Seismicity and its implication for the geodynamics of west Makran

Maryam Akbarzadeh Aghdam[1], Abdolreza Ghods[2], Farhad Sobouti[3], Khalil Motaghi[4], Mohammad Enayat[1]

[1] *PhD Student, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan, Iran.*
[2] *Professor, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan, Iran.*
[3] *Associate Professor, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan, Iran.*
[4] *Assistant Professor, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan, Iran.*

ABSTRACT

Makran subduction zone is a low angle subduction system with a very wide accretionary wedge situated at the SE of the Iran and SW Pakistan. The seismicity and focal mechanism pattern, the crustal structure, the azimuth of the subducting Arabian plate and the relationship between the seismicity with the overriding and subducting plates are not yet fully known. To resolve these issues, we use a temporary seismic network of 30 stations installed in west Makran by the Institute for Advanced Studies in Basic Sciences (IASBS) from 201606 until 201904. We locate 237 well-constrained earthquakes and derive a 1-D crustal model along with station corrections. The seismicity pattern at depth shows a good agreement with the geometry of the subducting plate derived from a recent receiver function study. Based on the seismicity pattern, the JazMurian depression is a solid aseismic block. We find there is an oblique NE direction for the convergence that could explain the sinistral E-W faults in the south of the JazMurian depression. The disagreement between the azimuth of the volcanic chain and the subducting plate could be justified by a gradual decrease of the slope of the subducting plate from west to east of Makran. The 1-D crustal model for the west Makran is very similar to that obtained for the south of Iran. The pattern of the station corrections implies a change from a transitional continental crust to a faster oceanic-like crust towards the east of Chabahar.

Keywords: Makran subduction zone, Subducting plate, Seismic network, 1-D crustal model, Station corrections, Aseismic block.

INTRODUCTION

Makran subduction zone is situated at the SE of the Iranian plateau and south of Pakistan. It is formed as a consequence of the subduction of Arabian plate beneath Central Iran (e.g. Farhudi and Karig 1977). The Arabian plate is subducting under Eurasia at a convergence rate of 23-25 mm/yr (e.g. Masson et al. 2007). The Makran subduction is a low angle subduction system which is unique by its wide accretionary prism and lack of a visible trench. The Makran subduction zone hosts two depressions (Farhoudi and Karig 1977), namely JazMurain depression in the Iranian side and Hamun-i-Mashkel depressions in Pakistan (Fig. 1). The role of the JazMurian in the seismic deformation has not been answered.

There are differences between the seismicity of the eastern (Pakistan) and the western (Iran) Makran. The eastern Makran (i.e., approximately to the east of Chabhar) is able to produce great low angle thrust earthquakes (Ambraseys and Melville 1982), which could produce a tsunami. In contrast, in the western (Iran) Makran no large megathrust earthquake has been reported. Also, the relationship between seismicity of the western Makran with overriding and subducting plates are yet unknown.

Due to limited GPS vectors, different GPS modeling has resulted in conflicting views on the state of locking in the thrust zone of Makran. Frohling and Szeliga (2016) estimate the Makran subduction zone is locked to a depth of at least 38 km. They also show a larger coupling for the eastern Makran. Based on GPS vectors, they suggest that the azimuth of convergence between the Arabian and Eurasian plates is slightly oblique.

To better resolve seismicity in the western Makran, estimate the azimuth of the axis of the oblique convergence in Makran, investigate the crustal variations along the accretionary prism, we use a temporary seismic network of 30 stations installed by IASBS from 201606 until 201904. We locate earthquakes using a single event method and also derive a 1-D crustal model along with station corrections for the region. The obtained velocity model and its corresponding station corrections will be used to study any possible crustal variations within the accretionary prism.

DATA

We use IRSC (Iranian Seismological Center, University of Tehran), IIEES (International Institute of Earthquake Engineering and Seismology) and BHRC (Road, Housing & Urban Development Research Center) data from 2006 to 201606 and IASBS data from 201606 to 201904. IRSC and IIEES networks are sparse within the study area. From 201606 onwards, the quality and quantity of the detected earthquake have improved because of IASBS dense network.

