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Stable Continental Regions Are More Vulnerable to Earthquakes than Once Thought

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Seismic events at shield areas throughout the world suggest that the stable continental regions (SCR) are much more vulnerable to earthquakes than was once thought. Earthquakes have struck SCRs at a number of locations, including the New Madrid Zone, United States; Tennant Creek, Australia; Ungava, Canada; and Kachchh, Koyna, Latur, and Jabalpur, India. In several developing countries, such as India, the problems caused by SCR earthquakes have become very serious because of high population density and the proliferation of structures not built to withstand earthquake damage.

A recent Chapman Conference on SCR earthquakes attracted 90 researchers from 12 countries. Eighty papers were presented. Globally, the stable continental region earthquakes account for about 0.5% of total seismic energy released. The largest SCR earthquakes occurred in the New Madrid Zone from 1811 to 1812, when three earthquakes of Mw 7.8-8.1 occurred within just 53 days. The fourth largest SCR earthquake ever registered of Mw 7.9 occurred in Kachchh, India, in 1819. This event caused a huge land scarp running some 100km in length and up to 6 m in height. In recent years, significant SCR earthquakes have occurred at Tennant Creek (1988), Ungava (1989), and Latur (1993). The Latur earthquake is now known to be the deadliest SCR earthquake ever.

The conference addressed several aspects of SCR earthquakes, such as seismicity and seismotectonics of different shield regions, structure and mechanics, stress and source parameters, repeatability etc. The 3-day-long presentation of papers and discussions were followed by field visits to the sites of destruction of the Latur earthquake, which struck 200 km from Hyderabad, and the site of a reservoir-induced earthquake at Koyna, which lies about 500 km west of Hyderabad. In addition to the scientific program, the delegates enthusiastically participated in India's Republic Day celebrations on January 26, 1998, enjoyed a cultural program featuring sitar and dance recitals, and dined on Hyderabad cuisine.

The New Madrid earthquake sequence of 1811-1812 provides unique historical earthquake record where three earthquakes of moment magnitude of Mw 7.8-8.1, at least three additional earthquakes of Mw 7, 18 events of Mw 6, and more than 200 events of Mw 5 occurred.

The total seismic moment release was equivalent to one Mw 8.3 ± 0.3 earthquake. Arch Johnston pointed out that the sequence provides possibly the only example world wide of co-seismic surface rupture of great thrust earthquakes that actually crossed and disrupted a great continental drainage river. Walter Mooney and Ge mma Musacchio found, from multi-parameter geophysical investigations in New Madrid fault zone, that there is no significant difference in the upper crust there than at other stable continental regions. However, the seismicity in the New Madrid seismic zone indicates either decoupling between the upper crust and middle /lower crust or weak middle/lower crust.

Roger Bilham has analyzed the historical data of the Kachchh earthquake of 1819 and assuming that the observed surface morphology was entirely formed by coseismic deformation in a single earthquake, a reverse fault slip of 10-13m is required. He also opined that one large event may have occurred previously in the region of Kachchh, although its location is unknown.

C.P.Rajendran and Kusala Rajendran presented interesting observations made during detailed field investigations of 'Allah Bund' in the Kachchh region. They found that the Kachchh earthquake produced one of the largest scarp – which runs 100 km in length and 2 – 6 m in height – and they surmise that large earthquakes in Kachchh are likely to reoccur within the order of < 4,000 years with a probable slip rate of 1.5 mm / year.

Several interesting papers presented reported results of studies of the Latur earthquake of 1993. Harsh Gupta, K.K.Dwivedy, and others presented the results of drilling conducted in the Latur earthquake fault zone to investigate subsurface structure, various layers of lava flows, depth of the basement, and nature of the fault zone. Four boreholes were drilled in the coseismic rupture zone. A comparative study of the corresponding lava flow contacts in the subsurface indicated movement of 3 to 6 m in thrust mode along the fault plane. The observed displacement of 3 m to 6 m is far too much to be accounted for by a single Mw 6.1 earthquake. They concluded that the fault associated with the Latur earthquake is a pre-existing one and has been involved with movements associated with previous earthquakes.

