# Imaging the shallow structure of the dipping slab and crustal thickness variations in the western Makran Subduction Zone

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## ABSTRACT

We apply the S-wave receiver function method to data from a temporary seismic network deployed in the western Makran region to obtain constraints on the geometry of the subducting and overriding plates. A migrated depth section of receiver functions shows a shallow northward-dipping slab with depth increasing from 30 km in the coastal region to about 100 km beneath the Taftan volcano. The continental Moho of the overriding plate is also observable in our profile. Beneath the northern part of the profile, in the Sistan Suture Zone, the crust is about 40 km thick, increasing to approximately 56 km beneath the Taftan volcano. We also present modeling of crustal thickness variations across the region using the joint inversion of P-wave receiver functions and fundamental mode Rayleigh wave group dispersion data. Our modeling confirmed the presence of a thick crust beneath the Taftan. The map of continental Moho variation also revealed a thick crust (50 km) in the southern part of Sistan zone near the Saravan Fault. In this area, which has experienced moderate to large earthquakes, the depth of oceanic Moho is between 55 and 63 km. Furthermore, our modeling of the oceanic Moho depth variation along the coastal Makran shows the oceanic crust is the thinnest beneath Chabahar and increases in thickness towards the Makran-Zagros transition zone.

**Keywords:** Subduction, Makran, Receiver function, Slab, Taftan, Moho

## INTRODUCTION

The Makran Subduction Zone is located in southeastern Iran and southwestern Pakistan, where the Arabian plate is currently subducting northward under Eurasia at a convergence rate of 2.7 cm/yr (Vernant et al., 2004a). Western Makran has several distinctive tectonic features: a broad accretionary wedge, high sediment input, a shallow-angle subducting slab and a low level of seismicity. The accretionary wedge extends ~1000 km along its strike from the Zendan-Minab Fault in the west, to the Ornach-Nal Fault system in the east, and is more than 350 km wide, with two thirds of it being subaerial. There have been several studies on its off-shore seismic structure while its on-shore structure has remained under-investigated. To the north of the accretionary prism lie two depressional basins, the Jazmurain in the Iranian side, and the Hamun-i-Mashkel in Pakistan. Both are interpreted as for-arc basins. The Taftan and Bazman volcanoes in Iran and Kuh-i-Sultan in Pakistan are thought to form the volcanic arc of the subduction zone. Due to scarce seismic data, the deep seismic structure of the various features of the subduction zone; the geometry and dip of the subducting plate, the underlying mantle-wedge, and the crustal structure of the overlying plate, all remain poorly known. In this study, we use data from the IASBS/CAM temporary seismic array (Fig. 1) to construct an S-wave receiver function image of the crust and upper mantle in the western Makran Subduction Zone from the Oman Sea to the north of volcanic arc. This image enables us to trace the subducting oceanic plate and identify the location where the shallow dipping slab begins to plunge into the mantle. In addition, we present modeling of the crustal thickness variations of the oceanic and continental plates across the region and estimate the Moho depth from shear-wave velocity structures derived from joint inversion of P-wave receiver functions and dispersion curves.

## DATA AND METHODOLOGY

The teleseismic data used in this study were recorded by a temporary seismic network (IASBS/CAM) deployed in the western Makran consisting of 39 station sites from June 2016 to September 2020 (Fig. 1, red triangles). In addition, the recordings of permanent broadband seismic stations of two Iranian national networks (IRSC and INSN) in this region and four temporary short-period seismic stations of Geo-Persian Company were included (blue, black and yellow triangles, respectively). We applied the S-wave receiver function method to the data to obtain constraints on the geometry of the subduction zone. To construct the receiver functions, we used waveforms of teleseismic events with magnitude larger than 5.5 and epicentral distances between 55˚- 85˚. The selected good quality waveforms were bandpass filtered between 0.03 and 0.5 Hz, cut to a window of 180 s starting 120 s before the S-wave onset, and rotated from ZNE the ZRT components. The time domain deconvolution of the radial component from the vertical was used to obtain the receiver functions. A Gaussian filter width of 2.0 was applied during the deconvolution process. To produce an image of the geometry of the subduction zone, the selected high-quality receiver functions were migrated to depth along two selected N-S profiles (Fig. 2), using the CCP stacking technique (Zhu, 2000).

