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ORIGINAL ARTICLE

Using Active Fault Studies for Raising Public Awareness and Sensitisation on Seismic Hazard: A Case Study from Lesvos Petrified Forest Geopark, NE Aegean Sea, Greece

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Abstract Seismic hazard is commonly assessed by using seismicity records and local geotechnical conditions. It is however important to accurately define the probable seismic sources of the broader study area and assess their seismic potential, as earthquake intensities are expected to increase in the close vicinity of active faults. Although onshore faults are considered more hazardous, due to their immediate proximity to inhabited areas, the offshore fault hazard is considerable too, due to their proximity to the islands. In this paper, the identified seismically active faults are used as main elements of an educational programme in the Lesvos Petrified Forest Geopark to raise public awareness and sensitivity on seismic hazard.

Keywords Seismic hazard · Active faults · Awareness · Educational programme · Lesvos · Greece

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Introduction

Earthquakes represent the sudden release of slowly accumulated strain energy and hence provide direct evidence of the ongoing tectonic processes. Earthquakes are the result of displacement at depth along faults. Regions characterised by such events and affected by such structures are commonly claimed to be seismically and tectonically active. Earthquakes are complex natural phenomena that can be studied from different perspectives and using a variety of methods. The exploitation of geological data and the use of geological methodologies in their broadest sense are crucial for investigating seismic events and in general the active tectonics of an area. Studies on active faults investigate the very recent activity of major structures, capable of being reactivated in the near future and are able to provide quantitative data that is extremely useful for seismic hazard estimates such as slip-rate, earthquake recurrence interval, elapsed time since the last large earthquake, amount of co-seismic displacement (or displacement per event), fault geometry and fault segmentation. Accordingly, these parameters can be used to evaluate both the size and the potential location of

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future earthquakes along a fault zone (Caputo and Pavlides 2008). Earthquakes strike violently and without warning. Identifying potential hazards ahead of time, and advance planning and preparedness of the population can reduce the dangers of serious injury or loss of life from an earthquake. Furthermore, social awareness and education on natural hazards is a crucial factor leading to enhanced public safety and to reduced losses. This paper refers to the use of the results of the research project entitled "Use of modern research tools in geosciences for seismic hazard management in NE Aegean islands" to raise public awareness on seismic hazard. The research project focused on seismological and geological studies dealing with seismic hazard assessment in the islands of the North Aegean region in Greece. Geological study included identification and mapping of the major active faults together with all associated co-seismic phenomena, like ruptures, cracks, fault offsets, liquefaction etc. The project also included public awareness activities on seismic hazard which took place in the main NE Aegean islands (Lesvos, Chios, Samos), including thematic exhibitions, seminars and educational programmes for schools.

Seismic Hazard in the North Aegean Region

According to the Greek National Statistic Agency (2001 consensus), the population of the North Aegean Prefecture is 204,108 residents while the population of Turkish coast cities and towns is several million. The North Aegean region is a geotectonically complex area, because its geodynamic status is directly affected by the North Anatolian Fault Zone, its westward continuation in the Aegean Sea, known as the North Aegean Trough and the West Anatolia Graben System in Asia Minor with significant historical seismicity (Papazachos and Papazachou 1997; Kiratzi and Louvari 2003; Papazachos and Kiratzi 1996). As a result of the interaction between these tectonic systems, there is a strong diversity in fault trending and

