Gondwana Research 42 (2017) 133–139

Contents lists available at ScienceDirect

Gondwana Research

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

Location of the pilot borehole for investigations of reservoir triggered seismicity at Koyna, India

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ARTICLE INFO

Article history:
Received 9 May 2016
Received in revised form 29 October 2016
Accepted 29 October 2016
Available online 3 November 2016

Handling Editor: M. Santosh

Keywords:
Koyna
Triggered earthquakes
Scientific drilling
Borehole
Target zone

ABSTRACT

Artificial water reservoir triggered earthquakes are now known to have occurred at over 120 sites globally. The part played by the reservoirs in triggering is not exactly known due to lack of near field observations of triggered earthquakes. Koyna, located near the west coast of India, where triggered earthquakes have been occurring since 1962 provides an excellent site for near field observations of the target M ≥ 2 earthquakes. A 6 borehole seismic network has been deployed recently in the Koyna region at depths of 981–1522 m to improve the hypocenter locations. During May–December 2015, a total of 1039 earthquakes of $M_L \geq 0.5$ were located using the borehole seismic network. The region is also monitored through a dense network of 23 surface broad-band stations. Our analysis indicates a significant improvement in the estimation of absolute locations of earthquakes with errors of the order of ±300 m, combining both the networks. Based on seismicity, and logistics, a block of 2×2 km^2 area has been chosen for drilling the first pilot borehole of ~3 km depth, where M ≥ 2 earthquakes have been occurring frequently since 2005.

1. Introduction

Artificial water reservoirs are created globally for irrigation, flood control and electric power generation. Reservoir Triggered Seismicity (RTS) is an anthropogenic effect of filling artificial water reservoirs. The first scientifically accepted case of RTS was reported from Lake Mead in USA (Carder, 1945). Over the years, RTS has been reported from over 120 sites globally (Mc Garr et al., 2002; Gupta, 2011). Earthquakes exceeding magnitude 6 occurred at Hsingfengkiang, China (1962); Kariba on Zambia- Zimbabwe border (1963); Kremasta, Greece (1966) and Koyna, India (1967). The M 6.3 December 10, 1967 earthquake at Koyna, is so far the largest RTS event globally. It claimed ~200 human lives and the Koyna township was in shambles. The Koyna region is located in the ~65 Ma old Deccan Traps near the west coast of India. Triggered earthquakes started at Koyna soon after the impoundment of the Shivaji Sagar Lake in 1962. Filling of another reservoir, Warna in the year 1985 gave a further impetus to RTS in the region. In this communication the Koyna-Warna region is generally addressed as the Koyna region. Over the years, the triggered earthquakes have continued in the vicinity of the Koyna Dam. These include 22 earthquakes of magnitude ≥5.0 and several thousand smaller events (Fig. 1). The entire seismic activity is confined to a small area of ~30 km × 20 km. It is shallow, mostly in the top 7 km and there is no other earthquake source within 50 km of Koyna Dam (Gupta and Rastogi, 1976; Gupta, 1992, 2002; Talwani, 1997). The association of RTS at Koyna with the loading and unloading of the reservoirs has been clearly demonstrated over the years (Gupta et al., 1972a, 1972b; Gupta and Rastogi, 1976; Kalpna and Chander, 2000; Gupta, 2002; Gahalaut et al., 2010) and several seismological studies have been carried out (Chadha et al., 1997; Talwani, 1997; Langston, 1981; Gahalaut et al., 2004; Srinagesh and Sarma, 2005; Gupta, 2011; Dixit et al., 2014). However, the triggering mechanism is not well understood due to lack of near field observations. In the second ICDP Koyna workshop, the scientific questions that need to be addressed were discussed (Gupta et al., 2014). Several of these have been taken from SAFOD program (Zoback et al., 2011). These include

1. What is the fluid pressure and permeability within and adjacent to the fault zone?
2. What are the composition and origin of fault-zone fluids and gases?
3. How do stress orientation and magnitude vary across fault zones?
4. How do earthquakes nucleate?
5. How do earthquake ruptures propagate?
6. How do earthquake source parameters scale with magnitude and depth?
7. What is the role of water reservoirs in triggering earthquakes?
8. What is the 3-D/4-D nature of the fault zone?

