Evaluation of seismic sources for hazard assessment in the Fujairah Emirate (UAE)

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Abstract: The Arabian Peninsula is separated from Africa by the Red Sea and from Iran by the Persian Gulf and the Oman Sea, and is bounded on the south by the Arabian Sea and the Gulf of Aden. Geologically, it consists of crystalline Precambrian basement overlain by low-dipping Phanerozoic sedimentary and volcanic rocks, and originated 25-30 million years ago as a consequence of rifting along the line of the eventual Red Sea and Gulf of Aden. At the present time, the northern part of the Arabian plate moves northwest, with respect to the Eurasian plate, at a rate of 20±3 mm/yr.

The United Arab Emirates is a part of Arabian Peninsula and lies at its northeastern part. Fujairah and the area under study is located in Northeastern Emirates. Based on geological data, mountains in the west of Fujairah consist of ophiolites. These ophiolites continue towards the south and southeast along the seashore with Quaternary deposits in the east.

The seismicity of the studied area, in particular, has received little attention. Considering its location on the southeastern part of the Arabian plate and the geological, tectonic and the limited seismicity information, the presence of a relatively low-to-moderate seismic hazard in this region is quite evident.

The major earthquake sources around the studied area are represented by the regional faults of the plate boundary. These occur at variable distances from the region. Other secondary earthquake sources are represented by the local crustal faults that cross the region in specific directions, mainly NE, NW, and N-S. In recent years, earthquakes have struck the region resulting in some damage.

In the paper the authors have tried to evaluate the seismic hazard in Fujairah Emirate which is essential for further study in order to carry out appropriate urban planning.

Résumé: La Péninsule Arabique se sépare de l’Afrique par la Mer Rouge et de l’Iran par le Golfe Persique et la Mer d’Oman. Elle est limitée au sud par la Mer Arabique et le Golfe d’Aden. Au contexte géologique, elle consiste en un socle Précambrien couvert par les roches sédimentaires et volcaniques du Phanérozoïque. Cette péninsule est formée, il y 25-30 Ma, en conséquence d’un rifting le long d’une trace qui a conduit à la formation de la Mer Rouge et du Golfe d’Aden. Actuellement, la partie septentrionale de la plaque d’Arabie se déplace vers le NW par rapport à la plaque d’Eurasie à une vitesse de 20±3 mm/an.

Les Emirats Arabes Unis forment une partie de la péninsule Arabique et se posent à sa partie NE. Fujaïrah et la région sou cette étude se trouvent dans le NE des Emirats. La sismicité de cette région n’est pas bien étudiée. En considérant la position de cette région sur la partie SE de la plaque d’Arabie et en liant sur les renseignements géologiques, tectoniques et sismologiques, on pourrait parler d’un risque sismique d’un niveau faible ou modéré.

Les sources majeures de la sismicité dans la région sont les failles régionales constituant la bordure de la plaque d’Arabie. Les événements sismiques surviennent dans des distances variables de la région Un deuxième group des sources de la sismicité est représenté par les failles régionales dans la croûte traversant la région dans des directions particulières, notamment NE, NW et N-S. Dans ces dernières années, les tremblements de terre ont touché la région et abouti aux dégâts considérables.

Dans ce papier, les auteurs ont tenté d’évaluer les aléas sismiques à l’Emirat de Fujaïrah. Cette évaluation serrait essentielle pour les études du futur pour exécuter un planning urbain satisfaisant.

Keywords: earthquakes, seismic risk

INTRODUCTION

Since its creation, the Arabian plate moved northeast away from Egypt and Sudan, north away from Somalia, and rotated counter clockwise about a point in the vicinity of the Gulf of Suez. Such movement is accommodated by compression and strike-slip faulting along the Bitlis and Zagros zones, where the Arabian plate collides with and subducts beneath the Eurasian plate, and by strike-slip displacement along the Dead Sea transform. Arabian Peninsula is limited by four major tectonic features, largely of post-Cretaceous age. The Red sea and Dead sea rift system at the west and northwest. The thrust zone from the Alpine orogeny at the north. The mobile belt of Zagros and Oman mountains at the east and southeast. The wrench fault associated with Owen fracture zone at the south.

