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A structural transect across the coastal mobile belt in the Brazilian Highlands (latitude 20°S): the roots of a Precambrian transpressional orogen

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Abstract

We present results of a detailed structural analysis from a 250 km-long, east–west-trending transect crossing the Coastal Mobile Belt, a part of the Precambrian orogen which lies between the eastern edge of the São Francisco craton and the Atlantic coast. The region exposes amphibolite–granulite grade metamorphic rocks and migmatites which formed at mid-lower crustal depths during the Brasiliano orogeny (0.63–0.52 Ga). This event marked the closure of the northernmost Adamastor Ocean and collision between the São Francisco and Congo Cratons during West Gondwana assembly. Brasiliano deformation resulted in W-vergent structures including thrust faults which accommodated kilometer-scale transport of crystalline basement, overturned kilometer-scale folds, sheath folds and penetratively developed gneissosity and schistosity. Isolated relics of an older folded fabric occur locally and may represent Transamazonian (2.2–2.0 Ga) deformation. The orogen is kinematically partitioned with the eastern 175 km dominated by moderately- to steeply dipping north-trending dextral strike-slip and oblique-slip faults and associated flower structures, whereas the western 75 km is dominated by W-vergent shallowly- to moderately east-dipping thrust faults. The boundary between these two provinces may mark a Brasiliano suture. Throughout the transect, quartzite and metasedimentary belts form strongly deformed zones between massive crystalline basement thrust sheets. The granulite-cored Serra do Caparaú massif, the highest mountains in South America outside of the Andes and Guyana shield, occupies a restraining bend between two Brasiliano dextral shear zones. The W-vergent Coastal Mobile Belt formed contiguously with the E-vergent Pan-African West Congo orogen now exposed along the conjugate margin of Africa. Thus an important late Precambrian boundary between structurally linked but kinematically opposed structural provinces must lie hidden in the extended offshore continental margins of either continent. Cretaceous opening of the South Atlantic and separation of the West Congo belt from the Coastal Mobile Belt may have been structurally influenced by this boundary. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

This study provides new observations from a 250 km-long east–west-trending structural transect across the Coastal Mobile Belt in eastern Brazil (Fig. 1). This belt comprises a portion of the Brazilian Highlands which lies between the Archean São Francisco craton and the Atlantic Ocean margin in the states of Minas Gerais and Espírito Santo (Fig. 1), and thus is a relict of one of the many Transamazonian (2.0 Ga) or Brasiliano (0.63–0.52 Ga; =Pan African) mobile belts which surround cratonic nuclei of Gondwana (Fig. 2). Prior to the Cretaceous opening of the South Atlantic, the Coastal Mobile Belt was connected to the Pan African West Congo Belt (Schermerhorn, 1981; Porada, 1989; Pedrosa-Soares et al., 1992; Maurin, 1993). Together, these belts represent opposite sides of a once larger orogen whose internal zones occur within the

uplifted shoulder and subsided continental shelves of both continents (Fig. 2).

The Coastal Mobile Belt has also been called the Ribeira Belt by some previous workers (e.g. Machado et al., 1996) and confusion exists in the literature over the correct terminology for the different Precambrian belts in eastern Brazil. At first order, the Proterozoic deformation belt between 32°S and 15°N is called the Mantiqueira Province (Almeida, 1977). The Ribeira Belt is a subdivision of the Mantiqueira Province and is commonly regarded as the Precambrian mobile belt which parallels the eastern coast of Brazil from Rio de Janeiro southwards. North of Rio de Janeiro, lithologic correlations between the deformation belts east of the São Francisco craton and the Ribeira Belt to the south are unclear. Thus this northernmost portion of the Mantiqueira Province is usually subdivided into a western zone, the Araçuaí Belt (Almeida and Hasui, 1984) and

Fig. 1. Map of part of eastern Brazil showing the regional topography and the location of the Coastal Mobile Belt and the geological transect.

Fig. 2. Jurassic Gondwana reconstruction prior to the opening of the South Atlantic showing positions of major cratons and Brasiliano/Pan African mobile belts. Coastal and West Congo belts are adjacent to each other and structurally linked. AS, Angola Shield; CC, Congo Craton; SFC, São Francisco Craton; RDJ, Rio De Janeiro; LU, Luanda.

an eastern zone, the Coastal Mobile belt (Mascarenhas, 1979) or Atlantic Belt (Leonardos and Fyfe, 1974). We prefer to use the term Coastal Mobile Belt for the area investigated here (Fig. 1) as used originally by Mascarenhas (1979) and more recently Wiedemann (1993).

The Coastal Mobile Belt exposes amphibolite–granulite-grade metamorphic rocks and igneous complexes which formed at mid-lower crustal levels during multiple phases of magmatism and compressional and transpressional deformation (Bayer, 1987). Thus the region provides a deep-

level exposure of the crystalline roots of a poly-phase Neoproterozoic orogen. Previous work in the region has largely focused on the petrology and geochemistry of the basement rocks without an understanding of their regional structural framework. Thus the primary objective of this study is to provide for the first time, the detailed structural architecture of the Coastal Mobile Belt from meso-scale to regional-scale. This study is also important because the region provides a natural laboratory for understanding the geometry and style of compressional and transpressional deformation at 15–25 km depths and the manner in which strain is partitioned in the mid-lower crust.

The Coastal Mobile Belt marks the location of Neoproterozoic–early Phanerozoic closure of the northernmost Adamastor Ocean and collision between the São Francisco and Congo cratons (Hartnady et al., 1985). Thus an additional aim of this study is to better understand the sequence of events which led to closure of the northernmost Adamastor Ocean and the kinematic evolution of the collision zone in the wider regional context of Gondwana assembly.

2. Previous work in the coastal mobile belt

Previous work on the detailed geology of the Coastal Mobile Belt includes regional lithologic, petrologic, geochronologic and geophysical data gathered during the Radambrasil Project (Machado Filho et al., 1983) and 1:100 000 geologic mapping and petrologic, geochronologic, structural and geophysical investigations for some areas in eastern Minas Gerais and Espírito Santo states by Companhia de Pesquisa de Recursos Minerais (CPRM). Extensive petrologic and geochronologic studies were carried out on metamorphic assemblages and igneous complexes between Ouro Preto and Vitoria (Fig. 1) by various German workers in the 1980s including Sluitner and Weber-Diefenbach (1989), Söllner et al. (1987, 1989), Bayer et al. (1986), Bayer (1987), Herbert et al. (1991), Schulz-Kuhnt et al. (1990) and Jordt-Evangelista and Müller (1986). A synthesis of all of the German geochronologic data across the

Coastal Mobile Belt which contains a model for the crustal evolution of the region is provided by Söllner et al. (1991). Machado et al. (1996) published U–Pb data from the Coastal Mobile Belt in Rio de Janeiro state and determined that the Coastal Mobile Belt attained peak metamorphic conditions at 590–565 Ma during Brasiliano deformation with youngest ages of deformation and metamorphism in the easternmost domains.

