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Seismicity and Seismic Hazard in Morocco 1901-2010

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Abstract. The seismic activity in Morocco is not as important as in other world areas such as Japan, California, Greece, Turkey, etc. Nevertheless, background seismicity in Morocco is not negligible and has produced a few historical and instrumental earthquakes with local magnitudes above 6. The Agadir earthquake 1960, for instance, destroyed this city with several villages and caused 12,000 deaths. Later, other remarkable earthquakes occurred: in Al Hoceima in 2004 in the North of Morocco, caused 629 deaths. The mechanisms governing the spatial distribution of these earthquakes and their frequency remain poorly understood. Most probably the seismicity of northern Morocco and Atlas mountain reflects primarily deformation induced by the ongoing collision between Africa and Europe (the convergence rate being of the order of 5mm/yr at most). In this work, we presented an earthquake catalogue covering the period 1901-2010, comprising about 25,000 events for the region lying between 0°W-20°w and 21°N-38°N. It results from raw data of Morocco, Spain, Portugal and Algeria seismic networks, enabling an input consisting of origin time H, geographical coordinates (longitude λ and latitude φ) and at least one of the following parameters: surface wave magnitude Ms, body wave magnitude M_b, epicentral intensities Io. A first application of this catalogue allows the drawing up of an updated Seismicity and maximum observed intensities map of Morocco. This map is obtained by using about 1,700 values of MSK intensity observed in 670 localities. This document may be useful in mapping the seismic hazard in Morocco. There is a similarity between this map and the seismic hazard map from the SESAME project.

Key words: seismicity, catalogue, intensity map, seismic, Morocco.

Sismicité et aléa sismique au Maroc 1901-2010.

Résumé. Le risque sismique au Maroc n'est pas aussi important que dans d'autres pays du bassin de la Méditerranée comme l'Italie, la Grèce, la Turquie ou l'Algérie, mais il n'est pas non plus négligeable. Sur plus de 110 ans d'observations macrosismiques et instrumentales, le Maroc n'a connu qu'un seul séisme de magnitude supérieure à 6, néanmoins, notre pays a connu quelques tremblements de terre catastrophiques : le séisme d'Agadir en 1960 (M=5.9), qui a détruit cette ville à plus de 75% et plusieurs villages avoisinants et a provoqué 12 000 victimes, alors que la ville d'Al Hoceima a connu en l'espace de 10 ans deux violents séismes, en 1994 et 2004, dont ce dernier (M_w=6.3) a provoqué la mort de 629 personnes et des dégâts considérables. Dans ce travail, nous présentons le catalogue des séismes du Maroc qui couvre la période 1901-2010, comprenant un peu plus de 27 500 séismes pour la région comprise entre 0 ° W-20 ° W et 21 ° N-38 ° N. Pour la localisation des séismes, nous avons utilisé les logiciels Hypo71 et HypoInverse et un modèle de vitesse adapté pour le Maroc. Pour les séismes localisés au Maroc, toutes les magnitudes ont été recalculées et les intensités réévaluées d'après les questionnaires, la presse et les archives dont disposent l'Institut Scientifique. Parmi les nombreuses applications du catalogue, nous avons établi des cartes de sismicité du Maroc et des régions limitrophes ainsi qu'une carte des intensités maximales observées au Maroc pour la période 1901-2010, cette carte a été obtenue en utilisant des valeurs des intensités maximales ponctuelles observées dans 670 localités. Ce document est utile dans la cartographie de l'aléa sismique au Maroc.

Mots clés : Sismicité, catalogue, carte des intensités, aléa sismique, Maroc

INTRODUCTION

Earthquakes are one of the natural disasters that man fears most. By their unpredictable nature and violence, they can devastate in a few seconds entire regions causing the destruction of houses, buildings, public facilities, communication routes, etc.

The outbreak of an earthquake can cause other natural phenomena such as flooding, avalanche, tsunami, landslide, fire, soil liquefaction, etc. These can, in turn, sometimes cause more damage than the earthquake itself.

Since the early twentieth century, the world is experiencing a huge population increase and an extraordinary economic expansion. Cities with high seismic risk have seen their populations increased dramatically. In addition to human concentrations, there is a large development of industrial units: power, nuclear and chemical plants, nuclear waste storage sites, dams, etc. so the question is what would be the extent of damage in the occurrence of a large earthquake?

At the present state of our knowledge, it is still impossible to predict earthquakes in a satisfactory manner. The nature of data required for forecasting the exact date, magnitude and location of an earthquake, is still insufficient, but this can be assessed by taking appropriate measures to limit casualties and material damage caused by earthquakes.

It is therefore necessary, when unable to predict earthquakes, to strengthen protective measures by the delineation of areas prone to earthquakes (i.e. seismic zoning) and seismic hazard assessment in these areas.

