

## NEWS AND NOTES

### *International Workshop on Deep Scientific Drilling to Study Reservoir Triggered Earthquakes in Koyna, India – Harsh Gupta, Shailesh Nayak, Y.J. Bhaskar Rao, R.K. Chadha, B. K. Bansal, D. Srinagesh, N. Purnachandra Rao and Sukanta Roy (Email: harshg123@gmail.com)*

An International Workshop on Scientific Deep Drilling at Koyna, India was organized by the National Geophysical Research Institute (NGRI), Hyderabad during 21-25, March 2011.

#### Background

The Koyna region located close to the west coast of India is the most outstanding example of Reservoir Triggered Seismicity (RTS), where triggered earthquakes have been occurring in a restricted area of 20x30 sq km since the impoundment of Shivajisagar Lake in 1962. These include the largest triggered earthquake of M~6.3 on Dec 10 1967, 22 earthquakes of M>5, about 200 earthquakes of M~4, and several thousand smaller earthquakes since 1962 (Figure 1). The RTS was further enhanced by impoundment of the nearby located Warna reservoir in 1993. There is no other source of seismic activity within 50 km of the Koyna Dam. The continuing seismicity at Koyna for the past 49 years, therefore, provides a unique opportunity to directly measure the physical and mechanical properties of rocks, pore fluid pressure, hydrology, temperature and other parameters of an intra-plate, active, fault zone in the “near-field” of earthquakes – before, during and after their occurrence. The focal depths are mostly in a region within 7 km that can be accessed by drilling with the available expertise. The proposed borehole observatory in this active zone will thus permit direct and continuous monitoring of an intra-plate seismic zone at depth, leading to a better understanding of the mechanics of faulting, physics of reservoir triggered earthquakes, and will contribute appreciably to earthquake hazard assessment and forecasting.

#### Workshop

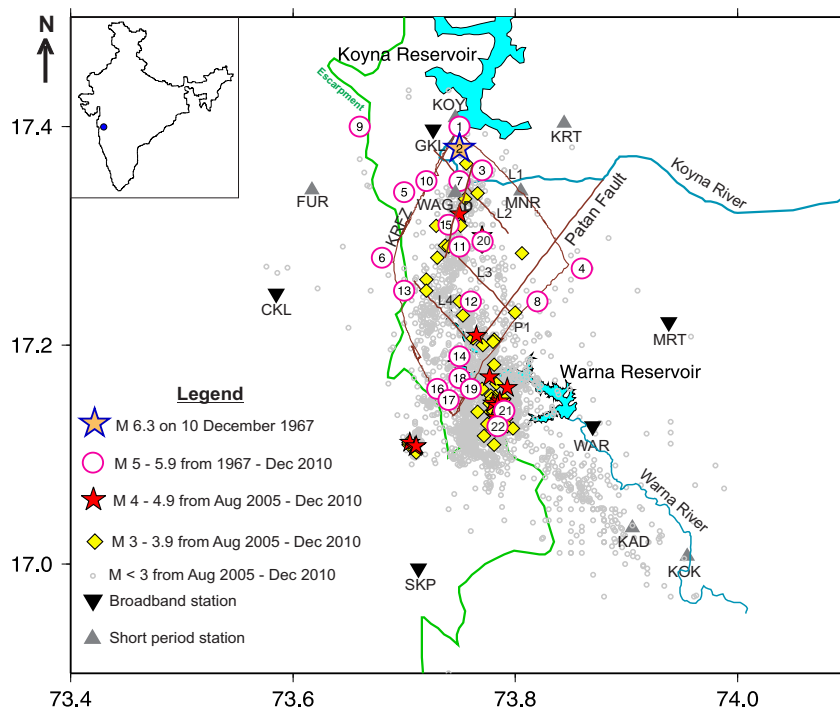
The principal objectives of the Workshop were to fully review the motivation behind deep drilling down to

focal depths of ~7 km at a classical RTS site in an intra-plate setting, and to design the entire experiment through discussions with national and international experts. The first two days of the Workshop were held at NGRI, Hyderabad, followed by a field trip to Koyna-Warna area and the final day's discussions at Karad in Maharashtra. The Ministry of Earth Sciences (MoES), Government of India and the International Continental Scientific Drilling Program (ICDP) supported the Workshop.