Previous structural studies of the Coastal Mobile Belt are limited, especially in eastern Minas Gerais and Espírito Santo at the latitude of this study. Quadrangle maps by CPRM (1:100 000) which cover most of Espírito Santo and some of eastern Minas Gerais provide information on important faults and regional structural trends. Bayer (1987) published an important monograph documenting separate structural events which have affected the region. Campos Neto and Figueiredo (1995) published geochemical, geochronological and structural data for the region that suggest Brasiliano deformation involved accretion of different microplates and development of a short-lived magmatic arc [see also Wiedemann (1993)].

Other important structural studies from the Coastal Mobile Belt outside of the area investigated here include Pedrosa-Soares et al. (1992) who proposed that the Araçuaí belt represents a closed Red Sea type basin with an ophiolitic suture zone and Cunningham et al. (1996) who documented the structural style of Brasiliano basin closure and inversion in the Governador Valadares region (Fig. 1). Haralyi and Hasui (1982) presented regional gravity data for eastern Brazil which included a discussion of the crustal structure of the northern Coastal Mobile Belt.

Important regional studies concerning the tectonic evolution of eastern South America includes Brito Neves and Cordani (1991) on the Proterozoic assembly and evolution of the entire South American continent, an overview of Precambrian terranes of eastern South America by Bernasconi (1987), a discussion of Proterozoic Transamazonian belts by Bertrand and Jardim de Sá (1990), a summary of Brazil–Africa geological links by Torquato and Cordani (1981), Porada (1979, 1989) and an overview of western Gondwana assembly including consolidation of

the Congo–São Francisco cratons in the Coastal Mobile Belt region by Trompette (1997).

3. Methodology

Our study differs from previous studies in the region because our structural transect involved studying every available rock and saprolite outcrop (>450 outcrops) along a 250 km length of highway (MG262 and BR262) with additional outcrop study along nearby roads and streams. Thus this study greatly condenses a considerable amount of outcrop information. Although existing regional lithotectonic subdivisions are acknowledged (Fig. 3), we prefer to report our lithological and structural data without a genetic bias.

Exposure along the transect varies in quality from abundant fresh rock exposures in the highlands between Pequiá and Viana (Fig. 3) to limited fresh exposure but abundant deeply weathered saprolite exposures (which preserve structures) between Ponte Nova and Pequiá. Between Viana and the coast, outcrops are scarce due to extensive Cenozoic sedimentary cover. Good quality 1:50 000 topographic maps produced by IBGE (Instituto Brasileiro de Geografia e Estatística) were used as basemaps for recording outcrop locations. The transect data were plotted on a single continuous cross-section divided into eight linear connecting sections (Figs. 3–5) which approximate the direction of MG262 and BR262. Outcrop data which do not fall directly on the transect line were projected onto the cross-section along the strike.

4. Observations

4.1. Structural domains of the transect

The transect begins ca 80 km east of the southeast corner of the São Francisco craton and terminates at the South Atlantic coast. Thus, it provides an across-strike account of the Proterozoic mobile belt which lies between the São Francisco craton and the Mesozoic rifted margin of South America. We divided the transect into three domains, west-

Fig. 3. Geological strip map of transect geology between Ponte Nova and Vila Velha, eastern Brazil, compiled from Machado Filho et al. (1983) and Bayer (1987). Some major fault zones from this study are indicated. Traditional boundaries between regional lithotectonic assemblages shown on top map (Söllner et al., 1991).

Fig. 4. Geological transect cross-section from Ponte Nova to Vila Velha showing major rock units and important faults. Section follows MG262 and BR262. See Fig. 3 for locations.

Fig. 5. Geological transect cross-section from Ponte Nova to Vila Velha showing major structures including attitude of dominant metamorphic foliation and sedimentary bedding. Also shown are locations of subsequent figures. Section follows MG262 and BR262. See Fig. 3 for locations.

ern, central and eastern, based on differences in lithologic content and structural style (Figs. 4–6). The western domain is distinguished by amphibolite to granulite facies gneisses and migmatites cut by W-vergent low- to moderate-angle thrust zones. The central domain is dominated by charnockitic rocks and steep faults and foliation attitudes. The eastern domain is characterized by diverse metamorphic and plutonic complexes deformed by W-vergent contractional and transpressional structures and overprinting dextral strike-slip zones. We describe the rock units and structural features of each domain from west to east as shown on Figs. 4 and 5.

4.2. Western domain

4.2.1. Lithologic assemblages

Bedrock in the western domain (Fig. 4) consists mostly of migmatitic biotite–amphibole orthogneiss, whose bulk composition ranges from granodiorite to tonalite (e.g. Herbert et al., 1991; Schulz-Kuhnt et al., 1990; Brandalise, 1991; Jordt-Evangelista and Müller, 1986; Teixeira et al., 1987). In general, these gneisses contain a mineral assemblage indicative of amphibolite facies, but from west to east across the domain, the rocks contain increasing amounts of plagioclase, biotite, and amphibole, and granulite-grade rocks occur

Fig. 6. Equal area lower hemisphere stereoplots of structural data from three separate domains within Ponte Nova–Vila Velha transect, eastern Brazil. Locations of domain boundaries shown in Fig. 5. Also shown is plot of all major faults and shear zones identified along transect and poles to ductile shear zones within transpressionally deformed orthogneisses directly W of Venda Nova. See text for discussion.

in a belt beginning 10 km west of Abre Campo (Herbert et al., 1991). In addition, migmatitic granitic gneiss occurs in a belt between 5 and 20 km west of Abre Campo. Multiple generations of both undeformed and deformed pegmatite dikes as well as boudinaged amphibolite dikes and sills occur in all rocks of the western domain, giving outcrops a heterogeneous appearance.

The granulitic rocks along the eastern edge of the western domain include north–south-trending slices of enderbite, amphibolite, quartzite and garnet quartzo-feldspathic tonalitic gneiss (Müller et al., 1991). The enderbite is brownish-green, granoblastic, and unfoliated to strongly foliated. Upper amphibolite-grade quartzite slices (containing muscovite, sillimanite and 80–90% quartz) separate gneiss bodies from one another. A coarse-grained garnet paragneiss containing bluish quartz crops out at Abre Campo. This unit, as well as the quartzite slices, can be traced along strike for at least 100 km (cf Cunningham et al., 1996) and thus are useful markers for defining regional structure.

