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Research Article

STRUCTURAL HISTORY OF THE NELLORE SCHIST BELT AROUND PAMUR-BOTLAGUDURU AREA OF PRAKASAM DISTRICT, ANDHRA PRADESH

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ABSTRACT
The Precambrian rocks in a part of Nellore Schist Belt of Prakasam district, Andhra Pradesh reveal a complex structural history involving five phases of folding, of which the imprints of the first, second and fifth are seen only on the mesoscopic scale while the third and fourth resulted in the development of regional folds in the area. The earliest recognizable deformation (D_1) is characterized by initial layer parallel compression followed by extension tectonism resulting in the transposition of the lithological layering (S_o), folds of isoclinals nature and formation of pervasive regional foliation (S_1). This foliation is the total function of strain during D_1 deformation and is axial planar to F_1 intrafolial folds. The second deformation (D_2) is seen in the form of minor crenulations while the major folds belong to third deformation (D_3) which controls the present lithological setting. Crustal shortening took place along NW-SE direction resulting, a series of anticlines and synclines in the area. Superposition of fourth phase of deformation (D_4) over the D_3 regional structures is more conspicuous throughout the region forming dome and basin (type 1 interference pattern), mirror image (type 2 interference pattern) and hook shaped (type 3 interference pattern). The progressive transformation from type 1 to type 3 is observed from the study area on the regional scale. The fifth deformation (D_5) is semi brittle to brittle type indicated by the presence of large scale fracturing and faults with occasional development of minor asymmetric folds as well as emplacement of pegmatite body along the axial planar direction of F_5 folds. The arcuate pattern with the convexity towards west to North West of all the lithotectonic units of the area, acts as a mirror image of the convexity of the Nellore Schist Belt which is probably caused due to the effect of D_4 deformational event.

Key Words: *Nellore Schist Belt, Prakasam District, Interference Patterns, Folds*

INTRODUCTION
A part of the Nellore Schist Belt (NSB) around Pamur and Botlaguduru area of Prakasam District of Andhra Pradesh (15^0 05' – $15^0$11'N; $79^0$28' – $79^0$37'E) has been mapped in detail with a view to evaluate the structural history. The NSB lies between the Easternghat Proterozoic mobile belt on the east and crescent shaped Cuddapah basin on the west and extends for a length of 200 km with an average width of 25 km. Nellore Schist belt has been recently renamed as Nellore Khammam Schist belt by Babu (2001) and occupies a unique position in the Precambrian history of Peninsular India. The southern part of the belt in Nellore district shows high grade metamorphics and a volcano sedimentary sequence, migmatites, granites, pegmatites and a number of basic igneous intrusive – named as Kandra igneous complex (Rao, 1992) against as Kandra ophiolite complex (Leelanandan, 1990). The northern part of the belt is relatively least studied but Khammam belt which was earlier treated as a separate schistose belt has been studied by a number of workers (HariPrasad *et al.*, 1999 and references therein). Over an all, the structural history of the whole belt has received relatively little attention in comparison with the schistose belt of Karnataka, South India. A concise tectonic history of the area is dealt with in this communication.

General Geology
Excepting geological mapping done by Geological Survey of India and a preliminary report of the western part of the area by Jagannadhan (1961) there was hardly any literature prior to mid 1960. The Chundi Malkonda area lying to the east of the present area has been mapped by Rao (1967). An unusual

bedded deposit of anthophyllite rock occurring to the north east of the present area has been described by Rao (1974). The south central part of the NSB near Kalichedu – Degapudi area has been mapped by Chetty (1983); Chetty and Kanungo (1986) and established three phases of deformation. Sarma (1995, 1996, 1998); Babu (2001), Mitra (2013), Sharma *et al.,* (2013) are some of the workers who have studied NSB from lithostratigraphic and structural aspects.

The dominant rock types of the area are metapelites interlayered with quartzite, banded iron formation, calc silicate rocks, amphibolites, quartz-hornblende biotite schist, quartzofeldspathic gneiss, migmatites, metadolerite, metanorite, lampophyre, pegmatites and quartz vein occur as bands or as intrusive (Figure 1). The rocks can be broadly grouped in the upper part of the Greenschist to amphibolites facies (Sarma, 1998). The different zonations from garnet to sillimanite zone are shown in the lithological map (Figure 1). Sillimanite zone is further subdivided into two sub zones – first sillimanite zone and second sillimanite zone and this has already been discussed by Rao and Sarma (1984). Lithostratigraphy and structure of the Precambrian rocks of the Batlaguduru area was studied by Sarma (1996) and a good correlation between schistose belts of the Southern Peninsula and Nellore Schist belt is dealt with.

Structure

A broad structural pattern of the NSB in the study area is the result of a polyphase deformational history (D_1 to D_5) and on the basis of overprinting criteria and structural analyses five phases of folding (F_1 – F_5), foliation (S_1 – S_5) and lineation (L_1 – L_5) could be established. Of these the imprints of D_1, D_2 and D_5 are seen only on mesoscopic scale while D_3 and D_4 results in the development of regional map scale fold structure. While identifying the fold generations minor fold asymmetry, sense of shearing, orientation of their axes along with respective axial planes and overprinting relationships have taken into consideration. In the entire hilly areas, metapelites and quartzites act as exposed wall like structure inclined at different angles and directions and they bear the identities of structural elements of different generations (Figure 4A). On the basis of structural homogeneity, complexity and superposition of the major folds the area have been divided into three structural sectors – eastern sector (a) the central sector (b) and the western sector (c) wherein all the structural elements are shown (Figures 2 & 3). There is a notable change in the fold interference on the regional scale in all the three domains. The rocks are predominantly represented by metasediment and the evidence of younging could be traced and hence the major folds are termed as anticline and syncline (not as antiform and synform as reported by Sarma (1996) and Sarma and Rao (1996). In the eastern sector, west of Malkonda, there is a major anticlinal structure, named as Ayyavarivalle anticline, which is about 10 km across, and show a broad closure towards north with a low angle plunge towards NE (Figures 1,2,3a). The central sector, lying between Kodigumpala in the north and Mopadu village in the southwest, shows a series of anticlines and synclines with a NE-SW axial trend plunging towards NE and / or SW. This is named as Kodugumpala- Mopadu composite synform (composite word is used in the sense that the major syncline is a series of constituent anticlines and synclines forming macroscopic en echelon pattern and not referred to here as synclinorium (Figures 2,3b). An overturned fold is the major structure in the western sector and is named as Vaggumpalle antiformal syncline (Figures 2,3c). Hence, the intensity of deformation increases gradually from SE to NW is well defined from lithological and structural map patterns (Figures 1,2,3).