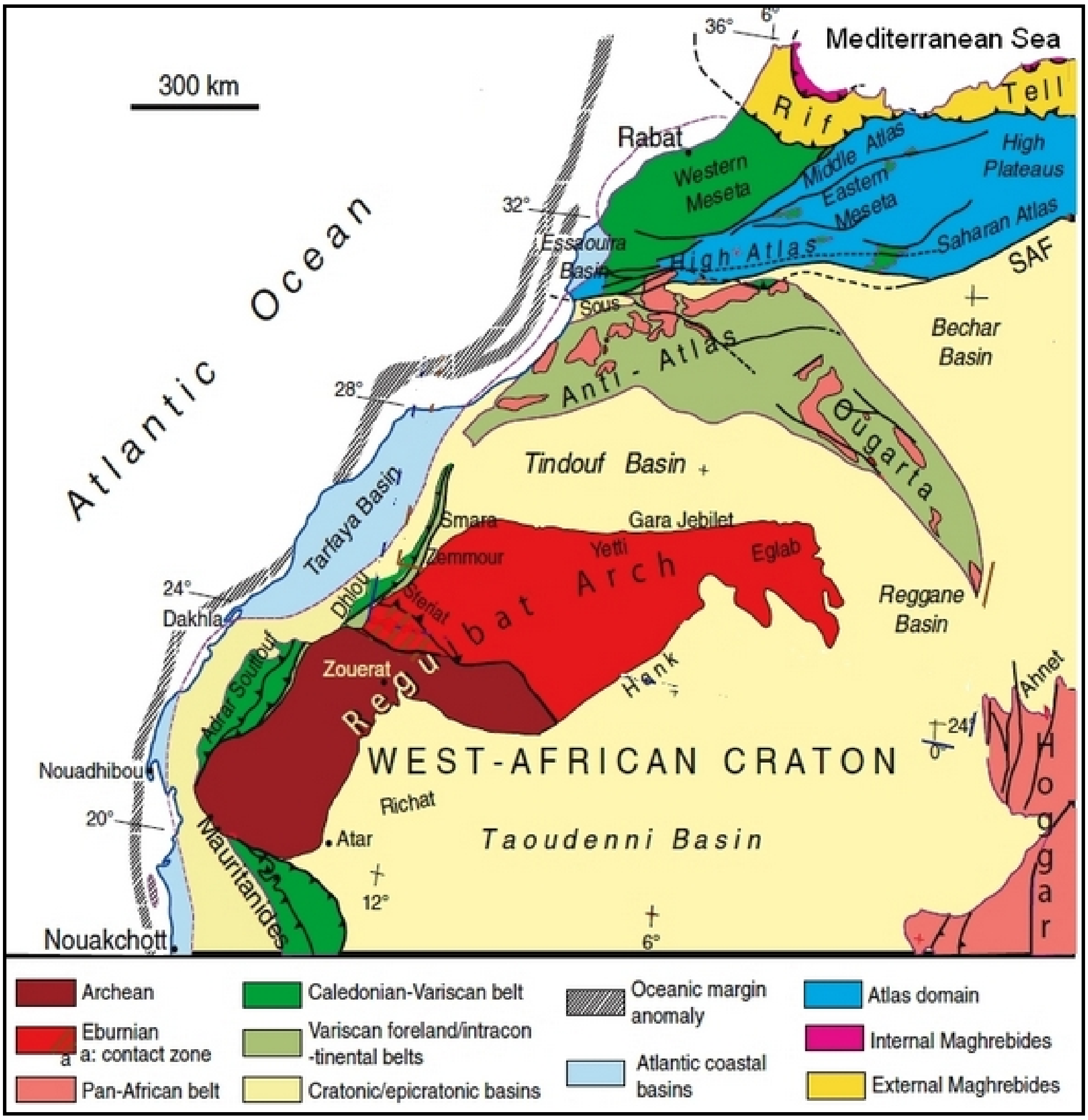


Figure 1. Tectonic map of northwesternmost Africa showing the northern part of the West African Craton (WAC) and the adjoining fold belts (Michard *et al*. 2008).

GEODYNAMIC SETTING OF MOROCCO

In recent decades, several studies have shown that the African plate is approaching the Eurasian plate at a steady rate of about 8 mm/yr at the longitude of Tunisia, decreasing to 4 mm/year near the Strait of Gibraltar with a WNW direction (e.g., Calais *et al*. 2003; Nocquet & Calais 2004, Fernandes *et al*. 2007). This movement has begun 7-8 Ma ago.

Indeed, Morocco has a great geological interest because it shows an almost complete succession of terranes, ranging from the Archaean to the Quaternary. Its location at the NW of Africa is the result of its geological history, having been in contact with two plates (America and Eurasia) and two seas (Atlantic and Mediterranean, i.e. Tethys). The geological structure and evolution of Morocco are complex and consist of alternating periods of quiescence and tectonic deformations that have structured the different zones and gave birth to mountain belts.

The geological structure of Morocco includes four main domains, each characterized by a specific orogeny. We can distinguish (Fig. 1):

– the Precambrian domain corresponding to the Anti-Atlas and the northern part of the West African Craton;

– the Caledonian-Hercynian domain which corresponds to the Moroccan Meseta;

– the Atlas domain that includes the High and Middle Atlas intracontinental belts;

– and finally the Rif domain, corresponding to the Rif Alpine belt and its foreland basins (Gharb, Saiss…).

These domains are separated from each other by a system of faults whose activity has been important throughout the geological history of the region. In addition, each domain includes faults (usually strike-slip) which also contributed by their movement to soil instability.

