Using the Maximum Effective Moment Criterion to Interpret Quartz <c>-Fabric Patterns

ZHENG Yadong, ZHANG Jinjiang and ZHANG Bo*

The Key Laboratory of Orogenic Belts and Crustal Evolution, School of Earth and Space Sciences, Peking University, Beijing 100871, China

Abstract: The Maximum Effective Moment (MEM) criterion predicts that the initial orientation of ductile shear zones and shear bands is ~55° relative to the maximum principal stress axis (σ₁) and that the kinematic vorticity number (Wₖ) is ~0.94. These preferred orientations should be reflected in the pattern of quartz <c>-fabrics in shear zones and shear bands. Common quartz <c>-fabrics in plane strain can be divided into low-temperature (L) and high-temperature (H) fabrics, with each group showing three patterns. A steady flow with a constant value of Wₖ<0.94 gives rise to L-1 and H-1 patterns, which are commonly characterized by a single <c> axis girdle normal to the shear zone and a single <c>-point maximum parallel to the shear zone. Once the conjugate set develops, L-1 and H-1 have opening angles of ~70° and ~110°, respectively. L-2 and H-2 are asymmetric patterns associated with variable deformation partitioning and vorticity values of 0< Wₖ<0.94. In contrast, L-3 and H-3 are symmetric patterns associated with 100% deformation partitioning and Wₖ=0. The opening angle in quartz <c>-fabrics is implicitly linked to the temperature during deformation. The opening angle is ~70° at low temperature and ~110° at high temperature. However, a linear correction between the opening angle and the temperature cannot be established. During deformation partitioning, synthetic shear bands form earlier than antithetic bands and are more easily developed. This may result in opening angles of <70° for low-temperature fabrics and >110° for high-temperature fabrics. The following criteria can be used to recognize reworked shear zones that have experienced multiple orogenic phases and changes in the stress state: 1) the initial Wₖ is larger or smaller than ~0.94; 2) the change in Wₖ is abrupt, rather than progressive; 3) inconsistent shear senses are inferred for the different phases of deformation; and 4) a negative value of Wₖ is found in reworked shear zones.

Key words: deformation localization, deformation partitioning, shear bands, vorticity Wₖ, quartz CPO patterns


I Introduction

Forty years ago, the metallurgical term “shear bands” was first used to describe oblique, partially penetrative, intrafolial, internal shears in mylonites (White, 1979) (Fig. 1). Three unresolved problems arise from the recognition of these structural features. First, it is unclear why the angle between conjugate shear bands is obtuse rather than acute, as predicted by the Mohr–Coulomb failure criterion. Ramsay (1980) suggested that progressive contraction could be responsible for increasing the angle between conjugate structures, but such a process cannot explain spaced shear bands that truncate a penetrative mylonitic foliation. Accordingly, the obtuse angle between conjugate shear bands is likely the original angle. Second, the maximum principal stress referred from the conjugate shear bands is normal to the shear boundaries rather than 45° predicted by the simple shear theory prevailing at that time or any other oblique angles by general shear theory nowadays. What a process changed the stress state from one to another? Third, the observation that synthetic shear bands (C') are so well developed raises the question as to why conjugate shear bands are asymmetric.

The Maximum Effective Moment (MEM) criterion was proposed by Zheng et al. (2004) to address the above problems. An increasing number of observations, both in nature and from experiments, have confirmed the accuracy of the MEM criterion (Fig. 2a-c). However, the criterion has so far not been applied in petrofabric analysis. The aim of this paper is tentatively to interpret crystallographic preferred orientation patterns (quartz <c>-fabric patterns) in the context of the MEM criterion.

