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Structural and Remote Sensing Studies of Achankovil suture of South India

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Abstract

Remote sensing studies based on Landsat imageries and relief map followed by field studies have been carried out along the Kayathar-Tirunelveli-Valliyur transect of Achankovil suture zone. Five patterns of lineaments, two sets of conjugate shear system of dextral Tenmalai shear of D_2 and sinistral Achankovil shear of D_3 were delineated. F_1 isoclinal rootless fold, E-W upright folds of F_2 of D_2; reorientation of F_2 upright folds during D_3 deformation, F_3 doubly plunging fold due to interference of F_2 and F_3 folds were identified. The major isoclinal 'S' type Vallanadu quartzite fold is a shear fold and its eatern limb displaced sinistrally for 11 km are highlighted from field and remote sensing studies. The F_1, F_2 and F_3 co-axial folding suggest continued subduction of Madurai block sediments under Kerala Khondalite block through Achankovil suture zone during periods from D_1-D_3 deformations of Neoproterozoic to Cambrian time. F_4 cross folding of F_2 and F_3 folds were formed during late D_4 deformation.

Keywords: Achankovil suture, South India, lineaments, folding episodes, Remote sensing.

Introduction

Finding the suture signatures are important in fitting of the Gondwana supercontinent. South India is a key area which existed as a centre of Gondwana land. The Palghat-Cauvery shear zone (PCSZ), located in South India[1] is widely assigned a major tectonic boundary and it may be a continuation of one of the Madagascar shear zones, either the Betsimisaraka suture of Madagascar[2-4] or the Bongolava Ranotsara shear zone (BRSZ)[5,6]. The Southern Granulite Terrain comprise of the Kerala Khondalite Block (KKB) in the south and Madurai Granulite Block (MGB) in the north separated by Achankovil shear zone (ASZ)[7,8]. The MGB, the largest crustal block in South India occurs immediate south of PSCZ. This block comprises dominantly of charnockite massifs with enclaves of metasedimentary rocks including pelites, iron formations, metamorphosed calc-silicate rocks and quartzites[9]. The southern boundary of Madurai block is marked by the late Proterozoic ASZ. This zone strike NW-SE to WNW-ESE and extends laterally to about 210 km and with a width of 20-50 km at places, and is considered as a shear zone that seperates the unique rock units to the north and the south[10,11]. The ASZ mainly consists of garnet-biotite gneisses, charnockites, cordierite gneisses, calc silicates and basic granulites, intruded by a number of late Neoproterozoic-Cambrian granites and also pyroxenites and hornblendites. To the south of KKB is the Nagercoil Block, consists of igneous charnockites with migmatitic metapelites and metacarbonates. Several research workers have correlated the ASZ with the Ranotsara shear zone (RSZ) in southern part of Madagascar[2,3,12,13]. Rajesh and Chetty[14] have explained the crustal-scale structures represented by the en-echelon pattern of lineaments in the ASZ[10] as the features suggesting the sinistral transpressional tectonics, assumed to be of Neoproterozoic time.

Folding episodes and different sets of lineaments were delineated from remote sensing studies of southern Betsimisaraka suture of Madagascar[4]. Different geodynamic settings can be identified through remote sensing studies[15]. From digital elevation model (DEM) studies of western Crete, Greece, the potential faults and lineaments were identified[16]. The change of landuse landcover detection using remote sensing and GIS techniques were attempted for Tuticorin coast[17] and for Golaghat district of Assam[18]. Manimaran et al.,[19] have identified four types of major shear-lineaments from Ambasumudram-Tenkasi transect of ASZ as follows: i. ENE-WSW dextral shear lineament of D_1 deformation. ii. NNW-SSE to NW-SE dextral shear lineament (Tenmalai shear) of D_2. iii. NW-SE to WNW-ESE sinistral shear lineament (Achankovil shear) of D_3 and iv. N-S sinistral shear lineament (Toranamalai shear) of D_4.

The present study is aimed at understanding of structural features like folds and shears in the Kayathar-Tirunelveli-Valliyur transect of the ASZ and tectonics of continental collision events along the tectonic boundary between Madurai Granulite block and Kerala Khondalite block. Shaded releif map prepared from shuttle Radar Topography Misssion (SRTM USGS)[14] and Google Landsat imageries are used to delineate various lineaments, shears and folds from the study area falling across the ASZ (Achankovil suture zone) and the confirmations are made through field checks during ground traverses.

