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CORRESPONDENCE

Deformation History of the Kunavaram Complex, Eastern Ghats Belt, India: Implications for Alkaline Magmatism Along the Indo-Antarctica Suture

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Abstract

The Kunavaram alkaline complex is a NE-SW trending elongate body located along a major lineament, the Sileru Shear Zone (SSZ) that is regarded as a Proterozoic suture related to Indo-Antarctica collision. The complex is hosted within migmatitic quartzofeldspathic gneisses, mafic granulites retrogressed to amphibolites, and quartzites. The structural evolution of the country rocks and the alkaline complex are similar. The first phase of deformation, D_1, produces a pervasive segregation banding (S_1) in all rock units within and outside the complex. A second deformation phase D_2 isoclinally folded S_1 along subvertical axial planes with shallow plunging axes. F_2 isoclinal folds are ubiquitous in the country rocks and the eastern extremity of the complex. In the interior of the alkaline body, D_2 strain decreases and S_1 is commonly subhorizontal. While amphibolite to granulite facies conditions prevailed during deformation, post-D_2 annealing textures testify to persisting high grade conditions. In the west, a NNE-SSW trending dextral shear zone with strike-slip sense (D_3) truncates the complex. Within this shear zone, quartzofeldspathic country rocks are plastically deformed, while hornblende-K-feldspar assemblages of the complex are retrogressed to biotite and plagioclase. Warping related to D_3 shears also resulted in fold interference patterns on the subhorizontal S_1 foliation in low D_2 strain domains. Based on its steep dip, north-easterly trend, and non-coaxial nature with dextral strike-slip sense, the D_3 shear zone can be correlated with the SSZ. Since this shear zone, i.e., the SSZ, is not associated with primary igneous fabrics and resulted in solid state deformation of the complex, it cannot be considered as a conduit for alkaline magmatism, but is probably responsible for the post-tectonic disposition of the pluton.

Key words: Eastern Ghats Belt, alkaline magmatism, Kunavaram complex, Sileru Shear Zone, deformation history.

Introduction

The Eastern Ghats Belt (EGB) is an intensely deformed, granulite facies terrain that fringes the Archaean Craton of peninsular India. Detailed metamorphic and geochronologic studies over the past two decades have established that this region has remarkable geological affinity with parts of East Antarctica (e.g., Sengupta et al., 1999; Kelly et al., 2002; Dasgupta and Sengupta, 2003; Dobmeier and Raith, 2003). It is now generally accepted that the EGB was at one time contiguous with the Antarctica continent, and collided with peninsular India in the period 980–920 Ma (Mezger and Cosca, 1999;

Kelly et al., 2002). The contact between the EGB and the Archaean Craton is therefore considered to be a Precambrian suture zone (e.g., Gupta et al., 2000; Bhadra et al., 2004).

Although the geological significance of the EGB-craton contact has been a topic of considerable dispute for over a century (e.g., Walker, 1902; Fermor, 1936; Crookshank, 1938; Gupta and Bhattacharya, 2000), the boundary appears as a prominent lineament on LANDSAT images (Chetty and Murthy, 1993). This lineament, christened as the Sileru Shear Zone (SSZ) by Chetty and Murthy (1994, 1998a), is also characterized by the siting of a number of alkaline complexes along its trend (see map of Ramakrishnan et al., 1998; Fig. 1). A part of the shear zone has also been referred to as the 'Elchuru-Kunavaram-Koraput' shear zone, after three of the most prominent alkali igneous complexes within the belt (Chetty and Murthy, 1998b). Emplacement of these alkaline complexes has been considered syntectonic with movement on the shear zone (e.g., Bose, 1971; Bose et al., 1971; Chetty and Murthy, 1998b), which effectively served as a channelway for the transport of magma from the mantle into the crust. This, in turn, has been used to argue in favour of the crustal-scale extent of this shear zone, and to reinforce the impression of the SSZ representing a suture zone (Chetty and Murthy, 1994, 1998a).

