CHAPTER 4

ANALYSIS OF DRAINAGE SYSTEMS AND THEIR RELATION WITH STRUCTURAL AND TECTONIC LINEAMENTS
ANALYSIS OF DRAINAGE SYSTEMS AND THEIR RELATION WITH STRUCTURAL AND TECTONIC LINEAMENTS

The Earth’s surface is so much fascinating as characterized by a number of structural, tectonic and topographic features. And these topographic features are directly or indirectly a complex architectural set-up related to the internal mechanics of plates movement which is more specifically influenced by mantle dynamics. Redefining this concept, it can be stated that all the geomorphic/topographic features of a region, in a much simplified manner, are the systematically arranged network of linear expressions reflecting the subsurface geological, structural and tectonic configuration of that region. Such intimate relationship between geologic and tectonic structures and topographic features, which have always been important research fields in modern geomorphology rather tectonic geomorphology (Gerasimov, 1946; Biot, 1958; Twidale, 1971) have stimulated a number of researchers in many parts of the world particularly in the study of the role of tectonics/neotectonics on the development of topographic features (Scheidegger, 1980, 1983; Ollier, 1981; Lanzhou and Scheidegger, 1983; Diamant et al., 1983; Morisawa and Hack, 1985; Cicacci et al., 1986; Caputo et al., 1993; Leeder, 1993 and Hovius, 2000). Assuming drainage systems as surface reflections of subsurface controlling structural and tectonic features, systematic study and analysis of the drainage systems of a particular region will enable us to reconstruct some of its tectonic evolutionary history specially in terms of its deformation mechanism, stress condition, sequence of evolution etc.

In and around Chandel district, there is close relationship between the structural and tectonic lineaments, and drainage systems. Specially the third and higher order streams and rivers are more or less exclusively controlled by tectonic structures while that of the first order streams are directly or indirectly related to neotectonic activities (cf. Centamore, et al., 1996). Antiforms are characterised by valleys which are eroded and occupied by streams and synforms by ridges. The most striking aspect displayed by majority of the streams and rivers of the district is the
transverse to oblique relationship to the regional trend which is very common particularly in thrust belts in many parts of the world. This chapter, therefore, attempts to provide the possible scientific explanations of the following aspects:

Is there any relationship between the topographic features and tectonic set up of Manipur? What is the mechanics that generally prevents thrust belts occupied by rivers or streams courses? And is there any preferred orientation of the streams and if it is so, what controls or influences them?

Prior to analyse the drainage system of the district and describing its relationship with tectonic lineaments, let us first see the analysis of structural and tectonic lineaments of the district and its outcome.

4.1 ANALYSIS OF STRUCTURAL AND TECTONIC FEATURES AND LINEAMENTS

According to O’Leary et al. (1976) “a lineament is a large scale mappable, simple or complex linear feature which could be either rectilinear or slightly curvilinear having distinct pattern from the adjacent features that reflects a subsurface phenomenon.” This definition reveals that all topographic features qualify to be called lineaments as long as they are observable as surface expressions of buried structures. They are generally manifested by topography including straight stream segments, vegetation or soil tonal alignments (Lattman and Parizek, 1964). Large scale faults or joints in rocks are the surfacial manifestation of the lineaments. Interrelationship between lineament and drainage network is a product of tectonic deformation.

In this section, an attempt is made to analyse the structural and tectonic lineaments of the district in order to establish their preferred orientations from which stress field can be evaluated with respect to the regional compression and extension directions.
The analysis adopts the following methods and steps.

A map of structural and tectonic features, and lineaments has been prepared (Fig. 4.1) on the basis of image interpretation of satellite data such as LANSAT TM, IRS 1C, LISS III, SPOT, PAN imageries, field checks and mapping data as well as published literatures.

Structural and tectonic features and lineaments are picked up on the basis of trends of morphological features such as straight ridges, discontinuities, straight river segment, abrupt turning in river course, escarpments, alignment of landforms and tonal textural contrasts etc.

From the lineament map, azimuths of about 123 lineaments viz, folds, faults, fractures etc. of usually 4km or more in magnitude are measured and analyzed.

Rosette and histogram plots (Fig. 4.2 A, B) are drawn where a class interval of 10° is used for the trend of lineaments. From the rosette and histogram plots, principal orientation directions of the compression, extension and transcurrent structures are evaluated (Fig. 4.3A) on the basis of regional compression and extension given by Soibam (2006).

4.2 INTERPRETATION OF THE DIAGRAM

The preferred orientation of the structural and tectonic lineaments shown in Fig. 4.2 A indicates high frequency around certain azimuths. For instance, the maximum concentration of structures/lineaments around N15°E-S15°W could be the cluster of compressive structures such as folds, reverse and thrust faults since this direction is parallel to the regional tectonic trend. The other preferred orientations around N45°W-S45°E and N55°E-S55°W may be all shear fractures (Fig. 4.3B) as these are developed at some angular relationship with the N15°E-S15°W direction as per the theory of brittle failure. The concentration around N45°W-S45°E can be that of antithetic shears or conjugate Riedel shear (R) while the other group N55°E-S55°W could be master faults parallel to the regional shearing direction (Soibam,2006) which could also be termed as Y-shears as per the nomenclature of
Fig. 4.1 Structural and Tectonic features, and Lineaments of the Chandel district and its adjoining region.
shears provided by Allen and Allen (1990, p121). Although no prominent preferred orientation around WNW-ESE (N75°W-S75°E) normal to the orientation of the regional compression structures is observed, a few lineaments are found trending around this direction.

Fig. 4.2B displays the relationship between the number and average length of the lineaments, structural and tectonic features. The compatibility between the curves suggests that not only high number of lineaments concentrate around the compression direction but relatively large and long lineaments also develop around the same direction. Although there are some variations, the overall distribution and preferred orientation patterns indicate that the structures/lineaments were formed by a WNW-ESE compression under the response of a particular stress field.

