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Geology of the onshore Makran accretionary wedge: Synthesis and tectonic interpretation

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ABSTRACT

This contribution is a synthesis of studies carried out since 2004 in the Makran accretionary wedge exposed in SE Iran. These studies were intended to improve our understanding of the behaviour of accretionary wedges and of the significance of the Makran wedge in the frame of Tethys tectonics. Reassessing the stratigraphy and structure of the Iranian Makran has allowed distinguishing four main litho-tectonic units. The lithological content of these four units is briefly described to discuss the sedimentary environments, which record the general filling of an oceanic basin with clastic sediments derived from the north. The petrology of ophiolites, exposed in the backstop region to the north of the accretionary wedge itself, demonstrates the existence of an oceanic basin formed in the Jurassic-Late Cretaceous to the north of continental slivers, which had separated from Central Iran. There is petrological evidence for a subduction-related magmatic arc during the Late Cretaceous, which sourced much of the clastic material in the Cretaceous-Lower Miocene turbidites present throughout the wedge. The literature survey shows that the Late Cretaceous to Present evolution of the Pakistan part of the Makran fold-and-trust belt is in its major attributes similar to that of the Iranian Makran. These observations and results are discussed in a tectonic model that integrates knowledge on the Oman Mountains, on the other side of the current Oman subduction.

1. Introduction – tectonic setting

The Makran accretionary wedge (Fig. 1) is exposed in SE Iran and SW Pakistan in a sparsely inhabited region with a traditional nomadic population, although cities on the coast of the Oman Sea are growing rapidly. The area is known for its ancient *ichthyophagi* population, the “fish-eaters” reported by Nearchus, Alexander the Great's admiral who led the Macedonian fleet from the Indus to the Persian Gulf in 325–324 BCE while Alexander, walking ca. 700 km across the desert Makran, was losing several thousand soldiers and followers in floods and by exhaustion, thirst and malnutrition before reaching Pura (present-day Iranshahr) in December 325 BCE (Faure, 1985).

The slightly arcuate Makran accretionary wedge (hereafter “Makran) extends ~ 1000 km along strike between the Minab – Sabzevaran dextral fault system to the west and the Chaman – Ornach-Nal sinistral fault system in the east. (Fig. 1). The northern part is delimited by the Quaternary cover of the Jaz Murian depression in Iran and the equivalent Mashkel depression in Pakistan (Fig. 1). From rear to toe, the wedge is about 350 km wide. It results from nearly N—S convergence between Arabia and Eurasia (e.g. DeMets et al., 2010) and grows both vertically and laterally by scraping and incorporating sediments off the subducting Arabian Plate lithosphere (Platt et al., 1985). The accretionary wedge is divided into a 100–150 km wide active submarine wedge to the south, and the 150–200 km wide onshore wedge to the north. These two parts are separated by a narrow (few kilometers wide) coastal belt where normal faults and mud volcanoes are prominent, both on- and offshore (e.g. Back and Morley, 2016; Von Rad et al., 2000). Makran is still a remote, difficult to access region that has therefore been the object of relatively few modern studies. Hence, this review summarizes the current status of understanding of the onshore Makran in the light of recent, published and unpublished work.

North-dipping subduction of the Arabian plate beneath the Central Iran and Afghan blocks is believed to have begun during the Cretaceous (e.g. Alavi, 2007; Berberian et al., 1982; Ricou, 1994) and is still going on. Geodetic data are scarce. GPS measurements document a nearly N—S convergence rate of ca 2 cm/a between the Arabian and Eurasian plates at the longitude of the Gulf of Oman (Masson et al., 2007; Vernant et al., 2004; Vigny et al., 2006). The toe of the Makran wedge has migrated southward at ~ 1 cm/a since the Pleistocene (Platt et al., 1985; White, 1982). Current motions recalculated from seafloor spreading rates and fault azimuths for the major plates account for convergence rates increasing from 35.5–36.5 mm/a in western Makran to 40–42 mm/a in the east (DeMets et al., 2010, Fig. 1). This is apparently corroborated by anticlockwise rotation of the rigid Arabian