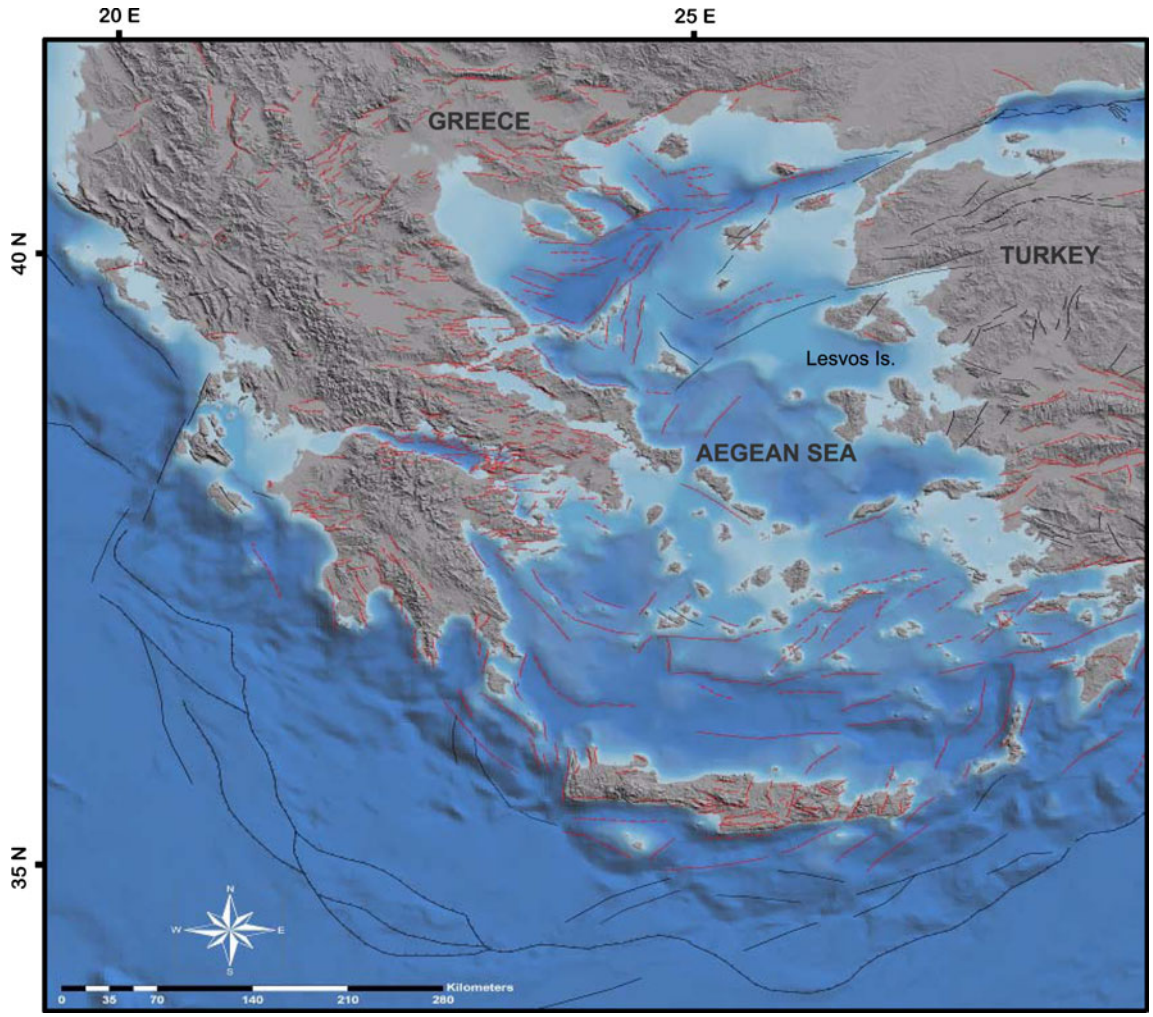

Fig. 1 Map of active faults in the Aegean region (Pavlides et al. 2009)

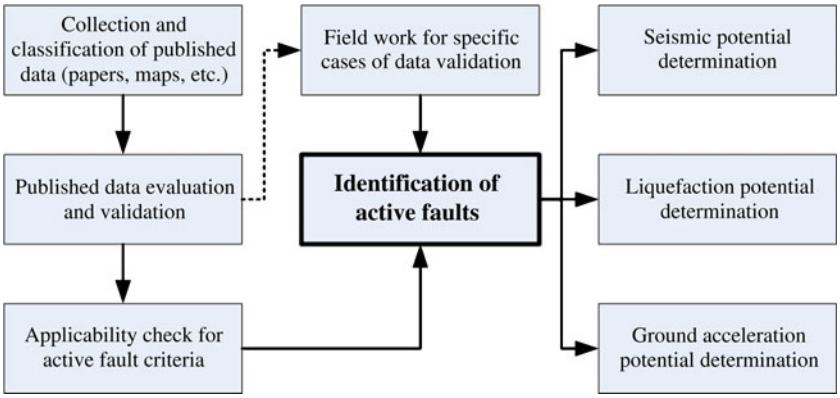

Fig. 2 Procedure flow diagram for the characterization of active faults (Pavlides et al. 2009)

character (Pavlides et al. 1990; Koukouvelas and Aydin 2002; Kreemer et al. 2004; Papanikolaou et al. 2006). These faults are located on islands as well as offshore, where they define seafloor morphology (Fig. 1). Furthermore, the faults on the Turkish coast should not be ignored in a seismic hazard analysis of the area, as they are situated a short distance from residential areas and are possible seismic sources.

