Anais da Academia Brasileira de Ciências (2008) 80(3): 565-577
(Annals of the Brazilian Academy of Sciences)
ISSN 0001-3765
www.scielo.br/aabc

Transpressive Dextral Shear in the Italva-Itaperuna Section, Northern State of Rio de Janeiro, Brazil

TIAGO R. KARNIOL[1], **RÔMULO MACHADO**[2] **and NOLAN M. DEHLER**[3]

[1]Programa de Pós-Graduação em Geoquímica e Geotectônica, Instituto de Geociências, Universidade de São Paulo, Rua do Lago, 562, 05508-080 São Paulo, SP, Brasil
[2]Departamento de Geologia Sedimentar e Ambiental, Instituto de Geociências, Universidade de São Paulo, Rua do Lago, 562, 05508-080 São Paulo, SP, Brasil
[3]PETROBRAS – E&P EXP/GEO/GEAT, Av. República do Chile, 65, 20031-912 Rio de Janeiro, RJ, Brasil

Manuscript received on September 17, 2007; accepted for publication on March 25, 2008; presented by ALCIDES N. SIAL

ABSTRACT

Structural analysis carried out on a segment of the Neoproterozoic Ribeira Belt, southeastern Brazil, show that it represents part of the transpressive dextral orogen related to the Central Mantiqueira Province. NNE-trending and steeply dipping regional mylonitic belts form anastomosed geometry, and describe a map-scale, S-C-like structure that is characterized by their deflection towards NE near the Além Paraíba Lineament. Lithological and structural control related to deformation partition were responsible for the formation of felsic mylonitic granulites with S-type granites lenses developed in ductile shear zones, alternated with less deformed intermediate to basic granulites associated with charnockites. The dextral shear sense indicators are consistent with transpressive deformation in the region and are common especially at the border of the main shear zones. The presence of S-type leucogranite may lead to variations of linear and planar relationships, which result in local extension zones. These elements are consistent with oblique continental collision considering the São Francisco Craton as a stable block.

Key words: Ribeira Belt, kinematics, transpression, syncontractional extension.

INTRODUCTION

Neoproterozoic transpression is well documented in the Ribeira Belt and is considered to be the main tectonic regime resulting from continental collision at this time (Machado and Endo 1993). The Brasiliano orogenic event occurred between 1.0 and 0.5 Ga (Almeida et al. 1973, Brito Neves and Cordani 1991). The so-called Central Mantiqueira Province (*sensu* Almeida and Hasui 1984) comprises a long and sinusoidal northeastern-trending array of shear zones developed at the southern border of the São Francisco Craton. The structure of the Province is attributed to collision event(s) during western Gondwanaland agglutination (Heilbron et al. 2004). In the Province, mylonitic rocks developed under low to high-grade metamorphic conditions, and magmatic bodies of different compositions were intruded during shear zone activity (Nummer et al. 2007). Because of their high silica or phyllosilicate contents, these shear zones form positive or negative features signatures in the relief that are recognizable in satellite or aero-geophysical images.

The Além Paraíba Lineament (Almeida et al. 1975) is one of the most important shear zones, and crosses the State of Rio de Janeiro parallel to the Paraíba do Sul river. It represents a vertical channel of ductile deformation and, at a large scale, has S-C' geometry related to transpressive dextral deformation. This portion of the continental crust is also considered part of the so-called

Correspondence to: Rômulo Machado
E-mail: rmachado@usp.br

Paraíba do Sul Shear Zone (Ebert 1968, 1971) or the Ribeira Belt (Cordani et al. 1973).

In this work, we focus on the structural pattern of the Italva-Itaperuna section at the the southeastern border of the São Francisco Craton. This section is located near the hinge of the Ribeira-Araçuaí orogenic virgation. We studied the structural geology of this region, and hope to contribute to the understanding of the transition between the Ribeira and the Araçuaí belts.

Geological Setting

In the investigated segment the structural trend changes from NE to NNE close to parallel 21°30′S (Fig. 1). This change is considered by some authors to define the limit between the Ribeira and Araçuaí belts (Pedrosa-Soares et al. 1992). Because of the lack of precise structural criteria to define this boundary, we prefer to consider this region as part of the central Mantiqueira Province. Furthermore, as a result of our observations, we believe that the segment of the Mantiqueira Province which extends southwards at least from the centre of the State of Espírito Santo in the Rio Doce valley to the northern region of the State of Rio de Janeiro represents part of the same orogenic system.

The transpressive character of deformation in this region is shown by the coexistence of transcurrent and compressive structures (Dayan and Keller 1989, Trompette et al. 1993, Vauchez et al. 1994, Ebert and Hasui 1998, Dehler and Machado 2002). Scale-independent shear sense indicators (Dayan and Keller 1989, Campanha 1981, Egydio-Silva et al. 2002, Karniol and Machado 2004) point to a dextral regime of deformation, although locally important sinistral displacements may also occur (Dehler et al. 2006).

A fan-like structure at the core of the orogen has been recognised since the 1960s, and consists of oppositely dipping foliations to SE in its northwestern limb, and to NW in the southeastern limb (Ebert 1968). This geometry is considered either as late folding due to northwestward thrusting (Heilbron et al. 1991) or as a mega flower structure related to dextral transpressive deformation (Machado and Endo 1993).

Recently, many authors have pointed to the importance of orogen-parallel tectonic structures related to Neoproterozoic deformation (Dehler and Machado 2002, Karniol and Machado 2004, Peres et al. 2004, Dehler et al. 2006), and to extensional or transtensional flow (Dehler et al. 2000, Dehler and Machado 2002, Dehler et al. 2007, Karniol and Machado 2004, Dehler et al. 2006, Marshak et al. 2006, Karniol et al. 2007). These processes are also well-described in international literature (Jarrard 1986, Ratschbacher et al. 1991, Beck 1991, Bird 1991, Chauvet and Séranne 1994, Lyberis and Mamby 1999, Harz et al. 2001, Seyferth and Henk 2004).

Lateral escape or extrusion tectonics (Dias and Ribeiro 1994, Jones et al. 1997) are reported in ancient and modern orogens, such as the Caledonides (Chauvet and Sérrane 1994, Lyberis and Mamby 1999), the Alps (Ratschbacher et al. 1991, Mancktelow 1992) or the Himalayas (Inger 1998). This process was modelled in two (Ratschbacher et al. 1991) and more recently in three dimensions (Seyferth and Henk 2004), and presents complex relationships of crustal behaviour in terms of time-dependent deformation mechanisms. Contributions to the characterization of this process in the Ribeira Belt have been made by Trompette et al. (1993), Vauchez et al. (1994), and Hackspacher and Godoy (1999).

We performed detailed geometric and kinematic analyses on a 40 km-long, SE-NW trending section between the towns of Italva and Itaperuna in the State of Rio de Janeiro.

METHODS

Field work was carried out at fresh and weathered outcrops on the BR-252 road. Geometric analysis consisted of description and definition of groups of structures as proposed by Hobbs et al. (1976). Kinematic analysis involved measurements of stretching and mineral lineations, foliation planes and pairs of S-C-C' foliations, as well as determination of shear sense based on the interpretation of asymmetric structures. A summary of the shear sense indicators used here can be found in many publications such as Platt and Vissers (1980), Simpson and Schmid (1983), Lister and Williams (1983), Hanmer and Passchier (1991), and Passchier and Trouw (1996). Oriented samples were collected for microtectonics, petrographical and geothermobarometric analyses.

