Structural Contrast across the Main Central Thrust in Bhutan Himalaya

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Abstract: The Main Central Thrust (MCT) in Bhutan Himalaya marks a contrast with regards to the structural geometry between the belts lying across it. The L-fabric occurs at high angle to the length of the orogen in overlying Central Crystalline Belt (CCB) and it is length-parallel in the underlying Southern Frontal Belt (SFB). Contrarily the S-fabric remains length-parallel in both the belts. The L-S fabric is developed parallel to the axial plane and axis of a set of isoclinal folds resulted due to buckling during north-south crustal shortening in the Himalayan Orogen. The L-fabric, developed parallel to the fold axis, was in E-W direction in both the belts in the initial stage of shortening which was subsequently rotated to N-S direction in CCB during its thrusting over SFB along MCT. However the SFB has retained the initial orientation implying a probable parautochthonous nature of the belt.

Introduction

The Bhutan Himalaya can be divided into three broad E-W trending tectonostratigraphic belts (Fig. 1) such as
- the Southern Frontal Belt (SFB),
- the Central Crystalline Belt (CCB) and
- the Tethyan Belt (TB) which are mutually separated by thrusts. The tectonostratigraphy is as follows (Jangpangi, 1978).

North:

<table>
<thead>
<tr>
<th>Tethyan Belt (TB)</th>
<th>Thimpu Formation</th>
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</thead>
<tbody>
<tr>
<td>Central Crystalline Belt (CCB)</td>
<td>Paro Formation</td>
</tr>
<tr>
<td><strong>Main Central Thrust (MCT)</strong></td>
<td>Shumar Formation</td>
</tr>
<tr>
<td>Southern Frontal Belt (SFB)</td>
<td>Buxa Formation</td>
</tr>
</tbody>
</table>

This includes locally developed Duri Formation, Thungsa Formation and Gordwana.

South:

The Main Central Thrust (MCT) separates the SFB from CCB. The underlying SFB consists of low to medium grade metasediments which are classified into lower Phuntsoling Formation, middle Buxa Formation and upper Shumar Formation. Locally developed Duri Formation, Thungsa Formation and Gordwana are included in this belt. The overlying CCB is marked by high grade metasediments belonging to Thimpu Formation and Paro Formation. These are intruded by numerous granite veins and batholiths. Tethyan Belt consisting of fossiliferous sediments occurs in patches in form of klippes within CCB. These belts are mutually separated by thrust planes which have acted as main translation surface. However, imbricate thrusts exist within each belt (Jangpangi, 1978; Ray et al., 1989). The amount of thrusting which decreases from north to south in Himalayan Orogen (Valdiya, 1984) possibly holds good for Bhutan Himalaya also.

The MCT in Bhutan Himalaya marks a zone of discontinuity with reference to the lithological association and metamorphic grade between SFB and CCB (Gansser, 1983). Apart from this a contrast in structural geometry can be deciphered between these two belts. In this paper a variation in the axial orientation of the deformational structures with their kinematic significance between the two belts is reported.

Due to inhospitable terrain and restriction to foreigners the structural data were collected along certain traverse lines covering nearly 500 line km such as at Haurikhola, Pashakha, Phuntsoling, Rongri, Bhurikho and Wangdiphodrang (Fig. 1) which is obviously not commensurable to the stretch of

![Fig. 1. Geological map of Bhutan (After Geological Survey of India, 1979 and Gansser, 1983). 1. Southern Frontal Belt (SFB), 2. Central Crystalline Belt (CCB), a- Thimpu Formation, b- Paro Formation; 3. Tethyan Belt (TB).](image-url)
MCT. However, a general interpretation has been put forward on the basis of similar observations at different points.

Structure

Southern Frontal Belt (SFB)

The SFB which is studied at different parts in Bhutan shows well developed slaty cleavage in E-W direction parallel to the regional trend of the belt (Fig. 2a). Intersection lineation developed due to the intersection of the above slaty cleavage with the bedding plane occurs as stripes on the cleavage surface. This lineation tends in E-W direction (Fig. 2a). The slaty cleavage (S₁) is developed parallel to the axial plane (ab) of a set of isoclinal folds, F₁, and the intersection lineation (L) occurs parallel to the fold axis (B) (Fig. 3a). The slaty cleavages show variation in orientation due to later folding, F₂. The F₂ folds are open to tight, Class 1B to Class 1C type and overturned to N (Fig. 3a, 4a). Therefore the slaty cleavage which is developed parallel to the axial plane of F₁ fold dips northward. Since the limb of F₁ fold occupies larger area in comparison to its hinge the slaty cleavages of F₁ fold and F₂ fold remain virtually parallel in the area. Hence the overall planar fabric in SFB strikes E-W and dips towards north (Fig. 2a). N-S warps (F₂ fold) are found in the slaty cleavage bringing variation in the plunge of the F₁ and F₂ folds. The fold axis also shows curving near the MCT suggesting thrust effect.