* Corresponding author. E-mail: geozhangbo@pku.edu.cn

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2 The MEM Criterion for Localization

Based on the analysis of conjugate shear bands and kinkbands, the following equation was formulated (Zheng et al., 2004) to describe the failure of a shear band with a certain width, for stresses applied on the boundaries of a finite unit cube (Fig. 2a):

\[ M_{eff} = \pm \frac{1}{2} (\sigma_1 - \sigma_3) L \sin 2\alpha \cos \alpha \]  

(1)

Where \( M_{eff} \) is effective moment; \( (\sigma_1 - \sigma_3) \) is the yield strength of the deformed material; \( \alpha \) is the angle between \( \sigma_1 \) and the shear bands; and \( L \) is a unit length (Fig. 2a-b).

The mathematical expression of the MEM criterion implies that once the differential stress reaches the yielding point of the material (for certain temperature, confining pressure, fluid pressure, and strain rate conditions), conjugate shear zones form at an angle of \( \pm 55^\circ \) relative to \( \sigma_1 \). The occurrence of pairs of conjugate MEM orientations follows the theorem of conjugate stress in the mechanics of materials, which states that shear stresses with opposite sense must have an equivalent absolute value (otherwise the finitecube would be unbalanced and rotate).

The shaded area in Figure 2c is the field of available data from natural and experimental observations. These observations were made at different scales in homogeneous, inhomogeneous, isotropic, and anisotropic materials. The fact that all data plot in a relatively narrow field may suggest that the MEM criterion is widely applicable to multiscale structural features in various materials.

Deformation does occur in the whole area of the considered unit (Fig. 2a, b) but is limited to pairs of kink bands, shear bands, or shear zone sets. Incipient shear zones may occur where the wall-rocks remain undeformed, and shear zones may decrease in thickness and increase in length. This implies that the shear zone boundaries are parallel to the extensional apophysis AP1 (see Section 3). Shear zones can become narrower in both extensional and compressional tectonic settings, for example, in association with low-angle normal faults, high-angle reverse faults, and wide-open V-shaped conjugate strike-slip faults (Zheng et al., 2011, 2015). For shear zones to become broader, a change in the stress state after formation is required, most likely caused by orogenic reworking.

3 Geometry, Kinematics, and Mechanics of Steady Flows and Ductile Shear Zones

Previous studies have demonstrated that ductile shear zones in nature are characterized by a range of vorticity numbers (Xypolias, 2010, and references therein). The different methods used to derive vorticity numbers have considered continuous and homogeneous deformation. For the simplified case of a two-dimensional ductile shear zone without volume loss, Bobyarchick (1986) and Passchier (1986) defined the kinematic vorticity number (\( W_k \)) as:

\[ W_k = \cos \nu \]  

(2)

where \( \nu \) is the angle between the flow apophyses, which can range from 0° to 90°.

An alternative definition can be given in stress terms (Weijermars, 1991, 1998):

\[ W_k = \sin 2\nu \]  

(3)

where \( \nu \) is the angle between the shear bands/zones. All data from field and laboratory observations are plotted in the shaded area, with the dark area indicating experimental data from Gomez-Rivas and Griera (2012).

Fig. 2. Derivation of the MEM criterion (after Zheng et al., 2004).

(a) Stress field applied on a finite cubic unit; (b) Mohr circle showing the state of stress in the finite unit cube; (c) Mathematical and graphical expressions of the MEM criterion. \( \sigma_1-\sigma_3 \) is the yield strength, \( L \) is the unit length, and \( \alpha \) is the angle between \( \sigma_1 \) and the shear bands/zones. All data from field and laboratory observations are plotted in the shaded area, with the dark area indicating experimental data from Gomez-Rivas and Griera (2012).
numbers in the range of 0.50–0.85 in natural shear zones were likely associated with a flow regime close to simple shear (Li and Jiang, 2010, and reference therein). In other words, most shear zones in nature have likely formed at an orientation of 55° relative to \( \sigma_1 \).

