Earthquakes and Tsunamis in the Region from Azores Islands to Iberian Peninsula

ELISA BUFORN¹ and MAURIZIO MATTESINI¹

On February 28th, 1969, a large earthquake ($M_w = 7.8$) strokes the Iberian Peninsula and northern Morocco, producing some casualties and important damage and economic losses. The off-shore focus, located 200 km west from the Cape Saint Vincent (SW of Iberian Peninsula), generated a tsunami that affected the Atlantic coasts SW of the Iberian Peninsula and NW of Morocco. This earthquake is the last large earthquake that has occurred in this region, very near where the catastrophic 1755 Lisbon earthquake took place. Seismicity in this region is associated with the western part of the plate boundary between Eurasia and Africa. From the Azores Islands to Algeria, this plate boundary has a complex nature, consequence of its proximity to the pole of rotation of the African plate. This complexity is shown by changes in the stress pattern from the Azores to Algeria, differences in plate velocities, seismicity rates and occurrence of intermediate and deep depth earthquakes in south Iberia and northern Morocco.

On March 6th–8th, 2019, on the occasion of the 50th anniversary of the 1969 earthquake, a workshop was held in Madrid, organized by the Universidad Complutense de Madrid (Spain) and the Instituto Geográfico Nacional (Madrid, Spain). Two invited lectures and 45 communications were presented covering different aspects of crustal structure, seismic and geodetic instrumentation, seismic archive data, studies of the 1969 earthquake, seismic sources, GPS results, Earthquake Early Warning Systems (EEWS), seismic hazard and tsunami studies. About 100 participants attended, from Europe, Northern Africa, America, and Asia. In this Topical Issue, we have

collected ten papers, representative of those presented at the workshop, including the two invited lectures, one paper on crustal structure, three on seismicity and a data archive, three focused on the 1969 earthquake, one on the seismic hazards.

The volume opens with the two invited lectures. The first one, by Allen et al. (2019), presents a description of the MyShake Platform, an operational framework to provide an earthquake early warning. The EEWS is a recent and powerful tool to prevent and mitigate the damage of earthquakes. MyShake uses smartphone technology to detect earthquakes and issue warnings; it has been operating for three years and more than 300,000 people have downloaded it. The paper describes the operational details, distribution, alert generation, and delivery, with a very interesting discussion of results and future directions. The second invited lecture, by Baptista (2019), is a review of tsunamis that occurred along the Azores-Gibraltar plate boundary. The paper starts presenting the tectonic regime along the plate boundary and continues describing the methods used in this study: back-ward ray tracing of tsunami travel times and inversion of tsunami waveforms. The large earthquakes of 1722, 1755, 1761, 1941, 1969 and 1975 are analyzed and a thorough discussion is presented. The author concludes that the six tsunamigenic events studied do not follow along a single plate boundary, confirming previous studies and show an image of the complex lithospheric region.

The paper, by Catalán et al. (2019), is a very interesting study of the plate boundary between Eurasia and Africa at the Gulf of Cádiz and the Canary Archipelago exploring the possible geodynamic connection between them. The study is based on tectonic, thermal, gravimetric and seismic observations. The gravity data and the Curie point depth

¹ Dept. de Geofísica Y Meteorología, Fac. CC. Físicas, Universidad Complutense, 28040 Madrid, Spain. E-mail: ebuforn@ucm.es; mmattesi@ucm.es

show a possible link between the two regions. The authors conclude about the presence of a lithospheric thinning between both regions and of an asthenospheric channel, which feeds and alters locally the plate boundary.

