Journal of Asian Earth Sciences 34 (2009) 781–795

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jaes

Upwarped high velocity mafic crust, subsurface tectonics and causes of intraplate Latur-Killari (M 6.2) and Koyna (M 6.3) earthquakes, India – A comparative study

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ARTICLE INFO

Article history:
Received 24 December 2007
Received in revised form 29 October 2008
Accepted 20 November 2008

Keywords:
Intraplate seismicity
Latur and Koyna earthquakes
Granulites
Regional uplift
Crustal structure
Mantle heat flow
Geochemical data
Killari borehole

ABSTRACT

A unique attempt is made to understand the genesis of intraplate seismicity in the Latur-Killari and Koyna seismogenic regions of India, through derived crustal structure by synthesizing active and passive seismic, magnetotelluric, gravity and heat flow data. It has indicated presence of relatively high velocity/density intermediate granulite (and amphibolite) facies rocks underneath the Deccan volcanic cover caused mainly due to a continuous geodynamic process of uplift and erosion since Precambrian times. These findings have been independently confirmed by detailed borehole geological, geochemical and mineralogical investigations. The crystalline basement rock is found to contain 2 wt% of carbon-di-oxide fluid components. The presence of geodynamic process, associated with thermal anomalies at subcrustal depths, is supported by a high mantle heat flow (29–36 mW/m^2) beneath both regions, although some structural and compositional variations may exist as evidenced by P- and S-wave seismic velocities. We suggest that the stress, caused by ongoing uplift and a high mantle heat flow is continuously accumulating in this denser and rheologically stronger mafic crust within which earthquakes tend to nucleate. These stresses appear to dominate over and above those generated by the India–Eurasia collision. The role of fluids in stress generation, as advocated through earlier studies, appears limited.

1. Introduction

The Deccan Volcanic Province, covered by a thick suite of volcanic rocks erupted 65 Ma ago, is one of the largest flood basaltic eruptions on the surface of the earth. It covers almost 1/6th of Indian land mass. These volcanics are composed of several gentle dipping tholeiitic basalt flows of both massive and vesicular-amygdaloidal type (Gupta et al., 2003), directly overlying 2.57 Ga old crystalline basement (Zacharaiah, 1998) belonging to eastern part of Dharwar craton (Southern Indian shield). This region has been experiencing moderate seismic activity since historical times. During 1594–1832, there were at least fifteen earthquakes felt (Gubin, 1968; Kelkar, 1968) on the western margin between Bombay and Goa where basaltic layer is thickest ($\geqslant$2 km). Many of the earthquakes, which occurred over this terrain, were destructive in nature, leading to heavy loss of human life and property. Some of the prominent events include, Koyna earthquake of December 10, 1967 (M 6.3); Latur-Killari earthquake of September 29, 1993 (M 6.2) (hereafter called as Latur earthquake); Jabalpur earthquake of May 21, 1997 (M 5.8); Gujarat earthquake of January 26, 2001(M 7.6), etc. In spite of several geophysical studies carried out by national and international agencies since last four decades, seismotectonics of these regions are still not understood well. For example, some scientists believe that Koyna earthquakes are reservoir induced (Rastogi et al., 1997; Gupta and Rastogi, 1976; Gupta, 1992; Talwani et al., 1996), while Lee and Rayleigh (1969), Rai et al. (1999), Krishna Brahmam and Negi (1973) and Agrawal et al. (2004) believe them to be of tectonic origin. Surprisingly, similar differing views persist in case of other Indian intraplate earthquakes also, bringing into focus the ubiquitously anomalous nature of the Indian crust/lithosphere.

The present study is an attempt to examine and compare the prevailing geologic and tectonic structure of the two well studied seismogenic regions of Latur and Koyna (Fig. 1). This is based on recently available deep geological and geophysical findings which includes detailed borehole geological and geochemical studies apart from broadband seismics/seismological, gravity, heat flow and magentotellurics. It is our belief that the results of this study have added an entirely new dimension to our pursuit in understanding the occurrence of intraplate earthquakes within a stable continental region.

2. Latur and Koyna seismic zones

Occurrence of Latur and Koyna earthquakes of magnitude 6.2 and 6.3, respectively, attracted global attention as being the

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1367-9120/$ - see front matter
doi:10.1016/j.jseaes.2008.11.014