The development of a penetrative S-foliation is the result of quasi-homogeneous deformation involving a loading rate lower than the relaxation rate. The spaced C-planes result from deformation localization associated with a loading rate higher than the relaxation rate. The coexistence of S- and C-foliations in mylonites, as suggested by Hubert-Ferrari (2003) and Gomez-Rivas (2008), can be regarded as a competing process between an external loading rate and the rate of viscous relaxation. If the former is higher than the latter, the differential stress increases until the yielding point is reached, thus producing ductile shear features that subsequently propagate. Alternatively, the imposed stresses will relax if the viscous relaxation rate is higher than the rate of external loading, leading to the development of a penetrative S-foliation. C/S fabrics reflect the competition of these two deformation mechanisms and imply that each set of foliations is developed in a critical state of dynamic balance. The situation is similar to the transition from a Lüders band to the Portevin–Le Chartelier effect, which describes a serrated stress-strain curve (or jerk flow) in inhomogeneous plastic deformation (Ananthakrishna, 2007). This effect has been attributed to the competition between diffusing solutes pinning dislocations, and dislocation breaking free of this stoppage (Abbadi et al., 2002), which is equivalent to the competition between deformation localization and homogeneous deformation. Therefore, the predicted \( W_\kappa \) of 0.94 also implies that the corresponding angle \( \psi \) between the two apophyses of flow is 20°.

Shear zones with C-surfaces are parallel to the extensional apophysis (\( \text{AP}_1 \)), with the conjugate set being expected to form normal to the contractional apophysis (\( \text{AP}_2 \)). This orientation is \( \sim 20° \) relative to the normal of \( \text{AP}_1 \) (Fig. 3).

Simpson and De Paor (1993) suggested that conjugate shear bands initiate parallel to the orientations of maximum (angular) shear strain. The two orientations are parallel to the bisectors of the acute (\( \text{AB} \)) and the obtuse (\( \text{OB} \)) apophyses, respectively. Although these predictions are widely accepted (e.g., Kurd and Northrup, 2008; Sullivan, 2009; Xypolias, 2010; Gillam et al., 2014), they contradict experimental data and field observations, which show a conjugate angle of \( \sim 110° \) rather than \( \sim 90° \) (Fig. 1; Zheng et al., 2004, 2009, 2011, 2014, 2015).

A case with two major synthetic shear band sets and one antithetic set has been discussed by Kurd and Northrup (2008) (Fig. 4a). In this analysis, the second set was regarded as the acute bisector, thus meeting the 90° angle predicted by the maximum-shear-strain-rate presumption. However, the angle between the first synthetic set and the antithetic set is \( \sim 114° \), and the angle between the second set and the normal to \( \text{AP}_1 \) is 55°. Both angles are in the range predicted by the MEM criterion (Fig. 4b).

The mylonitic foliation is, in fact, commonly truncated by synthetic and antithetic shear bands at different cut-off angles, with the cut-off angles of the synthetic shear bands (15°–35°) being lower than the cut-off angles (35°–55°) of the antithetic shear bands (Fig. 3a). The conjugate angle, however, is relatively consistent (\( \sim 110° \)). The mylonitic foliation is parallel to the shear zone boundary in the central section of the Alpine Fault mylonite zone, and the mean cut-off angle of the synthetic shear bands is \( \sim 30° \).
The antithetic shear bands have larger cut-off angles, typically ~40°. Gillam et al. (2014) regarded the 30° angle between the synthetic bands (C') and the shear boundary as the AB line. If the hypothesis that shear bands along the maximum angular shear strain rate directions was correct, the expected antithetic shear bands would be parallel to the OB line and normal to the synthetic shear bands. However, the observations do not support the presumption. According to the MEM-criterion, $W_k = \sin(20°) = 0.34$. Therefore, conjugate shear bands are more likely to be affected by the MEM criterion.
Fig. 6. Quartz $\langle c \rangle$-fabric patterns at low and high temperatures.