Mid-crustal section of ASZ: Recently, a tectonic model using pacific-type orogeny to explain the evolution of Neoproterozoics from the southern part of South India and its final amalgamation within the Gondwana Assembly was proposed[2]. The occurrance of arc magmatic rocks together with high P/T lithotypes denotes the deeply eroded zones of a subduction system[2]. Suture zones are rarely, well-defined or easily recognizable simple lineaments[20]. Suture mark the zones along which total subduction of oceanic lithosphere has been resulted and along which two previously seperated continental masses have joined. Coward et al.,[21] define suture zones as ductile shear zones produced by thrusting along convergent plate boundaries and they range from few hundred meters to tens of kilometers wide, suture zones become less distinctive at great crustal depth (i.e., a criptic suture), where they may be represented by a shear zone with similar metamorphic rocks on both sides[22].

There is an increasing evidence to infer that Pacific-type orogen must have prevailed in the past in various parts of the phanerozoic age. The tectonic evolution of southern India can be related to a dominant Pacific-type in the orogeny which was started as Andean-type in the Neoproterozoic and ended as Himalayan-type in the Cambrian. The pattern of orogen is difficult to reconstruct because of the lack of tectonic data. In previous studies, the two major crustal scale zones in southern India-the Palghat-Cauvery shear zone and Achankovil shear zone have been loosely defined as shear zones based on petrology, geochemistry, geochronology and available structural features the above two zones could be critical boundary markers (i.e. suture zones[2]). Dhanunjaya Naidu et al.,[23] studied two parallel magnetotelluric (MT) traverses across the Achankovil shear zone (ASZ) in southern India using a wide band data acquisition system and their derived model shows distinct high electrical resistivity (>1000 Ω) for the upper crust below the Madurai Granulite block (MGB) with a gentle dip towards south and a northerly dip below the Kerala Khondalite Block (KKB). The lower crust of MGB and KKB is resistive below while it is moderately conductive (500 Ω) below ASZ. The ASZ is a tectonic divide between the MGB to the north and KKB to the south. The seismic, gravity and heat flow data suggest a high dense and moderately conductive mantle material brought upto the mid-lower crust and a thermally eroded crust with a flower structure at depth are pointing out the collisional suture nature of ASZ. Hence the identification of structural features of the study area through remote sensing and field traverses are very vital to clarify the suture status of ASZ where the old mid-crustal section is currently exposed.

Remote sensing studies

Google landsat imageries and the shaded relief map (modified after Rajesh and Chetty[14]) prepared from Shuttle Radar Topography mission (SRTM-USGS) are used to delineate various lineaments, shears and folds from the study area. The figure 1 shows the lineaments, shears, folds and displaced lithological units of the Tirunelveli area of ASZ.

