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Evidence for right-lateral strike-slip environment in the Kutch basin of northwestern India from moment tensor inversion studies

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ABSTRACT

The Kutch region located in northwestern part of India is an ancient rift basin that was active until Cretaceous period. The region falls close to the India–Arabia and the India–Eurasia plate boundaries and has experienced devastating earthquakes in the past, namely the 1819 Allah Bund earthquake, the 1956 Anjar earthquake and the 2001 Bhuj earthquake. To understand the tectonics of this region with respect to the adjacent plate boundaries, we invert seismic waveform data of 11 earthquakes in this region recorded by a network of the Institute of Seismological Research (ISR) during 2007–2009. The study yields focal mechanism solutions of reverse fault and strike-slip type mechanism. The inferred fault planes correlate well with the local trends of the known tectonic faults while the principal stress directions derived from stress inversion based on a linearized least squares approach, trend agreeably with the ambient stress field directions. A consistently right-lateral sense of shear is found on all the local faults as derived from each of the matching planes of the focal mechanism solutions computed in the present study. It is inferred that in the Kutch region a right-lateral strike-slip environment prevails along predominantly EW to NW-SE oriented deep-seated pre-existing faults in an otherwise compressive stress regime. This, in conjunction with the left-lateral movements along the Girnar mountain in southern Saurashtra, inferred from previous studies, indicates a westward escape of the Kutch–Saurashtra block as a consequence of the northward collision of the Indian plate with respect to the Eurasian landmass.

1. Introduction

The Kutch region in northwestern India (Fig. 1) is characterized by the highest level of seismic hazard in the Seismic zoning map of India (BIS, 2002). The region has experienced several earthquakes of magnitude greater than 7.0 in the past (Gupta et al., 2001a). The most devastating of these are the 1819 Kutch earthquake of M 7.8, the 1956 Anjar earthquake of M 7.0 and the 2001 Bhuj earthquake of M 7.7. The 1819 Kutch earthquake occurred along the Rann of Kutch (Rajendran and Rajendran, 2001) causing severe damage leading to a 90 km long fault referred as the 'Allah Bund fault'. The Anjar earthquake of 1956 occurred on the Kutch Mainland Fault (KMF) causing several deaths (Chung and Gao, 1995). The 2001 Bhuj earthquake is considered the deadliest intra-plate earthquake (Gupta et al., 2001b) which devastated the Bhuj region and even the engineered structures in the city of Ahmadabad situated at a distance of 250 km (Rastogi, 2004). The Kutch region has also experienced soil liquefaction which was reported during the 2001 Bhuj earthquake (Rastogi, 2001). Interestingly all these earthquakes occurred close to tectonic plate boundaries comprising the India, Eurasia and Arabia plates. The influence of plate boundary stresses on seismogenesis in the Kutch region is still not so well understood. One of the most accepted interpretations for the 1819 as well as the 2001 earthquakes is the reactivation of pre-existing faults leading to reverse fault mechanism due to plate convergence, a model that is agreeable with most earthquakes in the Indian region (Johnston, 1994; Bodin and Horton, 2004).

The Kutch region is situated ∼400 km from the junction of the India, Arabia and Eurasia plate boundaries. The earthquakes in this region result from a diffuse plate boundary process rather than intra-plate deformation (Stein et al., 2002). The 2001 Bhuj earthquake occurred along the eastern edge of the Kutch Mainland Fault. Corresponding to a high seismic intensity value of *X* on the Mercalli scale, a lot of damage occurred in Kutch and the surrounding regions in the Gujarat state (Pande and Kayal, 2003). The aftershocks of the 2001 Bhuj earthquake show reverse fault and strike-slip fault mechanisms (Mandal, 2009a,b). The aftershock seismicity analysis and seismic tomography studies reveal the presence of an intrusive body in the epicentral region that may be responsible for the earthquake activity in the Kutch region (Kayal et al., 2002a,b; Mishra and Zhao, 2003; Mandal et al., 2004). Using spatial and depth wise variation of *b*-value and fractal dimension analysis Kayal et al. (2012) mapped seismic characteris-