Structural data were tabulated and projected in lower hemisphere Schmidt-Lambert diagrams. Illustra-

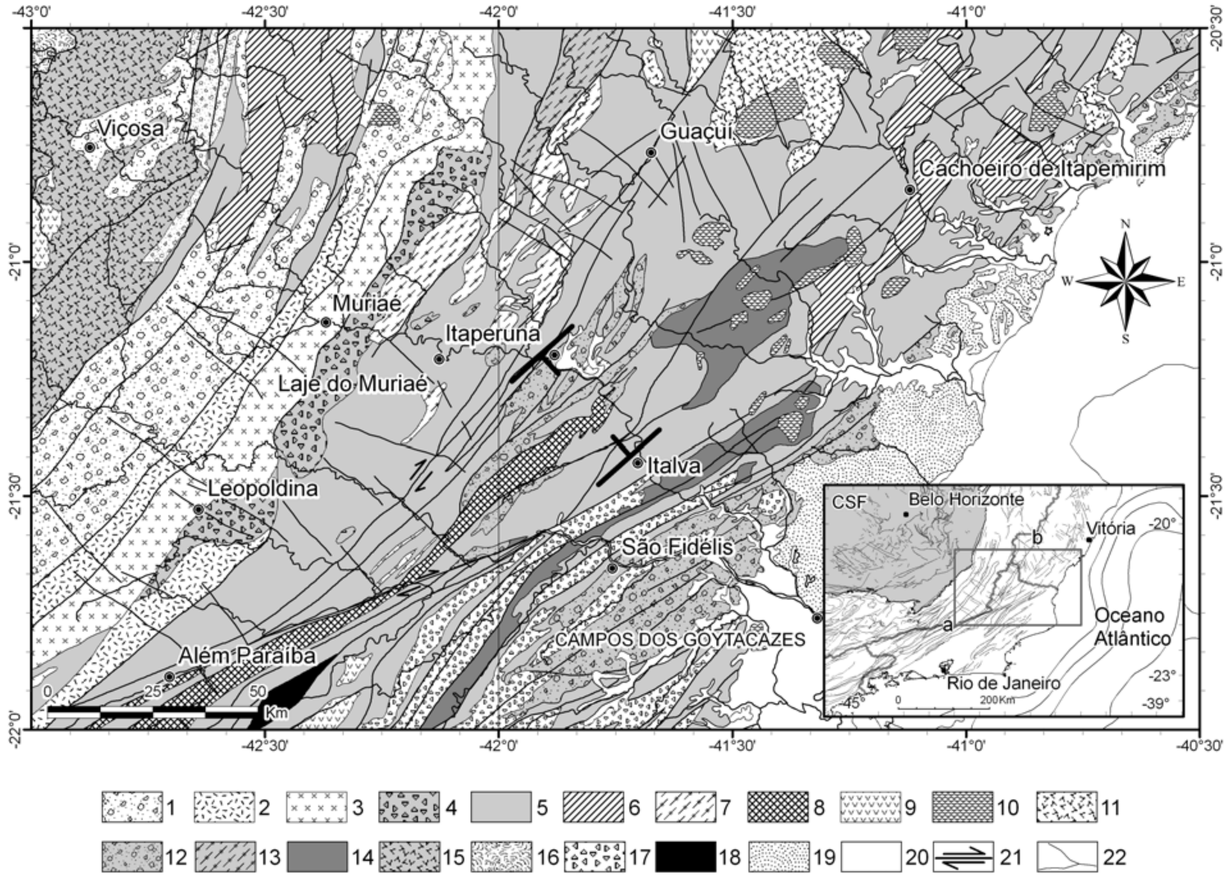

Fig. 1 – Geological map of northern region of the State of Rio de Janeiro with localization of the Italva-Itaperuna section (see Fig. 2). Sketch at right shows the location of the studied area and the regional structural pattern of the Central Mantiqueira Province with Além Paraíba Lineament (a) and Guaçuí Shear Zone (b). 1 – Juiz de Fora Complex; 2 – Quirino Suite; 3 – Muriaé Suite; 4 – Leopoldina Charnockitic Suite; 5 – Paraíba do Sul Complex; 6 – Cachoeiro Tonalite and Galiléia Suite; 7 – Eugenópolis, Varre-Sai and Natividade Granites; 8 – Serra da Araras Granitic Suite; 9 – Divinésia Granite; 10 – Santa Angélica, Alto Chapéu, Morro do Coco Intrusive Suites; 11 – Muniz Freire Suite; 12 – Bela Joana Suite; 13 – Caparaó Suite; 14 – Angelim Suite; 15 – Piedade Complex; 16 – Dom Silvério Group; 17 – Desengano Suite; 18 – Rio Negro Complex; 19 – Barreiras Group; 20 – Other Quaternary Deposits; 21 – Shear Zones and 22 – Rivers.

tions used are photographs of the outcrops, and refer mostly to XZ sections of the finite strain ellipsoid.

GEOMETRY

The region investigated comprises medium to high-grade metamorphic rocks such as aluminous gneisses, granulites, leucogranites and charnockites, separated by steeply dipping shear zones. High-grade mylonites and mylonitic granulites commonly develop planar to planar-linear fabric. Besides these shear zones, poorly deformed green to greenish brown granulites, charnockites and leucogranites are present. They have heterogeneously folded planar or sometimes sigmoid structures, where alternating centimetric to decimetric layers of felsic or mafic compositions characterize the main foliation.

Mylonitic to protomylonitic kinzigites are present in the eastern part of the profile. They contain an aluminous mineral assemblage with sillimanite, muscovite, cordierite, and normally have up to 3 cm rounded garnet porphyroclasts which form up to 40 to 50 vol% of the rock compositions. These rocks belong to the Paraíba do Sul Complex, and contain lenses of calcitic and dolomitic marbles, which are quarried near Italva town.

Geometrical and kinematic analyses are presented

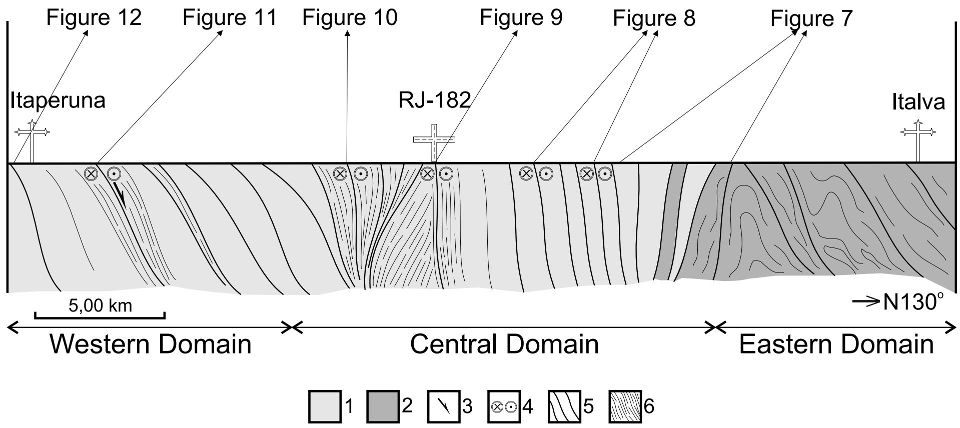

Fig. 2 – Italva-Itaperuna geologic profile. Legend: 1 – Paraíba do Sul Complex; 2 – Paraíba do Sul Complex – carbonated series; 3 – Sense of shear in profile; 4 – Dextral shear zones; 5 – Foliation parallel to composicional layering; 6 – Mylonitic foliation.

below from east to west (Fig. 2), according to Turner and Weiss (1963) conceptions of homogeneous structural domains.