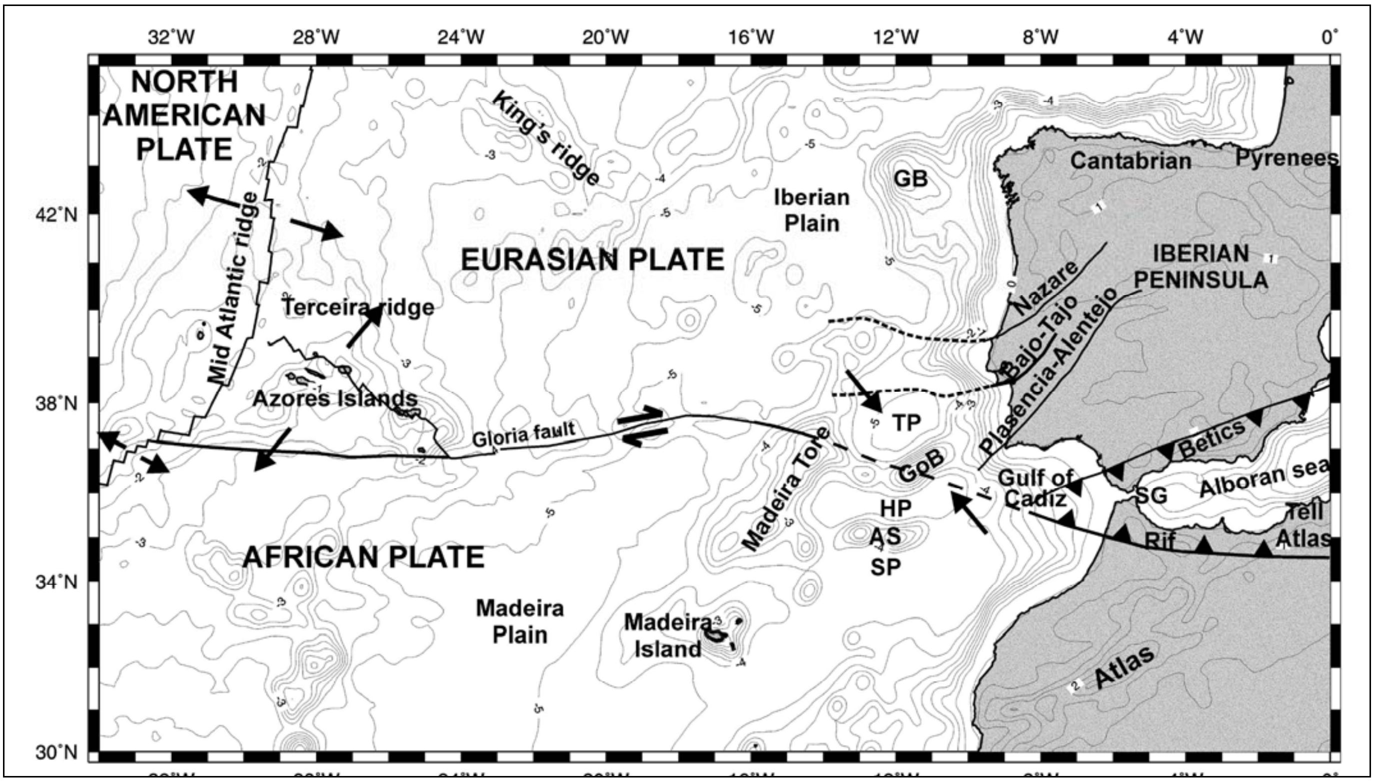


Figure 2. Geodynamic model of the Africa-Eurasia-North America plate boundary. Abbreviations: GB: Galicia Bank, TP: Tagus Abyssal Plain, GoB: Gorringe Bank, HP: Horseshoe Plain, AS: Ampere seamount, SP: Seine Plain, SG: Strait of Gibraltar (Jiménez-Munt *et al.* 2001).

Based on geophysical and geological data, the plate boundary between Africa and Europe from the Atlantic to the Mediterranean, shows different geodynamic contexts from west to east (Fig. 2):

– The extensional rift of Terceira in the central Atlantic.
– The dextral transform fault of Azores-Gibraltar (Gloria fault) that separates the North Atlantic and Central Atlantic oceanic crust.
– The intra-oceanic zone of deformation (Gorringe-Ampere bank) with the presence of crustal-scale thrust likely located within a larger strike-slip relay zone which can extend into the Iberian continental domain.
– A wide area of continent-continent collision (Africa-Europe) at the Gibraltar arc and the Alboran Sea, probably evolving eastward into a context of active margin with incipient subduction of the Algerian-Provençal oceanic crust (Argus *et al.* 1989, Platt *et al.* 1989, DeMets *et al.* 1990, Meghraoui *et al.* 1996, Le Gall *et al.* 1997, Buforn *et al.* 2004).

The geographical situation of Morocco, at the boundary between the African and Eurasian plates, explains that the seismicity in many Moroccan regions is governed primarily by the convergence of these two plates.

The boundary between the two plates is broadly defined between the Azores and west of the Gibraltar Strait; it is marked by earthquakes greater than magnitude 6 (e.g. the 1755 Lisbon earthquake: $M \approx 8.5$; 1941: $M_s = 8.4$; 1969: $M_w = 7.8$; 1975: $M_w = 7.7$; 1964: $M_s = 6.4$; 1915: $M_w = 6.2$; 2007: $M_w = 6.1$). The location of 1755 earthquake source and the rupture mechanism remain uncertain; the epicenter would be located somewhere between the Gulf of Cadiz and SW of St Vincent Cape, but this is still generating an intense debate (e.g., Johnston, 1996; Gutscher *et al.,* 2006; Santos *et al.* 2009, Zitellini *et al.* 2009) (Fig. 3), while the seismicity is diffuse east of the Gibraltar Strait, which is characteristic of continental collision zones where the blocks are deformable (Jiménez-Munt *et al.* 2001), magnitudes are generally lower. This distribution of earthquakes with dominant extensive or transcurrent mechanisms shows the complexity of the plate boundary in the Betic-Rif region.

SEISMICITY OF MOROCCO

Compared to other Mediterranean countries (Algeria, Italy, Greece, Turkey, etc.), Morocco is affected by a moderate seismic activity largely related to the convergence between Africa and Eurasia. However, every year there are earthquakes felt by the population and in some cases cause local damage that may be important. We have still present in memory the Agadir catastrophic earthquake with 12,000 deaths and that of Al Hoceima and its 629 victims.

The review of historical documents shows that much larger earthquakes occurred in the past in Morocco, and that cities like Fez, Meknes, Melilla and those along the Atlantic coast between Tangier and Agadir have undergone several times the earthquakes' damages.