The SSZ has been described as a 2–3 km wide zone that trends NE-SW and dips steeply to the south-east (Chetty and Murthy, 1994; Chetty, 2001). The Kunavaram alkaline complex (lat. 17°34' N; long. 81°15' E) lies on the SSZ, at the confluence of the Godavari and the Sabari rivers (Fig. 2). The complex is an elongate body trending NE-SW for a distance of 27 km, with a width of 5 km. While Bose et al. (1971) considered deformation of the complex to be synchronous with intrusion, Subbarao (1971) attributed folding and metamorphism to post-emplacement tectonism. Clark and Subbarao (1971) assigned ages of 1265±85 m.y. and 620 m.y. to intrusion and metamorphism, respectively. In the present study, the northern part of this complex has been remapped, and structural data collected across the complex into country rocks north, east and west of the body. The objective was to identify the SSZ in the Kunavaram area, and to confirm the relationship of the alkaline complex with movement on the shear zone. In effect, this study investigates whether the SSZ could indeed have served as a conduit for alkaline magmatism in the EGB.

The Country Rocks

Lithologies within the country rocks

The country rocks consist mostly of migmatitic quartzofeldspathic gneiss, and contain the typically granulite facies assemblage of quartz-feldspar-biotite-orthopyroxene-clinopyroxene-garnet, with biotite defining the dominant planar fabric. Amphibolites occur within country rocks along the western and northern contacts with the alkaline complex, and consist chiefly of hornblende, plagioclase, garnet and quartz. Occasional clinopyroxene and orthopyroxene relicts within hornblende suggest peak temperatures in the granulite facies. Mylonitised quartzofeldspathic rocks are restricted to a narrow zone along the western margin of the complex, sandwiched between the alkaline rocks and amphibolites. They contain feldspar and quartz with occasional garnet porphyroclasts. Highly weathered quartzites occur sporadically along the eastern margin of the complex. Garnet-sillimanite gneisses or khondalites are reported to the east of the alkaline complex (Subbarao, 1971). These rock types are compatible with the lithological association described from the EGB (Murthy et al., 1971), and are common in the "transition zone" (Fig. 1) fringing the craton (Gupta and Bhattacharya, 2000).

Structure of the country rocks

The country rocks have undergone three phases of deformation, identified from a correlation of early foliations with mesoscopic structures and their disposition

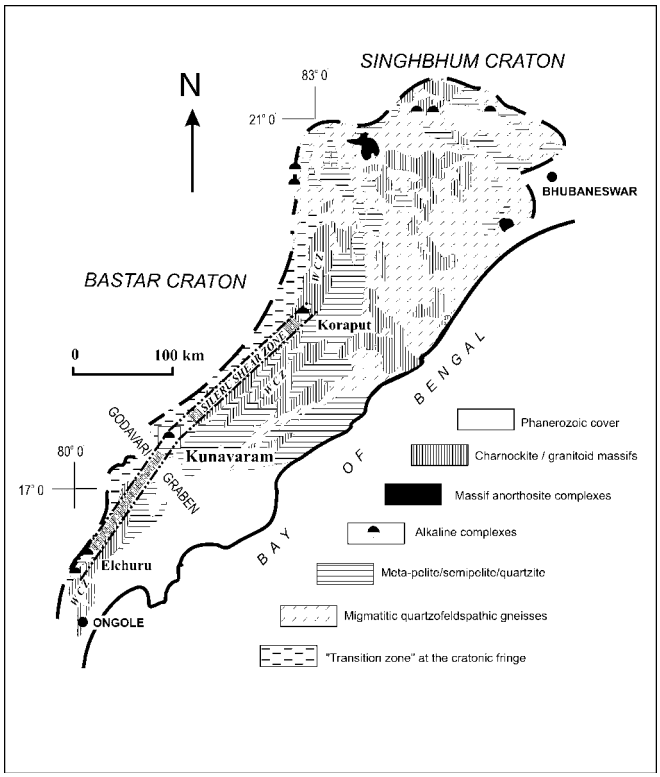

Fig. 1. Geological map of Eastern Ghats Belt (modified after Ramakrishnan et al. 1998) showing the distribution of different lithounits. The NE-SW trending Sileru Shear Zone and the location of important alkaline complexes are marked.

