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Seismicity of the Earth 1900–2013

Mediterranean Sea and Vicinity

Compiled by Matthew W. Herman,[2] Gavin P. Hayes,[1] Gregory M. Smoczyk,[1] Rebecca Turner,[3] Bethan Turner,[3] Jennifer Jenkins,[3] Sian Davies,[3] Amy Parker,[3] Allison Sinclair,[3] Harley M. Benz,[1] Kevin P. Furlong,[2] and Antonio Villaseñor[4]

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[1]U.S. Geological Survey
[2]Department of Geosciences, Pennsylvania State University, University Park, Pa., USA
[3]Department of Earth and Ocean Sciences, University of Liverpool, Liverpool, United Kingdom
[4]Institute of Earth Sciences, Consejo Superior de Investigaciones Cientificas, (CSIC), Barcelona, Spain

TECTONIC SUMMARY

The Mediterranean region is seismically active due to the convergence of the Africa Plate with the Eurasia plate. Present day Africa-Eurasia motion ranges from ~4 millimeters per year (mm/yr) (in a northwest-southeast direction) in the western Mediterranean to ~10 mm/yr (north-south) in the eastern Mediterranean. The Africa-Eurasia plate boundary is complex, and includes extensional and translational zones in addition to convergent regimes. This convergence began at approximately 50 million years ago (Ma) and was associated with the closure of the Tethys Sea; the Mediterranean Sea is all that remains of the Tethys. The highest rates of seismicity in the Mediterranean region are found along the Hellenic subduction zone of southern Greece and the North Anatolian Fault Zone of northwestern Turkey.

At the western margin of the Mediterranean region (in the eastern Atlantic Ocean), oblique Africa-Eurasia collision is accommodated by right lateral strike-slip faulting along the Azores-Gibraltar seismic zone and into the Gulf of Cadiz. One of the more prominent historical (pre-instrumental) earthquakes within this region was the 1 November 1755 Lisbon earthquake, with an estimated magnitude of 8.0. This event generated a tsunami that swept up the Portuguese coast, inundating coastal villages and the city of Lisbon, leading to a death toll of ~60,000.

In the region near the Alboran Sea, between Spain and Morocco, shallow earthquakes are characterized by a wide range of faulting mechanisms, though extensional to strike-slip mechanisms prevail. The region's tectonic activity cannot be simply explained by the collision of the Eurasia and Africa plates. It has been suggested that deeper lithospheric processes are controlling some of the deformation observed at the surface. Seismicity to depths of 600+ kilometers (km) beneath southern Spain is considered evidence of remnant subduction that still influences present-day tectonics.

The Atlas Belt extends along northern Africa and hosts normal and thrust earthquakes with the same west-east strike orientation as the Africa-Eurasia plate boundary as well as strike-slip earthquakes oblique to the plate boundary orientation. Along the North Africa coast, earthquakes form a narrow band and the region in northern Algeria between Oran and Algiers is particularly active. On 21 May 2003, an M6.8 earthquake in Algiers killed 2,266 people and injured 10,261.

Beneath northeastern Sicily and southern Italy, subduction occurs beneath the Tyrrhenian Sea at the Calabrian Arc, with seismic activity observed to depths of 500 km. Despite a slow convergence rate at the Calabrian Arc (0.8–1.1 mm/yr), this region has generated some of the most devastating historical earthquakes in Europe, including the 1693 Sicily earthquake that destroyed numerous towns along Sicily's east coast. The Messina Strait is an extensional back-arc structure between Sicily and Italy, which hosted an M7.0 earthquake on 28 December 1908 that caused 72,000 associated fatalities. To date, it is the deadliest documented European earthquake.

The seismicity of Italy is dominated by earthquakes within the northwest-southeast trending Apennine mountain chain, which extends from the Gulf of Taranto in the south, to the southern edge of the Po basin in the north. The Apennine Mountains formed as a consequence of thrusting above a west-dipping subduction zone, where the Adriatic Sea descends beneath the Italian peninsula. It is still debated whether the Adriatic Sea is a northern promontory of the Africa Plate or a separate block moving independently of the Africa and Eurasia Plates.

