Goharan earthquakes (2013, SE Iran) in western Makran accretionary wedge: An earthquake swarm or earthquake sequence?

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ABSTRACT

Makran accretionary wedge as one of the largest accretionary wedges on the world, has been formed by the convergence between Arabian and Eurasian Plates. Twelve earthquakes with magnitudes Mw ≥ 5.0 occurred in May and July 2013 in a low seismicity small area of western Makran accretionary wedge, SE Iran. The focal mechanism solutions show dominated strike-slip type. These events occurred on an ENE striking fault that allows the almost oblique convergence (N10ºE) to partition into deformation front-perpendicular motion on the subduction interface and deformation front-parallel motion on the Goharan fault. The aftershock sequence share common features with seismic swarm.

Keywords: Earthquake sequence, Earthquake swarm, Strike-slip fault, Makran accretionary wedge

INTRODUCTION

Earthquakes commonly occur either as mainshock-aftershock sequences or as seismic swarms (e.g. De Barros et al., 2019). The mainshock-aftershock sequences are characterized by the occurrence of a large event, followed by a decaying series of smaller magnitude events (e.g. De Barros et al., 2019). The earthquake swarms, have no predominant mainshock and occur in a very limited area within a relatively short period of time (Mogi, 1969). They often occur in the subduction, volcanic, geothermal or mid-ocean transform fault regions and could be attributed to magma movements or fluid flow (e.g. Fasola et al., 2019).

The driving mechanisms of the swarms and aftershock sequences are still questionable. According to De Baross et al. (2019), swarms and aftershock sequences may share common driving processes, related to fluids or to aseismic slip. These processes may be intertwined, as aseismic slip, fluid flow, and stress transfer may be simultaneously at play (e.g. De Baross et al., 2019).

In this study, we address these issues by study of the 2013 Goharan event, which occurred in the accretionary wedge of western Makran subduction zone (Figure 1), using a combination of seismology and satellite image.

TECTONIC SETTING AND SEISMICITY

The Makran accretionary wedge, in SE Iran and SW Pakistan, was formed as a result of the subduction of the Arabian plate under the Eurasian plate (Figure 1) (e.g. Burg, 2018), with convergent rate of ~ 20 mm yr^{-1} at the longitude of the Gulf of Oman (Vernant et al., 2004) (Figure 1). This accretionary wedge forms one of the most extensive accretionary complexes on earth (Kopp et al., 2000). Two features of this accretionary wedge are sediment thickness on the oceanic crust and extremely low subduction angle (Schluter et al., 2002).

Seismicity differs in the western and eastern parts of the Makran (Byrne et al., 1992). No great earthquake is known in the western Makran and modern instrumentation has not detected any shallow events along the plate boundary. In contrast, large and frequent thrust earthquakes characterize the eastern Makran (Byrne et al., 1992; Burg, 2018).

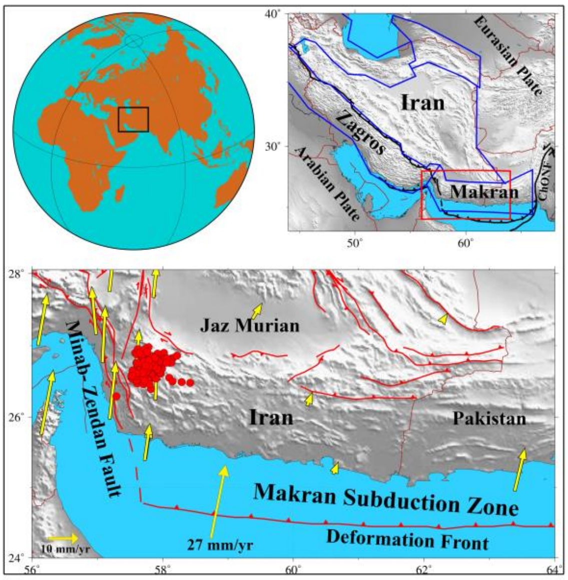

Figure 1. Major faults in SE Iran. The yellow arrow represents GPS estimated movement of the Arabian plate relative to the Eurasian plate (Khoramei et al., 2019). Red circles show the 2013 Goharan events from the catalogue of Mosavei et al. (2020) and Iranian Seismological Center (IRSC).