(a) Steady flows; (b) $R_\beta$-$\beta$ diagram showing deformation paths for the examples shown in (a); (c) non-steady flows due to deformation partitioning. The symbols used are the same as those of Figure 3.
developed parallel to the MEM orientations, with the conjugate angle of 109° being predicted by the MEM criterion.

### 4 Common Quartz <c>-Fabric Patterns

Basic quartz <c>-fabric patterns (Fig. 3b; 5a, b) have been predicted from numerical simulations of plastic deformation, based on the Taylor–Bishop–Hill model for slip-system activation (Lister and Hobbs, 1980). A variety of fabrics from both naturally and experimentally deformed samples support the results of numerical simulations (Tullis, 1977; Compton, 1980; Law et al., 1984; Price, 1985; Schmid and Casey, 1986; Law, 1986). The modeling result (Lister and Hobbs, 1980) shows that the central segment of quartz c-axis fabrics is orthogonal to the flow plane, indicating a basal <a> slip. Based on this relationship, the finite-strain/quartz c-axis-fabric (Rxz/β) method has been proposed to estimate the value of Wk (Wallis, 1995) (Fig. 6b, c).

For simplicity, the description here is restricted to plane-strain deformation, but patterns forming at high temperature are considered. At low temperature, the central segment of quartz c-axis fabrics is orthogonal to the shear plane, whereas at high temperature, the point maxima of quartz <c>-fabrics are parallel to the shear zone boundary. Therefore, the former can be regarded as the normal direction to the boundary of the shear zone and the latter as the direction parallel to the shear zone. If C-surfaces in C/S fabrics (Lister and Snoke, 1984) represent the orientation parallel to the shear zone (e.g., Passchier and Trouw, 2005; Xypolias, 2010), the most common quartz c-axis patterns shown in XZ-Cartesian coordinates will be associated with an anti-shear sense rotated by h (Fig. 5b). Using L and H for low and high temperature, respectively, the following patterns are recognized: 1) L-1 single girdle perpendicular to the shear zone boundary (AP1); 2) L-2 asymmetric crossed girdle normal to AP1; 3) L-3 symmetric crossed girdle normal to AP1; 4) H-1 single-point maximum on the AP1, perimeter; 5) H-2 asymmetric double-point maxima on the AP1, perimeter; and 6) H-3 symmetric double-point maxima on the AP1, perimeter. L-1 and H-1 represent steady flows without deformation partitioning, L-3 and H-3 represent 100% deformation partitioning, and L-2 and H-2 belong to another percentage of deformation partitioning. Representative cases are shown in Figure 6a and c.

#### 4.1 Type L-1

This type of fabric is characterized by a single <c> axis girdle, composed of slip systems (basal <a>, rhomb <a>, and prism <a>) that are normal to the shear zone boundary (Figs 5b and 6a). The opening angle is commonly zero, as cross-girdles are not developed. However, as shown in Figures 5 and 6a, there is a potential conjugate shear zone in another MEM direction, with its normal oriented ~70° antithetically relative to the single girdle. Once this conjugate shear zone forms, the opening angle is ~70° (Fig. 5b and wys-153 and 154 in Fig. 6). The predicted orientation of σ1 (or ISA) is ~55° synthetically relative to the shear zone boundaries (AP1), and the corresponding Wk is ~0.94 in plane strain (Fig. 3). As the shear zone initiated in one of the MEM directions, the β-angle between the S- and C-planes likely formed as ~35°. For steady flows, the flow apophyses with respect to the shear zone boundary remain constant throughout the deformation history. This means that the Wk remains constant despite the decrease in β during deformation (Fig. 6b). A number of examples from shear zones in nature and the expected deformation paths are shown in Figure 6a and b, respectively.