Rocks of the western domain have been alternatively correlated with the Archean Mantiqueira gneiss (Brandalise, 1991), or the Proterozoic Piedade gneiss (Ebert, 1968; Machado Filho et al., 1983). The Piedade gneiss has Transamazonian Rb–Sr whole rock isochron ages and Brasiliano Sm–Nd metamorphic ages (whole-rock, garnet, feldspar; H. Brueckner, pers. comm., 1997) but no evidence for an Archean origin (Teixeira, 1982; Machado Filho et al., 1983). Conversely, geochronological investigations of the Mantiqueira gneiss indicate an Archean origin [2.76 Ga Jequié Cycle, Cordani et al. (1973) and Machado Filho et al. (1983)] followed by upper amphibolite granulite-facies recrystallization during the Transamazonian event [2.0 Ga, Machado Filho et al. (1983)] and greenschist to amphibolite facies metamorphism and reworking during the Brasiliano event [0.6–0.5 Ga, Jordt-Evangelista and Müller (1986) and Schulz-Kuhnt et al. (1990) their Table 4]. North of our transect, the Mantiqueira gneiss is separated from the Piedade Gneiss by a metasedimentary and metaigneous assemblage which contains talc schist, serpentinite, and mafic and ultramafic lenses known as the Dom Silvério

Group (Jordt-Evangelista, 1992; Brandalise, 1991; Cunningham et al., 1996). At the latitude of this transect, however, the Dom Silvério Group lies to the west of our western domain (west of Ponte Nova). Thus we suggest that rocks of the western domain correlate with the Transamazonian basement of the Piedade Gneiss which was remetamorphosed and penetratively deformed during the Brasiliano event.

4.2.2. Structural geology

The biotite–amphibole gneiss which underlies the western two-thirds of the western domain records a complex deformational history. This rock is well banded, contains one dominant foliation and commonly contains pinch and swell structures, boudinage, high-strain shear zones and sheared pegmatite sheets [Fig. 7(a)]. Foliation undulates around horizontal or dips gently to the east (Figs. 5 and 6). Foliation intensity, as defined qualitatively by thickness of bands, density of planes, the degree of preferred orientation of mica, and the continuity of bands, varies both regionally and within an outcrop (we consider rock with thinner, densely concentrated bands, stronger preferred orientation of mica, and more continuous banding to be more intensely foliated). Locally, foliation is wavy and anastomosing, and strongly foliated intervals of gneiss surround more weakly foliated, less micaceous phacoidal lenses [Fig. 7(b)]. In these lenses, compositionally segregated quartzo-feldspathic bands with hornblende and biotite folia are locally deformed into intrafolial folds or a discordant often more steeply dipping foliation which represents either an early-formed Brasiliano fabric or relict Transamazonian fabric. Locally, the gneisses also contain a shallowly plunging northeast-trending mineral lineation defined by biotite aggregates. The kinematic significance of this lineation is unclear as it is generally subparallel to the strike of the shallowly dipping foliation and at a high angle to the westerly direction of fold overturning and thrusting (see below). It could represent retrogressive post-thrusting strike-slip displacements on low-angle surfaces as documented further south by Vauchez et al. (1994) but no other evidence was found to support this idea.

Fig. 7. (a) Outcrop sketch of SW-vergent isoclinally folded biotite-amphibole gneisses cut by undeformed to sheared and attenuated (arrow) syn- to post-tectonic pegmatite dikes. Location ca 5 km W of Rio Casca on MG262. Pegmatites in this area are numerous and commonly fill shear zones. (b) Outcrop sketch of road cut ca 14 km NE of Ponte Nova. Outcrop contains anastomosing system of ductile shear zones that step upwards towards the W and have accommodated top to W thrusting. Shear zones truncate folded foliation preserved in lenses that may be Transamazonian (2.0 Ga) in age.

Kilometer and outcrop-scale folds affect gneissic layering in the western two-thirds of the western domain. West of Rio Casca (Fig. 5), the metamorphic banding is deformed into upright, open, north-south-trending folds with wavelengths on the order of 1–5 km. East of Rio Casca, the dominant metamorphic fabric is folded into tight to isoclinal and W-vergent folds [Fig. 8(a and b)]. Throughout the domain, minor centimeter to meter scale folds within the gneiss are tight to isoclinal, westerly inclined to recumbent and shallowly plunging. West-closing mesoscopic sheath folds also occur. We observed a wide range of minor fold-axis trends (Fig. 6).

In the eastern third of the domain, gneissic foliation dips steeply to the east. Based on juxtaposition of contrasting lithologies (notably orthogneiss or enderbite placed over highly sheared and folded quartzites and schists), we documented several discrete top-to-the-west thrust faults in this region. Foliation within the narrow quartzite belts is intensely isoclinally folded; shear sense indicated by the vergence of folds within the shear zones is uniformly to the west. Top-to-the-west shear sense is also indicated by asymmetric mafic boudins which are abundant in the western two-thirds of the domain in almost all road cuts. Discrete, densely foliated, planar shear zones directly overly-

ing intensely folded and attenuated gneiss mark other ductile thrust zones. Some of these thrust-sense shear zones cut the principal folded fabric indicating later and possibly lower temperature retrogressive deformation [Fig. 8(c) and (d)].

4.3. Central domain

4.3.1. Lithologic assemblages

Basement in this domain consists dominantly of granulite-grade metamorphic rocks or quartzite of which 75% are orthopyroxene-bearing rocks of the charnockite series (Fig. 4). Rocks of this domain have traditionally been correlated with the Juiz de Fora Complex which is defined as a diverse assemblage of medium- to high-grade charnockitic rocks and garnet–biotite gneisses (Almeida and Hasui, 1984). The charnockitic rocks (dominantly enderbite) are generally massive, variably foliated, brownish-green and coarse-grained. Plagioclase is the most important component with lesser quantities of bluish quartz, orthopyroxene, amphibole, biotite and garnet (Schulz-Kuhnt et al., 1990). The charnockitic rocks are associated with, and locally grade into, biotite–garnet gneiss and clinopyroxene-bearing amphibolite (Schulz-Kuhnt et al., 1990). They also occur as distinctive zones and layers within biotite–garnet gneiss and locally contain leucosomes, garnet-rich patches and angular, fine-grained mafic xenoliths which give the rock an agmatitic appearance. The majority of orthopyroxene-bearing rocks range from enderbite (tonalitic) to noritic in composition (Herbert et al., 1991).