Earthquakes that took place before 201606 were located using data from regional and global networks. Only 85 earthquakes were recorded in this time period. Among the 85 events, there are only 21 event with magnitude greater than three and Pg azimuthal gap of less than 180˚. IASBS temporary network recorded 1306 earthquakes with 216 earthquakes with magnitudes greater than two and Pg azimuthal gap less than 180˚. It is clear that the quantity and quality of the located earthquake increased after installing IASBS temporary seismological network. All of the well-constrained earthquakes are shown in Fig. 2.

Due to sparse ray coverage in the study area, we prefer to select a small area with reasonable dense ray coverage to estimate the 1-D velocity model (Fig. 3). We kept 336 P and 216 S-arrival times with less than 0.7 s and 1.0 s arrival time residuals, respectively. We estimate the 1-D P-wave velocity model in the selected area using VELEST software (Kissling et al. 1995). The VELEST software requires initial reference models and hypocenter locations to solve the coupled hypocenter-velocity problem using the JHD method. We try to adjust the layering and determine a best 1-D P-wave velocity model (based on the minimum average RMS) in a trial-and-error process. Our optimum number of layer is seven layers with thickness of 5-15 km covering depths from -5 to 100 km. In this study, a relative good convergence of velocity of layers is found between 5 and 45 km depth. Fig. 4 shows the 10 best initial and calculated 1-D velocity models. The best calculated velocity model reduces the RMS from 0.62 s to 0.21 s (a RMS reduction of 66%). The station corrections are shown in Fig. 5. The station corrections related partially by geological setting beneath the stations and also possible systematic errors caused by wrong GPS timing.

CONCLUSION(S)

Seismicity

Fig. 2 shows the spatial epicentral distribution of 237 well located events (i.e., events with azimuthal coverage of less than 180˚). The seismicity of Makran is low comparing to other low angle subduction zones. The seismicity pattern shows that the JazMurian depression is relatively a solid aseismic block. The distribution of the deep earthquakes shows the convergence between the Arabian and Eurasian plates is oblique that could explain the sinistral E-W faults in the south of the JazMurian depression. The disagreement between the azimuth of the deep earthquakes lineament (NWW-SEE) and the volcanic chain (NEE-SWW) could be due to the gradual decrease of the slope of the subducting plate from west to east Makran.

Deeper earthquakes are observed far from the Oman Sea's shores between the latitude of 27˚ to 28˚. The location of these earthquakes is in good correlation with the shape of the subducting plate as calculated by a recent receiver function study (Mokhtarzadeh et al. 2018). In fact, comparing the results of the receiver function (Mokhtarzadeh et al. 2018) and the seismicity pattern reveal the relationship between the geometry of the subduction zone and the hypocenter of earthquakes (Fig. 6). Due to a low rate of seismicity, it is not possible to obtain the geometry of subducting plate by the sole pattern of seismicity.

Fig. 5 shows the focal mechanism of some earthquakes (ML > 3.6). All of the estimated focal mechanism solutions are limited to the JazMurian depression and its periphery. One of the important focal mechanisms has occurred in depth of ~90 km and nearby the western boundary of Makran with a normal component. This is the first deep earthquakes with significant strike-slip component ever reported in the western edge of the west Makran region. This observation of the strike-slip earthquake at the western edge of Makran subduction zone could be due to slip on the western extent of the subducting plate.

