Coeval perpendicular shortenings in the Brasilia belt: Collision of irregular plate margins leading to oroclinal bending in the Neoproterozoic of central Brazil

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ABSTRACT

The three belts which form the Tocantins province (central Brazil) records Neoproterozoic-EoPaleozoic collisions involving the Amazon and São Francisco paleocontinents and the Paraná continental block. The Brasília belt is a typical orocline bended around the WNW—ESE striking Pirineus Zone of High Strain (PZHS) and is comprised of the NE-trending (northern) and SE-trending (southern) segments. The Brasília dome is an N—S elliptical structural window situated in the center of the belt, at the eastern end of the PZHS. It evidences Di— D_2 and D_{3N} shortenings (~ 750—590 Ma) due to ocean closure and Amazon- São Francisco collision following a WNW—ESE path, and demonstrates similar evolution for both segments of the belt. However, in the southern segment, D_1—D_2 structures are deformed by shortening in the SW-NE direction (D_3S). New data demonstrating D_1—D_2 and D_{3N} tectonites deformed by D_3S struc- tures in the area close to the dome's SW margin and SE of the PZHS support understanding the Brasília belt and oroclinal bending as a consequence of the collision of two (Amazon and São Francisco) irregular continental margins leading to separation-rotation of the Paraná block from the Amazon paleocontinent and the Paraná-São Francisco collision.

Keywords: Structural analysis Brasilia; belt Tocantins province; Irregular continental; margins Paraná block; Oroclines

1. Introduction

The Brasília belt, a typical orocline, forms together with the Araguaia and Paraguay belts, the Tocantins province, the main orogenic unit stretching between the Amazon and São Francisco cratons, in central Brazil (Fig. 1a; Almeida et al., 1981). The province derives from the collision of the Amazon and São Francisco paleo- continents with participation of the Paraná continental block, and is a remnant of the ~ 750—510 Ma Brasiliano orogenic cycle responsible for amalgamation of the western Gondwana supercontinent (Trompette, 1994). The Paraná block comprises the lithosphere flooring the Paraná basin (Fig. 1a; Mantovani et al., 2005).

The Brasília belt comprises three fault-bounded longitudinal lithotectonic domains: the Magmatic Arc, the Internal Zone, and the External Zone (Fig. 1b; Fuck et al., 1994, 2006). The Distrito Federal of Brasília (DF) lies in the centre of the External Zone (EZ). Approximately at the latitude of Brasília, the belt becomes divided into the NE-trending northern segment and the SE-trending southern segment (Marini et al., 1984). The axial surface of the orocline is along the Pirineus Zone of High Strain (PZHS), a WNW—ESE striking narrow zone of high strain coincident in the field with an array of magnetic lineaments [~300-km-long; ~ 10- km-wide; aeromagnetic data in Blum (1995)]. The PZHS rotated the lithostructural grain (S_0—S_1/S_2) in the rocks of both the Internal and External zones, but its effects die out close to the western margin of the Brasília dome, which is the main geological feature inside the DF area (Fig. 2).

For three reasons the evolution of the Brasília dome, oroclinal bending and the PZHS must have been closely related: (1) in despite of oroclinal curvature, a vast inventory of structural data (D'el-Rey Silva and Barros Neto, 2002; D'el-Rey Silva et al., 2004, 2008; other references therein) show the persistence of D_1—D_2 ductile flow in the WNW—ESE direction across the belt, north and south of the PZHS; the direction for D_3 shortening is the same for D_1—D_2 in the northern segment, whereas in the southern segment the D_3 folds, foliations and faults which deform D_1—D_2 tectonites record SW-NE contraction (Fig. 1b); (2) the structures deforming the rocks in the Brasília dome and surroundings (Freitas-Silva and Campos, 1995; D'el-Rey Silva et al., in preparation) record progressive D_1—D_3 ductile flow and contraction in the WNW—ESE direction; and (3) the structural data in the area SW of the Brasília dome (this study) define a Box-junction Zone (Fig. 2) inside which is evident the superposition of structures due to shortening oriented SW—NE, typical of D_3 in the southern segment of the belt, upon D_1—D_3 structures which imply progressive WNW—ESE shortening typical of both the dome and the northern segment of the Brasília belt.

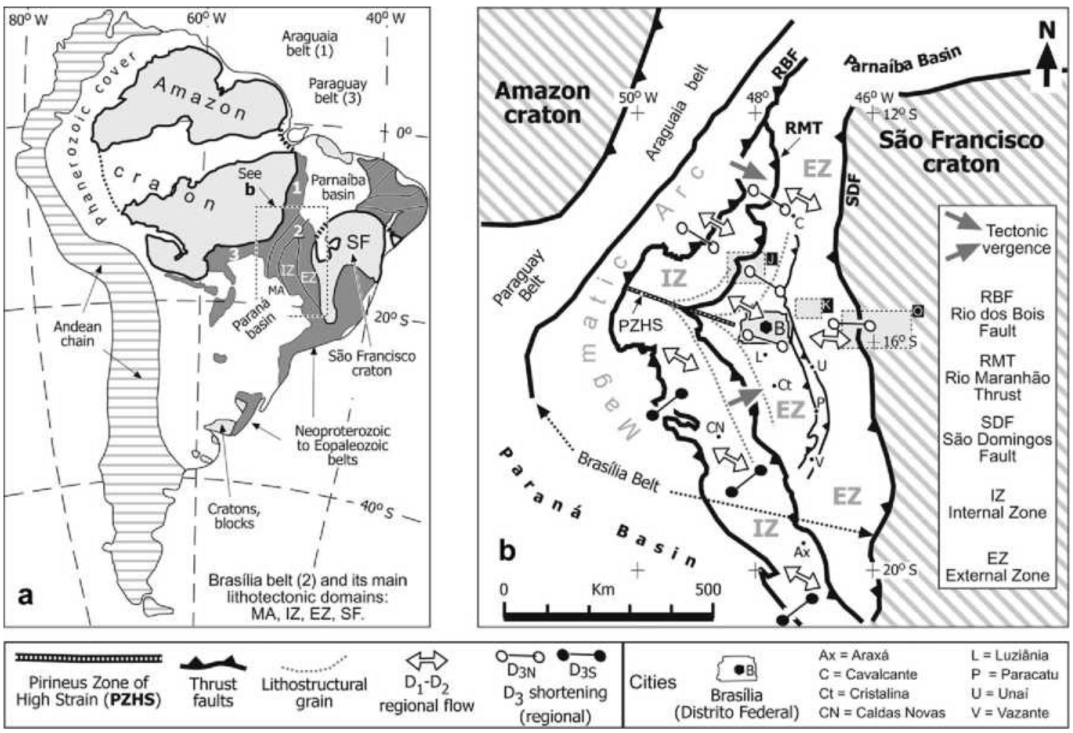

Fig. 1. a—b: Simplified map (a) emphasizing the lithotectonic units concerning to the evolution of the Tocantins Province: The Araguaia, Brasília and Paraguay belts, the Amazon and São Francisco cratons, and the Paraná and Parnaiba Phanerozoic basins. The simplified map (b) of the central part of the province (based on Marini et al., 1984; Fuck et al., 1994, 2006; Dardenne, 2000) emphasizes the lithotectonic domains and the bend of the Brasília belt. Arrows for D]—D_2 and D_3 regional shortening are based on detailed studies (D'el-Rey Silva and Barros Neto, 2002; D'el-Rey Silva et al., 2004, 2008; and references therein). Arrows for tectonic vergence are from plate-scale syntheses (e.g., Marini et al., 1984; Trompette, 1994). Areas J, K, and *O* are discussed in text.

