

GOVERNMENT OF INDIA  
MINISTRY OF EARTH SCIENCES

Report on International Workshop

Deep Scientific Drilling to Study Reservoir  
Triggered Earthquakes in Koyna, India

Hyderabad/Koyna, March 21-25, 2011

Organized by

National Geophysical Research Institute (CSIR-NGRI)  
Uppal Road, Hyderabad 500606, India

Sponsored by

Ministry of Earth Sciences (MoES), Government of India  
&  
International Continental Scientific Drilling Program  
(ICDP), Potsdam, Germany

1	Title of Workshop	<b>International Workshop on Deep Scientific Drilling to Study Reservoir Triggered Earthquakes at Koyna, India</b>
2	Duration	<b>21-25 March, 2011</b>
3	Venue	<b>National Geophysical Research Institute, Hyderabad with a Field Visit and On-Site Meeting at Koyna / Karad, Maharashtra</b>
4	Name and address of Host Organization	<b>National Geophysical Research Institute (Council of Scientific and Industrial Research), Uppal Road, Hyderabad 500606</b> <b>Email: <a href="mailto:director@ngri.res.in">director@ngri.res.in</a></b>
5	Name and Address of the Patron of the event	<b>Dr. Harsh Gupta, Panikker Professor</b> <b>National Geophysical Research Institute, Uppal Road, Hyderabad 500 606.</b> <b>Telephone: 23434669</b> Email: <a href="mailto:harshg123@gmail.com">harshg123@gmail.com</a>
6	Name and address of Organising Secretary of the Event	<b>Dr Sukanta Roy</b> <b>National Geophysical Research Institute, Uppal Road, Hyderabad 500 606.</b> <b>Telephone: 23434700 (x 2384); Mobile: 9490469980</b> Email: <a href="mailto:sukantaroy@yahoo.com">sukantaroy@yahoo.com</a>
7	Importance of the Koyna region	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. 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

		<p>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.</p>
8	Genesis of the Workshop	<p>Considering the importance of the Koyna region in understanding seismogenesis at depth, and also the natural confined laboratory that it provides for carrying out high science, a preliminary proposal was submitted to the International Continental Scientific Drilling Program (ICDP). The review and recommendations received from the Scientific Advisory Group of ICDP were highly encouraging. Also, India became a member of the ICDP on Jan 7, 2011. It was felt that the International Workshop would provide an opportunity 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. Hosting an International Workshop is a key requirement before applying for technical and financial support for the main scientific programme from ICDP.</p> <p>The proposal for the Workshop and subsequent deep drilling investigations at Koyna was discussed with heads / representatives of major Earth Science departments / institutions and universities on 14 December, 2011 at the Ministry of Earth Sciences, New Delhi. It was unanimously agreed that such investigations would provide unprecedented opportunity to acquire new information about the properties in the deeper parts of the Earth’s crust that will serve to constrain several processes including seismogenesis in intraplate settings and geologic evolution of cratons, apart from shedding new light on the mechanism of reservoir triggered earthquake genesis.. It was agreed that the proposed investigations would provide a unique opportunity for India to demonstrate its scientific leadership in the international arena.</p>

9	Objectives of the Workshop	<ol style="list-style-type: none"> <li>1. To provide an international forum for sharing and exchange of information gained from investigations on Reservoir Triggered Seismicity (RTS) worldwide (including at Koyna).</li> <li>2. To discuss with experts about the unique opportunity and modus operandi of deep drilling into the fault zone at a classical RTS site and to prepare a complete scientific plan including drilling.</li> <li>3. To plan the entire array of measurement / monitoring opportunities provided by deep drilling.</li> <li>4. To develop a Full Proposal on Deep Scientific Drilling at Koyna for submission to Ministry of Earth Sciences (MoES), GOI and International Scientific Deep Drilling program (ICDP).</li> </ol>
10	Number of participants	<p>No. of foreign Scientists: 26  No. of Indian Scientists : 55  <b>(List of participants is given in Appendix I)</b></p>
11	Source(s) of funds	<ul style="list-style-type: none"> <li>• All costs in India were funded by the Ministry of Earth Sciences. (Sanctioned Rs. 20 lakhs vide Order No. MoES/P.O.(Seismo)/3(27)/2010 dated 18.3.2011)</li> <li>• The international airfare for the foreign delegates was covered by the ICDP.</li> <li>• The event was hosted by NGRI.</li> </ul>
12	Detailed Report on the Workshop	<p><b>Workshop</b></p> <p>The principal objectives of the Workshop were to fully review the plan for 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.</p> <p>Participants to the Workshop included seismologists and experts associated with active fault zone drilling projects worldwide such as the San Andreas Fault Observatory at</p>

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, Sivaji University (Kolhapur), M.S. University of Baroda (**see Appendix I**).