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http://dx.doi.org/10.1016/j.gr.2016.10.014
1342-937X/

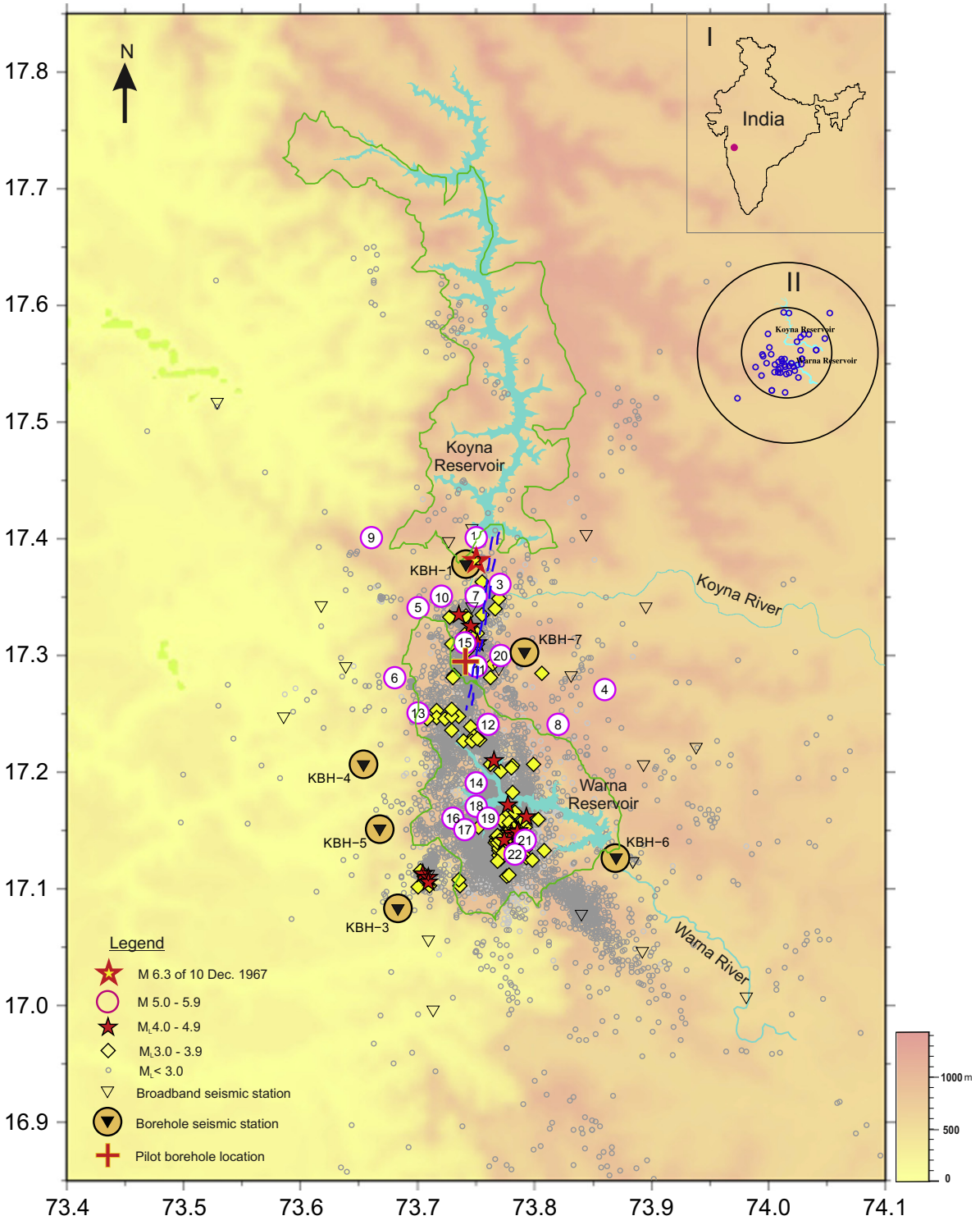

Fig. 1. Map of the Koyna-Warna region showing the locations of the 1967 main shock, M ≥ 5 earthquakes since September 1967 and M < 5 earthquakes during Aug. 2005–Dec. 2015. Numbers inside pink circles show the chronological order of occurrence of the M ≥ 5 events. The networks of seismic stations are also shown. Surface broad-band station is also under operation at the locations of borehole seismic stations. Dashed lines (blue) indicate the Donachiwada fault zone (Gupta et al., 1999). Topographic undulations of the region are plotted which marks the steep differences in the elevations (The elevation scale is in meters). The green curve is the forest boundary. Inset I: Location of Koyna in India. Inset II: shows the distribution of earthquakes of M ≥ 3.7 during 1967–2015 (USGS) in the vicinity of Koyna-Warna region and outer circle of 100 km radius which shows there is almost no seismic activity outside the Koyna-Warna region.

The second ICDP workshop fully supported drilling for the borehole laboratory. As a precursor to drilling the main borehole, it was recommended pilot borehole be drilled to depths of ~3 km (Gupta et al., 2014), similar to the preparation made in central California by drilling a 2.2 km pilot borehole before the main SAFOD drilling program (Zoback et al., 2010).

For a better comprehension of the mechanism of earthquake occurrence and the part played by reservoirs in triggering earthquakes, it was recommended to have two pilot and two main boreholes, hosting comprehensive sets of monitoring instruments. Originally only one pilot bore hole and one main bore hole were planned. However, an additional pilot bore hole and a main borehole located close to the second most