Compilation of the GSHAP regional seismic hazard for Europe, Africa and the Middle East

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Abstract

The seismic hazard map of the larger Europe-Africa-Middle East region has been generated as part of the global GSHAP hazard map. The hazard, expressing Peak Ground Acceleration (PGA) expected at 10% probability of exceedance in 50 years, is obtained by combining the results of 16 independent regional and national projects; among these is the hazard assessment for Libya and for the wide sub-Saharan Western African region, specifically produced for this regional compilation and here discussed to some length. Features of enhanced seismic hazard are observed along the African rift zone and in the Alpine-Himalayan belt, where there is a general eastward increase in hazard with peak levels in Greece, Turkey, Caucasus and Iran.

Key words *seismic hazard assessment – earthquakes – Europe – Africa – Middle East – UN/IDNDR*

1. Introduction

The compilation of the GSHAP global seismic hazard map, planned to be one of the main products of the program, is based on the integration of all results from GSHAP Regions and test areas in three greater GSHAP areas: 1) the Americas (North, Central and South); 2) Asia, Australia and Oceania, and 3) Europe, Africa and the Middle East. This report deals with the generation and compilation of the different seismic hazard data and the homogeneous mapping of hazard in the greater area (3) Europe, Africa and the Middle East, conducted by the GFZ Potsdam.

According to the original GSHAP planning (Giardini, 1999), the Europe-Africa-Middle East area was to be covered by the GSHAP Regions (3) Central-Northern Europe, (4) Mediterranean, (5) sub-Saharian Africa, (6) Middle East and the Arabian peninsula, and (7) Northern Eurasia (western portion only). However, the development of GSHAP in the Mediterranean and Middle East became more complex, and had to rely on the activation on a number of *ad-hoc* regional test areas (Ibero-Maghreb, ADRIA, Eastern African rift, CAUCAS; see below) and of independent but related projects (RELEMR, CirPan, Turkey; see below). In addition, for the super-regional compilation, specific national hazard maps were introduced in areas of pronounced border discrepancy (Slovenia, Greece) and a special effort was conducted at ETH Zurich to compile the hazard for those areas of Africa with no available maps.

In keeping with the approach of the GSHAP global map compilation, only the hazard maps were used, expressing peak ground acceleration expected at 10% probability of exceedance in 50 years, and no attempt was done to integrate the different models of seismic source zones.

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2. Compilation of regional seismic hazards

In the end, altogether 16 independent regional maps were collected, modified and integrated at GFZ Potsdam in order to produce a homogeneous hazard for the global map. The geographical extent of these different contributions to the greater GSHAP area is shown in fig. 1. Reports on most of the individual projects are included in this volume, and only a few comments are given here, with the exception of the hazard results for Western Africa, Libya and the Middle East, which are presented here for the first time. Therefore, these two areas are dealt with in detail. A brief description of the editing and compiling process is given below.

The numbering used in the following list corresponds to the area identification in fig. 1. It should be noted that in most cases considerable overlaps existed among different areas. This redundancy allowed to produce independent assessment of methodologies across boundaries and to obtain a smoothed mapping in agreement with several regional projects.

1. *Central Europe* – This vast area, including the United Kingdom, Ireland and the German speaking countries, has been compiled as the main part of the GSHAP Region 3. It also includes Southern France (south of 44°N), which was not originally included in Region 3 nor in the Ibero-Maghreb program (*cf.* 9 below) and which has been processed at GFZ (Grünthal *et al.*, 1999).

2. *Iceland* – Part of the GSHAP Region 3 (Grünthal *et al.*, 1999).

3. *Fennoscandia* – Part of the GSHAP Region 3 (Grünthal *et al.*, 1999).

4. *Northern Eurasia* – GSHAP Region 7 (Ulomov *et al.*, 1999).

5. *Poland - Czech Rep. - Slovakia* – Part of the GSHAP Region 3 (Grünthal *et al.*, 1999).

6. *Balcans north of Greece and northerly adjacent regions* (*cf.* 10) – CirPan project (Musson, 1999).

7. *Slovenia* – The national seismic hazard map for Slovenia was provided by Zabukovec (1998, personal communication), to improve the fit between the regional hazard maps.

8. *Italy* – Processed as the main part of the ADRIA GSHAP test area (Slejko *et al.*, 1999).

9. *Ibero-Maghreb* – GSHAP test area (Jiménez *et al.*, 1999).

