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Kinematic analysis using AMS data from a deformed granitoid

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A B S T R A C T

This study highlights the usefulness of anisotropy of magnetic susceptibility data from a deformed granitoid in deciphering its kinematic evolution vis-à-vis shear zone. Data are presented from the Chakradharpur Granitoid (CKPG) that lies to the north of the northerly dipping, ENE–WSW striking Singhbhum Shear Zone (SSZ; eastern India). Whilst the foliation recorded in the field in some parts of the granitoid is parallel to the SSZ, the magnetic foliation is N54°E/90° (mean orientation). It is suggested that the magnetic fabric provides a window into an evolutionary stage prior to the final shearing/thrusting event, the evidence of which is preserved on the mesoscopic scale. It is envisaged that during the initial stages of deformation there was simple shear along the evolving SSZ that resulted in sinistral strike-slip movement; the vorticity axis at this stage was steeply plunging and sense of rotation was anticlockwise. Space was generated in a direction ~N25°E (perpendicular to maximum-Instantaneous Stretching Axis) into which CKPG emplaced synchronously with regional deformation and evolving SSZ. With continued deformation, there was thrusting along the SSZ. The vorticity axis flipped to a sub-horizontal orientation, thus leading to the development of down-dip stretching lineations and sheath folds within the SSZ. However, at the same time, the vorticity axis responsible for fabric evolution within the syntectonically crystallizing/cooling CKPG was steeply plunging with clockwise rotation. The magnetic foliation (mean orientation N54°E/90°) developed during the final stage of syntectonic crystallization. However, deformation in the region and thrusting along the SSZ continued even after the CKPG had fully crystallized and solidified, which led to the development of the ENE–WSW striking mesoscopic foliation that is parallel with the SSZ. We propose that the angle between the magnetic foliation and the SSZ/foliation recorded in the field, enables to decipher the kinematic vorticity number of flow responsible for fabric evolution of the CKPG. It is concluded that transpression was an important mechanism, and during regional deformation, whilst the SSZ developed structures by dominantly simple shear, the CKPG underwent dominantly pure shear.

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1. Introduction

In the past few decades, anisotropy of magnetic susceptibility (AMS) has become a well-established technique to analyse internal fabrics in plutonic rocks, particularly granitoids, that do not show well-developed mesoscopic foliations and lineations (e.g., Hrouda, 1982; Tarling and Hrouda, 1993; Aranguren et al., 1996a,b; Bouchez, 1997; Borradaile and Jackson, 2004; Mamtani and Greiling, 2005; Raposo and Gastal, 2009; Žák et al., 2009). It is known that many granitic plutons emplace syntectonically with respect to regional deformation and that crustal anatexis, granite extraction, ascent, emplacement and crustal deformation may be interrelated and synchronous processes (e.g., Brown and Solar, 1998; Druguet and Hutton, 1998; Vigneresse and Tikoff, 1999; Vigneresse and Clemens, 2000; Petford et al., 2000; Demartis et al., 2011). An integration of field, microstructural and AMS data has played a key role in establishing: (a) time-relationship between granite emplacement, fabric development and regional tectonics, (b) superimposition of fabrics at various temperatures in a syntectonically cooling granite, and (c) fabric intensity variations and identification of strain gradient within plutons (e.g., Bouchez et al., 1990; Aranguren et al., 1996a,b; Leblanc et al., 1996; Benn et al., 1998; Sen et al., 2005; Sen and Mamtani, 2006; Majumder and Mamtani, 2009; Mamtani et al., 2011). Many granites have a proximity to shear zones and kinematic evolution of the two may be inter-linked. An important aspect of kinematic studies is the analysis of vorticity, which is the "*amount of rotation*" a flow type possesses (Means et al., 1980). It is well accepted that most

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deformations in nature result from a combination of pure and simple shear, i.e., general shear (Xypolias, 2010); with specific reference to granites, transpression, which involves both coaxial and non-coaxial deformation (Dewey et al., 1998), is considered as a common mechanism (e.g., Žák et al., 2005). The degree of non-coaxiality of flow is gauged by calculation of the kinematic vorticity number (W_n). This number characterizes the geometry of particle paths for individual flow types. An important characteristic of flow is the presence of "*flow apophyses*". These are theoretical lines that separate different domains of particle paths. These define material lines that do not rotate with respect to instantaneous stretching axes (*ISA*) during progressive deformation. Depending upon whether material points (or lines) are attracted or repulsed, two apophyses can be defined – extensional or shortening. The former is also referred to as the "*fabric attractor*" (Passchier, 1997). The angle between the two apophyses (α) is a measure of W_n using the equation $W_n = \cos \alpha$. For perfectly pure shear, $\alpha = 90°$, and $W_n = 0$. For perfectly simple shear, $\alpha = 0°$ and $W_n = 1$. Several methods have been proposed for practical determination of W_n (see Xypolias, 2010 for a review). One of the methods to calculate W_n is by using the equation $W_n = \sin 2\xi$, where ξ is the angle between the ISA_{max} (maximum *ISA*) and the extensional apophysis (Weijermars, 1991; Wallis, 1995). In the past, the orientation of quartz neoblasts within an oblique foliation has been used to identify the orientation of ISA_{max}, while the shear zone defines the extensional flow apophysis (Wallis, 1995; Xypolias and Koukouvelas, 2001). Granitic rocks tend to develop fabrics during syntectonic cooling, which have frequently been recognized from AMS studies. In areas where fabric in granitic rocks is related to the evolution of an adjacent shear zone, the magnetic fabric orientation may represent the orientation of ISA_{max}. As a consequence, these data may provide a possibility to quantify vorticity (W_n). To the best of our