GOHARAN EARTHQUAKE, 2013

The 2013 May 11 Mw 6.2 Goharan earthquake occurred east of the Strait of Hormuz, in the western part of the Makran accretionary wedge (Figure 1). This earthquake killed 2 and injured about 20 people (Berberian, 2014). There were four foreshocks with the magnitude over 3.0, and the largest one (M 5.0) occurred ~ 8 km southwest to the location of the main shock (Figures 2 and 3).

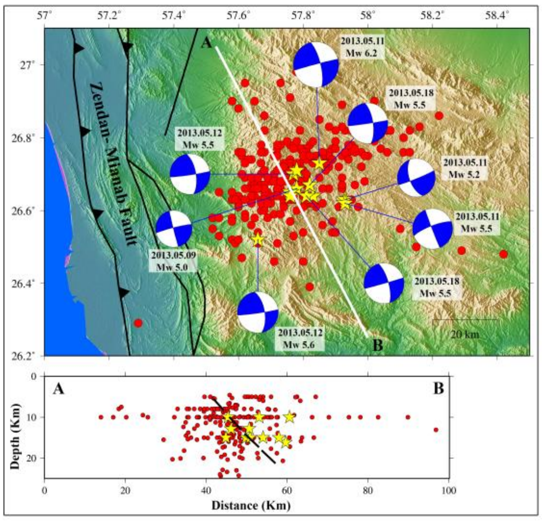

Figure 2. The spatial and depth distribution of the Goharan earthquakes.

Within 80 days after the mainshock, 290 aftershocks (M > 2.5) occurred in and around the epicenter of main shock (Figures 2 and 3).

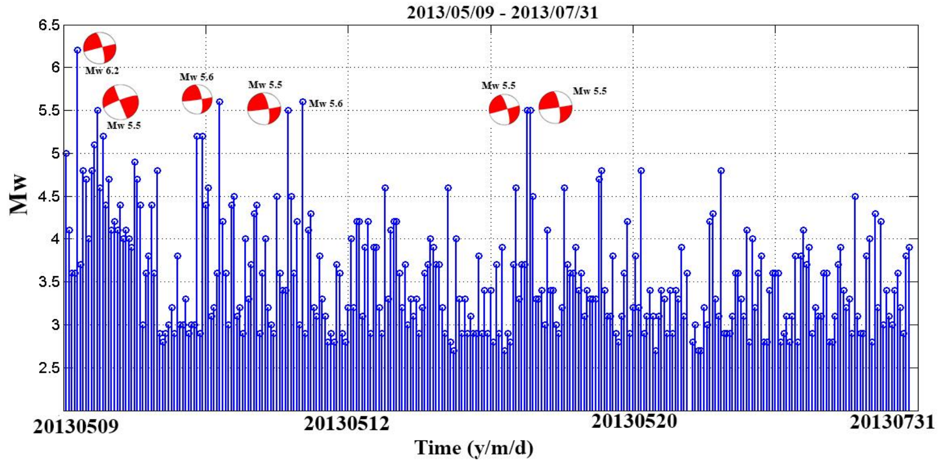

Figure 3. Earthquake magnitudes as a function of time (year/mon/day) for the 2013 Goharan earthquakes.

Using InSAR data, surface wave spectra and teleseismic body-wave modeling, Penney et al. (2015) and Kintner et al. (2018) suggested that the main shock occurred on near-vertical, left-lateral strike-slip fault. Kintner et al. (2018) also showed that aftershock activity migrated westwards along strike.

The epicenter distribution of the Goharan earthquake forms a wide zone of seismic activity trending ENE–WSW, which is almost perpendicular to the structural trend of the area (Figure 2). Depths of earthquakes were approximately between 2 and 25 km (Figure 2). The focal mechanism solutions from the Global Centroid Moment Tensor (GCMT) show pure NE-SW strike-slip mechanism (Figure 2).

CAUSATIVE FAULT OF GOHARAN EARTHQUAKE

An 8-km-long surface rupture trending N60º–70ºE, dipping steeply south with 20-cm left-lateral displacement cutting the deposits was reported near Irar (Berberian, 2014). Bolurchi et al. (2013) introduced a surface rupture trending N55–65E, dipping 80º south with a left-lateral displacement at least from Dourmush to Irar and beyond cutting all the regional structural trends. Penney et al. (2015) showed evidence of surface ruptures that followed the obvious E–W trending, and were en echelon right-stepping cracks, with a sense of motion consistent with left-lateral motion on the fault.