10. *Greece* – Greece participated in the ADRIA test area, which covered only part of the Greek territory. The national seismic hazard map for Greece was provided by K. Makropoulos (Athens University) to fill up the void left in the regional coverage. The original Greek map as it is used here covers the whole Southern Balkans, including Albania, Macedonia and the southern part of Bulgaria.

11. *Turkey* – Part of the «Turkey and neighboring regions» project, covering also the whole Caucasus and the Aegean (Erdik *et al.*, 1999).

12. *Near East* – Since 1993, the U.S. Geological Survey (USGS) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) have been cooperating with Eastern Mediterranean Region (EMR) earth science organizations of Turkey, Lebanon, Cyprus, Syria, Jordan, Israel, Palestinian Authority, Egypt, Saudi Arabia and Yemen under the program «Reduction of Earthquake Losses in the Eastern Mediterranean Region (RELEMR)». The European-Mediterranean Seismological Center (EMSC) has coordinated the exchange of seismicity data among these countries. Among the RELEMR goals was the compilation of the regional seismic hazard, which was performed under the GSHAP umbrella.

The Eastern Mediterranean region, because of its geological structure, seismicity, topography, and climate, has been subjected to many earthquake disasters during the past two thousand years, resulting in great losses of life and property. Earthquake ground shaking and tsunamis, the main causes of past disasters, are expected to continue to be the most dangerous threats to the built environment of each EMR