4.3 ORIENTATION OF STRESS FIELD

Interpretation of analysed diagram (Fig. 4.2A) indicates that the generalized trend of the compression structures is N15°E-S15°W (NNE-SSW). This trend will, therefore, be perpendicular to the compression direction and parallel to the extension direction of the stress field. Thus, the compressive force acts in N75°W-S75°E (WNW-
ESE) direction. Assuming this as the orientation of the principal compressive stress component, a number of structures developed under the response of the stress field can be deduced as shown in Fig. 4.3 A. From the figure, it is seen that there is specific angular relations between the structures and the compression direction and/or extension direction. Compressive structures such as folds, reverse and thrust faults are normal to the compression while the extensional structures e.g. normal faults, tension fractures etc. are parallel to the same. The extension direction N15°E- S15°W (NNE-SSW) is also characterized by development of structures such as boundinage and pinch and swells (Price and Cosgrove, 1990). Under the same stress field, we can get two more sets of fractures or faults according to the theory of basic mechanics of faulting and fracturing. These two sets of fractures represent the transcurrent or strike-slip faults/fractures develop at about 30° on either side of the compression direction. Theoretical discussion on the development of these structures in certain angular relation to each other under the mechanics of brittle failure is beyond the
Fig. 4.2 Rosette and curves of structural and tectonic features, and lineaments. A. Rosette showing trend vs number of all lineaments. B. Curves showing comparison between number and average length of lineaments.
Fig. 4.3 A. Orientation of compression and extension stress components of the Chandel district and the possible structures that can form under the stress field. Figures below are the principal stress orientation of the faulting in the region. B. Azimuths of maximum concentration of lineaments of the Chandel district for comparison with the diagram above.
scope of the present work, but can be referred to any standard structural geology texts e.g. Price and Cosgrove, 1990; Twiss and Moores, 1992 etc.

Comparison of the orientation of these structures with the major concentration azimuths of the lineaments (Fig. 4.3 B) as well as with Fig. 4.2 shows good compatibility, though there is a minor swing of about 5°-10°. It can be envisaged from the two compatible results that the structures in the district possibly developed under a fairly uniform stress field as indicated in Fig. 4.3A.

4.4 DESCRIPTION OF STRUCTURAL AND TECTONIC LINEAMENTS

Analysis of the structural and tectonic features and lineaments of the Chandel district as well as the resultant stress field has been deciphered in the foregoing sections. In this section, a brief description about the major structural and tectonic lineaments (major thrusts) found in the district is highlighted based on the field observation in terms of their nature, geometry, spatial relationship etc. as represented in Figs. 2.2 and 4.1. Although the subsurface configuration of the thrust faults are not clearly known, their spacing seems to be regular possibly in conformity with the geometric principles of thrust tectonics (Dahlstrom, 1969) since the hills of Manipur behave as a trailing imbricate thrust system (Soibam, 1998).

4.4.1 Tengnoupal-Narum Thrust (Ophiolite Thrust)

The Tengnoupal-Narum Thrust which is also termed as Ophiolite Thrust (Soibam, 1998) runs on the western side of the Ophiolite Melange Zone overthrusting the relatively younger Disang-Barail flysch sediments. On the eastern side of Tengnoupal near Khongkhang, there occurs approximately one and half Km wide highly crushed and weathered zones which characterize this thrust on the east of which ophiolitic bodies appear. This thrust seems to be branched out in the neighbouring Ukhrul district into smaller ones in the form of diverging and rejoining splays (Soibam, 1998). A detailed account on the thrust systems and various terminologies associated with thrust tectonics can be had from Boyer and Elliot (1992), Mc Clay (1992), etc. Although the actual displacement along this thrust is not known, it could be the main mantle rooted thrust as it has brought the ophiolitic rocks against the Disang-Barail flysch sediments as discussed in Chapter 2. And the
thrust sheet lying above it may be composed of a number of splays as indicated by interweaving/sandwiching nature of shale and ophiolitic bodies (Fig. 2.3). It is possible that all these splays may join the main mantle ophiolitic thrust at depth.

Association of anticlinal fold(s) as fault bent fold is, however, not observed in and around Tengnoupal-Narum Thrust. But, rivers and streams usually flow across this thrust zone, which is a typical feature of a major thrust zone (section 4.5.1). The Tengnoupal-Narum Thrust is generally moderate to high angle easterly dipping thrust. But at places, Ophiolite bodies are found dipping westerly possibly characterizing backthrusts or dip-reversal due to thrust flowering resulted from inversion of the thrusts, detail investigations of which are needed.

4.4.2 Chandel Thrust

This thrust is well developed along the Maha river (Fig. 4.1) through the district headquarters, Chandel and hence the name Chandel Thrust is given. It is found to be an anticlinal thrust where the fold itself is likely propagated by the thrust as a fault-bent fold. Because these types of fold are commonly found associated with thrust orogenic belts. A detailed study on various aspects of faults-bent folds can be found in Suppe, 1983 and 1985.

Wide occurrence of a number of exotic sandstones at Liwa Sarei area where the Maha river passes through, as well as their continuity towards south in and around Modi area or in another expression, the dissimilar rocks juxtaposed across the Maha river at Liwa Sarei area, confirms its thrust nature. The thrust continues northward through the Thoubal river and then the so called Thoubal thrust follows the Laniye river course and beyond forming a large regional thrust/lineament. It is also a high angle thrust dipping towards east as evident from the thrust bent anticline. Like the Tengnoupal –Narum Thrust, it also displays some sort of rejoining splay/imbricate on the northern part towards the western side of Ukhrul area (Soibam, 1998). Besides, the Chandel thrust sheet may also be made up of a number of leaning slices or horses, although not easily distinguishable in the field due to monotonous shale nature, as evident from small scale duplexes (Fig. 2.45).
In addition to the major thrusts mentioned above, the district has some important small transcurrent structures. Large scale transcurrent or strike-slip faults are few in number but some of the smaller ones such as Wangjing, Heirok, Langathel faults etc. are found in the north western part of the district while some similar ones are also found in the southern part of the district (Fig. 4.1). These faults and fractures usually trending in the NW-SE direction are commonly characterized by rivers and large streams. Sometimes these structures are found in association with small thrusts. Because strike-slip faults can end up into either normal faults or thrust faults (Twiss and Moores, 1992) depending upon the shearing or slipping direction of the fault. Possibly strike-slip faults as well as extension fractures act as connecting splays between larger thrust faults and folds. This could be one of the important reasons of lacking high frequency of large transcurrent and/or extension structures in the region.

Now let us proceed in the analysis of drainage systems of the Chandel district and its adjoining regions in order to study the intimate relationship between drainages and tectonic and structural lineaments.

