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Structural Features around the Archean-Proterozoic Terrain Boundary in Khammam District, South India

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Abstract

Boundary between the rocks of the Archean Nellore-Khammam schist belt and those of the Proterozoic Pakhal group occurs in Khammam district of southeastern part of India. The Archean terrain has undergone four phases of deformation, whereas the rocks of the Proterozoic terrain record two deformation events. The latest phase structural elements in the Archean terrain is similar to those of the first phase deformation of the Proterozoic Pakhal group. Furthermore, the above deformation is more intense toward the terrain boundary. These observations suggest that the latest structures of the rocks of the Archean terrain (D_{A4}) is superimposed structures resulted from first deformation (D_{P1}) during the Proterozoic. Evidence of the Proterozoic Eastern Ghats orogeny caused by NW-SE compressional stress regime in the Kinnerasani area of the Pakhal group and the Nellore-Khammam schist belt next to the former is noticed.

Key words : Archean-Proterozoic boundary, Eastern Ghats Mobile Belt, Nellore-Khammam Schist belt, Structural analysis

Introduction

The Nellore-Khammam schist belt (NKSB) (Ramam and Murthy, 1997), an Archean granite-greenstone belt forms a linear belt paralleling along the east coast of India. The schist belt is bounded by Eastern Dharwar craton on the west and Eastern Ghats Mobile Belt (EGMB) on the east. This belt has been considered to be a part of the Dharwar Batholith (Chadwick et al., 1996) and Circum East Antarctica mobile belt in East Gondwana (Yoshida, 1995). The NKSB is predominantly composed of metasediments and metaigneous rocks. It forms the basement rocks to the Proterozoic Pakhal group and Phanerozoic Gondwana sediments. The Proterozoic Pakhal group and Phanerozoic Gondwana sediments occupy at the flanks and central part of the Godavari rift, respectively. Except for the southeastern part of Khammam district, the Pakhal sediments are mostly unmetamorphosed and undeformed.

Detailed petrological, geochemial and geochronolgical work was carried out in the schist belt by earlier workers to understand the regional tectonic settings. However, only a few studies have been focused on the deformational and structural observations. The detailed field investigation of the structures with kinematic interpretation are needed to elucidate the structural and deformational history and its bearing on the tectonics of the NKSB. The present study area forms a narrow zone in between the western margin of EGMB and southeast end of the Godavari Rift zone. Considering the importance of the study area in respect to understanding the structural evolution, the present contribution concentrates on the detailed structural features of the rocks, emphasis is given on detailed lithological and structural map. An attempt has also been made to clarify the imprints of the Proterozoic orogenic event.

Regional Geological setting

The Godavari graben forms a major rift zone between the Dharwar and Bastar cratons, it extends upto the southeastern part of Andhra Pradesh merging with EGMB (Fig. 1). The mode of occurrence of the Pakhal group and major boundary faults of the Godavari rift both extend parallel to the general NW-SE strike of foliation in the rocks of the Dharwar and Bastar cratons. The boundary between the Proterozoic Pakhal group and the Archean NKSB are characterized by the presence of conglomerate bed (e.g., Sreenivasa, 1987).

The study area includes the boundary between the Archean and Proterozoic terrains (Figs. 1 and 2). The Archean NKSB is composed of quartzo-feldspathic gneiss, feldspathic gneiss, quartz-biotite-chlorite schist, augen gneiss and hornblende gneiss, with sporadic intrusions of pegmatite veins.

