Delhi), National Geophysical Research Institute (Hyderabad) and CSIR Centre for Mathematical Modelling and Computer Simulation (Bangalore) sponsored the workshop.

The main aim of the workshop was to discuss different research and development aspects of geological fluid mechanics. Nineteen research papers on different topics such as palaeoseismicity and neotectonism, palaeoclimate reconstruction, metamorphism, fluid processes associated with magma underplating, effects of fluid circulation on the thermal structure of evolving lithosphere, magma upwelling beneath the central Indian ridge, viscous effects in GPS geodetic observations, time dependent flow in a plume conduit, origin of hot springs in the west coast belt of India, mass excess in lesser Himalayas due to fluid circulation, sublithospheric deformation beneath the western continental margin of India, prediction of possible subsidence of Bassein field, power law random behaviour and seasonability bias of northeast earthquakes, seismicity and fractal dimension of fault network in Koyna region, role of pore pressure in inducing earthquakes associated with the Koyna and Warna reservoirs, modelling of groundwater flow dynamics, downward movement of moisture in shallow soil zone, and groundwater flow velocity measurements were presented and discussed. Besides these, an invited lecture was delivered on non-Newtonian flows in geosciences.

The following recommendations were made at the plenary session:

- Studies on the evolution of Indian Shield since Cambrian, regional groundwater flow due to tectonic evolution and lineament patterns should be carried out in close cooperation between geophysicists and geologists.
- Arrangements should be made for continuous monitoring of water table fluctuations, specially in problematic areas to device suitable measures for protecting the regional water balance and preventing environmental problems such as contamination of groundwater, water logging, depletion of aquifer, land subsidence, etc.
- Experimental and modelling works should be carried out to understand the complex problems of fluid dynamics such as dynamics of liquid core, mantle convection, hydrothermal circulation in oceanic environment and continental regions, etc.
- Studies on coupled interaction among atmospheric, ocean and solid earth systems should be taken up for better understanding of the dynamic behaviour of earth system.

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Earthquake recurrence: State-of-the-art and directions for future*

Palaeoseismology[1] is a multidisciplinary science of reconstructing the seismic history of an area using the geological evidences of palaeoearthquakes as a tool and dating them. The field of palaeoseismology has expanded vastly in the last two decades and has recorded several cycles of earthquake recurrence related to many important seismogenic faults. In order to assess the current status of the subject, an international workshop was held. From all over the world, 20 participants actively working on different aspects of palaeoseismicity were invited to present both the state-of-the-art on palaeoseismological studies in their respective countries, and the compilation of data set for their country. The workshop was attended by well-known palaeoseismologists like James McCalpin, David P. Schwartz (USGS); Kozi Okumura, Hiroshima University, Japan; Mark W. Stirling, New Zealand; W. L. Ellsworth (USGS) and John Haines, University of Cambridge.

The principal aims of the workshop were:

(i) to develop the outline of a proposed worldwide palaeoseismic database, including quantification of intrinsic uncertainties of existing data;

(ii) to make a project plan for the development and maintenance of the worldwide palaeoseismic database;

(iii) to determine the availability of scientists from the palaeoseismology/seismology community to gather data and/or in the field or country/part of world to assist the project; and

(iv) to investigate the availability of funding for data collection and interpretation including scientific collaboration.

Daniela Pantosti discussed the state-of-the-art in palaeoseismological data collection and the use of the data in earthquake recurrence modelling. Palaeoseismological data from different countries like USA, New Zealand, Japan and the Mediterranean, low to moderate seismicity areas of Europe, China, S–E Asia, Turkey and India were presented. Japan, New Zealand and USA have excellent palaeoseismology data sets. Attempts were made to discuss the importance of quantification of the intrinsic uncertainties of the existing data, absence of which may lead to misinterpretation of true seismic hazard of the area of interest. A qualitative method of describing uncertainties related to interpretation of palaeoseismological data was proposed. According to Kozi Okumura, 163 trenches on 122 active faults were made in Japan and only 10% of them brought timing of three or more

*Workshop convened by Daniela Pantosti of Istituto Nazionale di Geofisica, Rome, Italy, under the aegis of International Lithosphere Project (ILTP)-II-5, held at Rome, Italy during 22–26 February 1999.