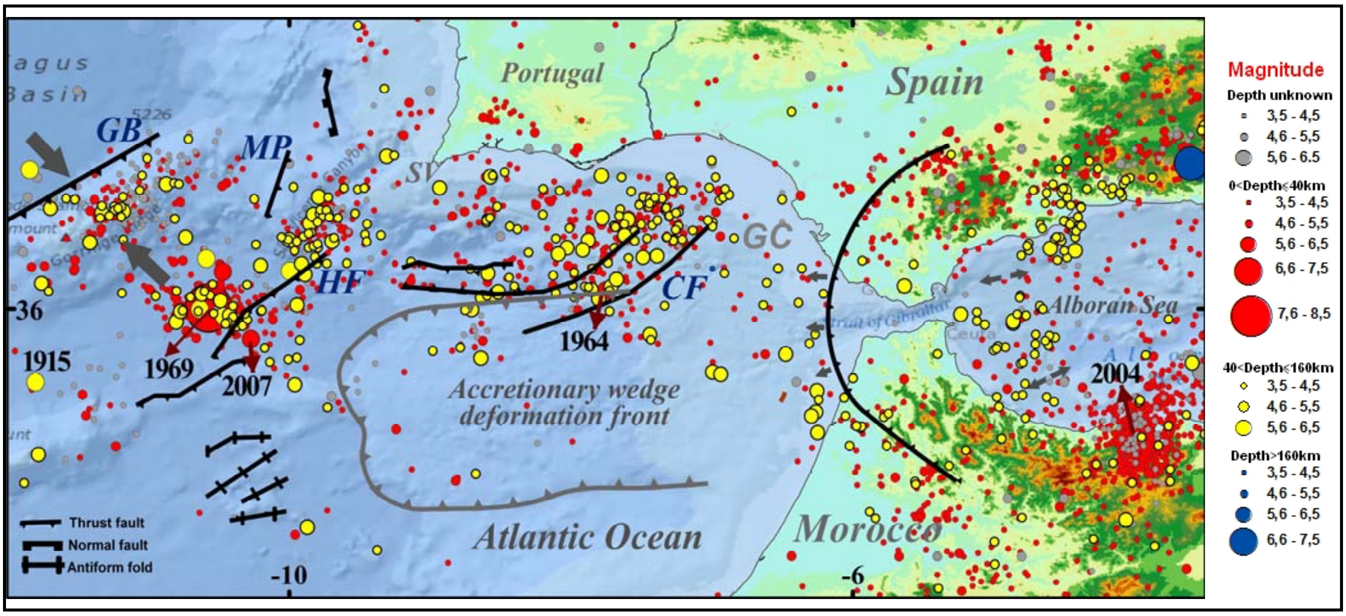


Figure 3. Major faults (from Gutsher *et al.* 2009 and Rosas *et al*. 2012) and distribution of earthquake hypocenters of M≥3.5 during 1901-2010 (from our catalog) of the area between the western part of the Alboran Sea and the Gorringe Bank. The largest earthquakes (M>6) are shown with date. Abreviations: GB= Gorringe Bank Fault, MP= Marquês de Pombal Fault, HF= Horseshoe Fault, CF= Cadiz Fault, GF= Gulf of Cadiz, SV= Cape Saint Vincent.

In the Moroccan setting, the seismicity can be viewed without consideration of the macro-seismicity because the instrumental data are not available before 1937 with the installation of the first seismic station by the Cherifian Scientific Institute (actually Scientific Institute).

Prior to 1901

The historical seismicity of Morocco was known until some twenty years only through the classic catalogs of Perry (1847), Galbis (1932, 1940) and Roux (1934).

Research of the original sources and gathering of documents (Vogt 1985, Levret 1985, 1991, El Mrabet 1987, Martínez Solares & Mezcua Rodríguez 2002) allowed us to establish a historical record for earthquakes felt in Morocco.

From this database, we can consider today that a sufficient level of knowledge the seismicity over a period of 1,000 years, from the macroseismic perspective, was reached without much uncertainty.

After 1901: the earthquake catalogue

In this synopsis, we used data from the file of earthquakes in Morocco and surrounding areas for the 1901-1984 period (Cherkaoui 1988, 1991). These data were completed by the events recorded between 1985 and 2010. We have prepared a catalog of more than 27,500 earthquakes in the area located between 21°N-38°N and 0°W-20°W. The input data consist of origin time ***H***, geographical coordinates (longitude ***λ*** and latitude ***φ***) and at least one of the following parameters: depth, magnitude, ***erh*** (standard error of the epicenter), ***erz*** (standard error of the focal depth), ***rms*** (root mean square), epicentral intensities I_o, etc. They were relocated with a homogeneous procedure, adapting and optimizing location parameters.

The evaluation of the earthquake intensity values is based upon a new and more reliable database established after investigating archives, libraries and original macroseismic questionnaires. The MSK-64 intensity scale (Medvedev & Sponheuer 1969) has been adopted.

The catalogue is periodically updated as new arrival time data for recent years become available.

The region was divided in two large areas:

a) for the area of latitude 21°-36°N and longitude 0°-14°Wt, more than 8,000 earthquakes were located using data from seismic networks of Morocco, Spain, Portugal and Algeria. The hypocentral locations were determined using the revised version of the HYPO71 computer program (Lee & Valdés 1985), and a standard velocity model for Morocco with Vp/Vs = 1.74 (Frogneux 1980).

b) for the rest of the region, we have generally used the determinations of different regional (IGN, Spain and IMP, Portugal) and international centers (CSEM, ISC and USGS) were compared. The choice took onto account the number of stations and resolution of each calculation. When great differences existed between the different locations, a new calculation was undertaken.