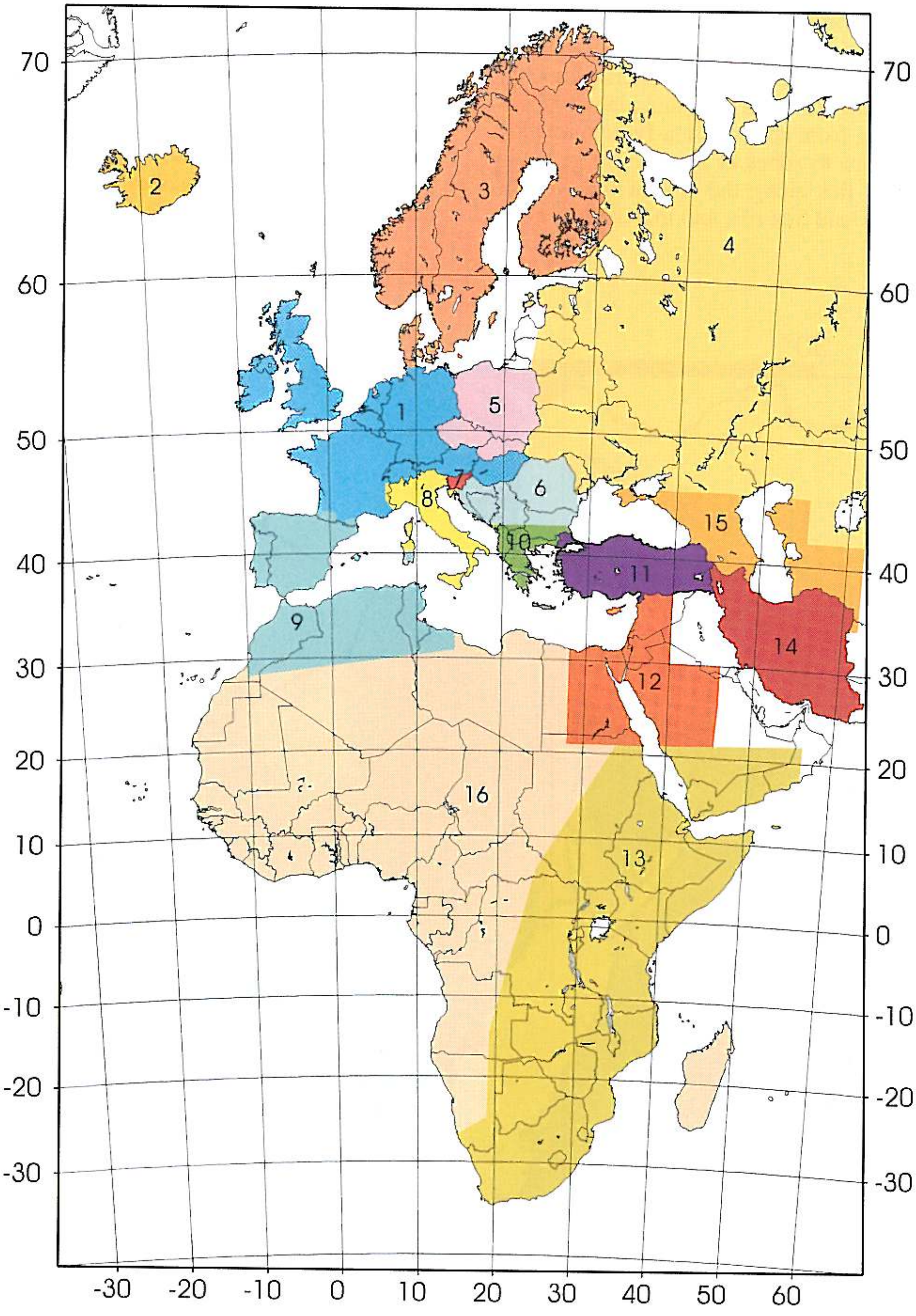

Fig. 1. Areal coverage of hazard maps compiled and integrated to produce the regional map for the Europe-Africa-Middle East region.

country. Seismicity in the EMR is mainly associated with the northward movement of the Arabian plate. The 1000 km-long western boundary of the Arabian plate is a complex plate boundary, extending from zones of sea-floor spreading in the Red Sea to zones of plate convergence in Turkey, and lies along the line of the Gulf of Aqaba, the Dead Sea rift, and the Ghab depression. The sense of motion along the transform fault system is left lateral, with the east side moving northward relative to the west side. Total displacement is estimated at about 107 km since Oligocene time, with an annual rate of about 0.5 cm over the last 7 to 10 million years. Seven damaging earthquakes have occurred in the EMR in the last decade. The M_s 7.2 earth-