4.5 ANALYSIS OF DRAINAGE SYSTEMS

In the discussion on topographic and drainage systems of the Chandel district (Chapter 1), it has been mentioned that there is a close relation between the topographic expressions, drainage patterns and structures of the region. It is also observed from the drainage map of the Chandel district (Fig. 4.4) that there are parallel and sub-parallel ridges with intervening valleys. The ridges are frequently cut across by short and transverse stream courses. Majority of the streams have sharp turnings before joining the main stream/river course or otherwise, when they change their courses. The tributaries also join the main course at relatively high angles. All these features probably indicate a more or less structural control of the drainage of the region. It is therefore, aimed at analyzing the drainage systems using simple statistical techniques in order to examine whether there is any relation between the structures and drainages of the area. The techniques and procedures adopted in the analyses are as follows:
Fig. 4.4 Drainage system of the Chandel district and its adjoining regions. The areas marked by B, T, R, and P indicate barbed, trellis, radial (centrifugal type) and sub-parallel to parallel drainage patterns respectively.
(i) The drainage map of the Chandel district and its adjoining area is prepared (Fig. 4.4) based on the Survey of India (SOI) topographic maps on 1:250000 (degree sheet) scale.

(ii) From the drainage map, about 263 streams and rivers of the second and higher order having a length of about 4 km or more have been counted and their azimuths have also been measured. The scale used cannot cover all the first order streams and so, their measurement, analysis and interpretation are highlighted in section 4.5.4. Analyses of the drainage systems of the whole district and separately for the three smaller systems (a) Yu-Khampat river system (b) Chakpi river system and (c) Sekmai river system have been conducted. The purpose of analyzing the three separate systems mentioned above is to examine whether there is a systematic change in the preferred orientation of the streams. Selecting streams of 4 km or more in length is to maintain the compatibility between the streams and lineaments.

(iii) Graphic representations in the form of rosettes and histogram curves are drawn for stream azimuth vs number and azimuth vs average length (Figs. 4.5 and 4.6). A class interval of 10° is used as in the case of lineament analysis.

(iv) From the diagrams, preferred orientation directions are evaluated and their relationship with the structural and tectonic lineaments is examined. And the factors and/or mechanisms basically controlling the drainage system of the region are further studied.

4.5.1 Yu-Khampat River System

A brief description of the river system has already been provided in Chapter 1 that the Yu-Khampat rivers flow through the Kabaw or Tamu valley of Myanmar. But they have been studied as a separate and important river system of the Chandel district since almost all the major streams and tributaries of the system arise from the eastern hills of the district and its neighbouring Ukhrul district. One of the most striking aspects of the river system is that with the exception of the Yu-Khampat rivers, the basin is exclusively devoid of NNE-SSW (N-S) trending streams which are common in the western and south-western parts of the region. In other words, it can be stated that very few streams run parallel to the regional strike but generally transverse to oblique to the regional strike. Such a situation gives rise to an asymmetric pattern of the drainage (Fig. 4.4) which can only be attributed basically to structural control of these streams.
Analysis of about 186 streams of the Yu-Khampat river basin is shown as rosette of stream azimuth vs number (percentage) in Fig. 4.5A. Highest concentration of streams is observed in N45°W direction and other major concentration directions are N75°W and relatively less along N05°E, N65°E. From the preferred orientation patterns, it is evident that the azimuth of stream concentration shows good compatibility with that of the lineaments (Fig. 4.1) though there is a swing of about 5-10°. For example, stream concentrations around N45°W and N65°E correspond to the N45°W and N55°E directions of lineament concentrations. Similarly the N05°E may correspond to the azimuths of compression structures or fractures developed parallel to them. And the concentration around N75°W is clearly the direction of compression and hence the tensile structures. From these, it is evident that the high concentrations of streams transverse to oblique to the tectonic trend of the region of this river system are not independent of structural and tectonic control. Because, had the streams been originated as a function of slope, they should have uniformly concentrated and distributed around the direction normal to the topographic longitudes, i.e., the regional strike.

The most remarkable aspect of the Yu-Khampat basin is that this basin is generally marked by thrust faults (Figs. 2.2 and 4.1) and lacks in antiformal and synformal folds. This could be one of the prime reasons why the basin is principally characterized by transverse to oblique drainage rather than the longitudinal ones. Thrust belts, as in the case of other orogenic belts of the world, are usually characterized by transverse to oblique drainage systems. Such drainage systems, could be, by and large, controlled by strike-slip and normal faults and similar fractures; and the concept of antecedent origin of these transverse streams is unlikely as pointed out by Oberlander (1965, 1985). In the same manner, the streams and rivers of the Yu-Khampat river system may also be, to a great extent, controlled by the transverse to oblique fractures produced during the IMR tectogenesis thereby causing to run across the thrust sheets. The simple mechanics why the occurrence of streams along the thrust faults is not permissible shall be examined at a latter section 4.6.
Fig. 4.5 Graphic representation of the stream analysis of the Chandel district and its adjoining regions as shown by rosettes of the stream azimuths vs numbers. A. Yu-Khampat river system, B. Chakpi river system and C. Sekma river system
4.5.2 Chakpi River System

The Chakpi river drains the central as well as the southwestern part of the Chandel district. It has been mentioned earlier in Chapter 1 that it originates from the high hill ranges of Tengnoupal, Moltuk, Joupi etc. and meets the Imphal river at Serou where its course changes in direction displaying barbed pattern. Such features may reflect a signature of tectonic control. The maximum concentration of streams and tributaries of this main river is in the NW-SE quadrant while some of its tributaries run more or less parallel to the regional trend.

Graphic representation of analysed data of about 45 streams in the form of rose diagram is presented in Fig. 4.5B displaying preferred orientation of the streams in some particular directions. The maximum concentration direction lies around N35°W while other concentration directions are around N20°E, N55°E and N80°W. All these directions reveal structural control since they have similar azimuths with that of the lineaments (Fig. 4.1). Moreover, the increase in the frequency of streams parallel to the regional strike, in comparison with that of the Yu-Khampat river system is evidently shown by the Fig. 4.5B. This might be due to the increase in number of streams that are associated and parallel to the antiformal folds of the region. It can also be observed in Fig. 4.1 that the southwestern part of the district is well characterized by antiforms and synforms. The crestal zone of these folds (antiforms) might have been eroded in course of geological past and get occupied by streams. This is probably one of the most important reasons of increase in the abundance of NNE-SSW trending streams in the southwestern part of the district.