Mesostructural Analyses

First phase Deformation

The structural elements of the earliest recognizable deformation (D_1) are marked by tight to isoclinals folds, highly pervasive axial plane foliation (S_1) and lineation (L_1). S_1 is the regional planar structure and used as tape recorder where history of the subsequent deformations is recorded. Occasionally, an earlier planar fabric marked by straight trails of inclusions of minute quartz and iron oxide is partially preserved within some garnet porphyroblasts of phyllitic rocks at different angles to S_1. Such early fabric might have been resulted from an earlier episode of deformation and metamorphism or may represent an earlier stage of D_1 deformation itself (Bowes and Write, 1975).

The F_1 folds are intrafolial, rootless or isoclinal in nature and well displayed by thin quartzite layers embedded in metapelites, ferruginious quartzites, calc silicate rocks and amphibolites. They are either dextral or sinistral in geometry showing thickened hinges and thin limbs, highly attenuated and often disrupted in the direction of tectonic flow in the form of discontinuous layers and lenses (Figure 4B). They are also of recline type. Folding angle Φ of F_1 folds worked out in transparent overlay varies from 160^o 180^0 while interlimb angle (l) varies from 0^0 to 30^0, both being indicative of tight to isoclinals folds (Figure 5A). The attitude of F_1 folds is highly variable due to the superposition of later deformations.

S_0 refers to the original lithological layering and S_1, being axial planar to F_1, becomes parallel to sub parallel to S_0 except near the F_1 fold hinges where S_1 cuts S_0 at maximum angle (Figure 4B). S_1 is defined by the preferred dimensional alignment of minerals like micas, staurolite, kyanite and stress controlled quartz and feldspar grains or grain aggregates (Figure 5B). Such matrix foliation is deflected round the rigid garnet, staurolite and kyanite porphyroblasts showing different degree of rotation. It is very difficult to establish whether the colour banding parallel to S_1 in quartzite and calc silicate rocks even after transposition represents primary banding or metamorphic banding. Statistical plots of the poles of S_1 and defined βs1 of different sub areas are shown in figure 3. The absence of a single defined point maxima or well defined π circle, the variation in the dip and strike of the S_1 is indicative of non parallelism in the orientation of the S_1 plane on the regional scale and it is apparently due to superposition of later folding. The wide variation of βS_1 is certainly due to later effect of major folding either at different stages of a single phase of progressive deformation followed by rotation (Ramsay, 1967) or of different deformational phases.

L_1 is represented by parallel alignment of prismatic minerals, minor fold axes, quartz rods, long axes of the pinch and swell structures and boudin axes (Figure 5A, B). Long crystallographic c- direction of some of the staurolite, kyanite, elongated garnet and quartz-sillimanite lenses show alignment parallel to the axes of the F_1 folding in metapelite and they define L_1(Figure 5B). The long axes of boudins, pinch and swell structures in 2- dimention have a close geometric relationship and are parallel to the axial surface of F_1 folds (Sarma, 1995).

Second Phase Deformation

Minor folds and small scale crenulation lineations are the characteristic manifestation of this deformation. No well developed planar structure is associated with this deformation although infrequent crenulation cleavage transecting S_1 along the axial surfaces of F_2 folds is seen in incompetent rock units. The size of F_2 folds varies from mm to cm scale; wavelength / amplitude ratio is relatively small. The F_2 folds (=L_2) plunge at a low to moderate angle either to NNE and/or SSW (Figure 5C, G). When the trend of the F_2 fold axis shows variation on either sides and it is apparently due to the effect of later deformations specially observed in the central sector where regional sinuosity is more pronounced (Figure 3B). The F_2 folds are inconspicuous or destroyed on the steep and shorter limbs of asymmetric F_3 folds while they are well preserved on the longer gentle limbs and make acute angle (<40^0) with F_3 fold axis. The sense of asymmetry varies from place to place as shown in figure 3. The F_2 and F_3 overprinting relationship is observed all throughout (Figures 3, 5CG). L_2 crenulation lineations are deformed by F_3 and make 15^0 – 25^0 acute angles with respect to F_3 fold axis (Figure 5G). Rarely S_2 intersects S_1 developing intersection lineation (L_2). Statistical plots of F_2 (=L_2) are shown in figure 3 av – bx_{iv}.

Third Phase Deformation

The overall structural framework of the area is dominantly controlled by D_3 deformation. F_3 folds are developed on the micro, meso and macroscopic scales. They are asymmetric in nature ranging in wavelength from mm to hundreds of meter scale, axial surface being essentially striking NE-SW with a dip towards NW and/or SE. Folds associated with crenulation cleavage are referred to here as crenulation fold which are common in incompetent lithounits but less common in other litho components. On the hand specimen scale they constitute enechelon pattern. Coarseness of crenulation increases with increasing metamorphism i.e. from staurolite-kyanite zone to sillimanite zone which corresponds with the decrease of amplitude and they are more common in the second sillimanite zone (Rao and Sarma, 1984).