Analysis of the macroseismic and instrumental data, for the Moroccan seismic activity during more than

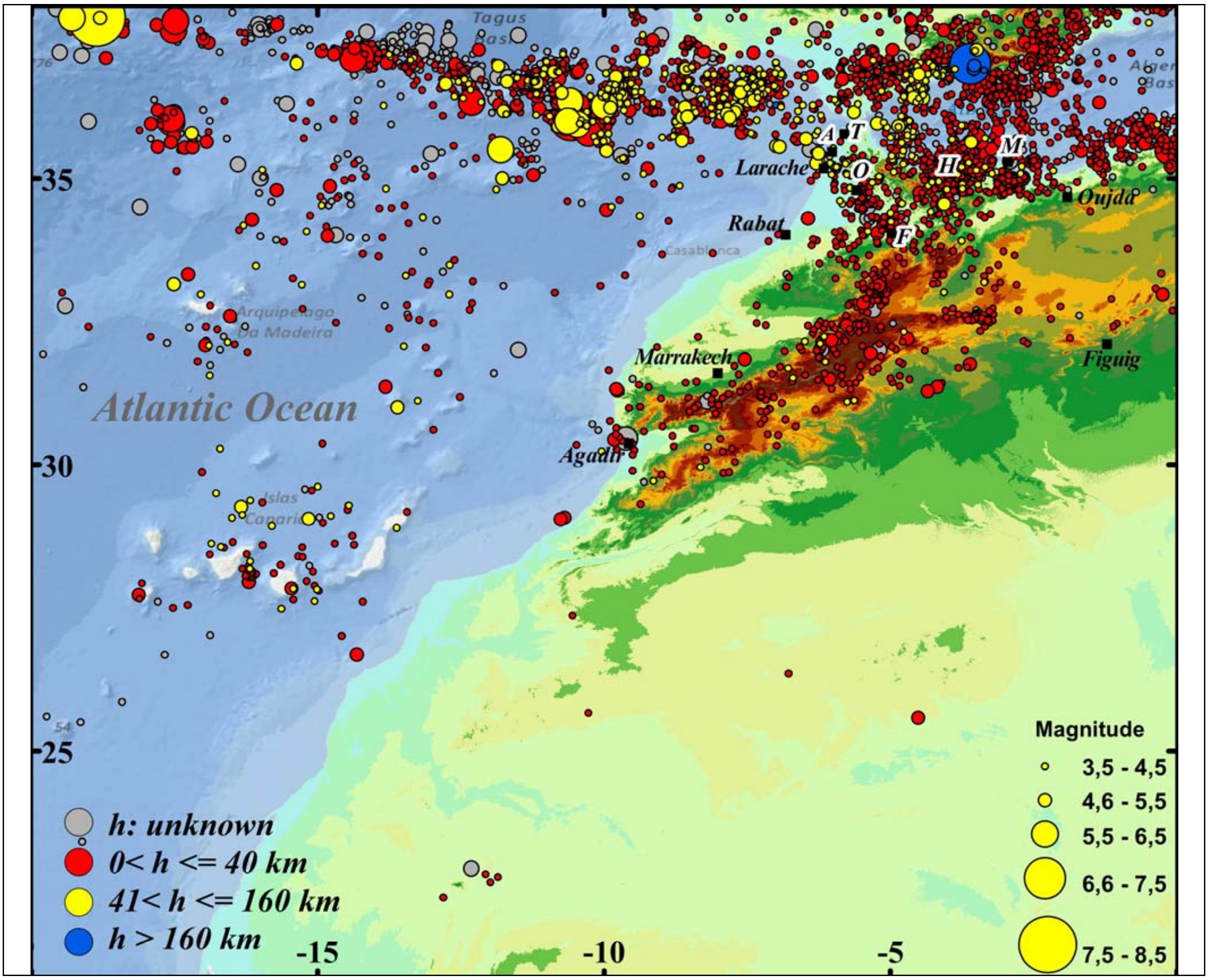


Figure 4. Seismicity of Morocco and surrounding area from 1901 to 2010 with $M \geq 3.5$. Abbreviations: A: Asilah, F: Fez, H: Al Hoceima, M: Melilla, O: Ouezzane, T: Tangier.

a century (1901-2010), shows that it is relatively moderate and only one event of magnitude greater than 6 was recorded in the province of Al Hoceima ($M_w = 6.3$). Unfortunately, at least four earthquakes have caused thousands of casualties and extensive damage (Tab. I), with multiple causes: dilapidated buildings, construction in risk areas, non-conformity with modern building standards, etc.

The review of the Moroccan seismicity map and adjacent regions for the 1901 - 2010 period (Fig. 4) shows that the seismic activity is concentrated in the Rif domain, mainly in the Al Hoceima region, in the Middle and High Atlas and in the Western Rif where a NW-SE significant seismic alignment is observed, starting roughly in the vicinity of Fez and passing between Larache and Asilah through Ouezzane.

Seismicity is generally shallow, concentrated in the first 30 km, but an intermediate seismicity exists at the eastern part of the Gibraltar Strait (40-150 km). At the Gibraltar Strait itself, seismic activity is low to negligible (Hatzfeld 1978, Cherkaoui 1991). We also note about thirty intermediate earthquakes (40-170 km) in the Middle Atlas (Hatzfeld & Frogneux 1981, Cherkaoui 1991) (Fig. 4).

In summary, the seismicity map of Morocco and surrounding areas for the 1901-2010 period shows that the epicenters are spread over three domains as follows (Ben Sari 1978, Hatzfeld 1978, Cherkaoui 1991) (Fig. 4):

The Atlas domain, where the seismic activity is mainly located in the Middle Atlas and the Central High Atlas. This seismicity is due in large part to the presence of a complex network of active faults. The South Atlas Fault, which starts from Agadir and passes close to Figuig, is marked by violent earthquakes that can be like the Agadir one (1960, $M_d = 5.9$).

Betic-Rif domain: the area between south-eastern Spain to the north and the Rif belt to the south is an intense site where

Table I. List of the main earthquakes that resulted in loss of lives and having caused damage in Morocco. The intensities are given on the macroseismic MSK-64 scale. For the earthquakes of marine origin the maximum intensity felt inland is indicated. *Roux 1934.