Participants to the Workshop included seismologists and experts associated with active fault zone drilling projects worldwide such as the San Andreas Fault Observatory at Depth (SAFOD) in western USA, the Chi-Chi earthquake of Taiwan, the Kobe earthquake of Japan, the Gulf of Corinth in Greece and the Latur earthquake of India. They included 26 international delegates

from the USA, Japan, Germany, France, Italy, Poland, Taiwan, Canada and New Zealand, and 50 national delegates representing major Earth Science Organizations, Institutes and universities in the country such as the MoES, NGRI, Geological Survey of India, Atomic Minerals Directorate for Exploration and Research, Oil and Natural Gas Corporation, North-East Institute of Science and Technology, India Meteorological Department, Institute for Seismological Research, Wadia Institute of Himalayan Geology, National Institute of Rock Mechanics, Central Water and Power Research Station, National Centre for Antarctic and Ocean Research, Pune University, Shivaji University (Kolhapur), M.S. University of Baroda.

Y.J. Bhaskar Rao, Director, NGRI welcomed the delegates and expressed happiness that NGRI was hosting this



**Fig.1.** A map of the Koyna–Warna region in western India indicating the current and past seismicity along with the existing seismograph network and fault zones. *Inset:* Map of India indicating the study region.

important Workshop. Harsh Gupta, Panikker Professor at NGRI introduced the audience to RTS studies in Koyna and the need for deep drilling to constrain rock mechanical properties in the seismogenic zone. Ulrich Harms, Head of Scientific Drilling and Executive Secretary, ICDP made a succinct presentation of the challenging research opportunities offered by deep drilling, ICDP's capabilities and role as a facilitator in this field. Shailesh Nayak, Secretary to Govt. of India, MoES addressed the delegates regarding its major policy initiatives on seismology in general and understanding RTS at Koyna in particular, the build-up to the Workshop including submission of preliminary proposal to ICDP and the recent discussions leading to India receiving the full membership of the ICDP. He was appreciative of NGRI's seminal contributions to Earth Science research in the country and for demonstrating scientific leadership in major R&D programmes in the Koyna-Warna region.

### Structure of the Workshop

The first part of the Workshop included four thematic sessions including (i) Global Review of Reservoir Triggered Seismicity,

