ELSEVIER

Journal of Structural Geology 28 (2006) 713–720

JOURNAL OF STRUCTURAL GEOLOGY

www.elsevier.com/locate/jsg

Constrictive deformation in transpressional regime: field evidence from the Cauvery Shear Zone, Southern Granulite Terrain, India

T.R.K. Chetty *, Y.J. Bhaskar Rao

National Geophysical Research Institute, Hyderabad-7, India

Received 22 July 2004; received in revised form 28 December 2005; accepted 21 January 2006
Available online 10 March 2006

Abstract

The paper describes a typical field example of rarely preserved complex structural patterns related to constrictional strain from the deeply eroded central part of the Neoproterozoic crustal-scale Cauvery shear zone system, southern India. The area exposes intense migmatisation and a distinctive map pattern of a broad domal structure with complex strain patterns. The field features such as interfering fold structures, extreme hinge line variation, domes and basins, highly asymmetrical and amoeboid shape structures, geometry of foliation trajectories and radial stretching lineations could be related to a single phase of D2–M2 constrictive deformation. Our observations suggest a close spatial and temporal relationship between transpressive deformation, deep crustal melting, assent of granite magmas and migmatisation synchronous with D2–M2.

Keywords: Constrictional deformation; Transpression; Extrusion; Radial stretching lineations; Cauvery Shear Zone; southern India

1. Introduction

Transpressional regimes are widespread in orogenic belts and give rise to complex strain patterns. Constrictional strain associated with transpressional zones is a typical deformational pattern due to shortening from two directions generating complex structures (Huddleston et al., 1988; Dias and Ribeiro, 1994). A complex pattern of non-planar or non-cylindrical folds is often related to a single phase of constrictional deformation giving rise to structures resembling those generated by superimposed folding (e.g. Ramsay and Huber, 1987). However, structures arising from constrictional deformation are distinctly different from those developed in other strain fields with systematic overprinting and geometrical relationships (Hopgood, 1999). Based on geometrical rules, it has been concluded that transpression zones generate oblate strain fields while prolate strain fields are restricted to transtension (Sanderson and Marchini, 1984; Fossen and Tikoff, 1998). However, descriptions of constrictional or prolate strains associated with transpressional zones are not uncommon (e.g. Huddleston et al., 1988). Further, under special circumstances, constrictional strains also develop in transpression zones giving rise to a spectrum of 3-D deformation types (Fossen and Tikoff, 1998).

In the field, constrictional strain is manifest as complex and systematic variations in orientation of both foliations and lineations and is dependent on: (i) the intensity of finite strain, (ii) obliquity of simple shear component, and (iii) the nature of kinematic partitioning within the deformation zone (Robin and Cruden, 1994). Although the study of such structures has been the subject of extensive laboratory experiments (Ghosh et al., 1995), there are few published field descriptions. Here, we present a preliminary account of structural geometry, kinematics and evolution of an exceptionally well exposed domal structure in a deeply eroded Precambrian crustal-scale shear system popularly known as the Cauvery Shear Zone system, the Southern Granulite Terrain (SGT), southern India as a possible field example for constrictional deformation.

1.1. The Cauvery Shear Zone system

The Cauvery Shear Zone system (CSZ) is, by far, the most prominent tectonic feature of the SGT. The east–west-trending CSZ (70 × 350 km) encompasses an anastomosing network of shear belts. Essentially, the CSZ system divides the SGT into discrete tectonic blocks, viz., the Archaean granulite blocks to the north and the Neoproterozoic granulite blocks to the south (Fig. 1). The CSZ has been described variedly as: (i) a collision zone and cryptic suture, evident from the occurrence of

* Corresponding author. Tel.: +91 40 23434611; fax: +91 40 23434651/+91 40 27171564.
E-mail address: chettytrk@yahoo.co.in (T.R.K. Chetty).

0191-8141/$ - see front matter
doi:10.1016/j.jsg.2006.01.007

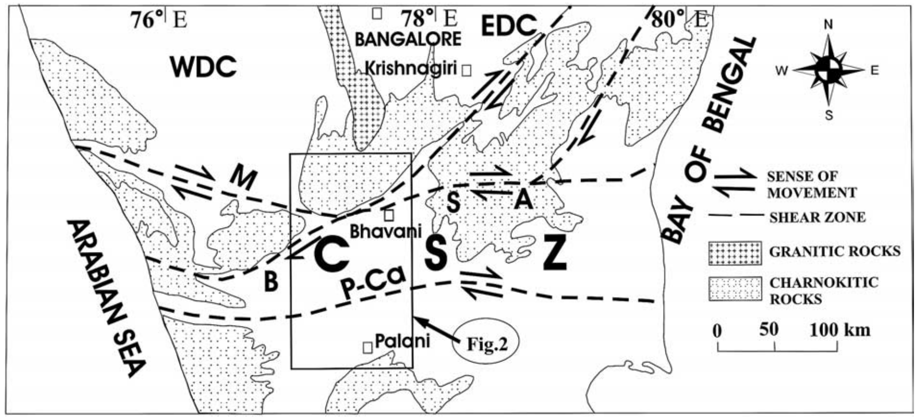

Fig. 1. Simplified geological map of the Southern Granulite Terrain (after Drury et al., 1984; GSI and ISRO, 1994) showing the study area. The major shear zones constituting the Cauvery Shear Zone (CSZ) include: Moyar (M), Bhavani (B), Salem-Attur (S-A), Palghat-Cauvery (P-Ca) referred to as the Chennimalai-Noyil shear zone (CNSZ in the study area). WDC and EDC: western and eastern parts of Dharwar craton, respectively.