Eastern Structural Domain

This domain is located near Italva town (Fig. 2) and comprises metasedimentary rocks including kinzigites, type-S leucogranites, and diopside-bearing marbles of the Paraíba do Sul Complex.

Linear-planar fabrics prevail and the foliation is characterised by biotite or sometimes muscovite-rich planes. Compositional layering of felsic and biotite-granet rich bands may also form a planar fabric. A biotite-sillimanite or quartz-feldspathic lineation is sometimes present.

Stereographic projection of planar structures for this domain indicates moderately to steeply, E-to-ESE-dipping foliation, as well as a secondary concentration steeply dipping to NW (Fig. 3A).

Folded planes fit a girdle whose axis plunges to NE, close to the measured fold axis (Figs. 3B e 3C). Mineral and stretching lineations are oriented close to the fold axis, and plunge shallowly or even moderately to E and NE (Fig. 3C). This parallelism suggests that simple shear caused the folding. Planar and linear data relationships are coherent with highly oblique dextral displacements in this domain.

Central Structural Domain

This domain occurs near the RJ-182 road that leads to Bom Jesus do Itabapoana town in the northernmost part of Rio de Janeiro (Fig. 2), and displays a typical fan-like structure. It comprises mainly granulites of the Paraíba do Sul Complex with some S-type leucogranitic and charnockitic lenses. Some hundreds of meters wide shear zones show extreme deformation and present typical mylonitic fabrics.

Foliation comprises lenticular, centimetric to decimetric compositional banding of quartz-feldspatic and pyroxene-anphibole-biotite layers that are well developed at the shear zones. Stereographic projections of this structural data show mainly steeply to vertical SE and secondary NW dipping planes (Fig. 4A). Linear plots plunge shallowly to moderately to NE and shallowly to SW and refer to fine-grained quartz-felspar-biotite lineation and fold axis data (Fig. 4B) which are consistent with predominance of directional to gently oblique movements.

Western Structural Domain

Near to or in Itaperuna town many outcrops occur along the BR-252 road. They are composed of granulites that may contain decimetric to decametric charnockitic and S-type leucogranitic lenses.

As we observed in all studied sections, strain rates are concentrated in maximum deformation shear zones

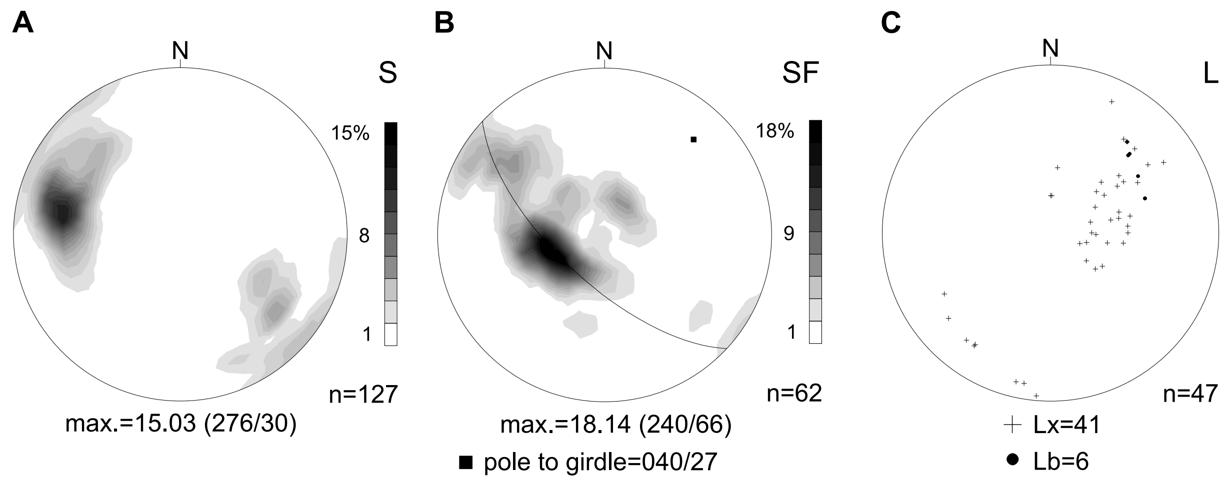

Fig. 3 – Structural data of Eastern Structural Domain. A – Poles to foliation (S), B – Poles to fold planes (SF) with statistically adjusted axis, C – Linear data (L): Lx – mineral and stretching lineation, Lb – fold axis. Equal area lower hemisphere Schmidt-Lambert stereographic projection. Number of data points (n) shown.

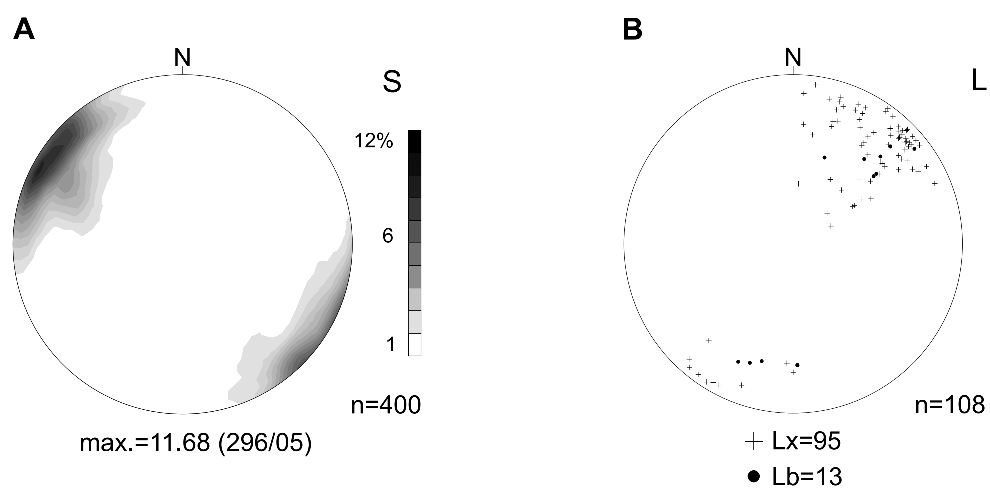

Fig. 4 – Structural data of Central Structural Domain. A – Poles to foliation (S), B – Linear data (L): Lx – mineral and stretching lineation, Lb – fold axis. Equal area lower hemisphere Schmidt-Lambert stereographic projection. Number of data points (n) shown.

where felsic mylonitic granulites and granites occur. Internally, heterogenous mafic charnockite lenses predominate. This structural/lithologic relationship is found at various scales, and represents one of the most important strain partitioning features in the region.

Stereographic projection of foliation shows a consistent, steeply ESE to E-dipping concentration (Fig. 5A). Fold planes are treated separately and define a girdle whose axis plunges shallowly to NE (Fig. 5B). This orientation is parallel to the principal lineation, and fold axis data show mainly gently NE and secondary SW dips (Fig. 5C), suggesting that rotation of fold axes occurred during simple shear deformation. These elements allow us to locate the main focus of oblique movements in this sector.