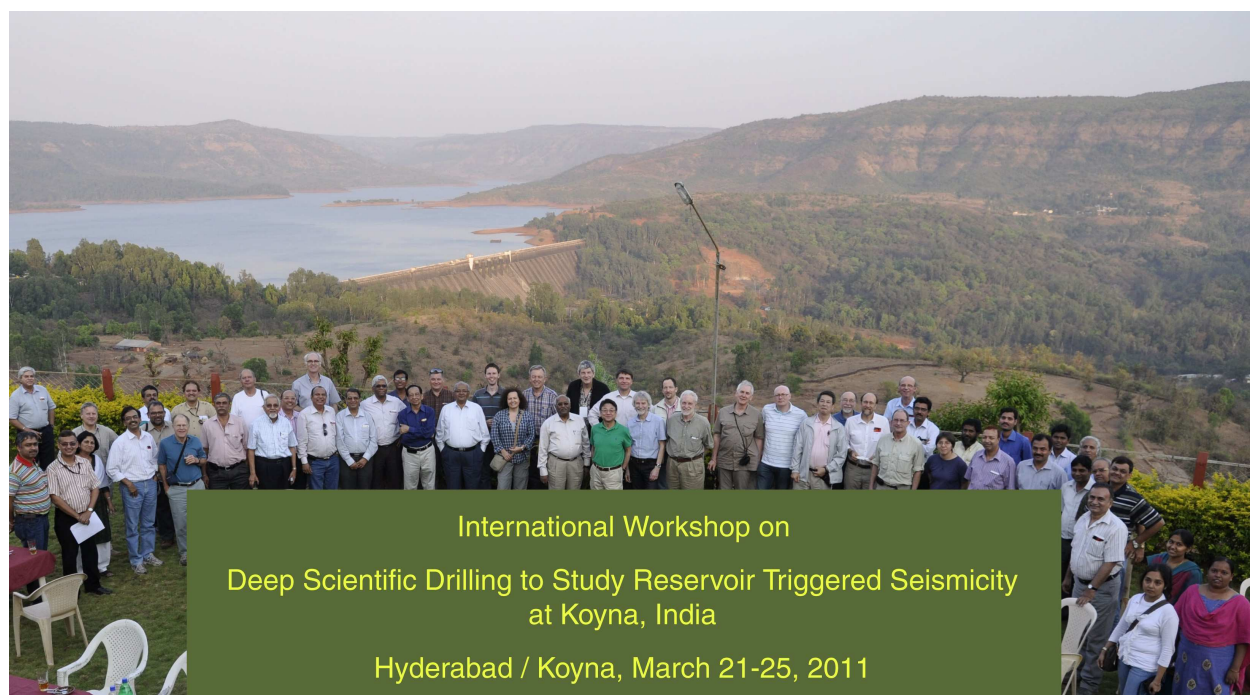
Models and Hypotheses; (ii) Geology and Geophysics of the Koyna Region; (iii) Global Status of Drilling into Fault Zones; and (iv) Designing the Koyna Experiment. The presentations provided an up-to-date status of expertise on fault drilling projects worldwide and brought out the core issues with respect to deep drilling investigations in the Koyna region. The four sessions served as a perfect setting to move on to the second part of the Workshop, which included a field trip to Koyna area and breakout group discussions to go into detailed planning for the investigations. The participants were divided into four break-out groups according to their key expertise: (i) Seismology / Borehole Location(s) / RTS (ii) Drilling / Coring / Geological Logging / Fault Zone Studies (iii) Geophysical logging / Petrophysical Properties / Long-term Monitoring and (iv) Temperature / Hydrogeology / Fluid and Gas Sampling. The break-out group discussions started at Hyderabad and continued through the field visit to Koyna and for another full day at Karad. The hallmark of the event was the conglomeration of experts from all major fault zone drilling programmes worldwide, all working together for addressing the

major challenges of undertaking the deep drilling investigations at Koyna.

### Outcome of the Workshop

On the basis of intensive discussions among the participants and important suggestions received from experts from India and abroad, a few key areas were identified for detailed preparatory studies. Foremost among those are the needs to establish the hydrological connectivity between the reservoir and host country rock and to constrain the fine structure of the seismic zone in the area including detailed mapping of the causative faults, both of which would be critical in locating the deep borehole observatory in the region. The following 3-tier action plan was agreed upon:

- 1 Revisiting old data and acquiring new data
  - Compile all available earthquake data for Koyna area and apply the most appropriate techniques to estimate improved hypocentral locations.
  - Deploy a larger number of seismic stations, especially in the region close to the active Warna seismic zone.
  - Take up geophysical surveys like



**Fig.2.** Group photograph of participants to the field trip at Koyna. Background view shows the Koyna dam and near-horizontal basaltic lava flows.

Seismic Reflection, Magnetotelluric, Deep Electrical Sounding, Gravity and Magnetics to constrain the fine structure of the seismic zone

- Acquire very high resolution Laser Induced Detection And Ranging (LIDAR) data

## 2 Studying hydraulic connectivity

- Initially drill about four test boreholes around the seismic zone, each going down about 200m into the pre-

Trappean basement

- Make suites of measurements in and across boreholes
  - Modeling of regional hydraulic connectivity
- 3 Planning the main borehole based on 1 and 2.

The major success of the Workshop was the unanimous agreement by all participants that Koyna is an outstanding world

geological site to plan a deep borehole experiment for earthquake studies. The MoES has extended complete support to the programme, and the ICDP has offered to make available their technical expertise in deep drilling and logging, training of manpower and support towards drilling. Experts from world over have offered to bring in new tools and techniques for measurements and modeling.