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Linear features registered on the Landsat imagery and seismic activity in the Dharamsala-Palampur region (NW Himalaya)

A. K. Mahajan and Surrendar Kumar

Wadia Institute of Himalayan Geology, Dehradun – 248001 India

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The Dharamsala-Palampur region of Kangra district (Himachal Pradsh, NW Himalaya) has been studied to infer the stress field pattern and tectonic movements responsible for the generation of high seismicity in the region. The referred area reveals large number of lineaments, generally a manifestation of various structural features like folds, faults, fractures, etc. The different types of lineaments were differentiated through a lineament filter map. The rose diagram and linear histogram of lineaments are drawn to reveal major trend of linears and their correlation with the seismicity of the region. The major thrust systems are cut and offset by the transverse lineaments which have direct relationship with the complex tectonic history of this region.

Linearne strukture opažene na Landsat snimkama i seizmička aktivnost područja Dharamsala-Palampur (SZ Himalaja)

Studirano je područje Dharamsala-Palampur u sjeverozapadnom dijelu Himalaja, radi određivanja polja napetosti i tektonskih pomaka koji tamo uzrokuju visoku seizmičku aktivnost. U tom je području opaženo mnogo lineamenata koji ukazuju na raznovrsne strukturne odlike: bore, rasjede, pukotine i sl. Vrste lineamenata odijeljene su filtriranjem, dok su njihovi pravci pružanja prikazani na polarnom dijagramu i u obliku histograma. Glavni reversni sustavi presječeni su i pomaknuti poprečnim lineamentima koji su u izravnoj vezi sa složenom tektonskom prošlošću ovoga područja.

Introduction

The current deformation along the Himalayan belt is evidenced by high seismicity and associated geological phenomena are related to the collision of the Indian and Eurasian converging plates. The stacking of the crust along the northern Indian plate margin leads to the development of a thrust system trending in NW–SE direction. However a number of geological studies have shown that in addition to the longitudinal thrust processes a number of transverse structures form remarkable features in the Himalaya. The fault plane solutions of a considerable number of earthquakes in the Himalayan region support the above inferences (Fitch, 1970; Molnar et al., 1973, Rastogi et el., 1973, Tandon and Srivastava, 1975; Kumar and Mahajan, 1991). It seems that the entire process of earth strain release in the Himalaya is rendered extremely complex by interaction in the pre-Himalayan lineaments and the geological heterogeneities with the stress fields along the Himalayan plate boundary. The main objective of this study is the analysis of major crustal features determined from the imageries, and their relationship with the neotectonic activity in the Dharamsala-Palampur area.

Geotectonics

The rocks in the Dharamsala-Palampur area show great structural heterogeneity from south to north with distinct geological attributes. According to the classification of Kumar et el. (1989) the study area has been divided into two main belts. The tectonic belts from south to north are as follows:

North
MAIN HIMALAYAN BELT
MAIN BOUNDARY THRUST
FRONTAL FOLDED BELT
South

The Frontal Folded Belt essentially consists of Subathus, Dharamsalas, Siwaliks and recent sediments; whereas the Main Himalayan Belt consists of Dharmkot limestone, Dharamsala traps, Chails and Dhauladhar granites. The various rock units are cut across by transverse faults trending NE–SW or N–S (Mahajan, 1991). These transverse features apart from longitudinal tectonic planes control the main structural pattern of the Dharamsala-Palampur area (Fig. 1).

In the present area, the rock lineaments are distinct and more frequent. The lineament analysis comprises study of their position, density, frequency, etc. as drawn in individual sketches. A systematic study of lineaments, specially faults and thrusts, are of paramount importance to pinpoint area of active tectonics.