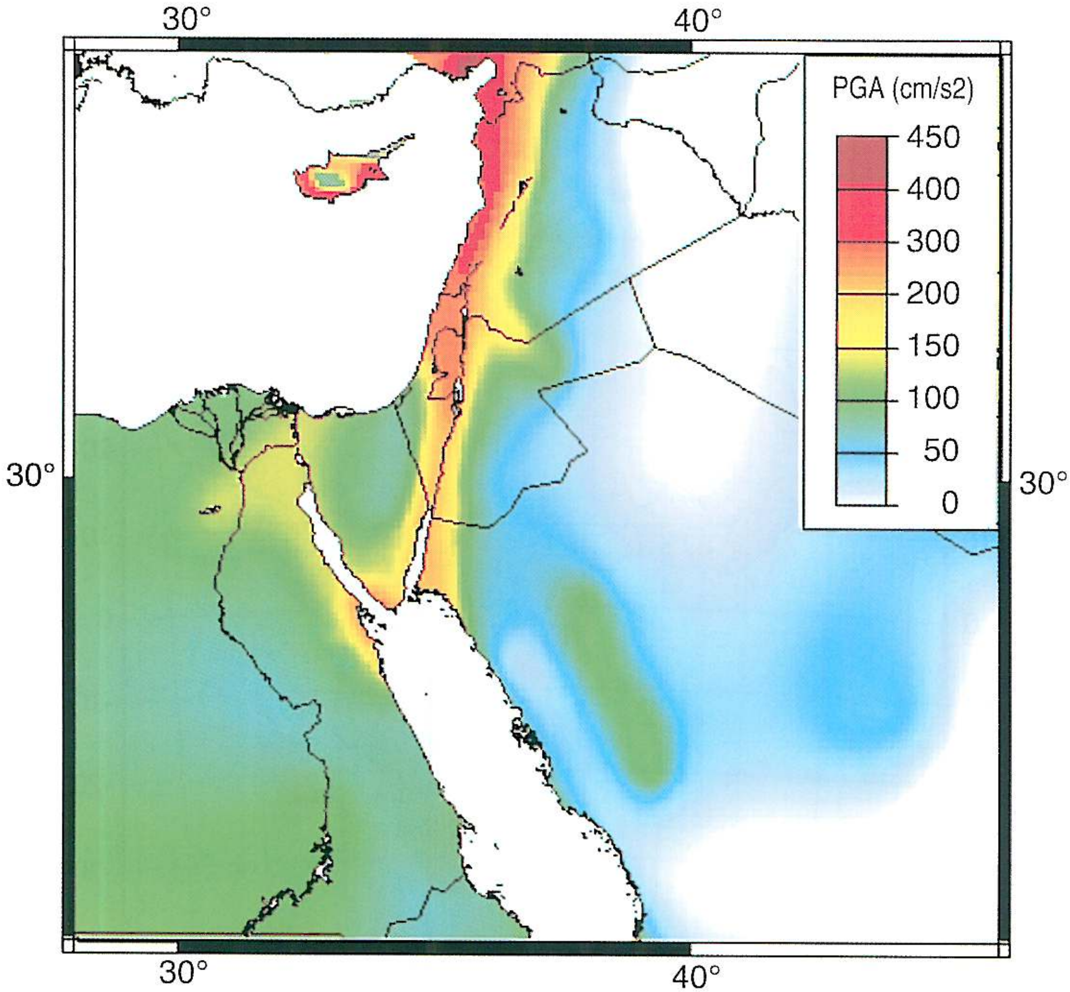

Fig. 2. Map of seismic hazard for the Near East region, expressing peak ground acceleration expected at 10% probability of exceedance in 50 years, produced jointly by GSHAP and the UNESCO/USGS RELEMR project (see text for details).

quake occurred in 1995 in the central Gulf of Aqaba region caused damage in nearby communities in Jordan, Egypt, Israel, and Saudi Arabia and was felt for more than 700 km; the aftershock sequence lasted for more than 1 year with numerous shocks exceeding M_S 5.0. For the first time, countries in the region worked together to process seismic data using various software packages and a unified data set. The magnitude of the main shock and the robust aftershock sequence demonstrate the threat that earthquakes continue to pose to the EMR.

The probabilistic ground shaking map for the EMR was assembled at ETH Zurich by D. Mayer-Rosa and S. Sellami, on the basis of maps contributions from G. Papakyriacou (Cyprus), S. Riad, E. Ibrahim and M. Sobaih (Egypt), A. Shapira (Israel), A. Amrat (Jordan), M. Al Haddad (Saudi Arabia; Al Haddad *et al.*, 1994), C. Tabet (Lebabon), and M. El Khoubbi (Syria; El Khoubbi, 1997); the RELEMR coordination was ensured by W. Hays of USGS. The resulting regional map is not a calculated map, but rather a smoothed composite map based on the existing ground shaking hazard maps of individual EMR countries. The main difficulty was that the available sources are very different in term of mapping parameters, probability levels and exposure times. The result integrates all the information into a unified map expressing peak ground acceleration expected at 10% probability of exceedance in 50 years (fig. 2). With modifications in both the level and spatial distribution of the peak ground acceleration values, especially at country boundaries, the map was presented at the 1998 ESC General Assembly in Tel Aviv and approved by RELEMR. A new RELEMR Task Group «Hazard Maps and Applications» has now been established to prepare future EMR probabilistic ground shaking hazard maps on a scale of 1:250000, on the basis of available data on the EMR source, attenuation path, and local site geology parameters.

13. *East African rift* – GSHAP test area (Midzi *et al.*, 1999).

14. *Iran* – Main part of the GSHAP Region 6 (Tavakoli and Ghafory-Ashtiany, 1999).

15. *Caucasus* – Main part of the CAUCAS GSHAP test area, covering also parts of Turkey and Iran (Balassanian *et al.*, 1999).

16. *West Africa and Libya* – In the global distribution of GSHAP regions and test areas, the largest region not covered by any project was the whole sub-Saharian Western Africa and Libya. In order to complete the global GSHAP map, a simplified seismic hazard map for Western Africa and Libya was compiled by S. Sellami and D. Mayer-Rosa at ETH Zurich.

Western Africa – This stable continental area, mostly a very ancient plateau, displays few clearly recognised, active tectonic features. The seismicity is not well known, due to the lack of historical records and of modern seismic networks, and different regions of Africa are not equally covered (Ambraseys and Adams, 1986, 1992). As input to the regional seismic hazard assessment, two seismicity data sets were used: 1) the catalogue from the British Geological Survey (Musson, 1994), containing earthquakes from 1600-1993 with magnitude larger than 4.0 and considered complete for magnitudes over 5 since 1950 and over 6 since the beginning of the century, and 2) the NEIC catalogue for more recent years (1993-1998). The NEIC catalogue of the significant destructive earthquakes was also used, in order to have a sketch of the zones who have already experienced damages.