remnants of probable ophiolitic sequence (Gopalakrishnan, 1996), (ii) a dextral shear zone as exemplified by the deflection of north–south Archean fabrics to near east–west disposition along the MBSZ (Drury et al., 1984), (iii) an analogue of the central part of the Limpopo mobile belt (Ramakrishnan, 1993), (iv) the Archean–Proterozoic Terrane boundary (Harris et al., 1994), (v) a zone of Palaeo- and Neoproterozoic reworking of Archean crust (Bhaskar Rao et al., 1996; Raith et al., 1999), and (vi) a Neoproterozoic dextral–ductile transpressive tectonic zone (Meissner et al., 2002; Chetty and Bhaskar Rao, 2003; Chetty et al., 2003a). In the reconstructions of the Gondwana supercontinent, the CSZ has been extended and correlated with the other Gondwanian shear belts such as the Ranotsara shear zone of Madagascar and the interface between the Napier and Rayner complexes, Enderby Land, East Antarctica (Chetty et al., 2003b; Chetty, 1995). However, recently, Collins and Windley (2002) have correlated the CSZ system with the Betsimisaraka suture zone in the eastern part of Madagascar. Recent results of integrated geological and geophysical multidisciplinary studies along a north–south geotransect across the western part of the CSZ and the northern part of the SGT support the view that the SGT is an ensemble of fragmented and imbricated crustal blocks related to collisional tectonics (Bhaskar Rao et al., 2003; Chetty et al., 2003a; Harinarayana et al., 2003; Reddy et al., 2003; Singh et al., 2003).

The deformational history of the region encompassing the CSZ system has been ascribed to two major tectono-metamorphic episodes: the D1–M1 (late Archaean) and the D2–M2 (late Neoproterozoic) (Bhaskar Rao et al., 1996; Chetty et al., 2003a). Broadly, the D1-episode produced regional scale north-verging thrusts and the structures associated with progressive coaxial folding. The D1–M1 episode culminated with pervasive regional high-grade metamorphism at ~2.52 Ga. The D2–M2 episode is associated with ductile shearing and localized higher-P metamorphism in a transpressional tectonic regime. The Archaean crust along the CSZ was affected by multiple events of melting, migmatisation, and attendant retrogression over a protracted period between ca. 800 and 500 Ma. Numerous kilometre scale granite bodies (variety of S- and I-types, reviewed by Nathan et al. (2001)) are emplaced into the deformed Archaean crust along the CSZ system as syn- to late-tectonic plutons between 650 and 500 Ma. Our preliminary field observations in the western part of the CSZ suggest that components of some larger plutons (e.g. Sankari–Tiruchengodu) present relationships akin to both stratoid and discordant granitoid complexes. The regional crustal architecture in the western part of the CSZ system reveals that the D2-strain is partitioned into a set of major east–west-trending shear zones with varying width and geometry (Fig. 2). The shear zones from north to south include: (i) Moyar–Bhavani Shear Zone (MBSZ), marking the northern boundary of the CSZ, (ii) Chennimalai–Noyil Shear Zone (CNSZ), which was referred to in the literature as Palghat–Cauvery Shear Zone (Drury et al., 1984), (iii) Dharapuram Shear Zone (DSZ), (iv) Devattur–Kallimandayam Shear Zone (DKSZ), and (v) Karur–Oddanchatram Shear Zone (KOSZ). The structural observations along the shear zones indicated that they are genetically and kinematically interconnected. The presence of a Moho upwarp associated with the shear zones indicates that the shear zones cut the lithospheric mantle. The foliation fabrics along the MBSZ show steep dips to south, while the foliations in CNSZ, DSZ and DKSZ exhibit moderate dips to north. Together with consistent interpretations from geophysical data (e.g. Reddy et al., 2003), the regional disposition, structural geometry, consistent dextral kinematics, complex behaviour of stretching lineations, heterogeneous strain patterns and the contemporaneity of mylonitic fabrics (~750–500 Ma; Bhaskar Rao et al., 1996; Meissner et al., 2002; Ghosh et al., 2004), the crustal architecture of the CSZ was modelled in terms of a crustal-scale positive 'flower structure' (Chetty and Bhaskar Rao, 2003) typical of transpressional tectonics in a convergent regime (Cunningham et al., 1996).We present here new observations on a large elliptical feature and a range of associated structures around Perundarai from the central part of the flower structure—'the Perundarai dome'—as a possible field example of constrictional deformation in a transpressional setting.