At the present time, the northern part of the Arabian plate moves northwest, with respect to the Eurasian plate, at a rate of 20±3 mm/yr. Because of extension regions, the southern, southwestern, and southeastern margins of the Arabian plate have weak to moderate earthquake activity. The compressive northerly and northeasterly margins, conversely, are regions of strong earthquake activity.

BRIEF GEOLOGY OF UNITED ARAB EMIRATES

The United Arab Emirates is a part of Arabian Peninsula and lies at its northeastern part. A vast area to the east of the Arabian shield including Qatar and U.A.E. has undergone periodic subsidence, which resulted in accumulation of a sedimentary sequences ranging in age from Cambrian to recent (figure 1).

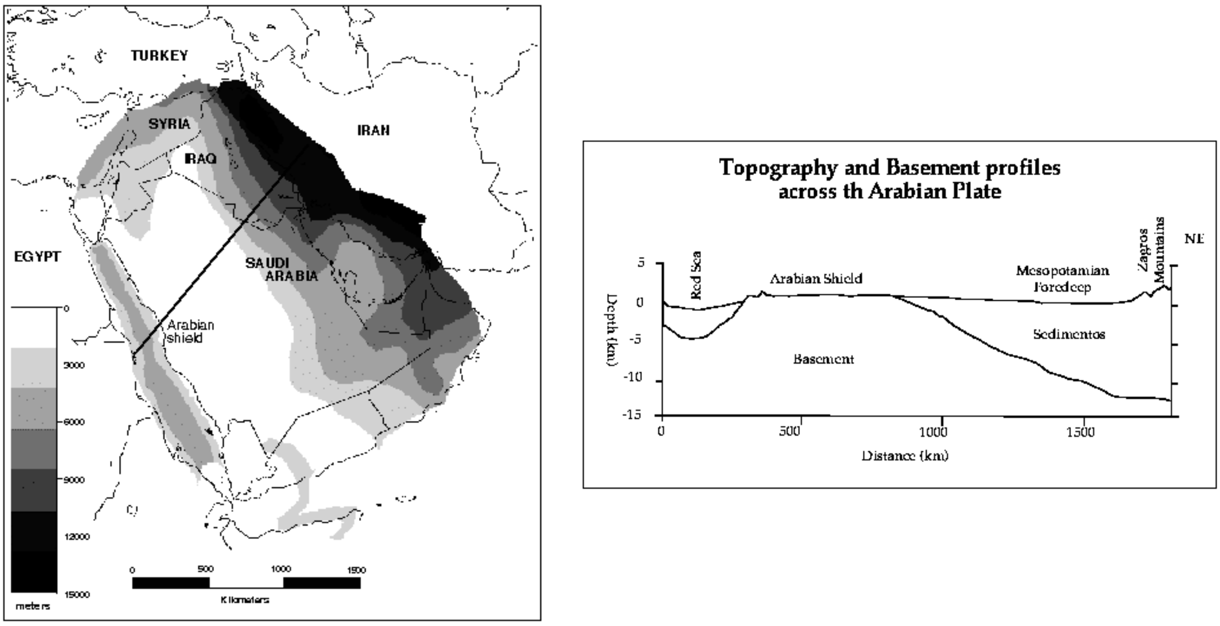

Figure 1. Middle East thickness of sedimentary cover (left), and basement profiles across Arabian plate (right)

The Arabian platform has remained a tectonically stable area resulting in the persistence of lithofacies over great distance through Permian to Upper Cretaceous. However, it has been affected by basement activated epeirogenic movements, which caused warping and formation of basins as in eastern Dubai and the Northern Emirates. The structural evolution of the Arabian platform has strongly influenced the sedimentation pattern in the U.A.E. After the Hercynian Orogeny (Upper Paleozoic) the prevailing sedimentary conditions changed drastically from mainly clastic to predominately shallow marine carbonates until the Eocene. During the Late Tertiary, the late paroxysms of the Alpine Orogeny (Miocene - Pliocene) re-established clastic deposition with subordinate carbonates.