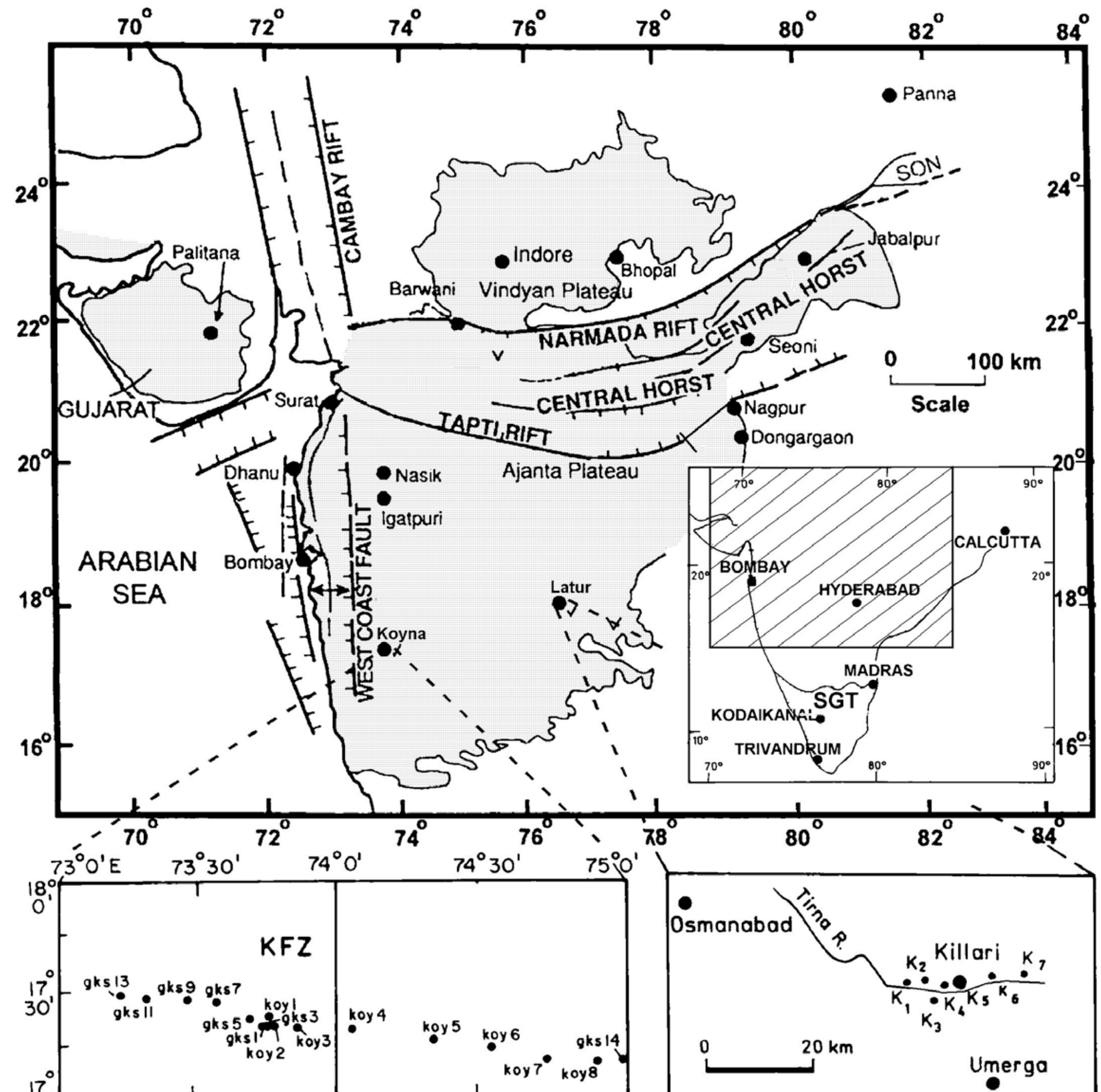

Fig. 1. Tectonic Map of the part of Peninsular India (as covered by hatched lines in the inset) showing locations of Latur, Koyna and major rift valleys. Solid dots in the bottom of the figure indicate locations of MT stations. Area covered by Deccan volcanics are shaded. SGT refers to Southern Granulite Terrain.

significant earthquake disasters of recent times. The epicenter of the Latur earthquake is located close to the eastern fringe of Deccan volcanics where trap thickness is only 338 m, while Koyna seismic zone is located close to uplifted Western Ghats near western margin (Fig. 1), where volcanics are almost 1.5 km thick. Both these regions have been experiencing earthquakes for quite some time. For example, paleoseismic evidences (Talwani, 1994; Sukhija. et al., 1998, 2006) indicate that Latur region may have been associated with number of earthquakes in the past, besides several felt earthquakes during 1962, 1967, 1980, 1984 and also between 1992 and 1993 (Gupta et al., 1993). These earthquakes are of tectonic origin. In contrast, recurring seismic activity at Koyna have an affinity with the Koyna-Warna reservoirs (Rastogi et al., 1997; Gupta,1992; Talwani et al., 1996, etc.) Here, earthquake swarm activity is now recorded for almost four decades. The seismic activity that was confined earlier to the Koyna seismic zone, has now extended further south towards Warna reservoir situated adjacently. In both seismogenic regions, earthquakes are mostly confined along dipping faulted planes up to a subsurface depth of about 8–10 km which are getting reactivated from time to time.

3. Seismic studies

Immediately after the disastrous Latur earthquake, a mobile station network was installed by the National Geophysical Research Institute, Hyderabad in collaboration with a German task force committee comprising the Geo Forschungs Zentrum (GFZ), Potsdam and some German universities to monitor the aftershock activity in the area. Accurate epicenters of the aftershocks, as located by a small aperture 3-station network (Baumbach et al., 1994), revealed that the majority of the epicenters were clustered in a rectangular area SW of surface rupture zone and the depth section of the recorded events had a strike of about 135°E and a dip of ~45°. Krishna et al. (1999) utilized these aftershocks and computed a synthetic seismogram section and also provided 1-D model of crustal P- and S-wave velocity structure using travel time and relative amplitude modeling of reflection phases. They found V_p and V_s of 6.1 km/s and 3.65 km/s, respectively in the uppermost part of crystalline crust.

However, for this region a much more reliable crustal seismic structure has now become available, which utilizes receiver function technique to analyze seismic data obtained from a broadband