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

#### **Appendix II: Technical Programme of the Workshop**

##### **Field Visit**

A field visit to Koyna area was organized on 23 March 2011, in which more than 50 scientists from India and abroad participated. The visit provided a glimpse of the geological setting of the Koyna Dam, the Western Ghats and several exposed vertical sections of Deccan flood basalt sequence in western India.

On 24 March, 2011, a select group of about 12 participants comprising experts from NGRI, ONGC and a few international participants associated with San Andreas Fault Drilling Project undertook detailed visits to potential drilling sites in Warna area and the Western Ghats escarpment. The remaining participants continued intensive breakout group discussions at Karad, close to Koyna. The breakout sessions were followed by a combined session of all participants, in which summary presentations for each breakout group were made by the respective team leaders. There was ample time for discussions. Dr Harsh Gupta made a summary of the recommendations of the breakout groups, and identified a three-tier approach for carrying out the investigations in the area. Several lines of investigations were identified. Dr B.K. Bansal, Head of Seismology, MoES, expressed satisfaction at the successful conduct of the Workshop and reiterated the support of the Ministry of Earth Sciences for conducting the future investigations in the area. Dr N.

		<p>Purnachandra Rao thanked all participants for contributing to the success of the Workshop and gave his concluding remarks.</p> <p><b>The hallmark of the Workshop was the conglomeration of experts from all major fault zone drilling programmes worldwide, all working together towards addressing the major challenges of undertaking the deep drilling investigations at Koyna.</b></p>
13	<b>Major Recommendations / Outcome</b>	<p>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:</p> <ol style="list-style-type: none"> <li>1. Revisiting old data and acquiring new data <ul style="list-style-type: none"> <li>• Compile all available earthquake data for Koyna area and apply the most appropriate techniques to estimate improved hypocentral locations.</li> <li>• Deploy a larger number of seismic stations, especially in the region close to the active Warna seismic zone</li> <li>• Take up geophysical surveys like Seismic Reflection, Magnetotelluric, Deep Electrical Sounding, Gravity and Magnetics to constrain the fine structure of the seismic zone</li> <li>• Acquire very high resolution Laser Induced Detection And Ranging (LIDAR) data</li> </ul> </li> <li>2. Studying hydraulic connectivity <ul style="list-style-type: none"> <li>• Initially drill about four test boreholes around the seismic zone, each going down about 200m into the pre-Trappean basement</li> <li>• Make suites of measurements in and across boreholes</li> <li>• Modeling of regional hydraulic connectivity</li> </ul> </li> <li>3. Planning the main borehole based on 1 and 2.</li> </ol>

		<p>4. Establishment of an organizational structure for the project at par with national space missions. Several examples of project structures for large-scale drilling projects are available and were discussed as good models for the Koyna Project. Based on these examples it was recommended that a high level Advisory Committee be created. This committee will advise the project leaders on the development of drilling proposals, the stages of the project and will oversee the work of task and discipline subcommittees. A number of key working groups and project teams should also be identified and established without delay.</p> <p><b>Major achievements</b></p> <ul style="list-style-type: none"> <li>• The major success of the Workshop was the unanimous agreement by all national and international participants that Koyna is an outstanding world geological site to plan a deep borehole experiment for earthquake studies.</li> <li>• 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.</li> <li>• Experts from world over have offered to bring in new tools and techniques for measurements and modeling.</li> </ul>
15	Recommended Follow-up of the Workshop	A Full Proposal for Scientific Deep Drilling Project at Koyna is being prepared for submission to MoES and ICDP. The Proposal will consider the 3-tier approach, which is the key recommendation from the Workshop.