Pre-Lower Cretaceous data on the geology of Northern Emirates are not available due to absence of drilled wells that reached the Jurassic-Paleozoic formations. Based on available geological maps, mountains in the west of Fujairah consist of ophiolitic melange. These ophiolits is continued toward south and southeast along the seashore with quaternary deposits in the east.

A seismic-refraction survey in southwestern Saudi Arabia indicated that the Arabian-plate lithosphere broadly consists of two layers, each about 20 km thick (figure 2).

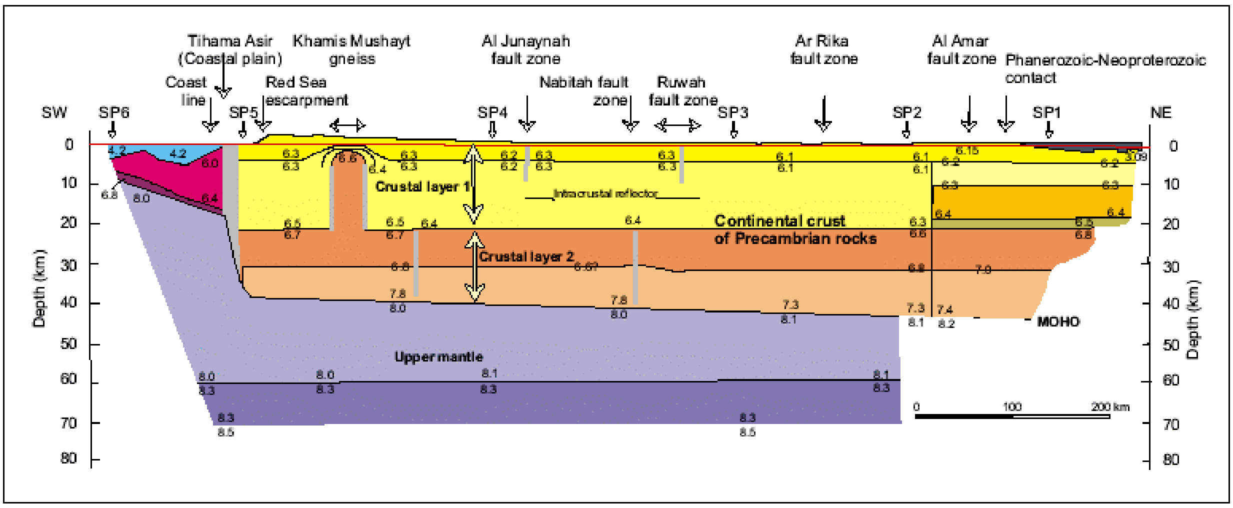

Figure 2. Seismic refraction crustal model for the southwestern part of the Arabian plate showing a principal twofold division of the crust and rapid thinning of the crust beneath the coastal plain (After Johnson, 1998)

The Moho, at the base of the lower layer separating the continental crust from upper mantle is 40-45 km below the surface, shallowing rapidly beneath the coastal plain at the southeastern and southern margins of the plate.

The uppermost layer is characterized by an average compressional-wave velocity of 6.3 km/s and probably consists of the types of deformed Precambrian rocks exposed at the present-day surface together with vast amounts of granitic rock. The exposed Precambrian volcanic and sedimentary rocks possibly extend only 5-15 km below the surface, bottoming in deeper intrusions or at subhorizontal faults, and constituting roof pendants or thrust sheets.

The deeper layer has an average velocity of 7.0 km/s, suggesting that it is mafic in composition, consistent with the composition of fragments of deep crustal material brought to the surface by Cenozoic volcanic eruptions in several places in the western part of the Arabian plate.