B.S.Sukhija and other provided geological evidence of a paleoseismic event that occurred 2200 ± 200yr B.P. close to the meizoseismal area of the 1993 Latur earthquake. Sukanta Roy and R.U.M. Rao reported results of heatflow measurements in a number of boreholes near the location of the Latur earthquake. A general low level of heatflow appears to be a characteristic feature of this area as well as other areas of the Deccan Volcanic Province (DVP). They found a consistent heatflow value of 43 mW/m2 . Most of the DVP might simply be a reflection of lower levels of heat production of the underlying crustal column.

Harsh Gupta pointed out that several artificial water reservoir-induced earthquake sequences have occurred in SCRs throughout the world. Koyna is a unique site of induced earthquakes; earthquakes there began soon after the Shivaji Sagar Lake was filled in 1962 and have continued until now. On December 10, 1967, the site experienced the largest reservoirinduced earthquake has experienced 10 earthquakes of M=5, over 100 earthquakes of M=4, and several hundred thousand smaller events. Detailed investigations reported by Prantik Mandal, B.K.Rastogi, and C.S.P.Sarma indicate that in recent years earthquakes in this region have been clustered in two north-northeast-south-southwest-trending blocks. Prantik Mandal reported that for some M=4 events nucleation starts at shallow depths and gradually deepens along the preexisting faults to cause the mainshock near the base of the seismogenic layer at about 8-12 km depth.

R.K.Chadha and H.J.Kumpel reported a very interesting experiment now being conducted in the Koyna region, where in-situ pore pressure is being measured in 13 confined wells drilled to depths of 130 to 250 m and equipped with digital toring of well level changes.

The well data are corrected for atmospheric pressure fluctuations and precipitation. The wells are sensitive to tidal fluctuations and have shown coseismic changes associated with earthquakes of M=4 in the immediate vicinity.

Paul Bodin and Arch Johnston have assembled observations of source parameters of SCR earthquakes, including ruptures with differing focal mechanisms. A special subclass of SCR earthquakes produce surface ruptures. Such events are rate and nearly always include thrust faulting. Soren Gregersen has investigated intraplate earthquakes in Scandinavia and Greenland and inferred the occurrence of large earthquakes about 10,000years ago. S.A.Kerkela addressed crustal structure, heat flow, and intraplate deformation in SCRs. She reported that observed seismic strain rates in Phanerozoic SCRs in eastern North America and western Europe are accurately predicted from cumulative lithospheric in such regions is in a steady-state failure equilibrium. I.M. Artemieva has investigated the thermal state of the Precambrian lithosphere and has prepared maps at depths of 50 km, 100 km, 150 km and 200 km for Europe, Siberia, India, and Australia. She reported that the lithosphere is much warmer in Europe and is expected to be very thick. Christopher Hartnady debated whether South East African SCR is in transition.

He inferred a recurrence interval of 500 years for M7 events in Senqu Belt and surrounding regions.

A few interesting papers discussed the May 21, 1997, Jabalpur earthquake of Mw 5.8 in central India. The earthquakes occurred at a focal depth of 38 km, which was much deeper than the other earthquake that occurred in the peninsular regions. Several explanations were offered. Prantik Mandal modeled stresses induced by topography and crustal density inhomogeneities and commented that these stresses are controlling factors in seismogenesis of stable continental regions of India. Vinod Gaur drew attention to the importance of global positioning system measurements in constraining fault rupture parameters. According to him, seismicity in the Indian continent and in the regions far to the north is due to N 44° E movement of the Indian plate at a rate of 58 ± 4 mm/yr.

The conference concluded with a panel discussion that stressed the need for global positioning system and geodetic measurements at suitable locations for the identification of plate movements and inturn stress where strain is accumulating. Fluids play a very important role in triggering earthquakes in many locations. RIS is a special category of SCR earthquakes. Koyna, India is an ideal site for carrying out all possible work to understand the physics of reservoirinduced earthquakes.

Whether the term "stable continental region" should be changed to some other name was discussed for some time. Participants concluded that the term should remain as originally defined.

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