The eastern side of the Apennine Chain is dominantly compressional, with associated thrusting earthquakes. On the western side of the Apennines, east-west extension occurs due to gravitational collapse of the mountain belt, resulting in normal faulting seismicity. The most damaging instrumentally recorded earthquake in this region occurred on 13 January 1915, near the town of Avezzano, which killed tens of thousands.

Deformation within the Alpine Mountain Belt is also associated with compression in response to the collision of northern Italy with Eurasia. The eastern Alps are particularly seismically active, with many shallow earthquakes occurring on north-dipping thrust faults, such as the M6.5 Friuli earthquake in northeast Italy on 6 May 1976 that killed approximately 1,000 people.

Near Crete, the Africa Plate subducts at a rate of almost 40 mm/yr beneath the Aegean Sea along the Hellenic Arc. Shallow-focus earthquakes (<50 km) are common in this region, and most earthquakes northwest of Crete have reverse or strike-slip mechanisms, accommodating the convergent motion at the subducting front. North-east of Crete, normal and strike-slip earthquakes arise from extension associated with regional back-arc spreading above the subducting Mediterranean oceanic crust. Beneath the southern Aegean Sea, and particularly under the Greek volcanic arc, several large intermediate depth earthquakes (>100 km) have also occurred. These deeper earthquakes are thought to have occurred as a consequence of subducting oceanic lithosphere sinking under its weight into the mantle.

The 1903 Kythira and 1926 Rhodes earthquakes, with estimated magnitudes of approximately 7.0, are among the largest earthquakes instrumentally recorded in the Mediterranean region. Historical sources and archeological studies suggest that earthquakes occurring near Crete in 365 AD and 1303 AD may have been much larger than any Hellenic Arc earthquake of the 20th century.

Along the eastern margin of the Mediterranean (near Turkey), the Sea of Marmara is a transition zone between the extensional regime of the back-arc of the Hellenic subduction system to the west, and the strike-slip regime of the North Anatolian Fault to the east. The North Anatolian Fault accommodates much of the right lateral strike-slip motion between the Anatolian Block and Eurasia Plate. Between 1939 and 1999, a sequence of 11 M6.7+ strike-slip earthquakes propagated westwards along the North Anatolian Fault. The most recent and farthest west of these earthquakes was the 17 August 1999, M7.6 Izmit earthquake, which killed approximately 17,000 people.

At the southern edge of the Anatolian Block lies the east-west trending Cyprian Arc, which hosts moderate levels of seismicity. The Cyprian Arc represents the convergent boundary between the Anatolian Block to the north and the Africa Plate to the south. The boundary is thought to join with the East Anatolian Fault zone in eastern Turkey; however no certain geometry or sense of relative motion along the entire boundary is widely accepted.

Along the eastern margin of the Mediterranean region there is complex interaction between the Africa, Arabia and Eurasia plates. The Red Sea Rift is a spreading center between the Africa and Arabia plates, with a spreading rate of approximately 10 mm/yr near its northern end, and 16 mm/yr near its southern end. Seismicity rate and size of earthquakes has been relatively small along the spreading center, but the rifting process has produced a series of volcanic systems across western Saudi Arabia.

Further north, the Red Sea Rift terminates at the southern boundary of the Dead Sea Transform. The Dead Sea Transform is a strike-slip fault that accommodates left lateral motion between the Africa and Arabia plates. Historically, earthquake activity along the Dead Sea Transform has been a significant hazard in the densely populated Levant region (eastern Mediterranean). For example, the November 1759 Near East earthquake is thought to have killed somewhere between 2,000–20,000 people. The northern termination of the Dead Sea Transform occurs within a complex tectonic region of southeast Turkey, where interaction of the Africa and Arabia plates and the Anatolian block occurs. This involves translational motion of the Anatolia Block west-wards, with a speed of approximately 25 mm/yr with respect to Eurasia, in order to accommodate closure of the Mediterranean basin.

DATA SOURCES

The earthquake locations shown on the main map and on the depth profiles (left) are taken from the global 1900–2007 Centennial catalog (Engdahl and Villaseñor, 2002), a catalog of high-quality depth determinations for the period 1964–2002 (Engdahl, personal commun., 2003), and USGS-NEIC for the period 2008-2010. Major earthquakes (7.5–8.2) are labeled with the year of occurrence, while earthquakes (8.0–8.2) are labeled with the year of occurrence and also denoted by a white outline (Tarr and others, 2010).