KINEMATIC ANALYSIS

Kinematic analysis consider asymmetrical structures whose vorticity sense can be interpreted as well as their relationship with planar and linear elements. Regionally there is a dextral configuration based on curved shear zones intercepted by the Além Paraíba Lineament (Fig. 1).

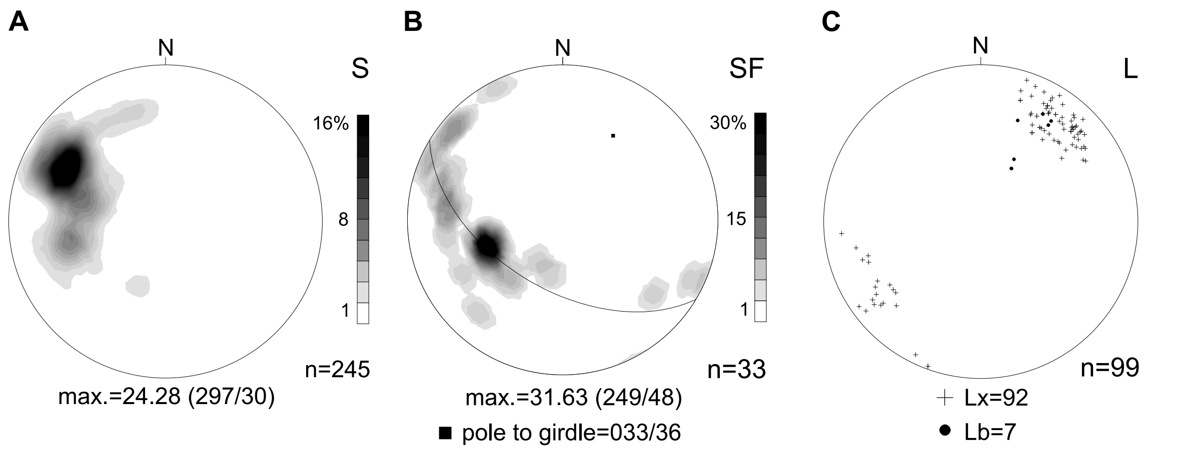

Fig. 5 – Structural data of Western Structural Domain. A – Poles to foliation (S), B – Poles to fold planes (SF) with statistically-adjusted axis, C – Linear data (L): Lx – mineral and stretching lineation, Lb – fold axis. Equal area lower hemisphere Schmidt-Lambert stereographic projection. Number of data (n) shown.

Global foliation data show mainly steeply SE and secondarily steeply to vertical NW dippings (Fig. 6A), a variation that may be attributed to the development of fan-like structures. The main lineation plunges gently to NE, but secondary shallowly SW and moderately E plunging lineations are observed (Fig. 6B). These data are consistent with oblique to directional tectonics.

Folded planes define a girdle which statistic axis plunges gently to NE, as well as measured fold axis (Figs. 6C and 6D). These data refer the tight to isoclinal folds under interference of decimetric to metric stretched anfibolitic and calcic-silicate enclaves (Fig. 7). The parallelisms of fold axis and lineation (Fig. 6D) implie in simply shear participation during folding processes.

At outcrops with steeply-dipping foliation, normally close to or in the shear zones of the eastern and central structural domains, mesoscale S-C and S-C' foliation planes, asymmetrical porphyroclasts, sigmoid granitic lenses, fractured quartz veins, bookshelf structures, among other shear sense indicators, are consistent with a dextral shear sense (Figs. 8, 9 and 10).

At two outcrops east of the RJ-182 Road, foliation planes adopt S-C (Fig. 8A) to S-C' geometry, where C' and S-parallel centimetric sigmoidal mafic lenses are present (Figs. 8B and 8C), or fold interference figures are evident (Fig. 8D). This kinematic behaviour is also coherent with that shown in a quartz-feldspatic vein deformed under a ductile-fragile regime (Fig. 8E). Figure 8F presents stereographic linear and planar data and suggests that directional movements are predominant.

In the western portion of the Central Domain at the BR-252 and RJ-182 crossroads, S-C foliation planes were observed at a weathered outcrop of an important high angle dextral shear zone (Figs. 9A and 9B).

West of this point, less deformed granulite also presents S-C foliation planes (Figs. 10A and 10B), which may be accompanied by S and C-parallel leucogranite bodies (Fig. 10C), and bookshelf structures in centimetric feldspatic porphyroclasts (Fig. 10D), all of them consistent with dextral dislocation. However, opposite sense S-C' structures associated with sigmoid leucogranites are also present and probably represent antithetic dislocation along the shear zone (Fig. 10E).

Close to Itaperuna town, S-C foliation planes that correspond to predominantly dextral shear (Fig. 11A) accommodate stretched leucogranite lenses. Stereographic plots of this outcrop show that these lenses are subparallel to foliation planes and that linear and planar relationship implies directional to gently top-down-to-the-SW extensional shear (Fig. 11B).

At the western limit of the section in Itaperuna town, ductile-ruptile foliations form an S-C structure that suggests top-down-to-W normal sense of shear (Figs. 12A and 12B), which may represent more recent extensional tectonics in the region, whereas ductile lineation and foliation data are consistent with the rest of