**Figure 1:** Group photograph of participants to the field trip at Koyna. Background view shows the Koyna dam and near-horizontal basaltic lava flows.

**Appendices:**

Appendix I

List of participants

Appendix II

Technical Programme of the Workshop

## APPENDIX – I: LIST OF PARTICIPANTS

### Koyna Workshop, March 21-25, 2011: International Participants

#	Participant	Affiliation	Specialization
1	William L. Ellsworth	Earthquake Science Center U.S. Geological Survey, MS-977 Office 1-650-329-4784; 345 Middlefield Road Fax 1-650-329-5143; Menlo Park, CA USA 94025	Seismology
2	Serge Shapiro	Prof. Serge A. Shapiro, Fachrichtung Geophysik, Freie Universitaet Berlin, Malteserstrasse 74-100, Build.D., D, 12249 Berlin, Germany	Seismology
3	Hisao Ito	Center for Deep Earth Exploration (CDEX), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 3173-25 Showa-machi, Kanazawa-ku, Yokohama, Kanagawa 236-0001 Japan	Continuous long-term monitoring of temperature and pore fluid pressure
4	Peter E. Malin	Professor and Director, Institute of Earth Science & Engineering, Rm 627, Level 6, 58 Symonds St., University of Auckland, Private Bag 92019 Auckland Mail Center, Auckland 1142, New Zealand	Seismology
5	Ze'ev Reches	GeoStructure group School of Geology and Geophysics, U of Oklahoma Norman, OK 73019	Seismology; Structural Geology; Faulting; Fracturing; Mapping fault zones at depth; Slip nucleation
6	David Simpson	President, IRIS Consortium, Suite 800, 1200 New York Ave NW, Washington D.C. 20005	Reservoir Triggered Seismicity
7	Pradeep Talwani	University of South Carolina	Reservoir Triggered Seismicity
8	Stanislaw Lasocki	Institute of Geophysics, Polish Academy of Sciences	Mining Induced Seismicity
9	Georg Dresen	GFZ Potsdam	Rock Mechanics
10	Hiroshi Ogasawara	Faculty of Science and Engineering, Ritsumeikan University, 1-1-1 Noji Higashi, Kusatsu, Japan 525-8577	Rock Mechanics
11	Marco Bohnhoff	Geomechanics and Rheology, Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum GFZ, Telegrafenberg, 14473 Potsdam	Rock Mechanics
12	Douglas R. Schmitt	Professor of Physics and Geophysics Canada Research Chair in Rock Physics Department of Physics, Mailstop 615 11322 89 Ave University of Alberta Edmonton, Alberta, Canada, T6G 2G7	Geophysical Measurements and Downhole Logging; Repeat Active Source Seismic Experiments (VSP)

13	David Chapman	University of Utah, Salt Lake City, USA	Heat Flow / Temperature Logs
14	Thomas Wiersberg	ICDP, GFZ Potsdam	Fluid chemistry and sampling of mud gas and fluids
15	James Jiro Mori	Professor Earthquake Hazards Division Disaster Prevention Research Institute Kyoto University Gokasho, Uji, Kyoto 611-0011	Seismology, Earthquake Hazard
16	Francois Cornet	University de Strasbourg, France	Hydrofrac induced seismicity
17	Mai-Linh Doan	Assistant Professor, LGIT - BP 53, 38041 Grenoble CEDEX 9, FRANCE	Fault Hydrology
18	Ulrich Harms	Scientific Drilling, GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany	Petrology; Scientific Deep Drilling
19	Hans-Joachim.Kuempel	BGR	Pore-pressure studies
20	Arthur Francis McGarr	USGS, USA	Seismology, Stress
21	Jochen Zschau	GFZ, Potsdam, Germany	Seismology
22	Ms. Kuo-Fong Ma	National Central Univ., Taiwan	Seismology
23	Ernst Huenges	GFZ, Potsdam, Germany	Geothermal / Temperature Logging
24	Dennis Lon Nielson	DOSECC, USA	Drilling
25	James David Kirkpatrick	Univ. California Santa Cruz, USA	Fault zone studies, hydrology
26	Ms. Maria Teresa Mariucci	INGV, Rome	Active stress data analysis