The Seismic Hazard and Relative Plate Motion figure (right) shows the generalized seismic hazard (Giardini and others, 1999) and relative plate motion vectors (open arrows with labels) using the Morvel model (DeMets and others, 2010).

Base map data sources include GEBCO 2008 shaded relief, Volcanoes of the World dataset (Siebert and Simkin, 2002), plate boundaries (Bird, 2003), and geographic information from Digital Chart of the World (1992), and esri (2002).

REFERENCES

Anderson, Helen, and Jackson, James, 1987, Active Tectonics in the Adriatic region: Geophysical Journal International, v. 91, p. 937–983.

Bird, Peter, 2003, An updated digital model of plate boundaries: Geochemistry Geophysics Geosystems, v. 4, no. 3, 52 p.

Chiarabba, Clavdio., Jovane, Luigi., and DiStefano, Raffaele., 2005, A new view of Italian seismicity using 20 years of instrumental recordings: Tectonophysics, v. 395, is. 3–4, p. 251–268.

Chu, Dezhi, and Gordon, R.G., 1998, Current plate motions across the Red Sea: Geophysical Journal International, v. 135, is. 2, p. 313–328.

D'Agostino, Nicola, D'Anastasio, Elisabetta, Gervasi, Anna, Guerra, Ignazio, Nedimovic, M.R., Seeber, Leonardo, and Steckler, Michael, 2011, Forearc extension and slow rollback of the Calabrian Arc from GPS measurements: Geophysical Research Letters, v. 38, is. 17, p. L17304.

DeMets, Charles, Gordon, R.G., and Argus, D.F., 2010, Geologically current plate motions: Geophysical Journal International, v. 181, no. 1, p. 1–80, doi: 10.1111/j.1365-246X.2009.04491.x.

Di Stefano, Raffaele, Kissling, E., Chiarabba, Claudio, Amato, A., and Giardini, Dominico, 2009. Shallow subduction beneath Italy—Three-dimensional images of the Adriatic-European-Tyrrhenian lithosphere system based on high-quality P wave arrival times: Journal of Geophysical Research v. 114, is. B05, doi:10.1029/2008JB005641.

Digital Chart of the World, 1992: accessed Mar. 9, 1996. http://earthinfo.nga.mil/publications/specs/printed/89009/89009_DCW.pdf.

Engdahl, E.R., and Villaseñor, Antonio, 2002, Global seismicity 1900–1999, in Lee, W.H.K., Kanamori, Hiroo, Jennings, P.C., and Kisslinger, Carl, eds., International Handbook of Earthquake and Engineering Seismology, v. 81(A), chap. 41, p. 1–26.

Esri, 2002, Esri data and maps: Redlands, Calif., Environmental Systems Research Institute (Esri). [Available at http://www.esri.com/data/data-maps.]

GEBCO, 2008, The GEBCO_08 Grid, ver. 20091120: GEBCO, accessed Jan. 8, 2010 at http://www.gebco.net/.

Giardini, Dominico, Grünthal, Gottfried, Shedlock, K.M., Zhang, Peizhen, and Global Seismic Hazards Program, 1999, Global Seismic Hazards Map: Global Seismic Hazards Map Program (GSHAP). Accessed Jan. 9, 2007 at http://seismo.ethz.ch/GSHAP.

Guangwei, Fan, and Wallace, T.C., 1998, Tomographic imaging of deep velocity structure beneath the eastern and southern Carpathians, Romania: Implications for continental collision: Journal of Geophysical Research, v. 103, no. B2, p. 2705–2723.

Knapp, J.H., Knapp, C.C., Raileanu, Victor, Matenco, Liviu, Mocanu, Victor, and Dinu, Cornel, 2005, Crustal constraints on the origin of mantle seismicity in the Vrancea Zone, Romania—The case for active continental lithospheric delamination: Tectonophysics, v. 410, is. 1–4, p. 311–323.

Kopf, Achim, Mascle, Jean, and Klaeschen, Dirk, 2003. The Mediterranean Ridge—A mass balance across the fastest growing accretionary complex on Earth: Journal of Geophysical Research v. 108, is. B8, p. 2,372.