The definition of active faults and their seismic potential is therefore of paramount importance for seismic hazard assessment and civil protection (Pavlides et al. 2009). The risks that earthquakes pose to society in the NE Aegean, including death, injury, and economic loss, can be greatly reduced by better planning, construction, and mitigation practices before earthquakes happen, and providing critical and timely information to improve responses after they occur.

Active Faults in North Aegean

North Aegean faults are variable in strike and character. A large percentage of them are affected by the local shear stress field, showing predominantly horizontal displacement, as derived from the focal mechanism of shallow earthquakes in the area. However, there are also many normal faults, while the majority of all faults are either normal oblique slip with left-lateral component or right-lateral component (Fig. 1). In this complex tectonic environment, the determination of the fault activity and the fault classification in active or possibly active faults is based on the following criteria (Pavlides et al. 2009; Fig. 2):

Fault geometry: the relation between the fault strike and the local stress field is very important for possible future reactivations. *Geologic age*: the age of the last reactivation of the fault is the one with the most recent deformed material. Faults that deform Upper Pleistocene–Holocene sediments are a priori active. *The morphologic impact on relief*: the identification of past earthquake ground ruptures, easily affected by exogenic processes, is a valuable indicator of recent fault activity; its weathering degree is directly dependent on the elapsed time since the last reactivation. Morphotectonic indicators may also affect various other structures, such as sharp fault scarps

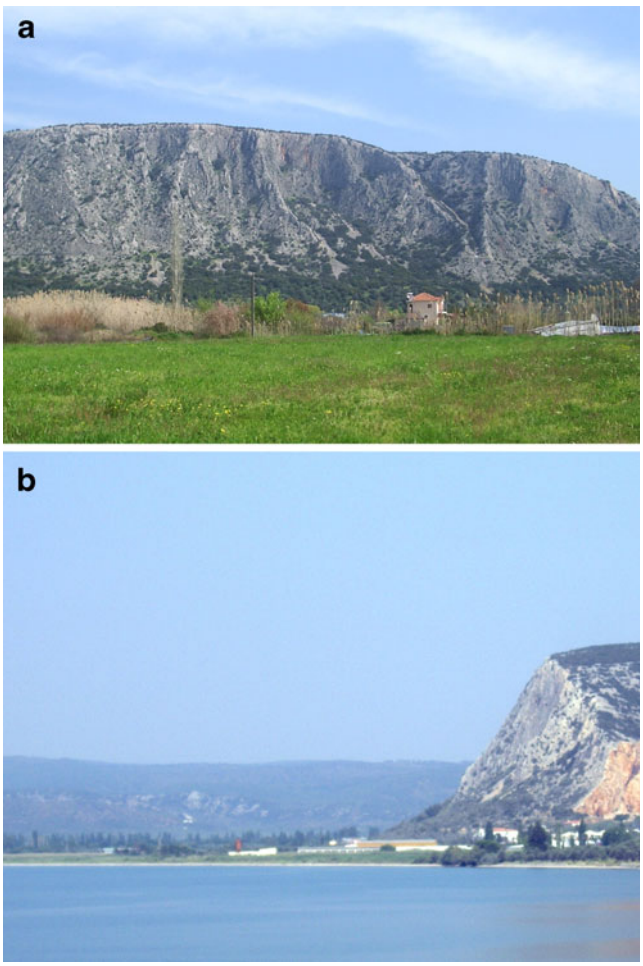

Fig. 3 The impressive Larsos fault scarp at the northern side of Geras gulf presents a good example of the morphologic impact of the active faults on the relief of Lesvos island

(Fig. 3), the differential and intense deep erosion at the upper part of a fault scarp, an observed linear arrangement of recent geomorphic features, etc. Analysis and evaluation of the morphologic impact requires careful study of geomorphic features and their association (or not) with faults.

The seismotectonic characteristics: some faults are associated with historic or instrumental seismicity; in this case they are classified as active. In cases where they produced surface ruptures during an event, it is easy to correlate them with specific tectonic structures. In the case of nonmorphogenic events (sensu Caputo 2005), the correlation with already mapped faults is inferred from focal mechanisms and microseismicity. *The morphotectonic indices*: the morphotectonic indices are strong proof of the activity level of a fault zone. These kinds of indices can be fault scarp sinuosity, drainage basin asymmetry, valley width/height ratio, etc. There are many indices that can be used for drawing conclusions in tectonically active regions, but in all cases they must be used in combination with geologic and tectonic data (Pavlides 2003). After applying the above-mentioned criteria to individual faults, together with field confirmation, they can be characterised as active, possibly active or inactive. This classification refers to fault zones and not individual fault planes (Pavlides et al. 2009). Active faults in the study area are presented in the seismicity and active fault map of the North Aegean Region as well as in more detailed maps for each island (Figs. 4 and 5, Zouros et al. 2008). In each island's map, expected magnitude and displacement are also presented. They were estimated by using Pavlides and Caputo (2004) relationships. It is important to note that the faults depicted in the maps should rather be considered as fault zones, instead of individual faults. Their exact trace has been identified by comparing various published data with field results. Faults located in Turkey were mainly extracted from Şarolu et al. (1992).