4.5.3 Sekmai River System

This river system occupies the northwestern part of the district. Some of the neighbouring streams such as the Wangjing river, the Heirok river and the Langathel river originated from Machi-Langgol hill range, flow in SE-NW direction, that is, transverse to oblique to the regional strike indicating an interesting drainage pattern. On the other hand, the Maha river nearly trends in N-S direction parallel to the regional strike. All these preferred orientations are the reflections of the controlling structural features.
Analysis of about 32 streams of this river basin reveals another interesting as well as preferred orientation pattern of the streams (Fig. 4.5C). In the Fig. 4.5C, four important concentration directions viz. N55°W, N05°E, N45°E and N65°E are well observed with maximum concentration along N55°W. These directions are also compatible with that of the lineaments of the district (Fig. 4.1) even if there is some variation in the direction. For instance, N45°W trending streams such as the Heirok river, the Wangjing river and Langathel river may correspond to the antithetic shear fractures while the N-S trending Maha river developed parallel to the regional strike may correspond to the compression structures. It is clearly evident from the field setting that this river is developed along the so called Chandel Thrust which is probably a thrust propagated anticline/antiform.

Another interesting observation is that as we approach from the Yu-Khampat river system to the Chakpi river system, it is observed that there is some increase in the frequency of streams trending NNE-SSW parallel to the regional strike (Fig. 4.4). This has been caused probably due to increase in anticlinal and synclinal folds produced either simply by buckling or as fault/thrust bent folds. Similarly, when we approach from the Chakpi river basin to the Sekmai river basin, though there is no remarkable change, certain increase in frequency especially of the streams trending nearly parallel to regional compression (WNW-ESE) and normal to regional strike (NNE-SSW) is observed. This phenomenon, therefore, deserves some explanations. Probably the increase in the number of small transverse streams was resulted from the frequently developed extension fractures of the relatively competent rocks such as sandy and silty dominated rocks in Langgol and adjoining areas of the basin. Thus, when the region undergoes extension in the NNE-SSW direction, these relatively competent rocks suffer more tensional fracturing than the incompetent Disang shales, which principally suffer flow or ductile deformation. Another possibility is that the evolution of Imphal valley as a transtensional basin (Soibam & Hemanta, 2007) due to NNE-SSW stretching might have been influenced development of stream courses nearly parallel to the regional compression direction (WNW-ESE).
4.5.4 Whole River System

It has been observed from the analyses of the three river systems of the Chandel district that there is a close relationship between the drainage and structural and tectonic lineaments of the region. Now let us examine the overall spatial distribution patterns of the streams of the district by combining analyses of the three river systems with some other major streams found in the district.

About 263 streams have been measured and their azimuths have been graphically plotted as rosette in Fig. 4.6. As in the case of the other river system of the district, analysis of the whole river system of the district display preferred orientation patterns around certain directions. Two-thirds of the streams lie within two particular azimuths of 280°-330° and 10°-30° with concentration directions around N45°W, N20°E and N65°E. These directions have some specific angular relations to one another and well in agreement with the stress field of the region and the structures that may form in response to the stress field (Fig. 4.3A). So, the streams that trend around N45°W (Fig. 4.6A) may well be controlled by antithetic shear fractures or conjugate Riedel Shear (R'). On the other hand, the group of streams trending N20°E may correspond to the compressive structures such as folds and other associated longitudinal fractures while streams around N65°E may correspond to the synthetic shear or Riedel shear (R). One interesting observation is that streams parallel to compression direction (N75°W-S75°E or E-W) are less in number or otherwise they have been overshadowed by streams trending N45°W- S45°E.

In order to study and examine the compatibility between the streams and lineaments of the district, histogram curves are drawn superposing one above the other and shown in Fig. 4.6B. Although there is a minor variation of about ±5°-10° in the orientation trend, the average length of the streams show good compatibility with that of the lineaments. But the compatibility between the stream numbers and the lineaments is less conformable, because fluctuation is much more in case of lineaments, particularly in the NE-SW direction. An important observation made from the figure is that large concentration of streams in a particular direction does not necessarily mean higher average length, the possible reasons of which is that a long stream or river may be composed of a number of segments.
Fig. 4.6 Graphic representation of the whole river system of the Chandel district and its adjoining regions. A. Rosette of stream azimuth vs number. B. Histogram curves of streams and lineaments.
In order to study the influence of topography, slope and other geomorphic parameters, a large number of streams of first order and other higher order were measured using SOI topographic maps on 1:50,000 scale. About 2760 streams azimuths as well as the lengths of the whole river system of the district were measured, of which 1517 belongs to first order streams and 1243 to second and higher order. Similarly, about 1510 stream azimuths and the lengths from the Yu-Khampat river system, 830 from the Chakpi river and 420 from the Sekmai river system were measured separately. The number of streams measured for different river system is shown in Table 4.1 where their azimuths and lengths are not included in order to avoid voluminous coverage of pages.

Table 4.1 Number of streams measured for the different river systems of the Chandel district.

<table>
<thead>
<tr>
<th>Name of the river system</th>
<th>Number of first order streams</th>
<th>Number of second &amp; higher order streams</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yu-Khampat</td>
<td>817</td>
<td>693</td>
<td>1510</td>
</tr>
<tr>
<td>Chakpi</td>
<td>467</td>
<td>363</td>
<td>830</td>
</tr>
<tr>
<td>Sekmai</td>
<td>233</td>
<td>187</td>
<td>420</td>
</tr>
<tr>
<td>Whole river system</td>
<td>1517</td>
<td>1243</td>
<td>2760</td>
</tr>
</tbody>
</table>

Graphic representation in the form of histogram for the three river systems as well as the whole river system of the district is shown in Figs. 4.7, 4.8, 4.9, and 4.10 respectively. The preferred orientations of the streams observed in the above figures are highlighted in Table 4.2.

Table 4.2 Preferred Orientations of the streams of the different river systems of the Chandel district.

