SEISMOTECTONICS IN CHEDRANG VALLEY AND ITS VICINITY

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The seismotectonics and the current state of stress for Chedrang valley and its vicinity are observed with the help of high precision seismicity data during the period 1982-2006. Microtremor activity is relatively more intense towards the east of Chedrang fault than its western part while Dapsi and Dauki faults indicate less activity. Since the maximum number of events in depth interval 0-30 km is higher in comparison to the depth interval 30 – 50 km, thus the bottom of seismogenic zone is inferred to be at 30km. Inferred focal mechanism suggests thrust faulting with a significant portion of strike-slip motion and the associated fault i.e. Chedrang fault dips towards north of northeast. The stress tensor inversion from 22 mechanisms suggests that the Chedrang valley and its vicinity are governed by NNW-SSE compression.

Introduction

Chedrang valley and its vicinity of Shillong Plateau was the rupture area of Great Assam earthquake of 1897(M~8.7), the region had ever experienced. This earthquake caused considerable damage and resulted highest ever ground motion in the valley. The important ground ruptures mapped by Oldham[1] were the Chedrang and Samin. Oldham[1] observed 11m of co-seismic slip down to the west of location of Chedrang Fault. The Chedrang fault ran for a distance about 20 km NNW direction from the headwater of Chedrang river through Dalbot (25.83ºN ; 90.73ºE), Dilma (25.01ºN ; 90.71ºE) and Jira (25.91ºN ; 90.68ºE) with a vertical throw varying from 0.60-10.60 meters, up through always being east[2]. In this study, we have prepared an earthquake catalogue based on relocated events since 1982 - the inception of real time seismic monitoring network established in northeastern region of India. This forms an input to the present seismotectonic study for the region. The relocated seismic database has been extensively used to investigate the shallow to intermediate tectonics of the valley. Simultaneously to know the physics of the earthquake processes and stress regime of the region, waveform and stress tensor inversion techniques are used. Though Angelier and Baruah[3] did a comprehensive study on the seismotectonics of Shillong Plateau with a sum of 25 no. of focal mechanism solutions, the present study tries to investigate the stress condition in a very localized area of Shillong plateau i.e, Chedrang fault and its vicinity. Notably, higher PGA values are expected in this region[4] and thus the region is tectonically very interesting. The major aim of the paper is to utilize the seismic catalogue concerning the distribution of earthquake foci to infer the seismotectonics of the Chedrang valley and its vicinity constrained by focal mechanisms and present stress regime.

Tectonic Setting

Tectonically Chedrang valley and its vicinity belong to highly complex zone which evolves the western part of Shillong Plateau surrounded by Main Boundary Thrust to the North and thick tertiary sediment cover to the South. Geologically Shillong Plateau has evolved during the Mesozoic to Tertiary times with an average elevation of

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about 1 km. Dauki fault is a major fault in the region where there is thousand meter south facing escarpment facing cretaceous ocean floor of Bengal Basin. The northern side is bordered by the Brahmaputra valley. The western side is characterized by a N-S trending Dhubri fault which separates Garo Hills (western Shillong Massif) from Indian subcontinent that separates the ancient continental crust of the Indian Shield from the cretaceous ocean floor. Apart from these, faults tectonics of this region is influenced by several secondary faults eg. Chedrang, Dudhnoi, Samin and Dapsi faults oriented NW-SE, N-S, E-W and NW-SE respectively. Out of these Chedrang fault is oriented along Chedrang River and joins the Krishnai river, a tributary to the Brahmaputra river (Fig. 1). The fault appears to be an expression of the fracture close to the Chedrang river. Chedrang fault inhibits an importance where Oldham[1] observed a 11m of co-seismic slip down to the west of location of Chedrang Fault. Formation of lake near Jhira village is an indication of the slip. A recent palaeoseismic study[5] from fissures and sand blown structures in the region identifies northern boundary fault as a major seismic source, now termed as Brahmaputra fault.