### Koyna Workshop, March 21-25, 2011: Indian Participants

#	Participant	Organisation	Specialization
1	Harsh Gupta	CSIR-NGRI	Seismology, RTS
2	Shailesh Nayak	MoES	Geology
3	Y J Bhaskar Rao	CSIR-NGRI	Geochronology / Isotope Geochemistry
4	V.P. Dimri	CSIR-NGRI	Signal Processing, Fractals
5	Dipankar Sarkar	CSIR-NGRI	Seismology, Seismics
6	R K Chadha	CSIR-NGRI	Seismology
7	Bijendra Singh	CSIR-NGRI	Gravity & Magnetism
8	D Srinagesh	CSIR-NGRI	Seismology
9	N Purnachandra Rao	CSIR-NGRI	Seismology
10	Sukanta Roy	CSIR-NGRI	Geothermics
11	D. Shashidhar	CSIR-NGRI	Seismology
12	Vineet Gahalaut	CSIR-NGRI	GPS Geodesy, Seismology
13	H V S Satyanarayana	CSIR-NGRI	Seismology
14	D V Reddy	CSIR-NGRI	Isotope Hydrology
15	T Seshunarayana	CSIR-NGRI	Engineering Geophysics
16	P Koteswara Rao	CSIR-NGRI	Seismics
17	D C Mishra	CSIR-NGRI	Gravity & Magnetism
18	V M Tiwari	CSIR-NGRI	Gravity & Magnetism
19	Ms Kalpna	CSIR-NGRI	Seismology
20	Sanjai Kumar	CSIR-NGRI	Seismics
21	M V M S Rao	CSIR-NGRI	Rock Mechanics

22	B S Sukhija	CSIR-NGRI	Isotope Hydrology, Radon Gas Sampling, Palaeoseismology
23	B R Arora	WIHG	Electromagnetics, Seismology,
24	B K Rastogi	ISR	Seismology, RTS
25	B K Bansal	MoES	Seismology
26	R S Dattatreya	IMD	Seismology
27	P.G. Rao	CSIR-NEIST	Chemistry
28	Kunal Niyogi	KDMIPE, ONGC	Exploration Geophysics
29	Jitendra Kumar	KDMIPE, ONGC	Exploration Geophysics
30	Pradeep Kumar	KDMIPE, ONGC	Petrology, Downhole Logging
31	N K Verma	Frontier Basins, ONGC	Drilling, Petroleum Geology
32	N R Karmalkar	Head, Dept. of Geology, University of Pune	Geology
33	N J Pawar	Sivaji University, Kolhapur	Geology
34	Prabhas Pande	G.S.I., Kolkata	Geology
35	D.K. Sinha	AMDER, Hyderabad	Geology
36	Anjan Som	AMDER, Hyderabad	Geology
37	K C Tiwari	M.S. Univ. of Baroda	Geology
38	P C Nawani	NIRM, Kolar	Rock Mechanics
39	Ms. V J Shende	CWPRS, Pune	Seismology
40	John Kurian	NCAOR, Goa	Marine Geophysics
41	R S K Srinivasulu	CSIR-NGRI	Mechanical Engineering
42	Ms Chandrani Singh	CSIR-NGRI	Seismology
43	EVSSK Babu	CSIR-NGRI	Geology / Isotope Geochemistry
44	B Srinivas	CSIR-NGRI	Geology / Isotope Geochemistry

45	T Vijaya Kumar	CSIR-NGRI	Geology / Isotope Geochemistry
46	M Ram Mohan	CSIR-NGRI	Geology
47	M Satyanarayan	CSIR-NGRI	Geology
48	Ms. Mallika	CSIR-NGRI	Seismology
49	Ms. Anuradha	CSIR-NGRI	Seismology
50	Ms Kusumita Arora	CSIR-NGRI	Gravity & Magnetics
51	Ms. G. Srijayanthi	CSIR-NGRI	Seismology
52	A. Omkumar	GSI, Hyd	Geology
53	Sumer Chopra	MoES	Seismology / Seismic Hazard
54	Arun Gupta	MoES	Seismology
55	Makarand Bodas	GSI, Pune	Geology

