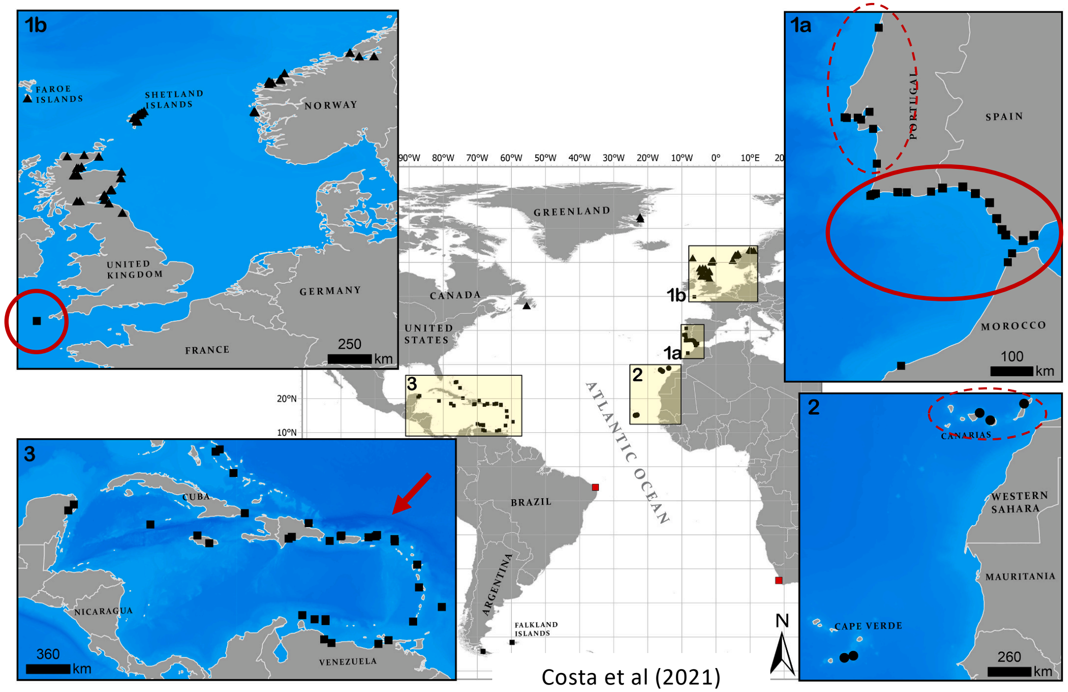
- Historical records around the N Atlantic.
- Tsunami deposits in SW Iberia, + some further.

<u>Run-up historical reports</u>



Barkan et al (2009)

<u>Tsunami deposits</u>



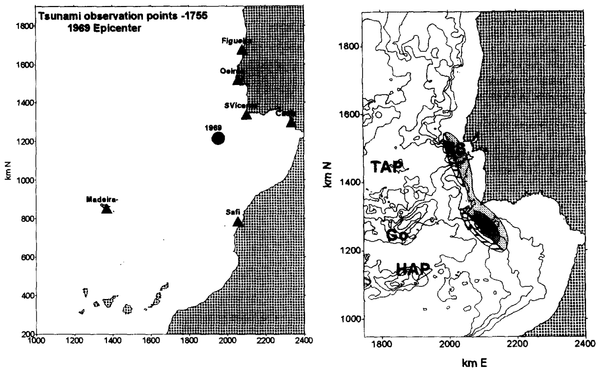
Costa et al (2021)

Which fault(s)?

Possibly a multiple fault rupture.

Tsunami arrival times & heights

Baptista et al (PCE 1996)

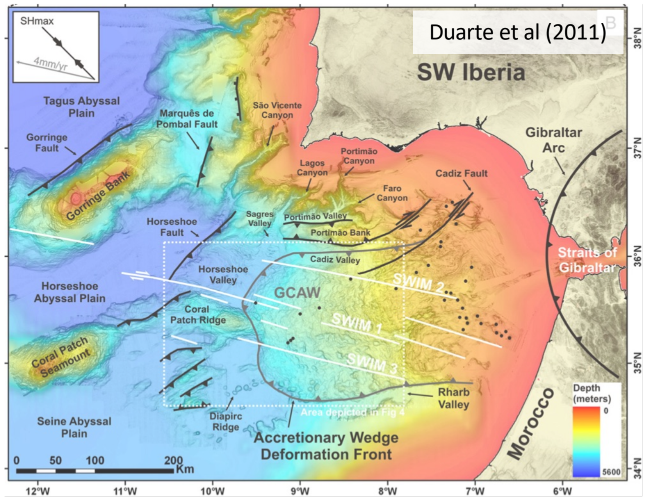


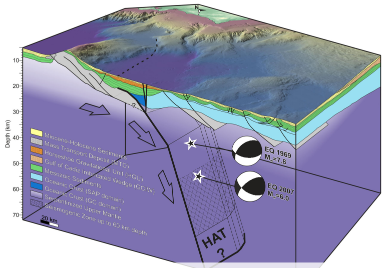
Baptista et al (NHESS 2003)

Location	Coordinates	Wave height (m)	Travel time (min) and estimated error
Portuguese west coast			
Porto	8.18° W,41.15° N	1	–
Figueira da Foz	8.88° W,40.14° N	–	45–50
Lisboa (Oeiras)	9.08° W,38.73° N	5	25 (estimated error±10)
Cabo S Vicente	8.99° W,37.00° N	> 10	16 (estimated error±7)
Gulf of Cadiz			
Cadiz	6.30° W,36.05° N	15	78 (estimated error±15)
Huelva	6.93° W,37.25° N	–	45 (estimated error±10)
Ceuta	5.32° W,35.88° N	2	–
Gibraltar	5.35° W,36.15° N	2	–
Madeira Islands			
Madeira	16.88° W,32.63° N	4	90 (estimated error±15)
Porto Santo	16.16° W,33.06° N	–	60 (estimated error±15)
Cornwall (UK)			
Penzance	5.53° W,51.52° N	2	315
Newlyn	15.56° W,50.10° N	–	279
Plymouth	4.15° W,50.31° N	–	390
Morocco			
Safi	9.33° W,32.30° N	–	26–34 (estimated error±20)