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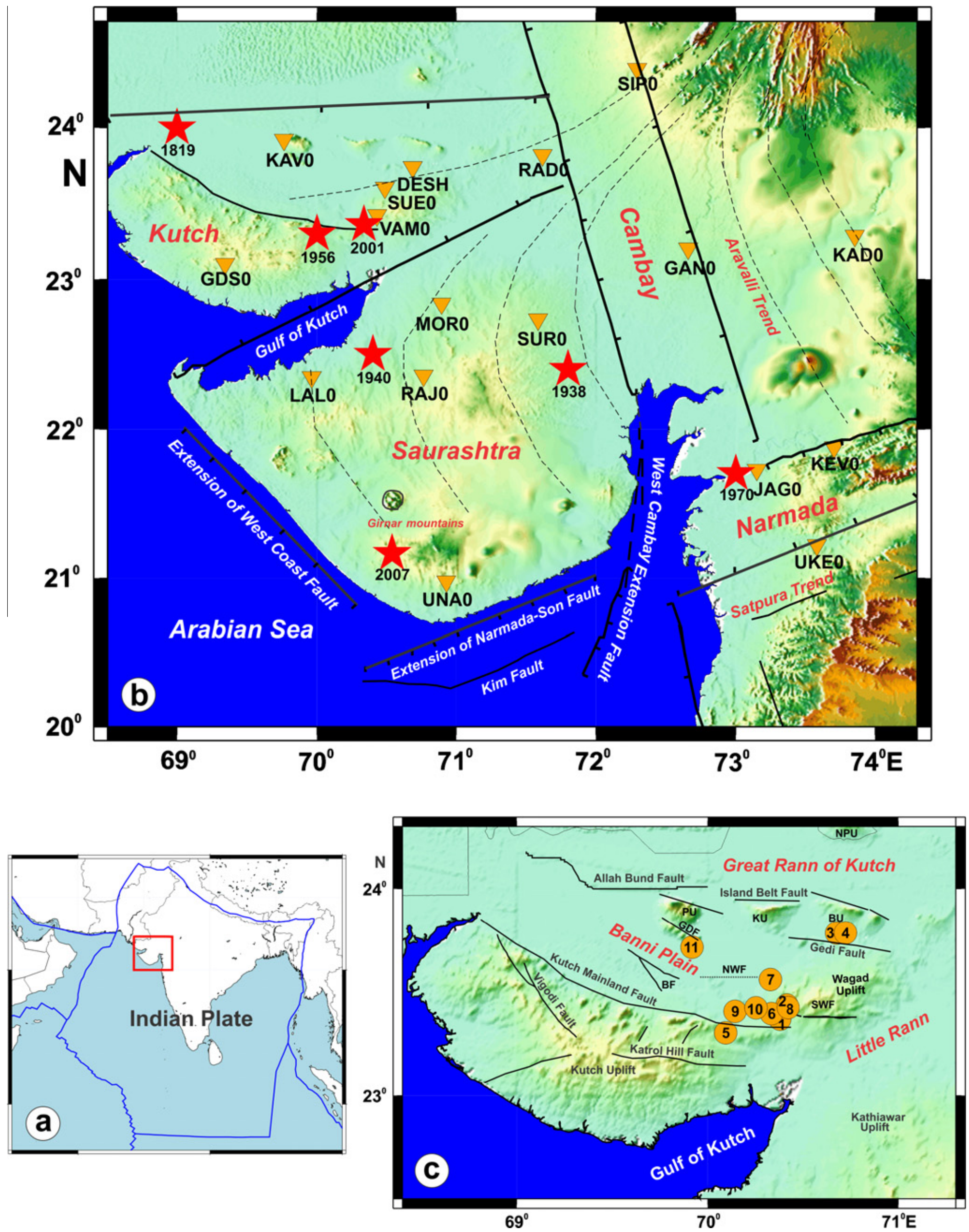

Fig. 1. (a) A map of the Indian plate region indicating the study region in the inset. (b) The Kutch and Saurashtra regions in northwestern India depicting the earthquakes of $M > 5$ in the region during the past (red stars) along with the seismic broadband stations of the ISR network (inverted triangles). (c) A close-up of the Kutch region indicating locations of the 11 earthquakes (orange circles) analyzed in the present study (also listed in Table 1). Also indicated are the major faults in this region. Allah Bund Fault; Island Belt Fault; Gedi Fault; Kutch Mainland Fault; Katrol Hill Fault; North Wagad Fault (NWF); South Wagad Fault (SWF); Gora Dungra Fault (GDF); Banni Fault (BF) and Vigodi Fault. The major rift basins in western India (Kutch, Cambay and Narmada) are indicated using thick lines. The regional Aravalli trend is indicated using dashed lines. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tics of the two known dipping faults, and suggested that Kutch Mainland Fault (KMF) is continuous down to 30 km as a northerly dipping fault zone, South Wagad Fault (SWF) is nearly vertical fault continuous down to 20–37 km. The opposite dipping faults of KMF and SWF intersect at the depth of the 2001 Bhuj earthquake and created a convergent zone. Earlier Biswas (2005) suggested a tectonic model which strongly matches with the seismicity trends in the Kutch region. Use of gravity and magnetic data suggested the existence of volcanic plugs of alkaline magmatic composition beneath the epicentral zone of the 2001 Bhuj earthquake (Chandrasekhar and Mishra, 2002; Mishra et al., 2005). The Moho depth using the receiver transverse function analysis is 42 km (Kumar et al., 2001), where, as controlled source seismic studies suggest a Moho depth of 40–43 km (Reddy et al., 2001).

One of the important factors contributing to damaging earthquakes in the Kutch region is the pop-up effect of the Indian lithosphere due to sediment loading in the Indian Ocean and the rising Himalayan mountains (Rao and Kumar, 1997; Thatcher, 2001; Bilham and England, 2001), stress recoil from the Himalaya (Rastogi, 1992; Bilham et al., 2003), stress concentration around an ultra high velocity body (Mandal et al., 2003). The high stress accumulation and high strain rate in the Kutch region are also attributed to its proximity to the junction of plate boundaries. Such junctions are believed to be the sites of stress build up and hence