Methodology

The available Thematic mapper (TM) imagery of composite bands, 4, 5 and 7 (17 April 1989, NRSA) and LANDSAT, MSS black and white imagery of scale 1:250,000 have been used. The images have been studied by conventional photo-interpretation techniques, i.e. by viewing the imagery for the

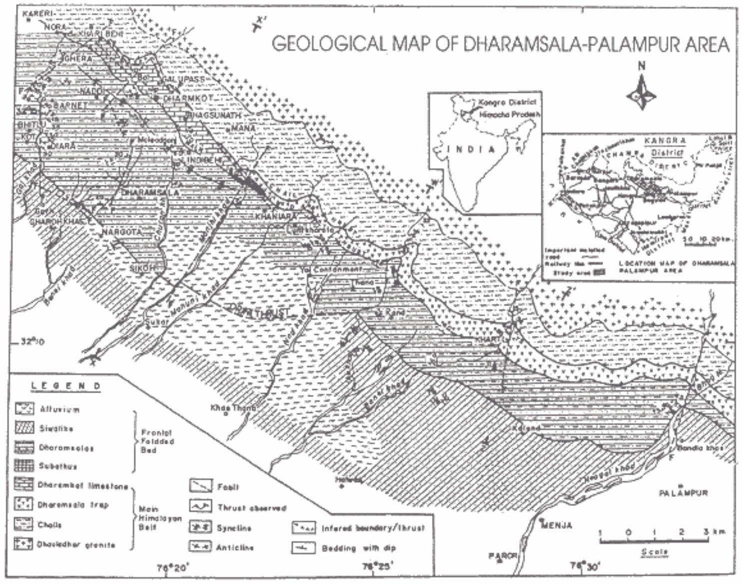

Figure 1. Geological map of the Dharmasala-Palampur area with lineament map and its control on surface geology. Inset shows location of the study area (after Mahajan, 1991).

purpose of classifying and delineating structural features and neotectonic zones. The elements of image interpretation, i.e. size, shape, tone, textural pattern, etc. (Ests and Simonett, 1975) are used for the present purpose.

The most remarkable features noticed on the LANDSAT imageries are generally photolinear (lineaments). They provide significant information about the structure and tectonic framework of the region. The significant lineaments have been tabulated in Table 1.

Table 1.

	Lineaments	Length (km)	Trend
1.	Naddi Lineament	26.67 km	20°–40°
2.	Manjhi Khad Lineament	20.56 km	00°–20°
3.	Yol Lineament	15.56 km	30°–40°
4.	Chachian Lineament	24.44 km	40°–60°
5.	Bandla Lineament	20.83 km	20°–30°
6.	Drini Lineament	37.39 km	290°–310°
7.	Kangra Lineament	16.67 km	34°–38°
8.	Gaggal Lineament	10.28 km	30°–40°
9.	Jia Lineament	21.39 km	325°–340°
10.	Paror Lineament	18.06 km	330°–340°
11.	Palampur Lineament	27.22 km	50°–60°

Classification and trends of the linears

The LANDSAT investigation in the Dharamsala-Palampur area (Himachal Pradesh) reveals a large number of lineaments (Fig. 2). These are generally manifestation of various structural features such as major thrust system as well as individual structural features like faults, fractures etc. According to the definition, lineament is a linear surface feature which may be physiographic (expressing relief) or tonal (expressing contrast). The physiographic expression may be due to either alignment of landforms or boundaries of distinct morphological or rock units or breaks in uniform terrain, while the tonal expressions are mainly due to breaks or discontinuities in uniform terrain or rock units. In the later care they are mostly caused by tectonic processes of faulting and fracturing of rocks and are often attenuated by surface geomorphic processes giving distinct tonal contrast and anomalies. The lineaments are therefore the lines or zones of structural discordance of more regional extent (Hobbs, 1911, Wilson, 1941; Brock, 1957; Lattman, 1958, Hoppin, 1974). The lineament features that were mapped range in length from few kilometers to hundreds of kilometers. In outline they appear as rectilinear or curvilinear features depending on the dip of the structural planes.

Different types of lineaments were not differentiated because they appear quite dense (Fig. 2). Their components are therefore difficult to distinguish from other linears, unless other data, generally known to reveal different types of structural features, are used to aid the analysis.