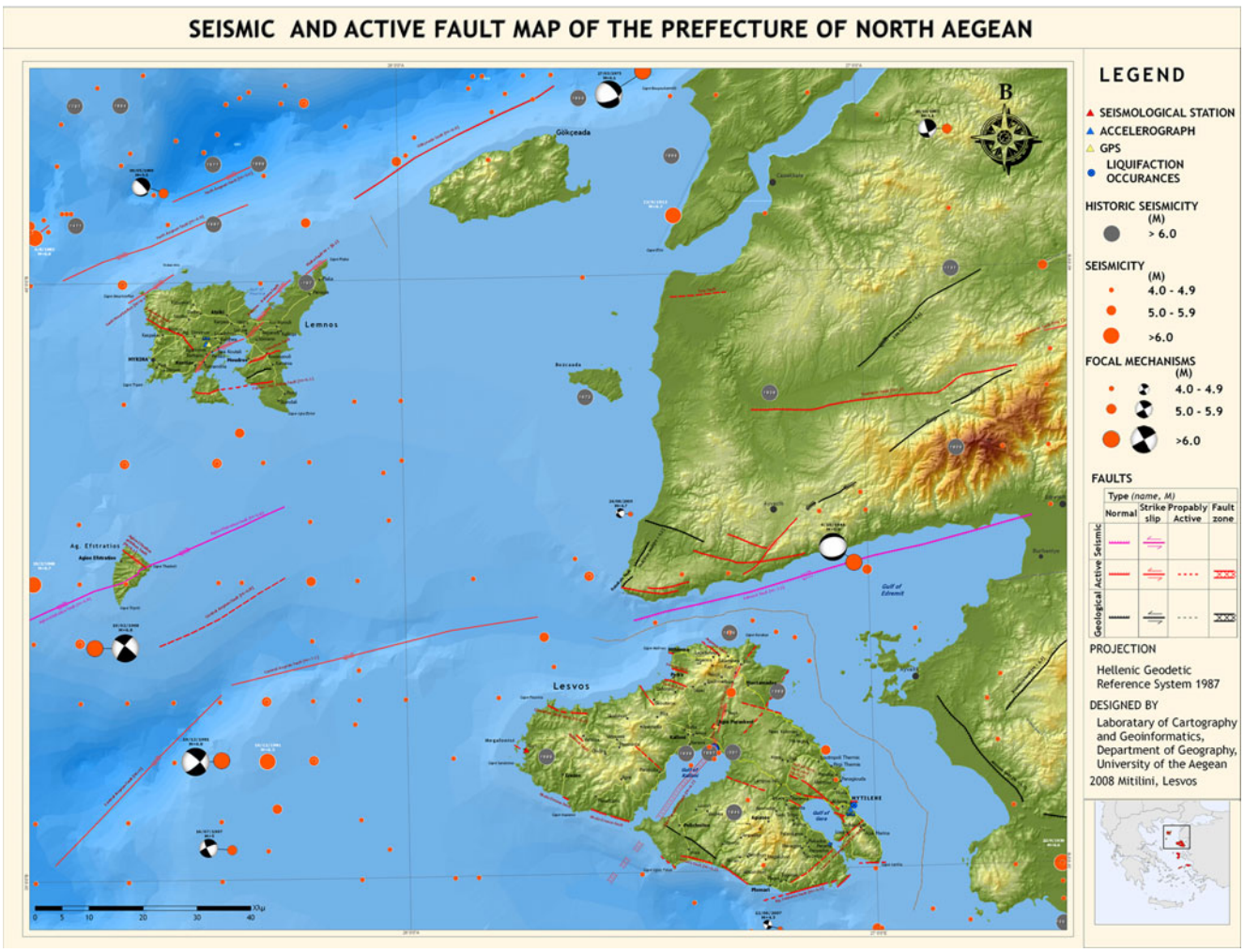

Fig. 4 Seismicity and active fault map of the North Aegean Region—north sheet (Zouros et al. 2008)