Rocks in the central domain have not been dated directly at the line of this transect. However, ages are available for correlative units along strike elsewhere in Minas Gerais to the SSW. Rb–Sr whole rock ages from similar granulites of the Juiz de Fora Complex have yielded ages of ca 2.0 Ga [i.e. Transamazonian; Cordani et al. (1980) and Teixeira et al. (1987)]. No older ages of these rocks have yet been reported (Söllner et al., 1991). Work in progress by H. Brueckner, (pers. comm., 1997) indicates Brasiliano 562 Ma Sm–Nd ages (whole rock, garnet, feldspar) for granulite metamorphism in biotite–garnet gneiss 50 km north of Matipo (Fig. 3)

Quartzites of the central domain occur in several discrete, strongly foliated belts which tectonically separate massive gneiss blocks. The quartzites contain minor amounts of muscovite, garnet, sillimanite and orthoclase. Locally, quartzite slivers contain isolated boudins of amphibolite, which possibly represent relics of flattened and sheared mafic dikes or sills (Fig. 9).

4.3.2. Structural geology

Throughout the central domain, metamorphic foliation dips steeply (Figs. 5 and 6). However, dip direction varies from easterly to westerly, locally creating asymmetric foliation fans which resemble the positive flower-structure geometry of transpressive shear zones (Fig. 5). The asymmetry of these apparent flower structures, oblique-slip NE-trending stretching lineations within the N-striking zones, and kinematic indicators suggest westward vergence coupled with a component of dextral strike-slip displacement (Figs. 6 and 9). Flower-like cleavage fans in the central domain occur in linear bands which have eroded to form valleys which stand out on satellite imagery as topographic lineaments. Because of their linear nature and their component fabrics, we suggest that the flower-like cleavage domains define the traces of regional-scale (length more than tens of kilometers) strike-slip or oblique-slip faults. One of the largest of these zones is the Manhauçu fault which crops out ca 3 km west of the town of Manhauçu (Fig. 5) and is represented by a 1 km-wide zone of strongly developed steeply dipping-to vertical foliation within enderbite gneisses. Dextral shear sense is clear from asymmetric fabric geometries and centimeter-scale folds of the foliation exposed in outcrops along the small river which flows along the fault zone 10 km SSW of Manhauçu. The occurrence of these faults and the regionally consistent steeply dipping foliation of the central domain provides the basis for distinguishing it from the western domain.

As in the western domain, foliation intensity varies with locality and lithology in the central domain. Charnockitic rocks tend to be blocky in appearance and fracture conchoidally rather than along gneissic banding. We identified two separate generations of gneissic banding in the enderbite of

Fig. 9. Outcrop sketch of dextral transpressional fault zone within massive layered supracrustal quartzite sequence 8 km W of Realeza on BR262.

the central domain, based on cross-cutting relations. Both foliations are defined by the alternation of pyroxene + amphibole + biotite layers with layers consisting of greenish brown plagioclase + quartz + minor garnet and biotite. Irregular zones or bands of migmatite cut the older fabric, but not the younger fabric, and the older fabric is preserved as isoclinal fold hinges and attenuated limbs, whereas the younger fabric is planar or wavy and pervasively developed. The older relict fabric was not measured because of its discontinuous and isoclinally folded nature. In contrast to the enderbites, biotite–garnet gneiss tend to display strong gneissosity, and fairly planar and continuous banding. Quartzite bands display a very closely spaced foliation defined by the alignment of flattened quartz grains and mica.

Kinematic indicators (e.g. extensional crenulation cleavages, centimeter-scale asymmetric folds) within all major fault zones in the central domain which we examined indicate top-to-the-west thrust components of shearing. However, tight to isoclinal folds (with wavelengths of 10–100 m) with westerly dipping axial surfaces and associated minor top-to-the-east shear zones occur immedi-

ately west of the town of Matipo suggesting a local zone of east vergence (Fig. 5).

4.4. Eastern domain

4.4.1. Lithologic assemblages

The eastern domain contains a wide variety of metamorphic and plutonic rocks which have been variously ascribed to different complexes, terranes, and assemblages by previous authors [Fig. 3, also see discussion in Bayer (1987)]. The justification for the various broad subdivisions is generally unclear and rather than using these conflicting and overlapping unit names, we prefer to descriptively summarize lithologic packages of the Eastern domain in sequence from west to east (see Figs. 3–5 for locality names).

4.4.2. Manhuaçu–Guaçu Fault

Lithologies between Manhuaçu and the Guaçu Fault have been traditionally assigned to the Pochrane Complex (Manhuaçu–Martins Soares) defined as biotite and hornblende gneisses, orthogneisses, migmatites, and subordinate schists and quartzites (da Silva et al., 1987); Paraíba do Sul

Fig. 8. Outcrop sketches of structural features along BR262 between Rio Casca and Abre Campo. See Figs. 3 and 5 for locations. (a) W-vergent overturned isoclinal folds, (b) NW-vergent overturned antiform and NW-vergent thrust fault, (c) intensely sheared and isoclinally folded metasedimentary sequence indicating top-to-the-W thrusting shear sense, and (d) W-vergent thrust faults and associated overturned, W-vergent folds.

Complex (Martins Soares–Ibatiba) defined as an assemblage of high-grade gneisses and migmatites with intercalations of metamorphosed supercrustal sediments including quartzites and marbles; or Juiz de Fora Complex [Ibatiba–Guaçuí fault, see previous definition, Fig. 3; Hasui and Oliveira (1984), Bayer (1987) and Machado Filho et al., (1983)].

Between Manhuaçu and Pequiá, outcrops consist of partially migmatized and extensively lateritized garnet gneiss and mica-garnet schist. Pegmatite locally intrudes both lithologies. Within this interval, ca 5 km east of Manhuaçu, there is a 3 km-wide belt of coarse muscovite-bearing quartzite and quartzofeldspathic schist.

Ten kilometers south of Pequiç (just off the transect line), the land surface rises abruptly to an elevation of almost 3 km, defining the Serra do Caparaó, the highest mountains in the southeastern Brazilian Shield (Figs. 3 and 10). The Serra do Caparaó consists of granulite-facies felsic to mafic orthopyroxene and garnet gneiss. Where we examined these units, along the trail from Vale Verde to the summit of Pico da Bandeira (Fig. 10), outcrops expose layered plagioclase–quartz–orthopyroxene $\pm$ garnet gneiss. Geochemical work by Söllner et al. (1991) suggests that the protoliths of these rocks were supracrustal sedimentary strata with calc-alkaline affinities, which formed during the Transamazonian event (2.1 Ga) but were metamorphosed to granulite during the Brasiliano event (0.59 Ga).