events. This shows the great interest in palaeoseismology in Japan with very large funding for prehistoric earthquake reconstruction studies through trenches. Schwartz described the agreement of characteristic model[2] earthquake obtained from 240 slip events that occurred in 77 sites on 70 faults. The data showed that high slip rate faults have less variability coefficient of variance (Cov = 0.31) and small slip rate faults higher for the slips conforming to the characteristic model. On the other hand, the palaeoseismological data from Japan and China show that the large earthquakes do not necessarily occur periodically. In fact, the Chinese palaeoseismological data[3] show clustering. The Japanese data show that tectonic stress is distributed and released in the complicated network of faults. Stirling *et al.*[4] demonstrated the probabilistic seismic hazard maps of New Zealand based on the distribution and long-term recurrence behaviour of active faults and the spatial distribution of earthquakes observed in historic time.

B. S. Sukhija discussed the approaches, potentials, and problems regarding palaeoseismic data in India[5]. A few institutions where palaeoseismological work has been initiated in India are National Geophysical Research Institute, Hyderabad; Wadia Institute of Himalayan Geology, Dehradun; Centre for Earth Science Studies, Tiruvananthapuram; Department of Geology, Baroda University; Department of Earth Sciences, Roorkee University, Roorkee.

Study by Mohindra and Bagati[6] on soft sediment deformation structures in the Spiti Valley, Himalaya, revealed reactivation of Kaurik–Chango fault at least nine times during Late Pliestocene–Holocene including the 1975 Kinnaur earthquake. Mohindra and Thakur[7] studied synsedimentary deposition, plume-like intrusion, and flame structure in Doon Valley and assigned an age of $100 < x < 400$ yr to these features based on soil development over them. Sukhija *et al.*[8,9] have extensively evaluated the palaeoseismicity of the Shillong Plateau, the site of one of the four great earthquakes. They provided palaeoliquefaction evidence and periodicity and timing of the large/major earthquakes in the Plateau using radiocarbon dating. Their study revealed four palaeoseismic events which occurred during 1450–1650 AD, 700–1050 AD, predating 600 AD besides the well-known 1897 event. Their study suggested a 400–600 yr recurrence period for great earthquakes as that of the 1897 earthquake in Shillong Plateau. Rajendran *et al.*[10,11] identified the existence of prehistoric seismicity in the Deccan Shield. Sohoni and Malik[12] inferred tectonic mechanism to be responsible for genesis of seismic events ($M > 5$) in the Kachchh region. For dating of palaeoseismic events, Singhvi *et al.*[13] and Banerjee *et al.*[14] are actively using thermoluminescence technique.

Palaeoseismology parameters were also discussed during the workshop. Implications in the seismic hazard assessment and relation between total trench area and the entire fault area were discussed by Atakan (Belgium) in assessing whether the trench provides the representative behaviour of the fault.

McCalpin discussed the assessment of sample context errors in dating palaeoearthquakes. Ambiguity in the identification of event horizons, i.e. the unconformities that separate pre- and post-earthquake sedimentation is very important.

Xu and Deng[3] (China) discussed the major factors (viz. geometry of faults and crustal movement style) affecting the palaeoseismic recurrence pattern on active faults. Ellsworth proposed a physically-based earthquake recurrence model for estimation of long-term earthquake probabilities.

A detailed discussion was held about the database of the palaeoseismological data, the format of presentation of data, individual involvements, responsibilities, etc.

Interactions and discussion with various participants in the workshop revealed that palaeoseismology is an actively growing area, and palaeoseismological studies need to be intensified in India. While extensive trenching and future paleoseismic projects are being planned elsewhere we have yet very little palaeoseismic information on the Indian sub-continent. In future a concerted effort will be needed to carry out extensive trenching, evaluation of palaeoseismological data with their uncertainties, and ultimately use these data in hazard evaluation. In India such studies also suffer from lack of important dating facilities like that of AMS and sufficient funding for trenching, etc. The Department of Science and Technology is the only major agency for funding such investigations; other funding agencies are requested to follow suit.

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