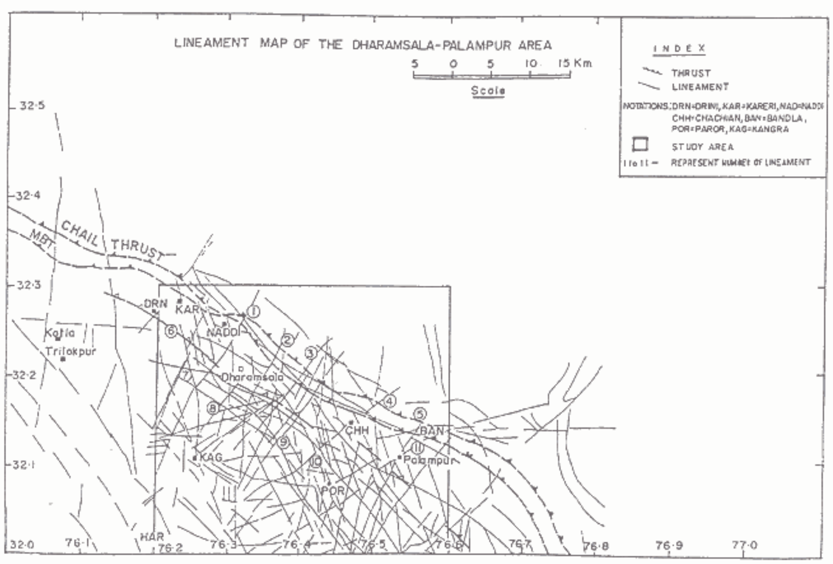

Figure 2. Lineament map of the Dharamsala-Palampur area.

Lineament filter map has been prepared (Fig. 3) in order to differentiate between different azimuthal directions of lineaments and their relation with other parameters. From the lineament filter map it is observed that at many places the demarcated lineament corresponds to faults or other structural dislocations mapped during field work. The information regarding dip, vertical displacement, throw etc. of lineaments could not be found out due to regional scale of imageries.

The regional lineament tectonic pattern and their natural relationship was observed by measuring length and trend of lineaments through the lineament filter map (Fig. 3). Figs. 3a and 3d reflect orientation of source structures at some stage of the geological evolution and later rejuvenation of the corresponding structures in their original position. They reflect a 15°–20° deflection of the corresponding structures within different lithological units and are assumed to belong to the same main trend of crustal shear. It seems obvious that the pattern of crustal shear have played an important role in the evolution of Dharamsala-Palampur area.

The significant trends found (N320°–N360^0, N70°–N110°, N20°–N60° and N300°–N320°) are reflected in bed-rock trend as well as in trends of significant faults and structural zones (i.e. minor fractures, joints, dikes, etc.).

Lineament map (Fig. 3) was filtered in four different azimuthal sectors (Fig. 3a, b, c, d). The filtering was performed with a 40° sector pass filter so that each maximum trend of the lineaments falls within at least one of the azimuthal sectors.

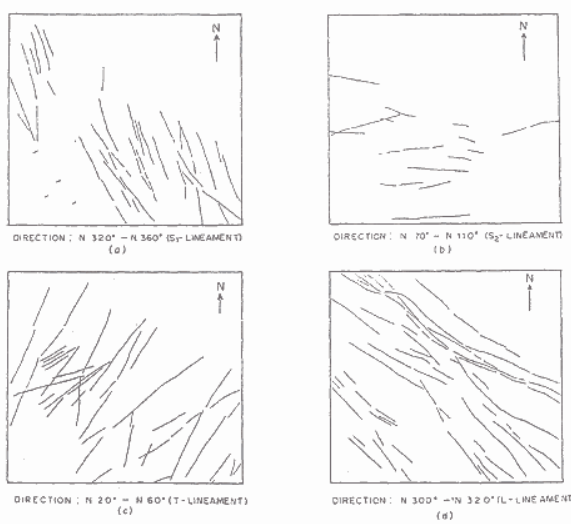

Figure 3. Lineament filter map of the Dharamsala-Palampur area.

