The catastrophic landslide of 16 July 2001 in Phata Byung area, Rudraprayag District, Garhwal Himalaya, India

On the fatal morning of 16 July 2001 (00.45 to 3.00 a.m.) heavy precipitation killed 27 persons and left several others homeless. The cloudburst caused more than 200 landslides and disturbed the entire communication and transport network, and completely damaged the water supply system of the area, which paralysed the life of this region. Memories of the 1998 tragedy in Okhimath, very close to this area, that took the lives of 103 persons[1] are still fresh, although this time the tragedy occurred only in a part of Mandakini Valley. Cloudburst occurs in areas where the mountains are high. As the floating clouds cannot find a passage, after sometime a thick layer of clouds accumulates and one day it bursts, creating such landslides. Heavy precipitation affected the slopes of Byung (Figure 1) and Gabni sub-watersheds of Mandakini Valley, resulting in massive debris avalanches and other forms of slope failure, evidenced by a large number of deep and shallow scars on the slopes on both sides of the valley.

The landslides and rockfalls that wiped out fifteen villages of this area, in the inner belt of Central Himalaya are not uncommon phenomena[2]. They occurred in the hazardous zone with active faults, and were of predicted severity and proportion[3]. A detailed survey of the area has revealed that 52.67 km^2 of the area received very heavy precipitation. The losses assessed by us and local government agencies are: 27 human lives, 64 heads of cattle, 22 houses and 43 ha of agricultural land. In all, 15 villages and 3924 people were affected. The road along the Kedarnath–Guptkashi segment suffered maximum damage and the major disaster was at Phata Market and along the Byung stream (Table 1).

The area falls under the Central Himalayan Zone[4], consisting of low to medium grade crystallines with intrusive of acidic and basic rocks (Figure 1). The rock types of this area are garnetiferous mica schist, granite gneiss, porphyritic gneiss, talc-sericite schist, schistose quartzite, marble and amphibolite[5]. This area is traversed by two major thrusts, namely Main Central Thrust (MCT-II) which passes below the tragedy area at Kund, and the Vaikrita Thrust (MCT-I) which passes above the area from north of Gaurikund. MCT is a nearly 10 km wide shear zone, inclined at 20° to 45° northward. A number of fracture zones parallel or oblique to the thrust have also been observed.

Three types of slope failures were observed: debris slide, block slide and rock-cum debris slides. These are mainly due to planar, wedge, translational or rotational failures (Figure 2). At Rail, Tarsali, Lolchhara, Semkurala and Dhani, the failures are mainly joint-controlled and slip has commonly taken place along dip, strike and oblique joints. Usually strike joints are more vulnerable and indicate failure along bedding planes, whereas dip joints sug-

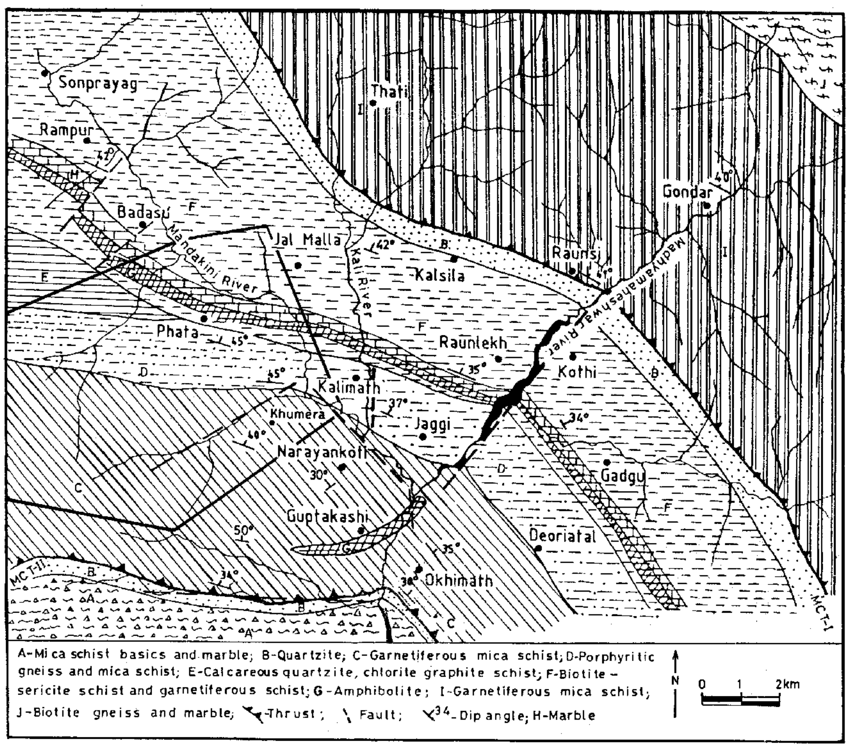

Figure 1. Regional geological setting of the area. Outlined area is the site of tragedy.