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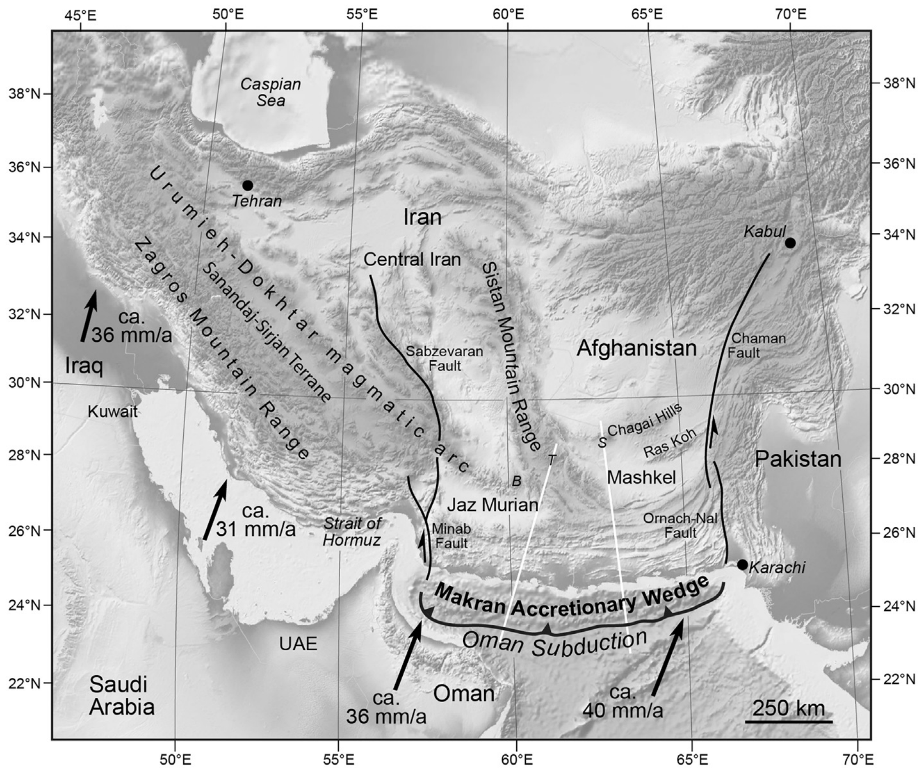

Fig. 1. General setting of the Makran accretionary wedge. Convergence rates from DeMets et al. (2010). UAE—United Arab Emirates. Background: shaded relief map from ETOPO1 (http://www.ngdc.noaa.gov/mgg/global/relief/ETOPO1). White lines: approximate location of cross sections with projected seismicity in Fig. 2. Italic B, T and S are placed on the Bazman, Taftan and Koh-i-Sultan volcanoes, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

plate with respect to Eurasia around a vertical axis located somewhere in Kurdistan (Hatzfeld and Molnar, 2010).

Seismicity differs in the eastern and western parts of the Makran subduction zone, with a boundary at about the Iran/Pakistan border (Abedi and Bahroudi, 2016; Byrne et al., 1992; Rajendran et al., 2013). No large-magnitude earthquake is known in the western Makran where the recorded seismicity is sparse. By contrast, large-magnitude and frequent earthquakes characterize the eastern Makran. This geographical dissimilarity in seismicity is attributed to a hypothetical segmentation of the subduction zone at ca 62°E longitude (Dykstra and Birnie, 1979; Rani et al., 2011), or to a locked plate boundary that experiences great earthquakes with long repeat times in the west (Byrne et al., 1992; Frohling and Szeliga, 2016; Jacob and Quittmeyer, 1979; Penney et al., 2017).

