

The Uttarkashi earthquake of 20 October: implications and lessons

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Not all the accumulated stress was relaxed by the recent earthquake, and it is prudent to prepare for coping with the hazards of a future earthquake of much higher magnitude.

The 20 October 1991 earthquake of magnitude (M) 6.1 (on the Richter scale) in the Uttarkashi–Tehri region in Garhwal has once again brought home the perils of living in areas of active faults and of the significance of advance signals given by microseismicity ($M \leq 3$). The earthquake—which violently shook a large part of north-central India and

killed over a thousand people, wrecked more than 28,000 homes and damaged another 20,650 houses—originated as a result of slipping on segments of faults in the active zone of the Main Central Thrust (MCT). Inclined $15\text{--}20^\circ$ and $30\text{--}45^\circ$ northwards, the MCT zone defines the tectonic boundary of the populated Lesser Himalayan terrain against the

snowy domain of the mighty Himadri (Great Himalaya) (Figures 1 and 2). The MCT zone is made up of a succession of severely sheared and considerably crushed rocks, split up by a large number of thrust planes into many tectonic slabs^{1,2}.

Repeated movements on active faults have not only weakened the rocks

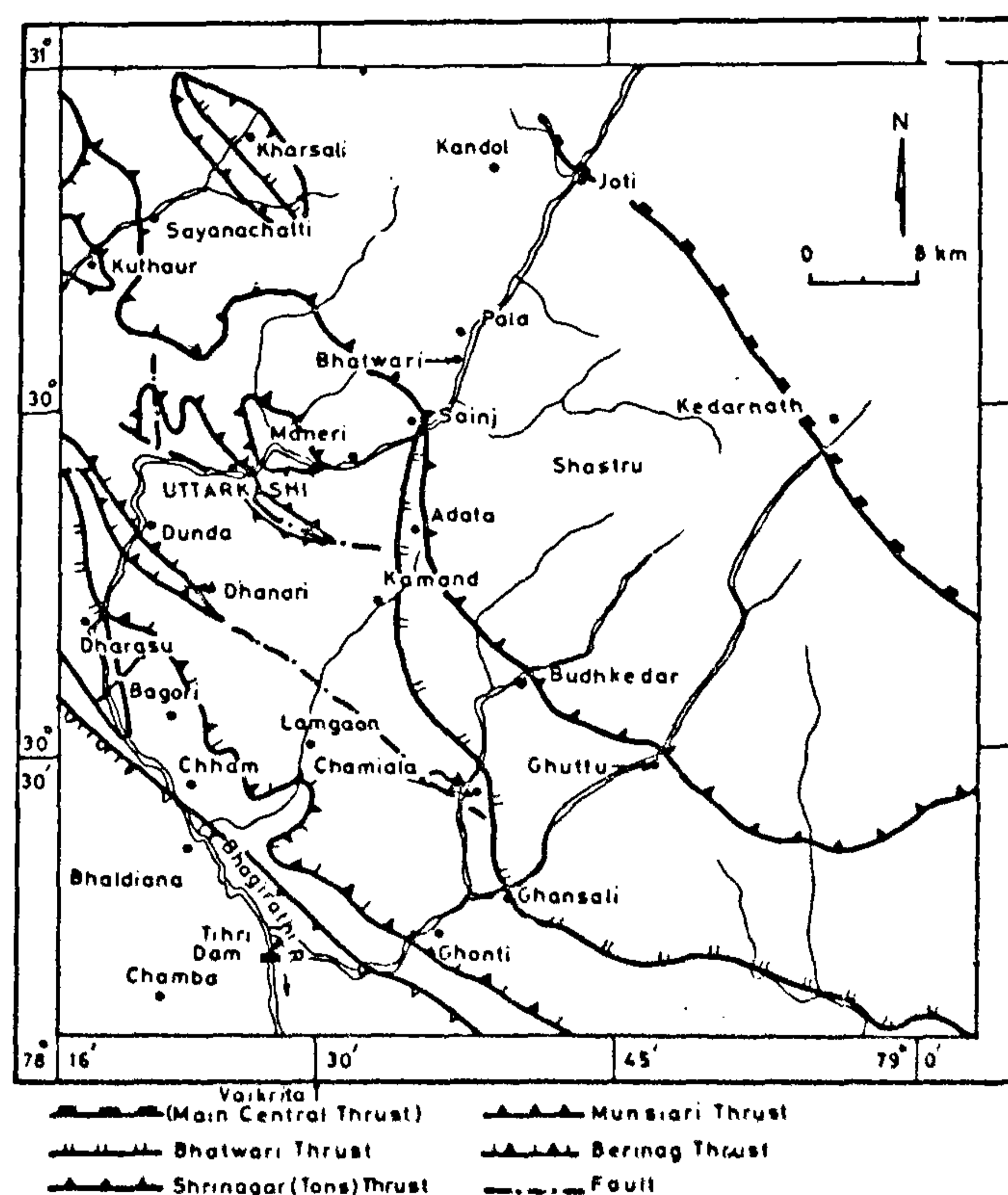
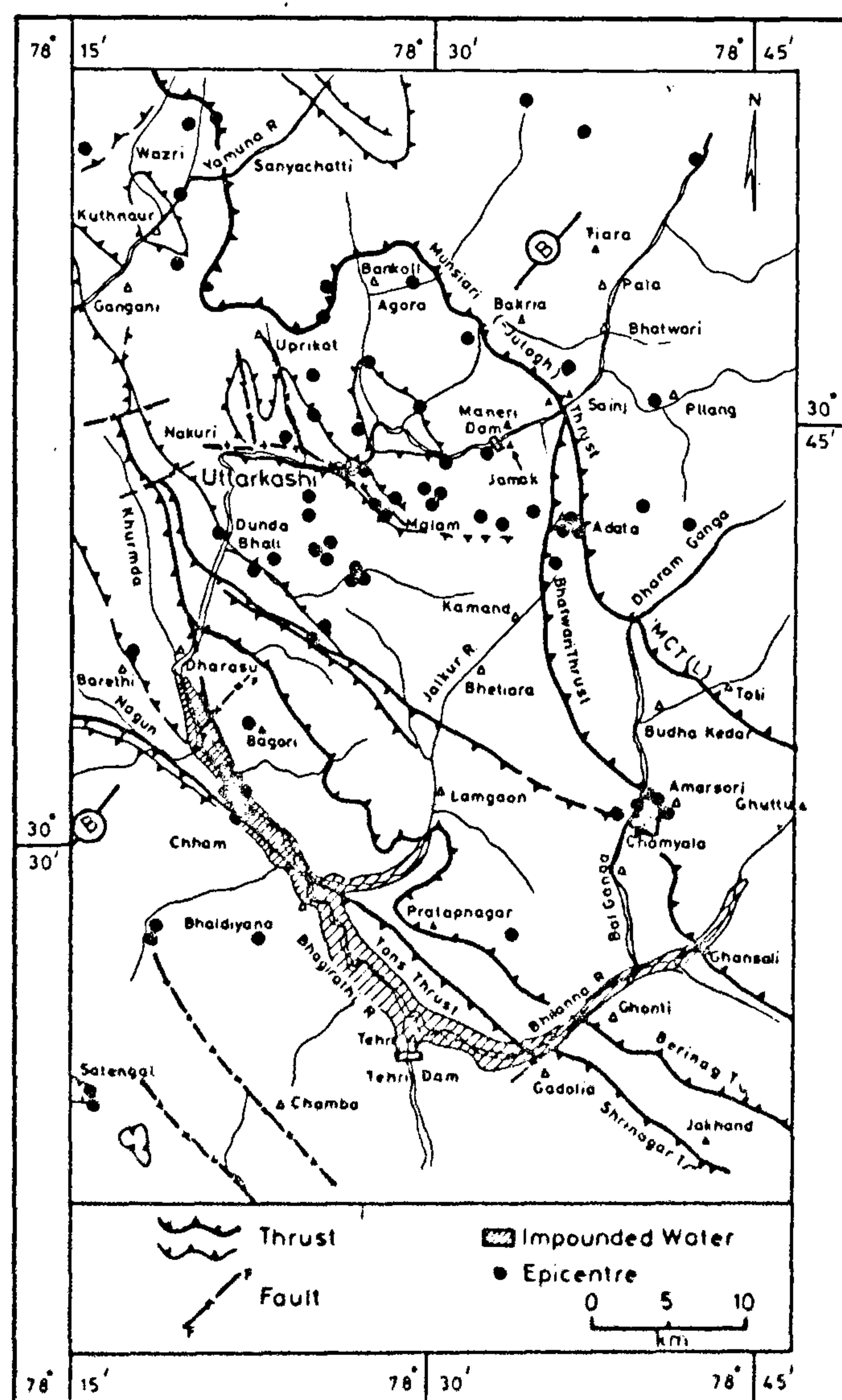


Figure 2. Simplified tectonic map of the northern part of the Garhwal Himalaya. (After Valdiya, ref. 6).