The results of filtering show several characteristic features in the distribution of lineaments in different trends (Fig. 3a, b, c, d). Especially the linears shown in Fig. 3d seem to be arranged in zones of longer parallel lineaments extending through the study area, whereas those shown in Fig 3a (the north-northwest lineaments) appear to be more abundant and shorter, mostly confined to the Dharamsala and Siwalik sediments (Fig. 1). The lineaments in sector C (Fig. 3c) are mostly transverse to the lineaments of sectors A and D (Fig. 3a and 3d) and are more abundant in the crystalline and basement complex. Northeasterly transverse lineaments appear in the whole of the Dharamsala-Palampur area and seem to be confined to the basement complex, whereas the lineaments in northwest-southeastern section are confined approximately to the formation boundary and the regional structural trends.

Repeated movements of the different segments at the basement along the various fractures and faults have played an important role in controlling the formation of sedimentation basin, the distribution of various rock types and the various phases of folding and faulting. The zones of Fig. 3d also coincide with the boundaries of basic intrusions. The lineament study has shown that there are long regional features continuing from one image to another. The rose diagram and linear-histogram of lineaments also reveal (Fig. 4) four major sets of lineaments.

L-Lineaments (N350°–N125° and N325°–N145°, longitudinal)

This set of lineaments is termed longitudinal, as it runs almost parallel to the strike of the rock formations. The MCT, MBT and Drini Thrust and other lineaments parallel to these thrusts were classified under this type.

S_1-Lineaments (N345°–N165°, transverse)

This set of lineaments (mostly trending NNW or in N–S direction) is extensively developed in the Dharamsala-Palampur area. They have large

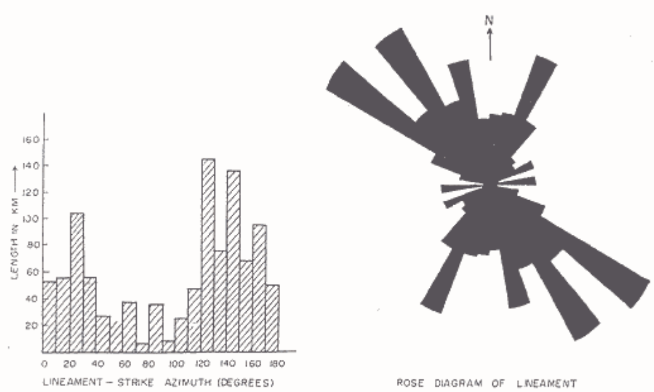

Figure 4. Linear histogram and rose diagram of lineaments of the Dharamsala-Palampur area.

extension running up to 30–40 km in length. They are present in the entire section of the Himalaya. Some of them show predominantly right lateral sense of displacement and appear to have displaced the crystalline nappe of the lesser Himalayan zone.

T-Lineaments (N25°–N205°, transverse)

This set of lineaments is developed in the Dharamsala-Palampur area and northwest of it. Their main characteristic is that they traverse the entire section of the Himalayan belt almost up to the Main central thrust. They show left-lateral sense of displacement. Most of these lineaments follow the drainage pattern of the area with structural dislocations as verified during field survey. The important ones are: Manjhi Khad lineament, Palampur lineament, Yol lineament, Bandla lineament, Gaggal lineament and Jia lineament (Table 1).

S_2-Lineaments (N65°–245°, transverse)

These lineaments are developed more or less oblique to the bedding planes or formational layering, which run oblique and parallel to the rock formation of the Himalaya. They are less developed than S_1-lineaments, and traverse the entire section of the Himalayan formation.

Lineament-tectonic interpretation

All the regional geological lineaments are the product of continent-continent collision between the Indian continent and the Tibet-Karakoram block. The MCT and MBT were developed as shortening structures resulting from the initial collision and subsequent convergence of the Indian plate along the Indo-Tsangpo Suture. This convergence leads to the development of late tertiary thrusts (Qureshy, et al., 1989). The Drini thrust/Palampur thrust (which are also called MBF-II by GSI, Kumar, et al. 1989) in the area also seems to have developed as shortening structures resulting in recent tectonic movements in the area. Several lineaments trending NW-SE almost parallel to each other, imply that the stresses which produced these features were not local but acted in a regional scale to produce a number of failures or weak zones parallel to a particular direction.