after subsequent rotation. While D_1 and D_2 fabrics are pervasive, D_3 structures are localized along the western margin of the complex. The first phase of deformation (D_1) led to the formation of a metamorphic segregation banding (S_1) with alternate leucocratic and mafic layers oriented parallel to lithocontacts. The second deformation (D_2) resulted in isoclinal folding of the S_1 layering, with gently southwesterly plunging axes and axial planes dipping steeply towards SE or NW. Late F_2 open folds occasionally coaxially refold F_2 isoclinal folds resulting in hook shaped (Type 3) interference patterns. Within migmatitic gneisses, S_1 foliations and F_2 axial planes commonly have melt segregations (Fig. 3a) suggesting upper amphibolite to granulite facies conditions.

The third and final phase of deformation (D_3) is dominantly shear-related, and is associated with the western contact between the alkaline complex and the country rocks. Mesoscopically, the NE-SW trending S_3 shears result in asymmetric folding of the S_1/S_2 foliation (Fig. 3a). Asymmetric porphyroclasts of quartz, feldspar and garnet within the mylonites suggest a dextral sense of movement (Fig. 3b). Transposition of lithologies during D_3 is evidenced by amphibolites immediately west of the contact that curve into the shear zone (Fig. 3c). Broad warps with sub-vertical axes related to D_3 shearing are developed on the S_1/S_2 fabric.

East of the contact with the alkaline complex amphibolites (hornblende-plagioclase-garnet-quartz) and quartzofeldspathic gneisses (quartz-K-feldspar-orthopyroxene-clinopyroxene-garnet) are characterized by coarse-grained granoblastic assemblages overgrowing S_1/S_2 fabrics (Fig. 4a). The high grade assemblages, the pervasive migmatization of the gneisses and the garnet-sillimanite assemblage reported from khondalites in the locality point to upper amphibolite-granulite facies conditions. Along the western contact, on the other hand, quartzofeldspathic rocks are intensely mylonitised, with granoblastic aggregates of K-feldspar alternating with domains of ribbon quartz (Fig. 4b). In adjacent amphibolites aligned D_2 hornblende grains (that replace clinopyroxene) are dissected and aligned along a new S_3 foliation (Fig. 4c), with local alteration to blue-green amphibole along grain margins. This suggests deformation under upper greenschist to lower amphibolite facies conditions, indicating a decrease in metamorphic grade during D_3 shearing.

The Alkaline Complex

Lithologies within the alkaline complex

The dominant rocks within the alkaline complex are nepheline syenites, composed primarily of microcline (perthite), plagioclase and nepheline with subordinate