Mauffret, Alain, 2007, The northwestern (Maghreb) boundary of the Nubia (Africa) Plate: Tectonophysics v. 429, p. 21–44.

National Oceanic and Atmospheric Administration (NOAA), 2010, National Geophysical Data Center (NGDC): National Oceanic and Atmospheric Administration, accessed Mar. 21, 2010 at http://www.ngdc.noaa.gov/hazard/hazards.shtml.

Özbakir, A.D., Sengör, A.M.C., Wortel, M.J.R., and Govers, Rob, 2013. The Pliny–Strabo trench region—A large shear zone resulting from slab tearing: Earth and Planetary Science Letters v. 375, p. 188–195, doi:10.1016/j.epsl.2013.05.025.

Papazachosa, B.C., Karakostas, V.G., Papazachosa, C.B., and Scordilis, E.M., 2000, The geometry of the Wadati–Benioff zone and lithospheric kinematics in the Hellenic Arc: Tectonophysics, v. 319, is. 4, p. 275–300.

Romeo, Roberto, and Pugliese, Antonio, 2000, Seismicity, seismotectonics and seismic hazard of Italy: Engineering Geology, v. 55, is. 4, p. 241–266.

Sallarès, Valenti, Gailler, Audrey, Gutscher, M.A., Graindorge, David, Bartolomé, Rafael, Gràcia, Eulàlia, Díaz, Jordi, Dañobeitia, J.J., and Zitellini, Nevio, 2011. Seismic evidence for the presence of Jurassic oceanic crust in the central Gulf of Cadiz (SW Iberian margin): Earth and Planetary Science Letters, v. 311, p. 112–123. doi:10.1016/j.epsl.2011.09.003.

Serpelloni, Enrico, Vannucci, Gianfranco, Pondrelli, S., Argnani, Andrea, Casula, G.A., Anzidei, M., Baldi, P., and Gasperini, P., 2007, Kinematics of the Western Africa-Eurasia Plate boundary from focal mechanisms and GPS data: Geophysical Journal International, v. 169, p. 1180–1200.

Siebert, Lee, and Simkin, Thomas, 2002, Volcanoes of the world—An illustrated catalog of Holocene volcanoes and their eruptions: Smithsonian Institution, Global Volcanism. Program Digital Information series, GVP-3, accessed Jan. 9, 2007 at http://www.volcano.si.edu.

Spakman, Wim, and Wortel, M.J.R., 2004, A tomographic view on Western Mediterranean Geodynamics, *in* Cavazza, William, Roure, F.M., Spakman, Wim, Stampfli, G.M., Ziegler, P.A., eds., The TRANSMED Atlas—The Mediterranean Region from crust to mantle: Berlin, Heidelberg, Springer-Verlag, p. 31–52.

Tarr, A.C., Villaseñor, Antonio, Furlong, K.P., Rhea, Susan, and Benz, H.M., 2010, Seismicity of the Earth 1900–2007: U.S. Geological Survey Scientific Investigations Map 3064, scale 1:25,000,000. [Available at http://pubs.usgs.gov/sim/3064/].

Tortorici, Luigi., Monaco, Carmelo, Tansi, Carlo, and Cocina, Ornella, 1995, Recent and active tectonics in the Calabrian arc (southern Italy): Tectonophysics, v. 243, is. 1–2, p. 37–55.

Wortel, M.J.R., Faccenna, Claudio., Fernandez, M., Grevemeyer, Ingo, Jones, A.G., Terrinha, Pedro, and TopoMed Team, 2010, TopoMed—Plate boundary re-organization in the western Mediterranean [poster] *in*, 6th TOPO-EUROPE Workshop, Nov. 4–7, 2010, Honefoss, Norway. ftp://ftp.geo.uu.nl/pub/posters/2010/TopoMed_Plate_bounary organization_in_the_western_Mediterranean-Wortel-2010.pdf.

Zitellini, Nevio, Gràcia, Eulàlia, Matias, L.M., Terrinha, P.A.G., Abreu, M.A., DeAlteriis, G., Henriet, J.P., Dañobeitia, J.J., Masson, D.G., Mulder, T.J., Ramella, Riccardo, Somoza, Luis, and Diez, Susana, 2009, The quest for the Africa–Eurasia Plate boundary west of the Strait of Gibraltar: Earth and Planetary Science Letters, v. 280, p. 13–50.