Between Pequiá and a point about 4 km west of Ibatiba (Figs. 3 and 4), bedrock consists of amphibole–biotite gneiss, amphibolite-facies migmatite, tonalitic orthogneiss and quartzite-rich metasedimentary slivers. Several small, undeformed to moderately deformed granitic bodies, associated with a batholith to the north, intrude these rocks. In the vicinity of Ibatiba, there is an 8 km-wide belt of quartzite interlayered with minor finely banded biotite schist and garnet–biotite gneiss. Purer quartzite dominates near the structural top of this interval. East of the quartzite belt, various acid-intermediate orthogneisses and migmatitic rocks dominate for ca 10 km. Unpublished Sm–Nd mineral ages from garnet migmatites within this belt give 578 Ma ages for amphibolite/granulite metamorphism (whole-rock, feldspar, garnet; H.

Brueckner, pers. comm., 1997). Between the migmatite and orthogneiss belt and the Guaçuí Fault (Figs. 3 and 4), a lithologic assemblage consisting of fine-grained biotite gneiss, mica schist and gray quartzitic gneiss crops out. Signorelli (1993) correlated this interval with other metasedimentary units in the region which have yielded 580–590 Ma Rb–Sr whole-rock isochron ages.

4.4.3. Guaçuí Fault–Domingos Martins

Lithologies between the Guaçuí Fault and Domingos Martins have previously been assigned to the Paraíba do Sul Complex (Machado Filho et al., 1983). Between the Guaçuí Fault and a point 10 km east of Venda Nova, the bedrock dominantly consists of orthogneiss with subordinate zones of weakly deformed to undeformed intrusions. This belt, which we refer to as the Venda Nova orthogneiss belt, ranges in composition from granitic to granodioritic west of Venda Nova, to tonalitic east of Venda Nova. The orthogneiss of the Guaçuí Fault–Venda Nova region is part of a NNE–SSW-trending block which can be traced for several hundred kilometers along-strike. Samples collected ca 60 km to the south-southwest have yielded zircons with Brasiliano ages (590 ± 4 Ma) for peak metamorphism (Söllner et al., 1987). Metasedimentary screens within the belt yield detrital zircons with a 2.1 Ga upper concordia intercept, suggesting that the protolith sediments came from a Transamazonian-age source terrane (Söllner et al., 1987).

About 5 km east of Venda Nova, the Aracê granitic massif (Figs. 3 and 4) intrudes the Venda Nova orthogneiss belt. This 15 km wide massif consists of undeformed medium-grained microcline and muscovite–biotite granite, with local biotite–hornblende diorite (Fonseca, 1979). Geochemically similar, undeformed late- to post-Brasiliano plutons in the region yield U–Pb zircon ages of 513 ± 8 Ma (Söllner et al., 1987, 1991; Signorelli, 1993), whereas similar deformed plutons have yielded U–Pb zircon ages of 590 ± 20 Ma (Féboli, 1993; Söllner et al., 1987). Within the Aracê massif, several intruded belts of quartzite-dominated metasedimentary sequences occur consisting of finely layered to massive tan-white

Fig. 10. Structural data collected along the northern margin and west-central zones of the Serra do Caparaó massif. Range consists of a NNE-plunging W-vergent antiform between two major N-S-trending Brasiliano dextral shear zones.

quartzite and black biotite-quartz schist, which locally contains garnet and sillimanite.

Between the eastern border of the Aracê massif and a locality 8 km west of Domingos Martins (Fig. 4), bedrock consists of narrow belts of amphibolite-granulite-grade migmatitic quartzofeldspathic gneiss separated by slices of metasedimentary rocks (including massive quartzite, locally >95% quartz and sillimanite-garnet-biotite-quartz schist). The entire interval has been

intruded by undated granitic stocks some of which are foliated.

4.4.4. Domingos Martins-Vila Velha

Lithologies between Domingos Martins and Vila Velha are dominantly amphibolite to granulite grade gneisses, migmatites, charnockitic rocks and kinzigites previously assigned to the Coastal Complex of Hasui and Oliveira (1984) or classified as high-grade basement- of the Paraíba do Sul

Complex (Bayer, 1987; Machado Filho et al., 1983).

Eight kilometers west of Domingos Martins the transect crosses a 3 km-wide interval of felsic-intermediate orthogneiss and then a 25 km-wide belt of massive graphite–cordierite–sillimanite–garnet–biotite gneiss [previously mapped as kinzigites by Signorelli (1993)] whose eastern border lies at Viana (Figs. 3 and 4). This gneiss belt is variably migmatized and widely cut by pegmatites. Féboli (1993) obtained a Rb–Sr reference isochron of 660 Ma and a K–Ar cooling age of 458 ± 13 Ma on biotite extracted from the gneiss.

Between Viana and the Atlantic coast at Vila Velha, Mesozoic and Cenozoic sedimentary units cover most Precambrian bedrock. Where basement outcrop is exposed, it consists of felsic-intermediate augen gneiss, enderbite, garnet–biotite migmatite, and undeformed granite or granodiorite plutons (Figs. 3 and 4). Regional mapping suggests that the gneisses in this interval are part of a NNE-trending belt of granulite-grade basement which parallels the coast. Söllner et al. (1987, 1991) dated zircons from biotite gneiss within this belt at a locality 35 km to the south of our transect and obtained a U–Pb age of 558 ± 2 Ma. Machado et al. (1996) report a younger metamorphic event at 535–520 Ma (U–Pb on zircon, monazite and titanite) along the coastal belt 300 km to the south.

4.5. Structural geology

Between Manhuaçu and the coast, the structural geology is complex, however, a few generalizations can be made; there is one dominant metamorphic foliation which generally dips eastwards and is of Brasiliano age, folds of the main foliation have axes which generally plunge NNE and structural vergence as indicated by thrust zones and fold overturning is towards the west (Figs. 5 and 6). As in the western and central domains, major faults and shear zones generally dip eastwards (Figs. 5 and 6). Sillimanite fiber lineations within ductile shear zones suggests that high-grade metamorphism accompanied deformation. Several major syn-post-Brasiliano dextral strike-slip shear zones cut north-northeasterly across the region.

We describe the structural geology of this domain from W to E as shown on Figs. 4 and 5.

4.5.1. Manhuaçu–Guaçuí Fault

Immediately E of Manhuaçu, metasedimentary rocks are intensely deformed into tight to isoclinal W-vergent folds on a centimeter to kilometer scale (Fig. 5). The folds generally plunge NE and locally are tubular and west-closing. These rocks are overlain in the E by a massive orthopyroxene–biotite gneiss with approximately homoclinal easterly dipping foliation attitudes. Because of the intense W-vergent deformation of the underlying metasedimentary rocks, the overlying gneiss is interpreted to have been thrust over them from the E although the thrust fault is not exposed. East of this gneissic block, a belt of quartzite-dominated metasedimentary rocks occurs which is internally deformed into W and SW-vergent upright to slightly overturned open to tight folds. Small E-dipping brittle-ductile thrusts were observed cutting outcrop-scale fold hinges possibly suggesting that larger displacement thrust faults cut the sequence, although they were not observed. The quartzites are bordered on the E by a biotite–garnet gneiss which contains a well developed homoclinal E-dipping foliation near its western contact but which further eastwards is internally deformed into complex folds verging both E and W.