Date	*Description*	*Max Intensity*	*Epicentral Region*
22 chawal 267 h May 26th, 881	Earthquake felt throughout **Andalusia** and from **Tangier** to **Tlemcen**. In **Fez**, the palaces were destroyed and the inhabitants fled into the countryside and most houses were overturned. The earthquake generated a tsunami on the southern coast of Spain.		Gulf of Cadiz
437 h 1045-46	Violent earthquake in **Fez** killing people and destroying houses.		Fez
1 rabia II 472 h October 1st, 1079	A violent earthquake [... as we had not been felt in the **Maghreb**, overthrew the towers, minarets and buildings, and infinite people died under the ruins ...]*, widely felt in **Morocco**. Would have caused deaths and important damage to **Fez.**		Gulf of Cadiz
811 h 1408	Violent earthquake caused the destruction of several houses and parts of the city walls of **Fez.**		
September 22th, 1522	A destructive earthquake caused the deaths of several hundred people and caused extensive damage in 160 km radius of the **Fez** city, it was largely destroyed. Damage was also observed in **Tetouan**, but that **Baddis (Penon de Velez de la Gomera)** that the damage would have been particularly important under the combined effects of the earthquake and tsunami. The epicenter was located in the Alboran Sea The maximum intensity observed at **Almeria** in SE Spain.	**VIII-IX**	Alboran Sea 36.5°N-2.5°W
October 21th, 1578	In **Melilla**, a violent earthquake destroyed homes, church and part of the ramparts.	**VIII**	Melilla 35.3°N-2.9°W
23 rajab 1033 h May 11th, 1624	A catastrophic earthquake destroyed almost completely **Fez** and has killed thousands of people and cause huge damage. Several other localities have been severely affected by the earthquake, as **Baddis** and **Meknes**. The earthquake was felt in **Sefrou**, **Taza** and **Beni Ouaryaghel** (in the region of Al Hoceima) in **Salé** and in **Safi**. Its epicenter was located near **Fez**.	**IX**	Fez 34.0°N-5.0°W
August 5th, 1660	Violent earthquake in **Melilla**, [... *population was terrorized. The walls were moved from the esplanade of more than a yard shaking buildings and destroying a few; la Torre Quemada, which monitors the main gates of the city was destroyed, half a bridge is collapsed, several other bridges were gutted and then completely destroyed by the rain, the fortifications were severely damaged.*]*.	**VII**	Melilla 35.3°N-2.9°W
26 muharram 1169 h November 1st, 1755	This earthquake is considered one of the largest earthquakes in the mankind history. It was felt over much of North Africa and Western Europe. The maximum intensity X (MSK) was observed in Lisbon, which was completely destroyed. The damage in Morocco was considerable: several thousand dead and many localities have been largely destroyed with Meknes. All localities on the Atlantic coast from Tangier to Agadir were severely affected by the combined effects of the earthquake and tsunami. The violent aftershocks of 18 and 19 November have helped to accentuate the damage, particularly in Meknes and Fez. The intensity due to the effects of seismic waves from the main shock of November 1st 1755, on the Atlantic coast of Morocco, can be assessed between VII and VIII (MSK) and, presumably, closer to VII (MSK) between Safi and Agadir.	**X**	SW St Vincent Cape 36.5°N-10.0°W

Table I (continued).

November 27th, 1755	This earthquake was so violent than the November 1st; it caused the destruction of several palaces, houses, mosques, and killing nearly 10 000 people in Meknes. On this earthquake, European sources are silent; our hypothesis is that two earthquakes had followed the great one of November 1st: the first, on November 18th, is considered an aftershock of the main shock, while the second, on November 27th, would, however, a local earthquake. A home located near Meknes seems justified, since the city was devastated by the earthquake. Here we will adopt an intensity of about IX (MSK) while in Fez intensity does not appear to have exceeded VII (MSK).	IX	Meknes 33.9°N-5.6°W
April 9th, 1761	The ground shook during 25 seconds in **Agadir**, causing the destruction of most homes and damaged those that are solids.		Agadir
April 12th, 1773	An intense earthquake was widely felt in Morocco: **Tangier** was almost completely destroyed, while in **Fez** several houses were destroyed. Felt also in **Salé**.	**VIII**	Gulf of Cadiz 36.0°N-7.0°W
February 29th, 1960	At 11:40 am. a terrible earthquake devastated the Agadir city and its region, the damage toll is catastrophic: more than 12 000 persons died, thousands injured and more than 75 % of buildings destroyed. Districsts like **Yachech**, **Kasba**, **Adouar**, **Founti Talborjt** over 90 % of buildings were destroyed or damaged. Despite its moderate magnitude (M_d = 5.9), the extent of damage could be explained by the poor quality of construction, the shallow depth (3 km) and its proximity to the city.	**X**	Agadir 30.45°N-9.62°W M_d=5.9
February 28th, 1969	Violent earthquake, the epicenter may have been close to the great Lisbon earthquake epicenter of November 1st, 1755 located south of the Gorring bank. Widely felt in Morocco caused extensive damage and killed a dozen of people in the cities of **Salé** and **Safi**.	**VI**	SW St Vincent Cape 36.01°N-10.57°W m_b=7.3
October 23rd & 30th, 1992	Two earthquakes have shaken the Tafilelt region killing 3 people and collapse some ksours in **Rissani**.	**VII**	Rissani 31.36°N-4.18°W M_d=5.2 31.29°N-4.35°W M_d=5.1
May 26th, 1994	Violent earthquake in **Al Hoceima** Province killed three people and caused extensive damage.	**VIII**	Alboran sea 35.27°N-3.96°W M_w=6.0
February 24th, 2004	A catastrophic earthquake struck Al Hoceima Province, the damage is considerable: 629 dead, 926 injured, 15 230 homeless and 2 539 houses collapsed.	**IX**	Aït Qamra 35.13°N-4.01°W M_w=6.3

the seismic activity emphasizes the convergence and collision of Africa and Eurasia tectonic plates. This convergence is marked by severe earthquakes in south-eastern Spain, in the Alboran Sea and in northern Morocco, as the recent earthquake in Al Hoceima of 2004 (M_w = 6.3).