STRUCTURAL FRAMEWORK OF THE NORTHERN & EASTERN EMIRATES

The Gulf of Oman is floored by a roughly triangular remnant of Late Cretaceous/ Early Palaeocene oceanic crust (figure 3). To the north the area is bounded by the rugged Makran coast, the onshore part of the Makran Accretionary Complex. The southeastern boundary is defined by the Murray Ridge, rising from the ocean floor almost to the surface. To the south and west the area is bounded by the narrow and steep continental margin of Oman. Onshore the Makran Accretionary Complex is bounded to the east and west by large transform faults: the Zendan-Minab Fault Complex in the west and the Ornach Nal Fault Complex to the east

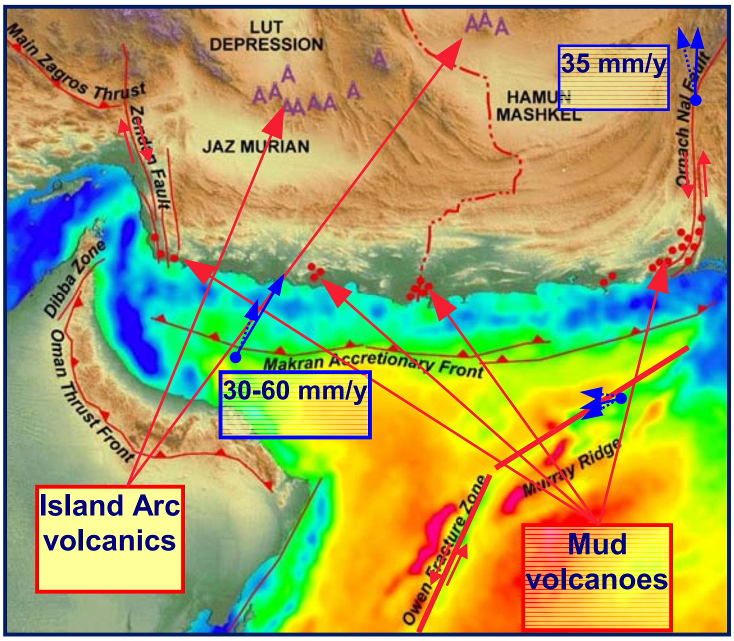

Figure 3. Plate tectonic setting of the Oman Sea

The variation in seafloor morphology in the Oman Sea is caused by different plate tectonic regimes at the plate boundaries, including:

Passive margin to the south: The continental margin of Oman marks the boundary between the continental and oceanic crust. Since the end of Cretaceous, when obduction in Oman came to a halt, the continental Arabian Plate and the Neo-Tethyan oceanic crust in the Oman Sea has acted as one plate tectonic unit, subducting beneath the Eurasian Plate along the Makran accretionary front.

Active compressional margin to the north: Convergence between the Arabian and Eurasian plates. The present accretionary front of the northward subducting Arabian Plate lies ~125 km offshore from the Iranian and Pakistani coast.

Transtensional and transpressional strike-slip to the east: The eastern border of the Makran Accretionary Complex is defined by a series of strike-slip faults. Onshore the north-south trending Ornach-Nal and Chaman fault system separates the Eurasian and Indian plates. This fault system meets the oceanic part of the Arabian plate in a triple junction near Karachi. Offshore the Murray Ridge and the Owen Fracture Zone defines the boundary between the oceanic parts of the Arabian and the Indian Plates.

Transpressional strike-slip to the west: To the west, in the Strait of Hormuz and the Persian Gulf the convergence between the Arabian and the Eurasian plates changes from oceanic-oceanic in the Oman Sea to continent-continent. The actual boundary runs along the north-south trending right-lateral transpressional Zendan-Minab Fault Complex. Offshore the fault complex continues into the accretionary wedge, where it terminates in a very complex way

STRUCTURAL INTERPRETATION OF THE NORTHERN & EASTERN EMIRATES

The Oman Line is a long-lived crustal feature of regional importance, probably dating back to the Precambrian, which marks the southeastern end of the Zagros range. It also marks the sudden termination of the post-Paleozoic sequence of the Persian Gulf and separates two entirely different sedimentary provinces: the carbonate platform to the west and the deep-water flysch and radiolarite facies to the east. Considerable dextral transcurent motion along the Oman line occurred at the southeastern termination of Zagros range.