Table 1. Survey details of the Phata Byung tragedy on 16 July 2001

Total number of villages affected – 15	
Total population affected – 3924	
Men	
Died – 27	
Injured – 11	
Livestock	
Died – 64	
Injured – 4	
Houses	
Completely damaged – 22	
Partially damaged – 55	
Cow-pens	
Completely damaged – 36	
Partially damaged – 52	
Agricultural land affected – 43.115 ha	
Motor road damaged (major) – 13 km (Davidhar to Barasu)	
Footpath – 42 km (approx.)	
Estimated loss because of motor road and footpath – Rs 2.75 crore	
Bridges	
Small and severely damaged – 5	
Completely washed-out – 2 (one arc and one steel)	
Grinder (grain) – 11	
Micro hydro power plant completely washed out – 1 (capacity 10 kW)	
Government buildings	
Completely damaged – 36	
Partially damaged – 58	

Table 2. Monthly rainfall data (in mm) over the years at Okhimath

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
January	14	117	96	11	68	35	42	0	0	8	11
February	53	106	101	2	90	105	28	63	4	1	4
March	113	55	120	0	32	60	58	71	15	5	3
April	125	5	21	77	24	13	129	52	0	10	7
May	35	121	97	0	12	33	91	36	3	4	9
June	90	76	242	200	136	505	250	85	82	475	242
July	414	523	352	534	616	535	597	796	449	582	540
August	537	904	336	452	489	479	383	626	721	606	
September	175	411	361	141	230	109	191	148	353	187	
October	2	7	5	0	27	46	77	31	63	0	
November	8	5	0	0	0	0	50	3	0	0	
December	29	1	0	11	5	0	48	4	0	3	

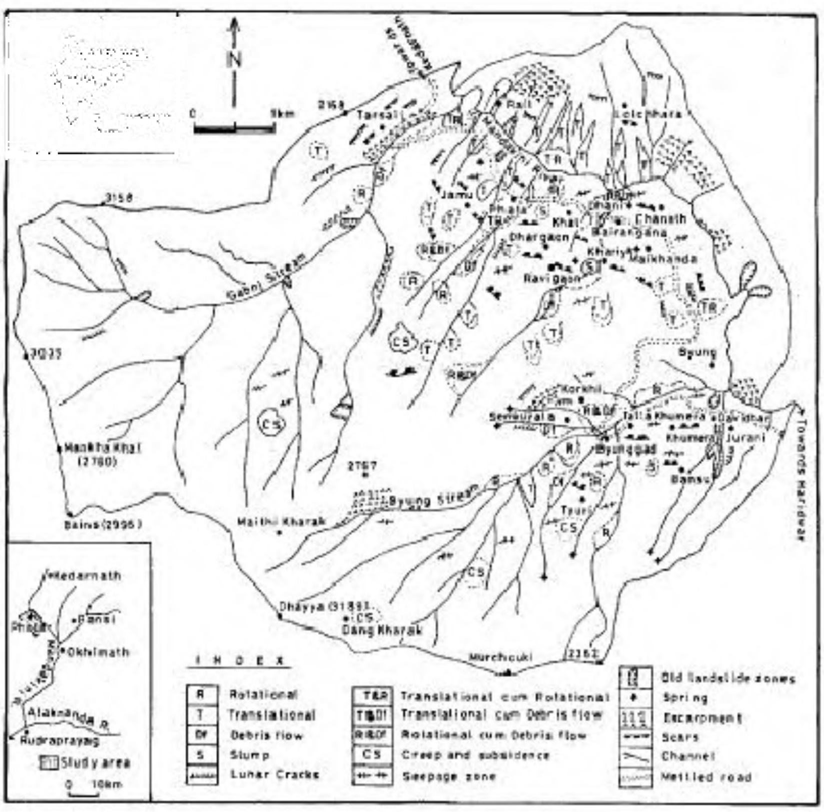

Figure 2. Location map showing the worst-affected villages and distribution of different landslides in Phata Byung area.

gest failure along fold axes. Vulnerability of strike joints may indicate influence of a strike slip fault. The strike joints generally have an east–west trend with 60°–75° dip towards south and the dip joints have mainly north–south trend with 55°–65° dip towards west, whereas oblique joints have NW–SE trend with 20°–25° dip towards NE and NE–SW trend with 70°–75° dip towards west. The intersection of two or more joint planes is marked with wedge failure. Slopes under small agricultural fields with thin soil cover, characterized by two or more sets of joints, were ravaged by the translational slide. Debris flows were common along high gradient tributary streams, the channels of which are narrow. The rotational slips, generally triggered by high pore water pressure, are developed along deeper slip surfaces where thickness of the regolith is 10–50 m or more. Slumping is also reported where the thickness of regolith is more and the basement is cut by some channels. Majority of the debris slides is confined to the mica schist and amphibolite, due to highly fractured and jointed nature of the bedrocks and presence of shear zones and other structures.