The data bring to light compelling evidence that two perpendicular shortenings co-existed during D_3, in space-and-time, here-in-after referred as D_3N and D_3S respectively for shortenings oriented WNW—ESE and SW—NE.

This study complements the structural analysis recently carried out across the DF area, after which the information collected in other 50 outcrops (Fig. 2) provided information enough to constrain the structural evolution of the

Brasília dome.

Coupled with a larger database which includes published U-Pb age data of syn- and post-tectonic granites throughout the Brasília belt, the new structural data support previous interpretation that oroclinal bending and the PZHS fit very well in events related to the first stage of evolution of the Paraná block and Paraguay belt (D'el- Rey Silva et al., 2004, 2008); place the evolution of the Brasília dome as slightly older than the PZHS; and allow interpreting the Brasilia belt and the Tocantins province due to the collision of irregular continental margins.

2. Summary of the regional geology and tectonic setting

The Brasília belt includes (Fuck et al., 1994, 2006; Dardenne, 2000; or as otherwise referenced): 1 - a continental crust basement comprising Archean and Paleoproterozoic high- and low- grade rocks, as well as metavolcano-sedimentary rocks of an event of intracontinental rift ca. 1.75 Ga ago; 2 - metasedimentary rocks of the Paranoá and Canastra Groups respectively record proximal- and distal-like sequences of a Meso-Neoproterozoic passive continental margin that existed along the São Francisco paleocontinent. They occur in both the External and Internal Zones (Fig. 3; Moreira et al., 2008; D'el-Rey Silva et al., 2004, 2008); and 3 - amphibolite-greenschist facies metamorphites derived from intrusive and volcanic and sedimentary rocks which compose the (intra-oceanic) Magmatic Arc and also the Araxá Group (back-arc basin; Fig. 3). Sm-Nd isotopes point to at least two superposed island arcs and back-arc basins, and for arcs- continent collage ca. ~750 Ma and 645—640 Ma, when actually started the collision involving the Amazon and São Francisco paleocontinents (Fuck et al., 1994, 2006). Metacarbonate and metasiliciclastic rocks (Bambuí and Ibiá Groups) complete the Neoproterozoic record and represent sedimentary input from the arc and the craton.

Granulite facies rocks displaying ~750 and ~645—635 Ma ages of high P-T metamorphism record subduction zone conditions. The older granulites occur in a series of three mafic-ultramafic layered complexes north of the PZHS (a very small part of the southernmost of these complexes, named Barro Alto, is seen in the NW corner of the map in Fig. 3). The younger are represented by ortho- and para- derived granulites which occur (Della Giustina, 2010) in the Uruaçu Complex (northern segment of the belt) and in the Anápolis-Itauçu Complex (Fig. 3).

D_1—D_2 nappes of Canastra and Araxá rocks propagated towards ESE, onto the San Franciscan margin, and surround the DF area (Fig. 3; Faria, 1995; Faria et al., 1997). In the southern and southernmost parts of the Brasília belt the D_1—D_2 nappes propagated lately, ~ 640—635 Ma ago (Valeriano et al., 2000, 2004) coevally with the younger even of granulitization.

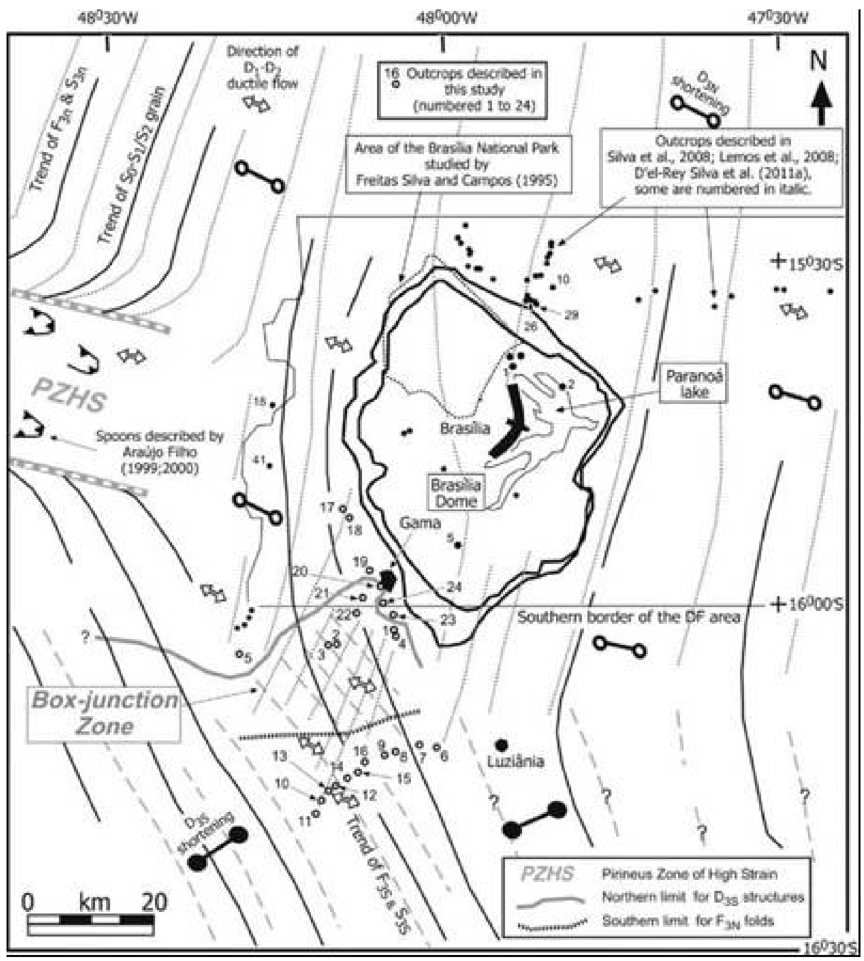

Fig. 2. Simplified structural map emphasizing the lithostructural grain (S_0—S_1/S_2); the Brasília dome (outlined by heavy-black lines); and the easternmost part of the Pirineus Zone of High Strain (PZHS). Note the 24 outcrops studied in detail (this paper) and other 50 outcrops described previously. The Box-Junction Zone is explained in text.

It is well-accepted that the Brasilia belt records (Fuck et al., 1994, 2006; Dardenne, 2000) polydeformation of Neoproterozoic age, whereas the southernmost end of the Brasilia belt was completed solely in EoPaleozoic times. In fact, in that part, the high P-T basement rocks of the Socorro-Guaxupé nappes propagated to ENE, 550—510 Ma ago, onto (D_1—D_2—D_3S) Neoproterozoic tectonites (Fig. 4; Valeriano et al., 2004; Campos Neto and Caby, 1999). The youngest time interval is basically the same for deformation in the Paraguay belt and also fits the obduction of the ~750 Ma old Quatipuru ophiolites onto a ~ 540 Ma old carbonate platform in the western margin of the Araguaia belt (Paixão et al., 2008).