<table>
<thead>
<tr>
<th>Name of the river system</th>
<th>Preferred Orientation directions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First order streams</td>
</tr>
<tr>
<td>a. Yu-Khampat</td>
<td>N15°E, N75°E, N55°W,N85°W</td>
</tr>
<tr>
<td></td>
<td>Second &amp; higher order streams</td>
</tr>
<tr>
<td></td>
<td>N15°E, N45°E, N65°E, N35°W, N75°E, N55°W</td>
</tr>
<tr>
<td></td>
<td>Combination</td>
</tr>
<tr>
<td></td>
<td>N15°E, N45°E, N75°E, N55°W, N85°W</td>
</tr>
<tr>
<td>b. Chakpi</td>
<td>N25°E, N65°E, N55°W,N85°W</td>
</tr>
<tr>
<td></td>
<td>N35°E, N65°E, N35°W, N65°W</td>
</tr>
<tr>
<td></td>
<td>Combination</td>
</tr>
<tr>
<td></td>
<td>N30°E, N65°E, N65°W, N85°W</td>
</tr>
<tr>
<td>c. Sekmai</td>
<td>N40°E, N65°E, N05°E, N75°W</td>
</tr>
<tr>
<td></td>
<td>N-S, N25°E, N45°E, N85°W</td>
</tr>
<tr>
<td></td>
<td>Combination</td>
</tr>
<tr>
<td></td>
<td>N45°E, N65°E, N05°W, N85°W</td>
</tr>
<tr>
<td>Whole river system</td>
<td>Combination of first, second and higher order streams of a, b and c.</td>
</tr>
</tbody>
</table>
From the above Table 4.2, it is observed that there is a wide range of the preferred orientations of the streams in each river system irrespective of first, second and higher order streams and their combination thereof. However, majority of the preferred orientations of the streams such as N15°E, N45°E, N55°W and N85°W are more or less compatible with that of the lineaments of the region (Fig. 4.1) even if there occurs variation of about 5°-10°.

From the bar histogram (Fig. 4.10B), it is also observed that the longer streams/rivers develop along the major concentration directions of the lineaments of the district. However, the high concentration azimuths are not necessarily marked by long streams but by large number of nearly equal lengths. Such observation is slightly reflected in the combined bar graph of the whole river system of the district probably due to the combined effects of a large number of streams.

Analysis of about 2760 streams of the whole river system of the district reveals some interesting feature that the maximum concentrations of the streams lie around N15°E, N45°E, N65°E and N55°W (Fig. 4.10A) which are also well compatible with the lineaments as well as the structures that may develop in response to the stress field (Fig. 4.3A) of the region. One important observation is that the maximum number of streams measured is greater in number for the first order streams than the higher order streams and therefore, the resulting orientation patterns shown in Fig. 4.10A might have been dominated by the preferred orientations of the first order streams. That is why, the NW-SE trending prominent streams such as N45°W do not reflect much in the above figure except the group of streams trending N85°W which develop along the compression orientation of the region or otherwise, for first order streams there could be some influence of geomorphic parameters such as slope or combination of geomorphic parameters and lithology beside structural control.
Fig. 4.7 Graphic representation of the stream analysis of the Yu-Khampat river system. A. Rosette of the first order stream azimuth vs number. B. Rosette of the second and higher order stream azimuth vs number. C. Rosette of the combination of the first, second and higher order stream azimuth vs number. D. Histogram of the total stream azimuth vs average length.
Fig. 4.8 Graphic representation of the stream analysis of the Chakpi river system. A. Rosette of the first order stream azimuth vs number. B. Rosette of the second and higher order stream azimuth vs number. C. Rosette of the combination of the first, second and higher order stream azimuth vs number. D. Histogram of the total stream azimuth vs average length.
Fig. 4.9 Graphic representation of the stream analysis of the Sekmai river system. A. Rosette of the first order stream azimuth vs number. B. Rosette of the second and higher order stream azimuth vs number. C. Rosette of the combination of the first, second and higher order stream azimuth vs number. D. Histogram of the total stream azimuth vs average length.
Fig. 4.10 Graphic representation of the whole river system of the Chandel district. A. Rosette of the stream azimuth vs number, B. Histogram of the total stream azimuth vs average length.
4.6 MECHANICS OF STRUCTURAL CONTROL ON STREAMS

In the previous sections, it has been observed that majority of the streams of the Chandel district do occur following certain preferred orientation patterns which are well compatible with that of the structural and tectonic features of the region. Now it is worth to study the possible mechanics that how certain structures control the streams while others do not. In order to study such aspect, let us recall the stress field rather palaeostress field and the deformation mechanism of the region exemplified in Fig. 4.3A. The figure displays regional compression (C) in the WNW-ENE direction and extension (E) in the NNE-SSW direction which is resulted from an approximate NE (N60°E) shearing (Soibam, 1998, 2006). And the structures that can form under such a stress field are all shown in the figure where compression structures such as folds, reverse and thrust faults run parallel to regional extension direction, NNE-SSW (N15°E-S15°W). Extension structures such as normal faults, tension joints and other fractures orient themselves in a direction normal to the compression structures i.e., parallel to the compression direction (N75°W-S75°E) while strike slip faults lie in the NE-SW and NW-SE quadrants respectively as synthetic and antithetic shear fractures. Hence, let us now briefly study how these various structural elements control the occurrence of the streams and what is the simple mechanics that permit to do so. Similar type of study on close relationship between structures and drainage has also been made by a number of workers e.g. Thornbury (1969), and even their relationship with regional stress fields has also been discussed by Scheidegger (1983).

4.6.1 Compression Structures

As mentioned above, folds (antiforms and synforms), reverse and thrust faults are the common compressional structures. Among these, antiforms (or anticlines) and synforms (or synclines) are by far the most common structures that control stream occurrences as shown in Fig. 4.11. Fig. 4.11A depicts antiforms and synforms resulted from buckling or other mechanisms. In the process the outer arc of the folded layer is extended due to bending of the strata and so, a number of longitudinal tension fractures/joints (T1) develop nearly parallel to the fold hinge. In addition to these longitudinal fractures, other transverse tension fractures (T1) may also develop under the response of the regional extension (E) and/or compression.
Fig. 4.11 Evolution and development of drainage system and topographic inversion representing through buckled antiforms and synforms (after Soibam, 1998, Soibam and Pradipchandra, 2006)
(C), and the localized extension of the beds parallel to the axis. So, the closure or hinge zone of the antiforms may be characterized by open fractures. These open fractures provide easy passage of water causing fast mechanical as well as chemical weathering of the hinge zone. This process, therefore, permits fast and gradual topographic inversion around the hinge zones of the antiforms. Thus, with complete and matured topographic inversion, the antiformal axes convert to valleys while the synformal axes become ridges (Fig. 4.11C). This type of drainage and structural relationship is very common in the central and eastern parts of the district.