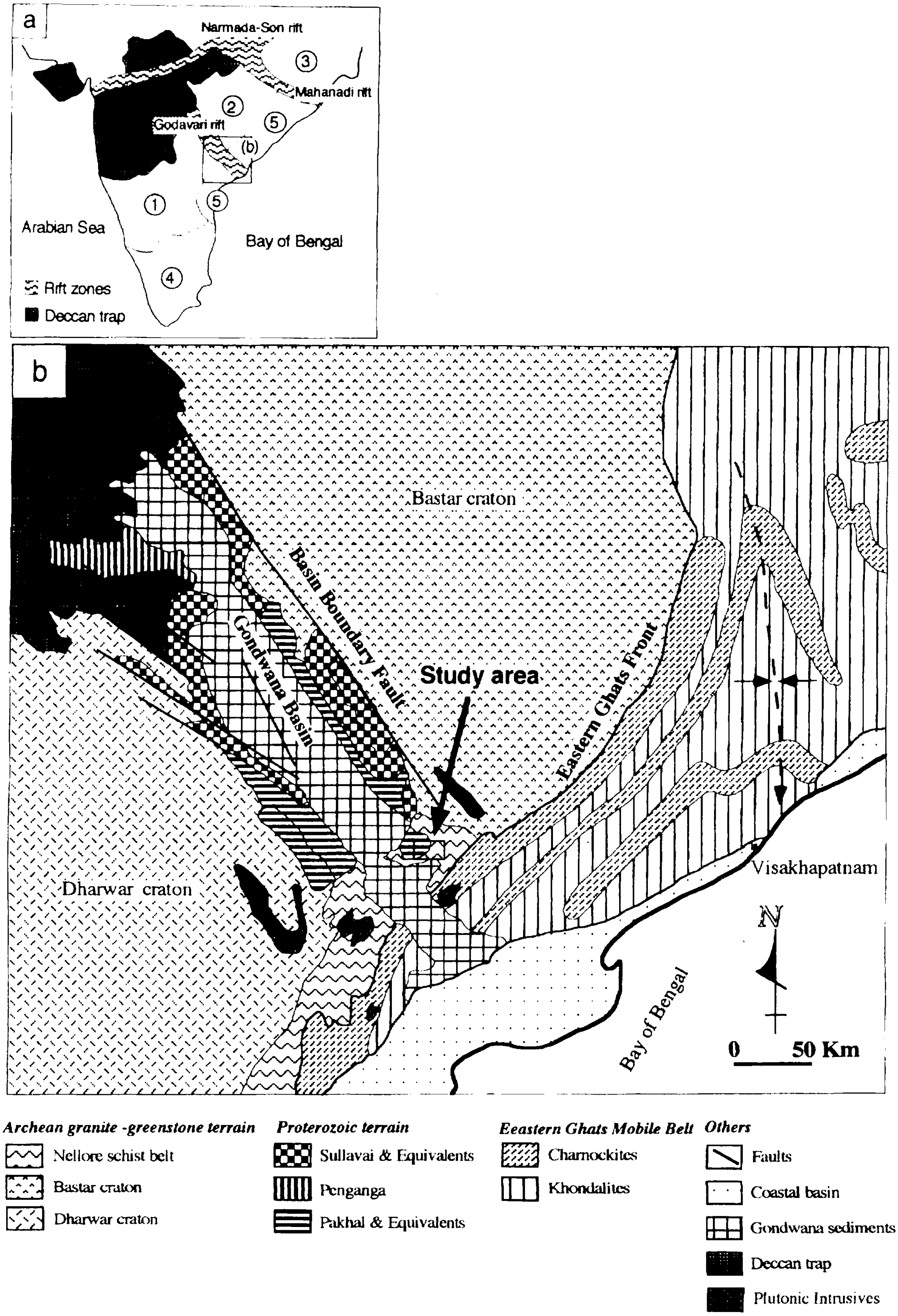

Fig. 1a : An outline geology of South India, major rift valleys in India (based on Krishna Brahmam and Negi, 1973). 1) Dharwar craton, 2) Bastar craton, 3) Singhbhum craton, 4) Southern granulites, 5) Eastern Ghats Mobile Belt.

1b : An outline geological map showing the spatial relationship between the Godavari rift and the EGMB. Godavari rift is located at the tectonic join between the Dharwar and Bastar craton. (modified after Laxminarayana, 1997).

Table 1. Summary of the structural characteristics of the study area

Archean		Proterozoic	
PHASE	STRUCTURES	PHASE	STRUCTURES
D_{A1}	mylonitization intrafolial tight to isoclinal folds (F_{A1})		
D_{A2}	macroscopic and mesoscopic NNW-SSE trending open to close folds(F_{A2})		
D_{A3}	E-W trending asymmetric open to close folds (F_{A3}) with north-vergence		
D_{A4}	NE-SW trending upright tight to isoclinal folds (F_{A4}) NE-SW trending faulting	D_{p1}	folds (F_{p1}) of banding structures with axial plane cleavage(S_{p1}) boudinage and pinch-and-swell structrues stretching of conglomerate pebbles
		D_{p2}	NE-SW trending kink type folds (F_{p2}), with steeply plunging fold axes

Quartz-biotite-chlorite schist mainly consists of quartz, biotite, muscovite, plagioclase and chlorite. Quartzo-feldspathic gneiss is composed dominantly of quartz, plagioclase and muscovite, with minor amounts of biotite and opaque minerals, and exhibits usually mylonitic fabric. Feldspathic gneiss is distributed in the central part of the study area and composed of plagioclase, quartz, biotite and muscovite with minor constituents of sphene and opaque minerals. Augen gneiss occurs as small discontinuous bodies and is comprised by medium- to coarse-grained biotite, plagioclase, quartz, chlorite and garnet. Hornblende and plagioclase are observed as porphyroclasts. Most of the hornblende gneiss is found as well continued layer.

Deformation structures

The study area can be subdivided into three structural domains for systematic structural analysis, domains I, II and III (Fig. 2). The domains I and II belong to the Archean terrain, whereas the domain III is of the Proterozoic terrain. While four deformational stages can be identified in the Archean terrain and termed as D_{A1}, D_{A2}, D_{A3} and D_{A4} from earliest to latest, two stages referred to as D_{P1} and D_{P2} are noticed in the Proterozoic terrain (Table 1).