F₁ and F₂ folds are coaxial and developed from a continuous deformation due to N-S directional buckling stress. Initial fold generation by buckling was followed by superposed homogeneous flattening (Ramsay, 1967). Flattening effectively tightened the F₁ fold and was largely responsible for the formation of the slaty cleavage. The slaty cleavage, intersection lineation and fold axis constitute the L-S fabric (Flinn, 1965) in the belt.

Central Crystalline Belt (CCB)

The rock types in CCB show development of schistosity, intersection lineation and stretching lineation. The schistosity strikes E-W, and intersection as well as stretching lineations are down dip on the schistosity surface and therefore occur at high angle to the length of the orogen (Fig. 2b). The schistosity is developed parallel to the axial plane of a set of Class 1C to Class 2 type isoclinal reclined fold, F₁, the axial plane (S₁) of which strikes E-W and the axis (L) is N-S (Fig. 3b). This fold is coaxially refolded by another set of isoclinal, Class 1B to Class 1C type reclined fold, F₂, which has E-W striking axial plane (S₂) and N-S trending fold axis (Fig. 4b). Due to isoclinal nature of F₂, the F₁ folds are totally transposed parallel to the axial plane of F₂ fold (Fig. 4b), as a result, it is difficult to separate the axial plane schistosity (S₁ and S₂) of individual folds. However, the overall planar fabric remains E-W (Fig. 2b). A stretching lineation parallel to the fold axis is observed on the schistosity surface (Fig. 4), more prominently adjacent to MCT. The schistosity in CCB is affected by a N-S warping, F₂ fold, which is found further coaxial with F₁-F₂ folds.

A N-S directed continuous simple shear is responsible for the development of the F₁ and F₂ folds and L-S tectonites in the CCB.
Kinematics of L-S Fabric Variation

The slaty cleavage or the schistosity defines the XY plane of the finite strain ellipsoid. The direction and magnitude of the resultant finite elongation decides the orientation of the fold axis (Sanderson, 1973). In response to N-S directed simple shear the XY plane of the strain ellipsoid in SFB marked by the slaty cleavage remained E-W. The fold axis (B) is parallel to the length of the belt points to the fact that the finite elongation along Y was in excess of the resultant finite elongation which prevented stretching perpendicular to the fold axis (Fig. 5a). In contrast the schistosity in CCB although remains parallel to that in SFB the fold axes and the stretching lineation are at high angle to the length of the orogen indicating the effect of lateral stretching. In a continuous deformation the later shears modified the shape of the earlier folds and when the resultant finite elongation exceeds the elongation in Y direction, the fold axis which was initially parallel to Y direction rotates towards X (Sanderson, 1974). The stretching took place subsequent to $F_2$ folding in CCB in response to its thrusting over SFB. The axial plane of $F_2$ has acted as plane of shear during thrusting. As a result the fold axis of $F_1$ and $F_2$ were rotated towards the X direction of finite strain ellipsoid i.e., direction of transport (Fig. 5b). As the right angle orientation of the L fabric is noticed across CCB thrusting was probably distributed throughout it by means of close spaced imbricate thrusting.
The XY plane of the finite strain ellipsoid as defined by slaty cleavage or schistosity in both the belts across MCT is parallel to the length of the orogen. Hence the F_1 and F_3 folds in CCB and SFB are considered to be contemporaneous and resulted due to a continuous simple shear in N-S direction. The fold axis was initially parallel to the length of the orogen and later assumed a high angle orientation in CCB due to stretching perpendicular to the fold axis consequent to thrusting of CCB over SFB along MCT. Existence of length-parallel L-fabric in SFB implies little transportation of the belt from its original position. F_3 fold is developed much later thereby affecting the earlier fabrics. The N-S warps and lineaments seen in the Himalayan Orogen are consequent to such late folding (Gansser, 1983).

The buckling followed by homogenous flattening are due to a N-S simple shear which is generated during closure of the basin. This simple shear continued further bringing thrusting and forming nappe in the Himalayan Orogen. As a result the fold axis was rotated towards parallelism with the direction of transport (Bryant & Read, 1969). This simple shear was consistent with the simple shear model proposed by Escher and Watterson (1974) and Kirkwood et al. (1994) for the deformation in nappe Belts.

Conclusion

The SFB and CCB have undergone three stages of folding contemporaneously. The L-S tectonites are primarily due to the F_1 and F_3 folding which have been resulted due to a continuous simple shear in N-S direction.

The fold axis was initially parallel to the Y axis of the finite strain ellipsoid. However, prolonged simple shear resulted in thrusting of CCB over SFB and translated the fold axis parallel to the direction of transport (X axis) in CCB. The SFB has retained the initial orientation of the fold axis for which it is considered to be para-autochthonous. The Tethyan Belt which occur as klippes within CCB amounts still greater transportation from its root zone which lies far to north. This corroborates to Valdiyas observation that the amount of transportation increases from south to north. The portion of SFB near the MCT shows effect of stretching in curving of the lineation.

The MCT has acted as thrust plane, as a result, this contains prominent stretching lineations and marks the difference in the orientation of fold axis of the adjacent belts.

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References