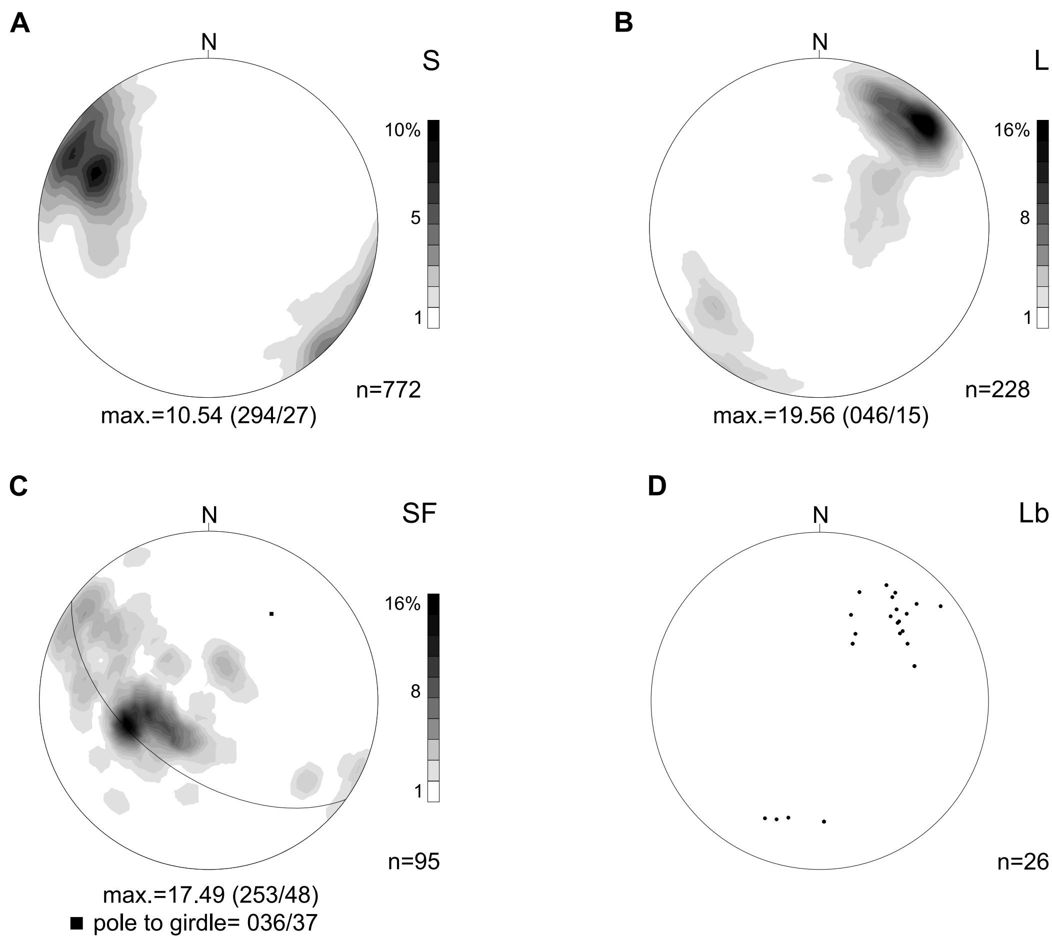

Fig. 6 – Global structural data. A – Poles to foliation (S), B – Mineral and stretching lineation (L), C – Poles to fold planes (SF) with statistically-adjusted axis and D – Fold axis (Lb). Equal area lower hemisphere Schmidt-Lambert stereographic projection. Number of data (n) shown.

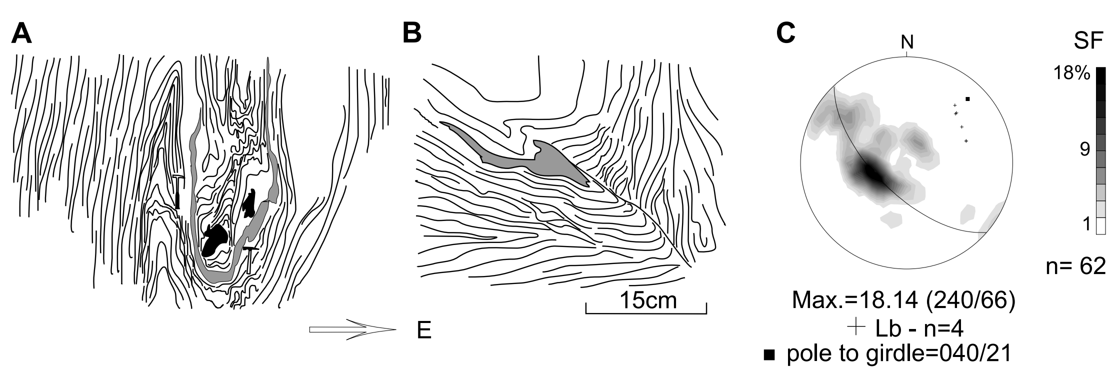

Fig. 7 – Pattern of folding near the road junction at Bom Jesus do Itabapoana, RJ. A – Meter-scale isoclinal fold with strongly thickened fold hinge in an antiform affecting a grey lenticular granite mass. This structure is affected by the presence of dark calc-silicate enclaves; B – Tight fold with thickened fold hinge associated with a grey granitic vein; C – Stereographic projection of the poles to the folded foliation (SF), fold axes (Lb) with pole adjusted to the girdle. The number of data points (n) and the direction of the section are indicated.

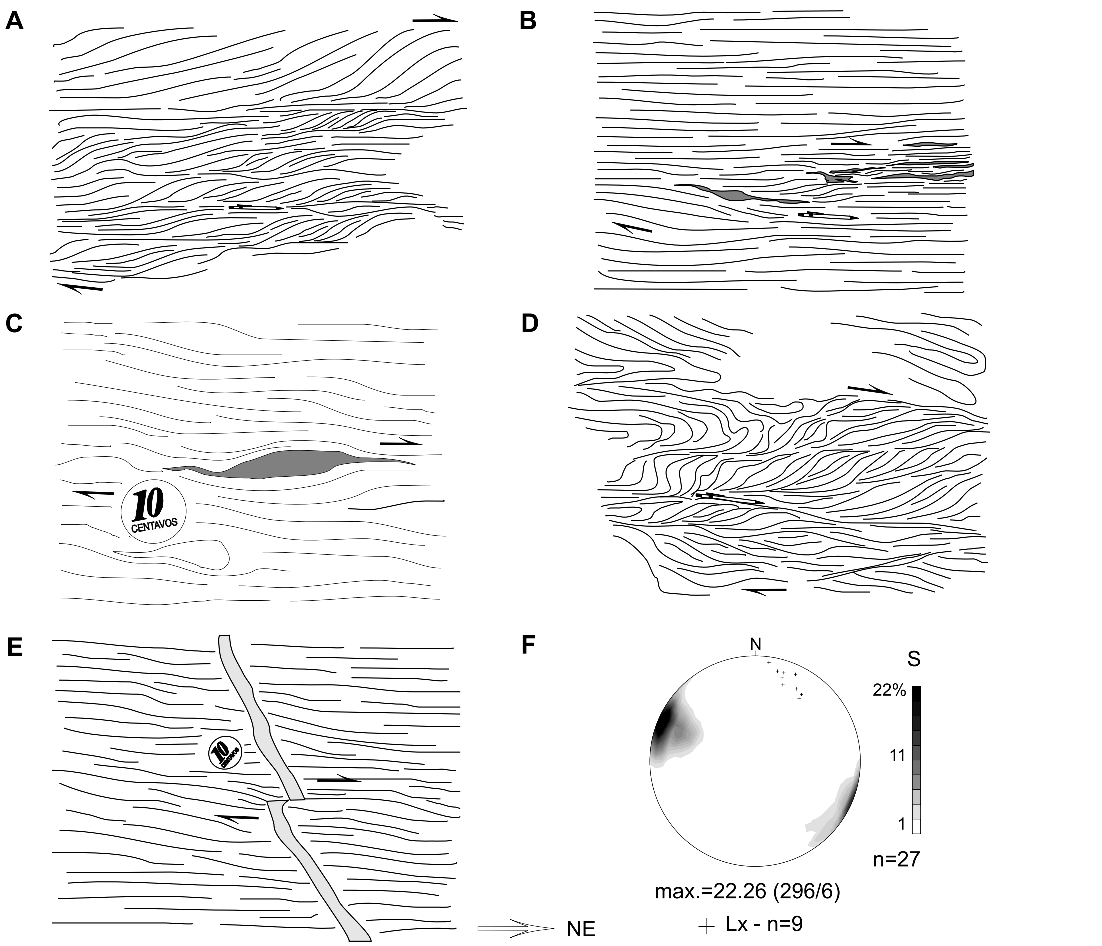

Fig. 8 – Dextral kinematic indicators in high-angle granulitic mylonites near the road junction at Bom Jesus do Itabapoana/RJ. Section parallel to the XZ plane of the finite strain ellipsoid with its direction identified. A – S-C fabric of the foliations; B – Mafic lenses parallel to the C and C′ planes (above the pencil); C – Sigmoid basic lens; D – S-C-C′ foliation pairs with interference fold patterns in the left-hand part; E – Quartz-feldspathic vein cut by a fault with centimetric reject; F – Stereographic projection of foliation planes (S) and stretching and mineral lineations (Lx). Number of data points (n) given.

the section, ductile-ruptile foliation planes have steep WNW dips (Fig. 12C). Furthermore, difficult definition of slickenslide directions on fault planes does not allow a more precise evaluation of this structure.