3. Geological background for the Distrito Federal area

3.1. Lithostratigraphy overview

The DF area encloses metasedimentary tectonites of the Paranoá, Canastra, Araxá and Bambui Groups (Fig. 3; Faria, 1995; Faria et al., 1997; Freitas-Silva and Campos, 1995, 1998). The D_3N- related Brasilia dome (Freitas-Silva and Campos, 1995; D'el-Rey Silva et al., in preparation) is cored by sub-greenschist facies rocks (Paranoá Group) and mantled by low-greenschist and greenschist facies rocks (Canastra and Araxá nappes, respectively). Rocks of both nappes occur imbricate in the SW surroundings of the DF area (Fig. 3). Low-grade metacarbonate rocks (Bambui Group) spread from the eastern limb of the Brasília dome towards the EZ- São Francisco craton border and beyond.

The **Paranoá Group** is a psamo-pelitic and carbonated regional sequence comprising slate, meta-argillite, metasiltite, quartzite and metacarbonate divided into several units (Faria, 1995) though in regional-scale maps, even around the Brasília dome, solely two or three units have been individualized, however (Moreira et al., 2008).

The **Canastra Group** has been divided into two sequences, one comprised of Quartz-sericite-chlorite phyllite with quartzite intercalations, another of carbonaceous phyllite with thin intercalations of mica-quartzite and metasiltite (Fig. 3; Moreira et al., 2008). In the DF area, the Canastra Group consists of yellowish- brown to light-grey colored quartz-sericite-chlorite phyllite locally exhibiting intercalated layers of thinly laminated quartzite, local carbonate-bearing schist, and lens of metacarbonate.

The Araxá Group comprises grey-green color muscovite-biotite schist (locally garnet-bearing) with lenses of quartzite and carbonate, and bodies of sheared metamafic igneous rocks.

3.2. Structures and structural evolution of the Brasília dome

After studying the Paranoá rocks in the Brasília National Park (northern part of the DF area; Fig. 3) Freitas-Silva and Campos (1995) concluded that rocks in the Brasília dome record: (1) three phases (D_1—D_3) of overall E—W regional shortening, and a phase of N—S shortening (D_4); (2) local shear zones of small or negligible strike-slip (D_5); (3) fractures and normal faults of minor effect (D_6). Freitas-Silva and Campos (1995,1998) defined a larger F3 synform controlling the Canastra nappes inside the DF area (Fig. 3) and interpreted the Brasília dome as a feature of F3 x F4 folding interference.

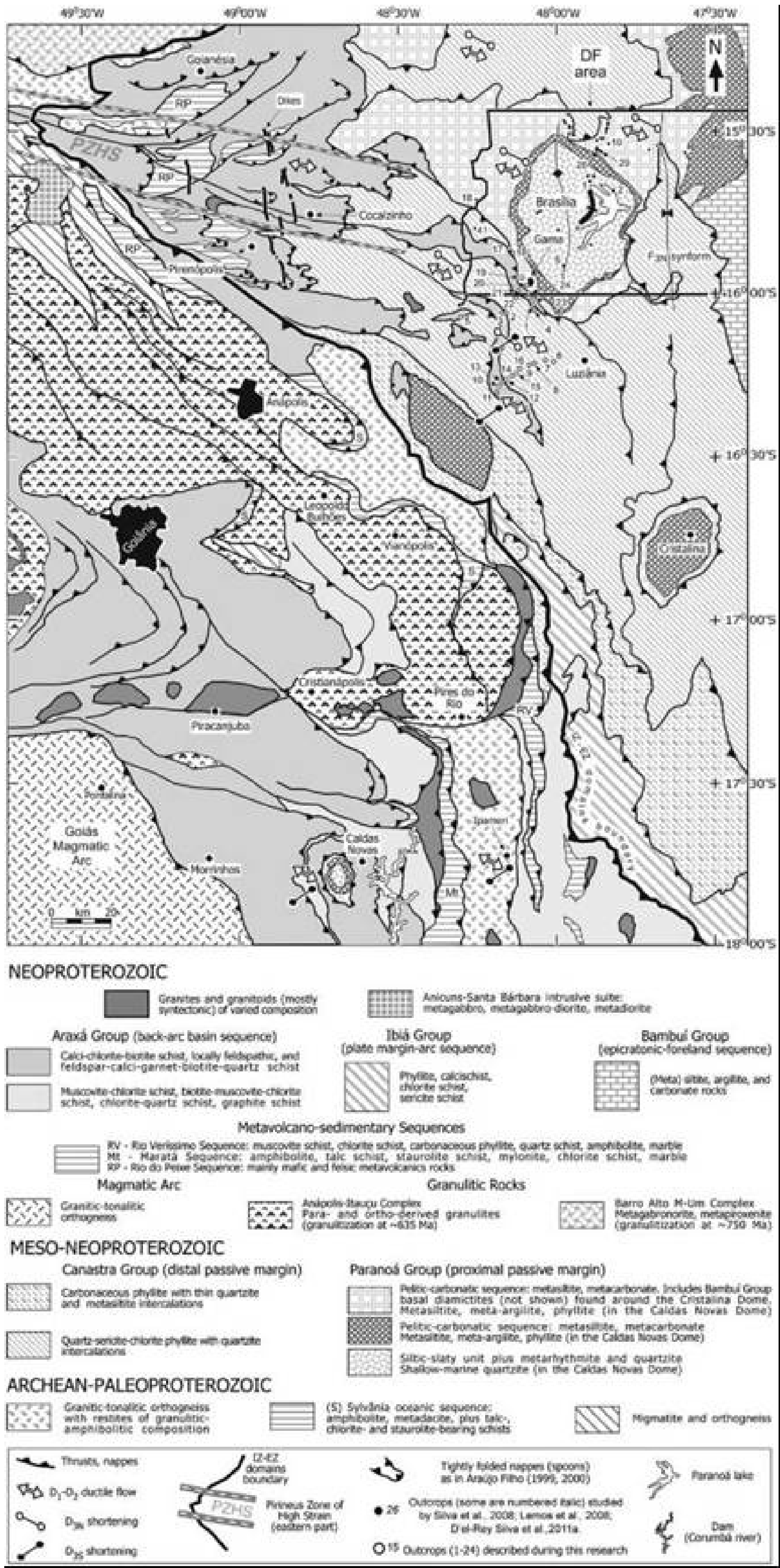

Fig. 3. Simplified geological map of part of the central-southern Brasília belt (based on Moreira et al., 2008) showing the same outcrops (as in Fig. 2) and emphasizing: the border between the Internal and External Zones; and geological

features inside the eastern part of the PZHS (imported from Fig. 1 in Araújo Filho, 2000). and emphasizing: the border between the Internal and External Zones; and geological features inside

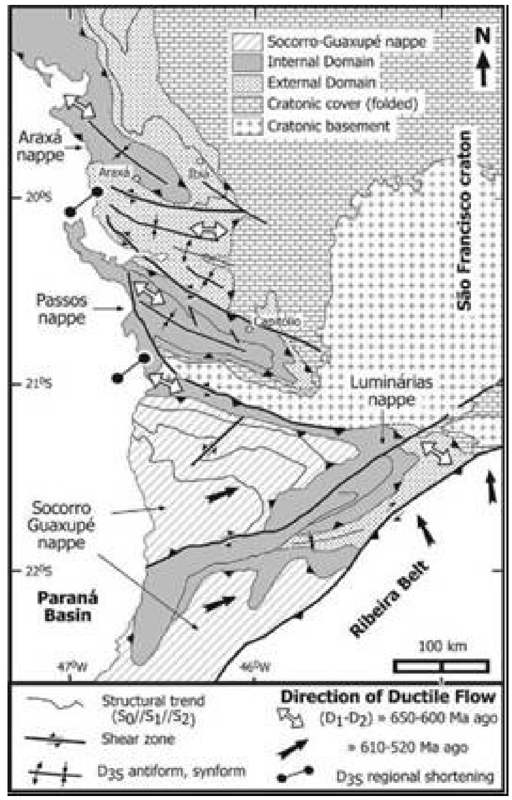

Fig. 4. Simplified geological map of the southernmost part of the Brasília belt (adapted from Valeriano et al., 2000; D'el-Rey Silva et al., 2004) emphasizing the directions of shortenings D]—D_2 and D_3S, as well as the EoPaleozoic nappes.