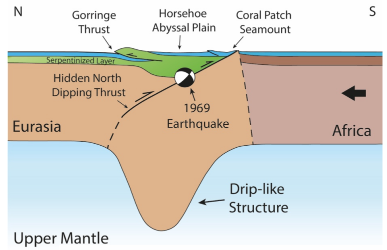
? (Blanc 2008)

Marine geophysics: The offshore faults





Martinez-Loriente et al (2021)



Duarte et al (2025)

Single faults:

- Gorringe (Machado 1966)
- Marquês de Pombal (Zitellini et al, 1999)
- Gibraltar arc system (Gutscher, 2006)

Multiple rupture fault:

- Marquês de Pombal + Guadalquivir (Baptista et al, 2003)
- Marquês de Pombal + Pereira de Sousa (Terrinha et al, 2003)
- Offshore + LTV (Vilanova & Fonseca, 2003)
- Horseshoe + SWIM1 (Rosas et al, 2016)

Horseshoe plain:

- “Horseshoe plain” (Barkan et al, 2009)
- Horseshoe Abyssal Thrust (Martinez Loriente et al, 2021)
- “Hidden north dipping thrust” (Duarte et al, in press)

Summary I: The 1755 earthquake

- Historical observations have limited accuracy; revision is needed.
- Reconciling datasets:
  - Macroseismic ground motion:
    - Complexities in the near (local effects) and very far field (other earthquakes).
    - Location: SW Iberia margin plate boundary.
    - Magnitude: M 7.7 (partial) - 8.7.
    - Multiple fault rupture: Suggested by duration (3x, 7-15 min) and complexity of intensities.
  - Tsunami:
    - Complexity in the near field (observational, multiple rupture).
    - Very large tsunami: Very shallow slip (Tohoku-type), low v_{rup} tsunami earthquake, …
  - Seiches & swinging of suspended objects throughout Europe:
    - Strong long-period surface waves: Shallow strong earthquake?
  - Marine geophysics:
    - No surface rupture imaged so far by marine geophysics.

Part III

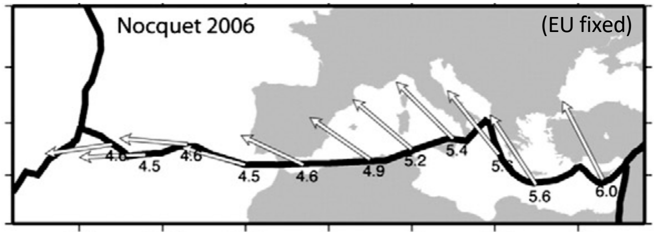
Beyond the 1755 earthquake

Seismic hazard and risk of the SW Iberia plate boundary

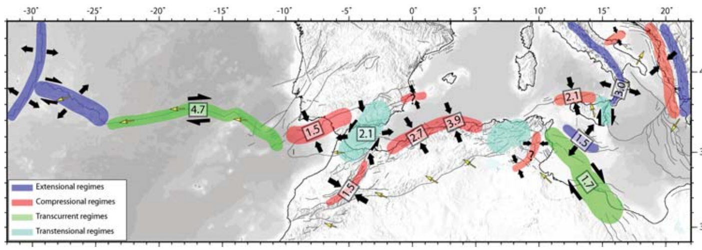
SW Iberia Plate Boundary

- NW-SE oblique convergence.
- Wide region of deformation.

<u>Plate convergence</u>

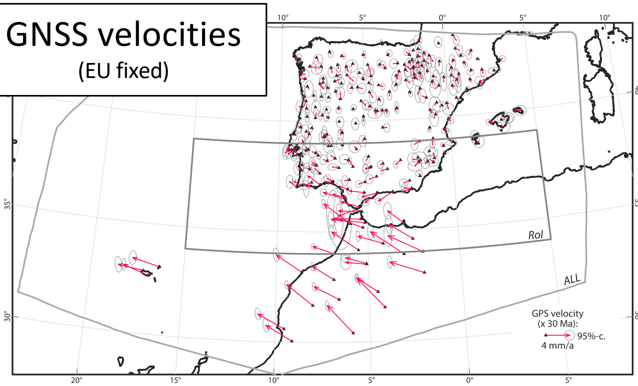


Nocquet et al, 2006

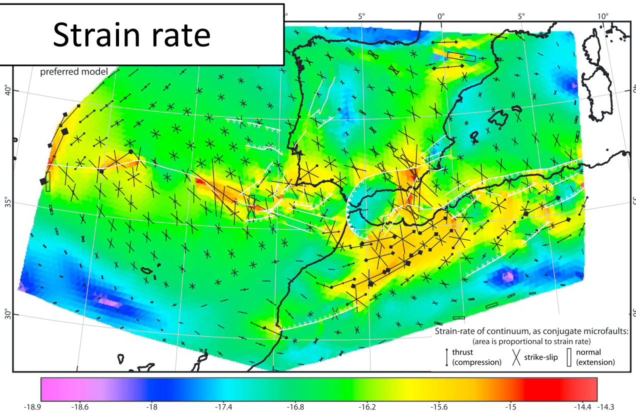


Serpelloni et al, 2007

GNSS velocities
(EU fixed)