Approximately 4–6 km W of Pequiá on BR262 at the northwest end of the Serra do Caparaó range (Figs. 3 and 10) several major kilometer-thick ductile thrust zones are exposed which contain highly sheared and schistose quartz–mica–garnet tectonites. Sense of shear is dominantly top to the WSW dextral reverse motion based on asymmetric fabric geometries and asymmetric tails on garnets. Previous structural investigations of the Serra do Caparaó have suggested that it is a large (20 km wide) W-vergent, nearly isoclinal antiformal structure (Lammerer, 1987; Bayer, 1987). Foliation trends measured along a transect made to the highest summit of the range from the W are consistent with this interpretation of the first-order structure (Fig. 10). The western limb of the anti-form is steep to locally overturned in Val Verde and horizontal quartz stretching lineations and fold asymmetries along the steep to vertical limbs

of parasitic folds indicate that dextral strike-slip shearing has also occurred (Fig. 10). These shear zones are along-strike with the dextral transpressive belt W of Pequiá on BR262 suggesting that the transpressive belt continues along the western margin of the range and forms the western structural boundary to the Serra do Caparaó massif (Figs. 3 and 10).

The NNE-plunging nose of the Serra do Caparaó antiform is exposed SE of Pequiá and consists of undulating foliation with 100 m and smaller-scale NE-plunging antiforms and synforms in the hinge zone. Immediately E of the hinge zone (Fig. 10) is a 6 km-wide zone of east-dipping mylonitic and ultramylonitic metasedimentary rocks which record thrusting and dextral oblique thrusting to the WSW. This is one of the widest and most highly tectonized shear zones in the region and records extreme attenuation of the metasedimentary rocks beneath orthogneiss which is thrust over the top of it from the E. Strongly developed quartz and sillimanite fiber elongation lineations indicate WSW transport directions whereas, sigmoidal fabrics, asymmetric tails on garnets and fold asymmetries all indicate thrusting and dextral thrusting shear sense. The major shear zones which bound the Serra do Caparaó and its internal antiformal structure suggest an overall regional-scale dextral restraining bend geometry with folding either preceding or accompanying wrenching and overthrusting.

From the dextral transpressive belt along the eastern side of the Serra do Caparaó until the town of Ibatiba the dominant structures are W-vergent thrust faults and overturned W-vergent folds cut by small undeformed to weakly deformed acid plutons. In general, within this zone, orthogneisses contain homoclinal to gently folded foliation attitudes whereas metasedimentary rocks between the orthogneiss blocks are intensely folded into tight to isoclinal W-vergent folds. Individual thrust faults which were identified in this zone provided top-to-the W or SW shear sense.

The town of Ibatiba is within a 10 km-wide belt of folded metasedimentary rocks (Figs. 4 and 5). The eastern half of the belt is intensely folded into closed to isoclinal WNW-vergent folds with 30–100 m wavelengths. Discontinuous outcrops

limit the interpretation for the western half of the belt but generally shallower dips of foliation and relict bedding there suggest more open folding or thrust repetition. This metasedimentary belt is bordered on the E by a massive 10-km-wide block of migmatite and orthogneiss. The boundary between the two assemblages is a 4-m-wide NNE-striking, steeply W-dipping, W-side up reverse fault. The migmatites immediately E of the fault are ubiquitously deformed into small-scale upright isoclinal folds with N–S-trending axes and steep E-dipping axial planes. They are intruded by a foliated granitoid and bordered to the E by a belt of massive intermediate orthogneiss which has very consistent NNW striking, ENE-dipping foliation over a 4 km width. The orthogneiss appears to form a rigid block lacking internal folding and major shear zones. Between this block and the Guaçuí Fault (Fig. 5) gentle, kilometer-scale upright folds deform massive banded gneisses. The folds generally plunge shallowly NE or NW.

The Guaçuí Fault is prominent on satellite imagery and is one of the longest structures which crosses the transect. It consists of a 1 km-wide ductile shear zone which can be traced for at least 200 km along strike (Bayer, 1987; Lammerer, 1987). Dragged foliation trajectories, sigmoidal fabrics, asymmetric porphyroclasts and quartz *c*-axis fabrics indicate dextral strike-slip displacements (Bayer, 1987). The amount of displacement is unknown. Where the fault crosses BR262 it is represented by a ductile sheared granitoid which is variably mylonitic with a well developed quartz stretching lineation. The shear zone strikes 346/54 NE and the lineation plunges 19/010. S–C fabrics indicate dextral shear sense.

4.5.2. *Guaçuí Fault–Domingos Martins*

East of the Guaçuí Fault an undeformed to weakly foliated granitoid crops out for ca 5 km and then a wide (8–10 km) belt of sheared quartz–biotite orthogneiss is encountered until the town of Venda Nova (Fig. 4). The western part of the orthogneiss is characterized by numerous top-to-the WSW meter-scale, NNW-striking, moderately to steeply ENE-dipping reverse shear zones (VN 24 area, Fig. 6) which cut through the dominant steeply dipping metamorphic foliation which itself

is folded into W-vergent folds. The shear zones are filled with pegmatitic or granitic material and generally appear to have individually accommodated tens of centimeters or less offset. However, locally they are pervasive and cut through every square meter of outcrop surface and thus *en masse* have accommodated displacements estimated to be on the order of hundreds of meters or more. The eastern part of this orthogneiss belt is characterized by N-striking, steep to vertical foliation and moderately N-plunging stretching lineations. Minor asymmetric W-vergent folds and small-scale, brittle-ductile and brittle thrust faults deform the main foliation. These minor structures coupled with oblique-slip biotite lineations which plunge moderately NNE suggest dextral E-side up transpressive deformation.

East of Venda Nova, felsic–intermediate orthogneiss crops out for 5 km and contains weakly to strongly developed east-dipping foliation. In one zone several kilometer E of Venda Nova, numerous W-vergent asymmetric tight-to-isoclinal folds of the foliation within ductile shear zones indicate top-to-the-W thrusting. Further E near the eastern end of this orthogneiss belt (Fig. 5), a N35E-striking vertical mylonite zone with moderately plunging NE-trending quartz stretching lineations occurs in sheared granite. Dextral shear sense is indicated by asymmetric sigmoidal foliation phacoids. Further E, quartzitic metasedimentary rocks are intruded by the undeformed Aracê pluton. The quartzite appears to be deformed into long wavelength open folds however, scarce outcrops limit this interpretation.