On the southern side of the Persian Gulf the Dibba zone is a prominent structural feature/lineament as defined in Oman, cutting across the Musendam Peninsula in a southwest/northeast direction (figure 4).

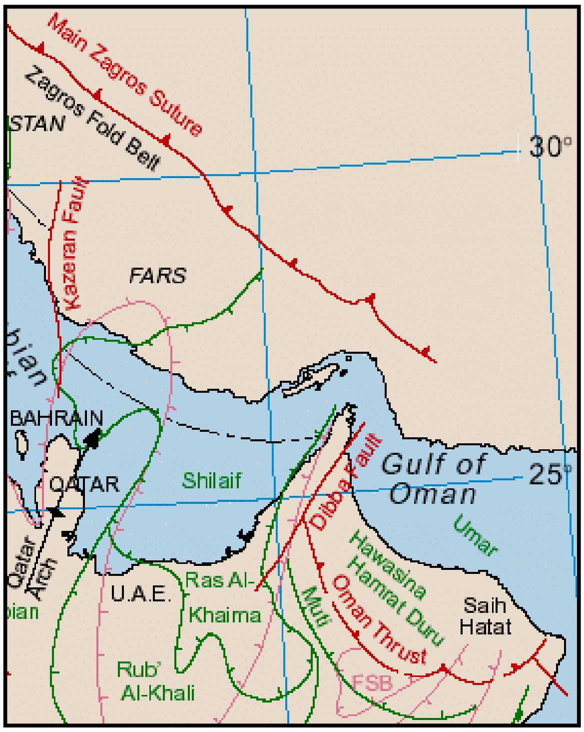

Figure 4. Structural interpretation of the Arabian Plate (After Ziegler, 2001)

In northern Oman the Dibba fault zone defines the western and northern extent of the ophiolite nappes. Onshore the Dibba fault zone is also a topographic feature. The offshore continuation in Iranian waters lines up with a system of a north-south oriented lineament, interpreted as a thrust front, and a conjugated set of northwest - southeast and northeast - southwest oriented normal faults. To the north the Dibba fault zone is bounded by a normal fault (down to the east), close to the southern boundary of the Musendam High (figure 5). To the northeast the Dibba fault zone terminates against the Zendan-Minab Fault Complex.

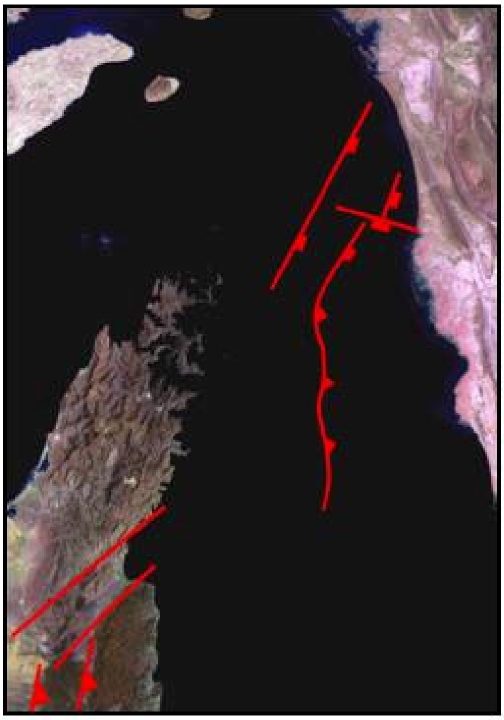

Figure 5. Dibba fault zone and its offshore continuation in Iranian waters

If the Dibba fault zone is related to the Late Cretaceous structuring on the Arabian plate margin it is not expected to have a continuation onto the Eurasian Plate. But, this fault zone has been extending further to the northeast and consumed in the right-lateral transpressional continent-continent collision.