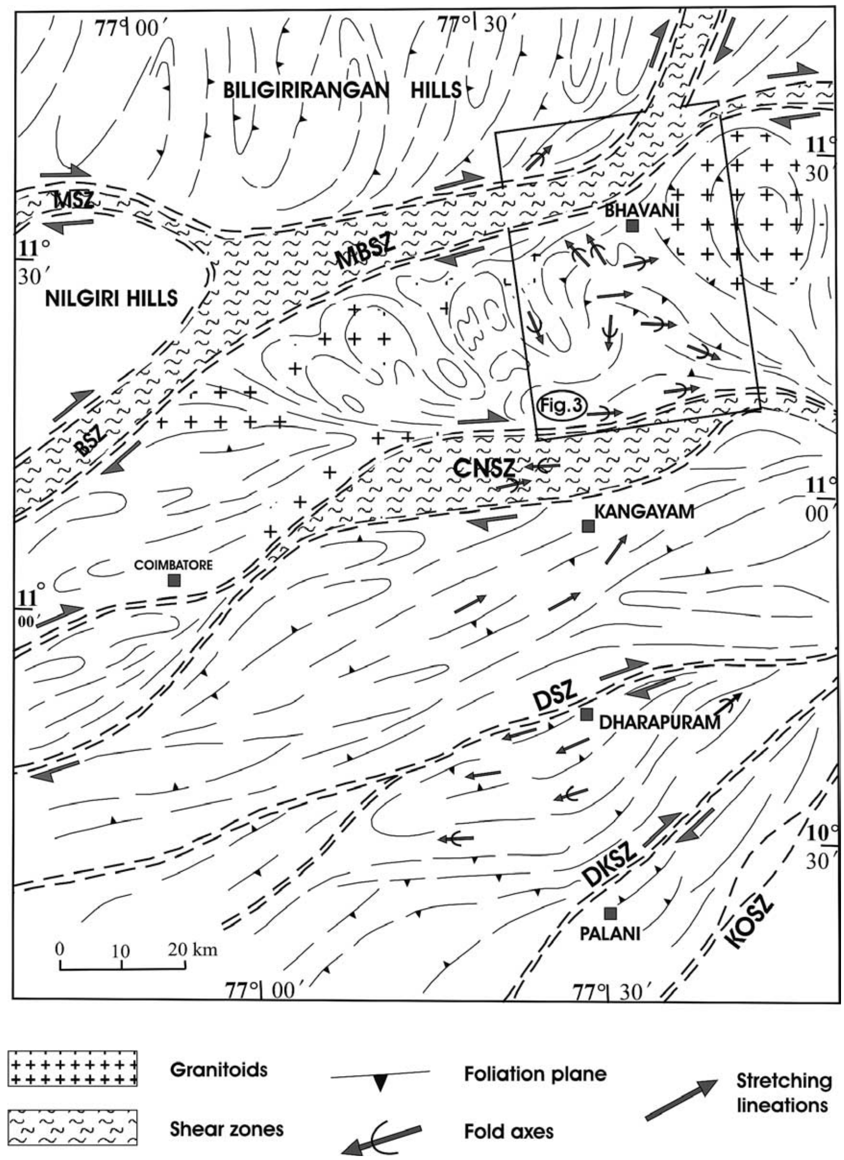

Fig. 2. Structural framework in the western part of the Cauvery shear Zone (CSZ) showing the distribution of major dextral shear zones: MSZ—Moyar; BSZ—Bhavani; MBSZ—Moyar Bhavani; CNSZ—Chennimalai Noyil; DSZ—Dharapuram; DKSZ—Devattur Kallimandiam; KOSZ—Karur Oddanchatram. Note the anomalous structural trends between MBSZ and CNSZ and marked study area.

2. Geology and structure of Perundarai Dome

The Perundarai structure (20×20 km; Fig. 3) is an elongate domal structure with the penetrative amphibolite facies foliation showing shallow dips in the centre gradually steepening towards margins. The region is a flat terrain with a few isolated mounds and presents a typical section across a relatively low D2-strain region of the CSZ. It is bound by high strain zones of MBSZ to the north and CNSZ to the south. The MBSZ, in general, is characterized by planar (mylonitic) fabrics with steep dips predominantly to south while the CNSZ shows moderate dips to the north that are developed in high grade supracrustal rocks such as metapelite and banded iron formation. Along the core of the Perundarai dome, quartzo-feldspathic migmatitic gneisses predominate while narrow bands of concordant high-grade supracrustal gneisses and amphibolites are increasingly abundant toward the periphery. Units of charnockite–enderbite gneiss showing a variable degree of retrogression are also common along the peripheral zones. The emplacement and metamorphism of the latter has been dated at ca. 2.52 Ga (Ghosh et al., 2004 and references therein) while field observations at many places, which are contiguous with the current study area, indicate their intrusive nature into the supracrustals implying a late Archaean minimum age for the predominant supracrustal gneiss suites of the study area. Consistent with the above age relationships, dismembered layered mafic–ultramafic complexes proximal to the southern limit of the Perundarai dome have been dated at ca. 2.9 Ga (Bhaskar Rao et al., 1996). The foliated migmatite gneiss along the core of the Perundarai dome is commonly intruded by shallow dipping sheets of granite–pegmatite that mimic the stratoid and discordant granite intrusions in the