Data

In this study, we have analyzed the data recorded during 1982 to 2006 in the Chedrang valley and its vicinity to understand the seismotectonics of the region. Using the arrival times of P and S waves to the HYPOCENTER programme (a software package of Lienert et. al.[6], about 491 earthquakes are relocated. The crustal velocity model of Mukhopadhaya et. al.[7] is used having P to S-wave velocity ratio of 1.75. Relocations are obtained by using the data for relatively large number of analog seismic stations (Fig. 1, black triangle) with reasonable degree of azimuthally coverage. The network detection threshold magnitude of 3.0 is inferred from the cumulative frequency – magnitude distribution of 491 events during the period 1982 – 2006 where the region is being monitored with a broadband network of five digital seismic stations (Fig. 1, red triangle**).**

These stations are Mendipather (MND), Jogighopa (JPA), Nagalbibra (NGL), Guwahati (GWH) and Shillong (SHL). The waveforms obtained from first four stations are used for determination of focal mechanism solutions through waveform inversion.

Waveform and Stress Tensor Inversion

Computation of Green's function is the prime approach for generation of synthetic waveform. Green's functions are calculated by discrete wave number (DW) method (Bouchan[8] & program AXITRA by Coutant[9]). Then Green's function are convolved with appropriate instrument response and source-time function. The calculated time window length is fixed to 40.96 seconds, so the frequency step is df=1/40.96=0.0244 Hz. 4096 complex data points allow the time increment of the synthetic seismogram of dt=0.01sec. Synthetic amplitude spectra are calculated for the trial values of the scalar moment, strike, dip and the rake. Final validation of the best fitting solutions is accomplished by comparing the observed and synthetic amplitude spectra after attempting several steps.

Stress tensor inversions resolve the orientation of the three principal stresses (S1=maximum, S2=intermediate, and S3=least) of the stress ellipsoid, their relative magnitude, and the homogeneity of the stress field, from a given heterogeneous set of focal mechanisms. The algorithm proposed by Gephart and Forsyth[10] is used to investigate the state of stress for the study region. The parameters of the stress tensor obtained by the method are the azimuth and plunges of the three principal stresses and a measure of stress magnitude, R, indicating the magnitude

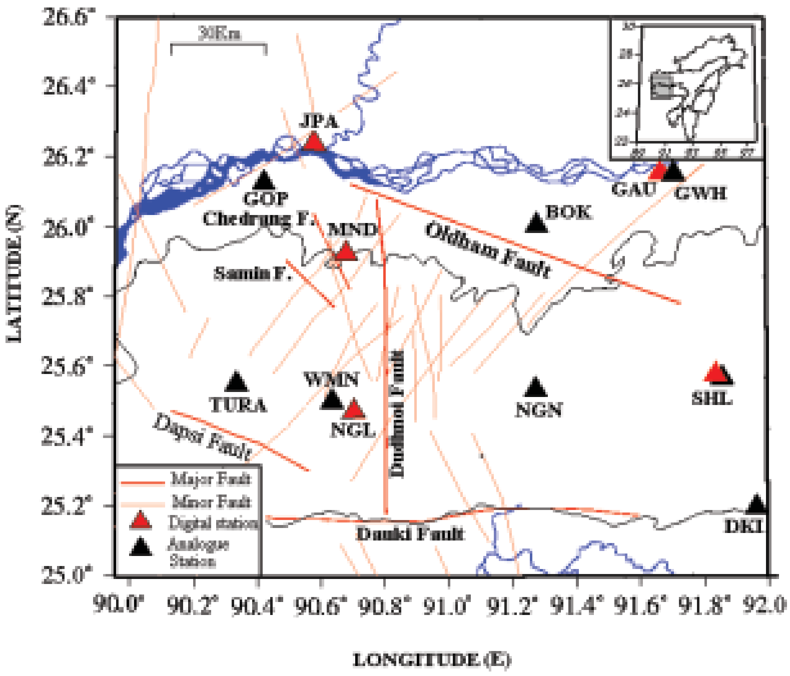

Figure 1. Map showing major tectonic features in and around Chedrang fault of Northeast India region after Nandy[2] and Baruah and Hazarika[11]. The major tectonic features in the region are indicated; Dauki fault, Dapsi thrust, Dudhnoi fault, Oldham fault, Chedrang fault and Samin fault. Triangles indicate seismic stations, Red colored: Digital, Black colored: Analog. Inset : Map of Northeast India.

ratio of the intermediate principal stress relative to two extreme ones ($R=S_1-S_2/S_1-S_3$), where S_1, S_2 and S_3 are the greatest, intermediate and least principal stresses, respectively. The best fitting stress tensor is found by minimizing the average of the individual misfits.