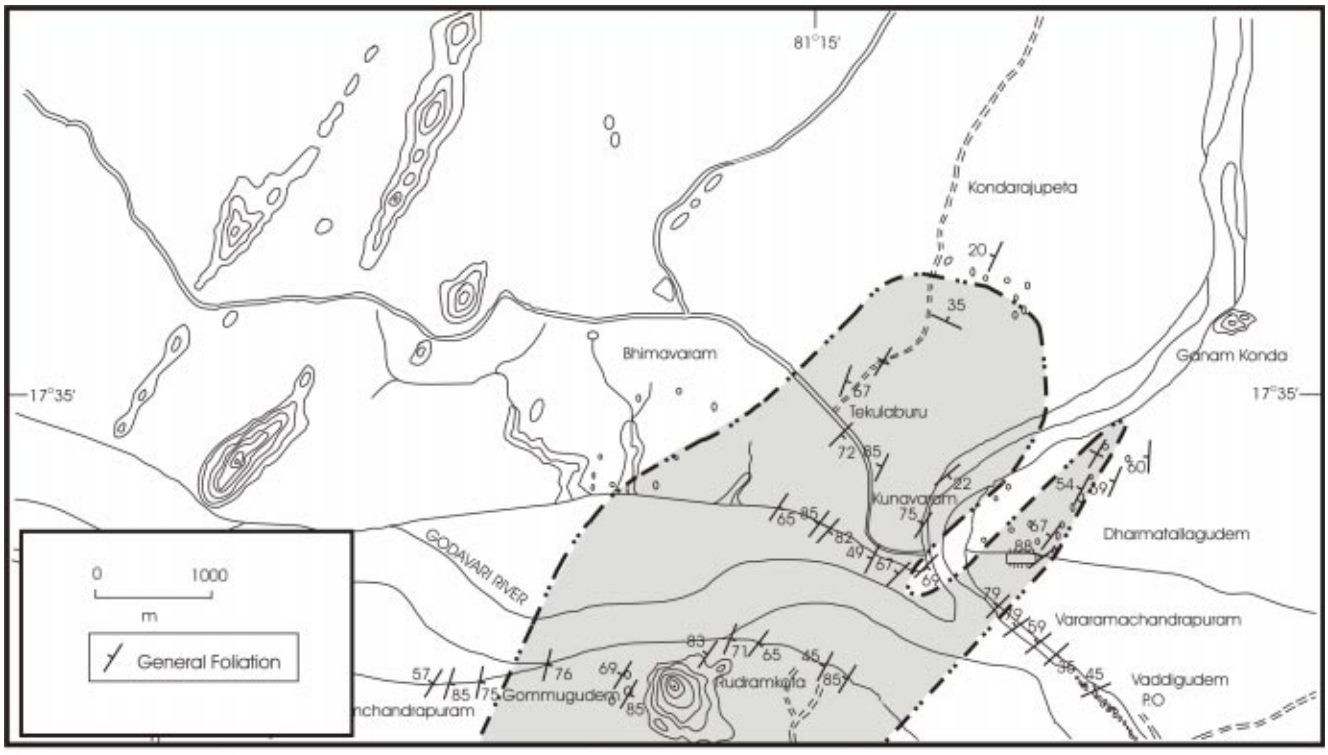

Fig. 2. Geological map of the northern part of the alkaline complex, note the consistent NE-SW trend of foliations within the country rocks and the complex.

biotite, hornblende, clinopyroxene, calcite, apatite and sphene. Depending on the proportion of hornblende, biotite and clinopyroxene the nepheline syenites in Kunavaram have been classified into hornblende bearing, bioite-bearing and clinopyroxene-bearing varieties (Subbarao, 1971). In addition to nepheline syenites, syenites (perthitic alkali feldspar, hornblende and/or biotite) and diorites (plagioclase and hornblende) occur on the bank of the Godavari. The complex is also traversed by coarse pegmatitic nepheline-bearing and granitic dykes. Nepheline-bearing pegmatites, with individual nepheline crystals having dimensions of 20–30 cm occur throughout the complex, while granitic veins preserving graphic intergrowth textures are restricted to the west.

Structure of the Alkaline Complex

The complex has undergone three phases of deformation, similar to the country rocks. The first deformation event, D_1, led to the formation of a segregation layering (S_1) defined by alternating leucocratic layers of K-feldspar, plagioclase and nepheline, and melanocratic layers of biotite and hornblende. The second phase of deformation, D_2 resulted in isoclinal folding of the S_1 segregation

