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Dharamsala seismotectonic zone—neotectonics and state of stress in the area

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Abstract: On 26th April, 1986 an earthquake of magnitude 5.7 (mb) was felt near Dharamsala, which caused fairly widespread damage in the region. Seismic open cracks and fissures (faults) were formed in the epicentral area. These cracks and faults have been mapped and their kinematics analysed. The studies have shown that the earthquake resulted from the reactivation of existing faults and that a splay occurred in the N-S direction between Drini Thrust and Main Boundary Thrust. Attempt has been made to measure the principal stress direction on the basis of slip vectors measured from seismic faulting and from the recent neotectonic activity in the field are almost in the same direction.

The Dharamsala-Kangra area is one of the most active earthquake zone in the Himalayan seismic belt and has experienced several destructive earthquakes in the 20th century namely 1905, 1968, 1978 and 1986. In view of the high seismicity of this area, seismologists, geologists and earthquake engineers have taken keen interest for understanding the mechanism of earthquake events. The Dharamsala-Kangra area lies in the northwestern Himalaya which was uplifted during Tertiary orogeny movements and has been experiencing tectonic adjustments even during the recent times as observed from high seismicity, neotectonic activity and areas of strain build up. The kinematic analysis has been done on the basis of data of the main earthquake of 26th April, 1986 and the surfacial evidences of slip and seismic crack developed due to neotectonic activity. Slip vectors measured from the seismic cracks and faults were also used to calculate the principal stress directions.

Structural Setting

The Himachal Himalaya lies in the western sector of the Himalaya and consists of a complete sequence of Paleozoic, Mesozoic and Tertiary rocks, which can be divided into two main tectonic belts (Kumar *et al.* 1989). The Main Himalayan Belt and the Frontal Folded Belt are separated by the Main Boundary Thrust. The Frontal Folded Belt is characterised by a number of tectonic planes, like Drini Thrust, and a number of longitudinal and transverse lineaments. This Frontal Folded Belt is highly folded and faulted. Northward sequence of the Frontal Folded Belt is cut by the Main Boundary Thrust from where the sequence of the Main Himalayan Belt starts, which consists of Dharmkot Limestone (≡ Shali Limestone) (Srikantia and Bhargava, 1976), Dharamsala Traps (≡ Mandi-Darla volcanics), Chails and Dhauladhar granites. All these formations are separated from each other by the tectonic planes; i.e., Kareri Thrust ≡ Chail Thrust ≡ Punjal Thrust and other local thrusts. Because of the nappe structurs and differential movements, the Main Himalayan Belt is highly folded and faulted.

The Main Boundary Thrust and the Chail Thrust merge with each other in the Kareri area, west of Dharamsala and are widely separated in the east of Dharamsala. Because of relative movement and differential stress variation, the joints developed in these sequences show different stress directions present in the Main Himalayan Belt and the Frontal Folded Belt.

The Himachal Himalaya is considered one of the seismically very active regions of the world. It could be assumed that energy built up in the area is the result of reactivation of these thrusts and faults present in the study area.

Location of Seismic Crack

The Naddi village which is situated about 10 km northwest of Dharamsala town (Fig. 1) demonstrates the presence of recent extensional tectonics activity in this area in the form of surfacial cracks. Field studies have indicated that these probably resulted mainly from a splay between Drini Thrust and Main Boundary Thrust zones where opening has occurred along the normal faults.

Seismic cracks have an oblique shear with an opening of about 1 cm. The cracks have been formed in Dharamsalas (Fig. 2). These seismic cracks are of stirke-slip type with fault plane trending N 30° W to N 45° W and with the down throw side in the NE direction.

Lineaments in the epicentral area have been mapped on 1 : 250,000 satellite image. In the field,