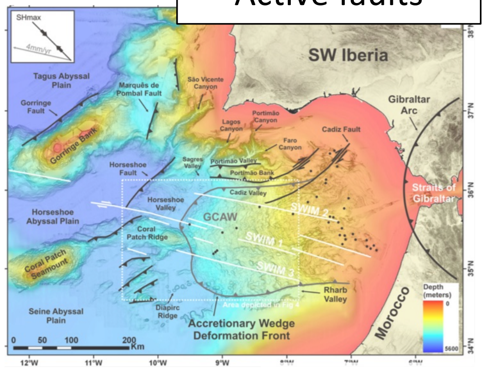


Strain rate



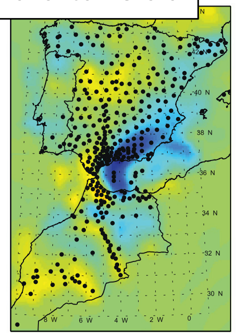
Neres et al, 2016

Active faults

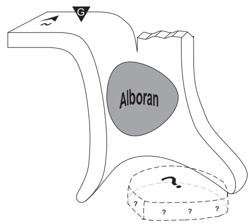


Duarte et al (2011)

Gibraltar slab



480 km

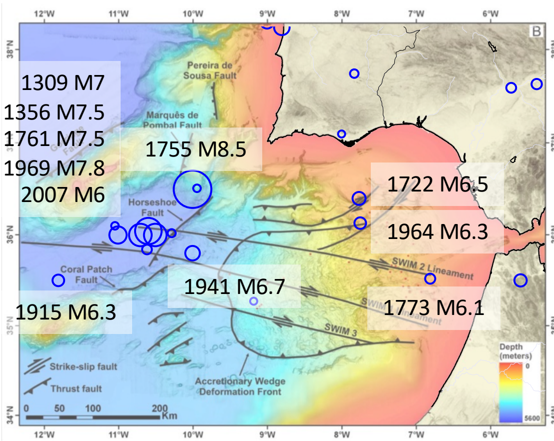


Bezada et al, 2013

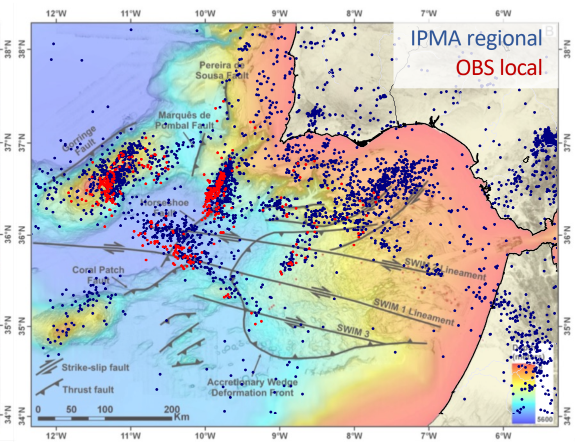
Seismicity

- Abundant offshore historical & instrumental earthquakes.
- Crustal faults remain mostly silent.
- Deep seismogenic faults (>20 km) remain blind.

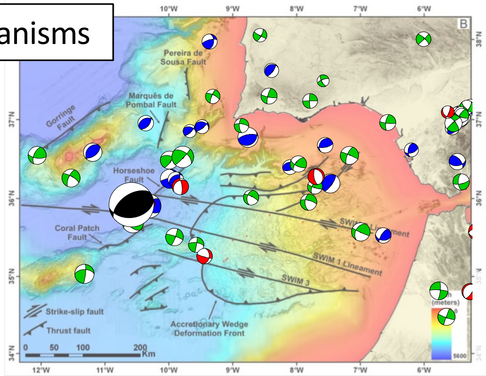
Historical earthquakes



Instrumental earthquakes (2007-2024)



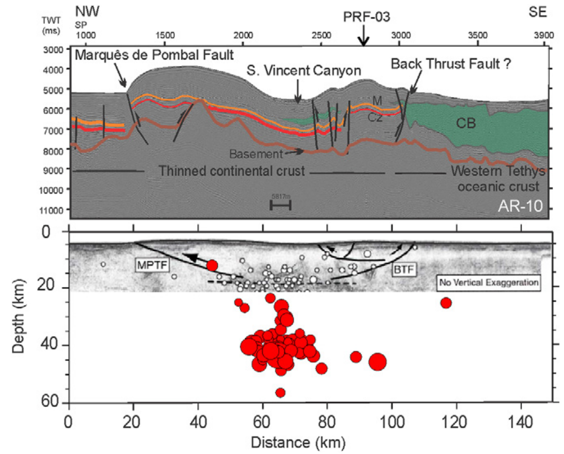
Focal mechanisms

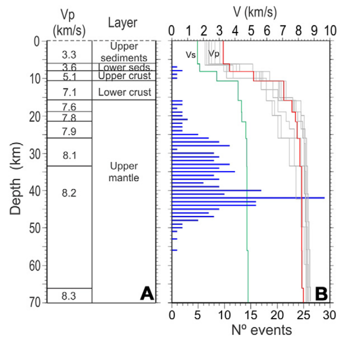


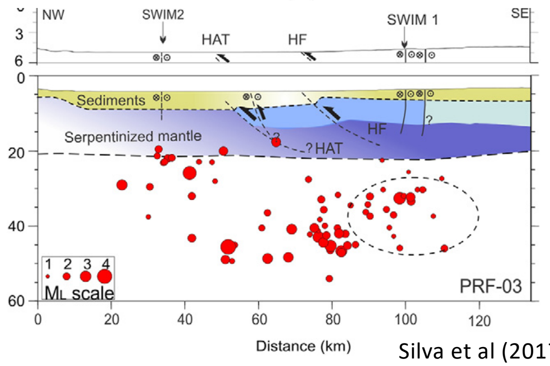
Reverse
Strike-Slip
Normal

EDSF, SHEEC, IPMA,
Custodio et al (2016a,b),
Duarte et al (2011)

High-quality OBS locations







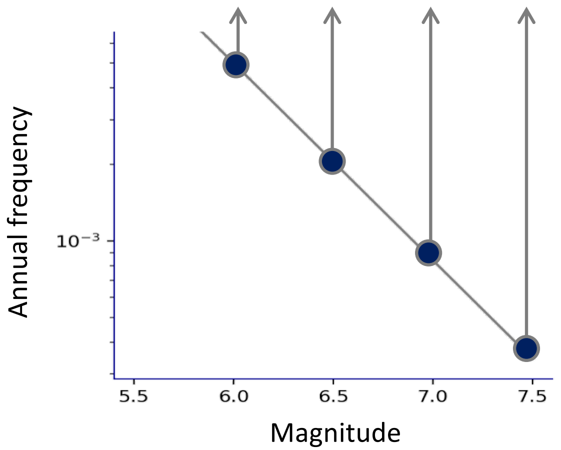
Silva et al (2017)

How often?