A combination of factors appears to have contributed to the present tragedy. This area is tectonically and seismologically a very sensitive domain. The strong tectonized rocks and the fragile mountain slope of the MCT zone in this area are vulnerable to rain, earthquakes, vibrations due to movement heavy vehicles, excavation work, etc. The MCT that has tectonically subdivided this area into three different zones, is characterized by the presence of fractured rocks and is thus, particularly vulnerable to extensive erosion and frequent failure. A large number of catastrophic landslides reported from this area, indicate of the presence of a number of fracture zones. The area lies in the seismic zone V. The recent seismicity of the Garhwal region reveals that a 5.0 magnitude earthquake had occurred in this area in 1996.

The present area falls in the zone of very high precipitation[6]. In such a zone, 200 to 500 mm of rainfall can be expected in one day, once in every 100 years (Table 2). There were incessant rains one day before this incident. Whenever the drainage density is high, the running water washes out the cohesive material from the soils and rock masses. The water pressure not only pushes the slope material forward, but also generates pore water pressure along joints and bedding planes. As the failure starts, the opening of rough joints is enlarged on dilation[7]. Thus the sliding plane acts as a natural channel for the flow of water. The secondary structural weaknesses present in the host rocks and pre-existing slip-surfaces in old landslide areas are also reactivated. Because of adverse hydrological conditions at higher reaches, active creeping and subsidence are also observed.

Since most of the soil here was deposited during Pleistocene in the form of solifluction lobes, it is usually loose and unconsolidated[8]. Most of the villages in this area, viz. Jamu, Phata, Ravigaon, Dhargaon, Dhani, Khariya, Maikanda, Tyuri, Bansu, Khumera, Davidhar appear to have been located over such solifluction lobes and hence have suffered massive landslides on solifluction. On the other hand, Rail, Tarsali, and Semkurala are situated over old landslide debris beneath a prominent escarpment. As there is a dominance of clay in such debris cones and it becomes impermeable whenever water infiltrates go beyond a critical limit, due to increase in pore water pressure, the water forces its way through the weak planes onto the slopes carrying hundred of tons of soil, rock fragments and trees. Also, the height of embanking wall and outward slopping of the terraces add to the problem. These terraces are in a destabilized position due to the heavy mass of soil and prolonged rains which saturate the soil. Straight slopes of Lolchhara and Rail experience debris slides initiated at higher topographic levels and take gigantic proportions downslope. Some slides also commence on the unstable convex slopes at higher elevations and take along the material resting over the straight slopes.

A combination of several factors like tectonically disturbed and fractured lithology of the MCT zone, seismic events, loose soil cover, solifluction lobes on steep slope and prominent seepage zone are responsible for this tragedy, but the action of water during the torrential rain appears to be the main triggering factor.

On the basis of our studies, the following conclusions are made:

(i) Many villages in this area like Dhani, Jamu, Semkurala and Talla Khumera may be washed away in the next rainfall. Hence people, livestock, etc. need to be shifted to safer places immediately.
(ii) There is an immediate need for identification of areas which are relatively more vulnerable to landslides and mass movements.
(iii) Future construction will only be allowed after detailed studies on the local stability of terraces and the evaluation of the geotechnical parameters of the allowable bearing pressure of the slope material. We must not formulate any development activity plan without an understanding of the tectonic setup of the region.
(iv) Building construction practices over solifluction lobes, landslides debris and MCT escarpment in this region should be stopped.
(v) Public awareness programmes to train people to cope with this problem and situation, must be initiated.

1. Naithani, A. K., *Geosci. Gaia*, 2001, **16**, 145–156.
2. Valdiya, K. S., *Geol. Soc. India*, 1998, **52**, 483–486.
3. Naithani, A. K. and Prasad, C., *Geol. Surv. India*, 1997, **48**, 37–42.
4. Valdiya, K. S., *Geology of Kumaun Lesser Himalaya*, Wadia Institute, Dehradun, 1980, pp. 1–291.
5. Naithani, A. K., Unpublished D Phil thesis, HNB Garhwal University, Srinagar, 1997, pp. 1–200.
6. Dhar, O. N., Kulkarni, A. K. and Rakhecha, P. R., National Workshop on Flood Estimation in the Himalayan region, Central Board of Irrigation and Power, New Delhi, 1986.
7. Deoja, B., Dhital, M., Thapa, B. and Wagner, A., *Mountain Risk Engineering*, ICIMOD, Nepal, 1991, pp. 1–875.
8. Naithani, A. K. and Prasad, C., *Curr. Sci.*, 1998, **74**, 365–372.

ACKNOWLEDGEMENT. A.K.N. thanks the Department of Science and Technology, New Delhi for financial support.

Received 14 August 2001; revised accepted 12 February 2002

AJAY K. NAITHANI*
DEEPAK KUMAR
C. PRASAD

Department of Geology,
P.B. No. 86,
HNB Garhwal University,
Srinagar (Garhwal) 246 174, India
**For correspondence.*
e-mail: ajay_naithani@hotmail.com