The increase of interlimb angle (20^0 – 100^0) and decrease of folding angle Φ from 80^0 to 160^0 can be observed with the increase in grade of metamorphism from staurolite-kyanite to sillimanite zone. Generally the F_2 folds are asymmetrically upright showing both sinistral and dextral geometry in cross section (Figure 4F, G). Type 3 interference pattern is marked by F_1 and F_3 (Figure 3C). The nature of fold apices varies from sub rounded through rounded to sharp, occasionally double hinged (Figure 4D, J, G). Geometric analysis of folds of this deformation points that in the incompetent rocks F_3 belongs to class 2 and 3 while in the competent rock they belong to 1b and 1c. Such variation of F_3 folds depends upon the rheological properties of the rock. F_3 folds plunge dominantly towards 40^0-60^0 and/or 220^0-240^0 at a moderate angle 20^0-30^0. Such variation is due to interference of F_4 (Figures 3av, bx_{iv}, cv).
Crenulation cleavage S_3 and widely spaced fracture cleavages are the associated non pervasive planar structure but they are rock selective, the former developing essentially in metapelitic rock while the latter is developed in incompetent rock (figure 5D). S_3 is marked by zonal crenulation cleavage defined by M and Q domains parallel to the axial planes of F_3 folding. Occasionally S_1 is strained and reoriented parallel to the steeper limb of F_3. Widely spaced fracture cleavage is associated with F_3 axial surface. On the minor scale lots of quartz veins are seen passing through S_3. Stereoplots of S_3 are shown in figure 3.
L_3 is marked by S_1 ^ S_3 intersections, minor fold/crenulation axes, mineral lineations and rod lineations (Figures 5C, E,F,G). Migration of mobile silicate melt from the limbs to the hinges of F_3 forms linear structure observed in the metapelitic rocks of second sillimanite zone and they form rod lineation. Average plunge of L_3 is 30^0 to 35^0 towards 045^0 – 060^0 and / or 225^0 – 240^0 and is congruous with F_3. Stereoplots of L_3 show wide variation (figure) but they approximately lie in one plane which suggests that the lineation is deformed F_4 fold of similar nature (Ramsay, 1960) and not to differential strain during D_3 deformation. L_3 is deformed by F_4 (Figures) and there is a large variation in the acute angle formed by L_3 ^ F_4 (35^0 to 85^0). Drawn out transparent overlay of L_1 and L_2 on the rolled surface of F_3 when unfolded, the early lineations show linear character. On the other hand L_3 is deflected away from the hinge zone of F_4 folding in a clockwise motion.

Fourth Phase Deformation

The intensity of D_4 deformation gradually increases from south east to North West resulting more and more complex type of interference over the major F_3 folds. The F_3 folds vary from asymmetric to overturned type (Figures 4 F,H,L; 5A). Asymmetric type is more pronounced in the eastern and central sectors while in the western sector, they are mostly overturned (Figure 3). Fold hinges are sharp and rounded to sub rounded type in the incompetent and competent rocks respectively. Dip isogons are showing both convergency and divergency even in a single multilayered fold. Such convergency, divergency and parallelism of isogons are competency dependent and accordingly folds form class 1b, 1c, 2 and 3 types. The drawn out dip isogon geometry shows maximum similarity with the fracture patterns developed in more competent rocks. There is no large variation in the folding angle, interlimb angle and wave length-thickness ratio of F_4 folds. On the different limbs of the regional F_3 folds like Ayyavarpalle anticline, Kodigumpala- Mopadu composite syncline, F_4 plunges in opposite directions either to SE or NW. The F_4 folds are dominantly overturned in the central and western sector (Figure 3b,c) and are invariably plunging towards NW at a low angle. Their axial planes are trending NW-SE showing moderate to steep dip towards SW or NW. Type 3 interference pattern marked by F_1 and F_3 folds is further compressed by F_4 folding which is observed from Ayyavaripalle area. Simple and conjugate kink bands are seen in metapelite and amphibolites, width of the kink bands varies greatly (Figure 4K). Orientation of the kink bands boundary coincides with the orientation of the axial planes of the F_4 folds and they are curviplanar. Within the kink bands, secondary kinks are developed. F_3 ^ F_4 angle varies from 60^0 to 90^0 (Figure 5E). Unlike S_3, S_4 is represented by crenulations cleavage and fracture cleavage which transect the crenulated S_1 and is often defined by either reorientation of preexisting minerals along axial planes or sometimes regrowth along the shorter limbs of F_4 fold. Rarely S_4 behave like transecting cleavage on 3-dimension and defined by probable growth of quartz, chlorite and micas. The long orientation of the some of the porphyroblasts also show syn D_4 rotation showing parallel orientation to F_4

fold axes. Neomineralisation of quartz along the kink bands/ planes shows discontinuous veins reflecting en echelon pattern. Stereoplots of poles of S_4 show a well defined girdle with the βS_4 axes lying in the NE, the generalized π circle trends $N48^0W-S48^0E$ (Figure 3cvii). This orientation is common all throughout the area. The generalized π girdle of S_4 and S_3 which are perpendicular to each other indicate the nature of interference which correspond with the trend of the associated F_3 and F_4 (Figure 3a,b,c).

L_4 crenulations are common while the mineral lineation and intersection of $S_1 \wedge S_4$ are infrequently developed. Mineral lineations are defined by reorientation of earlier platy and flaky minerals along the shorter limbs or axial planes of F_4. Such variations are shown in (Figure 3cvii). L_4 in the western sector show well defined maxima (Figure 3cv) which gently plunges 20^0 towards N45W. In a and b sectors of the figure 3, in addition to such maxima they also show 20^0 towards $N45^0W$ with minor concentration in the SE quadrant.

Fifth Phase Deformation

The fifth and the last phase of deformation include folds (F_5), lineation (L_5) and fracture cleavage (S_5). F_5 fold is essentially confined on mesoscopic scale. The spacing between the crenulations and associated fractures developing parallel to the axial planes of the F_5 fold is much wider than the earlier sets of crenulations (Figure 5G). The amplitude is less than 2cm and invariably shows sub horizontal plunge (5^0 to 10^0) towards N. The interlimb angle is higher than the earlier sets of crenulation. The widely spaced fracture planes are trending N-S showing sub-vertical dip towards west. They are invariably of asymmetric and upright types, the eastern limb when rotate beyond 60^0, the S_1 foliation reorients parallel to the steep limbs of F_5 folds thus transecting axial plane of F_5 at an acute angle. The F_5 folds cut all the earlier crenulations and a carbon impression copy shows the interference of the same (Figure 5G). Stereoplots of F_5 lie in the north (Figure 3bxiv).