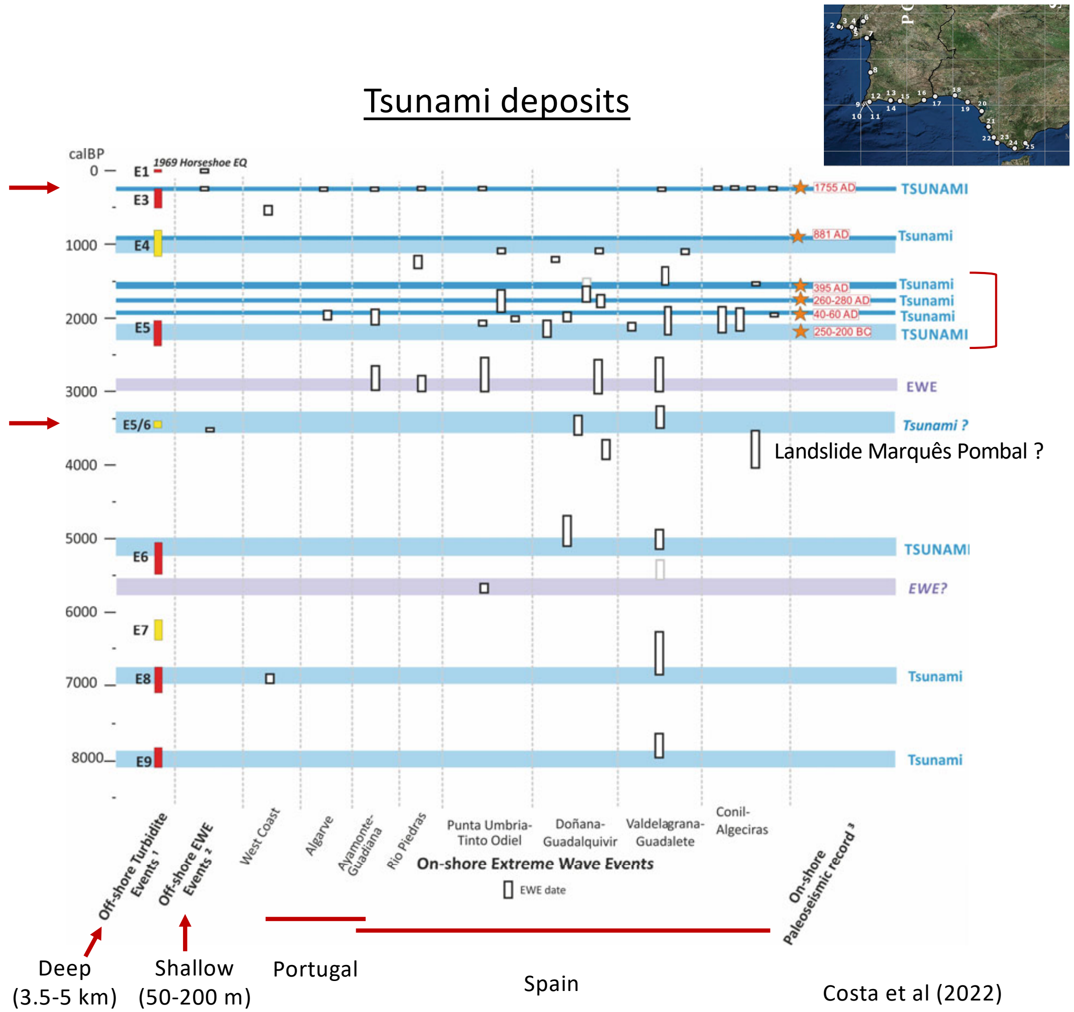
Frequency-magnitude & tsunami deposits: few thousands of years.

Frequency-magnitude recurrence times (years)

Magnitude	6	6.5	7	7.5
Marquês de Pombal	200	488	1192	2909
Horseshoe Fault	789	1927	4703	11476
Gorringe	253	619	1512	3691



Tsunami deposits

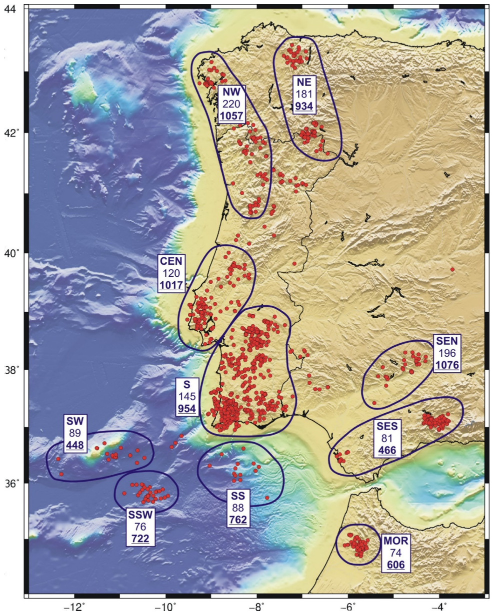


Costa et al (2022)