Besides the longitudinal lineaments, several transverse lineaments also occur as faults and fractures trending normally and obliquely to the Himalayan trend. The bedding planes of formational layering have also been mapped, which run almost in the E–W direction. Some of the major lineaments in the area are Naddi lineament, Manjhi Khad lineament, Yol lineament, Kangra lineament, Gaggal lineament, Chachian lineament, Palampur lineament, etc. (Table 1).

The longitudinal lineament, i.e. MCT and MBT, seem to have developed first followed by the transverse and oblique faults. The Drini thrust and the Palampur thrust may have also developed later than MBT, as they separate the Dharamsala group from the Siwalik group (Mahajan, 1991). Recent tectonic features and seismic activity have been observed along the Drini thrust, main boundary thrust and some of the transverse lineaments in the area of present investigations.

The stress field

The S_1, S_2 and T sets (transverse and obliques lineament, Fig. 4) present a closely interknit picture. T set of lineaments have suffered left-lateral sense of displacement and the S_1 set a right lateral sense of displacement. The S_2 set bisects the angle between T and L sets and is not accompanied by any displacement. It is inferred that the S_1, T and L sets of lineaments are produced by a major principal compressive stress parallel to S_2, a vertical intermediate principal compressive stress, and a least principal compressive stress oriented parallel to the strike of the S_1 set of lineaments. The dominant longitudinal and transverse lineaments are probably due to the northward push of India against the Eurasian plate.

Seismotectonic implications

The seismotectonic map of the area reveals interesting features when compared with the mesoseismal lines of all the past significant earthquakes (1905 Kangra earthquake and 1978 and 1986 Dharamsala earthquakes) that occurred in the study area (Fig. 5). This suggests that the Dharamsala area is tectonically highly disturbed causing the occurrence of earthquakes in the same compressional zone. The seismotectonic map suggests that the Drini thrust, the main boundary thrust, the Chail thrust and some of the transverse lineaments are tectonically active. The migration trend of the microearthquake activity from 1979 to 1988 shows the seismicity migration pattern along transverse linear features trending north-south and northeast-southwest apart from the activity along northwest-southeast trending lineaments (Fig. 6). The fault plane solutions drawn in the seismotectonic map for the 1968 and 1978 Dharamsala earthquakes suggest activity along the north-south trending lineaments. The isoseismals of 1978 Dharamsala earthquake show the longest axis oriented in a north-northeasterly direction, that may be correlated with the tear fault (Kumar et al., 1979). However the 1905 Kangra earthquake and 1986 Dharamsala earthquake are related with the main boundary thrust and the Drini thrust (Kumar and Mahajan, 1991) trending in northwest-southeast direction.

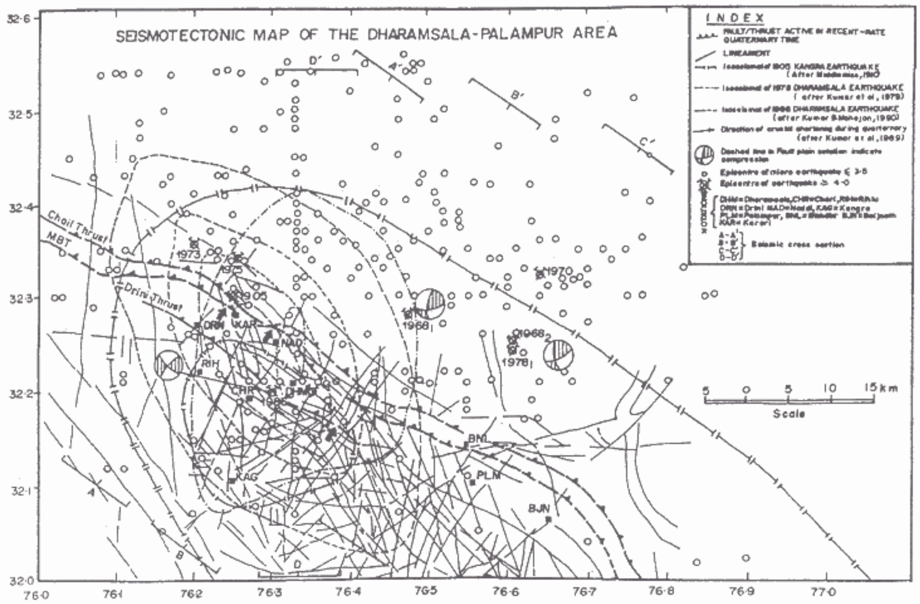

Figure 5. Seismotectonic map of the Dharamsala-Palampur area showing seismicity and fault plane solutions and their relationship with linear features (after Mahajan, 1991).