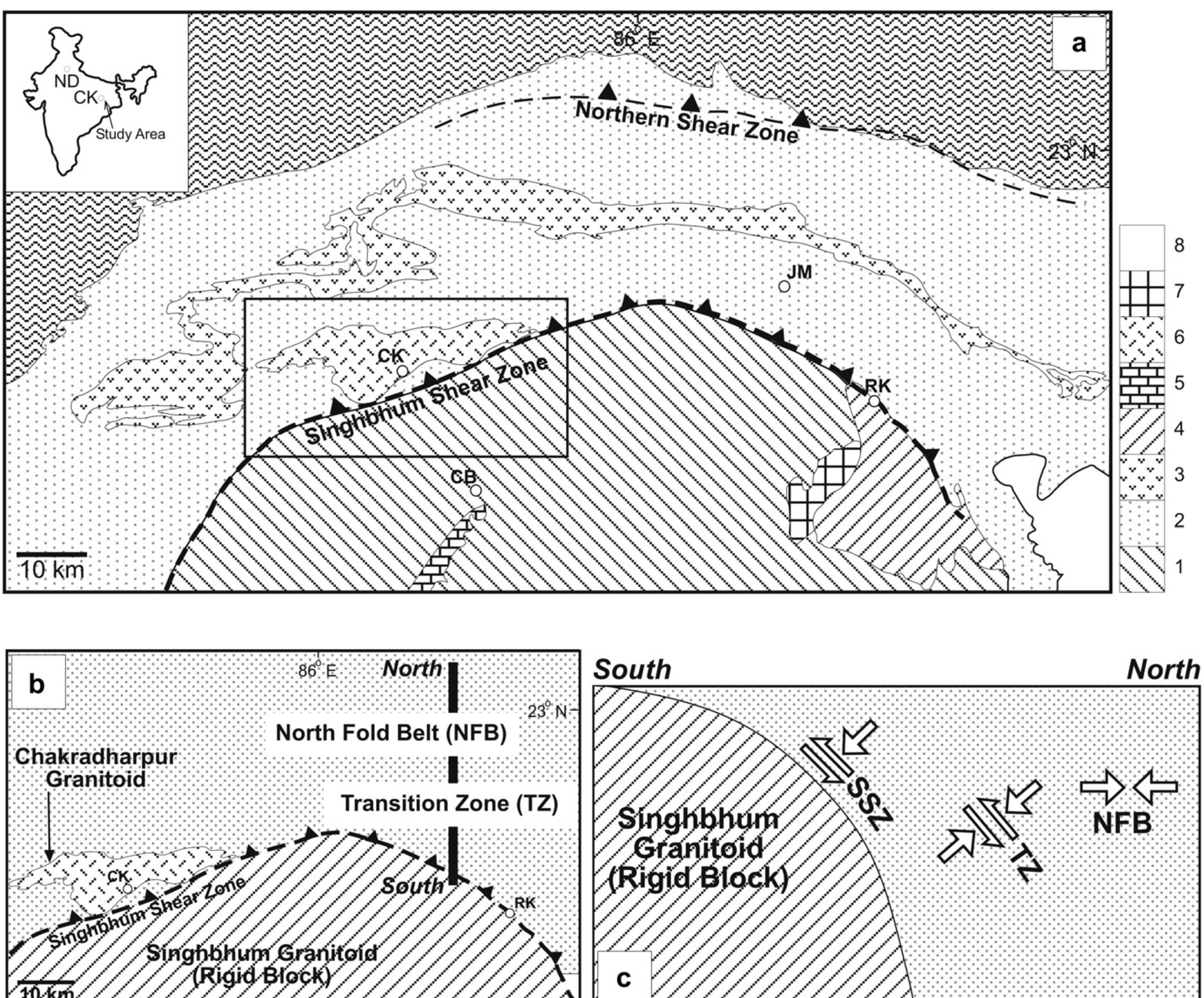

Fig. 1. (a) Generalized regional geological map of the rocks in the vicinity of the Chakradharpur Granitoid (CKPG) and the Singhbhum Shear Zone (SSZ) (after Saha, 1994). The arrow in the inset points to the study area in the eastern part of India. ND = New Delhi, CK = Chakradharpur, CB = Chaibasa, JM = Jamshedpur and RK = Rakha. Index: 1 = Singhbhum Granite and older rocks. 2 = Singhbhum Group rocks. 3 = Dalma Lavas. 4 = Dhanjori Group rocks. 5 = Kolhan group rocks. 6 = Chakradharpur Granitoid (absolute age uncertain). 7 = Proterozoic Gabbro, anorthosite and ultramafics. 8 = Alluvium. (b) and (c) are, respectively, the generalized map and section of the study area along the N–S oriented traverse from the North Fold Belt (NFB) through the Transition Zone (TZ) to the Singhbhum Shear Zone (SSZ) along which structures have been described by earlier workers (modified after Ghosh and Sengupta, 1990).

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