Archean terrain

D_{A1} structures

Structures of the D_{A1} deformation are characterized by NE-SW trending mylonitic foliation (S_1) and intrafolial folds (F_{A1}) of tight to isoclinal type (Fig. 3a). The axial surfaces of these intrafolial folds are parallel to S_1. The F_{A1} folds are usually observed in the domain I, whereas the F_{A1} folds cannot be recognized elsewhere in the domain II. In a stereographic projection (lower hemisphere), the F_{A1} fold axes show scattering with gentle plunge toward east (Fig. 6). Distribution of F_{A1} fold axes are not concentrated, but have gently eastward plunging. The scatter may be attributed to interference by the later folding.

D_{A2} structures

Structures of the D_{A2} deformation are characterized by NNW-SSE trending macroscopic folds of open to close type with moderate to steep dipping plunge towards southeast (F_{A2}). These macroscopic folds are conspicuous by the orientations of strike and dip of the S_1, as displayed on the geological map (Fig. 2). The macroscopic F_{A2} folds are well preserved in the domain I. On outcrop scale, mesoscopic F_{A2} folds in domain II can often be observed, although in domain I these folds cannot be recognized. These mesoscopic F_{A2} folds show asymmetric style, and almost all the fold axes show moderate to steep plunging (Fig. 3b).

D_{A3} structures

The structures of the D_{A3} deformation are characterized by the E-W trending open to close mesoscopic F_{A3} folds with an inclined axial plane and a horizontal fold axis. The F_{A3} folds are accompanied by a distinct axial plane cleavage (Fig. 3c). Asymmetric mesoscopic F_{A3} folds show northward vergence (Fig. 4a,b). Mesoscopic F_{A3} folds are developed in the