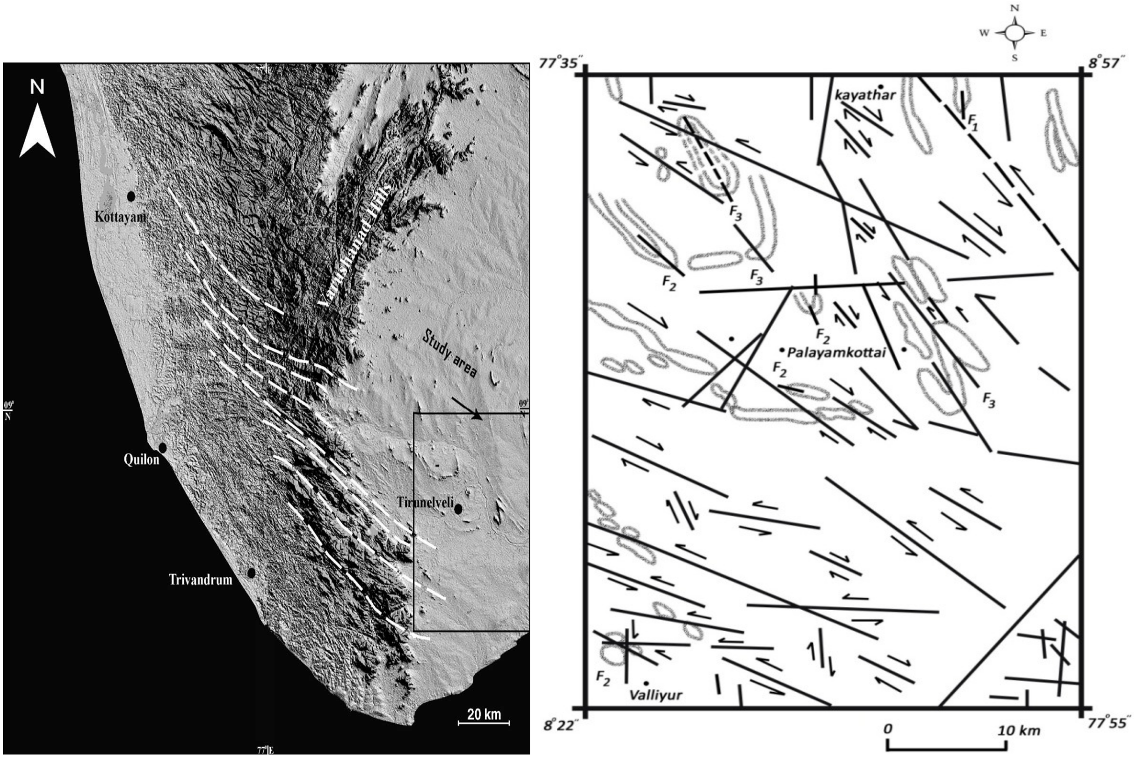


Figure-1 A, B
A shaded relief map from Shuttle Radar Topogrphy Mission (SRTM USGS) modified after Guru Rajesh and Chetty, 2006 showing the study area (figure 1 A). The lineament map showing lineaments, shears and folds of the Kayathar-Valliyur transect of ASZ, South India

Five set of lineaments namely i) E-W; ii) N-S; iii) NE-SW; iv) NW-SE to NWW-SSE and v) WNW-ESE to NW-SE are recognised from remote sensing studies. From the field studies, it is known that the area is mainly suffered with two sets of conjugate shearing. 1. A ductile natured, NNW-SSE to NW-SE main dextral shears (Y-shear of Tenmalai shear) conjugating with ductile NE-SW striking subordinate sinistral shears and 2. A brittle-ductile natured NW-SE to WNW-ESE striking sinistral shear (Achankovil shear) conjugating with N-S striking dextral, brittle-ductile shears are commonly observed in the field and shear sense are assigned to the lineaments. The geological map of the study area is given in the figure 2.

On examination of lineament map (figure 1) and geological map (figure 2), the Tenmalai conjugate shear system are seen in association with the genesis of grey granites, cordierite gneisses and F_2 folds of D_2. Whereas the Achankovil conjugate shear system are formed genetically related to bands of typical antiperthitic pink granites and veins and dykes of ultrabasic rocks of hornblendites and pyroxenites are unique features of the shear zone. F_3 folds are developed during Achankovil sinistral shearing event of D_3. The eastern limb of the 'S' type major quartzite fold sinistrally displaced for a length of 11 km are observed in the field. The careful examination of the grey granite linear band at Vallanadu also sinistrally displaced for a length of approximately 11 km and seperated by a band of cordierite gneisses are also traced in the field survey. The above feature suggests that the Achankovil shear systems of D_3 are of brittle-ductile nature. The ductile deformation of D_2 suggests that they are formed at deep seated conditions. Whereas the brittle-ductile deformation of D_3 suggests that it was happened during exhumation at higher-middle crustal level in the ASZ crustal section.