#### 4.2 Type L-2

This pattern is characterized by an asymmetric crossed girdle, which is composed of slip systems (basal <a>, slip, rhomb <a>–slip, and prism <a>) with an opening angle of <70° (Fig. 6a). Although the central girdle remains normal to the shear zone boundaries (AP1), two point maxima represent the second stage of deformation history with the vorticity value being 0 ≪ Wk < 0.94. The two point maxima imply that deformation partitioning has occurred with the front maximum representing the synthetic shear bands, which progressively changed their position from the original orientation of the C-plane because of the change in the stress state. Field observations show that synthetic shear bands are typically oriented 15°–35° relative to the shear zone boundaries (e.g., Berthé et al., 1979; Platt and Vissers, 1980), and numerical studies show that shear bands are non-rotating and shallowly inclined (<30°) with respect to the flow plane (e.g., Grasemann et al., 2003). As shown in Figure 4a, orientations of synthetic shear bands range from nearly parallel to the shear zone boundary (or C-planes) to 35° relative to it. This confirms that the synthetic shear bands resulted from deformation partitioning at different levels. The fact that spaces between C-planes are much narrower relative to the spaces between shear bands implies that the early stage of deformation was more penetrative and occurred at a higher temperature. The later low-temperature deformation was likely confined to the basal <a> slip system, with the central segment of the crystal fabric remaining undeformed. As such, shear bands form when the mylonitic foliation is already established, thus recording late syn-mylonitization or early post-mylonitization deformation (e.g., Passchier and Trouw, 2005; Xypolias, 2010). In a strict sense, once the shear bands form, there is no flow but only deformation localization. This is supported by numerical studies, which confirm that shear bands are of non-rotating features. Here, it is suggested that the central girdle forms at a medium temperature and remains frozen in the mylonitic foliations as the temperature drops, whereas the basal <a> slip system (associated with the shear bands) remains active and forms the front maximum. In cases that the basal <a> slip also occurs along the S-foliation or the conjugate shear bands, a trail maximum may form an angle of <70° relative to the synthetic shear bands. Once
When the shear bands develop, \( W_k \) can be estimated from the branch-out angle of the front maximum, which represents the normal to the basal \(<a>\) slip along the synthetic shear bands. The orientation of \( \sigma_1 \) (or ISA \(_3\)) is 35° backward relative to the front maximum. Depending on the degree of deformation partitioning, the trail maximum may either represent the normal to the S-foliation (for a trail maximum in the range of 0°–35°) or the normal to the antithetic shear bands, which ranges from 20° to 35°.

Central girdles that appear oblique to the shear plane likely rotated synthetically towards the shear direction with increasing strain and dynamic recrystallization (e.g., Heilbronner and Tullis, 2006). This deformation likely occurred at comparatively high temperature.

4.3 Type L-3

This pattern shows a central girdle that remains normal to the shear zone boundaries (\( AP_1 \)), and two symmetric point maxima ~35° from the central girdle. This means that a pair of \(<c>\)-fabrics represents normals to the conjugate basal \(<a>\) slip sets with an angle of ~110° between them. This pattern is identical to the pattern shown in Figures 1 and 7, suggesting that the two \(<c>\) point maxima are controlled by the conjugate shear bands and hence by the MEM orientations. The orientation of \( \sigma_1 \) (ISA \(_3\)), deduced from the obtuse bisector between the two point maxima, indicates that the value of \( W_k \) is zero, thus implicating a 100% deformation partitioning (Tikoff and Teyssier, 1994; Teyssier et al., 1995). In such a stress state, slip systems parallel to the shear zone boundaries cannot slip, and the central girdle segment is a historical record as the normal to the shear zone.

4.4 Type H-1

This pattern shows a single-point \( c \)-maximum on the perimeter at \( AP_3 \), associated with the prism \(<c>\)-slip system. The orientation is parallel to the shear zone boundaries (\( AP_1 \)) and the mylonitic C-plane. Opening angles are absent, as the potential conjugate maximum is commonly annihilated by the major shear zone (GPS-126-1-G, PNG-09-024b, and PNG-08-037c in Fig. 6a).