Results

Seismicity of Chedrang Valley *:* The hypocenters of all the events in Chedrang valley and its vicinity (Latitude 24.8 -26.6°N; Longitude 89.8 - 91.6°E) are shown in Figure 2 especially for the depths less than 50 km during the period from 1982 to 2006. The locations of Chedrang, Dudhnoi, Dapsi reverse, Dauki and Samin faults[2,11] are also shown for the purpose of correlation. The activity along these faults are attributed to Holocene upliftment of Shillong plateau due to the drag experienced by the Indian lithosphere near northern and eastern margins of Indian plate under Himalayan and Burmese arc system. From Figure 2 it is observed that epicenters align along with Dudhnoi, Chedrang and Samin faults for the earth tremors of magnitude 1.0 – 4.0, 2.1 – 5.0 and 2.1 – 4.0 respectively and the micro-tremor activity is relatively more intense towards east of Chedrang fault than its western part. Absence of seismic activity is observed in association with Dapsi reverse and Dauki faults. The activity is less south of Brahmaputra valley bordering to Meghalaya. Mostly, the activity is confined to the magnitude range 2.0 - 4.0.

The different depth ranges of hypocenters for the events are depicted in Fig.2a-e. Chedrang fault, by and large, active up to the depth of 20 km while in case of Dudhnoi fault, the activity is seen up to 30km depth.

In order to observe the distribution of the earthquake foci along or across the major tectonic features specifically Chedrang fault, Samin fault and Dudhnoi fault; the following depth sections are obtained.

a. A NW-SE directed section of the events that occurred in the Shillong Plateau are examined along the Chedrang fault. The considered events are shown by a shaded zone A-A´ in Fig. 2(a). The shaded zone includes about 10 km span in both ways from the fault line.