In reality, structural studies carried out in 100's of outcrops during the last decade across the External Zone (Fig. 1b; rectangles J, K, and O) plus the structural analysis based on 50 outcrops across the DF area (Fig. 2; Lemos et al., 2008; Silva et al., 2008; D'el-Rey Silva et al., in preparation) produced a large database which demonstrate a far more complete evolution.

The database includes: minor-scale structures, such as folds and/or spaced cleavage (pressure solution or crenulation type) deforming the limbs of some F_2 folds as well as quartz or carbonates veins, so that veins and cleavage parallel each other and co-exist within the of length of 10—20 cm in the same layer, all indicating minor contraction and coeval minor extension due to subordinated N—S movements in direction coincident with the geometric axis of F_2 folds (b tectonic axis); together with the D_1—D_2 features, such minor structures also occur deformed by F_{3N} folds and axial plane foliation; the limbs, hinges and axial plane foliation of F_{3N} folds also record coeval contraction-extension in the direction of the (F_3N) b tectonic axis; some tight F_2 and F_3N folds locally display the axial surface cut-across by sub-horizontal veins and spaced-or-crenulation cleavage, evidence for local contraction-extension in the vertical direction, compatible with coeval minor movements along the respective a tectonic axes; the F_3N folds, usually open-tight and normally strongly-inclined to the west, across the area, are rather isoclinal folds with sub-vertical limbs both affected by minor-scale sub-vertical shear zones subparallel to the gently-plunging hinges, in parts of the western margin of the Brasília dome.

Since then, the structural evolution of the DF area has been explained in terms of progressive ductile deformation according to D_1—D_2—D_3N phases ofWNW—ESE regional shortening coupled with nearly N—S movements in consequence of, respectively, D_2- and D_3N-related tectonic escapes (D_{2TE} and D_3N_{TE}) along the b and a tectonic axes of both the F_2 and F_3N folds, these escapes meaning a kind of transpression deformation of very local/minor importance.

Moreover, the data show that the F_3N_{TE} folds are very tight solely along the northern part of the Brasília dome, indicating the latest N—S horizontal shortening (D_3N_{TE}) strong in that part of the area and vanishing progressively to the south, across the dome, probably requiring the addition of another factor to the simple tectonic escape.

The greater magnitude of the latest N—S shortening in the northern part of the Brasília dome has been attributed to the uplift of crystalline basement rocks in the core of large-scale D_3N hinges in the area of Cavalcante, ~300 km north of Brasília (Fig. 1b). This interpretation is highly recommended because high-resolution satellite images (Moreira et al., 2008) display NNE-SSW continuous hinges of F_3N regional folds plunging to SSW, all across the northern segment of the External Zone, and show these hinges shortened N—S by F_3NTE-like folds solely in the narrow corridor limited to the south and north respectively by the towns of Brasília and Cavalcante, and to the east and west respectively by the areas labeled J and K (Fig. 1b). The data from the two latter areas show the lack of latest N—S shortening of large magnitude.

Most probably the uplift of the crystalline basement in the core of the large-scale F_{3N} antiforms promoted gravitational slide of part of the mechanically anisotropic stratigraphic section, down the SSW-plunging F_{3N} hinges still being formed, so the Paranoá layers folded tightly against the barrier created by the still-rising northern margin of the Brasília dome.

4. Structures and structural evolution in the area SW of the Distrito Federal (this study)

4.1. Summary of structures

The detailed description of the 24 outcrops allowed collection of ca. 340 attitudes of tectonic structures (Fig. 5 a—i). Key geological aspects observed in some outcrops are shown in Figs. g—11. The tectonic structures record a polyphase deformation consisting of D_1—D_2 ductile flow and D_3 shortenings. Nevertheless, D_3 structures characterize both shortenings in the WNW—ESE direction (D_{3N}), typical of the northern segment of the Brasília belt, and in the SW-NE direction (D_{3S}) which is exclusively found in the southern segment.

Structures in outcrops of the SW limb of the Brasília dome (17, 18,19, 23 and 24; Fig. 2) confirm the D_1—D_2—D_{3N} evolution of the DF area and that the late N—S shortening associated to D_{3N} actually vanishes towards the south. Such outcrops do not display any evidence of SW—NE shortening (D_3S) either, therefore establishing a northern limit for the occurrence of D_3S structures. Similarly, a southern limit can be established for the occurrence of F_{3N} folds, on the basis of the lack of these folds in a series of eleven outcrops (numbered 6—16) west of Luziânia. Foliation S_{3N} barely occurs in just two of these road-cuts (Figs. 10 and 11), however.

4.2. Phase D]

This phase is mostly represented by foliation S_1 and rare F1 folds. They deform the sedimentary bedding (S_0) which is easily recognized in the outcrops. In Paranoa siliciclastic rocks, S_0 is defined by the intercalation of compositionally distinct layers. In carbonate rocks, the best indicators are mm- to dm-thick layers of metamarl interleaved with layers of metacarbonate.