Seismic Hazard and Relative Plate Motion

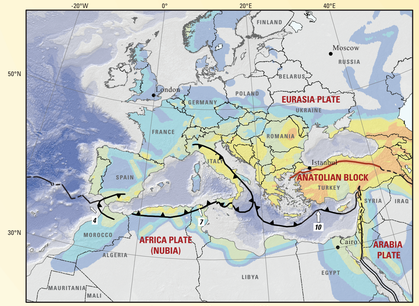
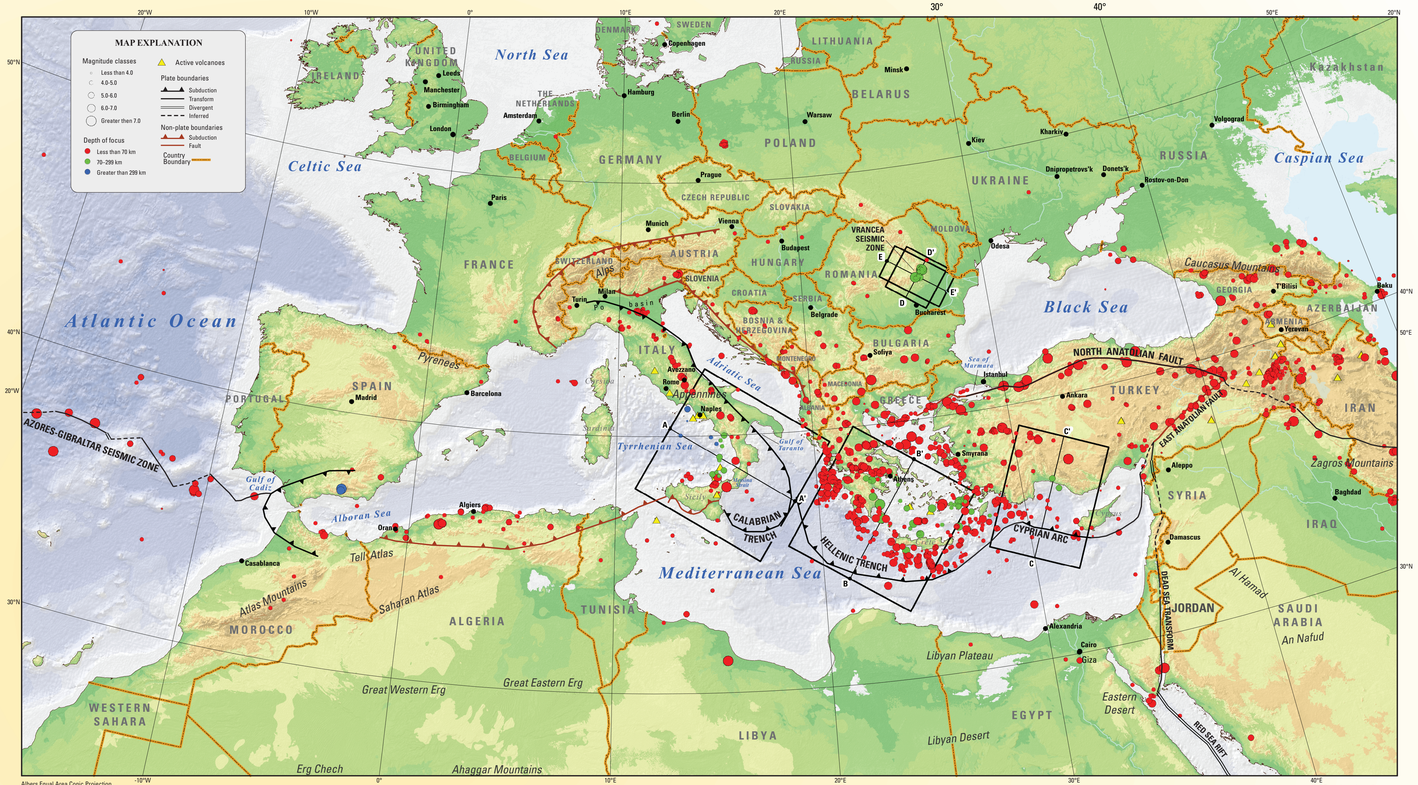