Ground motion modeling

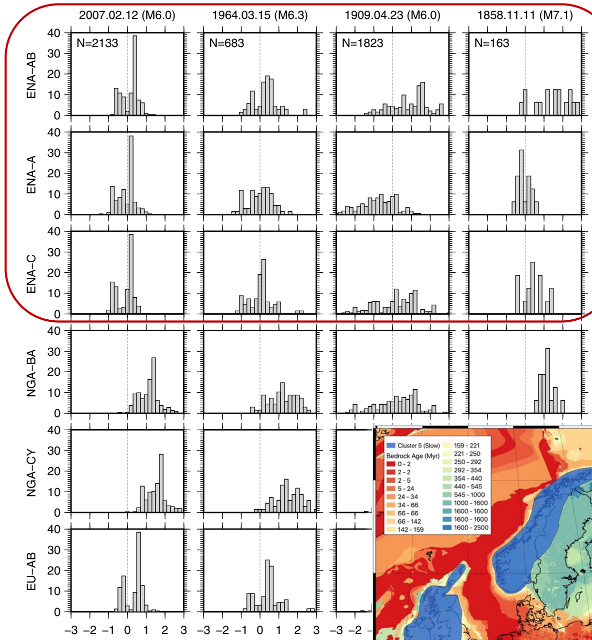
- Low attenuation in the mainland.
- Large lateral variations of Q.
- Regional model good! ☺, but lacks data at small R, high M.

Attenuation (Coda-Q)
Q_0(f=1 Hz) & Q_{10}(f=10 Hz)

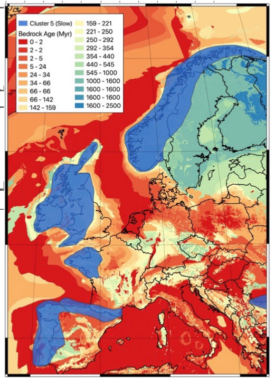


(Vales et al, 2020)

Attenuation (Global GMMs)

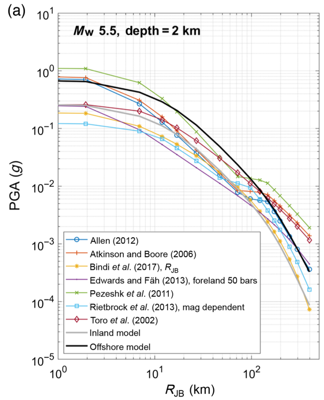


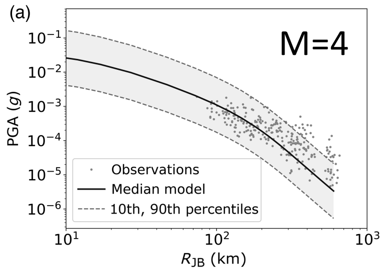
Observations – GMM
(Vilanova et al, 2012)



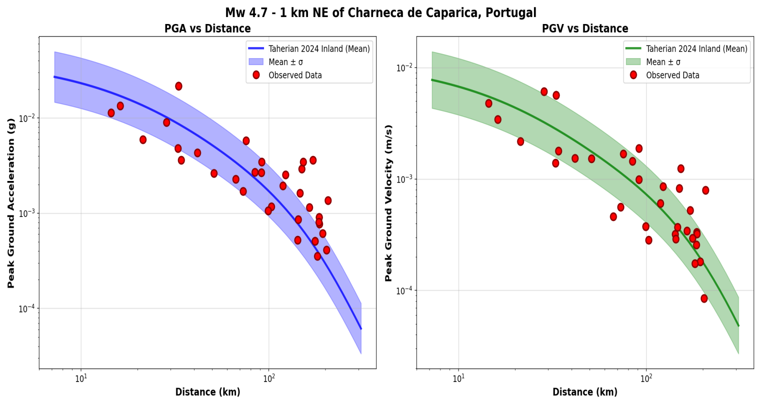
(Danciu et al, 2021)

Regional ground motion model





Taherian et al (2024)



Physics based modeling

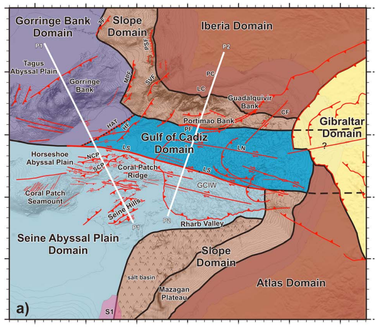
- Lack resolution of large shallow basins.
- GM->MMI ?
- Slip complexities are important.

Geological domains

Thinned continental

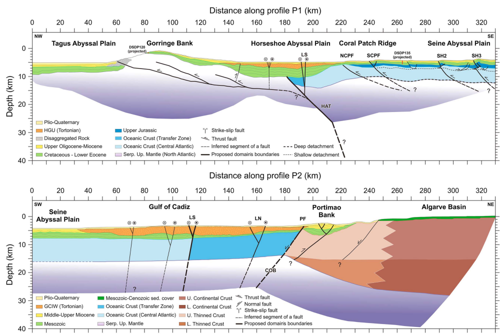
Exhumed mantle

Variscan continental



Jurassic oceanic (Central Atlantic)

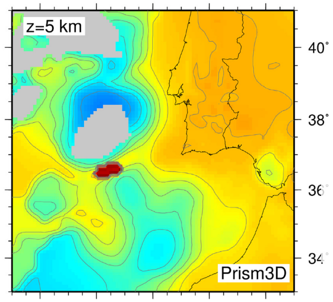
Jurassic oceanic (Western Thetys)

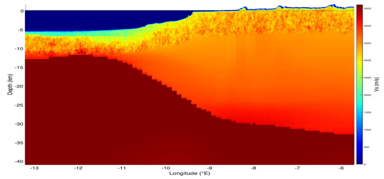


Martinez Loriente et al (2014)

3D Seismic structure

Arroucau et al (2021)