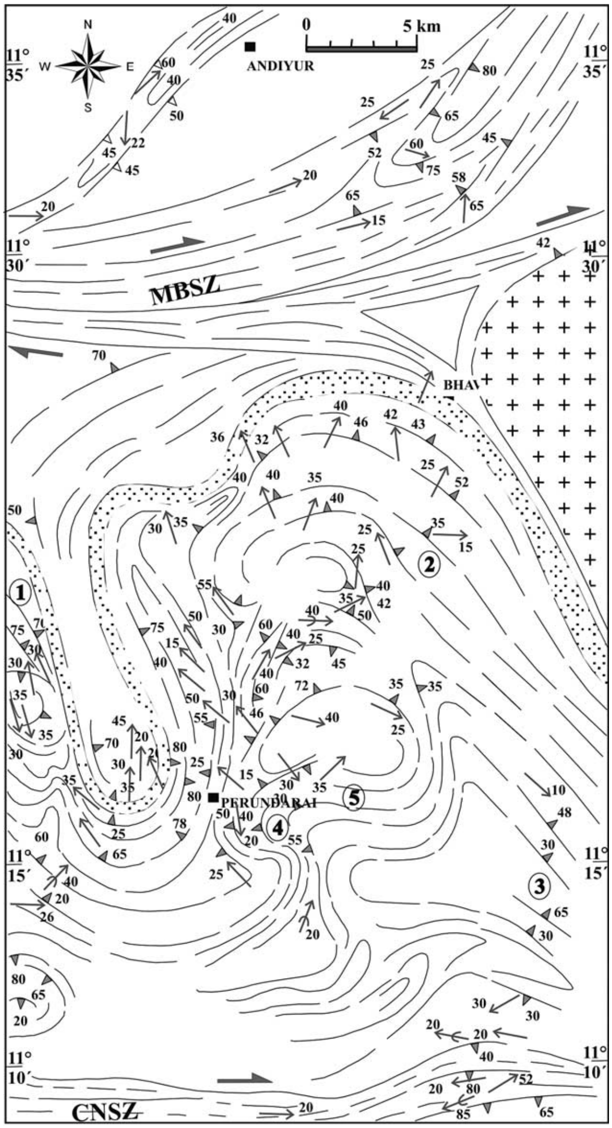

Fig. 3. Detailed geological and structural map of the study area together with interpretation from the satellite data, foliation trajectories, fold axes and mineral stretching lineations. Rock types: dots indicate two-pyroxene granulites; pluses indicate granitoids and the rest are occupied by high-grade gneisses and migmatites. Structural symbols are as shown in Fig. 2.

regions adjacent to Perundarai dome. Throughout the region, interlayered and boudinaged amphibolite bands concordant with the gneiss are deformed and migmatised together. Variation in the intensity of strain is evident in contortions, mylonitic fabrics and degree of melting (Fig. 4a–c). In the central part, at a few places, anatectic recrystallization is extensive, destroying the preexisting foliation. This produces a nebulitic texture preserving only the faintest relict structures. Fig. 4d shows the fragmentation of amphibolite layers and the development of scar folds within the leucocratic neosome generated by flow into low stress boudin necks. The amphibolite blocks are also associated with narrow, discrete leucocratic veins that are involved in complex styles of folding and fracturing. Often, trails of paleosome blocks define an open fold form. It has been possible to reconstruct the existence of large-scale structures from these mesoscopic features. A striking feature is the presence of a regionally folded two-pyroxene granulite–amphibolite band that serves as a marker horizon, which displays an antiformal structure (Perundarai dome) and a generally sinuous fold hinge line, in an otherwise monatanous migmatite–gneiss terrain (see Fig. 3). In the western part, the fold hinge line of this marker horizon has been rotated through large angles to give rise to an elongated noncylindrical fold structure with sheath-like morphology. Mesoscopic shear bands and kinks are common. A heterogeneous component of non-coaxial strain is indicated by widespread, though not pervasive, asymmetrical structural elements.

2.1. Foliation trajectories, fold styles and linear fabrics

The map of foliation trajectories (Fig. 3) has been constructed by tracing out the trends of continuous or discontinuous, thin-impersistent layers and the strike of foliation planes. Broadly, the map reveals a remarkable regional domal structure constituting the closed forms of large-scale folds in the form of dome and basin structures. The regional dome shows both equant and varied geometries and is bound by east–west-trending shear zones. The planar fabrics in the region include gneissosity and superimposed mylonitic foliation subparallel to gneissosity. The stereo-plot of foliation poles does not define a perceptible girdle indicating that the foliations strike in all directions with gentle to moderate dips (Fig. 5a).

Small-scale folds observed in the domal region are similar to dome and basin, conical fold or interference structures. The fold profiles vary from class IB to IC type (Ramsay, 1967) structures with rounded hinges through more kink-like or chevron geometries. The folds are generally asymmetric and mainly display NNE-vergence. Interlimb angles vary from gentle to very tight over a distance of a few tens of centimetres for individual structures. On an average, folds trend nearly east–west but, in detail, many hinges are curvilinear through a few tens of degrees. The 'hair-pin' bends of hinge lines and amoeboid outcrop patterns are also distinct. More extreme angles of curvature (50–100°) occur locally on a centimetre scale producing complex and irregular closed outcrop patterns (Fig. 6). Folds with curvilinear hinges are also frequently recorded and show the characteristics of interfering folds typical of constrictional deformation (Ghosh et al., 1995). Fold plunges are generally shallow ($<30°$) with azimuths predominantly in northeastern and southeastern quadrants. Overall, the orientations of fold axial planes are remarkably variable. The inferred crescents in Fig. 3 apparently display diverse orientations, nearly orthogonal to the early-formed folds (D1–M1), suggesting involvement of two distinct deformational events. However, there is no unambiguous evidence for superimposition or overprinting relationships or any observable structural sequence.