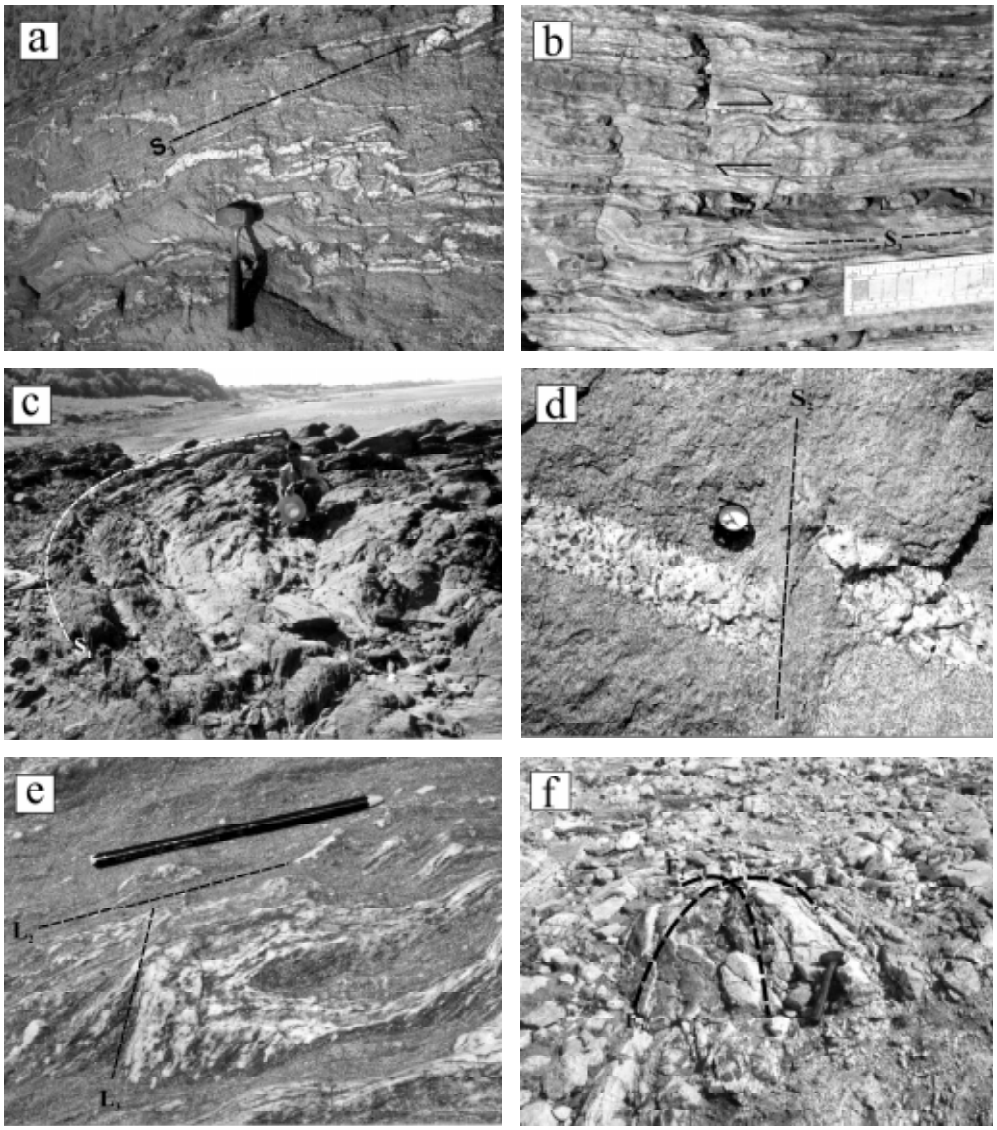

Fig. 3. Field relations in the Kunavaram area. (a) Asymmetric folding of S_1/S_2 segregation banding by S_3 shears in migmatitic quartzofeldspathic gneiss (b) Mylonitised quartzofeldspathic rock at the western contact of the complex. The mylonitic foliation is S_3. (c) S_1 within amphibolites warping into the D_3 shear zone along the western margin of the complex. (d) D_2 shear displacing nepheline-bearing dyke in the western part of the complex. (e) Axis of isoclinal fold (L_3) related to D_3 shearing in mylonitised nepheline syenite, plunging at a steeper angle than corresponding hornblende-defined L_2 lineation. (f) Axial culmination and depressions (Type 1 interference pattern) in nepheline syenite located in zones of low D_2 strain. The S_1 foliation in low D_2 strain zones is subhorizontal.

layering. Axes of F_2 isoclinal folds plunge gently towards SW and the axial planes are steeply inclined towards NW or SE. A penetrative foliation (S_2) defined by hornblende is developed parallel to F_2 axial planes. D_2 is most prominently manifested along the eastern margin of the complex, as a stack of isoclinal folds on the S_1 foliation that is largely transposed parallel to S_2. Open coaxial refolding of F_2 isoclinal folds about subhorizontal axes leads to Type 3 (hook-shaped) interference patterns, correlated with the waning stages of F_2 folding.