Figure 1. The Uttarkashi region, ridden with faults and thrusts, exhibits persistent microseismicity, ($M \leq 3$), indicating internal tectonic tumult. (After Valdiya, ref. 4).

considerably, but are also responsible for progressive increase in height of the Himadri (0.7 to 1.1 mm per yr). The continuing tectonic tumult is manifest in periodic shaking, trembling and twitching of the fault-ridden terrain, as evident from high microseismicity ($M \leq 3$) noticed^{3,4} in the Uttarkashi region (Figure 1). This is entirely to be expected, for the region is much dissected⁵⁻⁷ by E-W, ESE-WNW, NNW-SSE and NW-SE-trending faults and thrusts (Figures 1 and 2). Many of these are active and have registered vertical and horizontal movements in geologically recent times^{2,7,8}. Presumably there was sudden slipping on one or more of these active faults on 20 October at a depth of about 15 km, immediately beneath the MCT zone boundary (Figure 2), and the rocks of other fault zones in the proximity snapped, generating violent shock waves.

Belts of destruction

The belts of maximum damage are clearly identifiable with the faults and boundary thrusts (Figures 1 and 2). Between the northern and southern boundaries of the MCT zone in the Himadri domain and within the Bhatwari Thrust sheet, the surface waves travelled in a roughly N-S direction, implying overthrusting of the Himadri or underthrusting of the Lesser Himalaya beneath the Himadri pile. The passage of these N-S surface waves caused extensive slumping of the fan-shaped colluvial deposits resting on steep slopes. These fans consist of loose aggregates of debris deposited by mountain torrents and shattering damages (Figure 3), such as those seen on the slopes of the Kaldi Gad (e.g. Bankoli, Agora), Bhagirathi River (e.g. Gorsali, Saur, Bhatwari, Pala-Morara, Rainthal, Tiara), Bhilangana Valley (e.g. Gangi), Mandakini Valley (e.g. Gaurikund), and Helaun Gad (e.g. Gorti, Bajra).

The belt of most severe damage and destruction is related to the Munsiri Thrust defining the lower boundary of the MCT zone (Figure 2). It extends southeast from Bankoli-Agora through Sainj, Lata, Saur in the Bhagirathi Valley, the Belak Khal-Adata saddle (3400-3424 m), the Koti-Budhakedar-Thatikathur group of villages in the Balganga Valley, the Ghuttu group of settlements in the Bhilangana Valley to



Figure 3. Collapse of or damage to buildings constructed on fan-shaped deposits of ancient landslides and mountain torrents. Slumping of the loose aggregate of debris caused the havoc.



Figure 4. Differential settling of soft, unconsolidated sediments of riverine terraces was responsible for house destruction and damage

Triyuginarayan in the Mandakini Valley. Violent shaking due to slipping of active segments of faults caused deep ground ruptures and rockfalls, as witnessed in the Agora ($30^{\circ}51'N$, $78^{\circ}29'E$) and Belak Khal ($30^{\circ}41'N$, $78^{\circ}36'E$) segments. Similar phenomena, though of lesser severity, are seen in the Nailchami-Helaun valleys that follow the Bhatwari Thrust.

Immediately to the south, the second belt, of equally severe destruction, is related to the Uttarkashi Fault (Figures 1 and 2) traceable from NW of Nakuri, through Uttarkashi eastward to the Adata peak, where it seems to branch off from the Munsiri Thrust. It is linked with the NNW-SSE-trending, very active tear faults of the Rano and Shyalam streams. The fluvial terraces lining the Bhagirathi Valley at Nakuri, Uttarkashi, Gangori, Gawana, Netala, Maneri, Jamak, Dedsari, Lunthru, Bina—among many others—were subjected to rapid heaving by the E-W passage of strong surface waves. The differential settling of the soft, unconsolidated fluvial sediments is responsible for the collapse and cracking of structures (Figure 4). The E-W travel direction of the surface waves is significant, for this fact tends to show that there was a very strong component of strike-slip movements of the Uttarkashi Fault, and, as a matter of

fact, on all Lesser Himalayan faults branching off from the MCT boundary.