**CSIR-NGRI: National Geophysical Research Institute, Hyderabad (CSIR)**

**MoES: Ministry of Earth Sciences, New Delhi**

**GSI: Geological Survey of India**

**CWPRS: Central Water and Power Research Station, Pune**

**ISR: Institute for Seismological Research, Gandhinagar**

**NIRM: National Institute of Rock Mechanics, Kolar**

**CSIR-NEIST: North-East Institute for Science and Technology, Jorhat (CSIR)**

**NCAOR: National Centre for Antarctic and Ocean Research, Goa**

**AMDER: Atomic Minerals Directorate for Exploration and Research**

**ONGC: Oil and Natural Gas Corporation, India**

**WIHG: Wadia Institute of Himalayan Geology, Dehradun**

**IMD: India Meteorological Department, New Delhi**

## APPENDIX – II: TECHNICAL PROGRAMME OF THE WORKSHOP

### KOYNA WORKSHOP: DAY 1

9:00-9:05 AM	Welcome	Director, NGRI
9:05-9:15	Koyna Seismicity and the Need for Scientific Drilling	Harsh Gupta
9:25-9:35	Introduction to ICDP and its role in the Koyna Programme	Ulrich Harms
9:15-9:25	Address to Workshop Participants	Secretary to Govt. of India, Ministry of Earth Sciences
9:35-9:45	About the Workshop	Organizing Secretary

9:45 – 10:15     Tea / Coffee

### Session I : Global Review of Reservoir Triggered Seismicity (RTS), Models and Hypotheses

Chairs: William Ellsworth and B. R. Arora

10:15-10:45	Global Review of RTS and Continued Seismicity in the Koyna-Warna Region	Harsh Gupta
10:45-11:15	Reservoir induced seismicity: causal mechanisms, rapid changes in water level and implications for deep drilling	David Simpson
11:15-12:00	Short Comments (5 minutes) on global RTS, models and hypotheses	
	Insights into the mechanisms of reservoir triggered seismicity	Pradeep Talwani
	Identification of Fracture Pattern, Fluid Content and Strength of Rocks near Faults in Koyna Area through Deep Drilling Investigations of Reservoir Induced Seismicity	B.K. Rastogi
	Cyclic loading, seismicity parameters and triggered earthquakes	R.K. Chadha
	A comparative study of gravity and aeromagnetic fields of Koyna region and Kontinental Thief Borung (KTB) in Germany	D.C. Mishra
	Ocean Transform Fault Drilling and Water Injection: A Proposal for an Active Experiment to Trigger Earthquakes	James Jiro Mori
	Simulation of pore pressure in Koyna-Warna region	Kalpna
12:00- 2:15 PM	Induced seismicity in mines: some collective properties	Stanislaw Lasocki
12:15-12:30 PM	Water-ingress triggered seismicity in deep mines	Hiroshi Ogasawara

**KOYNA WORKSHOP: DAY 1 (continued)**

**Session II : Geology and Geophysics of Koyna Region**

Chairs: V.P. Dimri and Prabhas Pande

12:30-1:00 PM	Overview of geology in and around Koyna region, Satara district, Maharashtra	N.R. Karmalkar
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1:00-2:00 PM Lunch at NGRI Golden Jubilee Food Court

**Session II : Geology and Geophysics of Koyna Region (continued)**

Chairs: Y.J. Bhaskar Rao and P.G. Rao

Geophysical Studies in Koyna region: Brief Results		
2:00-2:20 PM	Seismological constraints on hypocentral depths and focal mechanisms in the Koyna region	N. Purnachandra Rao
2:20-2:30 PM	Seismicity patterns in Koyna-Warna region	D. Srinagesh
2:30-2:40 PM	Reservoir triggered seismicity (RTS) and well water level response in the Koyna region, India	Hans-Joachim Kuempel
2:40-2:50 PM	Koyna region: the velocity picture	D. Sarkar
2:50-3:00 PM	Nature of Gravity Anomalies in the Koyna Region, India: Geological Interpretation	V.M. Tiwari
3:00-3:10 PM	Low strain rate in the Koyna-Warna region	Vineet Gahalaut
3:10-3:20 PM	Hydrogeochemical and isotopic earthquake precursory studies in Koyna region	D.V. Reddy
3:20-3:30 PM	Heat Flow and Subsurface Temperature Regime in Koyna Region, western India	Sukanta Roy