The delineation of homogeneous source zones is very difficult in this area, owing to the sparse and incomplete seismicity record and the large uncertainties on the earthquake parameters. Because of the scale and scope of the study and the limitations in the input data, only large source zones were designed, on the basis of the distribution of seismicity together with a scheme of the tectonic pattern (Clifford and Gass, 1970). Only four source zones on the continent plus a unique source for Madagascar were used, without introducing background seismicity. The catalogue investigation and the delineation of the source zones were done with Wizmap (Musson, 1998). No specific attenuation relationship nor relevant instrumental data are available for the studied area. In the work for the Eastern African Rift GSHAP test area (Midzi *et al.*, 1999), an attempt was made to compare some regional relationships with those by Joyner and Boore (1982, 1988) for hard rock and a close agreement between the regional attenuation relation curves and those widely used globally was found. The Joyner and Boore (1982) relationship was also adopted for this study. We note that the strong motion attenuates strongly at distances greater than 100 km.

A probabilistic approach was applied (Cornell, 1968), using the code SEISRISK-III (Bender and Perkins, 1987) for calculations. In order to test the procedure, the same approach was applied also to neighboring source zones of Eastern Africa already included in the Eastern African rift test area (Southern Yemen, Eastern Kenya and South Africa; Midzi *et al.*, 1999), with very consistent values of hazard. The PGA values determined for Madagascar and the region between Angola and Namibia are in the range 0.02-0.04 *g*; the west part of Africa has maximum values around 0.08 *g* and equatorial West Africa slightly higher at about 0.1 *g*.

Libya – The seismic hazard for Libya was assessed using the same approach. The area however is much smaller and the information regarding the seismicity is more complete. Ambraseys (Ambraseys, 1984, 1994; Ambraseys *et al.*, 1994) published specific studies on the seismicity and the seismotectonics of Libya, which were used to prepare a catalogue. Other information on existing faults and the results from a previous hazard study (Mallick, 1977) was reported by Kebeasy (1981). Since no information on attenuation was available for the area, we applied the same law adopted in the Ibero-Maghreb GSHAP test area (Jiménez *et al.*, 1999); since a robust regional law is lacking, Ibero-Maghreb has choosen to adopt the relationship proposed by Joyner and Boore (1981). The PGA values range between 0.08 and 0.16 *g* in Northern-Central Libya.

3. Processing and results

The compilation of a homogeneous map of seismic hazard for the whole Europe-Africa-Middle East region required several iterations of smoothing and border matching between the different regional products. While all contributors have followed the same basic seismotectonic probabilistic approach, differences in the delineation of the seismic source zones or in the adopted attenuation relationships resulted in sometimes different hazard levels in border areas.

The largest difficulties were met in the Mediterranean, owing to the large number of independent test areas (fig. 1). To illustrate the different philosophies in defining source zones, the different seismic source zones produced by different projects for the Mediterranean region are shown together in fig. 3. Even here, however, it was easy in most cases to understand and adjust differences in obtained peak horizontal accelerations from different sources. There were homogeneous transitions when joining the Ibero-Maghreb data with those for Southern France, the Italian data with those from the GSHAP Region 3 to the north and northwest, and the Greek data with those from the Central Balkans. In the Eastern Alps the national map for Slovenia was introduced to smooth the transition among the different projects working in the area. The resulting peak horizontal acceleration map for the Mediterranean region is depicted in fig. 4.

Finally, some adjustment was done in the phase of integration of the global map. In particular, the attenuation relationships used in the Middle East region (Iran, Caucasus and Region 7) had to be integrated.

The only area left out from the regional compilation (shown in white in fig. 1) corresponds to the aseismic part of Iraq; here the hazard was mapped by simulating the attenuated effect of the seismic activity in the Dead Sea fault area (Near East) and in the Zagros province of Iran.

The joint PGA hazard map for the whole Europe-Africa-Middle East, based on the integration of the 16 different regional and national contributions, is shown in fig. 5. Features of enhanced seismic hazard are observed along the African rift zone and in the Alpine-Himalayan belt, where there is a general eastward increase in hazard with peak levels in Greece, Turkey, Caucasus and Iran.