As shown in Figure 3, a potential conjugate shear zone forms in the other MEM direction, at an angle of ~110° synthetically relative to the main shear zone and 20° relative to the normal to \( AP_1 \). Accordingly, a point maximum caused by the prism \(<c>\)-slip system may appear in this orientation. This point maximum tends to be mixed with the basal \(<a>\)-slip system at low temperature.

Deformation bands have been reported in high-temperature gneisses from the D’Entrecasteaux Islands, Papua New Guinea (Little et al., 2011, 2013). Abundant conjugate extensional shear bands in hornblende-bearing quartzofeldspathic gneisses from the carapace zones, as well as deformation bands in quartz from the core-zone gneisses, have been observed. These structures typically occur in pairs separated by an angle of ~70° or ~110° (e.g., PNG-06-034a in Fig. 6a and Fig. 8). Misorientation profiles reveal small (~2°) rotations of the crystal lattice across the boundaries of deformation bands, indicating...
that these structures have a similar origin as shear bands controlled by the MEM criterion. However, this quasi-orthogonal pattern is explained by the combination of activity along the basal <a>- and prism <c>-slip systems in quartz at high temperature, with the prismatic deformation bands being subparallel to the <c>-axis and the basal deformation bands perpendicular to it. These two types of CPO patterns seem to yield a quasi-orthogonal pattern of deformation bands. Although basal <a> slip may occur parallel to conjugate deformation bands/lamellae at low temperature (e.g., Gottardi and Tyssier, 2013), the major and secondary maxima would be normal to each other if the basal <a> slip activates in the same way as in the high-temperature case. As a representative case for a quasi-orthogonal pattern, it has an opening angle of 110°±10° (PNG-06-034a in Figs 6a and 8b). The angle between the two trace sets in Figure 7a is ~70° or 110° (rather than 90°). Therefore, they are conjugate prism <c>-slip systems. The parallelism between the orientation of deformation bands and grain shape fabrics in quartz likely resulted from deformation partitioning at the microscale.

4.4 Type H-2
This pattern is associated with a pair of point maxima that appear asymmetrically on the sides of the AP1, with the obtuse angle (≥110°) relative to the normal to AP1. The front point maximum represents the prism <c>-slip system on synthetic shear bands that deviate from the original orientation of the C-foliation. The predicted σ1 (or ISA3) is oriented 55° relative to the front maximum, implying a second stage of deformation caused by deformation partitioning. The two point maxima represent the second stage of deformation with the value of the vorticity number being 0<Wk<0.94. The trail maximum may represent either <c> slip on the S-foliation (for a trail maximum oriented 35°–0° relative to AP1) or <c> slip on the antithetic shear bands (for a trail maximum oriented 0°–35° relative to AP1), depending on the degree of deformation partitioning (Tikoff and Teyssier, 1994; Teyssier et al., 1995; Fig. 6a).

4.5 Type H-3
This pattern is associated with a pair of point maxima on AP1, with an obtuse angle (~110°) relative to the normal to AP1. The pattern represents 100% deformation partitioning of the shear zone (Tikoff and Teyssier, 1994; Teyssier et al., 1995), implying that the original shear zone has been transformed into a “pure shear” zone. In a strict sense, the zone is not a shear zone, but a contractional zone, because the <c>-slip system cannot function. The existence of this pattern confirms that the original shear zone was a quasi-simple shear, rather than a real simple shear zone, because the latter is characterized by a constant thickness with no shortening in the normal
direction.

The change in $W_k$ is different from the change associated with reworked shear zones, in which each orogenic event could be associated with a different state of stress. The latter may be recognized by 1) an initial $W_k \neq 0.94$; 2) an abrupt change in $W_k$; 3) an inconsistent shear sense, associated with different tectonic events; and 4) reworked shear zones with a negative value of $W_k$ (Simpson and De Paor, 1993).