DISCUSSION AND CONCLUSIONS

Geometrical and kinematic analyses on the studied cross-section allow us to discuss some aspects about the tectonic evolution of the Ribeira Belt. In this sector of the orogen, anfibolite to granulite facies rocks yield information on deep crustal behaviour in response to transpressive deformation. We consider this significant because in modern orogens, geologists can observe directly upper crustal levels, but the interpretation of deeper levels is mainly based on geophysical investigations.

The alternation of shear zones with felsic granulitic myonites and internal zones with heterogenous intermediate to basic granulites, charnockites and S-type leucogranites seems to have a major role in the deformation partitioning process. We observed that this relationship occurs at various scales, and probably represents a structural control on the rock units.

Shear zones may form from meter to some hundreds of meters wide segments. The linear forms of major ones are clearly observed on satellite and aerogeophysical

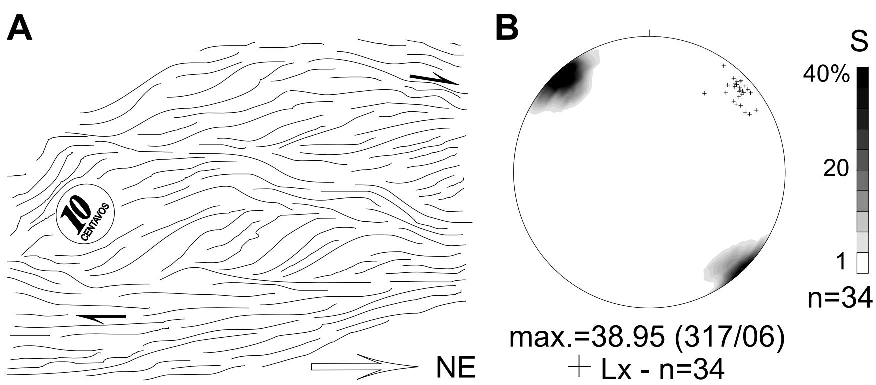

Fig. 9 – Kinematic indicators in dextral shear zones. A – S-C-C´ foliation pairs in mylonites at the Bom Jesus do Itabapoana road junction. Sections parallel to the XZ plane of the finite deformation ellipsoid, with its direction shown; B – Stereographic projection of foliation poles (S) and stretching and mineral lineations (Lx). Number of data points (n) shown.

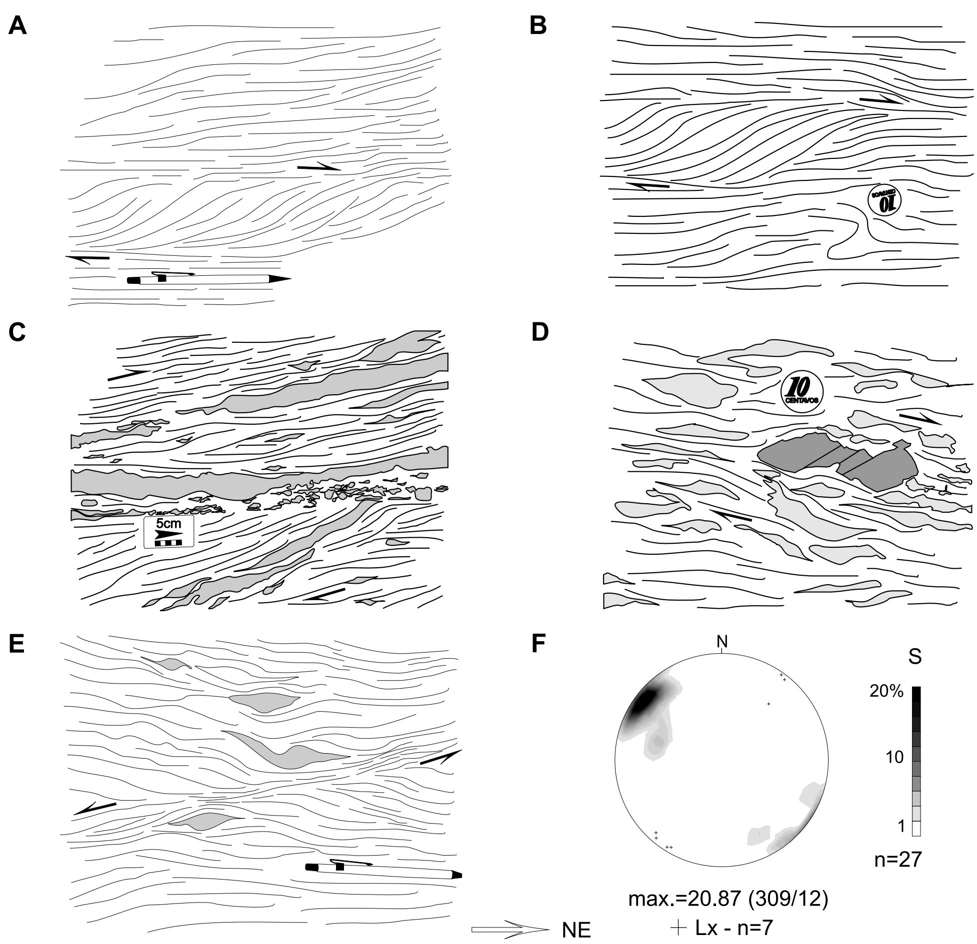

Fig. 10 – Kinematic indicators in granulitic mylonites with steeply dipping structures near the Bom Jesus do Itabapoana road junction. Sections parallel to the XZ plane of the finite deformation ellipsoid whose direction is indicated. A – S-C-C´ foliation fabric; B – S-C-C´ fabric of foliations with S-folds below the coin; C – Leucogranite lenses along the S-C´ planes; D – Feldspar porphyroclast with faulting antithetic to the main dextral movement forming book structures; E – Sigmoids in leucogranit formed under a ductile-fragile regime showing sinistral movement; F – Stereographic projections of foliations (S) and stretching and mineral lineations (Lx). Number of data points (n) indicated.

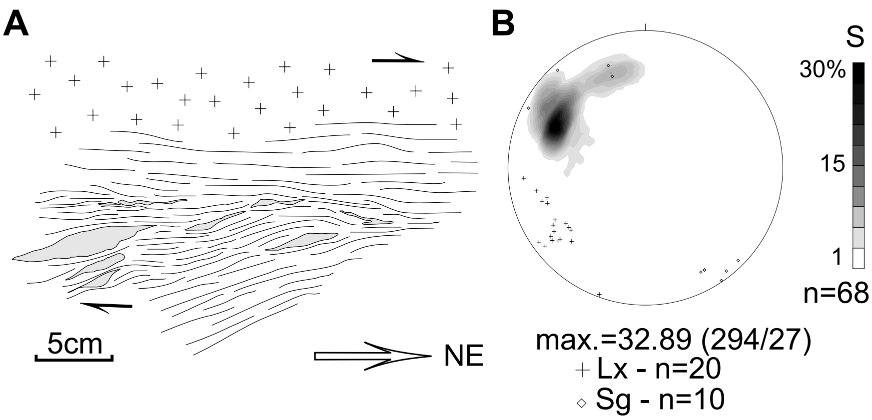

Fig. 11 – Leucogranitic lenses (grey) controlled by S-C foliation planes (A) developed in outcrop close to Itaperuna town. Dextral movements contain top-down to SW component (B), where foliation planes (S), mineral and stretching lineation (Lx) and leucogranitic (Sg) are plotted. Equal area lower hemisphere Schmidt-Lambert stereographic projection. Number of data (n) shown.