The third belt of damage follows the Dunda Fault traceable through Dunda, Thati Dhanari, north of Lamgaon (Jalkur Valley) to Silyara in the Balganga Valley. There it seems to join up with the Bhatwari Thrust. Widespread and intense damage is seen along the Bhatwari Thrust—as witnessed at Pokhar, Thayeli, Semaltha (in Bhilangana Valley), Chaunra, Thela, Tharti (in Nailchami Valley), and Budhna, Palakurali, Uchhana, Gorti, Bajra (within Helaun Valley).

The fourth belt, of moderate damage, follows the Berinag Thrust (Figure 2) traceable from Gamri, through Pratapnagar to near Ghonti in the Bhilangana Valley. The zone of Shrinagar (Tons) Thrust has registered but very mild damages, as witnessed at Dharasu, Chinyalisaur, Bhalidiana, Tehri and Gadolia.

It is obvious that the severity of the seismic shocks progressively diminished southwards from the MCT zone. Although there is perceptible change in the spring discharges, and mountain tops have crumbled in the severely rocked segments that slipped, the disastrous impacts of the changes in circulation of ground water and mass movements on ruptured slopes will be evident only after the rains.

Cause of high mortality

The high human mortality is attributed to the people getting trapped inside the collapsing houses as a result of the doors getting stuck or jammed owing to distortion of their frames. This distortion occurred owing to heaving and swaying of those buildings that were oriented in the travel directions of the ground waves—N-S in the MCT zone of the Himadri and the Bhatwari sheet and E-W in the Lesser Himalayan terrain.

Lessons

1. The hazard-prone zone, cut by active faults and consistently giving warning signals in the form of microseismicity, should be brought under a standing programme of hazard mitigation⁴. It is not only the Uttarkashi region in Garhwal that needs to be bestowed such attention, but also the Dharchula-Kapkot region in northeastern Kumaun (Figure 5), which is another candidate for a future earthquake of greater magnitude. This region has been extensively ravaged by recurrent mass movements and is registering the highest seismicity (going by the number of earthquakes of $M \geq 5$) anywhere in the Himalaya^{1,2,7,8}.

2. In these identified hazard zones, future buildings and structures on soft, unconsolidated or loose aggregates of sediments/debris of the riverine terraces and colluvial fans on mountain slopes should invariably have reinforced masonry or concrete foundations or pillars or both, the walls should be braced mutually or with the pillars, and the roof and floor securely tied to the walls. Furthermore, irrespective of design and orientation, houses should have at least two exits, on walls at right angles to each other. This will ensure easy exit in the event of one of the doors getting stuck or jammed owing to distortion of its frame.