Regional Structures of the Area

Ayyavaripalle Anticline

A large scale asymmetrical anticline from Malkonda Chatram to the east to Kodigumpalle - Mopadu hill complex to the west is established and is named as Ayyavarpalle anticline (Figures 2,3a). Minor F_3 folds show variable plunge from 20^0 to 40^0 to NE and / or SW, concentrations being more in NE rather SW which portray the geometry of the large scale anticlinal structure. Statistically defined βS_1 L_3 F_3 plots show plunge of the F_3 folds as 28^0 towards 60^0. Topographic expression in the form of an elevated zone of thick quartzite layer (sinusoidal quartzite marker bed of 20 to 30 m thick) marks the major fold and its closure to the north of Ayyavarpalle village (Figure 1). The eastern limb is short and steep showing 45^0 to 80^0 dip, dip direction being somewhat variable from NE through east to SE. Similarly the western limb also shows variable dip direction from SW through west to NW, amount of dip varies from 20^0 to 30^0 (Figure 2). The axial surface of major fold is curved showing convexity towards west or NW and it is apparently due to interference of F_4 folding which broadly corresponds to the regional curvature of NSB. Reversal of dip of S_1 form surface along the hinge zone of the anticlinal structure indicates dome and basin structure on meter scale (interference pattern 1 of Ramsay, 1967). Stereoplots of poles of S_1 from the two limbs and hinge zones of the Ayyavaripalle anticline (Figure 3a) and the synoptic diagram indicate that S_1 is deformed by F_3 fold plunging 28^0 towards NE.

Kodigumpala - Mopadu Composite Syncline

This structure occupies the entire Kodigumpala- Mopadu hill complex and is a composite fold consisting of 9 synclines and 5 anticlines of relatively larger size (Figures 2, 3b). The individual folds when measured along exposed axis never exceeds 0.5 km and shows either NE or SW plunge at relatively low to moderate angle. The composite fold has two closures located near Kodigumpala to the north and Mopadu reservoir to the SW showing low angle plunge on either directions. Sinistrally moving curvilinearity of the major fold axis is the result of F_4 folding which has made the regional structure sinuous. The physiographic expression of the S shaped hill is the mirror image of the macroscopic fold pattern. A number of quartz veins measuring 2 to 4 m across are traceable along the axial traces of the major F_3 and F_4 folds, stereoplots of S_1 (Figure $3b_{i-ix}$) are shown and confirmed the structural behavior of the area. Minor F_3 fold axis and associated lineations formed two fairly pronounced maxima in the NE and SW directions at a low to moderate plunge similar to Ayyavarpalle anticline (Figure $3b_{xi}$). The regional composite structure is of non plane non cylindrical fold. The core part is covered by first sillimanite zone while the outer part belongs to second sillimanite zone. The related minor structures of the syncline are shown in figure 3b and they reflect the image of the larger fold. The F_4 influence on regional scale , is relatively more intense in the central sector (b) and the original NE – SW trend of the plane non cylindrical syncline was made sinuous resulting the development of sinusoidal type of non plane non cylindrical fold (type 2 interference pattern). This has got the similarity with the third mode of superposed buckling fold (Ghosh, 1993).

Vaggumpalle Overturned Fold

The western sector is characterized by large scale overturned antiformal syncline with a closure towards north and belongs to D_4 deformation. The imprints of F_4 is best preserved in the western sector where the regional structure- an overturned antiformal syncline of reclined type belongs to D_4 deformation and developed by refolding of an earlier major F_3 fold (Figures 2,3c). Both the limbs are dipping towards NW at a moderate angle (average 20^0) and show a broad closure towards north (Figure 3ci, ii). It is apparent from the map pattern (Figure 1) that the Vaggumpalle fold structure represents a hook shaped interference pattern (type 3 of Ramsay, 1967) and the surface expression of the resulting structure is a “U” shaped reclined fold plunging NW at right angle to the trace of the axial surface of the major F_4 fold. The amount of dip of the western limb gradually increases towards the closure, the dip direction being changes from NW to N through vertical to SW and finally to NW again (Figures 2, 3c). Structural trend of the metadolerite dyke near Inimerla village is WWN-EES. Absence of any secondary planar and linear structure within the metadolerite excepting marginal crushing of the country rocks is observed. This dyke body was probably emplaced during D_4 deformation following the axial orientation of F_4 folding. Transition of this fold from original F_3 to its present disposition is worked out and accordingly the original fold was an anticline similar in orientation of the other major F_3 folds to the east. The effect of F_4 on F_3 was confined to a modification of their axial trend in the form of varying degrees of curvature (the sinuosity being more pronounced in the central sector than in the eastern sector), F_4 reaching its maximum intensity in the Vaggumpalle area resulting in the complete refolding of the earlier F_3 fold (Figures 1,2, 3).

Other Structures

The low lying area between Kodigumpalle - Mopadu hill complex and Vaggunpalle hill complex is mostly soil covered excepting a few streams which however provides some outcrops and, thus two relatively large anticlines and synclines on meter scale are established. Fold closures are well exposed with the same attitudes like Ayyavaripalle and Kodigumpala structure. The fold axis is plunging at low angle towards NE and SW and the core of the fold is occupied by metapellites of garnet zone. Barrovian zonation is shown in figure 1. The generalized NE-SW trend of the F_3 folds both on small and large scale with average south western dipping axial planes and contemporaneous S_3 foliation indicate that they were formed in response to a strong NW - SE compression.

RESULTS AND DISCUSSION

Discussion

A complex history of polyphase deformations in the form of five phases of folding with associated planar and linear fabrics could be deciphered in the area, of which D_3 and D_4 give rise to all the three interference patterns of Ramsay (1967) on the regional scale. There is a marked change in the regularity of the fold morphology from the low grade rocks to medium grade rocks. A probable D_1 event is inferred from the presence of internal quartz and /or iron ore fabric within some of the garnet porphyroblasts of garnetiferous phyllites.