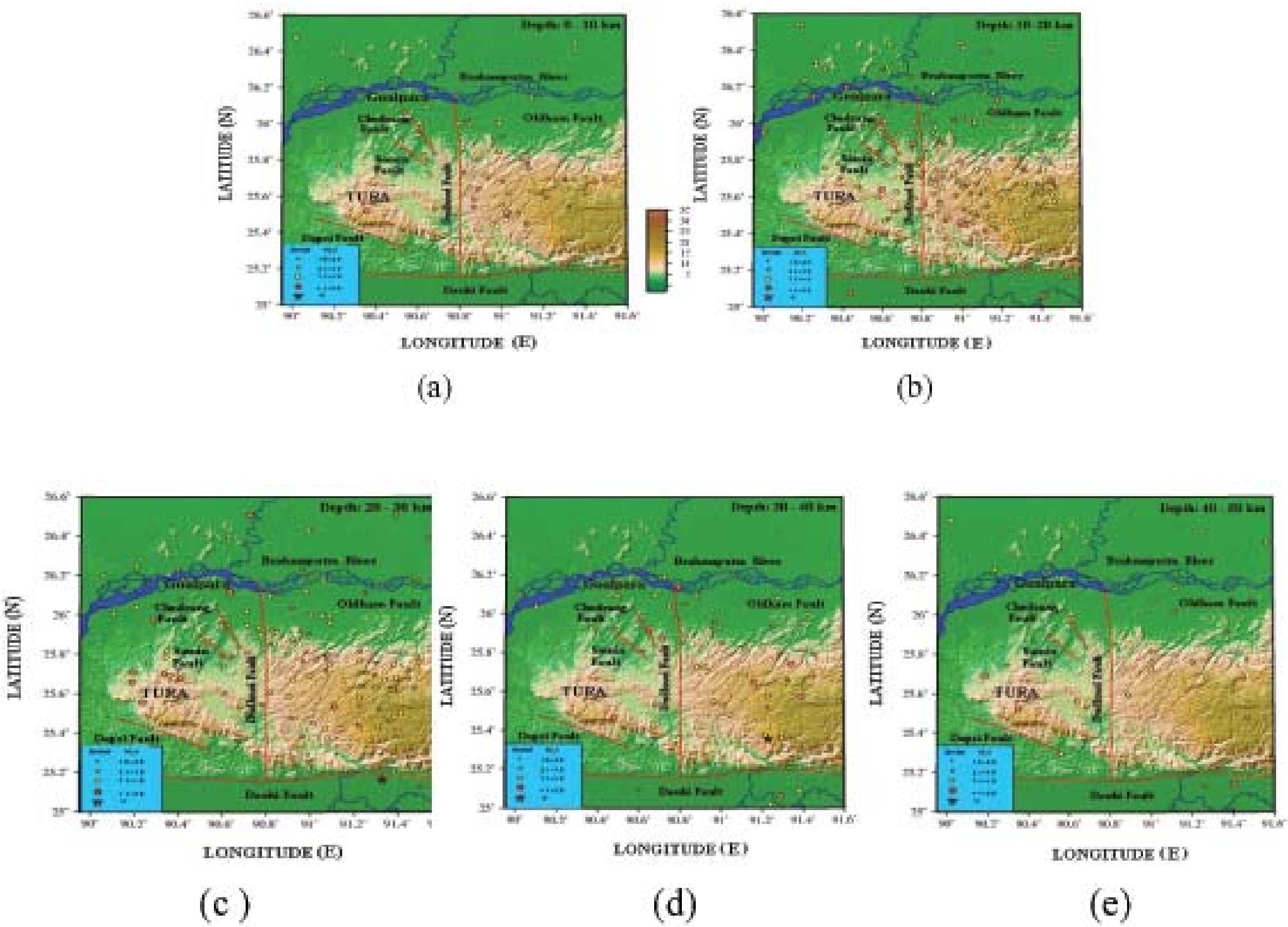

Figure 2. Epicentral plots of earthquake events for different depth e.g., (a) 0-10km, (b) 10-20km, (c) 20-30 km, (d) 30-40 km and (e)40-50 km. Other descriptions as in Figure 1.

b. A cross-section of the events is observed across the Chedrang fault (along SW-NE direction); the events considered in this section are shown by the shaded zones B-B´ in Fig.2 (b).

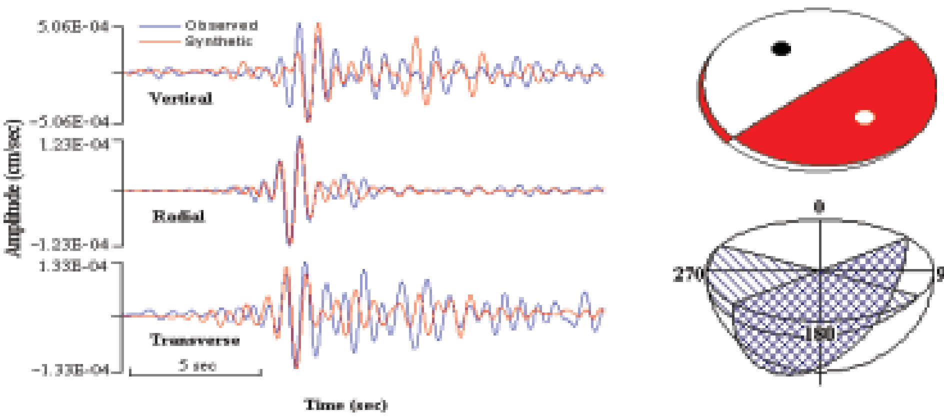

Figure 3. Matching of observed and synthetic seismograms. "Red" line indicates the Synthetic seismogram and "blue" line indicates the observed one. The preferred "beach-ball" is also show in lower hemisphere projection.

Focal Mechanism Solution : The focal mechanism solutions of the earthquake events in and around Chedrang fault are determined with the code of Zahradnik et al.[12]. As an example, waveform inversion for an earthquake events of 23rd August 2003 (Lat : 25.96º ; Long 90.61º , h=5 Km, MD=2.0) are discussed below:

First the Green's function is calculated at epicentral distance of 9 km for the station MND with source depth of 5 Km. As the SHL (Shillong) station did not record the event so focal mechanism could not be constrained using first motion polarity data from SHL station. The grid search technique produced many solutions with higher correlation coefficients both for P and S wave amplitudes. The inferred solution fails to predict the observed amplitude of P and S wave at MND. So the attention paid to modify the velocity model. The P velocities are decreased from 6.14km/sec to 5.88 km/sec at the depth 5 km with Vp/Vs =1.79 and the Green's function is recomputed for the station MND. The grid search is rerun. Figure 3 shows the admissible focal mechanism solution with the search technique satisfying amplitude and polarity. The mechanism is tested by predicting the observed mechanism at MND for P-wave group. Solution with Strike=330º, Dip=60º and Rake= 110º is found for best double-couple solution from the waveform prediction. The T-axis of this mechanism trends towards the northeast (azimuth=74 and plunge= 77) and the P-axis towards the southwest (azimuth=199 and plunge= 21).