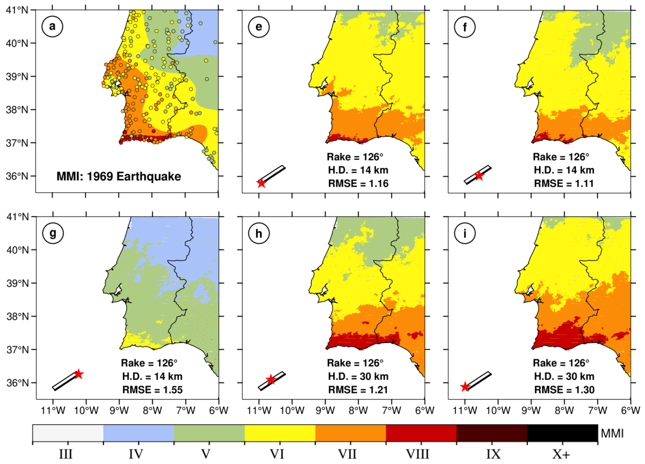


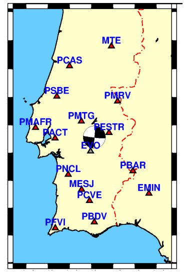
+ Small scale heteogeneities

+ VS30 (Vilanova et al, 2019)

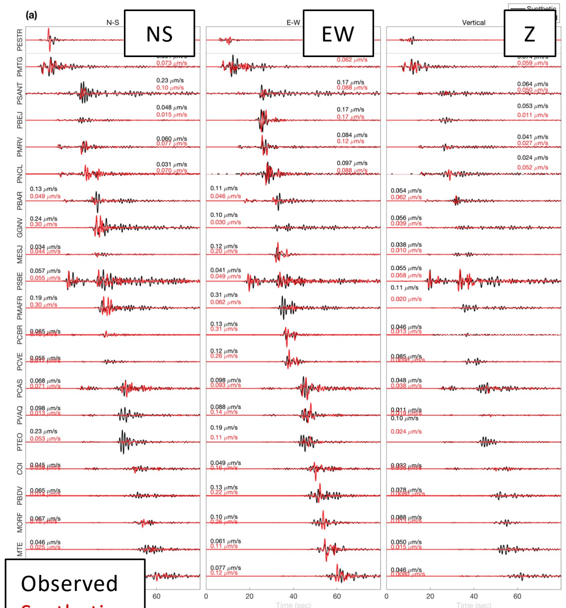
Source complexity

Patel et al (in progress)





Large sedimentary basins

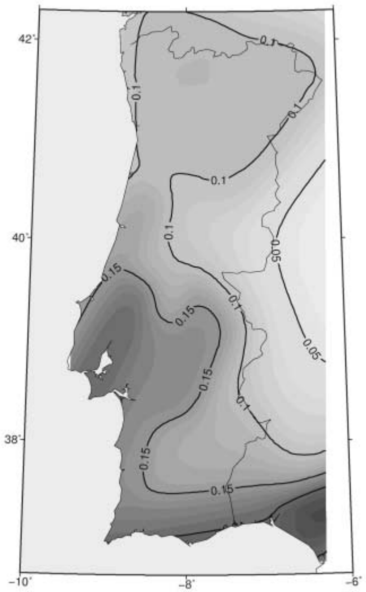


Patel et al (in prep.)

Hazard models (10% in 50 years, rock)

- Highest hazard in the Algarve and LTV.
- Max PGA ~0.2 g (10% in 50 years, rock).

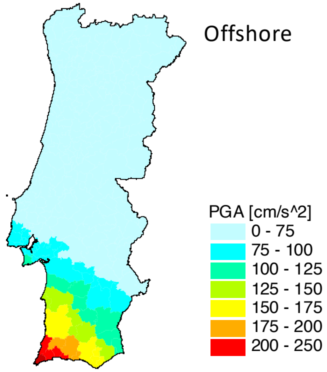
PSHA



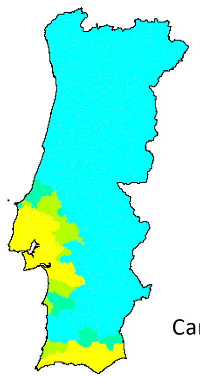
Vilanova & Fonseca (2007)

EC8

Offshore

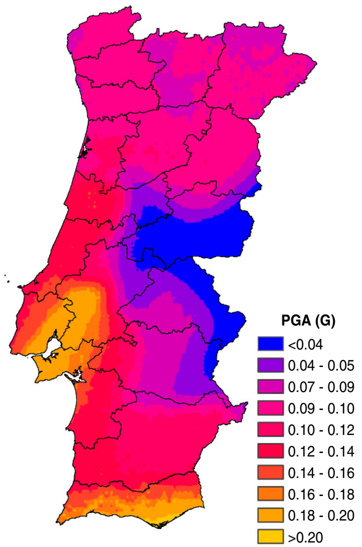


Inland



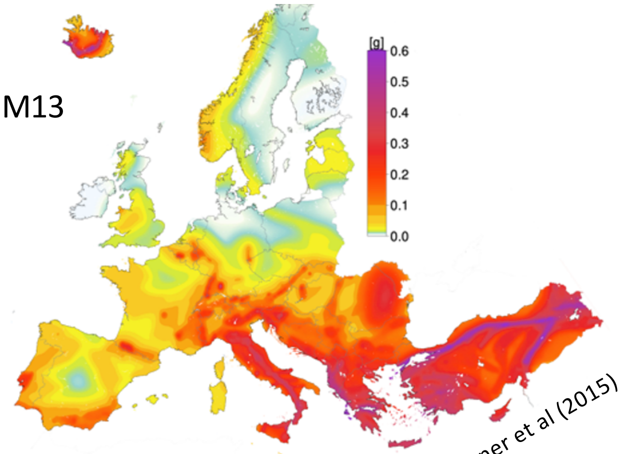
Campos Costa et al (2008)