1-D Tomography

The 1-D P-wave velocity model of western Makran is very similar to that of south Iran (Kianimehr et al. 2018). Fig. 5 shows most of the station corrections in the western and eastern parts are positive and negative, respectively. We could conclude that the crust of the eastern part is faster than the western part. A dichotomy in the nature of crust from west to east of Makran has been suggested to some degree by Al-Lazki et al. (2014) using Pn tomography. Recently Maheri et al. (personal communication) have shown that the Lg passing region is prevalent to the west of Chabahar but the region to the east of Chabahar is Lg blocking. Similarly, the amplitude of magnetic anomalies significantly increases to the east of Chabahar. All of these evidence might point to a profound crustal change possibly a change from a transitional slow continental crust of 25 km (Mokhtarzadeh et al., 2020) to a faster oceanic-like crust towards the east of Chabahar. If this is true we could attribute the suggested change in the slab coupling (Frohling and Szeliga 2016) and also change in the style of deformation of accretionary prism to the change in the crustal nature. This observation could lead to a conclusion that the western Makran (the region west of Chabahar) has a much lower possibility for hosting megathrust earthquakes relative to east Makran.

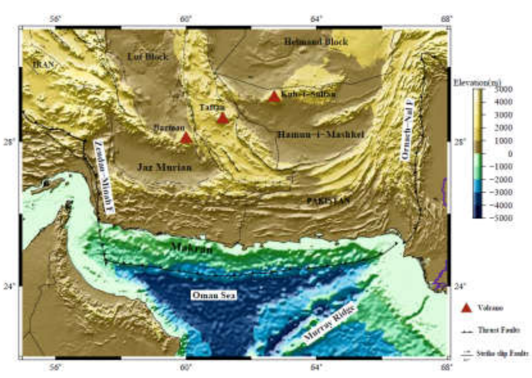

Fig. 1. Makran subduction zone is situated at the SE of the Iranian plateau and south of Pakistan. Quaternary volcanoes of Taftan and Bazman in Iran and Kuh-i-Sultan in Pakistan are thought to be part of the volcanic arc of the Makran subduction zone (Farhoudi and Karig

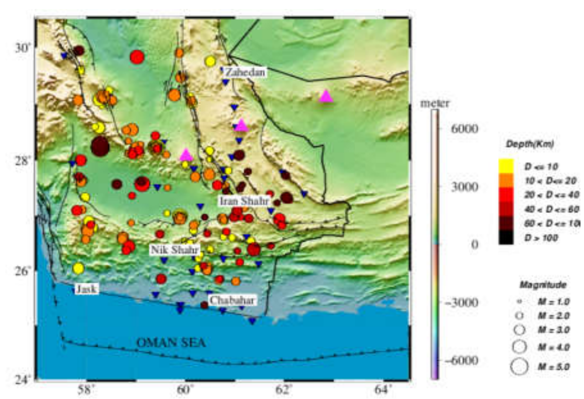

Fig. 2. The spatial distribution of 237 selected earthquakes happened from January 2006 to May 2019 in Makran. The location of seismic stations are denoted by blue triangles. Different colors of circle show the variation of earthquake depths. The pink triangles show the volcanic peaks.

1977).

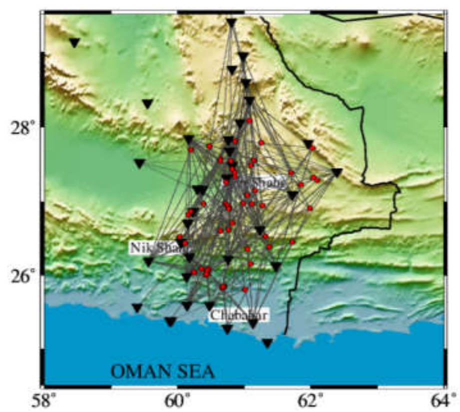

Fig. 3. The ray coverage of the selected study area. The black triangles shows the location of the selected seismic stations.

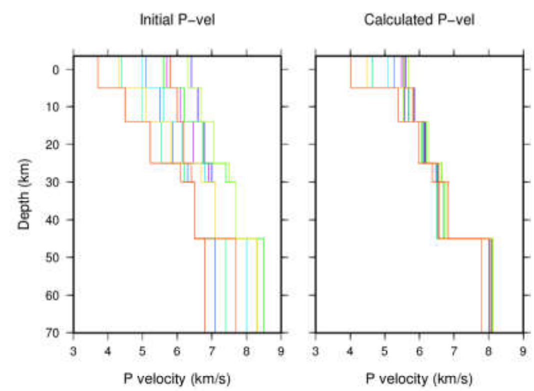

Fig. 4. The 10 best initial (a) and calculated (b) P-wave velocity models. Our optimum number of layer is seven layers with thickness of 5-15 km covering depths from -5 to 100 km. A relative good convergence of velocity of layers is found between 5 and 45 km depth.