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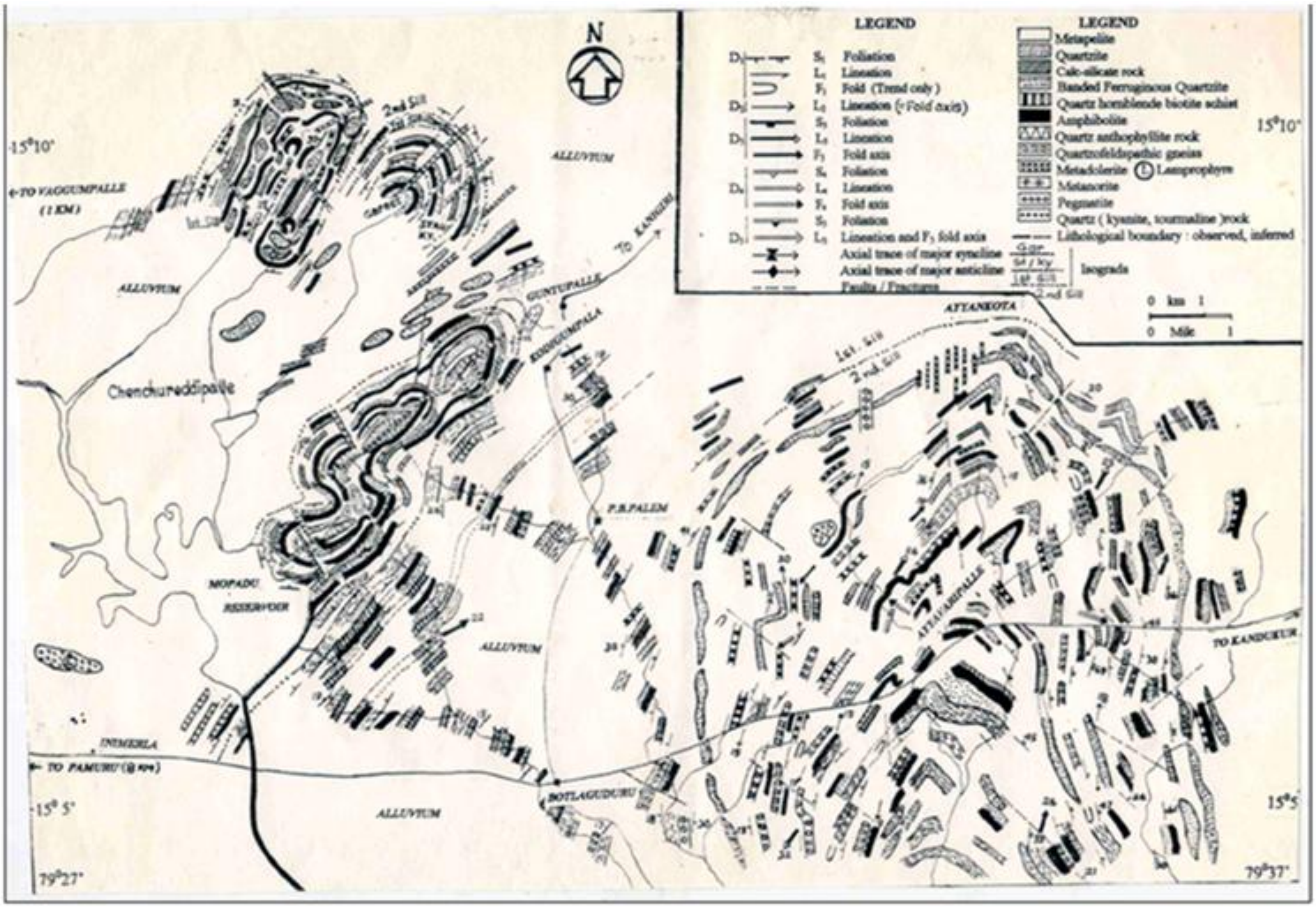

Figure 1: Lithological map of the Pamur-Botlaguduru area of Nellore Schist belt of Prakasam district, Andhra Pradesh

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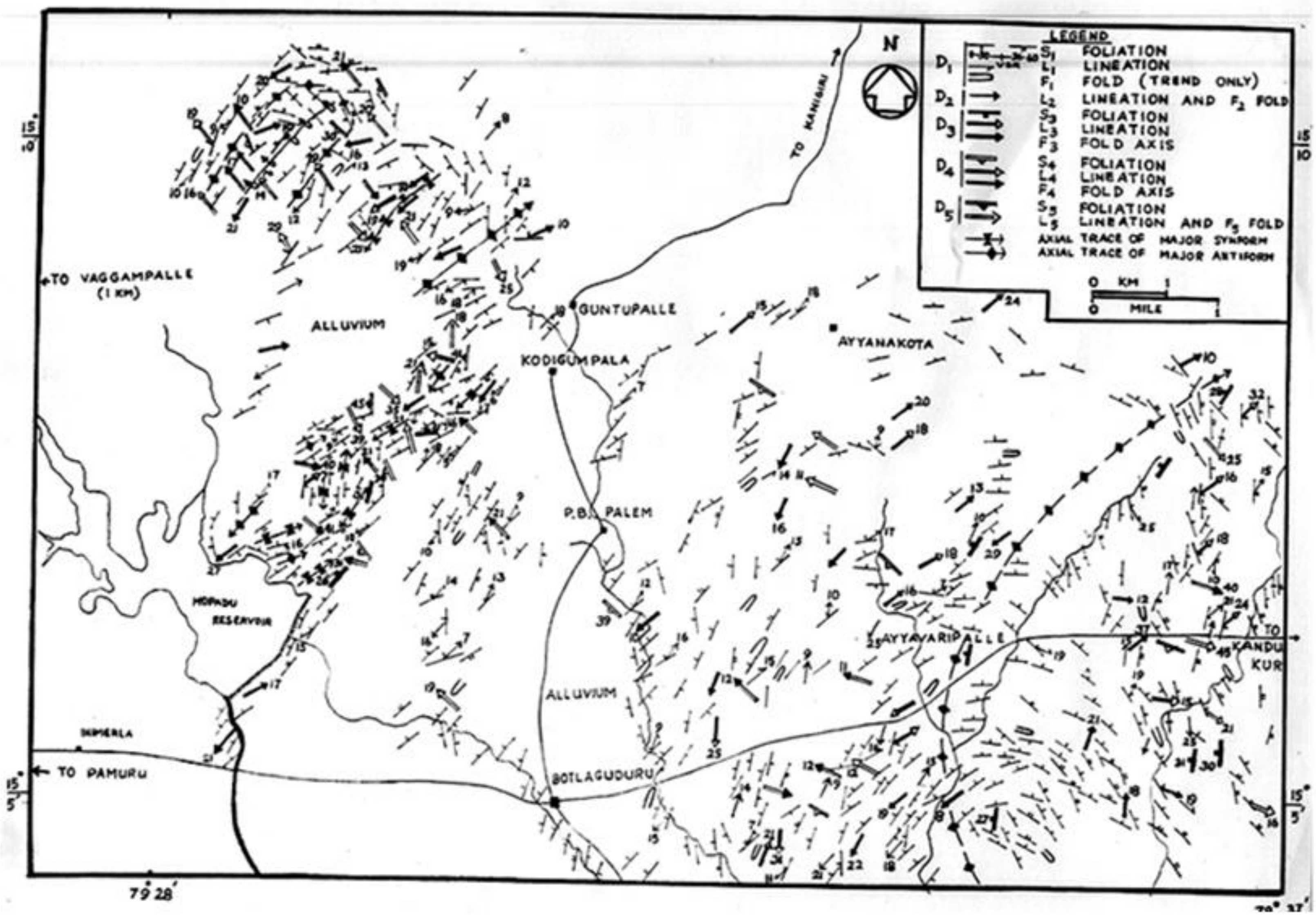