Figure 3 also shows the synthetic seismogram of this earthquake predicted for the station MND. A seismic moment of 3.1E+17 dyne-cm was used. The synthetics of MND correlate very well with the observed seismogram (P wave group) both in amplitude and phase for radial and transverse component while the vertical synthetic is not predicted well. Although the predicted amplitude range is found to be equivalent with the observed amplitude, the mismatch is due to contribution of high frequency existed in observed vertical seismogram. Whatever the mismatches of the seen in the seismogram can be adjusted by shifting either the observed or the synthetic trace as the starting time in either is quite arbitrary. This mechanism suggests that the event is caused by thrust faulting with a significant portion of strike-slip motion and the associated fault i.e. Chedrang fault dip towards north of northeast.

In this study, we discuss the source parameters of twenty two earthquake events (Fig. 4) occurred in Chedrang valley and its vicinity. We use 22 fault plane solutions, 5 by using P-wave first motions and 17 by waveform inversion. The sizes of the events are too small and recorded by the local broadband stations only. Event no. 17 and 6 are found close to Chedrang fault and Samin fault. Waveform of these two events allowed us to determine the focal mechanism solutions to characterize the above faults. Earthquake (event no. 7) close to Barapani shear and event no 19 close to Dapsi reverse fault show thrust faulting with strike-slip component. The focal mechanism solutions and the focal depth of the 22 earthquake resolve the style of faulting and sense of slip in Chedrang valley and its vicinity. Six earthquakes (Event no. 2, 11, 12, 13, 15, 17, 18) indicate a component thrust fault and the slip seems to have occurred in steeply dipping plane from shallower to intermediate depth. These indicate that the uppermost crustal deformation in Chedrang valley is basically governed by thrust/reverse kind of faulting. Event no. 11 and 16 are characterized by oblique faulting with the dip almost vertical. Event no. 17 occurred in a shallower most depth of 5km is associated with Chedrang fault which indicates pure compressional axis is oriented north of northeast. Three earthquakes (event no. 13,15,19) associated with the Dauki fault at depths 13 , 21 and 29km are characterized by mainly thrust solutions.