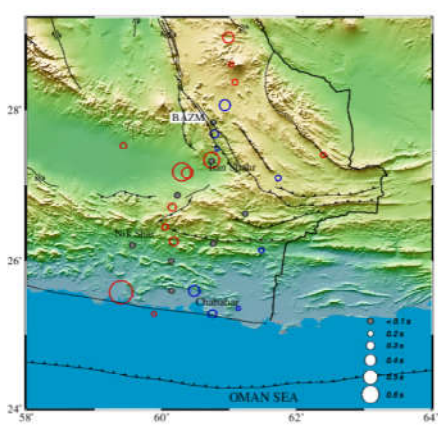

Fig. 5. The distribution of station corrections. There is a dichotomy in the pattern of station correction. Most of the stations in the western and eastern parts of the study area show positive and negative delays, respectively.

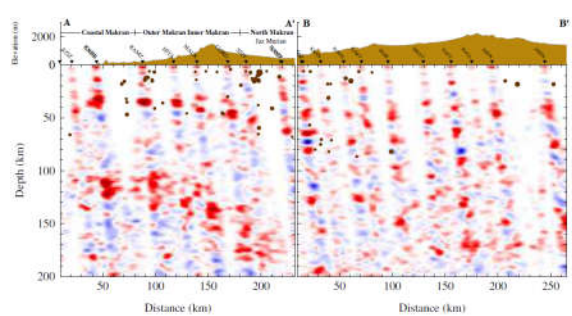

Fig. 6. The results of receiver function (Mokhtarzadeh et al. 2018) and seismicity (the black circles) reveal the relationship between the geometry of the subduction zone and the hypocenter of earthquakes. The earthquakes plotted on the RF section are the 237 selected relatively well-constrained earthquakes used in the 1-D velocity modelling.

REFERENCES

Al-lazki, A. I., Al-damegh, K. S., El-hadidy, S. Y., Society, G., & Publications, S. 2014. Special Publications Pn -velocity structure beneath Arabia − Eurasia Zagros collision and Makran subduction zones, Geological Society, London, http://doi.org/10.1144/SP392.3.

Ambraseys, N.N. Melville, C.P., 1982. A History of Persian Earthquakes, Cambridge Univ. Press.

Farhoudi G. Karig DE., 1977. Makran of Iran and Pakistan as an active arc system, Geological Society of America, 5, 664-668.

Frohling, E., & Szeliga, W., 2016. GPS constraints on interplate locking within the Makran subduction zone, Geophysical Journal International, 205, 67–76.

Kianimehr, K., Kissling, E., Yaminifard, F., and Tatar, M. 2018. Regional minimum 1-D P-wave velocity model for a new seismicity catalogue with precise and consistent earthquake locations in southern Iran, (August). http://doi.org/10.1007/s10950-018-9783-4.

Kissling, E., Kradolfer, U. & Maurer, H., 1995. VELEST User's Guide-short Introduction, Institute of Geophysics and Swiss Seismological Service, ETH, Zurich.

Masson, F., Anvari, M., Djamour, Y., Walpersdorf, A., Tavakoli, F., Daignieres, M., Nankali, H. and Van Gorp, S., 2007. Large-scale velocity field and strain tensor in Iran inferred from GPS measurements: new insight for the present-day deformation pattern within NE Iran. Geophys J Int, 170, 436–440.

Mokhtarzadeh R, Sobouti F, Priestley K, Ghods A, Motaghi K. 2018. Structure of the western Makran subduction zone from seismological studies. 2nd TRIGGER International Conference, Tehran.