In the analysis of Yu-Khampat river system, it was mentioned that there is considerably less number of streams that follow the regional strike. It was also mentioned that this phenomenon might be due to the thrust faults present in this part of the district, since thrust belts are usually characterized by transverse to oblique drainage as pointed out by Oberlander (1965, 1985). So, there should be some mechanical aspects that prevent occurrence of streams along the thrust faults. In order to explain such nature, the state of stress acting on the fault plane, in terms of normal stress \( \sigma_n \) and shear stress \( \sigma_s \) will be considered. The easiness of eroding the rocks along the thrust zone or plane depends on the openness of the fault plane itself. That is, whether the fault will remain open or not will be determined by normal stress \( \sigma_n \) acting perpendicular to the plane. Now expressing these stress components, acting on the fault, in terms of the principal stresses, \( \sigma_1 \) (maximum) and \( \sigma_3 \) (minimum) under plane stress condition, we get,

\[
\sigma_n = \frac{\sigma_1 + \sigma_3}{2} - \frac{\sigma_1 - \sigma_3}{2} \cos \theta \quad (4.1)
\]

\[
\sigma_s = \frac{\sigma_1 - \sigma_3}{2} \sin \theta \quad (4.2)
\]

where \( \theta \) is the angle between the fracture and the maximum principal stress.

Details of deriving the equations either as plane stress analysis or as Mohr's stress circle can be referred to any standard text book of structural geology or rock mechanics e.g. Ramsay (1967), Hobbs et al. (1976), Jaeger and Cook (1979), Price and Cosgrove (1990), Twiss and Moores (1992) etc. In equation (4.1), if \( \sigma_n \leq 0 \), the fault may remain relatively open thereby permitting passage of water allowing both mechanical and chemical weathering. That is to say, the least value of normal stress should be either 0 or tensile (i.e., negative) in character, then only the fault may be
relatively opened. From the above equation, it is seen that the minimum value of the normal stress can be obtained when \( \theta = 0^\circ \), that is, a condition where component of the maximum principal stress on the plane is minimum or 0, since \( \sigma_1 \) is parallel to the thrust plane. Putting \( \theta = 0^\circ \), in the same, then the whole equation can be reduced to \( \sigma_n = \sigma_3 \), that means the least possible value of the normal stress is equal to the minimum principal stress. And so, the closeness or openness of the fault will be determined by the magnitude and nature of the minimum principal stress, \( \sigma_3 \). In other words, if \( \sigma_3 \) is compressive (+ ve) the fault will not be opened and if \( \sigma_3 \) is tensile (- ve), the fault will be opened relatively.

For thrust faults, as we know \( \sigma_3 \) is oriented vertical while \( \sigma_1 \) and \( \sigma_2 \) are horizontal (Fig. 4.3A). As a result, magnitude of \( \sigma_3 \) will be given by the weight or gravity of the upper block i.e., hanging wall. Rewriting this in the form of an equation we have,

\[
\sigma_3 = \rho gh
\]

where, \( \rho = \) average relative density of the hanging wall block, \( g = \) acceleration due to gravity, \( h = \) average thickness of the upper block (or the depth at which fault is to occur). And for faulting to occur,

\[
\sigma_1 = C_0 + \tan^2 \alpha \sigma_3
\]

i.e.,

\[
\rho gh = \frac{(\sigma_1 - C_0)}{\tan^2 \alpha}
\]

where \( C_0 = \) uniaxial compressive strength, \( \alpha = 90^\circ - \theta \), is the angle between \( \sigma_1 \) and normal to fracture (cf. Jaeger and Cook, 1979, p 97 & 427). From the above equation (4.3) it is clearly evident that \( \sigma_3 \) will be hardly 0 unless \( h \) is equal to zero, and will never be negative since the value of \( h, \rho \) and \( g \) cannot be negative. Similarly, condition of \( \sigma_3 = 0 \), from equation (4.4), is also an impossible condition because for thrust faulting, \( \sigma_1 \) has to be always be greater than \( C_0 \) as \( \alpha \) can never be zero. And since thrust normally develop in the deeper part of the crust below the surface, the minimum possible value of normal stress, \( \sigma_n \) on the thrust will be weight or gravity of the hanging wall block which is likely always positive. And moreover, even it, the thrust is emergent on the surface, it is very unlikely to be opened since \( \sigma_3 = 0 \) cannot be negative i.e., tensile. So, there is little possibility of opening of the thrust faults under normal conditions. And this is the reason why, streams generally do not occur along the thrust faults. The Yu-Khampat drainage system of the region, being
characterized by thrust faults, therefore, has principally transverse to oblique streams and rivers in the same manner.

4.6.2 Extension Structures

Analyses of stream orientations and their comparison with the structural and tectonic features or lineaments reveal that streams that are oriented WNW-ESE (or roughly E-W) may be controlled by extension structures such as normal faults, tension joints and fractures that develop parallel to the regional compression direction normal to the regional extension, NNE-SSW direction. It is also observed that there is high frequency of stream occurrence around this direction as evident from the analysed data. And such high frequency indirectly suggests that there is relative ease with which streams can develop along these fractures/joints. It further suggests that these structures may remain relatively open due to the regional stress field and thus, mechanical and chemical weathering and erosion may act upon them quickly and easily.

