# Microflanking Structures & Their Rheological Significance

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ABSTRACT

We report flanking structures from micro-scales from sheared rocks in the Himalaya, and designate them as 'microflanking structures'. Cleavages and grain boundaries of host minerals act as shear plains and also impart anisotropy during shearing event. Rheological possibilities, other than a weaker host within a stronger matrix, have been encountered.

## INTRODUCTION

Flanking structures are "deflection of planar or linear fabric elements in a rock alongside a cross-cutting object"[1]. Components useful in describing such structures are given in Figs. 1a & -b and their captions.

This work aims at (i) documentation of flanking structures in micro-scales; and (ii) deciphering their rheological significance.

These observations are made under optical microscope, and are from thin-sections of ductile sheared rocks of the Higher Himalayan Crystallines from Indian Himalaya. These rocks are medium- to high-grade metamorphosed and of greenschist- and amphibolite facies.

## NATURAL OBSERVATIONS

The studied thin-sections, under microscope reveal that some of the nucleated mineral grains cut and deflect cleavages (if any) and/or grain boundaries of the host mineral grains. These nucleated minerals are designated as the cross-cutting elements (CE), the deflected cleavages and grain boundaries as the host fabric elements (HE), and the CE-HE together as the microflanking structures (MFS) (Figs. 2, 3).

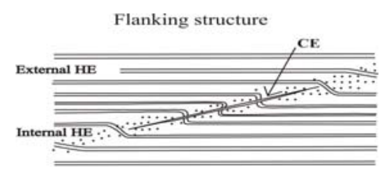


Fig. 1a

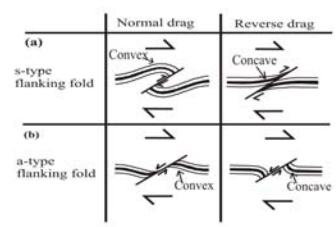


Fig. 1b

Figure 1a. Flanking structure. Dragged part of the host fabric element (HE), near the crosscutting element (CE), is called the 'internal HE'. Away from the internal HE is straight and undisturbed 'external HE' (reproduced from Passchier[1]). The region where the internal HE is confined, is called the 'internal HE zone'.

Figure 1b. Senses of slip & -drag of HE for flanking structures. For this purpose, identification of the ‘marker HE’, shown by thick line, is required (reproduced from Fig. 1 of Grasemann et al.[2]).

## RHEOLOGICAL INTERPRETATIONS

In addition to imparting mechanical anisotropy[3] in the ductile shear deformation regime, the grain boundaries and the brittle cleavage plains of the host mineral(s) acting as the HE, also efficiently act as ductile primary shear plains leading to the crystal-plastic deformation of the CE.

None of the MFS encountered in the present study reveals melt phase/ recrystallization at the HE-CE contacts. This indicates that, for the MFS, rheological weakening at these contacts is not an essential criterion for the HE to get dragged (and probably slipped) along the CE margin.

Presuming Newtonian viscous rheology of the HE-CE composite and neglecting the possible anisotropic effect of by the HE, the constitutive relationship of the MFS, under general shear regime, is given by:

$$\tau_{ij} = B.\ \dot{\varepsilon}_{ij} \qquad (1)$$

where $\tau_{ij}$: deviatoric components of stress tensor; B: a number denoting the ratio of viscosity between the HE and the CE; and

$$\dot{\varepsilon}_{ij}=[\partial u_i /\partial x_j+\partial u_j /\partial x_i] \qquad (2)$$

is the strain rate tensor (simplified from Grasemann and Stüwe[4]).

Strain rate is defined in Eq. 2 in terms of velocity ‘u’ in the two Cartesian directions ‘i’ and ‘j’. Note that Eq. 1 is valid for the MFS with the CE nucleated over a single mineral.