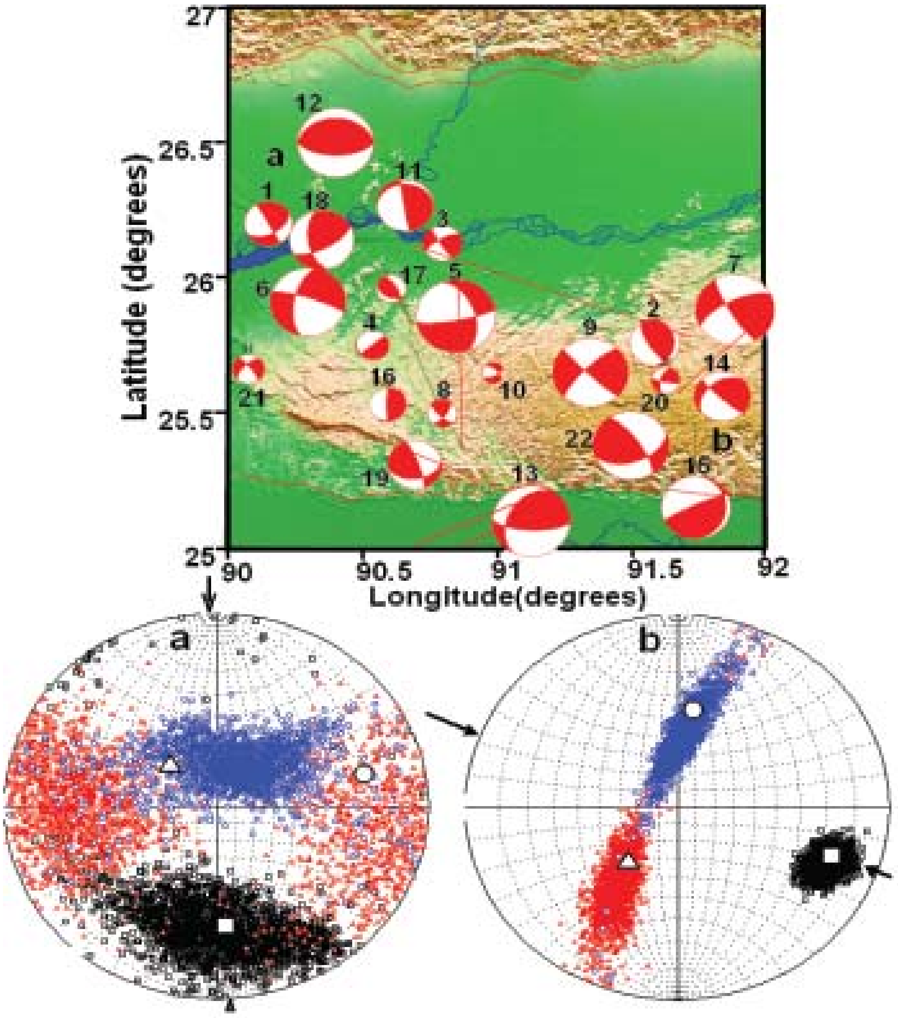

Figure 4. Results of stress tensor inversion as derived from Gephart and Forsyt[10] . The convergent arrows indicate the direction of compressive axis for different clusters a & b. The maximal principal stress direction is indicated by square in corresponding stress map for the both the clusters. The arrow indicate the compressive stress direction.

Stress Tensor Inversion Results : The stress tensor inversion results using 22 focal mechanisms are shown in Figure 4. Based on stress inversion of 22 double couple focal mechanisms of earthquakes, we determine the regional seismotectonics stress in Chedrang valley and its vicinity. We observe two different stress regimes for two different clusters of events(a & b) considered in the region which is characterized by N-S (for cluster a) and NNW-SSE (for cluster b) (Fig 4). Consistent with India-Eurasia convergence, N-S compression dominates in the studied area. Considering the kinematic implications of the published geodetic information, we observe the relationship between the present day relative displacements of the studied region and the seismotectonic stress regimes that we have determined using focal mechanisms of earthquake.

The extensional regime concentrates towards alluvial Brahmaputra valley to the north east and Bengal basin towards south west, highlights the active flexure of the upper crust of the Shillong plateau beneath the frontal zone of the eastern Himalaya.

Discussion and Conclusion

The seismotectonic study of Chedrang valley and its vicinity reveals the pattern of microseismic activity and makes an assessment of active seismogenic zone. The study indicates a clear variation of seismicity with earthquake size distribution. The microtremor activity is relatively more intense in case of Chedrang fault in comparison to Samin and Dudhnoi fault having the earthquake magnitude ranged between 2.1 – 5.0. Notably, intense microseismic study is found to occur within the depth range of 30 km indicating the bottom of seismogenic zone inferred to be 30km. The focal depth of the earthquake that we have studied along Chedrang fault deepens north of northeast beneath the western part of Shillong plateau with the orientation of the thrust plane towards Brahmaputra valley.

It is clear that the top 10km thick crust (Fig. 2a) contributes low tremor activity in and around Chedrang fault compared to that of the crustal depth 10-20km (Fig. 2(b)). The crustal activity associated with Dudhnoi fault in the depth range of 20-30 km (Fig. 2(c)) is more in its eastern part compared to that of its western part. From the inter comparison of Figs. 2a-e, it may be observed that (a) the micro-tremor activity is mainly associated with Chedrang, Dudhnoi and Samin faults at the depth 0 – 20km (285 shocks), (b) the activity is least in the depth interval 40 – 50km (30 shocks) and (c) absence of activity in association with Dapsi reverse and Dauki fault.

So far the seismotectonics of Chedrang Valley and its vicinity is concerned; the study throws a new insight for the region. Within the framework of intraplate earthquake, the concept of seismogenic zone is inferred to be at 30km. On the other hand focal mechanism solutions associated to Chedrang fault portray pure thrust and thrust faulting with strike-slip component.

The results of the mapping of the stress tensor for the Chedrang valley and its vicinity (Fig 4) show the predominance of a thrust style of faulting with a NNW trending maximal principal stress. Mapping out the variance of the best fitting stress tensor, we find anomalously high variance near the rupture areas (Fig. 4).

The direction of compression is not conformable with the general trend of stress of NER, India, which is NNE directed. Sudden change of stress regime from prevailing NNE to NNW is an indication of probable occurrence of a large earthquake.

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