Between the Aracê intrusion and the Vitor Hugo intrusion the prominent foliation in the quartzites, biotite schists and paragneisses is folded into a large W-vergent overturned antiform which is overthrust westwards above a duplexed zone of massive quartzite (Fig. 5). The antiform contains smaller synforms and antiforms and can thus be considered a foliation anticlinorium.

East of the Vitor Hugo pluton is a 9 km wide zone of westerly directed thrusts and folds within metasedimentary assemblages between rigid blocks of gneissic basement (Fig. 5). Quartzites are thrust and duplexed, biotite schists are isoclinally folded and the massive gneiss blocks are

internally folded and ductilely sheared. Westerly vergence is indicated throughout this zone by fold asymmetries and sense of fold overturning within shear zones, sigmoidal shear fabrics and asymmetric boudinage. Sheath folds and attenuated limbs on isoclinal folds suggest high strains. The sequence is interpreted to be overthrust by orthogneisses from the east because of the presence of strongly overturned isoclinal folds in the easternmost metasedimentary rocks. However, the contact is not exposed.

4.5.3. Domingos Martins–Vila Velha

The transect segment between the easternmost quartzite belt 8 km west of Domingos Martins and the town of Viana (Figs. 4 and 5) is characterized by long-wavelength (kilometer-scale) SW-vergent closed to isoclinal, inclined to overturned folds of the principal metamorphic foliation. Upright east-dipping limbs on the major folds are generally homoclinal whereas the shorter overturned limbs are strongly buckled by parasitic folds whose asymmetries suggest westward overturning. The town of Domingos Martins is located near the crest of a regional W-vergent overturned antiformal nappe whose long eastern limb extends along the topographic transition zone from the highland plateau at Domingos Martins to the coastal plain at Viana (Fig. 5). Immediately east of Domingos Martins this fold limb is characterized by pervasive W-vergent centimeter–meter scale isoclinal folds and sheath folds. Five to eight kilometers E of Domingos Martins the limb is characterized by densely developed, homoclinal E-dipping foliation.

The prominent Batatal Fault (Fig. 3) passes through the town of Domingos Martins and cuts through the vertically dipping W limb of the regional antiform (Fig. 5). Attempts to study exposures of the fault around Domingos Martins were unsuccessful due to thick laterite and rain forest cover. It has previously been mapped as a dextral transcurrent fault by Féboli (1993) who reported dextral sigmoidal structures along the fault zone.

From Viana to a point 5 km to the W, brittle and brittle-ductile E-side down normal faults are exposed in many outcrops within the topographic transition zone between the coastal plain and the

Fig. 11. Outcrop sketch of E-side-down normal fault from zone of brittle extension W of Viana. See Figs. 3 and 5 for location. Numerous normal faults occur within this area and are believed to be the westernmost expression of Cretaceous rift-related extensional faulting along the Atlantic margin.

highland plateau. The fault zones dip between 50–70°E, cut the main regional foliation which is locally dragged into the fault zone, and internally contain asymmetric folds and dragged wall rock indicating normal slip sense (Fig. 11). Of the ca 15 faults we observed, displacements are on the order of several meters or less. Abundant E-dipping pegmatite layers also mark zones of normal motion as indicated by deflected foliation in the adjacent wall rock.

Between Viana and the Atlantic coast, the paucity of outcrops hindered our structural investigations. Discontinuous migmatite and orthogneiss exposures contain varying foliation attitudes possibly suggesting large-scale foliation folds or differential block tilting due to normal faulting associated with Cretaceous development of the continental margin.

5. Discussion of results and implications for Gondwana assembly

Although this work is focused largely on the structural geology of a single transect, important regional conclusions can be drawn from our observations and the transect data. Except for a local zone of backfolding near Matipo (Fig. 5) the entire transect records W-directed shortening and dextral transpression as far E as Viana (Figs. 5 and 12).

This suggests that a change in structural vergence between the Coastal Mobile Belt and the originally linked West Congo Belt, which has easterly structural vergence (Maurin, 1993), must lie E of Viana in the coastal or extended offshore continental crust of eastern Brazil or West Africa.

The strongly sheared shallowly dipping gneisses in the western domain ultimately root to the east and may represent a basal shear zone into which higher level thrust faults root (Figs. 5 and 12). Together these structures converge in the zone of steep faults and shear zones in the Abre Campo region where granulitic rocks have been brought to the surface. A large positive gravity anomaly at Abre Campo which continues along strike for hundreds of kilometers (Haralyi et al., 1985) correlates with the granulite exposures and this proposed structural root zone. An increase in basic compositions in basement gneisses towards this structural root zone (Herbert et al., 1991) and the presence of thick amphibolite units near Abre Campo (Brandalise, 1991) suggests that this zone could be a cryptic suture of Transamazonian or Brasiliano age (Fig. 12). However, the lack of ophiolitic rocks weakens this argument, and the extent to which previous continental rifting progressed, and whether true oceanic crust was ever generated prior to closure is unclear.

The central domain and western part of the eastern domain are dominated by steep faults and flower structure foliation geometries. There is no surface indication that these structures become low-angle with depth or root into a basal decollement. Similarly, between the Serra do Caparaó and the Atlantic coast, it is unclear if individual thrust faults and dextral oblique-slip faults are regionally linked and root into a basal decollement zone. However, gravity modeling for the region suggests a low-angle detachment zone exists between 10 and 15 km depth between Ibatiba and Vitória and at progressively shallower depths (3–10 km) between Ibatiba and Rio Casca (Signorelli, 1993). Unpublished magnetotelluric data from the Ribeira belt 300 km to the southwest likewise suggest a detachment zone at 12 km depth for over 200 km across the orogen (S. Fontes, pers. comm., 1998). Thus it appears likely that the steep faults and foliation zones which we document in

Fig. 12. Block diagram summarizing major geological structures along Ponte Nova-Vila Velha transect, eastern Brazil. A–F refers to transect segments as in Figs. 4 and 5. MF, Manhuacu Fault; GF, GUAÇUI Fault; BF, Batala Fault; FI, Flower structure fault geometry or foliation fan.

the central and eastern domains root into a low-angle zone at depth. There appears to be a fundamental partitioning between frontal thrust kinematics in the western domain and dextral transpression and strike-slip kinematics in the middle core region of the orogen where orogen parallel movements were accommodated (Vauchez and Nicolas, 1991). On a local scale, many block boundaries are marked by highly deformed metasedimentary belts suggesting that these units have lower mechanical strength and acted as the dominant glide horizons for W-directed overthrusting. Large dextral transcurrent faults like the Guaçuí and Batatal faults appear to cut through all older contractional structures and thus are interpreted to be late-post Brasiliano in age.