For normal faulting, we know that, $\sigma_1$ is vertical while $\sigma_2$ and $\sigma_3$ are horizontal (Fig. 4.3A). And the stress components acting on the fault plane, normal stress ($\sigma_n$) and shear stress ($\sigma_s$) are given as in equations (4.1) and (4.2) respectively. Using the same principle as in the previous section, the possible least or minimum value of $\sigma_n$ can be obtained only when $\theta = 0^\circ$. That is, $\sigma_n = \sigma_3$, and the fault may open if $\sigma_n < 0$ i.e., tensile in nature. Since the maximum principal stress, $\sigma_1$ is vertical, it is given by

$$\sigma_1 = \rho gh$$

Therefore, $\sigma_3 \leq \rho gh$  

(4.5)

(4.6)

The nature of $\sigma_3$, the minimum principal stress, may be negative (i.e. tensile) if $\sigma_1 = \rho gh$ is less than the uniaxial compressive strength of the rocks in which these fractures develop (cf. Jaeger and Cook, 1979). So, from equation (4.4) it follows that,

$$\sigma_3 = \frac{(\rho gh - C_u)}{\tan^2 \alpha}$$

(4.7)

At shallower depth, $\sigma_3$ can be very well negative. For example, assuming $\rho = 2.6$ gm/cc, $g = 981$ cm/sec², and $h = 100$ m, we get, $\sigma_1 = 2.55$ MPa (Mega Pascals), and $\sigma_1 = 25.5$ MPa at $h = 1$ km. These values of $\sigma_1$ at shallower depths are relatively much less than the average unconfined or uniaxial compressive strength of
sandstones/siltstones (40-100 MPa) and shales (20-45 MPa) (cf. Bell, 1972). So, at relatively shallow depth, the value of \( \sigma_3 \) will be negative which can be obtained by substituting the above values in equation (4.7) and thus, these fractures may remain relatively open. Moreover, for these extension structures, the orientation of the minimum principal stress, \( \sigma_3 \) is also nearly parallel to the regional extension direction, NNE-SSW (Fig. 4.3A) and so, always possible to be negative thereby allowing the fractures to remain open. This is probably the basic mechanical reason why larger number of streams, although short, occurs in the WNW-ESE azimuth of the region.

4.6.3 Transcurrent Structures

Transcurrent structures having neither pure extension nor compression can develop at certain angular relations with the compression direction. In the Chandel district, we have already pointed out the lineaments that developed around N40°-45° W could be these types of structures. Similarly another group of fractures may also develop around N60°-70°E. Abundance of streams, controlled specially by these NW-SE trending structural elements have already been pointed out above. So, now let us briefly examine the mechanical aspects that control as well as forbid the occurrence of streams along these fractures or lineaments.

For strike-slip faulting or transcurrent structures, \( \sigma_2 \) the intermediate principal stress is vertical i.e., \( \sigma_2 = \rho gh \) and so, there could be two different stress conditions under which these fractures may develop.

That is, in one case, \( \sigma_2 = \sigma_1 \), i.e.

\[
\sigma_2 = \rho gh = C_0 + \tan^2 \alpha \sigma_3 \tag{4.8}
\]

and in the other case, \( \sigma_2 = \sigma_3 \), i.e.

\[
\sigma_1 = C_0 + \tan^2 \alpha \rho gh \tag{4.9}
\]

Equation (4.8) is comparable to that of the normal faulting condition (4.7) and so, faulting may take place relatively easier and the fractures or faults may also remain open comparatively. On the other, equation (4.9) is similar to the condition of thrust faulting where normal stress may be high giving little room for opening of the fractures.

However, out of the two fracture systems of strike-slip faults found in the region, which one will have the condition given by equation (4.8) above is practically
difficult to visualize. Because, the two fracture systems, the antithetic shears trending nearly NW-SE and the synthetic shears trending nearly ENE-WSW (N75°E-S75°W) have equal angular relations with the regional extension direction, NNE-SSW and compression direction WNW-SEE (Fig 4.3A). But, we have already pointed out that the group of antithetic shears, trending NW-SE control quite substantial number of streams. While the other group, synthetic shears do control very little number of streams although, a few streams run parallel to them. So, probably the condition given by equation (4.8) is applicable to the fractures or structures oriented in the NW-SE quadrants. However, the regional stress field may not have any preferential influence in the development of the drainage systems of the district. So, some other factors may influence to have such a condition. An important aspect that may permit relative opening of the shear fractures trending NW-SE might have resulted from the Myanmar (Burma) – China plate interaction as discussed by Curray et al. (1979). Because, the motion between the two plates acts N or NNW direction close to these fractures. Similarly, the interaction between Shillong plate and Myanmar plate (Evans, 1964) also gives a NW-SE compression. And since this compression, resulted from the plate interaction, is nearly parallel to these NW-SE trending fractures, they may be kept relatively open. That is why, they control stream occurrence. On the other hand, this compression is nearly normal to the synthetic shear fractures, so opening is not permitted and this could be the reason of infrequent stream occurrence along these synthetic shear fractures trending ENE-WSW (N75°E – S75°W) (Soibam, 2006).

4.7 DRAINAGE PATTERN AND ITS SIGNIFICANCE

We all know that drainage pattern is the spatial arrangement of streams in the form of a definite pattern, design or mutual relationship. Their formation is influenced by a number of factors such as initial slopes, competency contrast in rocks, structural controls, recent tectonic activities etc. Frequently drainage is found closely related to structural and lithological subsurface configuration (cf. Thornbury, 1969). In the Chandel district and its adjoining areas, some classic drainage patterns have also been displayed by the streams/rivers. So, in this section, we shall study what could be significant relationship between drainage patterns and structures present in the district by considering a few of them.
Besides the most common dendritic and sub-dendritic drainage patterns, characterized by irregular branching of tributary streams in different directions at any angle but usually less than 90° implying a notable lack of structural control, some of the typical drainage patterns found both in large and small scales are parallel and sub-parallel, trellis, radial, barbed etc.

**Parallel and sub-parallel drainage patterns** (P in Fig. 4.4) are those patterns in which a series of streams and their tributaries flow parallel or nearly parallel to one another. They are indicative of an area of pronounced slope or structural controls (Thornbury, 1969). These patterns are shown by the tributaries of the Yu-Khampat rivers in the southeastern part of the region. The major tributaries display parallel or near-parallel arrangement (Fig. 4.4) and show transverse to oblique relationship to the main Yu-Khampat rivers trending NNE-SSW direction which is parallel to the regional strike. As mentioned earlier (Section 4.5.1), such attributes could only be possible in the thrust belts as in the case of other orogenic belts of the world where they are characterized by transverse to oblique drainage systems. Similar is the case where the Tengnoupal-Narum Thrust sheet (Fig. 4.1) is characterized by the transverse to oblique drainage systems of the Yu-Khampat rivers which might be controlled by the similar strike-slip faults/fractures produced during the IMR tectogenesis. The most interesting similar observation is that the major streams and rivers rising in such thrust sheet, not only maintain parallelism but also show more or less equal spacing which is a remarkable signature of structural and tectonic control (Hovius, 2000).