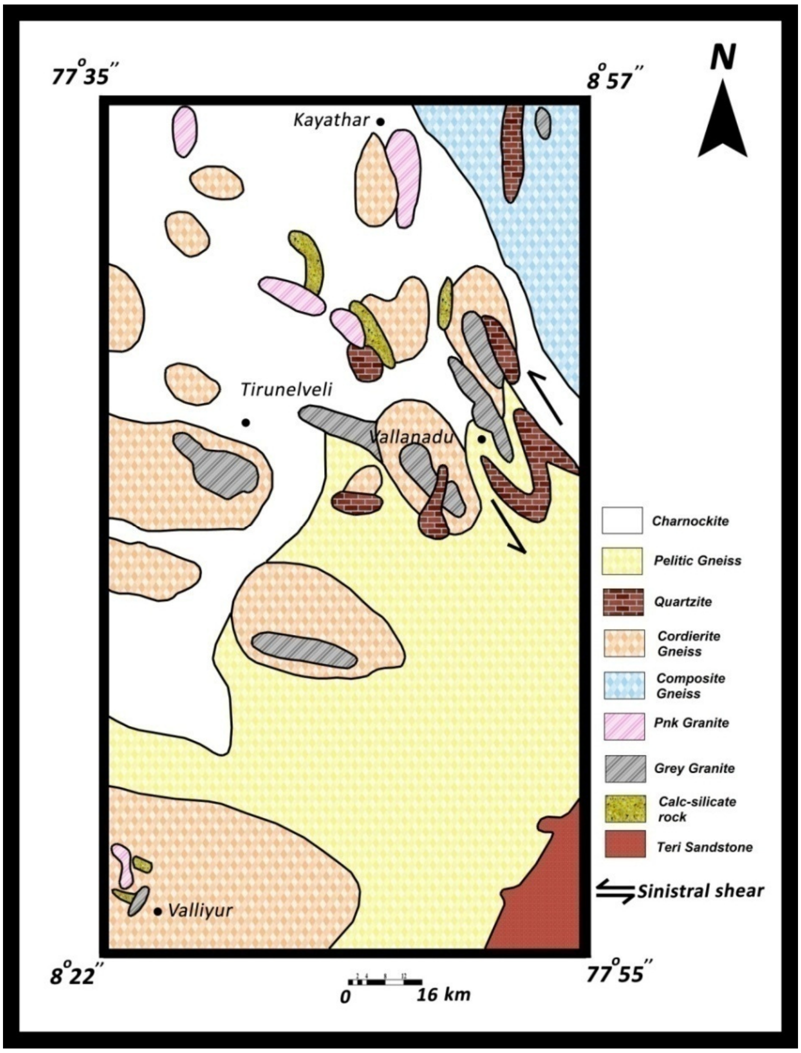


Figure-2
The geological map of Kayathar-Valliyur transect of Achankovil Shear Zone, South India

Folding episodes

Folding episodes are well preserved in the calc-silicate rocks and khondalites and they are also delineated from granites and charnockites also. The F_1 isoclinal, tight fold with N-S axial planes with very steep dipping towards SE are observed in pelitic gneisses of Ervadi and calc-silicate rocks of Thalaiyuthu and are formed during D_1 deformation which resulted in the development of gneissic foliation. When it is associated with other folds F_2 and F_3 it shows different attitudes due to the rotation of F_1 folds. The east of Kayathar a quartzite showing isoclinal tight F_1 folds striking N-S dipping 60°W are traced in the field (figure 1). North of Palayamkottai at Keelapattam the F_1 quartzite fold again folded during D_2 dextral deformation. The axial plane of F_1 is along N-S and dipping steep towards E (70°) is observed in the field. The F_2 isoclinal sheath fold with axial plane striking N45°W 50°N; and a co-axial F_3 plunging fold with axial plane striking N40°W dipping 55°SW and a doubly plunging co-axial folds with fold axes plunging 55° N45°W and 35° S42°E are traced from the northwestern corner of the study area. The above folds are observed in charnockite and calc-silicate rocks. The co-axial F_2 isoclinal fold with axial plane N35°W 70°SW and F3 co-axial plunging fold with axial plane striking N55°W are also observed in the field.

The grey granite of Maruvathalai shows elongate upright F_2 folds which is showing F_3 open folding formed during D_3 due to ENE-WSW compression. The F_2 of D_2 is formed during N-S compression. Both Tenmalai dextral shearing of D_2 and Achankovil sinistral shearing of D_3 are observed in the grey granites of Maruvathalai. The earliest ENE-WSW dextral shear terminating against the grey granite and dextrally displacing the quartzites are also seen in middle of the imagery (figure 3).