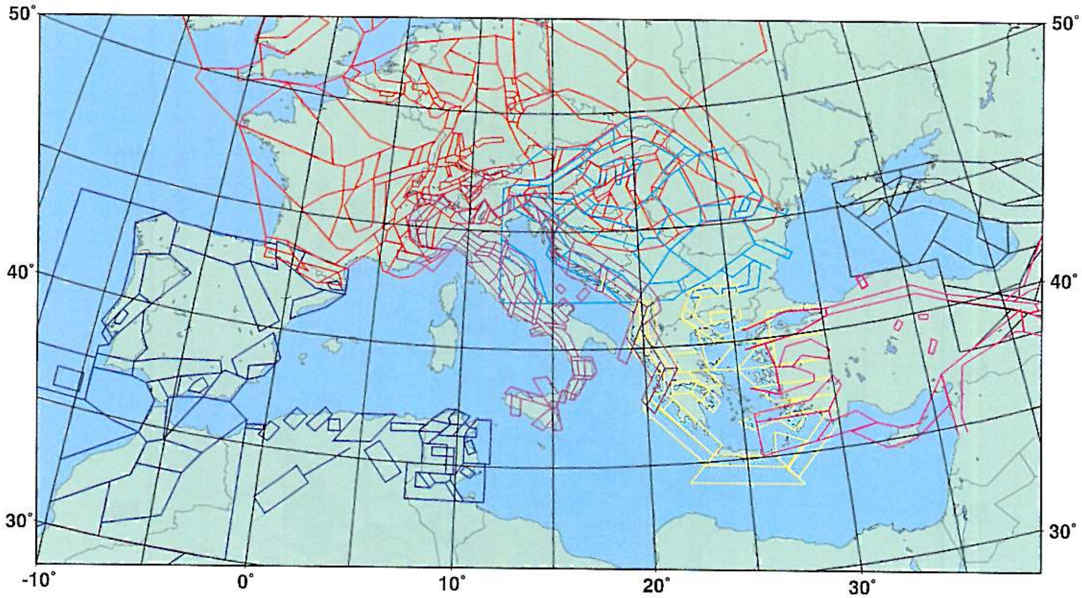

Fig. 3. Compilation of all the seismic source zones produced for the test areas in the larger Mediterranean area.

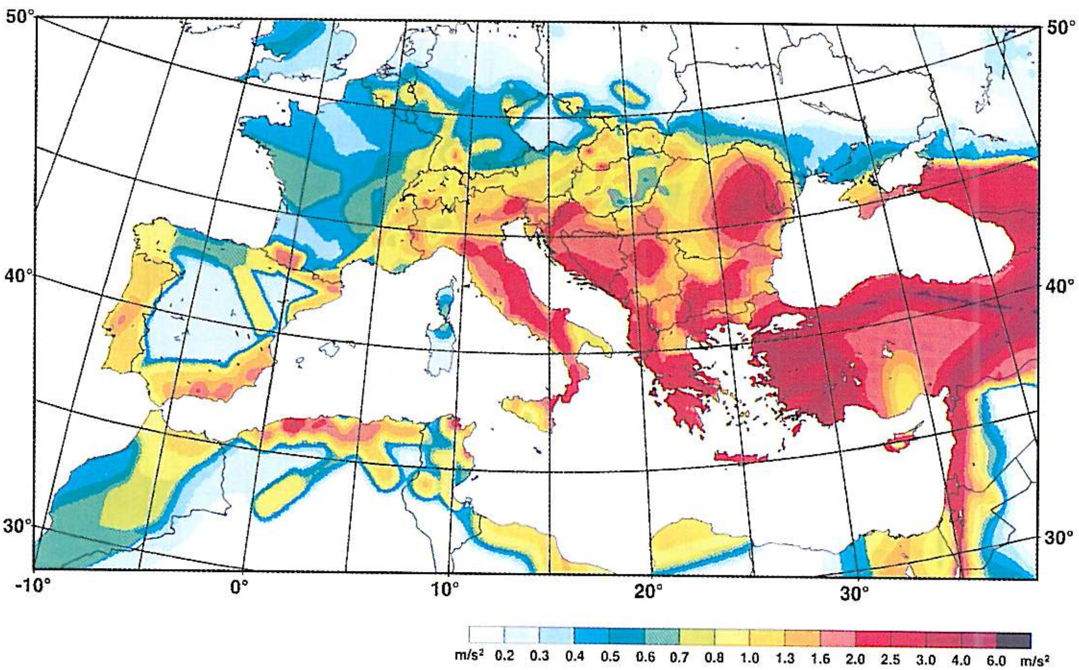

Fig. 4. Horizontal peak ground acceleration seismic hazard map representing stiff site conditions for an exceedance or occurrence rate of 10% within 50 years for the Mediterranean region.