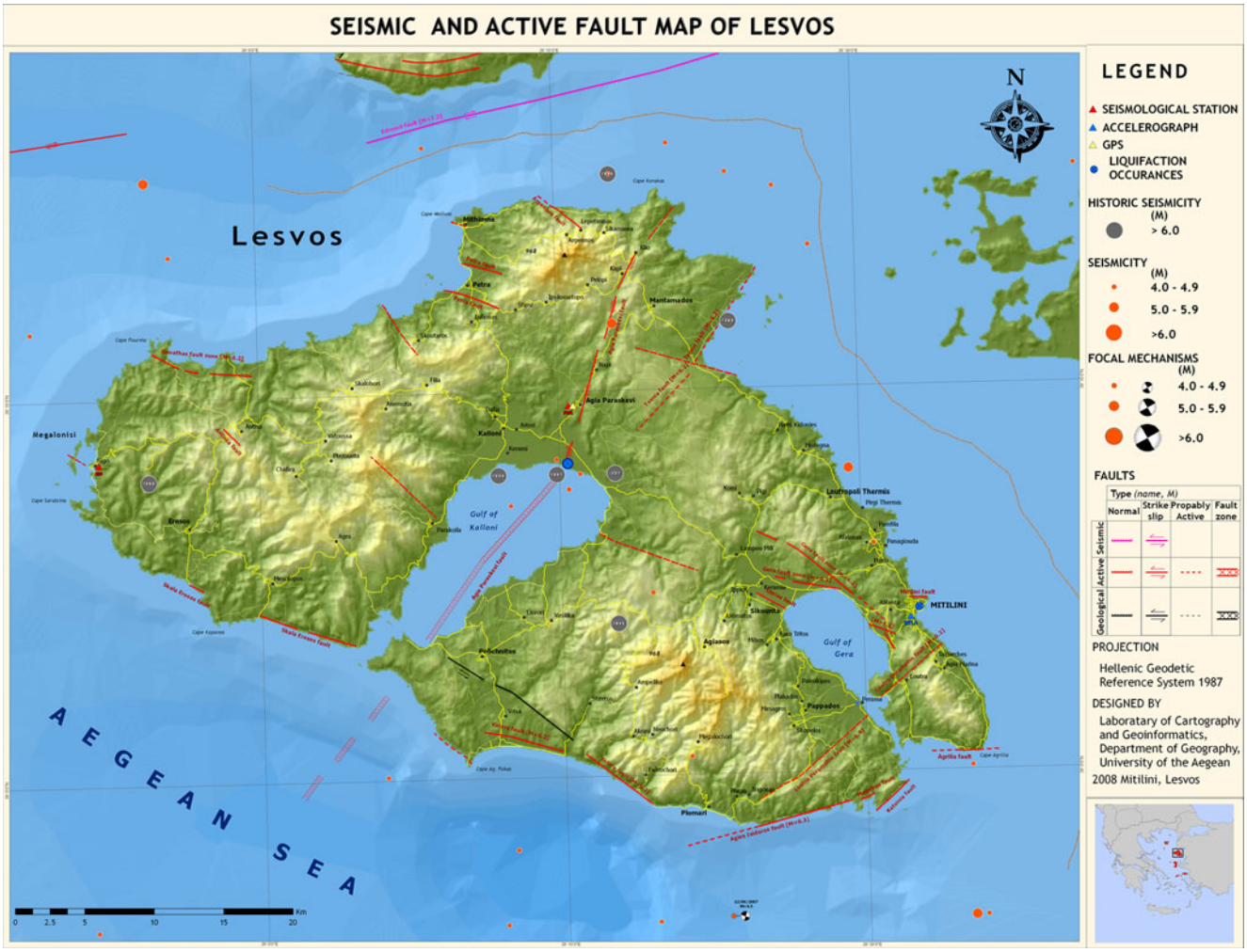

Fig. 5 Seismicity and active fault map of Lesvos Island (Zouros et a. 2008)

Active Faults on Lesvos Island

Lesvos Island is the most populated island in the NE Aegean Sea and is the capital of the N. Aegean Region and Lesvos Prefecture, so its seismic potential has special social–economic meaning not only regionally but also broadly. Lesvos, the third largest Greek island, is dominated by Neogene volcanic rocks responsible for the characteristic landforms and landscapes. On its western side, an entire Miocene fossilized forest has been unearthed, the well-known "Petrified Forest of Lesvos", a protected natural monument covering an area of 15,000 ha (Velitzelos and Zouros 2006). Lesvos Island is affected by significant active faults (Soulakellis et al. 2006) located both onshore and offshore (Fig. 5). North of Lesvos lies the Edremit fault, which shows high seismic potential and is one of the most hazardous seismic sources for the broader area. It defines the southern coastline of Biga Peninsula (Turkey), right opposite the northern shore of Lesvos, while its