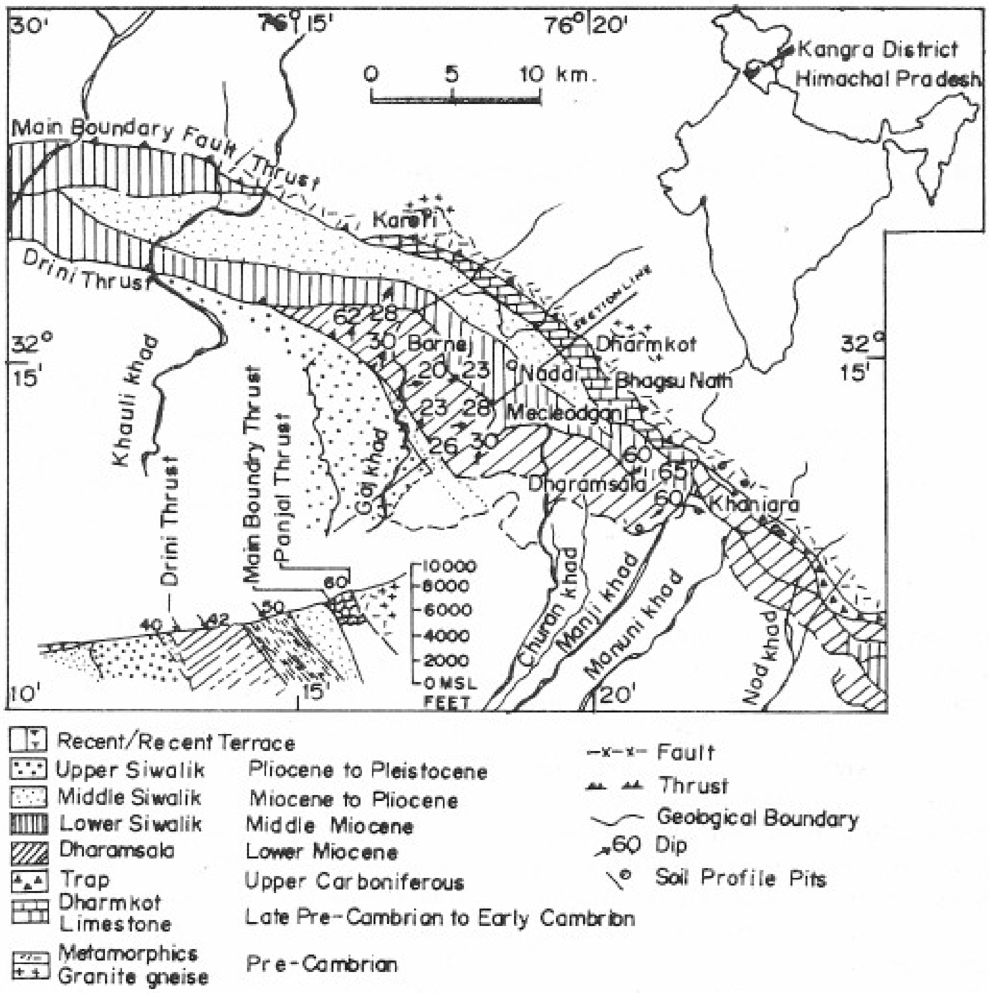


Fig. 1. Geological map of Dharmsala area (after Dhar and Jha, 1978) with a cross section showing the dip of the beds and the place of 26th April, 1986 Dharmsala earthquake epicentre.

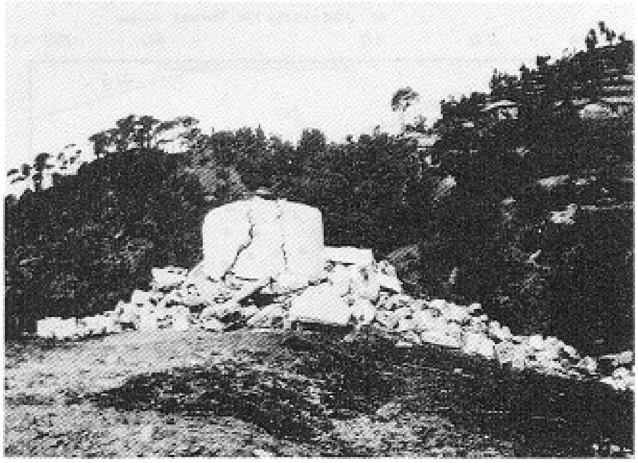
some of these lineaments strike transverse to the main Himalayan trend cutting across the entire geological sequence and show their association with the basement rocks. Some northeasterly lineaments show rejuvenation as reflected through the abrupt change in flow directions of the streams and seismic activity in the area (Kumar *et al.* 1979). But the lineaments in the NNW direction are shorter, abundant and mostly confined to the Dharamsalas and the Siwaliks, which are bounded by the tectonic planes like the Drini Thrust, the Main Boundary Thrust and the Main Frontal Thrust. In this zone the thrusts dips to the north, while the seismic cracks dip towards southwest. The fault shows prominent normal movements within the epicentral zones. This fault caused maximum damage in the study area along a line shown in Fig. 3.