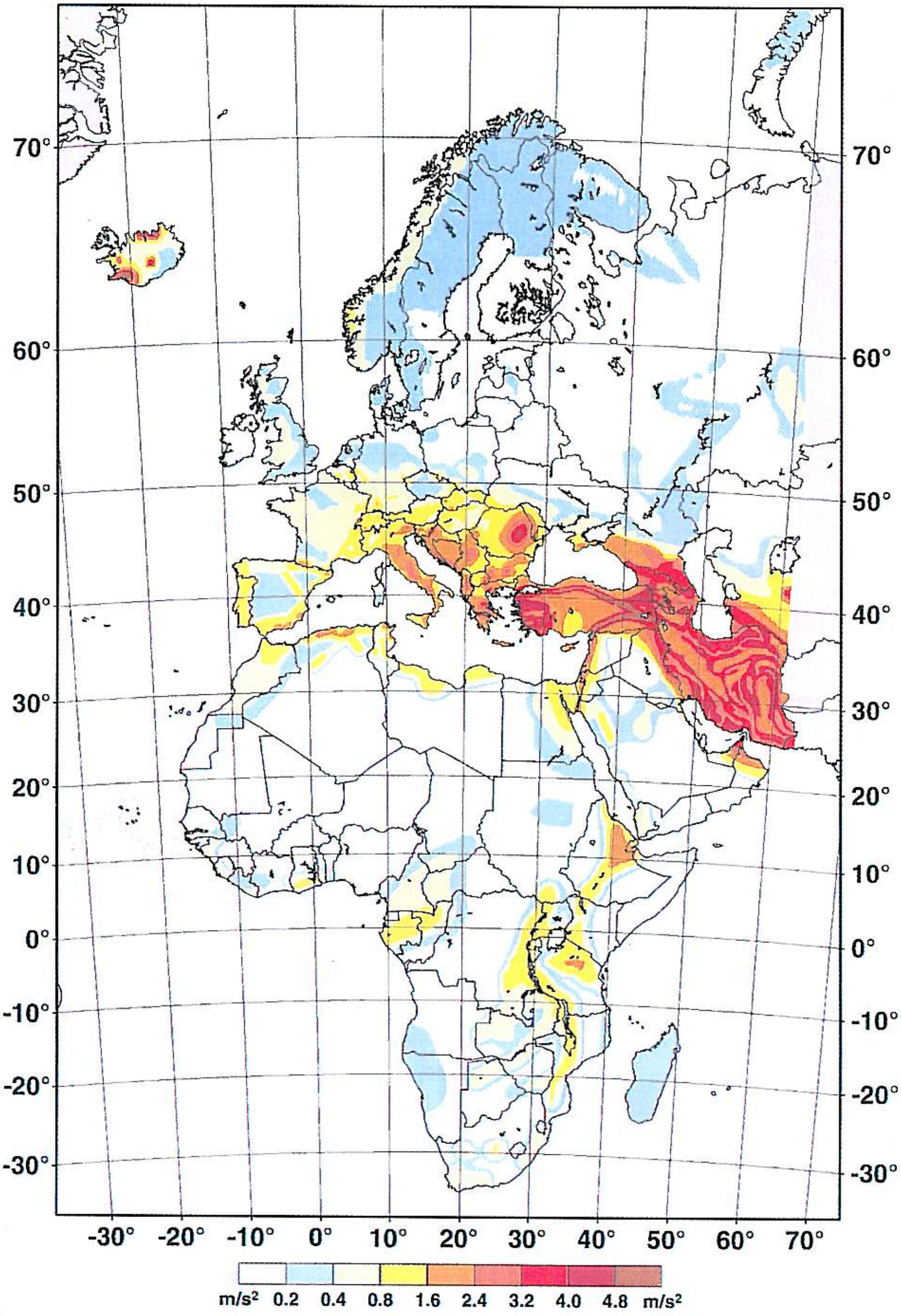

Fig. 5. Horizontal PGA seismic hazard map representing exceedance of 10% within 50 years for the whole greater GSHAP area covering Europe, the Mediterranean, Africa, and the Middle East.

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