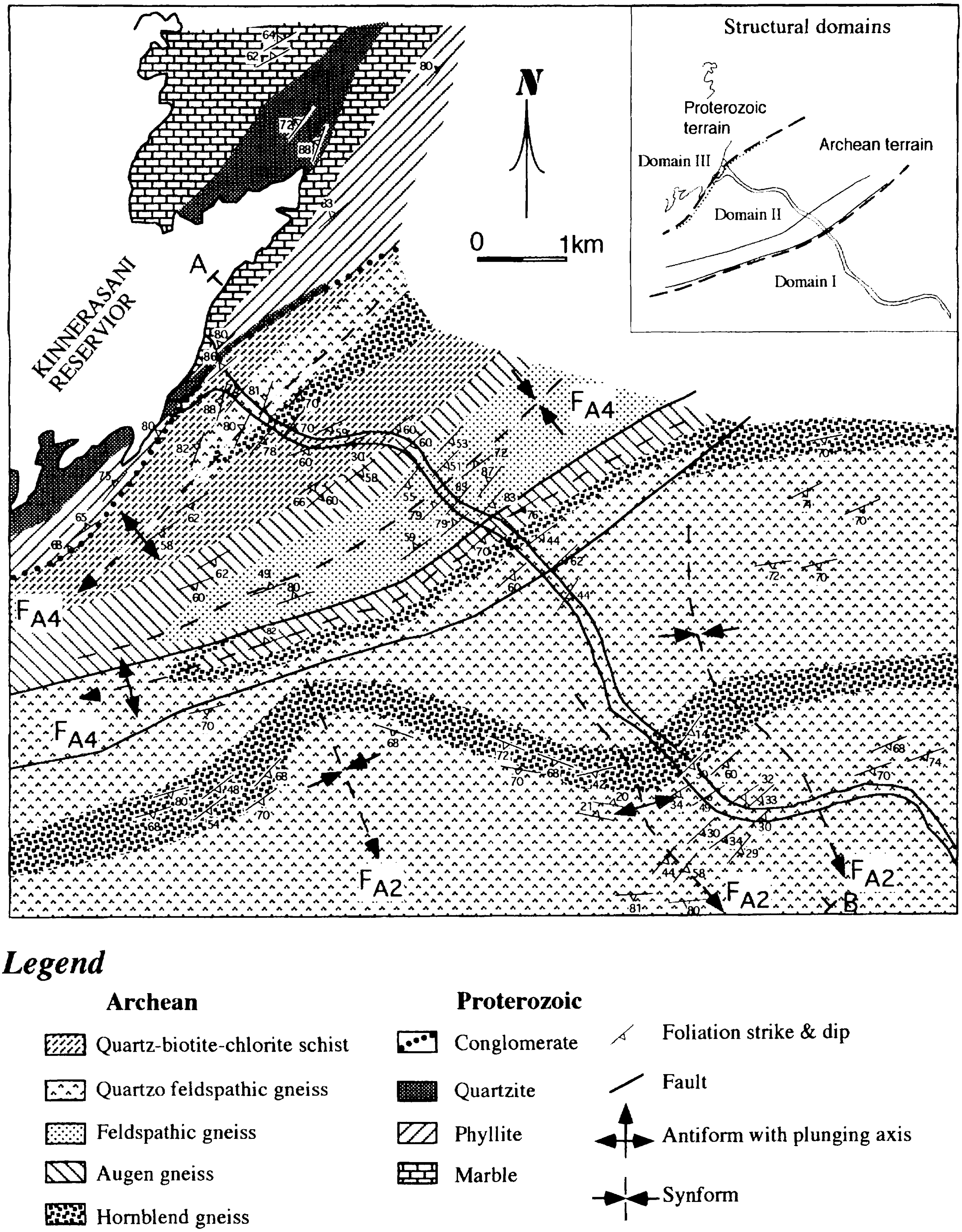

Fig. 2 Geological map of the Kinnerasani area.

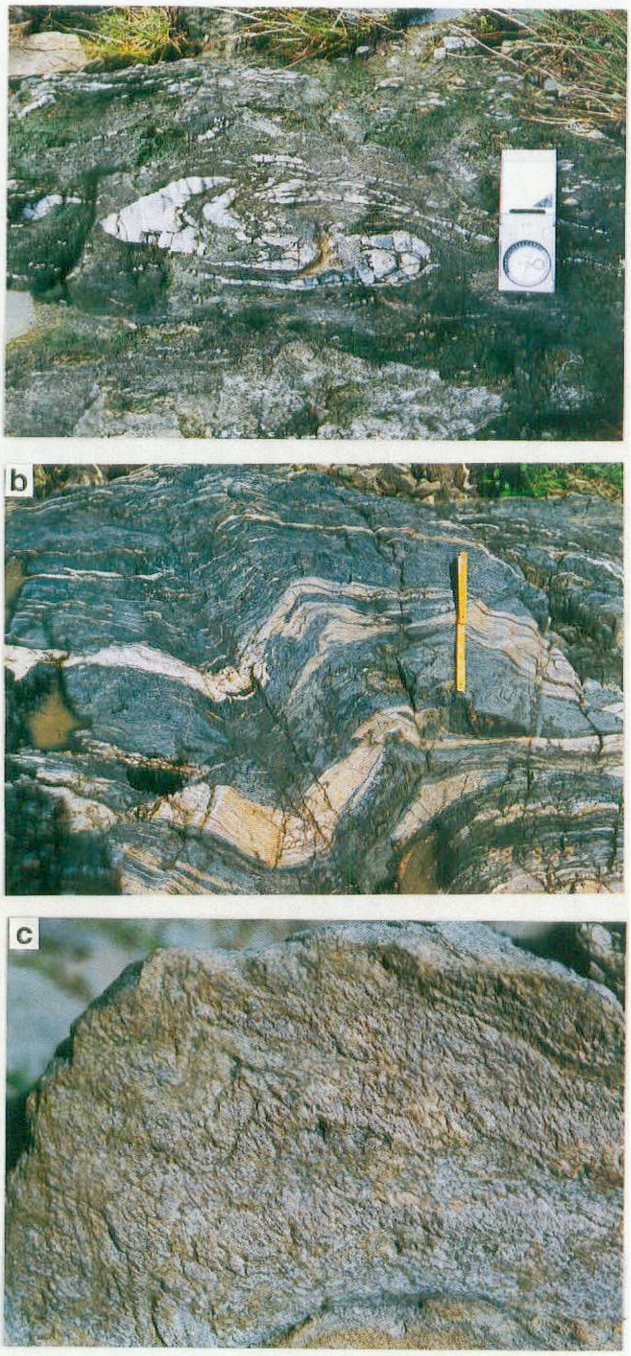

Fig. 3 Photographs showing occurrences of deformational structures in the Archean terrain a: Intrafolial tight to isoclinal type fold (F_{A1}) in feldspathic gneiss. b: Photograph showing open to close folds F_{A2} belonging to D_{A2} deformation. c: Asymmetric F_{A3} folds (with Z-type geometry) in quartzo-feldspathic gneiss.