The next three papers deal with the study of the seismicity, historical and instrumental, and about an archive of early seismic documents for the region. The paper by Udías (2019) is a review of large tsunamigenic earthquakes that occurred at SW of Iberia before the 1755 Lisbon earthquake. The author carries out a very detailed analysis of the historical sources with information about the occurrence of earthquakes and tsunamis in the region Cape Saint Vincent-Gulf of Cádiz, separating those occurred before and after the year 500 A.D. He concludes that the 1755 earthquake and tsunami is not an isolated event in SW Iberia and other ones have occurred before the great Lisbon event. The next paper by López Muga et al. (2019) presents the Spanish Geophysical Data National Archive. This center is part of the Instituto Geográfico Nacional (IGN, Madrid, Spain) and its objective is to collect and preserve geophysical information from the IGN observatories. Among the data stored is that corresponding to seismic information (analogical records, seismic bulletins, macroseismic questionnaires, historic photographs, etc....) for the period of 1914 to 1990. As an example of the archive information, the authors show the information available for the 1969 earthquake. The content of the Archive is available for researchers. The last paper of this group, by Cabieces et al. (2020), is a study of the seismicity and focal mechanism of earthquakes that occurred in the SW Cape Saint Vincent-Gulf of Cadiz using an amphibious network (OBS and land stations) during a temporary survey. The hypocenters are located using a nonlinear algorithm and different crustal velocity models, including 3D models, and some cases are analyzed in detail. Focal mechanisms of larger recorded earthquakes have been estimated from first motion polarities and inversion of moment tensor. The authors conclude that the use of the amphibious networks together with a 3D crustal velocity model and non-linear algorithms improve the determination of hypocenters, reducing the depth uncertainties.

The 1969 earthquake was the object of a special interest in the workshop. Bufo et al. (2019), have carried out a re-evaluation of seismic intensities for this earthquake using original documents, some of them not used previously, from Portugal, Spain, and Morocco, obtaining a new intensity map for the whole region affected by the earthquake. Using a new 3D crustal velocity model for the region and non-linear methodology, the 1969 seismic sequence has been relocated, obtaining for most of the foci depths between 30 and 50 km. From the comparison between the observed intensities for 1969 and the large 1755 Lisbon earthquake, the authors propose a different focal mechanism for these earthquakes.

The Aparicio Florido (2019) paper is an interesting contribution to the effects of the 1969 earthquake describing how the earthquake and tsunami were felt on ships at the sea. The observations of these effects on six ships in the Atlantic with different tonnages and located at different epicentral distances and azimuths from the epicenter are given with great detail. It is important to remark that according to this information, the effects of the earthquake and tsunami were perceptible even on deep water. The last paper of this group, by Pro et al. (2020), is a study of the PGV, strong motion and intensity data for the 1969 earthquake using synthetic data to address the lack of strong-motion observations and not-saturated records. To test their methodology, the authors previously generated synthetic ground velocity records for the 2007 and 2009 earthquakes, occurred in the region and with available digital data. By using this approach, they generated synthetic PGV for the 1969 earthquake and from them derived the instrumental intensities for Iberia and northern Morocco. The results show a good agreement between the synthetic and observed intensities.

The last paper, by Fontiela et al. (2019), is an estimation of the human losses and expected damage in Faial (Azores islands), using as scenario the damaging 1980 and 1998 earthquakes, both with magnitude larger than 6.0. The authors used the 2001 and 2011 census to estimate the future population. The damages caused by the 1980 and 1998 shocks are then used to study the distribution of buildings according to the EMS-98 vulnerability classes. Different ground motion prediction equations were

tested to choose the more adequate one for the island. Finally, the authors propose two scenarios for future off-shore and inland earthquakes (ranging magnitudes between 6.0 and 6.9), with an estimation of 110–620 dead and 330–1750 injured.

Summarizing, the collected papers in this issue present new results on the structure, seismicity, seismotectonics, seismic hazard, and geodynamics of this complex region from the Azores Islands to the Iberian Peninsula. The Editors would like to dedicate this Topic volume to Dr. Alfonso López-Arroyo (1927–2017) and to Prof. Agustín Udías, for their pioneer contribution on the study of the seismicity, seismotectonics and seismic risk of Iberia. Alfonso and Agustín were two early career geophysicists when in 1972 they published the first study of the 1969 earthquake and its seismic sequence (López-Arroyo and Udías, 1972). Their germinal research efforts laid the foundation for creating an extraordinary research group in Madrid (Spain) that formed and inspired a number of generations of geophysicists. Most of the Authors, which contributed to this Special Issue, were actually former members of this research group or at least indirectly related to it.

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