Mineral stretching lineations are moderate to well-developed in the rocks and are defined by hornblende, biotite, quartz and feldspar along the foliation planes. They display a down-dip orientation with moderate plunges (20–45°) with no

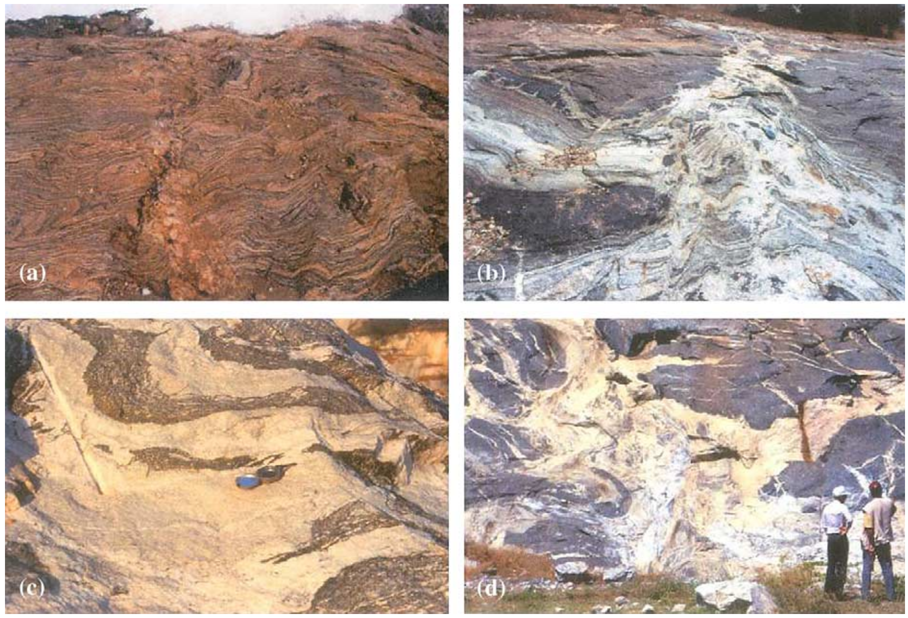

Fig. 4. Field photographs showing: (a) highly asymmetrical elements and contortions in migmatitic gneisses, (b) relict paleosomes and neosomes associated with melting giving rise to agmatitic structure, (c) well preserved folded bands of biotite bearing melanosomes within the leucosomes, (d) resistant amphibolite blocks traversed by quartz veins surrounded by leucosomes. Also note the presence of folded relict mafic bands and nebulite structures within the leucosomes.

systematic orientation. But, in the central part, where domes and basins occur, they are plunging to east while they become shallow and strike parallel away from the regional domal structure. Interestingly, the disposition of stretching lineations show distinct radial pattern on a map view (Fig. 3), while in an equal area stereo-plot they exhibit a small circle girdle implying an upright conical geometry (Fig. 5b).

2.2. Structural cross-section

A north–south structural cross-section across the study region reveals an overall antiformal and/or domal structure (Fig. 7) with the foliations dipping away from the centre. Progressive tightening of folds and intensification of foliation on either side are inferred to be through a single phase of constrictional deformation during transpressional tectonic regime (D2). Lithologically, the granitoids are predominant in the central part while mafic–ultramafic complexes are more common at the margins, proximal to the bounding shear zones.

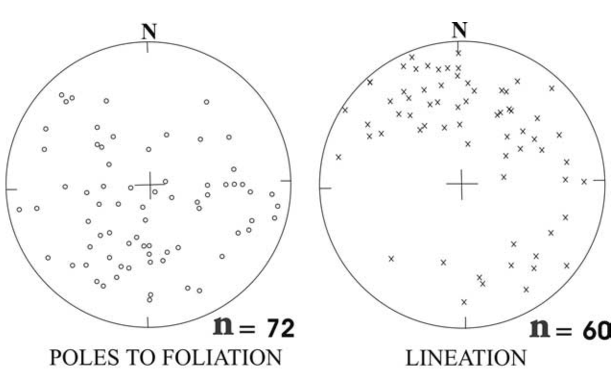

Fig. 5. Lower hemisphere equal-area projection of (a) foliation and (b) lineation fabrics.

Our observations indicate that the MBSZ is a southerly-dipping structure, which is consistent with south-dipping reflection fabrics obtained from deep seismic surveys (Reddy et al., 2003). The CNSZ shows moderate northerly dips (40–50°). While the MBSZ is interpreted as a north-verging frontal thrust, the northerly-dipping CNSZ and other shear zones in the south are considered as back thrusts related to the MBSZ. The location and configuration of CNSZ, DSZ and DKSZ are correlatable with the seismic velocity depth model of Vijaya Rao and Rajendra Prasad (in press). Their geometrical disposition with consistent dextral sense of movements and their contemporaneity clearly define a crustal-scale positive ‘flower structure’ (Chetty and Bhaskar Rao, 2003), which is typical of a transpressional tectonic regime (Fossen and Tikoff, 1998).