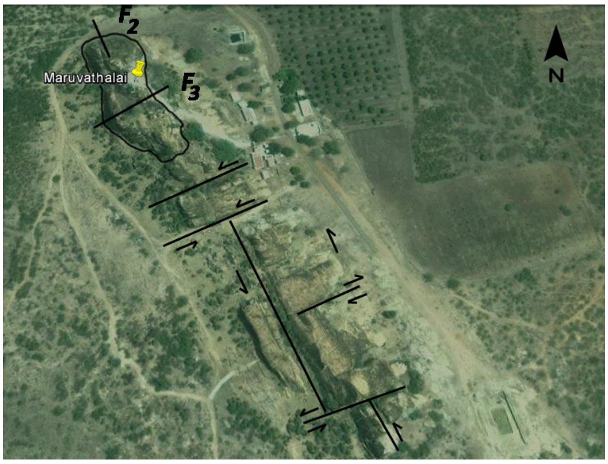
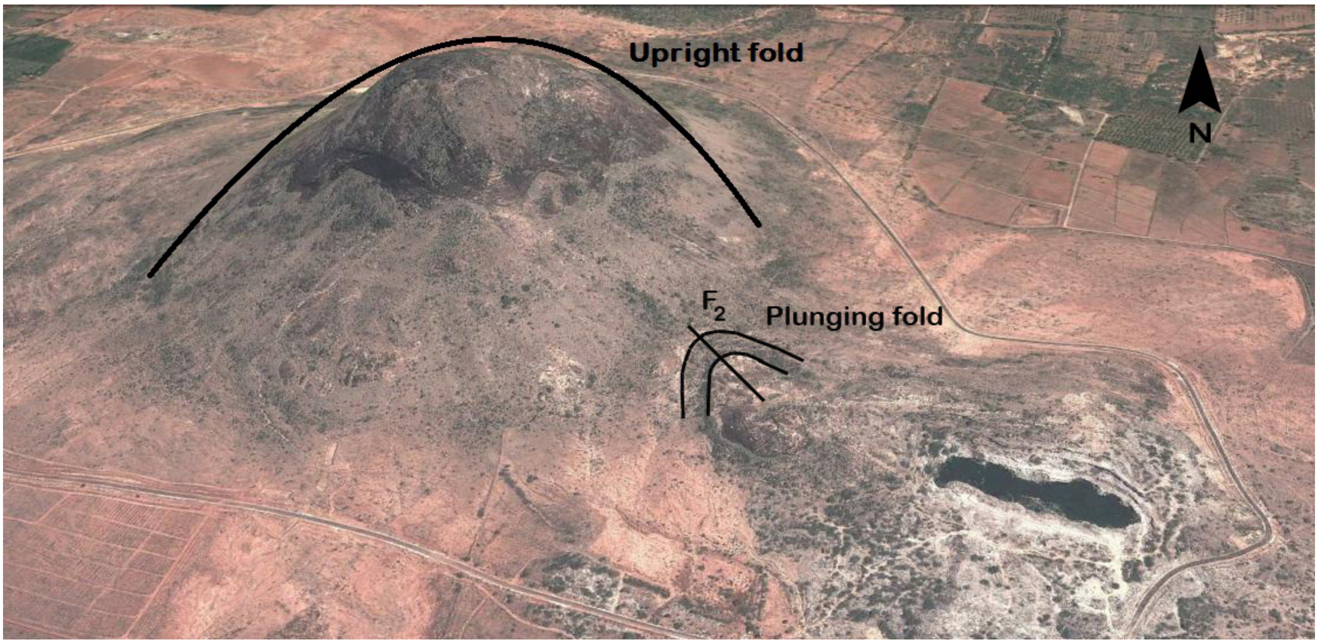


Figure-3
The F_2 upright fold of D_2 in grey granite at Maruvathalai. It is a sinistrally reactivated F_2 fold during D_3 resulted in a F_3 open fold, (courtesy-Google image)

At Samiyarpottai, F_2 upright fold (Lingamalai) formed in cordierite gneiss exposed near Ervadi and a westerly moderately plunging calc-silicate F_2 fold with axial plane striking NW-SE and with steep dip towards NE is also visible at the southeastern side of Samiyarpottai F_2 upright fold (figure 4).