3:30 – 4:00 PM Tea / Coffee



**KOYNA WORKSHOP: DAY 1 (continued)**

**Session III: Global Status of Drilling into Faults Zones**

Chairs: N.K. Verma and Uli Harms

4:00 - 4:30 PM	Scientific Drilling Provides Opportunities to Access Deep Crustal Processes	Uli Harms
4:30 - 5:00 PM	The San Andreas Fault Observatory at Depth: General Overview	William Ellsworth
5:00 - 5:30 PM	SAFOD and Stress / Heat Flow Paradox	Arthur McGarr
5:30 - 6:00 PM	Nojima Fault Zone Drilling: After the 1995 Kobe Earthquake	Hisao Ito
6:00 - 6:30 PM	Monitoring microseismic and aseismic motions triggered by forced fluid flow	Francois Cornet

**7:30 – 9:30 PM Dinner at Secunderabad Sailing Club Annexe**

**KOYNA WORKSHOP: DAY-2**

**Session III: Global Status of Drilling into Active Faults Zones (continued)**

Chairs: P.C. Nawani and R.S. Dattatreya

9:30-10:00 AM	Taiwan Chelungpu-fault Drilling Project (TCDP) and Borehole Seismometers Observatory	Kuo-Fong Ma
10:00-10:30 AM	Borehole investigations in the surface rupture zone of the 1993 Latur earthquake, Deccan Volcanic Province, India	Sukanta Roy

10:30-11:00 Tea / Coffee

**KOYNA WORKSHOP: DAY-2 (continued)**

**SESSION IV: Designing the Koyna Drilling Experiment**

Chairs: Art McGarr and B.K. Bansal

11:00 – 11:20 AM	Deep Drilling Investigations at Koyna : Preliminary Plan	Harsh Gupta, Shailesh Nayak, R.K. Chadha, Y.J. Bhaskar Rao
11:20 – 11:40 AM	Critical Parameters for constraining RTS	Art McGarr
11:40 – 12:00 AM	Earthquake rupture at focal depth: The 2002 M2.2 earthquake along the Pretorius Fault, Tautona mine, South Africa	Zeev Reches
12:00 – 12:15 PM	Planning for Deep Drilling	Uli Harms
12:15 – 12:30 PM	Deep Drilling: Lessons from SAFOD	William Ellsworth
12:30 – 12:50 PM	Geophysical Logging: Objectives; Challenges at high P & T conditions	Doug Schmitt
12:50 – 1:10 PM	Challenges for measurement of temperature	David Chapman
1:10 – 1:30 PM	Borehole Seismology: Challenges at high temperatures and pressures	Peter Malin

1:30-2:30 PM                      Lunch at NGRI Golden Jubilee Food Court

2:30 – 2:50 PM	Mineralogical, Petrological, Geochemical and Isotopic Studies from the Proposed Koyna Deep Drill Hole, India	Y J Bhaskar Rao
2:50 – 3:10 PM	Physics of fluid induced seismicity and its magnitude distribution	Serge Shapiro
3:10 - 3:30 PM	Fluid-induced fracture and AE activity in laboratory tests	Georg Dresen