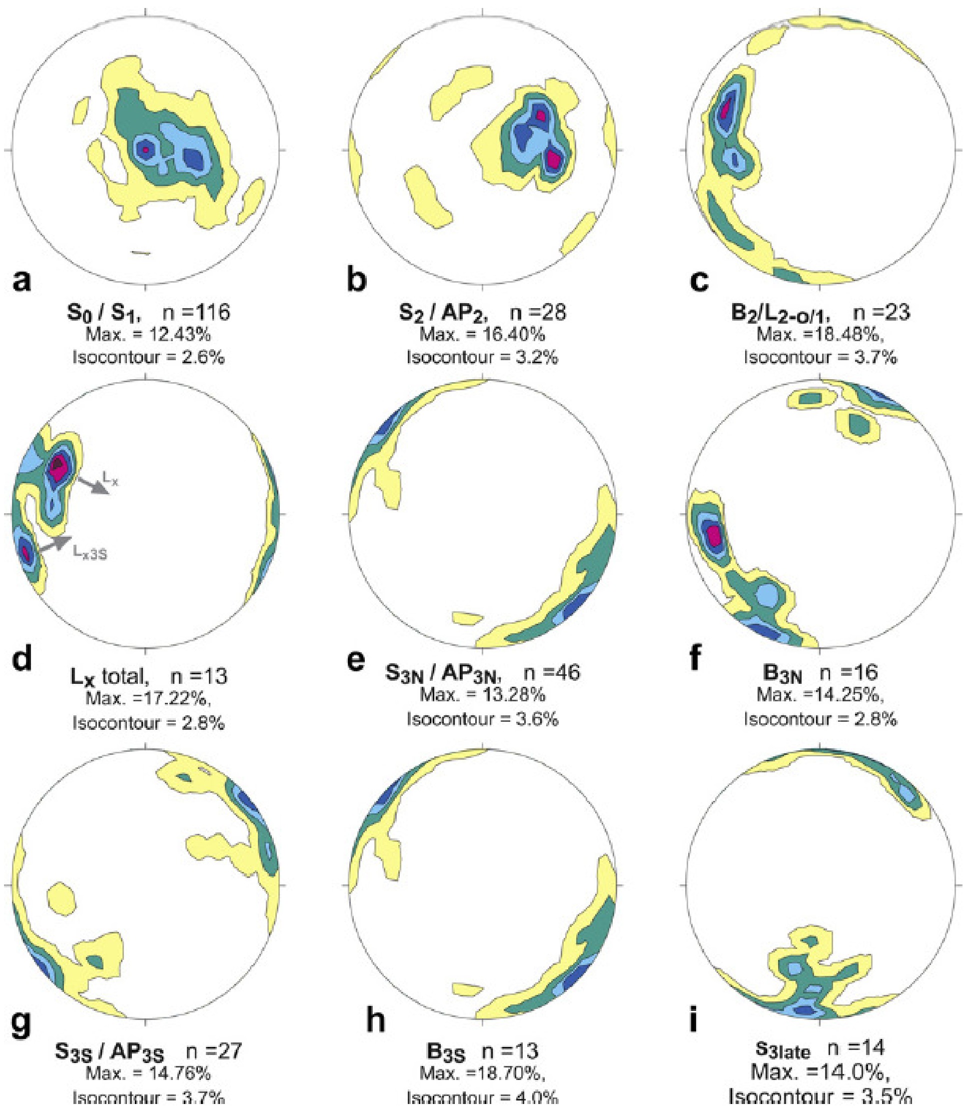

Fig. 5. a—i: Statistical distribution for D]—D_2, D_{3N} and D_3S structures. More details in text.

Foliation Si is sub-parallel to S_0 and varies in intensity and morphology. In rocks of the nappes, S] is the most prominent planar feature, but the definition of S_0 is possible because these rocks commonly exhibit intercalated strata (quartzite or metacarbonate) parallel to the layers of schist or phyllite. In these rocks, S_1

is commonly marked by micaceous minerals (chlorite, white mica) respectively sized ~ 1 mm and ~ 1 cm. Biotite is also found along Si in the Araxa schist. S_1 commonly displays S—C geometry, with the plane of flow (C) coincident with the bedding. Lens-shaped, mm- to cm- thick bodies of quartz may be found along C surfaces (e.g. in outcrop 6).

Identification of S_1 was not priority in Paranoa rocks because it has been done in several outcrops across the dome (D'el-Rey Silva et al., in preparation; Freitas-Silva and Campos, 1995, 1998). The few examples of F1 folds (seen inside the dome) are isoclinal and intrafolial relative to S_0.

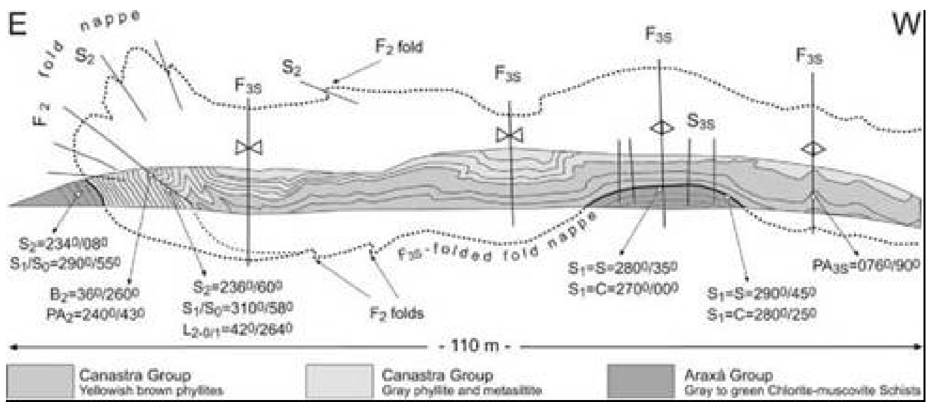

Fig. 6. Sketch of the southern road-cut in outcrop 16 (805971 E; 8197733 N; Zone 22S) to show a 100 m-sized isoclinal fold nappe (F_2) shortened SW-NE by open to gentle-style F_3S folds. Note the Araxa schist structurally below the Canastra phyllite in the overturned limb.

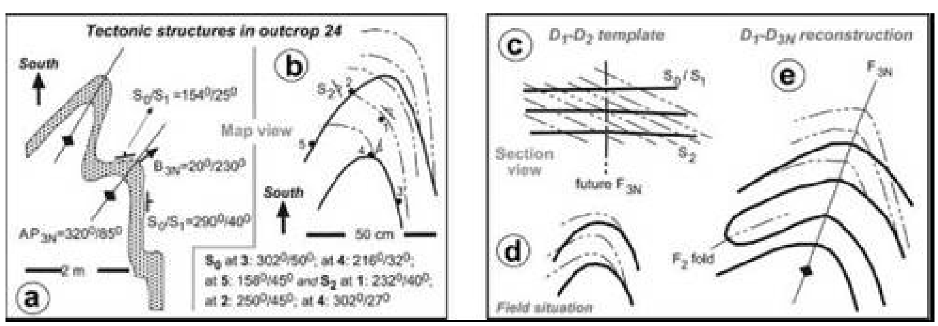

Fig. 7. a-e : Main tectonic structures and structural evolution portrayed in outcrop 24, a ~10 m2 map-like exposure (812915 E; 8223513 N; Zone 22S). A ~20 cm-thick layer of quartzite (part of a sequence of Paranoa metarhythmite; not ornamented) is deformed by tight F_3N folds (a) which also deform foliation S_2 (detail in b). The out-of-scale diagram (c) reconstructs the D]— D_2 template before F_3N folding, whereas the actual field situation (in d) allows envisaging the outcrop as part of a larger F_2 fold refolded by F_3N (e).

4.3. Phase D_2

F_2 folds are tight-isoclinal, asymmetric, gently-moderately inclined, with gently- to moderately-plunging fold axis (B2). They are commonly 10's of centimeters to few meters sized, though the detailed reconstruction in outcrop

16 (Fig. 6) shows that some may reach up to 100's of meters, with thinned overturned limb typical of fold nappes (e.g. McClay, 1992).

Foliation S_2 is very penetrative and also varies morphologically. It is a slaty cleavage in Paranoa metapelite; a finely-spaced cleavage in metasandstone, metacarbonate and quartzite, in certain cases associated with fine-grained white mica; or a very fine-grained mineral foliation (commonly marked by very small grains of white mica) or a crenulation cleavage in the Canastra phyllite and Araxa schist.

The similar statistical distribution of S_2/AP_2 and S_0/S_1 (Fig. 5 a—b) evidence how tight, asymmetric and ESE-verging are the F_2 folds. It also indicates ductile flow D_1 in the same ESE direction of mass (and nappe) propagation implied by the F_2 folds and permits envisaging that S_0 and D_1—D_2 structures underwent similarly- oriented shortenings afterwards (D_3 phase).