5 The Opening Angle of Quartz <c>-Fabrics and Shear Bands

The opening angle of quartz <c>-axis fabrics, according to Kruhl (1996, 1998), may be used as a deformation thermometer in plane strain. This widely used thermometer is based on empirical data that show linear relationships between the opening angle and the deformation temperature in the range of 250 to 650°C (Morgan and Law, 2004). The opening angle is also sensitive to other parameters, such as water weakening, strain rate, and strain regime. Nonetheless, according to Law (2014), the deformation temperature can be estimated with an uncertainty of ±50°C. For deformation at higher temperatures (650–1050°C), Faleiros et al. (2016) suggested a slightly different linear relationship. The change in the opening angle is attributed to a change in the mechanism of dynamic recrystallization.

It is important to note that low- and high-temperature quartz <c>-fabrics have different definitions for the opening angle. At low temperature, the opening angle is the angle between the normals to two basal <a>-slip sets (Fig. 9a). At high temperature, this angle is measured between the two prism <c>-slip sets (Fig. 9b). Statistically, the most common opening angles in low- and high-temperature fabrics are 70° and 110°, respectively (Figs 7 and 9). Both angles are consistent with the MEM orientations. The abrupt change from 70° to 110° may reflect the transition from a basal-a<->slip to a prism <c>-slip at low temperature (~400°C) and high temperature (600–650°C), respectively (Lister and Domsiepen, 1982; Mainprice et al., 1986; Morgan and Law, 2004; Passchier and Trouw, 2005; Langille et al., 2010; Zhang et al., 2017). Establishing a linear correction between the two peaks is problematic owing to the abrupt change in the opening angle.

Quartz fabrics are sensitive to other factors in addition to temperature (Law 2014, and references therein). Therefore, thermometers that are based on a single criterion are problematic. The MEM criterion (Eq. 1), which considers the yielding point of the material based on multiple parameters (e.g., temperature, confining pressure, fluid pressure, and strain rate), may better account for the development of quartz <c>-axis fabrics and the associated opening angles.

6 Conclusions

Shear bands and deformation bands/lamellae nucleate in the orientations predicted by the MEM criterion, with $\sigma_1$ or ISA3 oriented 55° relative to the shear boundaries. In a steady state, spaced C- and penetrative S-foliation develop alternatively in a critical state of dynamic balance. The low-temperature basal <a>-slip and the high-temperature prism <c>-slip in quartz are both parallel to the shear boundaries, forming a single girdle in the direction normal to the AP1 and a unimodal maximum in the AP1 direction, respectively. Consequently, opening angles of ~70° (for low-temperature fabrics) and ~110° (for high-temperature fabrics) are produced. Non-steady deformation is most likely caused by deformation partitioning induced by changes in the stress state. In this case, synthetic shear bands progressively rotate from the orientation of the C-foliation until they reach an orientation of 35° relative to AP1. The major opening angle for low-temperature fabrics is ~70° and for high-temperature fabrics is ~110°. As synthetic shear bands occur earlier than antithetic bands during deformation partitioning, opening angles may be smaller than 70° for low-temperature fabrics and larger than 110° for high-temperature fabrics.

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associate EIC YANG Jingsui


About the first author
ZHENG Yadong, male, born in January 1936, Professor in Structural geology and Tectonics, School of Earth and Space Sciences, Peking University, Beijing 100871, China.

About the corresponding author
ZHANG Bo, Associated professor in Structural geology and Tectonics, School of Earth and Space Sciences, Peking University, Beijing 100871, China. Mainly engaged in structural geology and micro-structural geology. Main aspects of interest are based on macro-microscopic structural analysis, to reveal the tectonic geometry, kinematics, tectonic geomorphology and dynamic process of the intracontinental deformation and orogenic belts. The study area is mainly in the Tibet Plateau, western Yunnan and Southeast Asia.