**Barbed drainage pattern** is not a common pattern. Presence of such pattern throws a significant indication in the morphotectonics of the basin/region. In this pattern, tributaries do not flow in the same direction in which the main stream does. This pattern (B in Fig. 4.4 & 4.12A) is observed at Serou where the Chakpi river course changes its original flow direction by joining the Imphal river flowing southerly. Capturing or beheading or piracy of streams or topographic inversion, produced by differential erosion is a frequent phenomenon effecting drainage reversal of part of a separate system (Thornbury, 1969; Ahmed, 1985). From the field observation, it can be inferred that capturing by the process of erosion through the connecting
Fig. 4.12 The Chakpi river displaying barbed pattern at Serou (A) where the river attains maximum widening, and localized braidings in the Manipur river (B).
splays of the major fractures present seem to be the compatible mechanism by which the Chakpi river shows barbed pattern with respect to the Imphal/Manipur river.

As the Chakpi river originates from the high hill ranges of the central part of the district where the emergent Tengnoupal-Narum Thrust belt lies, it has greater erosivity or larger discharge through its short journey than that of the Imphal river which flow a long distance through the Imphal/Manipur valley. So, the Chakpi river and its tributaries may cut down more vigorously as compared to the Imphal river. The superiority of one of the streams as regards to downcutting and headward erosion may also be accentuated due to local or regional tectonic activities. With the passage of time, the more vigorous Chakpi river may integrate to the Imphal river as seen in Figs. 1.6 A&B and 4.4.

The nature of the barbed pattern displayed by the Chakpi river is possibly shaped by the Imphal river which is believed to be an antecedent river associated with the older tectonic activities of the region. The interior valleys of the mountainous Kangpokpi area in the Senapati district where the Imphal river originated hold vast as well as thick column of gravel accumulations, which are now dissected into old terraces is one of the supporting evidences of the antecedent origin of the Imphal river across the ranges. This is the basic reason why, the Imphal river does not fall into the Loktak lake, the depressed part of the whole valley. Had it been originated later or synchronous with the development of the valley, it will fall into the lake as other major rivers do because the formation/development of the Loktak lake might be in consanguinity with the Imphal valley.

Trellis drainage pattern (T in Fig. 4.4) is probably the next most common and extensive after dendritic pattern. It is characterized by a group of parallel and sub-parallel streams developed along the strike as well as dip directions of the rock strata. These patterns generally reflect a marked control of the drainage by parallel to sub-parallel folds, joints/fractures, alterations of hard and soft rock beds etc. Thrust propagated antiforms and rhythmically intercalated shale and sandstone provide an ideal condition for the development of trellis pattern in the Chandel district. These patterns are exemplified by the Maha river and also partly by the Chakpi river near Chandel (Fig. 4.4) which seem to be intimately associated with thrust propagated
antiform. The main river display more or less parallel to the regional strike whereas
the transverse and short main channels as well as the tributaries are parallel to
regional compression direction displaying good compatibility with the structures of
the region (Soibam, 1998).

Radial drainage pattern, mainly of centrifugal type (R in Fig. 4.4) is also a
common pattern well developed in the central as well as south-eastern part of the
district. Such pattern resembles the radius of a circle where the streams radiate in all
directions from a highland or higher point and intersection of a water divide. Since
the streams follow the slope, they are basically consequent streams. This type of
drainage pattern is well displayed by the Chakpi river basin near Phiran Khullen and
Momni (Fig. 4.4) where it seems to be produced by an antiformal fold still forming
topographic high hill range. On the south eastern part near Sheklon, this pattern
seems to be controlled partly by structure and partly by topography. This is probably
due to the matured topographic inversion of the eastern ranges of the district as
discussed in section 4.6.1. In the upper (near Bongli) and lower parts (near Khengji)
of the Yu-Khampat river basin also, presence of isolated residual hills, buttes and
mesas are possibly the controlling factors for the development of the radial pattern.

Apart from the typical drainage patterns described above, various types of
drainage anomalies have also been identified in the region. Local deviation from the
regional drainage and/or stream pattern is collectively known as drainage anomaly.
The expected pattern is regarded as the norm and deviations are anomalies (De
Blieux, 1949). Drainage anomalies provide information on local structural features,
active deformation, differential subsidence or changes in the hydrologic regimes
(Howard, 1967). Some of the anomalies identified in the district are abrupt and
localized braiding, compressed meanders, localized meanders, anomalous pinching
and swelling of valleys etc.
Fig. 4.13 Compressed meandering in the Sekmai river (A) and the Chakpi river (B) based on SOI Toposheet No. 83 L/3 (1969-70). Maximum widening is also shown by the Sekmai river.
Fig. 4.14 Google image showing compress meandering in the of Sekmai river (A) and the Chakpi river (B) respectively.
Abrupt and localized braiding are found best in the Manipur river near Thingkhangphai, Biyang and Tyang (Fig. 4.12B), the western peripheral villages of the Chandel district. Inability to transport the bed load by streams/rivers or less velocity by slumping of the river valley either due to faulting/fracturing or sudden change in lithology from hard and compact sandstone to soft and highly erodible shale seem to be the causative factors leading to form such braiding feature, which is characterized by two or more channels with bars and small islands. When some/several meanders of continuous series are squeezed, compressed and incised, it is known as compressed meanders. Such anomaly is observed both in the Sekmai river and Chakpi river (Fig. 4.13 A, B; 4.14 A,B) where their compressed orientation is nearly parallel to the regional compression direction possibly indicating close relationship with the regional deformation. Similar is the case shown by the Taret river at the easternmost periphery of the district.

Local widening and narrowing of channels are not repetitive feature of regional drainage patterns and may indicate local structural disturbance (Howard, 1967). Such type of anomaly is found both in the Sekmai river and the Chakpi river courses (Fig. 4.13). At the upper reaches near Khudei Khullen, the Sekmai river is pinching whereas it becomes wider between Kongoi Lugmi and Pallel (Fig. 4.13A). Similar phenomenon is also found in the Chakpi river. At the upper and middle course, the Chakpi river show pinching behaviour. However, it gets widening between Chakpikarong and Serou area. The maximum widening take place when the river enters the Serou area (Fig. 4.12 A).

From the discussions made above on the drainage patterns and their significance, it is evident that there is a close and intimate relation between the structures and drainage patterns. Therefore, it further signifies the observations made earlier that the results of structural and tectonic lineaments analysis and stream analysis are well compatible to one another.