The orientation of the axial plane (AP_2) and axis B2 may vary largely in one outcrop, or from one to another outcrop, in consequence of F_2 sheathing and/or refolding. Sheaths of dm- to m- scale are observable in Canastra phyllite of outcrop 17. The sheaths define, together with striations seen on the surface of layers (of quartzite, in particular) or large mica grains, a stretching lineation down-dip on So/Si and S_2 surfaces (Lx; Fig. 5d). The penetrative striation seen on the Canastra quartzite of outcrop 10 (Fig. 11) resembles the stripping lineation described by Sengupta and Ghosh (2007) therefore it may be taken as evidence of intense ductile flow to ESE, during nappe propagation.

Few normal faults were noticed. They display straight and ~5 m-long traces and may be taken as evidence of progressive ductile flow during the propagation of the nappes, because their attitudes and the down-to-WNW (outcrop 17) or down-to-ESE movement (outcrops 12 and 7) of their hanging wall fit well in the finite ellipsoid of D_2 strain, in which the fault planes play the role of T-type fractures further rotated and used as planes of local slip during progressive flow. Moreover, the Araxa schist in outcrop 13 clearly exhibits the pair S—C = S_1 deformed by extensional crenulation cleavage indicating top-down-to ESE slip, candidates for playing Riedel shears or c' foliation (e.g., Lister and Snoke, 1984) associated to D_1 deformation. Nevertheless, because their spacing (>10 cm) is much larger than the cm-scale of the S—C pair in the outcrop, and because they cut several C (=S_1) planes, they rather suggest development during progressive D_2 flow (nappe propagation).

Fig. 8. a-d: D_2, D_3N and D_3S structures deforming Paranoa metarhythmite in outcrop 21 (811740 E; $822_3$870 N; Zone 22S). An overall view of the outcrop (a) showing, in the wall beyond the stream, the dam-sized hinge of an up-right F_3N fold deforming 10 cm-thick layers of metasiltite intercalated with thinner layers of metapelite. The flat floor (foreground) exhibits the traces of S_3N and S_{3S} spaced cleavages. A more detailed look permits (b) observation that the F_3N fold deforms the long limb of an ESE-verging and highly-asymmetric F_2 fold, the hinge of which is cut by the typical S_2 slaty cleavage (see inset). On the opposite side of the stream (c) the F_3N hinge keeps evident (background) whereas the outcrop's flat floor exhibits vertical surfaces of the axial planar foliation S_3N (white dots) and the S_{3S} cleavage (black arrows; detail in d) axial planar to $^F{}_{3S}$ folds that shorten both S_3N and B_{3N} (fold axis). Fold axes B_{3S} are sub-vertical or gentle, depending whether the F_{3S} hinges deform surfaces of S_3N or layers (S_0). Because of F_{3S} folding, the surfaces of S_0 and S_2 both dip to N-NE in the northern part of the outcrop (behind the authors; c) and to S—SW in the southernmost part (see in a). The white arrow in (a) stands for the axis B_{3S}.

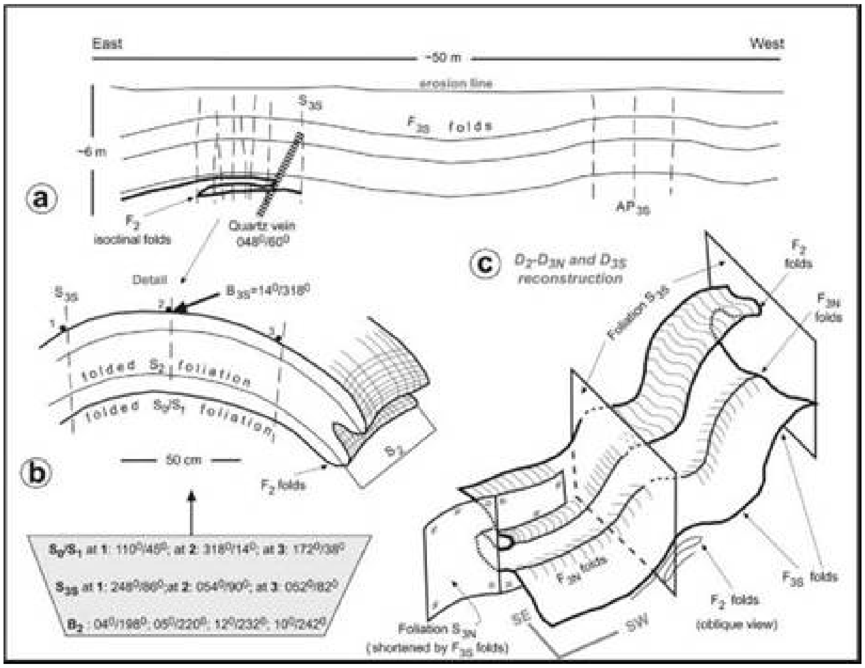

Fig. 9. a—c: Diagrams illustrating key structural relationships in Canastra rocks of a 50 m-long road-cut, outcrop 4 (813017 E; 8219865 N; Zone 22S). Open to gentle-style F3S folds and the S_3S axial planar foliation are evident on the wall of the road-cut (a). F_2 isoclinal folds are noticed refolded by F3S (detail in b). The 3-D diagram in (c) summarizes the relationship in the outcrop: F_{3N} folds refold Di— D_2 structures and F3S folds refold Di—D_2 and D_{3N}. Structures D_{3N} are more difficult to see because they strike oblique at low-angle with the road-cut wall.

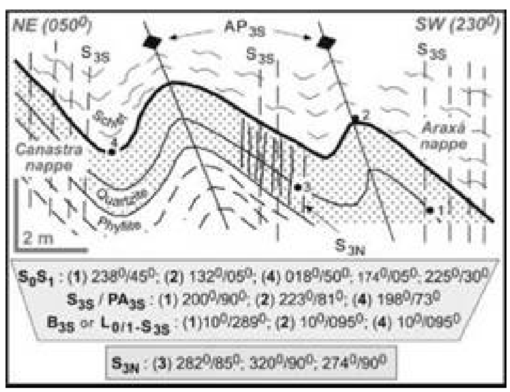

Fig. 10. Sketch of F_{3S} folds deforming rocks of the nappes in the southern part of the study area (outcrop 14; 804659 E; 8196079 N; Zone 22S). The folds are outlined by a w1 m-thick packet consisting of dm-thick quartzite layers interleaved with schist (above) and phyllite. Foliation S_{3N} is restricted to the quartzite layers and occurs also shortened by open-style, generally dm-scale F_{3S} folds.

4.4. Structures evidencing WNW—ESE (D_{3N}) shortening

Structures recording WNWeESE shortening comprise mostly the folds (F_{3N}), their axial planar foliation (S_{3N}) and thrust faults. They are common and evident solely in outcrops closer to the Brasília dome. Moreover, F_{3N} folds are generally tight-open in outcrops 17-21 and 24, nearest the dome, but become gentle-open, away from the dome.