Figure 2: Structural map of the Pamur-Botlaguduru area of Nellore Schist belt of Prakasam district, Andhra Pradesh

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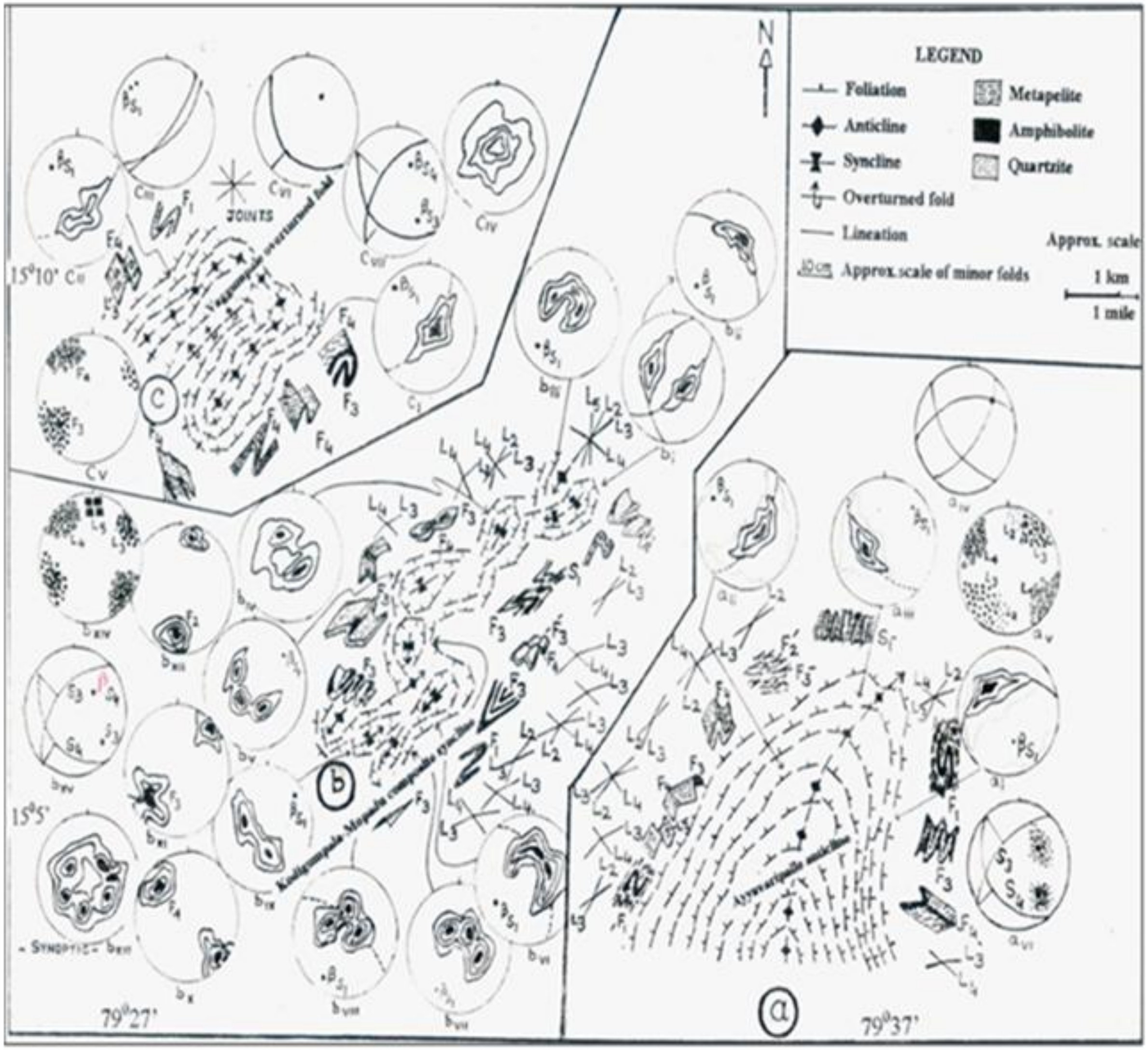

Figure 3: Structural map of the Pamur-Botlaguduru area of Nellore Schist belt of Prakasam district, Andhra Pradesh showing varieties of minor structures sector wise

