NOTES

THE CHAMOLI EARTHQUAKE OF MARCH 29, 1999

The M6.8 Chamoli earthquake of March 29, 1999 (local time 0:35 hrs, UTC: 19:05 hrs of 28th March, 1999) is the latest addition to the earthquakes that have been occurring in the region around Chamoli (between 78°-83°E and 29°-33°N). According to records, before the Chamoli earthquake, eight earthquakes of mb≥6.0 occurred in this region during the past 35 years. The locations of these earthquakes are shown by '✤' in Fig.1; the number next to the '✤' sign refers to the serial number of the event listed in Table 1. The Table gives UTC times, body wave magnitudes (mb), surface wave magnitude (Ms) and depths of these earthquakes. Every occurrence of a destructive earthquake compels us, at least, to once again address the question of earthquake prediction.

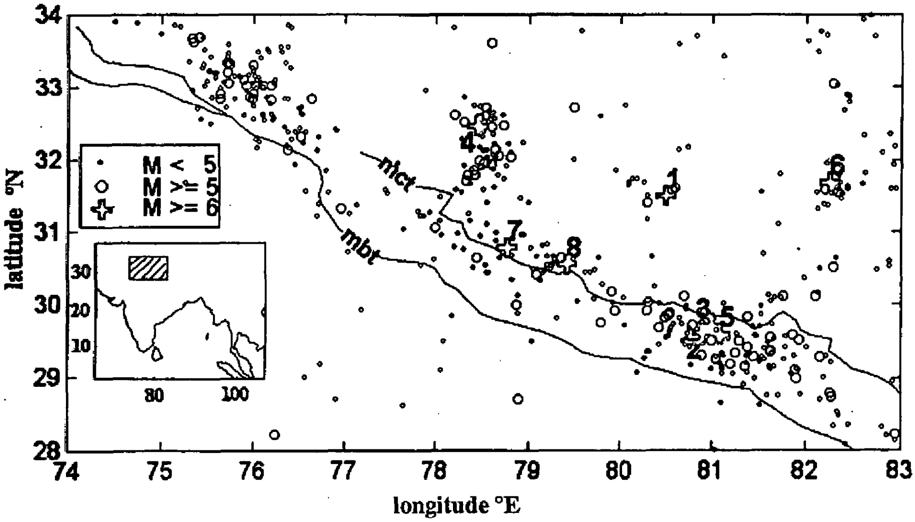

Fig.1. Earthquakes in the region around the Chamoli earthquake.

Earthquake Prediction

The question of whether earthquake prediction is possible requires that first we specify what kind of prediction we are talking about. The latest debate on earthquake prediction has been concluded recently (8th April 1999 in Nature-online; available on the web at http://helix.nature.com/debates/earthquakes). The debate started on 25th February 1999 in Nature-online with Ian Martin as the moderator. A sliding scale of earthquake 'prediction' was defined as (1) time-independent hazard, (2) dependent hazard, (3) earthquake forecasting and (4) deterministic prediction. All of the contributors to this debate who expressed an opinion agreed that the deterministic prediction of an individual earthquake, within sufficiently narrow limits to allow a planned evacuation program, is an unrealistic goal. Indeed, even the first three kinds have not been unequivocally agreed upon as possible. Studies of prediction have been based on the concepts of the seismic gap hypothesis, precursors and self-organised criticality. The question posed was (Ian Martin, 25th February 1999 in Nature-online), "So if we cannot predict individual earthquakes reliably and accurately with current knowledge, how far should we go investigating the degree of predictability that might exist?"

Table 1. List of earthquakes of mb≥6.0 in region around Chamoli area

S.No.	Year	Month	Day	Hour	Minute	mb	Ms	depth (km)	
1	1966	3	6	2	15	6.0		50	
2	1966	6	27	10	41	6.0		33	
3	1966	6	27	10	59	6.0		13	
4	1975	1	19	8	2	6.2	6.8	33	Kinnaur earthquake
5	1980	7	29	14	58	6.1	6.5	18	
6	1982	1	23	17	37	6.0	6.5	33	
7	1991	10	19	21	23	6.5	7.0	10	Uttarkashi earthquake
8	1999	3	28	19	5	6.6	6.8	30	Chamoli earthquake

The conclusion to this debate was (Ian Martin, 8th April 1999 in Nature-online) "We remain a long way from proving that any earthquake prediction scheme can succeed better than predictions based on the statistics of earthquake clustering, but this debate has highlighted in the clearest terms possible that when scientists speak of 'earthquake prediction', they do not imply the type of accurate short-term prediction that might allow public evacuations before an individual event. Instead the predictions implied come under the general category of probabilistic forecasts for a population of earthquakes. Such forecasts may instead serve as a motivation for aseismic design, and maintained vigilance by the general public and civil defence agencies.