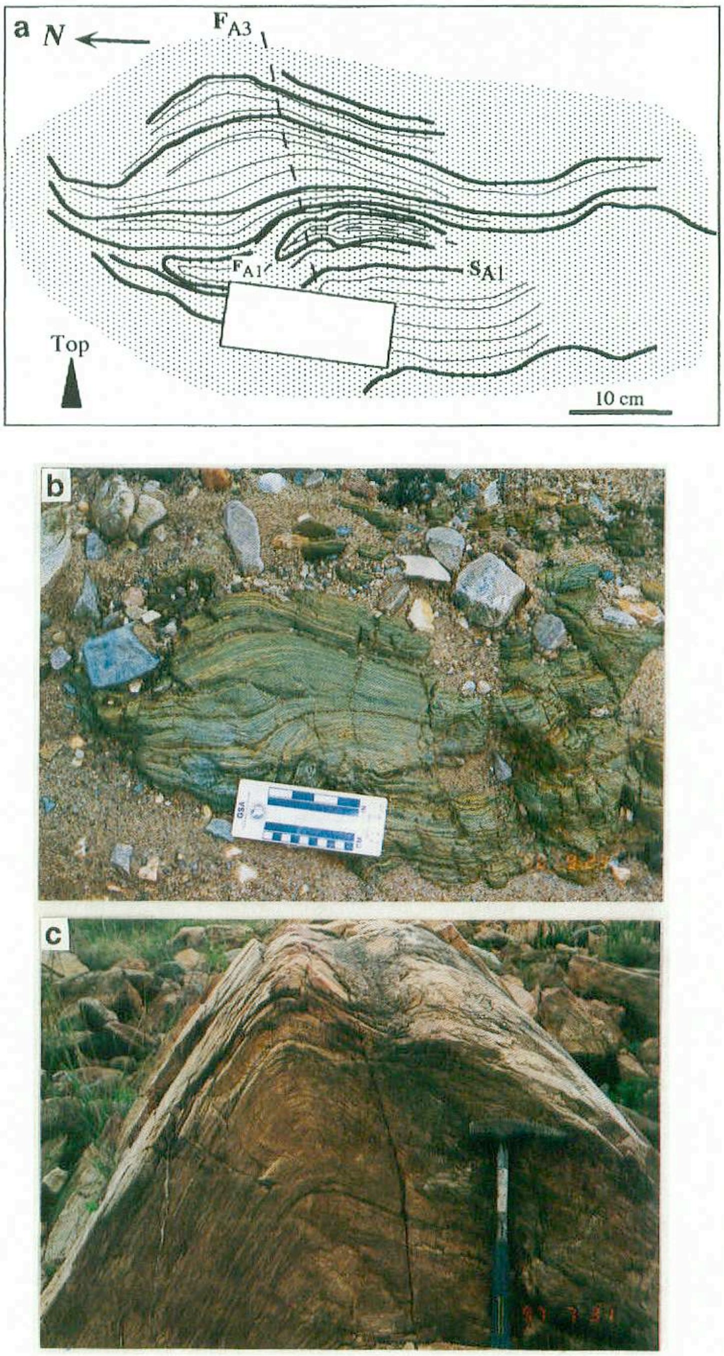

Fig. 4 a: An interpretive sketch of the photograph (b). b: Photograph showing the field occurrence of the F_{A3} folds. c: Photograph showing the mode of occurrence of upright tight to isoclinal F_{A4} folds in feldspathic gneiss.

domain I, whereas in domain II F_{A3} is not found. The distribution pattern of contours of π-poles of the S_1 forms a great circle girdle with a ß-maximum plunging gently toward east. Almost all the axes of the mesoscopic F_{A3} are plotted around the ß-maximum (Fig. 6).

D_{A4} structures

D_{A4} structures are characterized by macroscopic to mesoscopic upright folds. Mesoscopic upright tight to isoclinal folds with steeply dipping axial surface with a horizontal to sub-horizontal fold axes along NE-SW axis characterize these folds (Fig. 4c). These folds are observed in many