The Dibba fault zone is a N-NE- to S-SW- trending lineament in the northeastern U.A.E. that resulted from the fragmentation and rifting of an east-facing carbonate platform in the Middle to Late Triassic during the development of a shelf edge. The margin collapsed in the mid- and Late Cretaceous and formed the limit of Oman orogen.

This fault zone separates the oceanic crust of the Gulf of Oman-Makran on its eastern side from the continental crust to the west. In all probability, the line acted as an ocean-continent transform fault during the Mesozoic along the boundary between the Arabian Plate and Tethyan Ocean.

SEISMICITY AND SEISMIC HAZARD

Geodynamic processes acting mainly in the Arabian and Red Sea result in deforming the Arabian plate in different ways. The most obvious is its NNE relative movement and the presence of regional geological structures, mainly faults and fault systems that run in the N, NE, NW and EW directions. Earthquake activity shows a clear concentration along the boundaries of this plate and its intra-regional fault systems (figure 6). Recent, historical and pre-historic seismicity data indicate the occurrence of some destructive earthquakes in and around this plate with a noticeable correlation with its major tectonic elements.

The seismicity of UAE in particular has received little attention. Considering its location on the southeastern part of the Arabian plate and the geological, tectonic and the limited seismicity information, the presence of a relatively low-to-moderate seismic hazard in this region is quite evident. The major earthquake sources around studied area are represented by the regional faults of the plate boundary. Other secondary earthquake sources are represented by the local crustal faults that cross the country in definite directions, mainly NE, NW, and N-S. Some of these are known to be associated with the ophiolite occurrences.

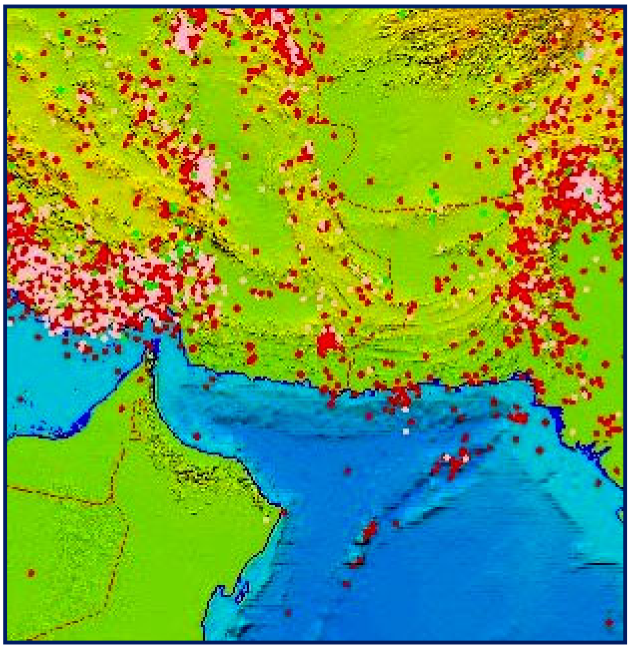

Figure 6. Location of earthquake epicentres in the study area. No earthquake data of magnitude >3 are available

CONCLUSION

As we discussed, the major earthquake sources around the area investigated are represented by the regional faults associated with the plate boundary. These occur at variable distances from the region. Other secondary and more important earthquake sources for the area are represented by the local crustal faults that cross the region.

The Dibba fault zone is the most important faults in the region and cutting across the Musendam Peninsula in a southwest/northeast direction. To the northeast this fault system terminates against the Zendan-Minab fault complex in Iran. Based on available data the Dibba fault zone should be extended further to the northeast and consumed in the right-lateral transpressional continent-continent collision. Though a detailed regional active fault map for the area does not exist, as a priority, at least a preliminary fault map should be prepared. Based on such a map we propose to design a seismic and GPS network around the regional faults to be sure about this important assumption for seismic hazard evaluation of Fujairah Emirate.

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