3. Since the Aravali Ridge of the northward-drifting Indian subcontinent

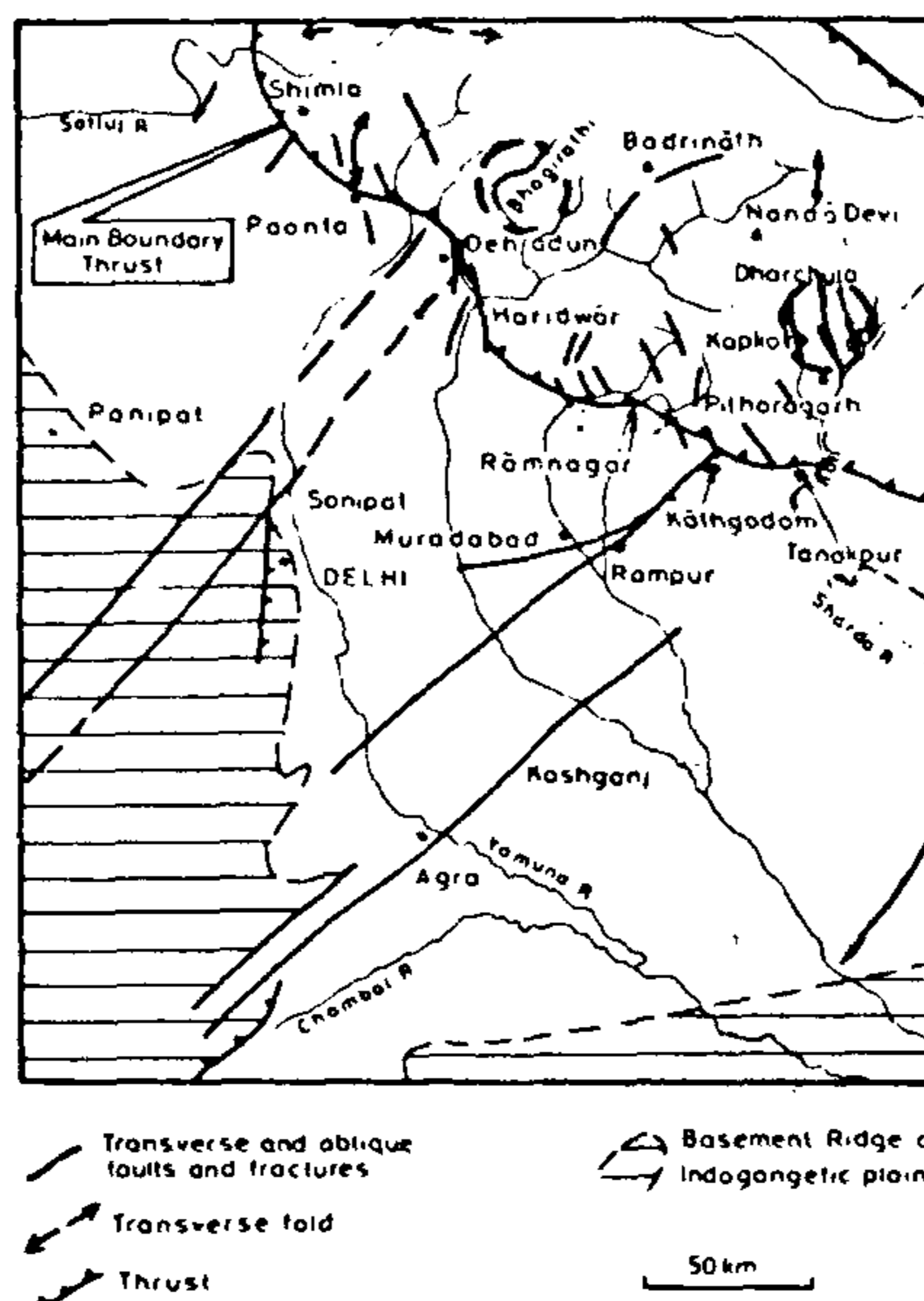


Figure 5. The fault-lined Aravali Ridge is prodding the Himalaya like a battering ram. The Uttarkashi area happens to be in the line of this ridge. Likewise in the line of the hidden Muradabad Fault of the Ganga Basin lies the Kapkot-Dharchula-Bajang region in northeastern Kumaun, which is frequently and severely rocked by earthquakes and ravaged by mass movements. (After Valdiya, ref. 7).

is persistently pressing the Himalaya^{2,7,8} like a colossal battering ram (Figure 5), considerable stresses are accumulating in the body frame of the orogen in front of the promontory. The last major earthquake (M 7.5) in the region occurred 164 years ago in 1828, and not all the accumulated stress was released by the 20 October earthquake of M 6.1. It is clear that a significant amount of the residual stress is waiting to be released by a future earthquake, whose magnitude must be M 8 or higher⁹. The severity would be much greater, and the extent of destruction and damage would stretch far beyond the Shrinagar Thrust.

The Shrinagar Thrust is doubtless an active fault that has registered pulses of uplift in geologically recent past. This is borne out eloquently by a number of geomorphological features in the stretch of the Bhagirathi River south of the Shrinagar Thrust within the Krol Belt—six levels of fluvial terraces com-

pared to the normal three, incised meandering, and canyon course of the otherwise old and mature river, extremely steep gradient of the north-flowing streams tumbling down into the Bhagirathi, huge fans of debris avalanches triggered presumably by earthquakes related to the uplift of the southern massif, and high microseismicity near Chham.

The controversial 260.5-m-high Tehri Dam will come up on a location about 4 km south of the active Shrinagar Thrust, cutting through a region that is likely to be rocked by a future earthquake of magnitude 8 or higher^{9,10}.

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