The F_{3N} folds developed a NEeSW trending and steeply-dipping or sub-vertical axial planar foliation (S_{3N}; Fig. 5e). They are generally 1e10 m sized, mostly up-right or steeply-inclined, ESE-verging Metre-scale and gentle F_{3N} folds and cm-dm sized F_{3N} crenulations could be found as far to the south as in outcrop 4 (Fig. 9), but not in outcrops farther south.

Folds F_{3N} refold F_2 folds and are refolded by F_3S folds. Coaxial patterns of F_{3N} X F_2 folding interference [type 3 of Ramsay (1967)] are noticed in outcrops 24 and 4 (Figs. 7 and 9). The similarlystriking axial planes and axial planar foliations, and folds axes of F_{3N} and F_2 (Fig. 5 b,c; e,f) show that D_{3N} and D_2 regional shortenings were similarly-oriented WNWeESE, entirely confirming earlier predictions based on the detailed study of the Brasília dome. Examples of F_{3N} refolded by F3S are common, too (Figs. 8 and 9). Foliation S_{3N} is normally a 1 to 10 cm-spaced cleavage (locally marked by iron oxide) which cuts $S_0/S_1/S_2$ and displays varied degree of anastomose. The larger spacing is found in quartzite or arenaceous metarhythmite, or quartz-rich micaceous rocks of the nappes. In the outcrops to the west of Luziânia (Figs. 2 and 3), shortening D_{3N} is almost absent, apart from three outcrops (14, 12, and 10) where foliation S_{3N} occurs as a local feature shortened by F3S folds.

In outcrop 14, S_{3N} is characterized by stylolite-type surfaces, anastomose, spaced w1 cm and perpendicular to bedding in a w1 m-thick packet of F3S-folded quartzite layers. The surfaces of S_{3N} generally do not cut-across the schistose layers above or below (Fig. 10) indicating strain concentration and pressure solution due to D_{3N} layer-parallel shortening but not strong enough for folding the layers in the southern part of the area. The S_{3N} surfaces cut fold axis B3S perpendicularly and are F3S-folded, similarly as in outcrop 10 (Fig. 11).

Thrust faults locally seen (outcrops 1 and 17) exhibit short traces in the road-cuts and their attitude is indicative of WNWeESE shortening.

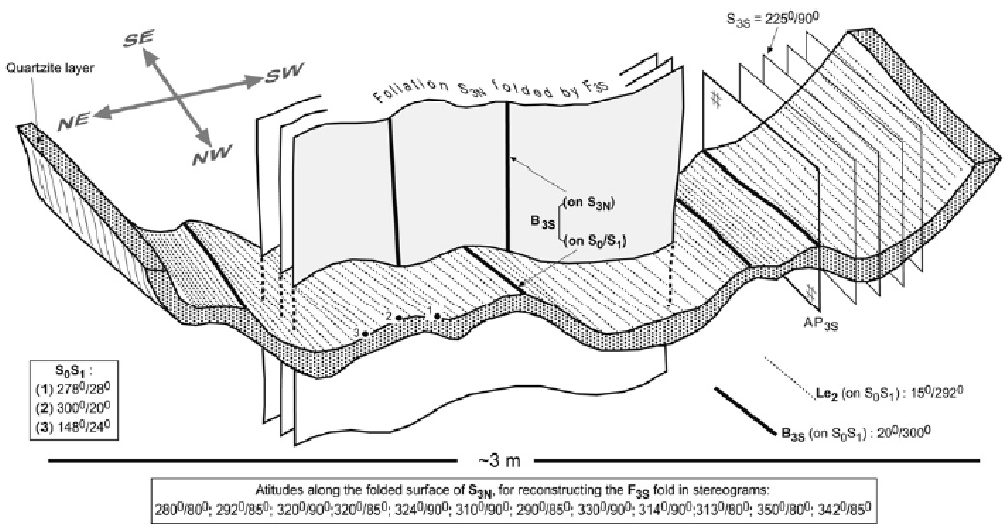

Fig. 11. A 3-D diagram illustrating the main structural relationships found in the southern road-cut which composes outcrop 10 (802260 E; 8193549 N; Zone 22S). A guide layer (10 cm-thick) of quartzite (ornamented within a packet of phyllite) displays a strong and quite evident striation (Le_2) and is folded by F_{3S} folds with axis B_{3S} virtually parallel to Le_2. Foliation S_3N (a dm-spaced cleavage) is clearly folded by F_{3S}, too. Note the axis B_{3S} is sub-vertical or sub-horizontal, according to the dip of the folded surface.

4.5. Structures evidencing SW—NE (D_3S) shortening

Structures such as folds (F3S) and their axial planar foliation (S_3S) constitute the main evidence of shortening in the SW—NE direction (D_3S). In outcrops closer to the Brasília dome (e.g., 1—4, 21 and 22) they are observable upon detailed observation, although in outcrop 21 they are large-scale and quite evident (Fig. 8).

Otherwise, F_{3S} folds dominate in outcrops away from the dome (e.g. 6—16 west of Luziânia; see Figs. 10 and 11). They are sized from few centimeters up to 100's meters, trend NW—SE, are mostly upright to steeply-inclined, generally verging to NE (Fig. 5g—h), and normally display an axial planar foliation (S_3S) characterized by surfaces of 1—10 cm-spaced cleavage.

The ratio between the folds height and width (the aspect ratio by Twiss and Moores, 1992) is larger in outcrops 6—16 and the S_3S surfaces become much more evident there than elsewhere, indicating increasing intensity of shortening D_3S towards the south-ernmost part of the area.

Folds F_{3S} refold both D_2 and D_3N structures. Coaxial patterns of folding interference were noticed due to the oblique orientation of certain road-cuts (e.g. in Fig. 9a—b) but may form where fold axes B2 and B3S are sub-parallel. Interference patterns of type 2 (Ramsay, 1967) are spatially reconstructed (Fig. 9c) and are expected to form due to the original orientation of F_2, F_{3N} and F_{3S} fold axes and respective axial surfaces.

Outcrops 2,3,10,11 and 13 fall in a slice of Araxá schist imbricate within Canastra rocks (Fig. 3) therefore indicating the existence of thrust faults. At three different parts of outcrop 2 (a ~ 50 x 50 m large exposure) the schist dips 22° to SW and contains large crystals of muscovite marked by two sets of striations oriented respectively ESE and ENE. The ESE-trending ones are taken as evidence of D_1—D_2 flow, the others as evidence of D_3S flow.

5. Discussion

5.1. Structural evolution

The top-bottom stacking of Araxá schist, Canastra phyllite, and Paranoá (lower grade) metapelite, coupled with the metamorphic mineral assemblages related to D_1 and D_2; the spaced cleavage associated to D_{3N} and D_3S; and the structural database in the previous sections, all permit understanding that: 1 - the rocks in the SW surroundings of the DF area underwent a first phase (D_1)ofinter-and intra-layer slip still in their original sites of formation. M1 metamorphism varied from intermediary- to high-greenschist facies in Araxá rocks (up to garnet zone) to intermediary-greenschist facies in Canastra rocks, and sub- to low-greenschist facies in the Paranoá rocks; 2 - during the second phase of deformation, the nappes of Canastra and Araxá D_1-tectonites were successively pushed to ESE, onto autochthonous Paranoá D_1-tectonites; 3 - the highly anisotropic D_1—D_2 stack underwent shortening D_{3N}, so that F_{3N} folds refolded F_2 co-axially; and 4 - the entire packet (D_1—D_2—D_{3N} tectonites) was shortened in the SW-NE direction (D_3S), so that F_{3S} folds trend perpendicularly to F_{3N}.