3. Discussion and conclusions

The Cauvery Shear Zone system (CSZ) shows several features typical of a deeply eroded transpressional orogen such as: high-grade metamorphism characterized by a clockwise P–T–t trajectory with a steep isothermal decompressive segment, ductile strike-slip shearing, convergence of crustal-scale shear systems at depths reaching the lithospheric mantle, evidence for significant Moho upwarp, heterogeneous strain variation, widespread melting, granite magmatism and migmatization. The two-pyroxene granulite ridge, a marker horizon in the study area, defines a non-cylindrical antiformal fold structure. The development of such large-scale domal structures can be ascribed to a multiplicity of mechanisms including: (i) interference by discrete deformational events or by a single progressive deformation event, (ii) rise of diapirs and associated deformation, (iii) large-scale sheath folding, (iv)

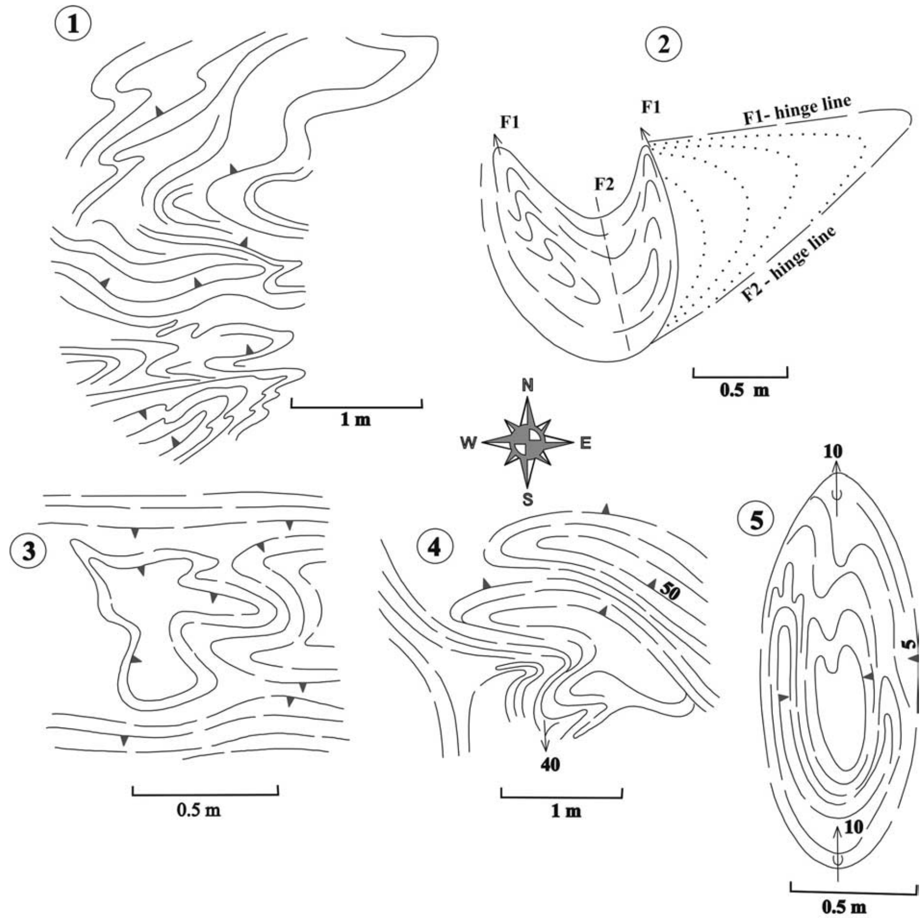

Fig. 6. Field sketches showing complex structures such as non-cylindrical folds, closed structural forms and irregular and amoeboid structures.

metamorphic core complex development, and so on. Based on the available geothermo-barometric information of the rocks in the CSZ system and the distribution of metamorphic equilibration pressures, the region does not qualify as a metamorphic core complex. As emphasized earlier, we relate the dominant structural features of the CSZ to a D2–M2 episode rather than D1 in the light of overwhelming evidence for Neoproterozoic ages for the mylonitic fabrics (Meissner et al., 2002), as well as syn- to late-granite intrusions (data summarized by Nathan et al. (2001) and Bhaskar Rao et al. (2003)). A heterogeneous component of non-coaxial strain is indicated by widespread asymmetrical structural elements that include domes and basins, curvilinear and hair-pin bends of hinge lines, amoeboid forms, interfering folds and associated planar and linear fabrics, which are typical of constrictive deformation. Further, the following criteria clearly distinguish the interference structures of the study area from those of superposed deformation: (i) close association of non-planar and non-cylindrical folds with domes and basins, (ii) strong arcuate hinge lines of more or less open folds, (iii) characteristic outcrop patterns resulting from the convergence of three or more differently oriented folds, and (iv) the absence of consistent overprinting relationships between folds of different orientation. Additionally, the detailed geometry of

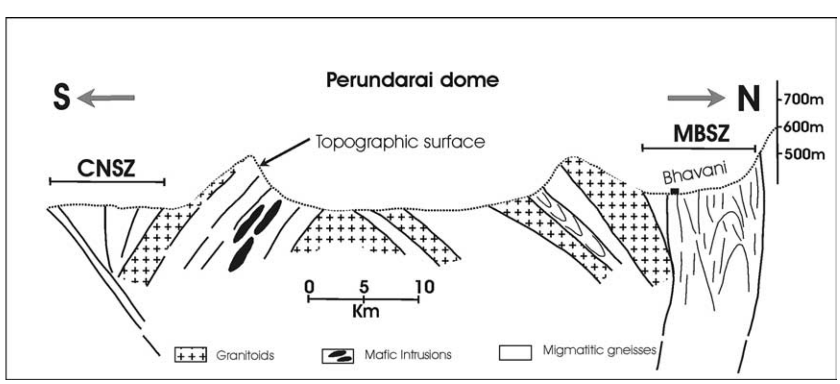

Fig. 7. Interpreted structural cross-section across the Perundarai dome, between the MBSZ and the CNSZ.

foliation trajectories and the behaviour of rarely preserved radial stretching lineations described in the earlier sections is the other strong evidence in favour of a single phase of constrictive deformation (D2–M2) in the study area.