We also jointly inverted P-wave receiver functions and the fundamental mode Rayleigh wave group dispersion data to constrain the shear-wave velocity structure of the crust and upper mantle, and estimate Moho depths beneath the western Makran. The procedure for computing the P-wave receiver functions was described in Priestley et al. (2022). We took the group velocity dispersion data in the 5-70 period range for station sites in the western Makran from the study of Irandoust (2021) which used the earthquake and ambient seismic noise data recorded by broad-band stations in Iran, including the Makran temporary network to extract dispersion information. We employed the linearized least-squares inversion algorithm of Herrmann (2013) to jointly invert the two dataset. To obtain velocity models with smaller number of layers and lower complexity, we simplified the velocity model results of the inversion. From the station 1-D velocity models we estimated the depth of the Moho for all stations. In order to show the Moho depth variations of the oceanic and continental plates across the region, the contour maps of the Moho depth were plotted separately (Fig. 3a, 3b).

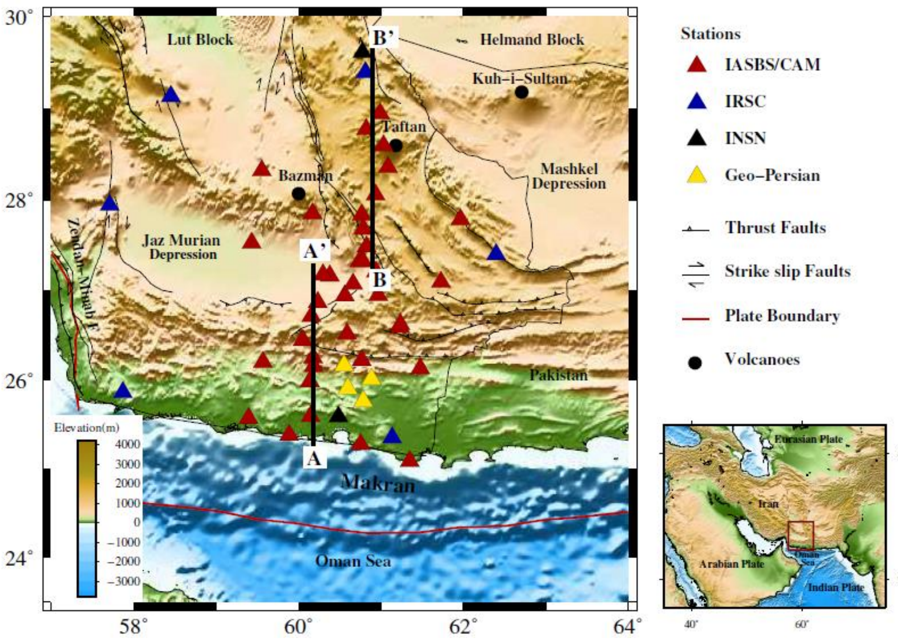


**Figure 1. Topography and bathymetry in the Makran region and the major structural features of the**

**subduction zone. Triangles show the locations of seismic stations. Solid black lines show the locations of receiver function profiles shown in Fig. 2.**

## RESULTS AND DISCUSSION

The migrated depth section of receiver functions along two south-north profiles, starting from the coast of the Oman Sea and ending in the north of the Taftan volcano, is shown in Fig. 2. We also project the seismicity on the profiles (brown circles, Fig. 2). The locations of the hypocenters were taken from Penney et al. (2017). The Moho of the subducting oceanic plate is imaged in our profile as the strong positive pulse (red) arising from the velocity contrast between the oceanic crust and the mantle lithosphere. The profile traces the oceanic Moho from the coast to the northern boundary of the Jazmurian depression (dashed line in Fig. 2). There is a very close correlation between the Moho below the top of the slab and the loci of the earthquakes. The slab has a shallow dip. From the coast to the Jazmurian margin it is relatively flat. Its dip increases from the Jazmurian to latitude of Taftan. The depth of the oceanic Moho is >30 km in the coastal region and increases to 60 km beneath Jazmurian. This is consistent in depth and dip with the P-wave receiver function stacking result along a similar profile by Priestley et al. (2022). Furthermore, our results show the top of slab beneath the volcanic arc should be in the 90-110 km depth range which was not clear in the result of Priestley et al. (2022). In addition, the Moho of the overriding continental crust is clearly visible in our profile. The thickness of the continental crust in profile BB' is between 40 to 56 km, having the maximum value beneath the Taftan volcano. The Moho depth map derived from the joint inversions also confirms the presence of a thick crust beneath the Taftan (Fig. 3b). Under the Bazman volcano the continental crust is considerably thinner (42 km) (Fig. 3b). The existence of a thick curst beneath the Taftan might be confirmed by geochemical data (e.g., Biabangard and Moradian, 2008; Saadat and Stern, 2011). The map of the continental Moho also reveals a thick crust (50 km) in the southern part of the Sistan Suture Zone near the Saravan Fault (Fig. 3b). In this area, which has experienced moderate to large normal faulting earthquakes, the depth of oceanic Moho is between 55 and 63 km (Fig. 3a). This range is consistent with the depth of 60-km estimated by Penney et al. (2017) for the slab earthquakes in the Saravan area. Fig. 3a shows a considerable variation of crustal thickness along the coastal Makran from west to east. The crust reaches its minimum thickness of ~30 km in Chabahar, while it thickens to about 38 km in the westernmost Makran near the transition zone to the Zagros Mountains.