Fig. 6 Fault scarp of the Aghia Paraskevi fault affecting Miocene volcanics in Lesvos island

Fig. 7 Striations indicating left-lateral strike slip movement along the Aghia Paraskevi fault

Fig. 8 Fault scarp along the Antissa left-lateral strike slip fault affecting Miocene volcanics within the Lesvos Petrified Forest Geopark

synthetic and antithetic faults are possible seismic sources of lower potential. On Lesvos Island, the most significant faults–potential seismic sources are the following:

- The right-lateral Aghia Paraskevi fault (Fytikas et al. 1999; Figs. 6 and 7) was the one activated when the 1867 earthquake (Ms=6.8 R) occurred. It cuts off the central part of the island from N to S, while its visible length onshore has earthquake magnitude potential of 6.7. This means that it continues to the sea, as far as the Kalloni gulf possibly, as it arises from the microseismic epicentre distribution.
- The WNW–ESE trending faults on the southern shore of the island play an important role in shaping the coastal morphology. According to the length, the maximum earthquake magnitude potential is 6.6–6.8.
- The ENE–WSW striking fault at the SE coast of Lesvos is active. Microseismicity shows a nice linear offshore distribution implying the fault's presence and continuation. According to the length, the maximum earthquake magnitude potential is 6.8.
- The faults in the Gulf of Gera (Fig. 3) comprise a zone that has particular importance because of the short distance from the town of Mytilene. The earthquake potential reaches the value of 6.5.

Several other smaller faults, i.e. Antissa fault (Fig. 8) and Plaka fault (Fig. 9), have been identified on Lesvos island affecting Miocene volcanic formations and showing characteristics which fit well with the active stress pattern.

Geoparks as Educational Tools

The Lesvos Petrified Forest Geopark is located on the western part of Lesvos Island and includes a core zone of 15,000 ha, the Petrified Forest protected area with large accumulations of exposed fossilized tree trunks, and a broad buffer zone, covering more than 20,000 ha of the central volcanic terrain. The Natural History Museum of the Lesvos Petrified Forest was founded in 1994 to protect and efficiently manage the Petrified Forest. It is a nonprofit organization that defines the management structure of the Lesvos Petrified Forest Geopark. The Lesvos Geopark, the very first Greek Geopark, already counts one decade of successful operation (Zouros 2007). Geoparks are areas with well-defined limits and a large enough surface area which comprise a number of internationally important geological heritage sites on any scale, or a mosaic of geological entities of special scientific importance, rarity or beauty. These features are representative of a region's geological history and the events and processes that formed it.

Fig. 9 Right-lateral displacement of a petrified tree trunk in the Lesvos Petrified Forest along an E–W trending strike slip fault which shapes the southern coast of the Plaka peninsula

Geoparks provide and organize support, tools and activities to communicate geoscientific knowledge and environmental concepts to the public (e.g. through museums, interpretive and educational centres, trails, guided tours, popular literature and maps, modern communication media). It also allows and fosters scientific research and cooperation with universities, and between geoscientists and the local populace (UNESCO 2008). Educational activities represent the core of the Lesvos Geopark's operation. Environmental education programmes organized for primary and high school students cover a broad range of activities aiming at raising the awareness of the local inhabitants and diffusing geoscientific knowledge on various issues like the understanding of natural processes, geoforms and landscapes, the importance of the environmental protection and management, the conservation of the Earth's heritage and natural hazards. In this framework, the Lesvos Geopark participated in the research project entitled "Use of modern research tools in geosciences for seismic hazard management in NE Aegean islands" and hosts the modern Seismological Station of Sigri which is connected to a telemetric network of the Seismological Station of the Aristotle University of Thessaloniki, which consists of 14 permanent regional stations, covering the entire region of northern Greece. The Natural History Museum of the Lesvos Petrified Forest was responsible for the organization of the outreach activities including thematic exhibitions and educational programmes aiming to introduce young students to the geo-scientific knowledge of earthquake hazards. All activities are accompanied by a variety of educational publications.