In terms of the distribution of D2 strain, the CSZ system can be visualized as a tectonic zone with alternating east–west-trending belts of flattening and constrictive strain regimes. But, overall, the gross geometry comprises a near vertical crustal-scale ‘flower structure’ (Chetty et al., 2003a). Such an interpretation accounts for the geological and kinematic relationships of the study area. For instance, the bounding shear zones with intense flattening strains also coincide with limits of stratoid Neoproterozoic granite intrusions and stromatic migmatites while the interlying region featuring the Perundarai dome abound in inhomogeneous migmatites. Pods of relict, high-pressure granulite facies assemblages are scattered and well preserved proximal to the bounding shear zones despite the widespread effects of retrogression, where pressures up to ca. 11.8 kbars have been obtained in garnet-bearing granulites (Bhaskar Rao et al., 1996). The steep near isothermal decompressive P–T trajectories noted commonly for these assemblages indicate a rapid exhumation history related to transpressional deformation. The MBSZ, in the north, is an oblique dextral shear zone with thrust shear sense, while normal shear sense movements characterize the CNSZ. The close spatial association of such kinematically distinct shear zones combined with petrological evidence for rapid exhumation is characteristic of ductile extrusion (e.g. Grujic et al., 1996). In the light of the evidence presented above, we infer a spatial and temporal relationship between transpressive deformation, deep crustal melting, ascent of granite magmas and migmatisation in the study area during D2–M2. Similar tectonic scenarios have been demonstrated recently along the Main Central Thrust in the Himalayan orogen as well as the Kaoko belt, Namibia (Goscombe et al., 2005). Thompson et al. (1997) suggested that the lower crustal rocks can be extruded upward like toothpaste in a tube in convergent orogens and the rate of extrusion is controlled by the geometry of the bounding shear zones and the rate of convergence of the lithospheric plates.

Acknowledgements

The authors are grateful to: Dr V.P. Dimri, Director, for facilities, encouragement and permission to publish this paper, the Department of Science and Technology (DST), New Delhi, for financial support, and the two referees (anonymous) for critical reviews.

References

Bhaskar Rao, Y.J., Chetty, T.R.K., Janardhan, A.S., Gopalan, K., 1996. Sm–Nd and Rb–Sr ages and P–T history of the Archean Sittampundi and Bhavani layered meta-anorthositic complexes in Cauvery shear zone, south India: evidence for Neoproterozoic reworking of Archean crust. Contributions to Mineralogy and Petrology 125, 237–250.

Bhaskar Rao, Y.J., Janardan, A.S., Vijaykumar, T., Narayana, B.L., Dayal, A.M., Taylor, P.N., Chetty, T.R.K., 2003. Sm–Nd model ages and Rb–Sr isotopic systematics of charnockite gneisses across the Cauvery shear zone, southern India. In: Ramakrishnan, M. (Ed.), Tectonics of Southern Granulite Terrain, Kuppam–Palani Geotransect Geological Society of India Memoir 50, pp. 297–317.

Chetty, T.R.K., 1995. A correlation of Proterozoic shear zones between Eastern Ghats, India and Enderby land, east Antarctica based on Landsat imagery. In: Yoshida, M., Santosh, M. (Eds.), India and Antarctica during the Precambrian Geological Society of India Memoir 34, pp. 205–220.

Chetty, T.R.K., Bhaskar Rao, Y.J., 2003. The Cauvery Shear Zone, Southern Granulite Terrain, southern India: evidence for Neoproterozoic Transpressional Tectonics. Centenary Publication, Geological Survey and Mines Bureau, Sri Lanka, pp. 33–36.

Chetty, T.R.K., Bhaskar Rao, Y.J., Narayana, B.L., 2003a. A structural cross-section along Krishnagiri–Palani, southern granulite terrain, India. In: Ramakrishnan, M. (Ed.), Tectonics of Southern Granulite Terrain, Kuppam–Palani Geotransect Geological Society of India Memoir 50, pp. 255–278.

Chetty, T.R.K., Vijay, P., Narayana, B.L., Giridhar, G.L., 2003b. Structure of the Nagavali shear zone, Eastern Ghats Mobile Belt, India: correlation in the East Gondwana reconstruction. Gondwana Research 6, 215–229.

Collins, A.S., Windley, B.F., 2002. The Tectonic evolution of central and northern Madagascar and its place in the final assembly of Gondwana. Journal of Geology 110, 325–340.

Cunningham, D., Windley, B.F., Dorjnamjaa, D., Badamgara, G., Saandar, M., 1996. A structural transect across the Mongolian Western Altai: active transpressional mountain building in central Asia. Tectonics 15, 142–156.

Dias, R., Ribeiro, A., 1994. Constriction in a transpressive regime: an example in the Iberian branch of the Ibero-Armerican arc. Journal of Structural Geology 16, 1543–1554.

Drury, S.A., Harris, N.B.W., Holt, R.W., Reeves-Smith, G.J., Wightman, R.T., 1984. Precambrian tectonics and crustal evolution in South India. Journal of Geology 92, 3–20.

Fossen, H., Tikoff, B., 1998. Extended models of transpression and application to tectonic settings. In: Holdsworth, R.E., Strachan, R.A., Dewey, J.F. (Eds.), Continental Transpressional and Transtensional Tectonics Geological Society, London, Special Publication 135, pp. 15–34.