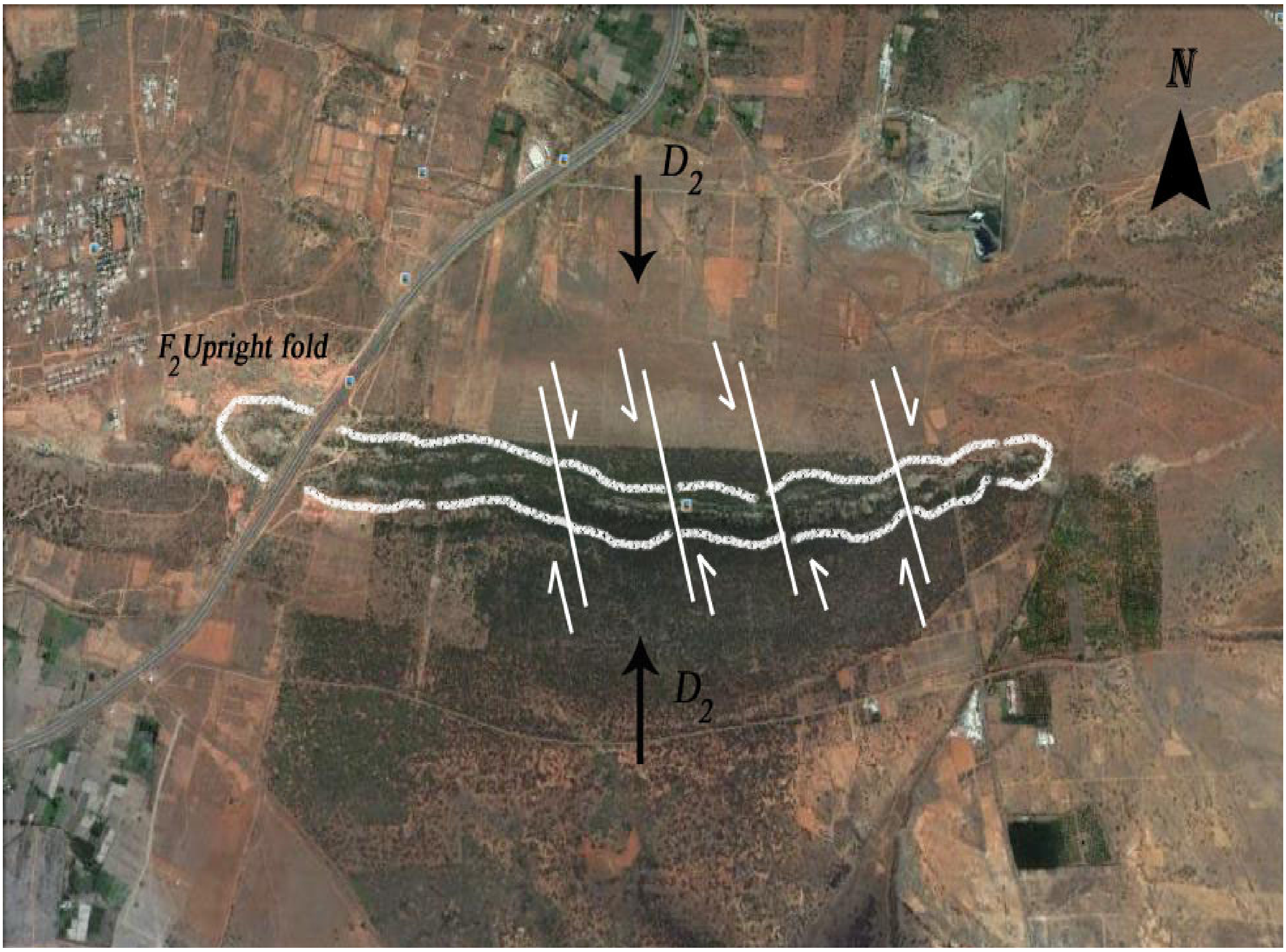


Courtesy-Google image

Figure-4
F_2 upright fold of cordierite gneiss at Samiyarpottai near Ervadi. Also seen a westerly plunging F_2 fold in calc-silicate rock

The E-W running elongated Rettiyarpatti hill (figure 5) is examined at highway road cutting and was identified as upright train fold with axial plane vertical and with subhorizontal fold axis plunging 10-15° towards west. It is an upright box like train fold running for a length of 7 km and amplitude of the fold is 50 to 70 metres above the ground surface. At places across the length of the fold NW-SE striking dextral Tenmalai shearing (D_2) are mainly observed. At places also NW-SE Achankovil sinistral shears (D_3) resulted in F_3 open fold with N-S axial plane are also observed. Repetition of quartzite and khondalites are seen in the upright antiform and synform folds. Both core and limbs of the fold were intruded by later formed hornblendites and pyroxenites. The style of the F_2 upright train fold suggest that it was formed due to a strong N-S subhorizontal compression during the subduction of N-S striking sedimentary units and buckling of N-S striking pile of sediments might be resulted in F_2 upright train folds and upright dome type and lingam like F_2 folds.