OpenQuake



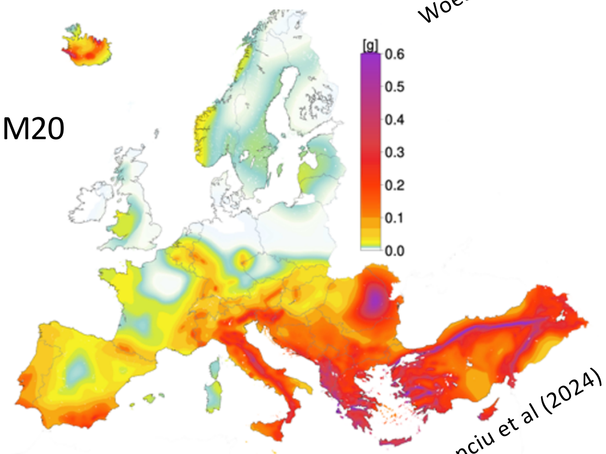
Silva et al (2015)

ESHM13



Woessner et al (2015)

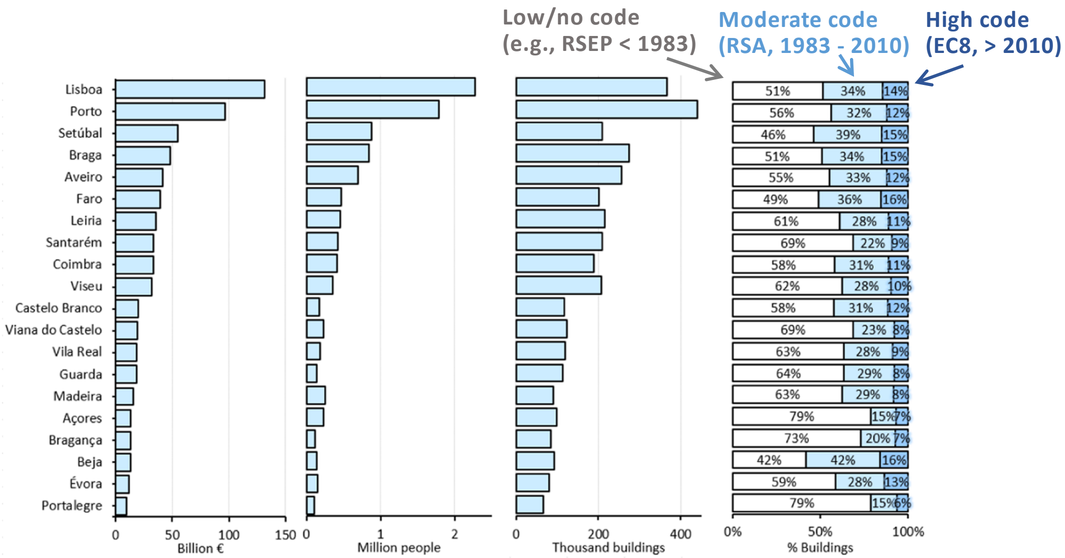
ESHM20

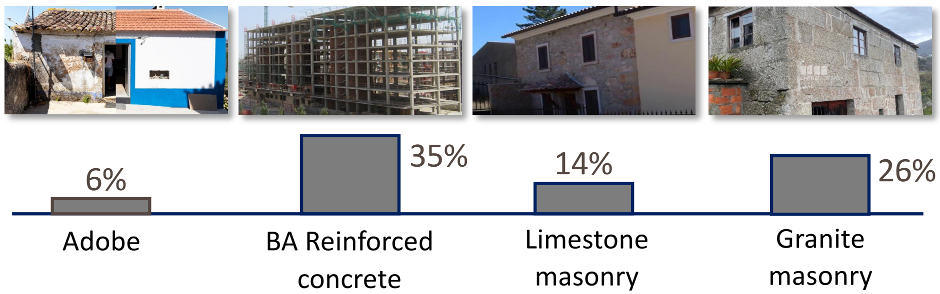


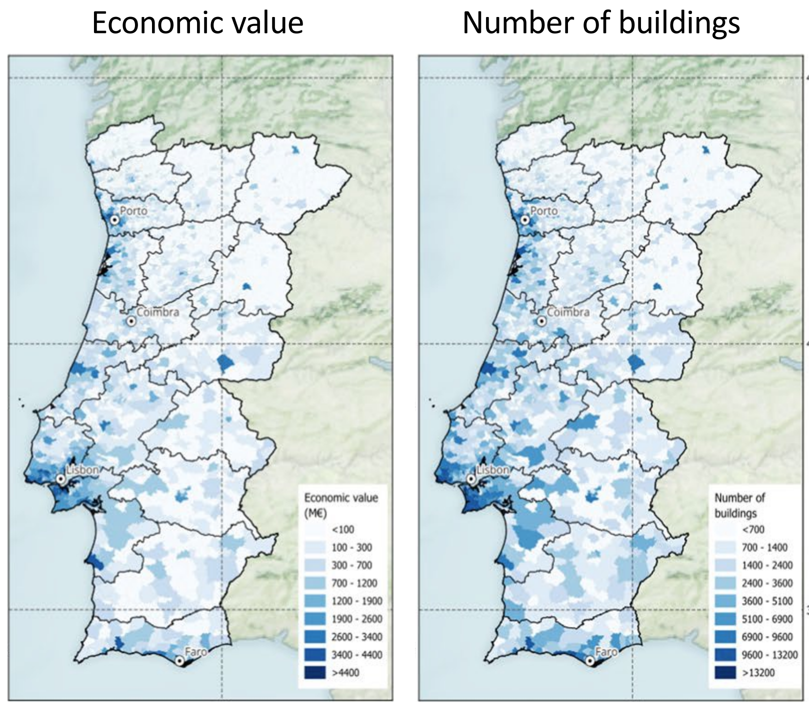
Danciu et al (2024)