In the end it is not earthquakes themselves which kill people, it is the collapse of manmade structures which does most of the damage. While we continue to explore the degree of predictability of earthquakes on rigorous observational, statistical and theoretical grounds, we should therefore not lose sight of the fact that the best way of preparing for the inevitable remains in the development of land use plans, and building and infrastructure design codes to mitigate their worst effects".

The Tehri Dam and Reservoir Induced Earthquakes

Reservoir induced earthquakes are known to have occurred at over 100 sites globally after impounding the reservoir. At the four sites, namely at Kariba (Zambia-Zimbabwe Border), Kremasta (Greece), Hsinfengkiang (China) and Koyna (India), earthquakes in the magnitude range of 6 to 6.3 have occurred. At most other sites induced earthquakes did not exceed magnitude 5, the largest earthquake occurred at Koyna on December 11, 1967 and it was of M6.3. It is therefore a reasonable assumption that reservoir induced earthquakes will not exceed M7.

In the context of the Tehri Dam, normal (not induced) earthquakes of up to M8 (for example, the Kangra earthquake of 1905), have occurred in its vicinity. Therefore, the dam has to be designed to withstand possible M8 earthquakes in the future. This automatically takes care of induced earthquakes. Moreover, it is well established that reservoir induced earthquakes occur in normal fault and strike-slip fault environments. Thrust fault environment is not conducive for reservoir induced earthquakes to occur, which is mostly prevalent in the Himalayan mountain ranges (Gupta and Rajendran, 1986).

Vulnerability of Tehri Dam to Earthquakes

The debate, on whether Tehri Dam's design is capable of withstanding accelerations generated by an M8 earthquake in its vicinity, has been going on between engineers and seismologists for a long time. It is important to note that while it is possible to make a structure capable of withstanding high acceleration, one has to bother about environment. The slopes on the hills in most Himalayan regions are very fragile. During the 1991 Uttarkashi earthquake there were huge landslides which put in a lot of debris in the reservoir, thereby reducing the life span of the reservoir and therefore its economic viability. This factor needs to be kept in mind and the option of a number of small dams should be examined.

References

GUPTA, H.K. and RAJENDRAN, K. (1986). Large artificial water reservoirs in the vicinity of the Himalayan foothills and reservoir induced seismicity. Bull. Seismol. Soc. Amer., v.76(1), pp.205-215.

IAN MARTIN (1999). Debate on earthquake prediction: available in Nature-online at http://helix.nature.com/debates/ earthquake.

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2nd SYMPOSIUM ON GONDWANA COALS, DEPARTMENT de GEOLOGIA FACULDADE de CIENCIAS, UNIVERSIDADE DO PORTO. PAPER AND POSTER ABSTRACTS, PORTO (PORTUGAL), 19th SEPTEMBER, 1998. 43p.

During this Symposium a total of 20 papers were presented by different authors. Conclusions of some important papers are succinctly stated below for the benefit of the readers.

A modern integrated assessment of coal for trade and utilisation purposes, by G.J. Broodryk. In South Africa, electricity generation and metallurgical markets are the main areas of coal utilisation. Eight database questions are put forth, as a result of which the quality of specific coal product can be properly evaluated. Five different criteria were used to develop the database. This will bring a new approach to coal assessment, and coal quality for power station performance and environmental pollution.

Rank variation in the Permian of Australia, by A.C. Cook. Based on vitrinite reflectance, rank of the Permian coals of the Sydney-Gunnedah-Bowen basins, near the eastern seaboard; Galilee, Cooper and Pedirka Basins, to their west; and of Perth basin is presented and discussed. In the first basin, most of the coals exceed 1.2% vitrinite reflectance, while in others it is reached at deeper levels. In the second basin, vitrinite reflectance is very low (0.3-0.35%). Lateral rank variation in the Cooper basin is significant form 0.45% to 1.3% reaching 0.2% per km, the unusual high rank being due to regional coalification rather than contact alteration. Many of the Permian basins have high rank coals. Peak rates of coalification seem to have occurred in Jurassic and early Cretaceous, relevant to timing of oil and gas generation within the coal seam sequences.

Testing of national coal-related standards – The Australian perspective and experience, by A.M. Depers. The major differences between ISO standards and ICCP scheme for maceral content standard are compared. Annual round robin exercises to test National standards are considered essential towards commercial application of coal petrography.

Total moisture versus moisture holding capacity as a measure of bed moisture: Implications in coal classification, by D.Flores, C. Garcia, R. Juan, M.J. Lemos de Sousa, M. Marques, H.J. Pinheiro, C. Rodrigues and M.C. Ruiz. Basin results best obtained from ASTM D1412 standard procedure, coals from Spain were classified in the International Classification of In-