FIGURE EXPLANATION

10% in 50 year peak ground acceleration: 0–2 m/s²; 2.1–3.4; 3.5–4.8; 4.9–6.8; 6.9–9.2; 9.3–12.2; 12.3–16.4; 16.5–22.0

Relative plate motion: > 10 mm/yr; 10 – 10 mm/yr; Relative Plate motion in mm/yr: Nubia-Eurasia

Plate boundaries: Subduction; Transform; Large active faults; Divergent; Others



DEPTH PROFILE SUMMARY

Profiles A, B, and C highlight two of the main subduction zones in central southern-Europe; the Calabrian Arc (A) and the Hellenic Arc (B and C). Deep earthquakes occur in a diagonal line across the profiles. This reflects the slip occurring between the subducting slab and the mantle, as the Africa Plate moves downwards beneath the Eurasia Plate. Near surface earthquakes occur in both plates, though more are generally observed in the overriding Eurasia Plate.

The Calabrian Arc is one of the narrowest subduction zones in the world and has a steeply dipping subducting slab that is seismically visible to depths of approximately 500 km. In this locality, the northwest-south-east collision between the two plates causes uplift to the northwest generating the mountainous terrains across the southern Italian Peninsula. As slabs descend they release a significant amount of water into the mantle. This lowers the melting temperature of the mantle generating molten material which then rises to the surface, generating a linear belt of volcanoes parallel to the Calabrian Arc, including Mt. Etna and Stromboli.

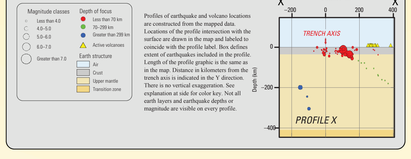
The Hellenic Arc slab subducts at a gentler angle and thus earthquakes are observed down to much shallower depths. Volcanoes in this region, such as Milos and Santorini, run parallel to the Hellenic Arc but, due to the shallower dip angle of the slab, they occur at a greater distance from the Arc than in the Calabrian region.

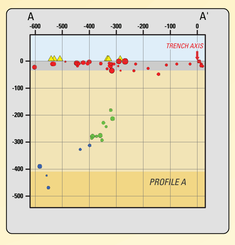
The seismically active region located at the join of the Eastern and Southern Carpathian mountain ranges in Romania is known as the Vrancea seismic zone. This area has a high earthquake density within a geographically restricted area, including deep earthquakes (70–200km), in the otherwise seismically inactive region of central Eastern Europe. Bucharest is among the most vulnerable European capitals due to the high levels of activity in the Vrance region, with four major earthquakes ranging from M6.9 to M7.4 occurring within the last century.

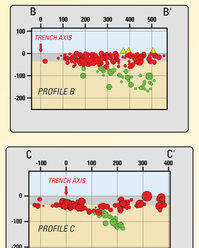
As seen in cross-sections D and E, seismic activity in this region is restricted to a narrow band dipping towards the northwest in a near vertical orientation. The causes of seismicity in this area are still a highly debated issue. Some suggest it is caused by the remnants of a subducted slab of oceanic lithosphere, whereas others believe it represents a section of the lowermost continental lithosphere which is peeling away and sinking down into the mantle in a process known as lithospheric delamination.

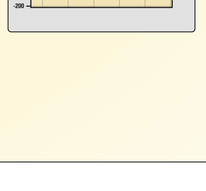
DEPTH PROFILE EXPLANATION

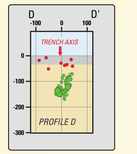
Profiles of earthquake and volcano locations are constructed from the mapped data. Locations of the profile intersection with the surface are drawn in the map and labeled to coincide with the profile label. Box defines extent of earthquakes included in the profile. Length of the profile graphic is the same as in the map. Distance in kilometers from the trench axis is indicated in the Y direction. There is no vertical exaggeration. See explanation at side for color key. Not all earth layers and earthquake depths or magnitude are visible on every profile.

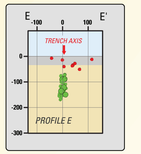












For region to the southeast see: USGS Open File Report 2010 1083K Middle East and Vicinity http://pubs.usgs.gov/of/2010/1083/k

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