Absolute values of viscosities of minerals are not known. Nevertheless, few theoretical comments can be made from Eq. 1 and from our micro-scale observations. When both the host- and the nucleating mineral are of same viscosity, i.e. they are of the same mineral species, e.g. a biotite grain nucleating within a biotite host grain, B should be ideally equal to 1 and the deformation simplifies to deformation of a single object[1], where drag and slip of the HE are not expected. However, in the present study, drag of cleavages of the host grain has been noted under microscope even if the MFS is defined by the CE and the HE belonging to the same mineral species (Fig. 2) Range of B for such cases should, therefore, be close (but not equal) to 1. For the MFS with a rigid CE within a weaker host mineral (Fig. 3), e.g. a feldspar or apatite grain within muscovite, B is <1. In this situation, a-type flanking structure is expected (Grasemann and Stüwe[4]), but can not be checked for the studied MFS due to the unavailability of the HE as marker. The third possibility, i.e. the MFS defined by weak CE and a more viscous HE, i.e. B>1, numerically simulated for a simple shear heterogeneous deformation regime with flow perturbation (Passchier et al.[5]), and for which n-type flanking structure is expected for B >>1 (Grasemann and Stüwe[4]), has not been encountered in the present study. Do you have any example of MFS for B>1?

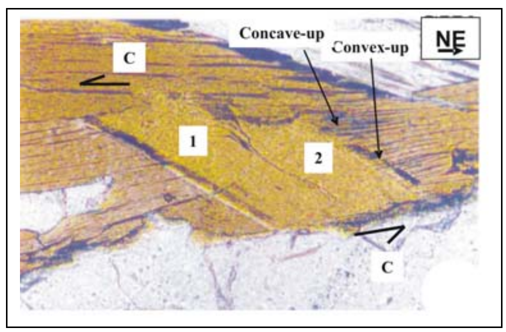


Figure 2. MFS defined by two biotite minerals defining cross-cutting elements (‘1’ & ‘2’), and dragged cleavages host fabric elements of the host biotite. The thin-section is from sheared rock of the Higher Himalayan Crystallines at Joshimath, Alaknanda valley. Photomicrograph length: 1mm.

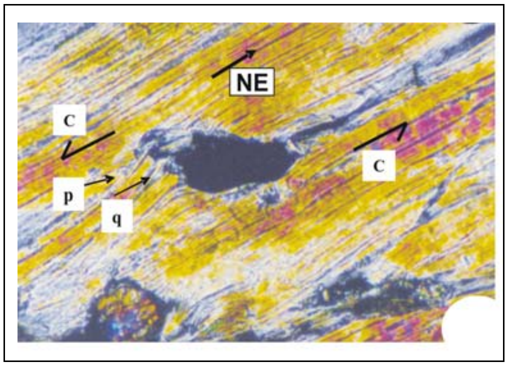


Figure 3. Sigmoid alkali feldspar as the CE and dragged cleavages of the muscovite host grains as the HE. The HEs are intensely dragged into both convex-up and concave-up senses at the same margin of the CE, and are shown by arrows ‘p’ and ‘q’ respectively. One of the margins of the feldspar grain is inclined to the C-plane in the direction of shear at $134^0$. At one side of the CE, from arrow ‘q’ towards arrow ‘r’, the convexities of the internal HEs are gradually reduced. At the other margin of the CE, the HEs are gently convex-up. The thin-section is from the sheared rock of the Higher Himalayan Crystallines, Joshimath, Alaknanda valley. Photomicrograph length: 1 mm.

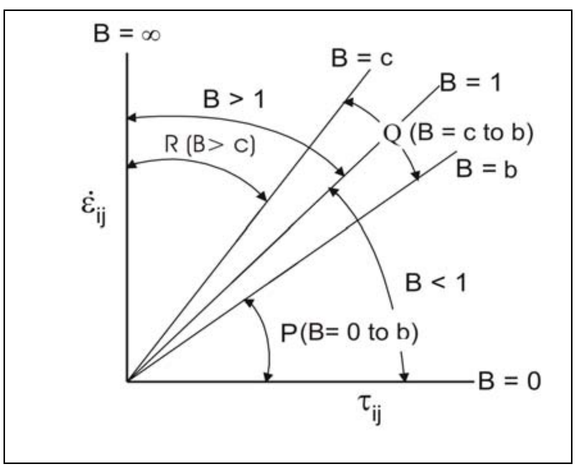


Figure 4. Domains of observed MFS in a graph. The X- and the Y-axes and the B parameter are defined in Eqs. 1 & -2. of the CE. Lines B=b and B=c are boundaries that separate P: b>B>0, Q: c>B>b, and R: B>c domains. The numerical values of ‘b’ and ‘c’ are close to 1 with b<1<c, though their exact values are not known. A MFS, with more viscous CE nucleating within a less viscous host, comes within the P-domain; that defined by the CE and the host of the same mineral, plots within the Q-domain. A MFS, with less viscous CE and more viscous host, i.e., that falling within the R-domain, has not been encountered.

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