Conclusions

On the basis of lineament analysis the following conclusions emerge:

1) A large number of longitudinal and transverse lineaments are related to structural features S_1-lineaments show right-lateral whereas T-lineaments show left-lateral sense of movement and show evidence of strike-slip related to the zone of compressional failure. These lineaments seem to be conjugate with each other and related to the stress field with the axes in the following directions: 1 – N65°, 2 – vertical and 3 – N165°–N345°. The bedding plane lineaments might have been in existence ever since the time of sedimentation.

2) The presence of transverse lineaments is observed between Chamba and Dharamsala-Palampur areas. Most of the streams/khads in the area follow these lineaments. Some of the S_1 type and T type lineaments have cut the crystalline nappe in the lesser Himalaya indicating their reactivation in time and space.

3) The seismotectonic map shows that the seismic activity is confined to transverse and longitudinal linear features which delineate the seismic zones. Srivastava et al. (1987) studied the seismicity pattern of Himachal Pradesh and concluded that the earthquakes of 1968 and 1978 do not follow the

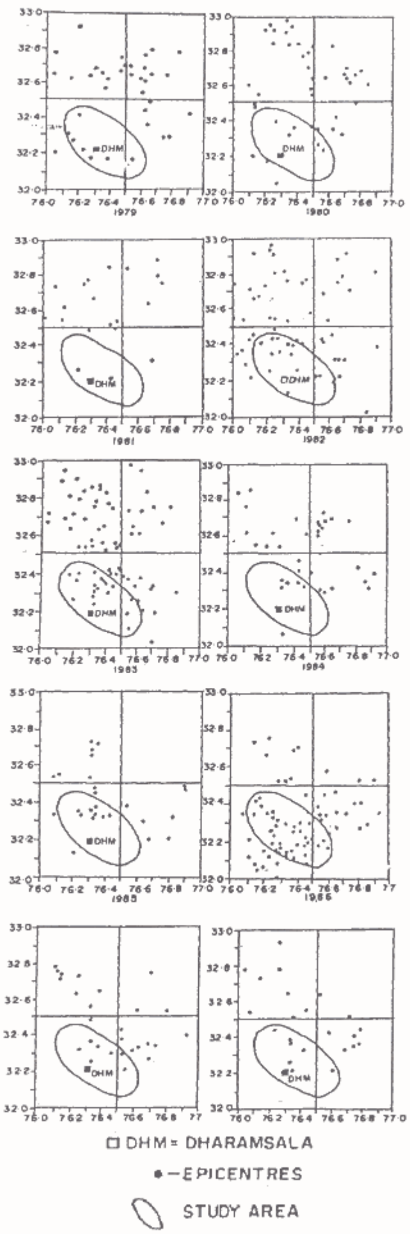

Figure 6. Spatio-temporal variation of seismicity in the study area from 1979 to 1988 and the relation of seismicity migration pattern with lineaments (after Mahajan, 1991).

regional trend but are attributed to the lineaments identified on the basis of Landsat imagery. Kumar and Mahajan (1991) correlated the Dharamsala earthquake with the splays present in between the Drini thrust and the main boundary thrust (Fig. 1).

From lineament study it appears that there are two types of movements occurring in the region – one due to regional tectonics in the basement not exceeding 40 km depth and other due to the neotectonic activity in the sedimentary sequence confined mostly to the 0–10 km depth (Mahajan, 1991).

When lineament map is overlaid over the geological map of the area (Fig. 1) it is observed that the faults marked on the basis of geological studies are in good agreement with the lineaments (Fig. 2).

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Corresponding author's address: A. K. Mahajan, Wadia Institute of Himalayan Geology, Dehradun – 248001 India