Seismic Hazard Awareness Activities

The Natural History museum of the Lesvos Petrified Forest organized public awareness activities on seismic hazard, while information related with the seismic hazard in the North Aegean Islands was published in an informative booklet and distributed to the local authorities and the public. Three seminars for local authorities and engineers were organized in Lesvos, Chios and Samos islands which were accompanied by thematic exhibitions and educational programmes for schools (Fig. 10). The educational activity "Earthquakes: natural processes and hazards on planet Earth—Living on an earthquake island" aims to familiarize students and citizens living on the Aegean Islands with earthquakes, active faults and seismic hazard. With this activity, the Natural History Museum of the Lesvos Petrified Forest is offering to students the opportunity to increase their understanding while it motivates them to learn more, and to explore the fascinating world of Earth-sciences (Fig. 11). Information on earthquakes and plate tectonics, suitable for middle school and high school students, as well as the general public, is conveyed with the help of numerous illustrations and three-dimensional models. The 2-h educational programme, which is designed to address the basic and secondary educational levels, includes six main volumes:

(a) Multimedia presentation on earthquakes and active faults. The presentation focuses on the causes of earthquakes, the ways in which seismic waves travel through the Earth and the catastrophic effects they

Fig. 10 Students visiting exhibition on seismic hazard in Samos island—May 2008

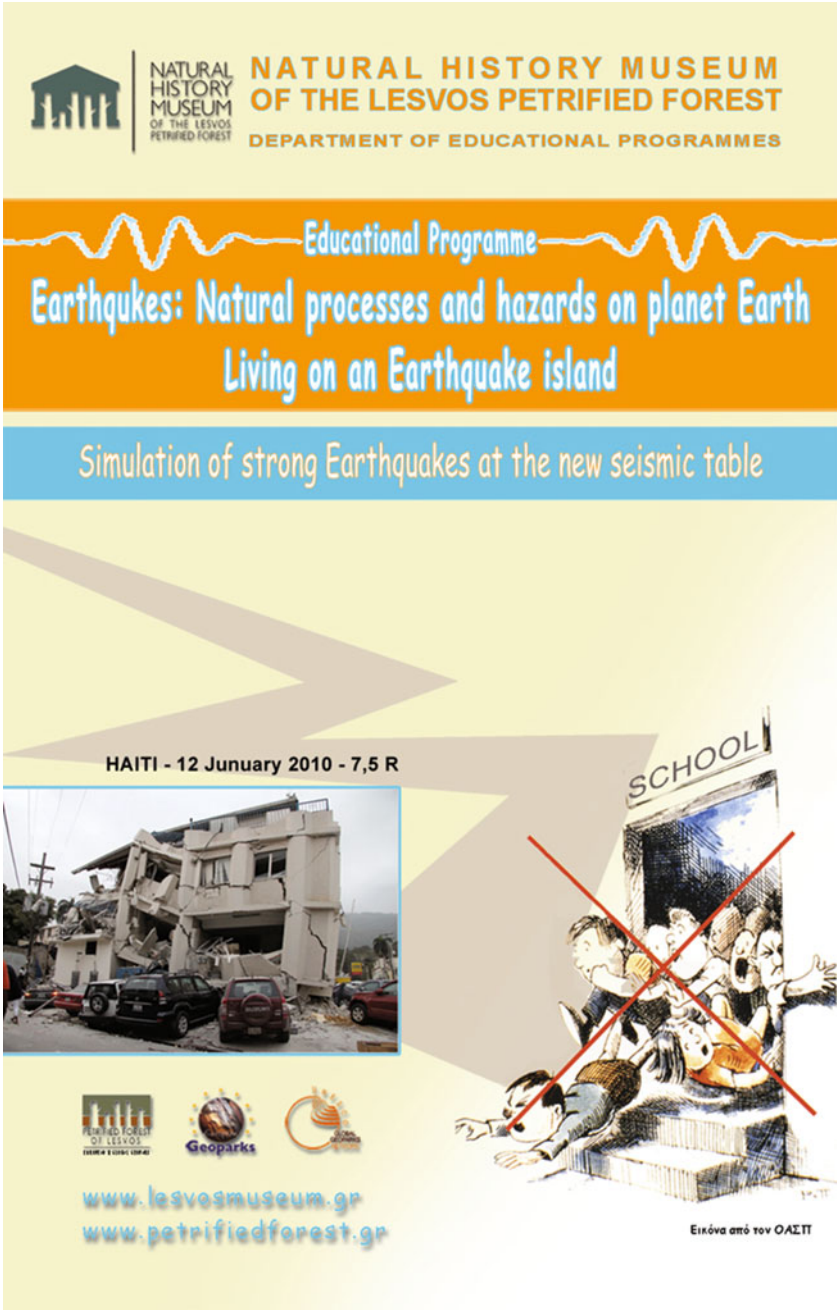

Fig. 11 Leaflet of the educational activity "Earthquakes: natural processes and hazards on planet Earth—Living on an earthquake island"

might have. Videos from recent earthquakes and photographs from historic ones illustrate seismic damage and community disaster response.