South of Ervadi, double upright folds called Erettamalai are observed (figure 6). The above upright folds and plunging folds of F_2 suggest that the area was subjected to N-S subhorizontal compression of D_2. Cordierite gneiss exposure at Muthuswamigal Sidhirakoodam near Valliyur (figure 7) shows a N-S striking F_1 isoclinal folds. The NW-SE striking right over-stepping sinistral shear lineaments indicate sinistral transpression during D_3. It also shows coaxial F_2 and F_3 folds. An excellent major S type F_3 fold is exposed in quartzites at Vallandu hills (figure 8). It is an isoclinal, steeply NE dipping (65-75°) fold with axial plane also dipping NE and fold axis plunging 30° towards NW.



Courtesy-Google image

Figure-5

The E-W running F_2 upright train fold at Rettiyarpatti near Palayamkottai. F_3 open fold developed due to later formed sinistral Achankovil shearing of D_3 are also highlighted

Courtesy-Google image

Figure-6

Double upright folds aligned along E-W called Erattamalai observed at south of Ervadi are seen

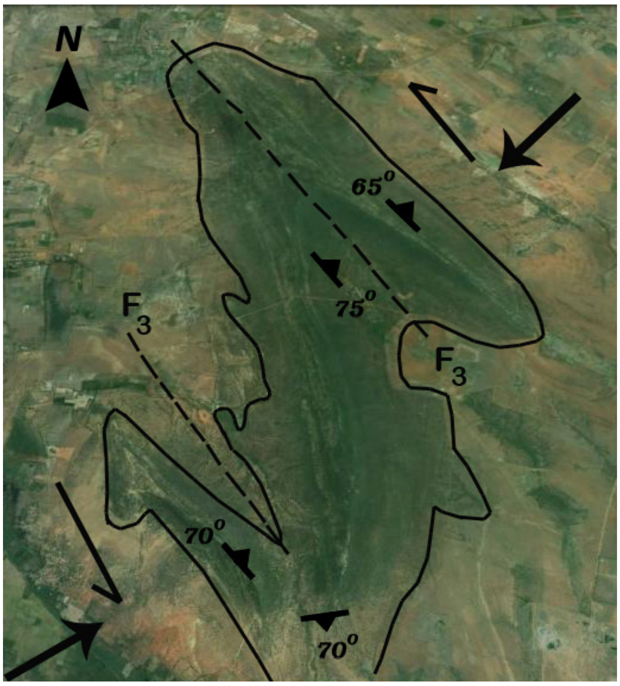
Courtesy-Google image

Figure-7

A hillock at Muthuswamigal Sidhirakoodam near Valliyur showing N-S striking F_1 isoclinal folds and N-W striking F_2 and F_3 co-axial folds. NW-SE right over stepping sinistral shear lineaments indicates sinistral Transpression

The eastern limb of this isoclinal synform fold shows sinistral displacement of quartzite for a length of 11 km was found during field mapping (figure 1,8). Based on the orientation of NW-SE sinistral shear lineaments and 'S' type F3 isoclinal plunging folds with NW-SE striking and NE steep dipping suggest that the D3 deformation was of sinistral transpression nature and formed under a ENE-WSW subhorizontal compression.

The NW-SE striking doubly plunging F3 fold at north of Valliyur was folded openly as F4 fold are observed near Samiyarpottai (figure 9) suggest that the F4 folding was formed from NW-SE compression of D4. The F4 folds are not well developed in the present study area.