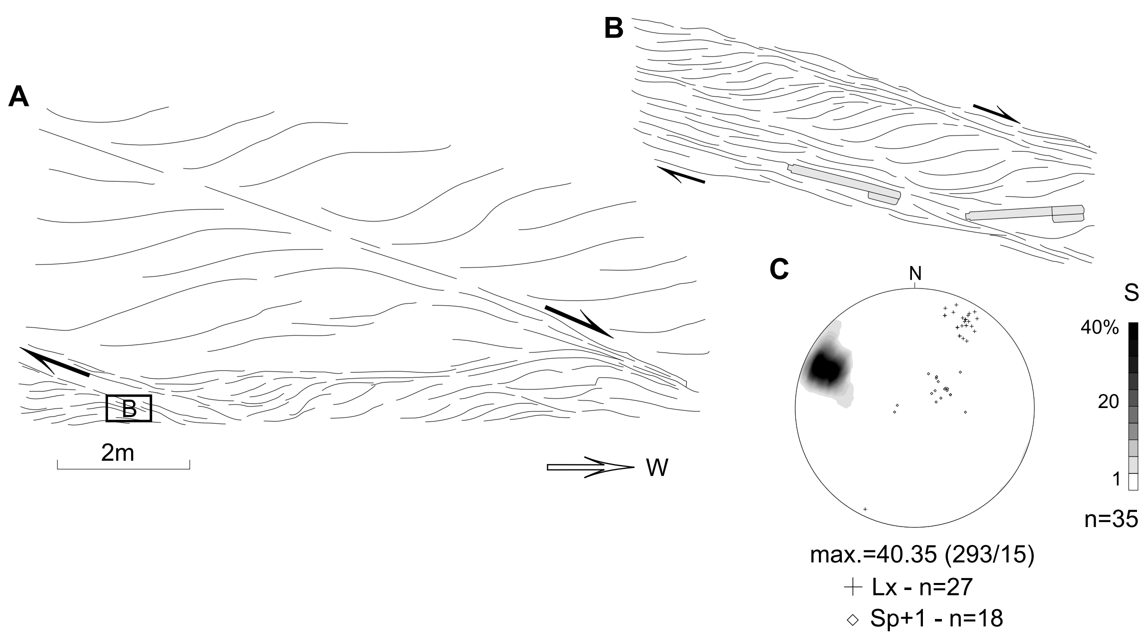

Fig. 12 – S-C foliation fabric associated with top-to-W extensional tectonics seen at metric (A) and centimetric (B) scales. These structures are related to a late-stage deformation with development of low-angle fragile surfaces which are discordant of the main foliation in the granulites (C). Banded granulite outcrop in Itaperuna.

images. They consist of steeply dipping structures with oblique to directional lineation.

S-C and S-C' foliation planes, asymmetrical porphyroclasts, sigmoid granitic lenses, and fractured quartz-feldspatic dikes all indicate dextral shear in many outcrops of this section. We consider that they were formed under a regional transpressive regime related to the Neoproterozoic consolidation of western Gondwana, which is related to orogen-parallel flow towards SW, considering the São Francisco Craton as a reference.

The formation of granite lenses seen close to Itaperuna town may be due to local variations of planar and linear relationships during development of extensional shear. Top-down-to-west brittle-ductile structures have also been described in Itaperuna, and may be related to a more recent extensional event during the tectonic evolution of Ribeira Belt.

We still need complementary data in terms of geochronology and geothermobarometry for a more precise characterization of its tectonic evolution. However, our results are consistent with transpressive deformation at the Central Mantiqueira Province.

RESUMO

A análise estrutural efetuada num segmento neoproterozóico do Cinturão Ribeira, Sudeste do Brasil, mostra que ele representa parte do orógeno transpressivo destral, relacionado com a Província Mantiqueira Central. Caracteriza-se regionalmente por um cinturão milonítico de direção NNE e mergulhos subverticais, com geometria anastomosada, descrevendo em escala de mapa estruturas do tipo S-C, que são defletidas para direção NE nas proximidades do Lineamento de Além-Paraíba. O controle estrutural e litológico e a partição da deformação foram responsáveis pela formação de granulitos miloníticos félsicos com lentes de granitos tipo-S, desenvolvidos em zonas de cisalhamento dúcteis, alternados com granulitos básicos a intermediários menos deformados com charnockitos associados. Na região, os indicadores cinemáticos do cisalhamento simples, destral, são consistentes com a deformação transpressiva, que é particularmente comum nas bordas das zonas de cisalhamento mais importantes. A presença de leucogranitos tipo-S pode levar a variação das relações planares e lineares, as quais condicionam, localmente, zonas extensionais. Estes elementos são consistentes com uma colisão continental oblíqua, considerando o Cráton do São Francisco como um bloco estável.

Palavras-chave: Cinturão Ribeira, cinemática, transpressão, extensão sincontracional.

REFERENCES

Almeida FFM and Hasui Y. 1984. O Pré-Cambriano do Brasil. São Paulo: Edgard Blücher, 378 p.

Almeida FFM, Amaral G, Cordani UG and Kawashita K. 1973. The precambrian evolution of the south american cratonic margin south of Amazon river. In: Nairn EM and Stehli FG (Eds). The ocean basins and margins. Plenun, New York, p. 411–446.

Almeida FFM, Hasui Y and Carneiro CDR. 1975. Lineamento de Além-Paraíba. An Acad Bras Cienc 47: 575.

Beck ME. 1991. Coastwise transport reconsidered: lateral displacements in oblique subduction zones, and tectonic consequences. Phys Earth Planet Int 68: 1–8.

Bird P. 1991. Lateral Extrusion of Lower Crust from Under High Topography, in the Isostatic Limit. J Geoph Res 96: 10.275–10.286.

Brito Neves BB and Cordani UG. 1991. Tectonic evolution of South America during the Late Proterozoic. Precam Res 53: 23–40.

Campanha GAC. 1981. O lineamento Além Paraíba na área de Três Rios (RJ). Rev Bras Geocienc 11: 159–171.

Chauvet A and Séranne M. 1994. Extension-parallel folding in the Scandinavian Caledonides: implications for late-orogenic processes. Tectonophysics 238: 31–54.

Cordani UG, Delhal J and Ledent D. 1973. Orogéneses superposées dans la précambrien du Brésil Sud-oriental (États de Rio de Janeiro et Minas Gerais). Rev Bras Geocienc 3: 1–22.

Dayan H and Keller JVA. 1989. A zona de cisalhamento do Rio Paraíba do Sul nas vizinhanças de Três Rios (RJ): uma análise da deformação dada por algumas feições estruturais. Rev Bras Geocienc 19: 494–506.

Dehler NM and Machado R. 2002. Geometria e cinemática da aba sul da estrutura divergente do Rio Paraíba do Sul ao longo da seção Areal-Três Rios, Rio de Janeiro. Rev Bras Geocienc 32: 481–490.

Dehler NM, Machado R and Vasconcelos CS. 2000. Tectônica extensional oblíqua no sul do estado de São Paulo. Rev Bras Geocienc 30: 699–706.