(b) Active seismicity and plate tectonics. In the Museum's Aegean exhibition hall participants can visualise the movements of the Earth's plates and their links with the occurrence of earthquakes, with the aid of interactive models and global map, to cover plate tectonics, volcanoes and earthquakes (Fig. 12).

(c) Monitoring seismicity. This part includes activities for the familiarisation of the participants with the scientific research in seismology. A traditional seismograph records the waves that the children produce on the ground while walking, while screens show the records of the modern digital seismographs in Sigri and Thessaloniki in real time. Additionally of interest is the Active Seismicity Monitor, an interactive, educational display of current Greek seismicity that monitors earthquakes in near real-time. The display is updated every 20 min using data from the National Seismographic Network (Fig. 13).

(d) Seismic hazard in the North Aegean. This thematic exhibition on seismic hazard in the Aegean islands

Fig. 12 Elementary students participating in the educational programme on earthquakes. Through an educational game they explore the movements of the Eurasian and African tectonic plates in the Aegean

presents data from the seismic history of the area and the new set of active fault and seismic hazard maps of the northeast Aegean islands. The exhibition provides further information on the connection between mythological characters and natural phenomena. It also provides information on historical earthquakes in the islands of the northeast Aegean, the links between large faults in these islands and the most recent tectonic activity in the Aegean area and other catastrophic natural phenomena linked with the earthquakes.

(e) Active fault study. Participants become earthquake geologists introducing them to the study of a real fault including field observations on active fault morphological characteristics, geometry and appearance. The children have a great opportunity to see a real fault in the back-yard of the Museum and understand how the rocks deform, fracture and move along the fault plane (Fig. 14).

(f) Earthquake simulation. The highlight of the programme, without any doubt, is the seismic table installed in the Museum. The installation can simulate the seismic movement of some of the most destructive earthquakes during recent years. Students can sit at their desks of a school-classroom and experience the tremors felt by the people of Athens, Greece on the 5 of September 1999, of Kobe, Japan, on the 17 of January 1995 (Mw=6.8), or of Gujarat, India, on the 26 of January 2001 (Mw=7.9).

Fig. 13 Students investigating the characteristics of a geological fault affecting Miocene volcanics at the Natural History Museum in Sigri

Fig. 14 Explaining the process of monitoring earthquakes by the Sigri seismic station

Fig. 15 Students participating in educational programme on earthquakes on the seismic table

This activity aims to familiarize the students with the correct procedures that need to be followed during and immediately after an earthquake. The programme enables them to learn and practice these procedures in a perfectly safe environment (Fig. 15).

(g) Educational activities. With the support of the Museum staff, participants take part in a variety of activities including practical information—tips on how to survive an earthquake and how to stock an emergency survival kit.

This new educational activity of the Lesvos Petrified Forest Geopark has proved a huge success. More than 3,000 students participate, gaining new experiences thus contributing to better understanding earthquakes and Earth's natural processes. The great value of this programme in an area with very intense seismic activity such as the NE Aegean is obvious.

The programme aims to familiarize children, students and the general public with earthquakes and their natural consequences. Knowledge is the most successful weapon against the catastrophic effects of earthquakes.

Conclusions

Protection against seismic hazard is a necessity for modern societies. The tragic pictures from the devastating earthquake that struck Haiti on January 12, 2010 (Mw=7.0), remind us of the need to be prepared to confront natural disasters. Greece is situated at the front of the Eurasian Plate on a collision zone, i.e. a convergent plate margin where the Eurasian and African plates collide. Greece is therefore one of the most seismically active countries in Europe. Earthquakes are frequent in some areas.

As prediction of earthquakes is still not possible, research projects focusing on better understanding of the seismic hazard in each area help communities to establish better planning and construction systems that will save lives and avoid severe disasters in urban areas and constructions. But scientific knowledge needs to be spread to society through initiatives helping civilians to protect themselves from natural disasters. Yet even with an ever-increasing knowledge about the crustal deformation of the Earth, we are not able to tell when the next earthquake will occur but we can help people better understand how to built to avoid disasters. As earthquakes happen along the main seismic faults, there is a necessity to familiarize the population with the geoforms and geosites related with active faults and recent seismic activity. For this reason, the subject of educational activity in the Lesvos Geopark is a burning issue not only in Greece but for many other countries where towns and villages are located along tectonic plate boundaries. The programme has been enthusiastically welcomed by the schools of Lesvos, and also by other Greek areas who visit the Natural History Museum on the island of Lesvos.

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