Kinematics of Seismic Cracks and Faults and Stress Field

The cracks observed in the sediments near the village Naddi appears as small reverse fault in terms of a compressional mechanism. The main crack is a curved fracture opening. As a rule the slip movements on the active fault plane takes place only where a required overburden pressure is reached. Such fracture is caused due to the upward decrease of the angle θ between the shear plane and the vertical principal stress axis σ_z. This is related to upwards decrease of the vertical load (Fig. 4). On the surface $\sigma_z = 0$ therefore a tension gash opened up perpendicular to the minimum (tensile) principal stress σ_x so that its dip is nearly vertical. Seismic cracks opened up in the form of fine fabrics on the surface which show lateral movements and dipping in NNW direction. On stereoplots (Fig. 5) it gives a slip vector in NE direction.

Seismic fault movement mostly results from reactivation of pre-existing faults thrust i.e. the Main Boundary Thrust and Drini Thrust. The slips on the faults are independently represented by striations on the fault plane which has to be parallel to the tengential stress (τ) and is a function of the orientation of the principal axes related to the principal stress (σ_1, σ_2 and σ_3).

The kinematic analysis of the slip vector on the fault plane is a useful component to know the



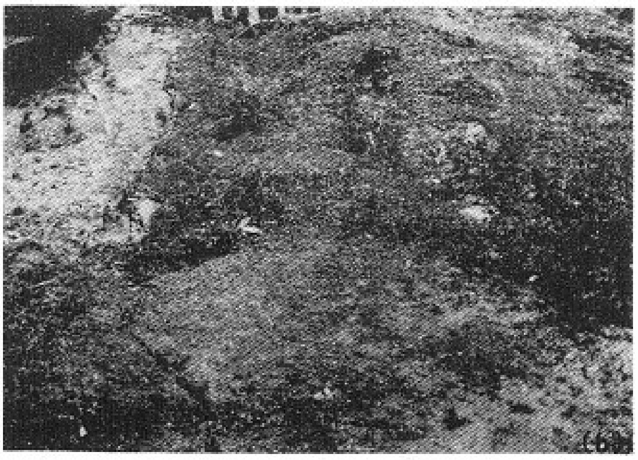


Fig. 2a. Siva temple total distruction due to main epicenter area at Naddi. 2b. Seismic crack developed due to 1986 earthquake, shown by arrow.

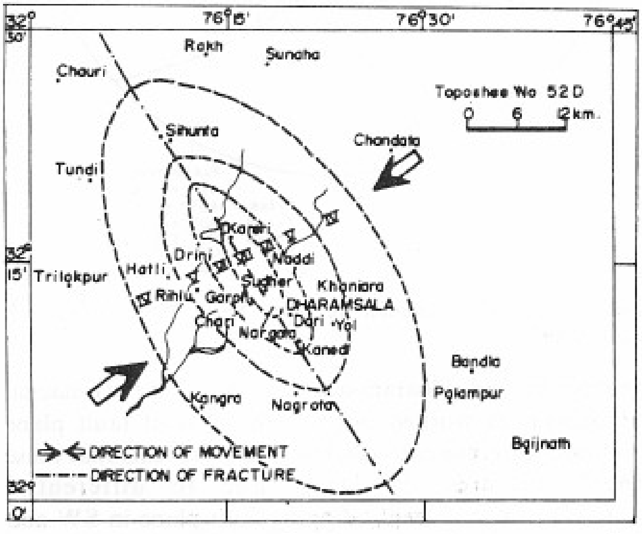
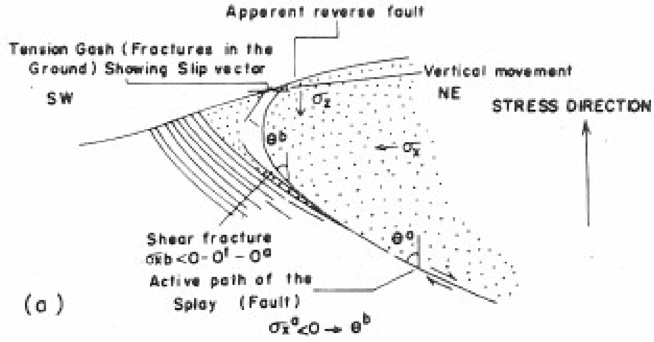
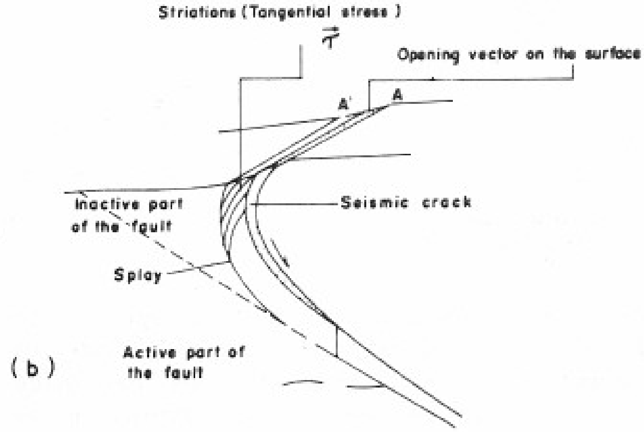


Fig. 3. Isoseismal map of 26th April, 1986 Dharmsala earthquake (after Kumar & Mahajan, 1990).