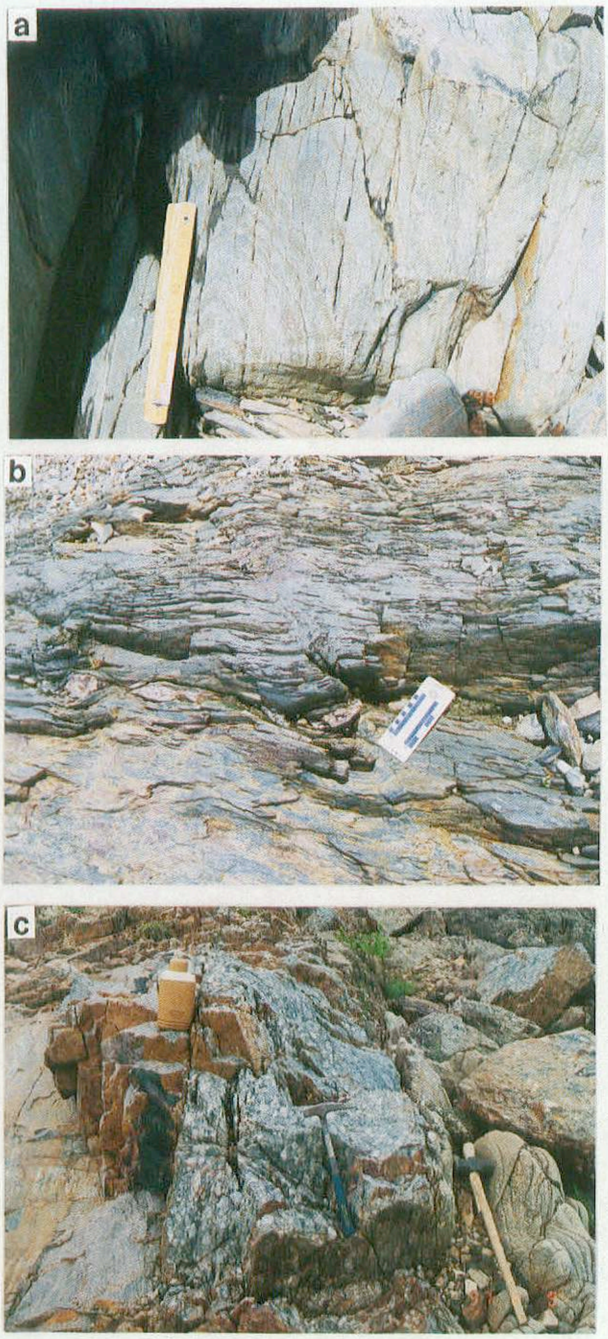

Fig. 5 a: Photograph showing the mesoscopic FP_1 folds with axial plane cleavage in phyllites. b: Kink type folds (F_{P2}) in phyllites. c: Field occurrence of the boundary between the Archean terrain and Proterozoic conglomerate bed.

outcrops in the domain II, whereas in domain I the F_{A4} folds have been not recognized. The distribution pattern of contours of the π-poles of S_1 form a great circle with gently SW plunging ß-maximum (Fig. 6). Distribution of the mesoscopic F_{A4} fold axes is plotted around the ß-maximum.

NE-SW trending faults are well identified on geological map (Fig. 2). These faults are truncating the early folding structures of D_{A1}–D_{A4}, implying their latest stage of the tectonic imprint in the Archean terrain.

Proterozoic terrain

D_{P1} structures

The structures of the first deformation are characterized by axial plane cleavage, folding (F_{P1}) and pinch-and-swell structures. Mesoscopic folds are characterized by the open to tight folds, with steeply plunging fold axes mainly along NNE-SSW direction. The axial planar cleavage is most striking planar structure in this domain (Fig. 5a). Orientation of fold axes of F_{P1} are mainly NNE with steeply plunging (Fig. 6).

D_{P2} structures

The kink folds or crenulation folds (F_{P2}) are characteristics of D_{P2} structures. These folds are nearly ENE-WSW trend with steeply plunging axes. The axial planar foliation of F_{P1} is clearly folded by this kink folds (Fig. 5b). Crenulation folds are commonly noticed in phyllites. The distribution pattern of contours of π-poles of axial plane cleavage of F_{P1} form a girdle circle with ß-maximum. The fold axes of F_{P2} folds cluster around the ß-maximum, and their orientation is similar to that of F_{P1} folds.

Discussion

The boundary between the Proterozoic Pakhal group and the Archean NKSB are characterized by the presence of conglomerate bed (Fig. 5c) (e.g., Sreenivasa, 1987). The Proterozoic Pakhal group mainly consists of by phyllites, quartzites, marbles and conglomerate. The pebbles of this conglomerate can be classified into A- and B-type pebbles, based on their color. Difference in color between A- and B-type pebbles are resulted from the different amount of opaque minerals. The conglomerate pebbles display the imprint of high strain as evidenced by elongated and cigar shape (Fig. 7c). The axial ratio measurements were made in the XY and YZ sections of the pebble ellipsoids and plotted in a Flinn strain diagram (Fig. 7a). Most of the pebbles lie in the constrictional type strain ellipsoids field, whereas some of the pebbles are lie in the flattening type strain ellipsoids. Because most of the pebbles show constrict type strain and their long axes (X)(Fig. 7b) coincide with orientation of the mesoscopic F_{P1} and F_{P2} folds axes, the most likely interpretation is that the elongation of pebbles is the result of the intense Proterozoic deformation.

For the Archean NKSB and other schist belt in the Dharwar craton, Babu (1998) has given around 2500-2000 Ma ages for a series of deformation events, F_1 (NNW-SSE), F_2 (NW-SE) and F_3 (E-W) folds. Such structural sequence