On satellite images of the study area, in the region between Tider and Dourmush, where the Goharan earthquake was situated, indications of left-lateral strike-slip deformations can be observed (Figure 4). West of the Kermestan, two ENE striking sinistral fault segments that incised the regional structural trends, runs parallel with a right stepping arrangement (Figure 4).

The presence of such strike-slip faults within accretionary wedge is probably due to the almost oblique convergence (N10º E; Byrne et al., 1992) of the Arabian plate relative to the Eurasian plate (Figure 5).

Kintner et al (2018) introduced Goharan earthquakes as an earthquake sequence. This sequence includes twelve moderate earthquakes with magnitudes $5.0 \leq Mw \leq 6.2$ (Figure 3). Although a mainshock (Mw 6.2) started the sequences but the aftershock sequences share common features with seismic swarm. Due to the magnitude of the mainshock, the rupture length was ~8km (Berberian, 2014) but size of the aftershocks zone was much larger (~ 850 km^2) than it (Figure 2), which is one of the characteristics of the swarms (e.g., Vidale & Shearer, 2006).

The subduction zones, especially those with significant accretionary wedges, have long been recognized as potential fluid-rich systems (Smit et al., 2014). Fluids can originate both from the subducted oceanic crust (Peacock, 1990) and the sediment overlying it (Moore and Vrolijk, 1992). Fluids can influence accretionary wedge morphology and the seismogenic behaviour of the forearc faults and plate boundary fault (e.g. Tobin and Saffer, 2009).

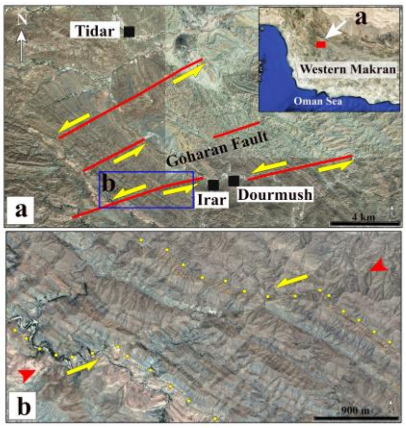

Figure 4. (a) Google Earth satellite imagery of left-lateral faults in the Goharan region. (b) Left-lateral deflection of the strata and a drainage west of the town of Irar.

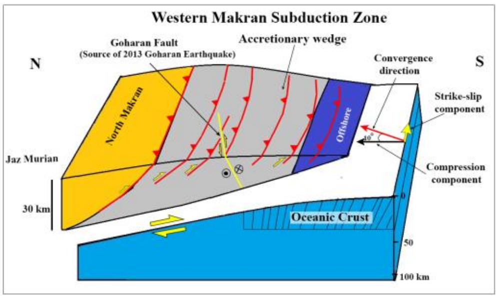

Figure 5. Diagram illustrating the occurrence of Goharan earthquakes on the strike- slip fault zone at the western Makran accretionary wedge.

In the Makran subduction zone, compaction of accretionary and underthrusted thick sediments are expected to be the dominant fluid source (Smith et al., 2014). Fluid migration has been suggested in Makran accretionary wedge (e.g. Grando and McClay, 2007). Grando and McClay (2007) proposed that the sediments during the underplating process release fluids into the accretionary wedge with possible formation of overpressured fluid, shale diapirs and mud volcanoes. According to Grando and McClay (2007), the rapid uplift of the Makran wedge and the onset of extensional faults favor the extrusion of overpressured sediments and fluids/gas along thrust faults on the seaward side of the prism. Therefore, it is possible that fluid processes in addition to stress perturbations controlled the alternating swarms and mainshock/aftershock sequences in Goharan region. Such an aftershock sequence has therefore an intermediate behavior between the two end-members; the fluid-induced seismicity and the tectonic-driven earthquakes (e.g. De Barros et al., 2019).

CONCLUSION

On 2013 May 9, a swarm-like earthquake sequence including twelve earthquakes with magnitudes 5.0 ≤ Mw ≤ 6.2 initiated in Goharan region of western Makran. The largest event was an Mw 6.2 earthquake that occurred on May 11, 2013. The aftershock sequence share common features with seismic swarm. It is most likely that fluid processes in accretionary wedge and stress perturbations controlled the alternating swarms and mainshock/aftershock sequences.

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