Towards west, the spacing between D_2 foliation planes gradually increases, and the extent of transposition of the S_1 foliation parallel to S_2 shows a corresponding decrease. This is interpreted as a decrease in D_2 strain towards the western part of the complex. In these low-D_2 strain domains S_1 is sub-horizontal, but broad warps correlatable with open F_2 refolding can be observed. Further westward, close to the contact with the country rocks, the S_1 foliation is itself poorly developed and the nepheline syenites are almost isotropic entities. Pegmatitic dykes of nepheline

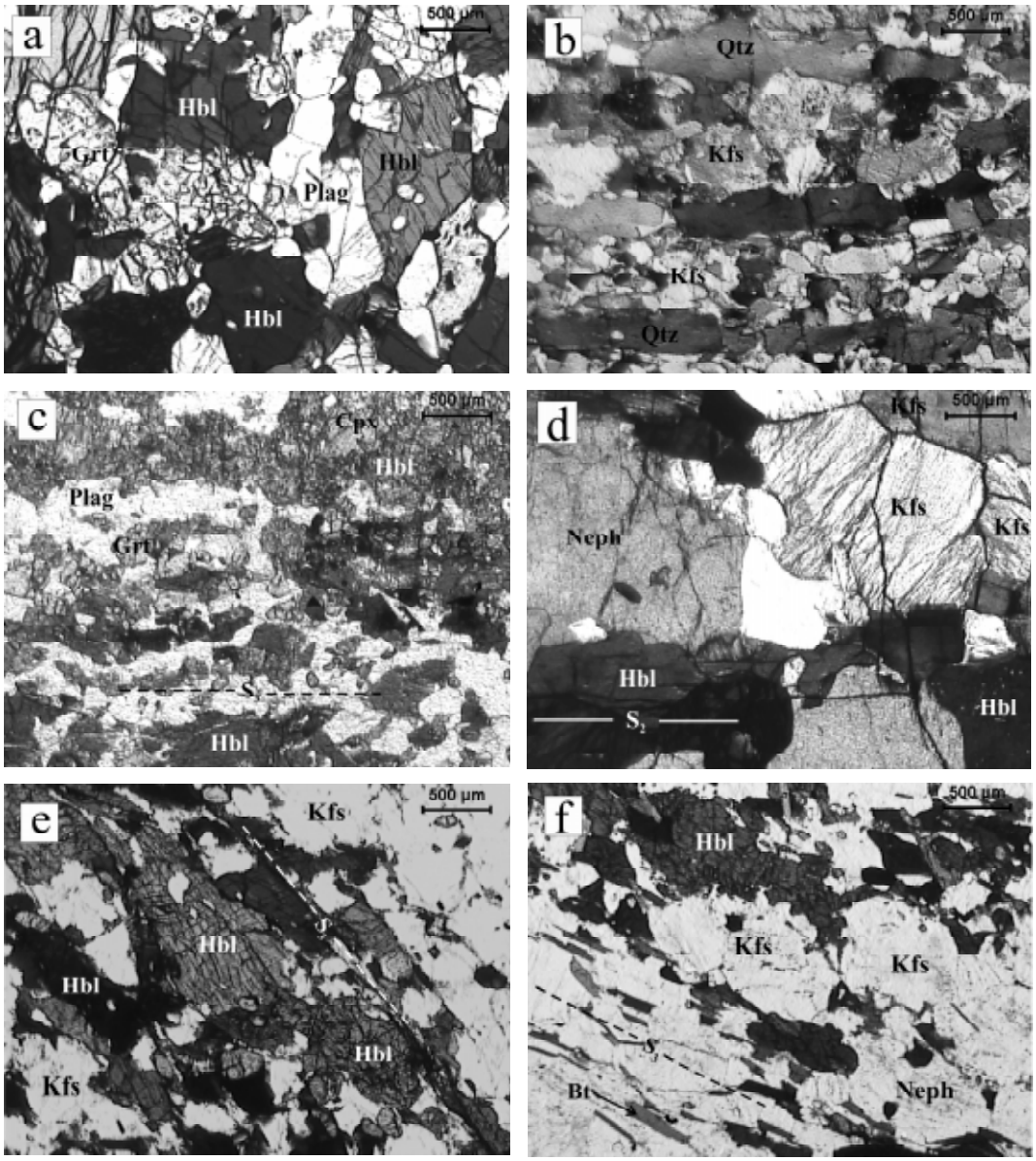

Fig. 4. (a) Granoblastic assemblage of hornblende-plagioclase-garnet overgrowing S_1/S_2 fabric in country rock amphibolites. (b) Granoblastic aggregates of K-feldspar alternating with domains of ribbon quartz in mylonitised quartzofeldspathic rocks along the western contact of the alkaline complex. (c) D_2 hornblende (replacing clinopyroxene) in amphibolites along western margin dissected and aligned along a new S_3. (d) Hornblendes defining S_2 in nepheline syenites anchored to post-D_2 granoblastic mosaic. (e) S_3 shears dissect coarse D_2 hornblende grains in nepheline syenite along western margin of complex. (f) S_3 biotite in mylonite zone replacing hornblende-K-feldspar assemblage in nepheline syenite.

syenite truncate the S_1 layering but curve into sporadically developed D_2 foliation planes. Characteristically, hornblendes defining the S_2 fabric in the nepheline syenites are anchored to a granoblastic mosaic testifying to post-D_2 annealing recrystallization (Fig. 4d).

In the western part of the complex nepheline syenite is almost undeformed, apart from the presence of occasional D_2 shears that displace nepheline-bearing dykes (Fig. 3d). This gradual westerly decrease in strain is interrupted by pervasive shearing (D_3) along the western margin of the complex. D_3 shears trend NNE-SSW and have a prominent strike-slip movement component. Folds initiated on S_1/S_2 concomitant with D_3 shearing plunge steeply to the south, normal to the sub-horizontal movement axis, and can be distinguished from shallow plunging L_2 lineations (Fig. 3e). Interference