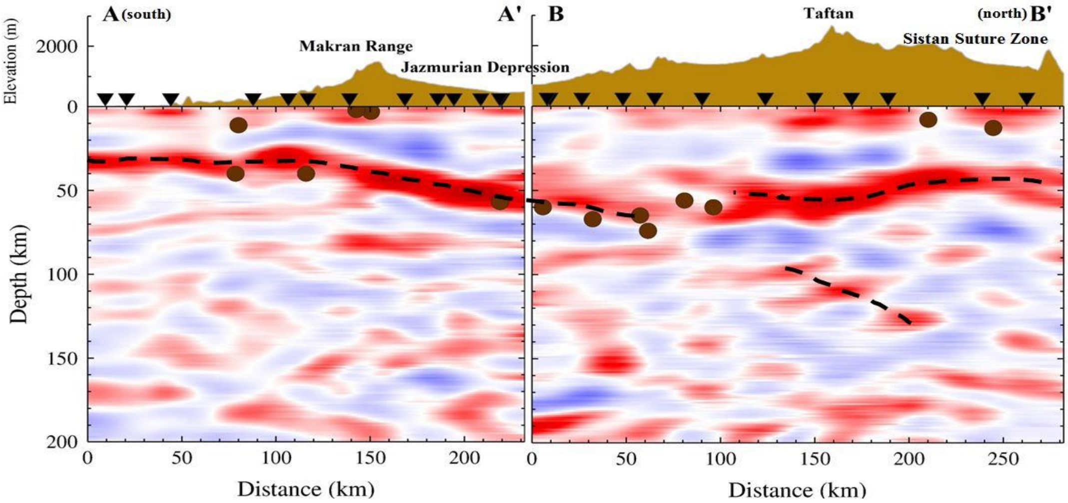


**Figure 2. Migrated depth section of S-wave receiver functions along two profiles in Fig. 1. The dashed lines in the shallower depths delineate the oceanic and continental Mohos. The dashed line in the 90-130 km depth range below the Taftan, shows the possible position of the top of the oceanic slab.**

## CONCLUSIONS

We have obtained constraints on the geometry of the subduction zone and crustal thickness variations across the western Makran region using receiver function analysis and joint inversion of receiver function and surface wave dispersion data from a temporary seismic network. A shallow northward-dipping slab with depth increasing from 30 km in the coastal region to about 100 km beneath the Taftan volcano is mapped. The Moho of the overriding continental plate has a depth of 40 to 56 km. The modeling of crustal thickness variations confirms the presence of a thick crust beneath the Taftan. Near the Saravan Fault, the depth of the Moho of subducting slab is between 55 and 63 km.

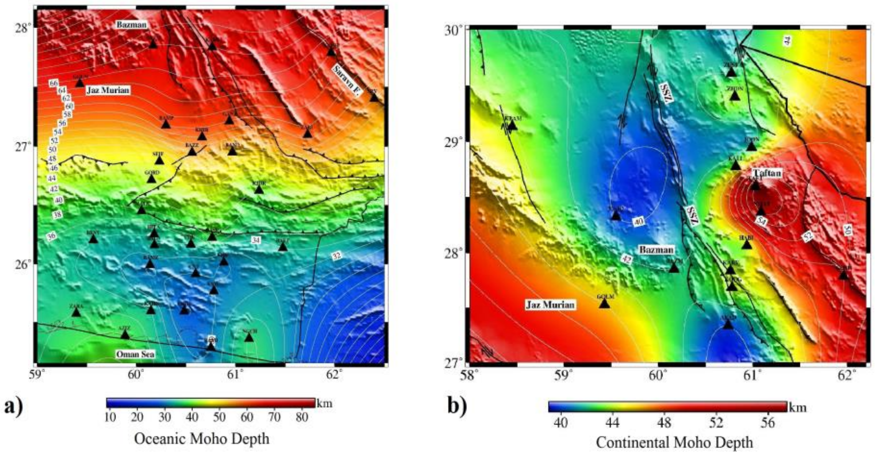


**Figure 3. Maps of oceanic (a) and continental (b) Moho depths in the western Makran estimated from the shear-velocity models of the stations.**

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