Courtesy-Google image

Figure-8
A sinistrally displaced 'S' type quartzite fold at Vallanadu

Courtesy-Google image

Figure-9
The F_4 cross folding observed in doubly plunging F_3 fold at north of Valliyur

Results and Discussion

The formation of ductile shear zones remains an enigma of geology[24]. A shear zone is a planar zone of high deformation/strain compared to the adjacent domain[25]. In coaxial strain (pure shear) the deformation is termed as compression or shortening/flattening and in non-coaxial strain (simple shear) it is termed as shearing[26]. The combination of both pure shear and simple shear is common in transpression tectonics (general shear[27]). Flattening co-axial strain features were identified by Ghosh et al.,[28] and Radhakrishna et al.,[29]; and intensely transposed fabrics, shallow plunging to sub-horizontal stretching lineations and asymmetric structural features were identified from ASZ by Rajesh and Chetty[14] are non-coaxizl feature. Fossen and Tickoff[30], Dewey et al., [27]and Rajesh and Chetty[14] envisage the importance of steep to subvertical foliations as a supportive evidence of transpressional regime.

As highlighted from the present study area of ASZ both subhorizontal and subvertical stretching lineations, Tenmalai dextral ductile shearing of D_2 followed by Achankovil sinistral brittle-ductile shearing of D_3 and common observation of steepto subvertical foliations suggest the general shear zone pattern (transgression regimes) to the ASZ. From the field evidence it is known that both shearing and folding of ASZ are genetically related. Based on seismic, gravity and deep electrical sounding and petrological studies suture status is now assigned to ASZ[2,3,31].

The ubiquitous interaction of veins and brands of hornblendites and pyroxenites in ASZ suggest mantle derived ultrabasic intrusive of mid-crustal level during a subduction of Madurai block sediments through Achankovil suture/shear zone (ASZ) under kerala khondalite block. The identified isoclinal, tight recumbent to reclined F_1 fold with differently oriented axial plane striking N-S to NW-SE suggests that a layer parallel subduction (compression) (N-S to NNE-SSW striking S_0 planes) was inferred for F_1 of D_1 deformation. The F_2 upright folds and F_2 plunging folds with axial plane striking NW-SE and associated with NW-SE striking dextral shear planes dipping steeply NE were formed due to N-S subhorizontal compression during D_2 episode. The doubly plunging F3 folds (NW and SE or NNW-SSE) and NW-SE striking F3 co-axial plunging folds, ‘S’ type plunging co-axial folds and F3 co-axial upright folds are identified from remote sensing studies and field observations. The above structures are related to NW-SE striking sinistral shear planes dipping steep SW were resulted due to ENE and WSW compression during a continued subduction of sediments under ASZ. The cross folding (F_4) of earlier folds due to NW-SE compression related to N-S striking Toranamalai shearing[19] are seldom observed in the present study area of ASZ. During D_1, D_2 and D_3 the formation of F_1, F_2 and F_3 co-axial plunging folds were identified and these folds might be resulted due to a continued subduction of sediments during D_1 to D_3 deformation i.e. multiphase co-axial folds represents fingerprints of subduction signatures?, which warrants further studies or supportive evidence studies from other suture zones of the world.

Conclusion

The N-S Tirunelveli sector of Achankovil shear zone is mainly sheared with two sets conjugate shear system of D_2 (dextral Tenmalai shear) and of D_3 (sinistral Achankovil shear). From the field evidence, it is observed that shearing was followed by folding events. The F_1 rootless isoclinal folds of different orientation are due to rotation of F_1 folds during subsequent deformations. E-W oriented upright folds of F_2 and NNW-SSE oriented rotated F_2 folds during later shearing events of D_3; Northwesterly and southwesterly doubly plunging folds are formed due to interference of F_2 and F_3 folds. The isoclinal ‘S’ fold observed in quartzite hillock Vallanadu was formed during sinistral Achankovil shearing followed by a shear folding along Achankovil shear and also displacements of quartzite and associated grey granite for a distance of 11 km were happened. The observed F_1, F_2 and F_3 co-axial folds with NW-SE to NNW-SSE striking axial planes, suggest a continued subduction from F1 of D1 through F_2 of D_2 to F_3 of D_3 deformation episodes. A continued subduction of Madurai block under Kerala Khondalite block along Achankovil suture envisaged for the period of 670 to 550 Ma. The late D4 deformation openup the folds F_2 and F_3 resulted in open type cross folds with E-W or N-S oriented axial planes.

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