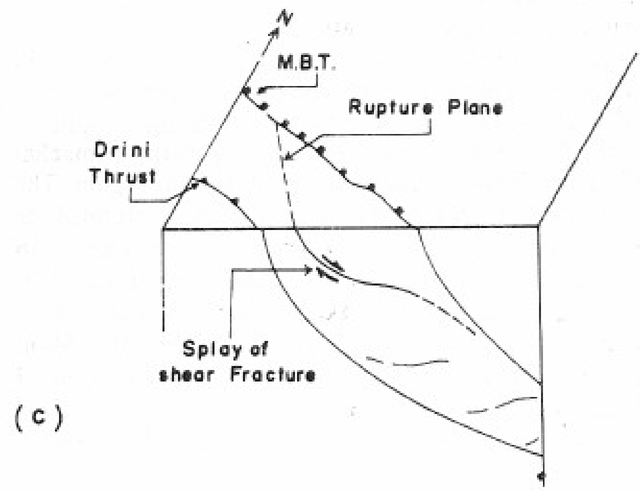


Fig. 4a. Curved fracture formed in shallow consolidated sediments above the existing fault plane. Compression is vertical which decrease upwards and become zero at the surface. Tension is horizontal it becomes negative on the surface. Movement on the active fault plane at depth opens the curved fracture which becomes an open crack. 4b. The seismic crack drawn on the basis of actual observations in the field after 26th April, 1986 earthquake. 4c. Schematic diagram showing splay between Drini thrust and Main Boundary thrust on the basis of field observations.

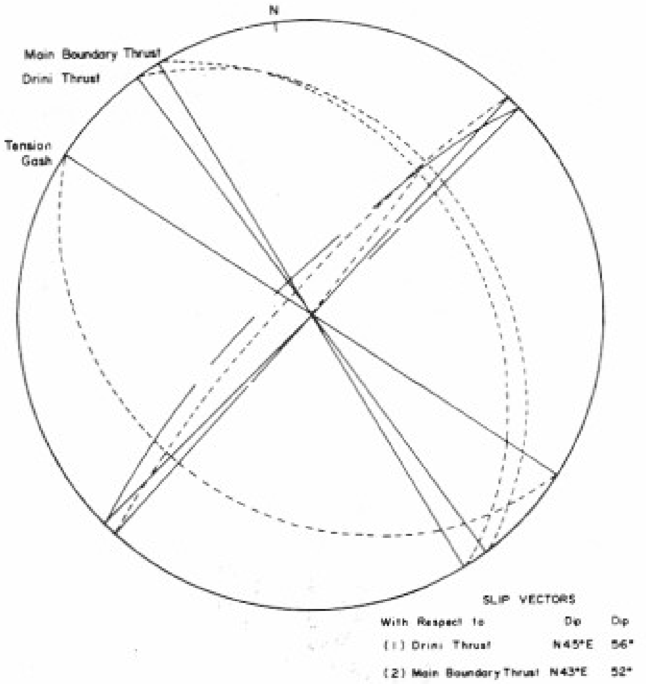


Fig. 5. Tension gash showing slip vector with respect to Drini Thrust and Main Boundary Thrust.

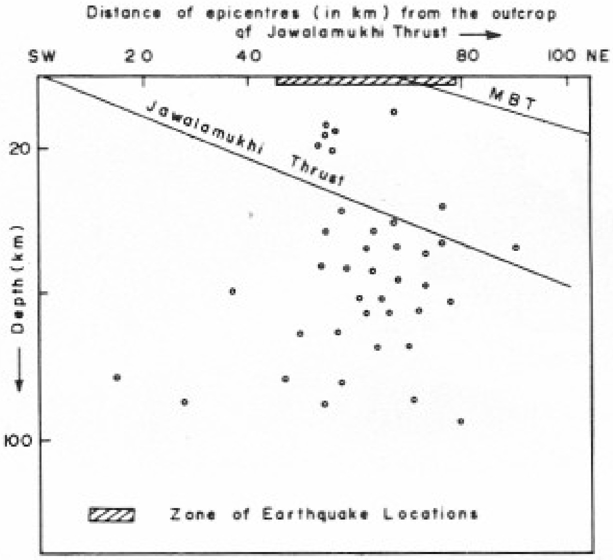


Fig. 6. Depth section with respect to Jawalamukhi Thrust and Main Boundary Thrust. Data taken from IMD from 1979 to 1985.