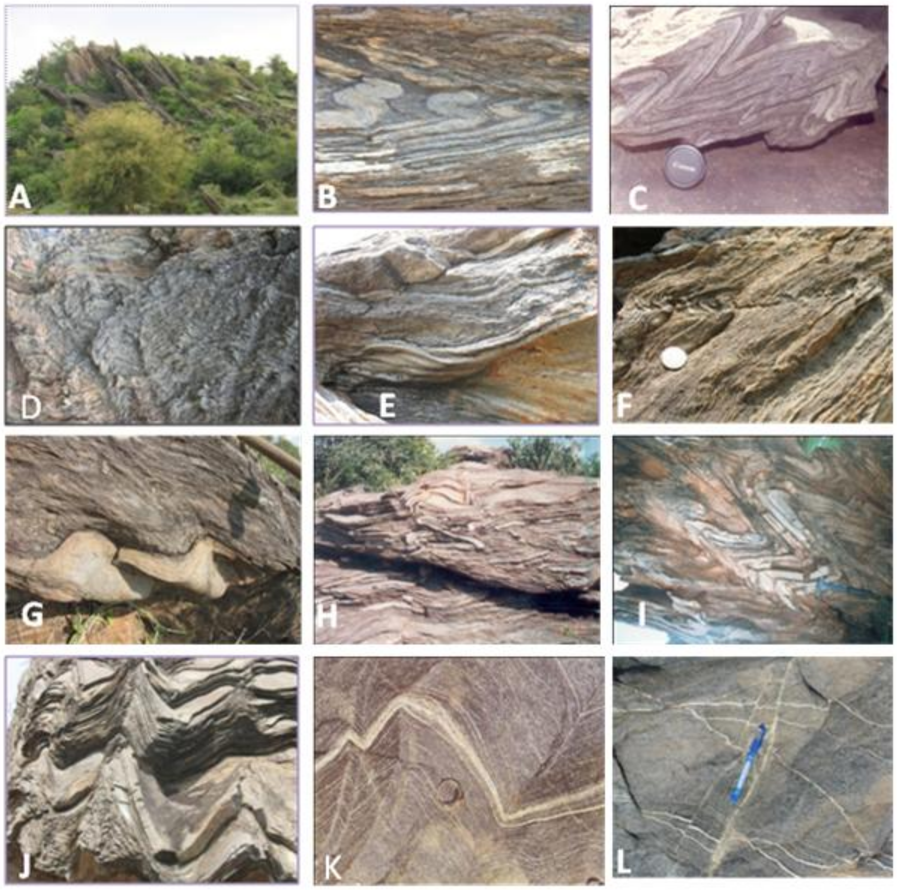

Figure 4: A: Surface outcrops of metapelite of Mopadu area (central sector-b) showing generalized dip towards NW.
B: Tight to isoclinals F1 fold of disharmonic nature marked by quartzite in the metapelitic host showing attendant axial planar foliation (S1). Location: Near Mopadu reservoir.
C: Z type of tight overturned F3 folds (i>e in quartzite and i< e unassociated metapelite) from Mopadu hill complex. Diameter of the camera lens is 5 cm.
D: Crenulations in metapelite showing conjugate habit from Kodigumpalle hill.
E: Rolled over L2 crenulation lineations are distorted by open F3 fold in quartzite.
F: Sinistral shear plane (S3) trending NE-SW is observed in metapelite from Ayyavaripalle area. Diameter of the coin is 2.2 cm.
G: Moderately NE plunging F3 fold of similar nature is marked by quartzite layers. In associated metapelite S1 is transected by axial planar S3. Thin sheared out quartzite layers are enclosed within metapelite. Length of the hammer handle at top right is 12 cm. Location: central sector.
H and I: Interference between F3 and F4folds in quartzites associated with metapelites. Fracture zone is along the axial planar orientation of F3. Location: Mopadu –Kodigumpalle hill complex. Length of the hammer is 35 cm.
J: Similar to I above. Moderate plunge due SW. Incompetent layers are showing multiple folding against singular competent fold. . Location: Mopadu –Kodigumpalle hill complex.
K: Kink folds in metabasic rock mimicked by intensive small vein quartz. Kink bands defining S4 are curviplanar due to interference of F5 folding. Location: Western sector. Diameter of the finger ring is 2 cm.
L: Conjugate fault planes (S5) trending N-S are mimicked by quartz veining in metabasite. Displacement portrays mini graven. Length of the pen is 13 cm. Location: Western sector.