Ghosh, J.G., de Wit, M.J., Zartman, R.E., 2004. Age and Tectonic evolution of Neoproterozoic ductile shear zones in the Southern Granulite Terrain of India with implications for Gondwana studies. Tectonics 23, TC3006. doi:10.1029/2002TC001444.

Ghosh, S.K., Khan, D., Sengupta, S., 1995. Interfering folds in constrictional deformation. Journal of Structural Geology 17, 1361–1373.

Gopalakrishnan, K., 1996. An Overview of Southern Granulite Terrain, India—Constraints in Reconstruction of Precambrian Assembly of Gondwana Land. Gondwana Nine 2, Oxford and IBH, New Delhi, pp. 1003–1026.

Goscombe, B.D., Gray, D., Hand, M., 2005. Extrusional tectonics in the core of a transpressional orogen; the Kaoko Belt, Namibia. Journal of Petrology 46 (6), 1203–1241.

Grujic, D., Casey, M., Davidson, C., Holister, L.S., Kundig, R., Pavlis, T., Schmid, S., 1996. Ductile extrusion of the higher Himalayan crystalline in Bhutan: evidence from quartz microfabrics. Tectonophysics 260, 21–43.

GSI and ISRO, 1994. Project Vasundhara: Generalized Geological Map (Scale 1:2 million). Geological Survey of India and Indian Space Research Organization, Bangalore.

Harinarayana, T., Naganjaneyulu, K., Manoj, C., Patro, B.P.K., Kareemunnisa Begum, S., Murthy, D.N., Madhusudana Rao, V., Kumaraswamy, T.C., Virupakshi, G., 2003. Magnetotelluric investigations along Kuppam–Palani geotransect, South India—2D modeling results. In: Ramakrishnan, M. (Ed.), Tectonics of Southern Granulite Terrain, Kuppam–Palani Geotransect Geological Society of India Memoir 50, pp. 107–124.

Harris, N.B.W., Santosh, M., Taylor, P.N., 1994. Crustal evolution in South India: constraints from neodymium isotopes. Journal of Geology 102, 139–150.

Hopgood, A.M., 1999. Determination of Structural Successions in Migmatites and Gneisses. Kluwer Academic Publishers. 346pp.

Huddleston, P.J., Schiltz, E.D., Southwick, D.L., 1988. Transpression in an Archean greenstone belt, Northern Minnesota. Canadian Journal of Earth Sciences 25, 1060–1068.

Meissner, B., Deters, P., Srikantappa, C., Köhler, H., 2002. Geochronological evolution of the Moyar, Bhavani and Palghat shear zones of southern India: implications for Gondwana correlations. Precambrian Research 114, 149–175.

Nathan, N.P., Balasubramanian, E., Ghosh, S., Ray Barman, T., 2001. Neoproterozoic acid magmatism in Tamilnadu, south India: geochemical and geochronological constituents. Gondwana Research 4, 714–715.

Raith, M., Srikantappa, C., Buhl, D., Kohler, H., 1999. The Nilgiri Enderbites, south India: nature and age constraints on protolith formation, high-grade metamorphism and cooling history. Precambrian Research 98, 129–150.

Ramakrishnan, M., 1993. Tectonic evolution of the granulite terrains southern India. Geological Society of India Memoir 25, 35–44.

Ramsay, J.G., 1967. Folding and Fracturing of Rocks. McGraw-Hill, New York. 568pp.

Ramsay, J.G., Huber, M.I., 1987. The Techniques of Modern Structural Geology. Vol. 1. Strain Analysis. Academic Press, London.

Reddy, P.R., Rajendra Prasad, B., Vijaya Rao, V., Sain, K., Prasada Rao, P., Khareand, P., Reddy, M.S., 2003. Deep seismic reflection and refraction/wide-angle reflection studies along Kuppam–Palani transect in the southern granulite terrain of India. In: Ramakrishnan, M. (Ed.), Tectonics of Southern Granulite Terrain, Kuppam–Palani Geotransect Geological Society of India Memoir 50, pp. 79–106.

Robin, P.Y.F., Cruden, A.R., 1994. Strain and vorticity patterns in ideally ductile transpression zones. Journal of Structural Geology 16, 447–466.

Sanderson, D.J., Marchini, W.R.D., 1984. Transpression. Journal of Structural Geology 6, 449–458.

Singh, A.P., Mishra, D.C., Vijay Kumar, V., Rao, M.B.S.V., 2003. Gravity magnetic signature and crustal architecture along Kuppam–Palani geotransect, South India. In: Ramakrishnan, M. (Ed.), Tectonics of Southern Granulite Terrain, Kuppam–Palani Geotransect Geological Society of India Memoir 50, pp. 139–163.

Thompson, A.B., Schulmann, K., Jezek, J., 1997. Thermal evolution and exhumation in obliquely convergent (transpressive) orogens. Tectonophysics 280, 171–184.

Vijaya Rao, V., Rajendra Prasad, B., in press. Structure and evolution of the Cauvery Shear Zone System, Southern Granulite Terrain, India: evidences from the Deep Seismic and other geophysical studies. In: Chetty, T.R.K., Fitzsimons, I.C.W., Brown, L.D., Dimri, V.P., Santosh, M. (Eds.), Crustal Structure and Tectonic Evolution of the Southern Granulite Terrain, India. Gondwana Research.