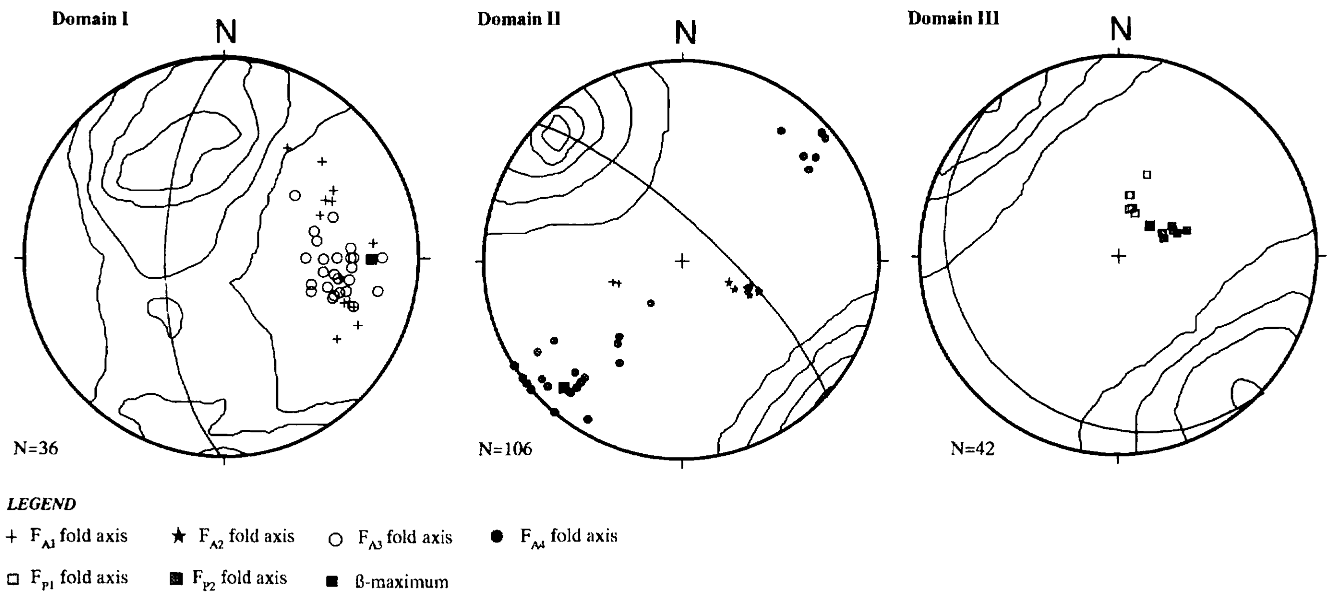

Fig. 6 Equal area stereographic projections (lower hemisphere) of the structural data of domain I, domain II and domain III in the Kinnerasani area. Kamb contours of π-poles of compositional banding and mylonitic foliation with great circle. The contour interval is 2σ.

coincides with F_{A1}–F_{A3} deformation events, excluding F_{A4} of the present study area. On the other hand, D_{A4} structural elements is similar to those of the D_{P1} of the Proterozoic Pakhal group. The D_{A4} structure is more intense toward the boundary between two terrains. These observations suggest that the D_{A4} structures of the rocks of the Archean NKSB is superimposed structures resulted from D_{P1} deformation during the Proterozoic. Although effect of D_{P2} on Archean rocks is not recognized, it does not necessarily mean that did not affect the Archean rocks. The Archean lithologies are more competent and have coarser fabric compared to the Proterozoic lithologies (phyllites). Thus, the effect of milder deformation could be less "visible" in the Archean rocks.

The Pakhal group was presumably formed during the Proterozoic rifting (Rogers, 1986), which have NNE-SSW extension direction, along the tectonic join between the Dharwar and the Bastar cratons (Laxminarayana, 1997). Pakhal group is generally undeformed and unmetamorphosed, whereas deformation and metamorphism is most pronounced to the southeast part, including the present study area (Subbaraju, 1975, Rogers, 1986, Sreenivasa, 1987, Laxminarayana, 1997). D_{P1} phase structures of Pakhal group such as NNE-SSW trending upright folds and pinch-and-swell structures are considered to have formed under the compression perpendicular to their axial surfaces. Thus, the buckling caused by the WNW-ESE compression, i.e. NNE-SSW extension, was the main reason for the F_{P1} folds. According to Naqvi and Rogers (1987) and Chetty and Murthy (1994,1998), a continent-continent collision tectonics operated during the evolution of the Proterozoic Eastern Ghats mobile belt and the northwestward verging thrusts substantiate a SE-NW compressional stress regime. Because compression direction of the Proterozoic Eastern Ghats orogeny and of the F_{A4} and F_{P1} folds studied here is nearly consistent, these tectonic events may be correlatable.

Conclusions

1. The detailed structural study in the Kinnerasani area of southeast India, where the Archean-Proterozoic terrain boundary is located, indicates that the area had undergone polyphase deformation. Deformation structures in the Archean NKSB can be classified into a sequence of four deformational phases (D_{A1}–D_{A4}), whereas, deformational phases in the Proterozoic Pakhal group can classified into two phases as D_{P1} and D_{P2}.