The Atlantic domain, where can be clearly distinguished the boundary between the two plates, represented by the Azores Gibraltar Sicily seismic line. This is punctuated by earthquakes with magnitude 6 or greater. Moreover, these oceanic earthquakes, particularly those located SW of St Vincent Cape, affect the Iberian Peninsula and Morocco, as was the case during the 1755 earthquakes (M ≈ 8.5) and 1969 (M_s = 7.3) having largely affected northern Morocco (Figs 3 and 4).

SEISMIC RISK IN MOROCCO

The seismic risk defined for a region depends on the probability of occurrence of an earthquake causing a certain level of ground shaking (seismic hazard) and on the structural vulnerability of the built structures. It varies widely depending on population density and on the economic potential of that region. The seismic risk is zero in a desert region whatever the importance of seismicity.

The seismic risk assessment depends on the one hand by the probability of occurrence of earthquakes, hence the seismic hazard, and on the other hand, on the vulnerability of the threatened buildings.

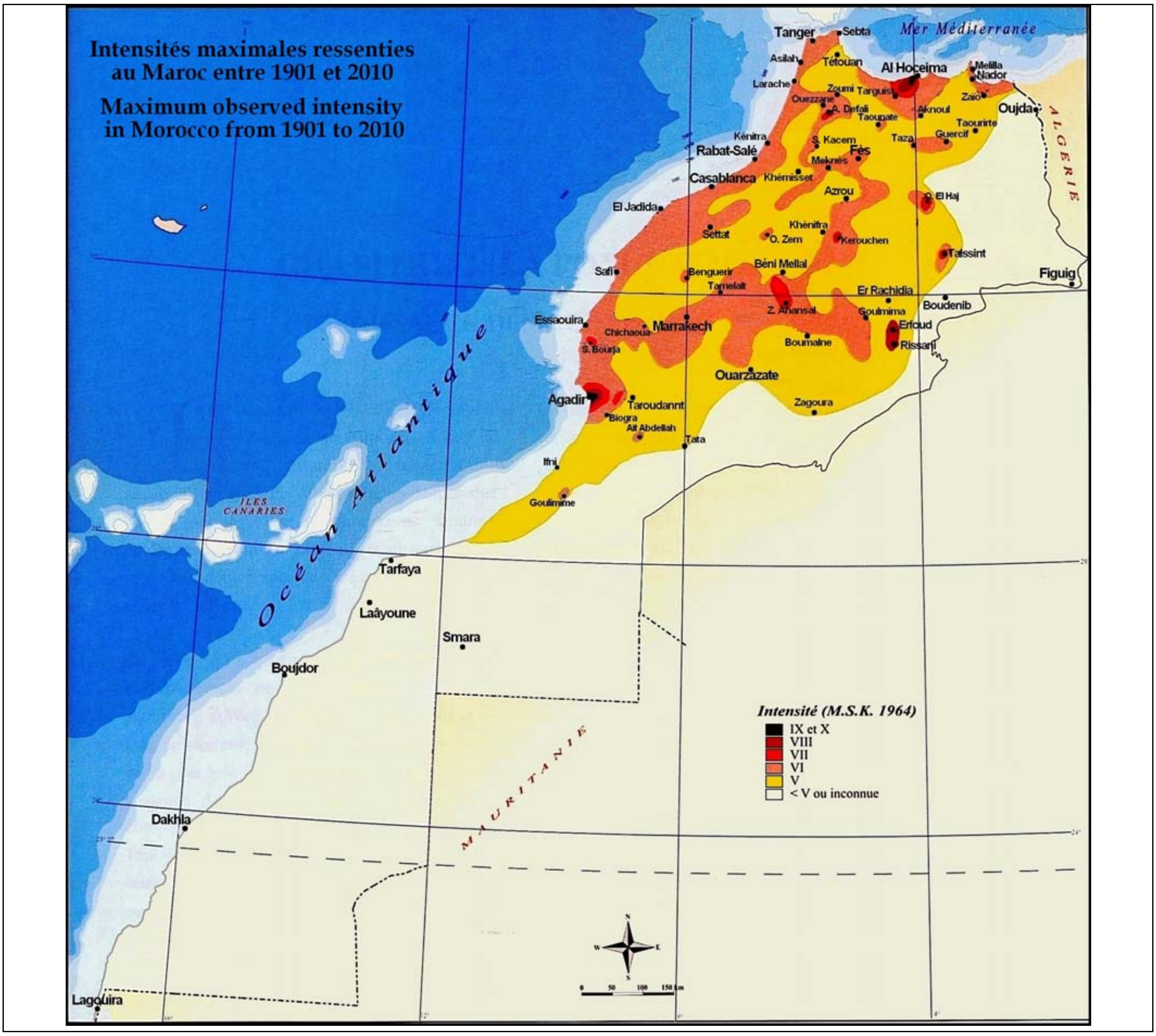


Figure 5. Maximum intensity map from 1901 to 2010.

The vulnerability of a building is defined as the ratio expressed as a percentage of the cost of repair after an earthquake with certain intensity on the building cost. It is practically zero for earthquakes of intensity <VI (MSK), which do not damage the buildings. For earthquakes of intensity >XI (MSK), the seismic vulnerability of buildings is 100 %.