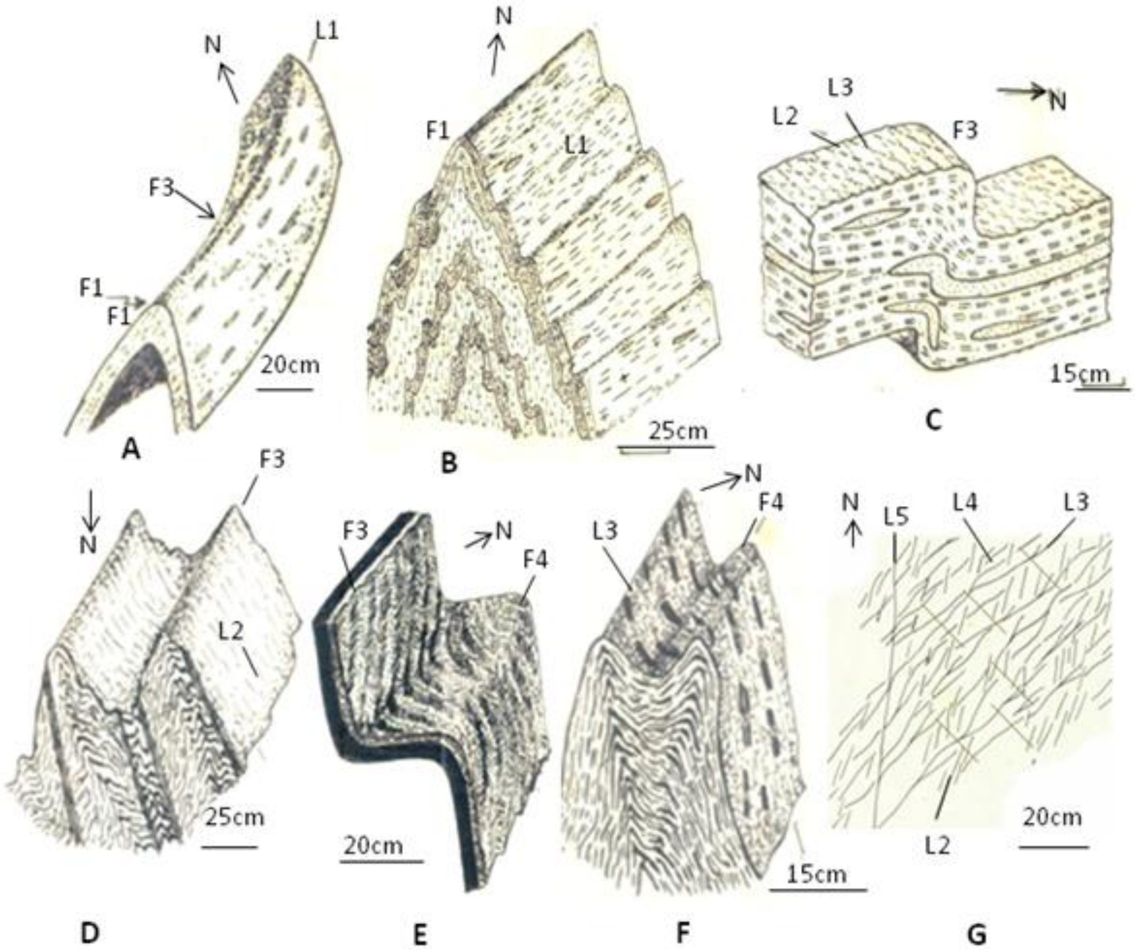

Figure 5: Field sketches showing structures of different deformations:
A & B: Tight F_1 fold showing thickened hinge and thin limbs associated with axial planar foliation (S1). L_1 lineation is marked by quartz sillimanite lenses. Mild effect of F_3 is observed. Locality. Eastern limb of Ayyavaripalle anticline.
C: Interference between F_1 and F_3. On XY plane L_2 and L_3 makes angular relationship (<40^0). Locality: From Kodigumpala hill.
D: Tight F_3 folds in metapelite associated with axial planar S_3. Locality: Mopadu hill complex.
E: Cross folding marked by F_3 and F_4 in a layered sequence of amphibolites and metapelite. Locality: From central sector (b).
F: Conjugate F_4 fold bears the imprints of pre L_3 lineation at high angle in metapelite. Locality: From Mopadu reservoir area.
G: Carbon copy negative impression of lineation of different generations-L_2,L_3,L_4 and L_5. Locality: From Kodigumpala –Mopadu hill complex.

The present disposition of the lithological layering, its discontinuity and thickening and thinning nature, development of regional S_1 foliation parallel to the lithological layering and axial plane to F_1 folding indicate layer parallel slip along stratification during bulking and transposition. The gneissic layering and compositional banding in QFG also form the reference surface of F_1 which is parallel or sub parallel to the lithological layering except near the fold hinges where it cut across the fold noses. It seems probable that the original attitudes of the layering / beds were horizontal to sub horizontal in nature and the effect of near horizontal shear couple on beds results the formation of near recumbent or isoclinals folds which were ultimately transposed into intrafolial, rootless folds showing NE-SW axial traces. The tectonic separation of noses from their limbs, the attenuated limbs into discontinuous layers and lenses in the direction of tectonic transport, boudinage, the intensive recrystallisation and crystallization giving rise to the dominant S_1 plane, growth of most of the rigid porphyroblasts and their syngenetic rotation during the intensive shearing state, are some of the significant imprints of this intensive layer parallel extension tectonism under the influence of activated homogeneous strain. The D_2 deformation was of very mild type finding expression only in the form of minor folds and crenulations with insignificance axial plane foliation.

The D_3 is characterized by shortening along NW-SE direction resulting, the development of anticlines and synclines. The arcuate nature of the axial trace of the F_3 Ayyavaripalle anticline is a total reflection of F_4 superposition on the regional scale. The original attitudes of the Ayyavaripalle anticline was not altered much by the interference of F_4, but Kodigumpala-Mopadu composite syncline was influenced to a greater extent by F_4 resulting in the sinuous nature of the regional 'S' shaped major synclinal structure (type 2 interference pattern).

In the Vaggumpalle area, the influence of F_4 was so great that the major F_3 fold was made overturned to a maximum extent forming a 'U' shaped reclined fold of type 3 interference pattern. The regional outcrop pattern of all the three sectors shown in figure 3 - a, b, and c are formed by the interference of F_3 and F_4 phases resulting Ramsay's type1, 2 and 3 interference patterns respectively. Both dextral and sinistral kinking is related to shearing movement. Although the development of kink bands are considered as resultant of semibrittle deformational event (Jablinski and Holst, 1992), but in the study area they are syngenetic to D_4 deformation and deformed by F_5 folding. Early and late ductile shears are observed and such shear zones are restricted to millimeter to centimeter scales only. The D_5 has reached its highest intensity towards the later part in the field of brittle deformation and is manifested by regional layer oblique joints and faults throughout the area.

Whether such successive phases of deformations are the products of a single major progressive deformation (Bryant and Read, 1969; Wood, 1979; Talbot, 1979; Jacobson, 1984; Ghosh and Sengupta, 1985) is an open question.

Broad structural correlation between the Nellore schist belt and the Eastern Ghat Proterozoic mobile belt can be made and it is observed that the F_1, F_2 and F_3 folds of the latter belt corresponds with the F_3, F_4 and F_5 folds of the Nellore schist belt. On the other hand, Nallamalai Group of the Cuddapah basin experienced two episodes of F_1 and F_2 folds which correspond with the F_3 and F_4 folds of the Nellore schist belt. Chetty and Murthy (1983) also suggested that the Cuddapah basin and Nellore schist belt must have suffered similarly at least a part in their deformational history. Thus, a regional study incorporating all the three belts their arcuate nature and westward convexity along with the similar surface expression of the East Coast of Indian peninsula (which might be the product of D_4 deformation), may act as a keyboard in working out the most complex tectonic configuration of the region.

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Research Article

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