The geometry of the present-day subduction (hereafter the Makran subduction) is imprecise, because of rather scarce instrumental information (Bijwaard et al., 1998; Hafkenscheid et al., 2006), but the generally accepted shape (after White and Klitgord, 1976) displays a shallow angle, northward deepening of the slab with a flexure beneath the trench slope break at the surface (Fig. 2). The eastward increasing distance from the Miocene-Holocene, subduction-related Bazman, Taftan and Koh-i-Sultan volcanoes to the trench (Figs. 1 and 2, Farhoudi and Karig, 1977) suggests a shallower dip-angle of the slab under the Pakistan (eastern) Makran. A shallow dip of the slab (< 5°, e.g. Jacob and Quittmeyer, 1979; Regard et al., 2010) is consistent with the mantle wind (Doglioni et al., 2007; Ficini et al., 2017). Refined imagery suggests that the slab tip is not deeper than ca. 250 km (Simmons et al., 2011). However tomographic profiles trace it down to at least ca 400 km after a sharp bend located to the north of the Jaz Murian and Mashkel Basins, approximately beneath the Bazman, Taftan and Koh-i-Sultan volcanoes (Figs. 1 and 2); beyond this bend, the slab dips steeper (Frohling and Szeliga, 2016; Manaman et al., 2011). Seismic tomography suggests that the high-velocity Arabian lithosphere has a sharp contact with a low-velocity region beneath western Makran, which in turns has a sharp boundary with a high-velocity zone beneath eastern Makran (Al-Lazki et al., 2014). This lithospheric-scale information supports segmentation of the Makran subduction zone, but the seismic station network is insufficiently dense to provide high resolution pictures of the active system.

The main tectonic units of Iran defined by Stöcklin (1968) have been repeatedly sketched and presented in a multitude of papers to which the reader should refer (e.g. Ajirlu et al., 2016, and references herein; Berberian and King, 1981; Sengör et al., 1988; Takin, 1972). In brief, the nearly 2000 km long and 100 km wide, NW-SE trending Sanandaj-Sirjan Terrane borders Central Iran, to the northeast, and the Zagros Mountain Range to the southwest (Fig. 1). Central Iran is a multipart, Precambrian, roughly triangular continental terrane in the middle of Iran. The Zagros Mountain Range is an Alpine-Himalayan fold-and-thrust belt formed on the northeastern edge of the continental Arabian plate. The Late Cenozoic Tethys suture is generally traced along the fault contact between the Zagros Mountains and the Sanandaj-Sirjan Terrane (e.g. Agard et al., 2011).

Similar metamorphic, magmatic and sedimentary characteristics have been advocated to consider the narrow Bajgan-Durkan continental ribbon in North Makran as the eastern termination of the Sanandaj-Sirjan Terrane (e.g. McCall and Kidd, 1982). The Bajgan-Durkan continental block was separated from Central Iran by the Early Jurassic – Late Cretaceous Nain-Baft oceanic basin (the “Fannuj Ocean” of McCall, 2002, Fig. 3). Ophiolites of the Nain-Baft basin were obducted, i.e. thrusted southward on the northern margin of the Bajgan-Durkan microcontinent in the Late Cretaceous (Hunziker et al., 2017). They both formed submarine highs and islands in the Late Cretaceous – Eocene and perhaps until the Early Oligocene (Burg et al., 2013; McCall, 1985b). The Nain-Baft oceanic basin, whose remnants are possibly covered by the present-day Jaz Murian Basin (Fig. 1, see also Shahabpour, 2010), remained the site of shallow water marine sedimentation (Eocene-Oligocene shelf limestones and proximal turbidites). The Jaz Murian Basin is also interpreted as the fore-arc of the mostly Eocene, linear Urumieh-Dokhtar Magmatic Belt, which stretches along the NE side of the Sanandaj-Sirjan sliver before continuing towards the southeast on the northern side of the Jaz Murian depression (Fig. 1, e.g. Alavi, 1994; Alavi, 2007; Berberian et al., 1982; Farhoudi and Karig,