Dehler NM, Machado R, Dehler H, McReath I and Nummer A. 2006. Kynematics and geometry of structures in the southern limb of the Paraíba do Sul divergent structural fan, SE Brazil: a true transtensional shear. An Acad Bras Cienc 78: 1–17.

Dehler NM, Machado R and Fassbinder E. 2007. Shear structures in the Serra do Azeite shear zone, southeastern Brazil: Transtensional deformation during regional transpression in the central Mantiqueira province (Ribeira belt). J South Am Earth Sci 23: 176–192.

Dias R and Ribeiro A. 1994. Constriction in a transpressive regime: an example in the Iberian branch of the Ibero-Armorican arc. J Struc Geol 16: 1543–1554.

Ebert H. 1968. Ocorrências de fácies granulíticas no sul de Minas Gerais e em áreas adjacentes em dependência da estrutura orogênica: hipóteses sobre sua origem. An Acad Bras Cienc 40: 215–229.

Ebert H. 1971. Os Paraibides entre São João Del Rey, Minas Gerais e Itapira, São Paulo, e a bifurcação entre Paraibides e Araxaídes. In: SBG, Congr Bras Geol 25, Bol. Especial 1: 177–178.

Ebert HD and Hasui Y. 1998. Transpressional tectonics and strain partitioning during oblique colision between three plates in the precambrian of southeast Brazil. In: Holdsworth RE, Strachan RA and Dewey JF (Eds), Continental transpressional and transtensional tectonics. London: Geol Soc Spec Publ 135: 231–252.

Egydio-Silva M, Vauchez A, Bascou J and Hippertt JF. 2002. High temperature deformation in the Neoproterozoic transpressional Ribeira Belt, southeast Brazil. Tectonophysics 352: 203–224.

Hackspacher P and Godoy AM. 1999. Vertical displacement during late-collisional escape tectonics (Brasiliano Orogeny) in the Ribeira Belt, São Paulo State, Brazil. J Afric Earth Sci 29: 25–32.

Hanmer S and Passchier CW. 1991. Shear Sense Indicators: a review. Geol Sur Can Pap 90–17, 72 p.

Harz EH, Andresen A, Hodges KV and Martin MW. 2001. Syncontractional extension and exhumation of deep crustal rocks in the east Greenland Caledonides. Tectonics 20: 58–77.

Heilbron M, Valeriano CM, Almeida JCH and Tupinambá M. 1991. A Megassinformal do Paraíba do Sul e sua implicação na compartimentação tectônica do setor central da Faixa Ribeira. In: SBG, Simp Geol Sud 2: 519–527.

Heilbron M, Pedrosa-Soares AC, Campos Neto MC, Silva LC, Trouw RAJ and Janasi VA. 2004. Província Mantiqueira. In: Mantesso-Neto V et al. (Orgs) Geologia do Continente Sul-Americano: Evolução da Obra de Fernando Flávio Marques de Almeida, p. 203–235.

Hobbs BE, Means BWD and Williams PF. 1976. An outline of structural geology, New York: J Wiley & Sons, 379 p.

Inger S. 1998. Timing of an extensional detachment during convergent orogeny: New Rb/Sr geochronological data from the Zanskar shear zone, northwestern Himalaya. Geology 26: 223–226.

Jarrard RD. 1986. Terrane motion by strike-slip faulting of forearc slivers. Geology 14: 780–783.

Jones RR, Holdsworth RE and Bailey W. 1997. Lateral extrusion in transpression zones: the importance of boundary conditions. J Struc Geol 19: 1201–1217.

Karniol TR and Machado R. 2004. Análise geométrica e cinemática de um segmento na região do baixo Rio Doce entre Aimorés (MG) e Colatina (ES). Rev Bras Geocienc 34: 373–382.

Karniol TR, Machado R and Vicente LC. 2007. Tectônica extensional no Cinturão Paraíba do Sul no noroeste do Rio de Janeiro: análise estrutural na seção Itaperuna (RJ) – Muriaé (MG). Rev Bras Geocienc 37: 625–636.

Lister GS and Williams PF. 1983. The partitioning of deformation in flowing rock masses. Tectonophysics 92: 1–33.

Lyberis N and Mamby G. 1999. Continental collision and lateral escape deformation in the lower and upper crust: An example from Caledonide Svalbard. Tectonics 18: 40–63.

Machado R and Endo I. 1993. A megaestrutura em flor positiva do Vale do Rio Paraíba do Sul no Rio de Janeiro e suas implicações tectônicas regionais. In: SBG, Simp Geol Sud, 3., Atas p. 208–213.

Mancktelow NS. 1992. Neogene lateral extension during convergence in the Central Alps: Evidence from interrelated faulting and backfolding around the Simplonpass (Switzerland). Tectonophysics 215: 295–317.

Marshak S, Alkmim F, Whittington C and Pedrosa-Soares AC. 2006. Extensional collapse in the Neoproterozoic Araçuaí orogen, eastern Brazil: a setting for reactivation of asymmetric crenulation cleavage. J Struc Geol 28: 129–147.

Nummer A, Machado R and Dehler NM. 2007. Pluton emplacement in a releasing bend in a transpressive regime: the Arrozal granite in the Paraíba do Sul shear belt, Rio de Janeiro. An Acad Bras Cienc 79 (2): 299–305.

Passchier CW and Trouw RAJ. 1996. Microtectonics, Berlim: Springer-Verlag, 289 p.

Pêcher A. 1991. The contact between the higher Himalaya crystallines and the Tibetan sedimentary series: Miocene large-scale dextral shearing. Tectonics 10: 587–598.

Pedrosa-Soares AC, Noce CM, Vidal P, Monteiro RLBP and Salazar E. 1992. Toward a new tectonic model for the Late Proterozoic Araçuai (SE Brazil) – West Congolian (SW Africa) belt. J S Am Earth Sci 6: 33–47.

Peres GG, Alkmim FF and Jordt-Evangelista H. 2004. The southern Araçaí belt and the Dom Silvério Group: geologic architecture and tectonic significance. An Acad Bras Cienc 76: 771–790.

Platt JP and Vissers RLM. 1980. Extensional structures in anisotropic rocks: J Struct Geol 2: 397–410.

Ratschbacher L, Frisch W, Linzer H and Merle O. 1991. Lateral extrusion in the eastern Alps, part II: Structural Analysis. Tectonics 10: 257–271.

Seyferth M and Henk A. 2004. Syn-convergent exhumation and lateral extrusion in continental collision zones – insights from three-dimensional numerical models. Tectonophysics 382: 1–29.

SIMPSON C AND SCHMID SM. 1983. An evaluation of criteria to deduce the sense of movement in sheared rocks. Geol Soc Am Bull 94: 1281–1288.

TROMPETTE R, EGYDIO-SILVA M, TOMMASI A, VAUCHEZ A AND UHLEIN A. 1993. Amalgamação do Gondwana Ocidental no Panafricano-Brasiliano e o papel da geometria do Cráton do São Francisco na arquitetura da Faixa Ribeira. Rev Bras Geocienc 23: 187–93.

TURNER FJ AND WEISS LE. 1963. Structural Analysis of Metamorphic Tectonites. New York: McGraw Hill, 545 p.

VAUCHEZ A, TOMMASI A AND EGYDIO-SILVA M. 1994. Self indentation of a heterogeneous continental lithosphere. Geology 22: 967–970.