of NNE trending D_3 shear warps with more northeasterly trending open F_2 folds leads to axial culminations and depressions on the subhorizontal S_1 foliation in low D_2 strain zones (Fig. 3d). Petrographically, S_3 shears dissect coarse D_2 hornblende grains, leading to grain-size reduction in the mylonite zone (Fig. 4e). Mylonitized nepheline syenites develop a strong fabric (S_3) defined by biotite and plagioclase at the expense of hornblende and K-feldspar (Fig. 4f). This suggests a decrease in metamorphic grade, similar to that in the country rocks. Pegmatitic dykes of granitic composition intruded the complex after the D_2 deformation event. In general, these granites are undeformed and preserve graphic intergrowth textures, but are strongly sheared and foliated along the western margin of the complex. Consequently, granitic pegmatites are considered to have intruded prior to D_3 shearing.

Discussion and Conclusions

The most conspicuous feature of the structural set-up in the Kunavaram area is the parallelism of the NE-SW trending foliation in the country rocks and the general trend of the alkaline complex. The country rocks and the complex have both experienced two phases of penetrative deformation that are comparable in style and orientation. S_1 foliation pole distribution girdles are strikingly similar in both units, with b-axes that cluster around L_2 lineations and F_2 fold axes (Fig 5). The country rocks and the alkaline complex are therefore demonstrably co-deformed, with F_2 folding controlling the structural disposition. D_2 strain was preferentially partitioned along the margins of the complex. In the interior, narrow zones of high D_2 strain alternate with wider domains characterized by a subhorizontal S_1 fabric with occasional, broad F_2 warps. Such evidence for strain partitioning reflects the relatively rigid nature of the complex during D_2 deformation, which clearly operated on a solidified rock mass with a pre-existing planar fabric. In addition, microstructural study indicates that the L_2 fabric is annealed into a granoblastic mosaic; this implies high temperature recovery of a crystalline body consequent to solid-state plastic deformation.