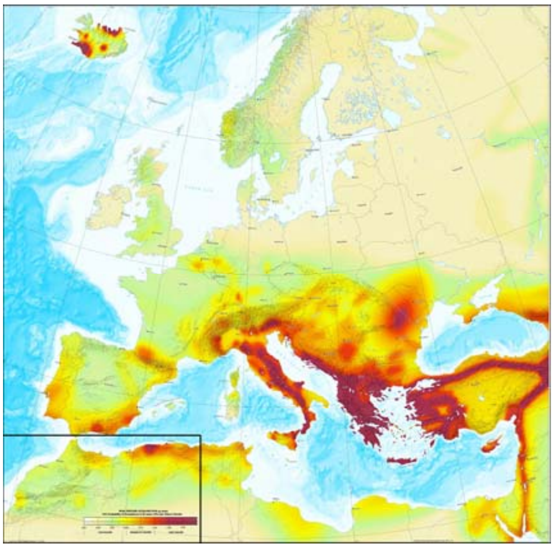
Maximum intensity map

Maximum seismic intensity map for Morocco was elaborated using the observed intensity data from 1901 to 2010. The maximum observed intensities map was obtained by taking the maximum intensity at every point from the intensity maps of each individual earthquake. About 1,700 values of (MSK) intensity spots observed in 670 localities spread over a large part of Morocco were used (Fig. 5).

The destructive intensities (X and IX) are observed in Agadir and its surroundings (X MSK) caused by the devastating earthquake of 29th February 1960, and in the Al Hoceima province (IX MSK) during the catastrophic earthquake of 24th February, 2004.

High intensities (VIII and VII) are located in different parts of Morocco. Intensity VIII was observed in the Al Hoceima area (1994 and 2004), Agadir (1960) and Rissani (1992) while intensity VII was observed in Melilla (1926), Outat el Haj (1929) , Aïn Defali (1930), Tilougguite (1936), Talsinnt (1941), Kerrouchen (1950) and Talat n'Nos (1955).

The moderate to strong intensity (VI) is due to the local seismicity for regions inside the country and to the Atlantic seismicity for the coastal areas from Tangier to north Agadir.



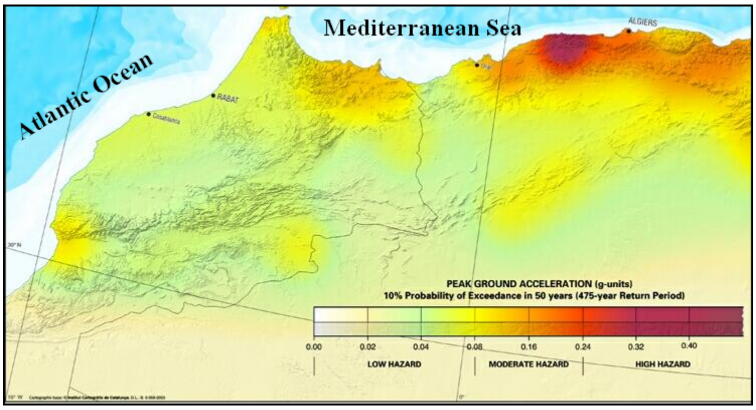


Figure 6. (Left) SESAME European-Mediterranean seismic hazard map for the peak ground acceleration (g units) with 10 % probability of exceedance in 50 years, corresponding to a return period of 475 years, for a firm soil condition. (Right) an enlarged extract from this map of northern Morocco (Giardini *et al.* 2003).

The medium intensity (V) predominates in the rest of Morocco, except in the east and south where the seismicity seems low to negligible.

Seismic hazard evaluation

The seismic hazard is defined as the level or value of the parameter representing ground movement (e.g. maximum acceleration) that has a specific probability of being exceeded during a defined period of time. Usually, what is obtained is the annual probability of exceeded, from which the relevant value for any other time span can be determined.

Little work has been performed to evaluate the seismic hazard in Morocco; the only studies are those of Cherkaoui (1991), Tadili (1991) and Badran (2008). Other studies have been conducted under international programs such as the Global Seismic Hazard Assessment Program (GSHAP), the Seismic Hazard and Seismotectonics Assessment of the Mediterranean Basin (SESAME) and the latest is that of the European Seismological Commission Working Group on Seismic Hazard Assessment (ESC / WG-SHA).

The seismic hazard map from the ESC / WG-SHA project (Giardini *et al.* 2003) indicates the bedrock maximum horizontal ground acceleration with 10 % chance of being exceeded in the next 50 years (equivalent to 475 years return period) (Fig. 6).

There is a similarity between this map and the maximum intensity map (Fig. 5). Areas where the seismic threat is highest, with accelerations between 0.08 and 0.16 g, experienced in the past large earthquakes such as in Al Hoceima and Agadir. These areas correspond to intensities (MSK) IX and X of the maximum intensity map (Fig. 5).

Areas of moderate seismic threat are located between Tangier and Essaouira and in some regions within the country: Fez, Meknes, Tafilalt, the Rif domain and Middle Atlas, they correspond to the VI, VII and VII intensities (MSK).

Tsunami risk assessment

The Gorringe bank (Figs 2 and 3) is known to be the locus of strong earthquakes that caused serious damage in Portugal, Spain and Morocco, which was amplified in some cases, on the coastal areas by tsunami waves. The whole Atlantic coast of Morocco between Tangier and Agadir is exposed to the effects of Atlantic tsunamigenic earthquakes.

The historical earthquake for which we have the most satisfactory information is the November 1st, 1755 event, known as the “Lisbon earthquake” that ravaged almost the entire northern half of Morocco. In addition to the seismic wave effects, the cities of Tangier, Asilah, Salé, El Jadida and Safi were inundated by waves of more than 15 m in height in some places (Levret 1985).

Moroccan Mediterranean coast is not shelter to tsunamis. Historical seismicity reveals that during the 1522 earthquake, the area between Al Hoceima and Kala Iris was submerged by water following the earthquake (Cherkaoui & Asebriy 2003).

CONCLUSION

The historical and instrumental seismological data for Morocco show that it is not immune to the earthquakes that has caused and may continue to cause casualties and damage to property.

An earthquake catalogue covering the period 1901-2010, comprising about 27 500 events, allowed us the drawing up of an updated seismicity and maximum observed intensities maps of Morocco.

Prevention measures need to be taken into consideration in the Al Hoceima and Agadir areas, and to a degree in other areas of Morocco, which show less significant seismic activity.

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