Built environment

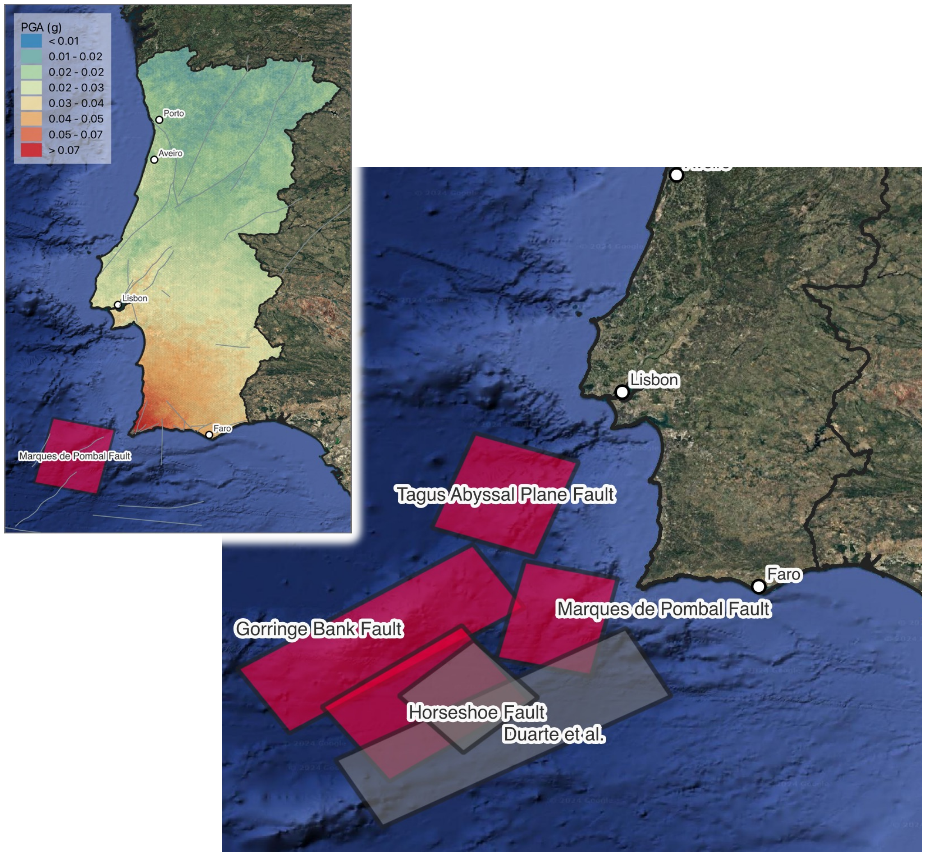
- Highest economic value close to the coast.
- Most houses built before codes.
- Problematic enforcement of codes.







What if it were today?



Economic Losses

Fault	M Max	M8.0	M7.5	M7.0	M6.5	M6.0
Marques de Pombal (M_{max} = 7.5)	3.1	-	3.1	0.9	0.27	0.08
Ferradura (M_{max} = 7.7)	2.7	-	1.8	0.5	0.13	0.03
Planicie Abissal do Tejo (M_{max} = 7.5)	5.9	-	5.9	2.4	0.80	0.27
Banco de Gorringe (M_{max} = 8.0)	7.2	7.2	2.5	0.7	0.18	0.04
Fukao (1973) (M_{max} = 8.0)	5.2	5.2	1.8	0.5	0.14	0.03
Duarte et al. (2025) (M_{max} = 8.6)	18.0	6.0	2.1	0.7	0.19	0.05

Extreme impact (>5 billion EUR)	High impact (0.5-5 billion EUR)	Moderate impact (0.1-0.5 billion EUR)	Low impact (<0.1 billion EUR)

Fatalities

Tipo de falha	M Max	M8.0	M7.5	M7.0	M6.5	M6.0
Marques de Pombal (M_{max} = 7.5)	174	-	174	30	2	0
Ferradura (M_{max} = 7.7)	172	-	92	16	3	0
Planicie Abissal do Tejo (M_{max} = 7.5)	416	-	416	102	19	4
Banco de Gorringe (M_{max} = 8.0)	530	530	120	18	2	0
Fukao (1973) (M_{max} = 8.0)	418	418	93	15	5	1
Duarte et al. (2025) (M_{max} = 8.6)	1,885	860	113	21	2	0

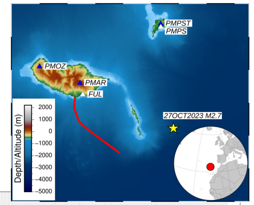
Extreme impact (> 1000 fatalities)	High impact (100-1000 fatalities)	Moderate impacto (5-100 fatalities)	Low impacto (<5 fatalities)

Summary II: Hazard of the SW Iberia plate boundary

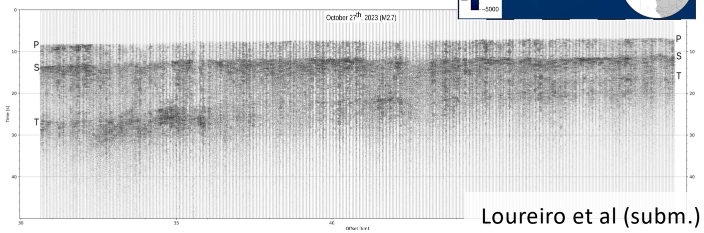
- Challenges:
  - Source:
    - Shallow crustal faults vs deep seismogenic faults.
    - Non-stationarity and fault interaction.
  - Earth structure:
    - Ground motion models at small R, high M.
    - Large shallow basins likely to be important.
  - Site effects:
    - Very shallow structure.
    - Topography of material interfaces.

- Opportunities:
  - Offshore instrumentation: OBS, SMART cables, DAS.
  - …
  - <u>**Discussion today: 12:30-14:00, room C.3.16**</u>

SMART cables
(operations due 2027)
Continent – Azores – Madeira



DAS (Madeira)



Loureiro et al (subm.)