Three major structural events are interpreted to have affected the region. The first event is represented by relict zones of folded gneissic banding, intrafolial folds and discontinuous banding in massive charnockitic and migmatitic gneisses. These fabrics may have formed during the Transamazonian event or during progressive Brasiliano deformation. Rocks throughout the transect are penetratively overprinted by Brasiliano amphibolite–granulite-grade metamorphism and deformation. However, zircon geochronology indicates that many basement gneisses have a Transamazonian origin and some contain Archean zircons possibly derived detritally from the São Francisco craton (Teixeira et al., 1987; Söllner et al., 1987, 1991; Machado et al., 1996). Basement gneisses within the West Congo Belt in the Ogooué region of Gabon/Congo which were formerly connected to eastern Brazil have also been dated as Transamazonian [equivalent to the Eburnian; Cahen et al. (1984) and Bertrand and Jardim de Sá (1990)]. Previous work on the São Francisco craton [e.g. Marshak and Alkmim (1989)] suggests that the relics of a northwest-verging Transamazonian fold-thrust belt crosses the southern end of the São Francisco craton, to the west of the region of the transect discussed here. Thus, we suggest that the Coastal Mobile Belt at the latitude of Vitoria and Ponte Nova contains relics of the roots of a Transamazonian orogen, cross-cut and obscured by later Brasiliano deformation and metamorphism.

The second and dominant deformational event recorded within the Coastal Mobile Belt is the Brasiliano transpressional event. It is characterized by west-directed thrusting W of Abre Campo, dextral transpression and contraction between Abre Campo and the coast, and late-stage NNE-trending dextral transcurrent faulting. Like modern-day transpressive orogens it probably was a protracted event with separate deformational phases. However, fabrics formed during peak metamorphic conditions have generally obliterated or transposed earlier features. The conspicuous absence of elongate quartz lineations throughout most of the region in quartz-rich tectonites may be due to static quartz recrystallization associated with elevated crustal temperatures during emplacement of syn-post-tectonic intrusions. Alternatively, Brasiliano contractional/transpressive deformation may not have persisted during sub-amphibolite facies cooling when basal slip in quartz instead of rhombohedral slip would have taken over as the dominant slip mechanism (Goodge et al., 1993). Söllner et al. (1991) and Machado et al. (1996) citing zircon, monazite and titanite U–Pb ages suggest that the timing of maximum levels of Brasiliano metamorphism and deformation is younger to the E from 622 ± 7 Ma in the São Francisco craton to 590–565 Ma in the Serra do Caparaó region to 560–520 Ma along the Espírito Santo coast. The dextral component of deformation suggests non-orthogonal collision between the Congo and São Francisco cratons or that the curved southeastern margin of the São Francisco Craton (Fig. 1) modified the deformation field as previously suggested further south in the Ribeira Belt by Vauchez et al. (1994).

Cambrian syn- to post-tectonic intrusions such as the Aracê granite may be spatially related to the large late-stage transcurrent faults such as the Guaçuí Fault and were perhaps emplaced during a period of localized dextral transtension (Söllner et al., 1987). Cunningham et al. (1996) report structural evidence for post-Brasiliano orogenic collapse from 150 km to the north. Thus the possibility exists that similar zones of localized transtension/extension occur within the area investigated here but were not observed due to incomplete outcrop exposure.

Fig. 13. Six-stage evolutionary model for structural development of Coastal Mobile Belt, eastern Brazil and consolidation of São Francisco and Congo Cratons during Neoproterozoic–Early Phanerozoic.

The final major event to have affected the region is the Early–mid-Cretaceous continental rifting which led to the opening of the South Atlantic. This event is manifested by numerous E-dipping brittle normal faults at the extreme eastern end of the transect. These faults are believed to mark the western fringe of the normal faulted terrain which comprises the Espírito Santo continental margin. Associated with Cretaceous rifting is the elevation of the Brazilian continental margin and subsequent erosion exposing deeper levels of the metamorphic basement. Ultimate separation of the two continents appears to have occurred along the former vergence boundary between the W-vergent Coastal Mobile Belt in Brazil and the E-vergent West Congo Orogen in West Africa perhaps by reactivation of weak Brasiliano fault zones. Interestingly, W of our transect, a separate array of Cretaceous–Tertiary E-side-down normal faults are visible on satellite imagery directly W of Ponte Nova and have been mapped further north along strike by Saadi (1991). These faults appear to be responsible for the development of the Rio Doce Basin in the Ponte Nova area (Fig. 1).

Based on these considerations, an evolutionary model divided into six stages is proposed to explain the tectonic evolution of the Coastal Mobile Belt from the Early Proterozoic to the present (Fig. 13). In stage 1, the Archean São Francisco and Congo cratons are separated by an ocean of unknown width. An active island arc with adjoining subduction complex of Transamazonian age forms at ca 2.2–2.1 Ga and in stage 2 collides with both cratons as the ocean closes (ca 2.1–2.0 Ga). The relative timing of collision between the arc and two cratons is unknown. The Dom Silvério Group W of Ponte Nova possibly marks the suture zone in Brazil [see discussion in Cunningham et al. (1996)]. In stage 3, the Transamazonian collisional belt collapses and extends during the mid–late Proterozoic (ca 1.0–0.78 Ga) into a wide zone of ensialic rifting. Rifting may have progressed to the point where oceanic crust was generated (Pedrosa-Soares et al., 1992). Platform quartzites and other rift-related sedimentary rocks are widely deposited in the ensialic sea which represents the northernmost seaway of the Adamastor Ocean (Hartnady et al., 1985). In stage 4, a new phase of inversion

and uplift of the West Congo Belt occurs between ca 0.8 and 0.6 Ga prior to closure of the Coastal Mobile Belt (Porada, 1989). Contractual and dextral transpressive closure of the western (Brazilian) side of the rift basins follows during stage 5 between ca 0.6 and 0.5 Ga. East-directed subduction during closure of the ocean may have led to the development of a short-lived magmatic arc in Espírito Santo (Wiedemann, 1993; Campos Neto and Figueiredo, 1995). Previous Transamazonian structures are overprinted, amphibolite–granulite-grade metamorphic conditions are reached and syn-post-tectonic intrusions invade Espírito Santo possibly localized by late-stage dextral strike-slip and transtensional transcurrent faulting. Quartzite-dominated platform facies sediments are intensely deformed between massive basement blocks during rift inversion. In stage 6, early–mid Cretaceous rifting leads to rift shoulder uplift, subsequent erosion and exhumation of mid–lower-crustal rocks and separation of the West Congo Belt from the Coastal Mobile Belt as the South Atlantic opens.

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