2. The latest phase (D_{A4}) structural elements in the Archean terrain is similar to those of the first phase deformation (D_{P1}) of the Proterozoic Pakhal group. Furthermore, the D_{A4} structures is more intense toward the boundary of the Proterozoic terrain. These observations suggest that the D_{A4} structures of the rocks of the Archean terrain is superimposed structures resulted from D_{P1} deformation during the Proterozoic.

3. Conglomerate including stretched pebbles has undergone intense constrictive. The maximum stretching axes of the pebbles parallels the fold axes of the Proterozoic folds. This implies, the elongation of pebble occurred during intense Proterozoic deformation.

4. Evidence of the Proterozoic Eastern Ghats orogeny

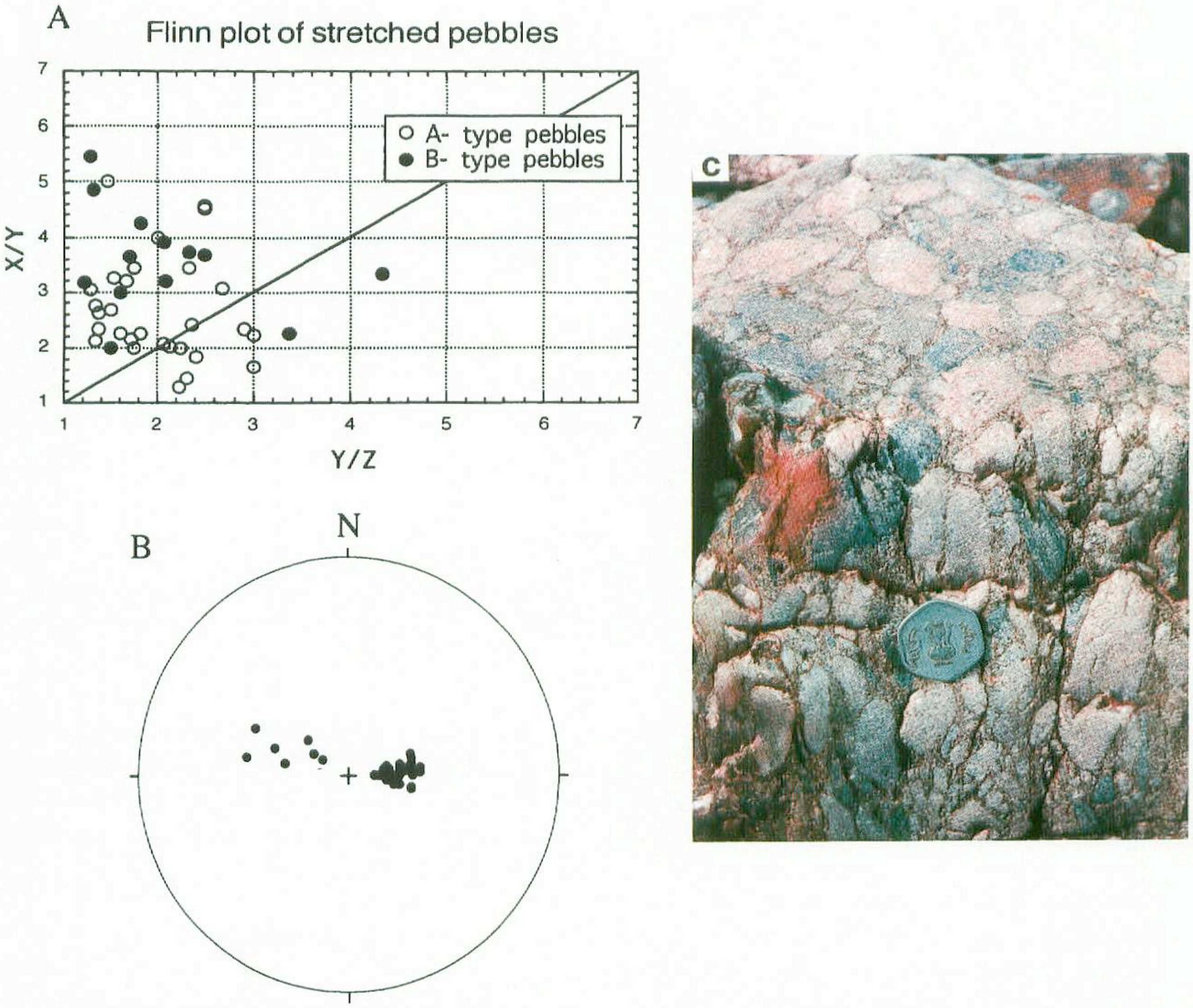

Fig. 7 a: Plot of axial ratios of pebbles in Flinn's diagram. b: Stereoplot of measured long axes (X-axes) of elongated pebbles. c: Photograph showing the mode of occurrence of elongated pebbles. The pebbles appears as circular in shape on the horizontal surface and as cigar shape on vertical face.

caused by NW-SE compressional stress regime in the Kinnerasani area of the Pakhal group and the NKSB next to the former is found.

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