Along its western margin the alkaline complex is truncated by a NE-SW trending shear zone that has transposed all earlier fabrics. The shear zone has a dextral sense of movement, and is associated with retrogressive metamorphism. These features are consistent with the reported nature of the Elchuru-Kunavaram-Koraput Shear Zone (Chetty and Murthy, 1998b), or the Sileru Shear Zone of Chetty and Murthy (1994), suggested to be the locus of alkaline magmatism in the Eastern Ghats Belt. D_3 shearing in the Kunavaram area can therefore be attributed to movement along the SSZ. D_3 truncates or transposes earlier deformation fabrics; D_3 related warps result in fold interference structures on the S_1 foliation. Clearly, D_3 was not accompanied by any major alkaline magmatic activity.

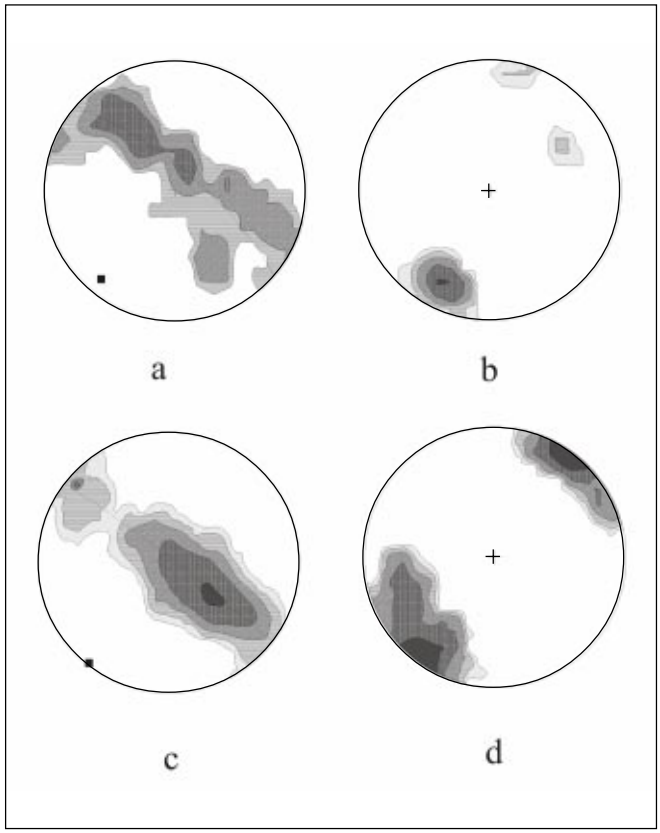

Fig. 5. (a) Distribution of S_1 foliation poles within the country rocks (n = 49; contoured at intervals 2, 4 and 8%). Calculated girdle 310º/76ºN, calculated β-axis 14º → 220º. (b) Distribution of L_2 lineations in the country rocks (n = 24; contour interval 4, 8, 16, 32 and 64%). Mean direction: 17º → 207º. (c) Distribution of S_1 foliation poles for the alkaline complex (n = 60; contour interval 1, 2, 4, 8 and 16%). Calculated girdle 308º/88ºN, calculated b-axis 2º → 218º. (d) Distribution of L_2 lineations within the alkaline complex (n = 60; contour interval 1, 2, 4, 8 and 16%). Mean direction: 9º → 225º.

Based on these observations in the Kunavaram area, we conclude that the SSZ was associated with solid-state deformation and possibly, metamorphism of the Kunavaram complex during the Indo-Antarctic amalgamation process. It may be argued that the lineament represents the site of a fossilized rift zone that was reactivated during subsequent collision tectonics. At present, it would be presumptuous to advocate such a possibility since substantiating data are not available. What can be concluded however, is that the SSZ was most certainly responsible for the post-tectonic disposition of the complex, rather than serving as a conduit for alkaline magmatism which clearly predated shearing deformation.

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