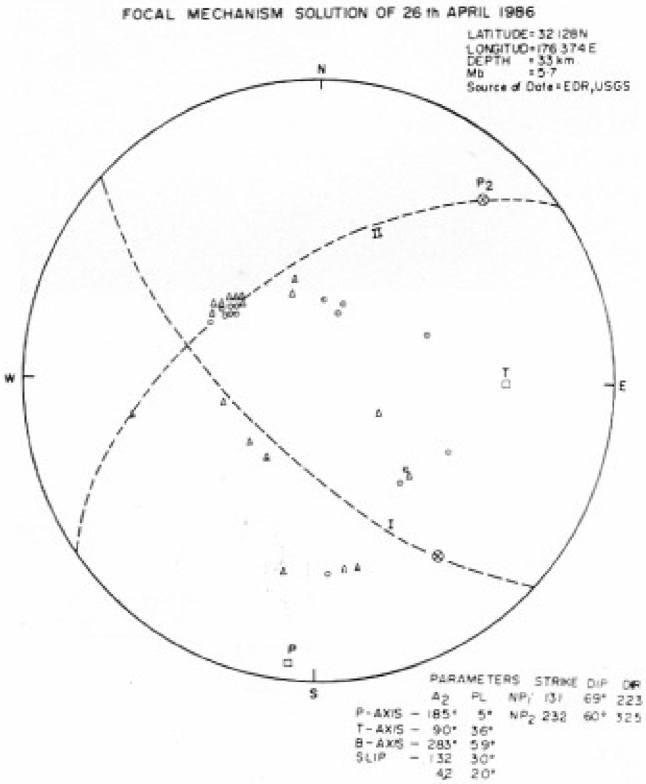


Fig. 7. Fault plane solution of 26th April, 1986 Dharmshala earthquake.

behaviour of seismicity and fault at depth i.e., to correlate the focal mechanism and its geometry by aftershock analysis. This analysis has given visualization of the seismotectonic activity in the Dharamsala region.

Seismotectonics

Earthquake occurrences in the Dharamsala region appear to be a distinct feature. This is well understood from earthquake locations and the dip of the Main Boundary Thrust (MBT) passing through this zone. Dharamsala—the seismically active tectonic zone is about 50 km wide and 100 km. long in the Himachal Himalaya between Chamba and Palampur region. The focal depth of earthquakes of moderate to intermediate magnitude occuring in this zone range from 3 km to 96 km with an average of 20 km (Das Gupta *et al.*, 1982) (Fig. 6). These earthquakes appear to have some relation with the local thrust faults, i.e., the Main Boundary Thrust, the Drini Thrust, the Jawalamukhi Thrust, etc. for the following reasons:

1) shallow northeastward dip of the local thrust belts,

2) focal depth distribution of earthquakes located in this zone, and

3) the local internal deformation in the regional blocks due to stress build up at splay points.

This seismotectonic zone indicates that the large seismic activity may be indicative of activity along deeper rupture in the basement much below the NE shallow dipping local thrust planes. This neotectonic regime in the Dharamsala region of the Himachal Himalaya, as worked out on the basis of fault plane solution of recent earthquakes (Fig. 7) reveals that these local fractures developed due to differential readjustment on steeply dipping fault plane in SW and NW directions. Based on local crustal models (Kamble *et al.*, 1974) the focal mechanisms of 1968 and 1978 earthquake indicate thrusting with left lateral strike-slip movement on a plane in a northerly direction (Srivastava *et al.*, 1987). This seismotectonic zone may, therefore, be behaving as neotectonically active zone related to the skin tectonics due to the crustal shortening of the sedimentary sequence. From the microseismicity, and occurrence of major earthquakes pattern within the depth range of 20-90 km in the region, it appears that there are two types of movements occurring in the region—one due to regional tectonics in the basement, and second, is neotectonic activity in the sedimentary sequence in the form of seismic activity (Fig. 4). This seismotectonic zone is still capable of generating large magnitude earthquakes. The seismic fault developed by the earthquake on 26th April, 1986, appears to be normal with a small left lateral component which is in agreement with data provided by structural analysis of seismic faults. The fault plane solution shows movement along the Drini Thrust with strike-slip component. The tensional direction deduced from Seismic faulting and recent neotectonic faulting is compatible with the regional tension axis deduced from focal mechanisms. In highly fractured rocks, geometry of faults is the result of the state of stress that has affected the region and material. Thus, kinematic analysis of superficial seismic faults is a useful tool to study the behaviour of faults at depth.

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