## BREAK-OUT GROUP DISCUSSIONS

3:30 -6:15 PM	Breakout Groups (Tea / Coffee will be available throughout the session)	
	<p>1. Seismology / Borehole Location(s) / RTS</p> <p>Lead : Harsh Gupta, William Ellsworth</p> <p>Rapporteur: N Purnachandra Rao</p>	<p>Harsh Gupta, Shailesh Nayak, Dipankar Sarkar, William Ellsworth, Zeev Reches, V.P. Dimri, David Simpson, Pradeep Talwani, B.K. Rastogi, R.S. Dattatreya, B.R. Arora, B.K. Bansal, Jim Mori, Francois Cornet, Stanislaw Lasocki, Jochen Zschau, R.K. Chadha, D. Srinagesh, N. Purnachandra Rao, D Shashidhar, HVS Satyanarayana, Vineet Gahalaut, Marco Bohnhoff, Serge Shapiro, Sanjai Kumar, Chandrani Singh, Bijendra Singh, Kunal Niyogi</p>
	<p>2. Drilling / Coring / Geological Logging / Fault Zone Studies</p> <p>Lead: Uli Harms, Zeev Reches</p> <p>Rapporteur: EVSSK Babu</p>	<p>Shailesh Nayak, Zeev Reches, Uli Harms, James Kirkpatrick, Dennis Neilson, Y.J. Bhaskar Rao, P.G. Rao, N.K. Verma, Nikhil Chandra, D.K. Sinha, Anjan Som, N.R. Karmalkar, N.J. Pawar, K.C. Tiwari, EVSSK Babu, B. Srinivas, T. Vijaya Kumar, M. Ram Mohan, M. Satyanarayan, Jitendra Kumar, , Kuo-Fong Ma, John Kurian</p>
	<p>3. Geophysical Logging / Petrophysical Properties / Long-term Monitoring</p> <p>Lead: Art McGarr, Georg Dresen</p> <p>Rapporteur: T. Seshunarayana</p>	<p>Peter Malin, Hisao Ito, Art McGarr, Serge Shapiro, Georg Dresen, Maria Teresa Mariucci, Hiroshi Ogasawara, H.-J. Kumpel, Doug Schmitt, Vineet Gahalaut, Sukanta Roy, M.V.M.S. Rao, T. Seshunarayana, V.M. Tiwari, P C Nawani, V.J. Shende, Mai-Linh Doan, Pradeep Kumar</p>
	<p>4. Temperature / Hydrogeology / Fluid and Gas Sampling</p> <p>Lead: David Chapman, Ernst Huenges</p> <p>Rapporteur: Thomas Wiersberg</p>	<p>David Chapman, Sukanta Roy, Ernst Huenges, Thomas Weirsberg, B.S. Sukhija, D.V. Reddy, Mai-Linh Doan</p>
6:15– 6:30	Arrangements for Field Visit to Koyna	Organizing Secretary

7:30 PM: Dinner at NGRI Guest House

### KOYNA WORKSHOP: DAY 3

8:00 AM Departure for Hyderabad Airport  
10:30 – 11:40 AM Hyderabad – Pune flight  
12:00 – 8:00 PM Travel to Koyna and Field Visit  
Overnight Stay at Karad

### KOYNA WORKSHOP: DAY 4

7:30 AM - 3:00 PM Field visit to possible drilling sites [Coordinators: R K Chadha, D Srinagesh, Vineet Gahalaut]  
Participants: D Srinagesh, Vineet Gahalaut, D. Shashidhar, N.K. Verma, Nikhil Chandra, Serge Shapiro, Jitendra Kumar, Dennis Nielson, Art McGarr, William Ellsworth, Pradeep Talwani, Uli Harms

10:00 -12:30 PM	Breakout Group Meetings (continued)
	1. Seismology / Borehole Location(s) / RTS
	2. Drilling / Coring / Geological Logging / Fault Zone Studies
	3. Geophysical Logging / Petrophysical Properties / Long-term Monitoring
	4. Temperature / Hydrogeology / Fluid and Gas Sampling

12:30 – 3:00 PM Lunch + Free Time

3:00 – 3:20 PM	Presentation by Breakout Group # 1	Harsh Gupta, William Ellsworth
3:20 – 3:40	Presentation by Breakout Group # 2	Uli Harms, Zeev Reches
3:40 – 4:00	Presentation by Breakout Group # 3	Art McGarr, Georg Dresen
4:00 – 4:20	Presentation by Breakout Group # 4	David Chapman, Ernst Huenges
4:20 – 5:00	Panel Discussion: The Way Ahead	Chair: Shailesh Nayak Panelists: Harsh Gupta, H.-J. Kumpel, Georg Dresen, Serge Shapiro, William Ellsworth, Art McGarr, Uli Harms, Y.J. Bhaskar Rao
5:00 - 5:20 PM	Conclusion of the Workshop	N. Purnachandra Rao

## **KOYNA WORKSHOP: DAY 5**

9 AM: Departure for Pune after breakfast

2 PM: Arrival at Pune Airport; Departure for Hyderabad / other destinations in India

### **26 March, 2011**

Free day at Hyderabad to tie up loose ends / visits