D_1 and D_2 structures demonstrate a regime of dip-slip shearing along surfaces practically coincident with shallowly-moderately dipping layers, a typical regime of WNW-dipping frontal ramps. D_{3N} and D_3S structures sliced the entire crust (exhumation of granulites) and shortened thicker packets of upper crustal D_1—D_2 tectonites.

The data confirm the Brasília dome as a D_{3N}-related structural window and also that late N—S shortening (D_{3NTE}) vanished towards the south, across the dome. Actually, outcrops 17—20 and 24 (this study; Fig. 2) do not show evidence of any late shortening deforming F_{3N} folds. The succession of folding events (F_2, F_{3N}, F_{3S}) is unequivocal in this study area, and the attitudes of F_{3N} and F_{3S} parameters (Fig. 5) leave no doubt about the directions of D_{3N} and D_{3S} shortenings.

The preservation of the WNW—ESE direction of the stretching lineation (Lx) across the Brasília belt, even after orocline bending, was possible because shortening D_3S was perpendicular to the direction of ductile flow responsible for D_1—D_2 tectonites, conse-quently the parallelism of fold axis B3S with Lx is common in the field (e.g. outcrops 10 and 14; Fig. 11). These outcrops demonstrate the same relationship (B3S/Lx) deduced previously, but on an indirect basis, around the Caldas Novas dome (Fig. 3), where the L2 stretching lineation remained constant (WNW—ESE) even after the dome's uplift (D'el-Rey Silva et al., 2004).

5.2. Crossed D_3S x D_{3N} and the actors playing collision tectonics in the Tocantins province

D_1—D_2 data in the study area fit very well the direction of D_1—D_2 flow reported elsewhere in the Brasília belt: in the External Zone and Brasília dome (D'el-Rey Silva et al., 2008, in preparation; Freitas-Silva and Campos, 1995); in Araxá rocks inside or close to the eastern part of the PZHS (Fig. 3; Araújo Filho, 2000); and in nappes surrounding the towns of Caldas Novas and Ipameri and further south in the Brasília belt (Figs. 3 and 4; Valeriano et al., 2004) or inside the Magmatic Arc (D'el-Rey Silva and Barros Neto, 2002; and other references therein).

Moreover, the continuity of D_{3N} shortening across the Brasília dome, plus the constant direction of the Lx stretching lineation on both sides of the PZHS, altogether shows a WNW—ESE path for collision that would have remained, if another tectonic agent had not produced SW-NE shortening (D_3S) in the southern segment of the Brasília belt. The Paraná block is the unique agent capable to explain D_3S in the Amazon-São Francisco scenery of collision.

5.3. Relationships between shortenings D_3N and D_3S, the Brasília dome, and the PZHS

For understanding that D_3S x D_3N structures co-existing just SW of the DF area, the Brasília dome and the PZHS are closely related makes necessary to consider that the PZHS rotates: (A) imbricate slices of Anápolis-Itauçu granulites and Araxá schist existing along the Internal-External Zones border; (B) imbricate slices of Araxá, Canastra and Paranoá rocks to the NW, W and SW border of the DF area (Fig. 3; Araújo Filho, 2000; Moreira et al., 2008; this study); and (C) the granulite belt characteristic of the Internal Zone (Marini et al., 1984; Araújo Filho, 2000).

Also relevant are the ~ 645—635 Ma age of granulitization in rocks of the Anápolis-Itauçu and Uruaçu Complexes (see section 2) and the ~ 620 Ma age of Itapuranga syn-tectonic granite emplaced in the PZHS (U-Pb and geology data by Pimentel et al., 2003).

The above geological data imply: 1 - Canastra and Araxá D_1—D_2 tectonites already formed a continuous blanket of allochtonous rocks over D_1—D_2 autocthonous Paranoá tectonites in the areas of the future Internal and External zones, before exhumation of the belt of granulites, i.e. before D_3N and D_3S shortenings; and 2 - because the PZHS affect both the Rio Maranhão Thrust (RMT in Fig. 1b; D'el-Rey Silva et al., 2008) then the RMT must have evolved in the ~ 635—620 Ma age interval and the PZHS is most likely aged ~620 Ma.

5.4. Age intervals and the co-existence of shortenings D_3N and D_3S

The age intervals ~ 750—640 Ma (D_1—D_2) and ~ 640—590 Ma (D_3N) are respectively supported by: U-Pb age data of ~ 750—640 Ma and ~ 635 Ma for diachronous amalgamation of the back-arc basins, north to south along the São Francisco paleocontinent margin; the ~ 645/635—620 Ma interval for granulite formation-and-exhumation; the link between D_{3N} regional shortening and the Amazon-São Francisco collision; and the ~ 590—580 Ma age of post-tectonic granites in the Brasília belt (Pimentel et al., 1999; Valeriano et al., 2004).

The age interval for deformation D_3S (~ 630—590 Ma) and the D_{3N} x D_3S co-existence are constrained by the following U-Pb age data and structural relationships: (1) emplacement of Araxá nappes ~640—635 Ma ago, in the southern segment of the Brasília belt (Valeriano et al., 2000, 2004); and (2) exhumation of granulites ~ 630—620 Ma ago in both the northern and southern segments of the belt, respectively due to D_{3N} and D_3S, because (as already discussed) the PZHS rotates the whole granulite belt and encloses the ~ 620 Ma old Itapuranga granite.

Thus, although D_3S overprints D_{3N} structures, these two shortenings must have been coeval during granulite exhumation because the SW—NE direction of shortening is remarkably the same recorded by regional folds deforming the D_1—D_2 tectonites further south-southwest of the DF area, up to Caldas Novas and Ipameri (Fig. 3) and beyond, around Araxá and Capitólio (Fig. 4), and the structural data reported for these areas (D'el-Rey Silva et al., 2004; and references therein) indicate the inexistence of post-D_1—D_2 shortening in any other direction different of SW—NE (D_3S), in particular the WNW—ESE direction of D_{3N}.

Nevertheless, the EoPaleozoic events in the very southern end of the Brasília belt (Fig. 4) and the obduction of the Quatipuru ophiolite ~540 Ma ago (Paixão et al., 2008) justifies further discussing whether the lower age for D_3S is actually 590—580 Ma or 540—510 Ma (section 5.5).

5.5. Tectonic model

A feasible tectonic model for the Brasília belt and Tocantins Province should consider that the structural evolution of the Brasília dome implies the PZHS developed in an area already shortened by D_{3N}. Moreover, the geology data in the Tocantins Province fit in the expected consequences of the collision of irregular continental margins (see also D'el-Rey Silva et al., 2011) and the D_1—D_2 and D_{3N} structural data here summarized indicate the Amazon and São

Francisco always along a WNW—ESE-trending route of collision (Fig. 12 a—b).

As explained ahead, the crystallization age of ~ 780—750 Ma for the Quatipuru ophiolite and its obduction ~540 Ma ago onto a carbonate platform (Paixão et al., 2008) make necessary envisaging the very beginning of A-subduction of the Amazon paleo- continent, by the time the magmatic arc was pushed against São Francisco paleocontinent margin, leading to the blanket of nappes on the sites of the future Internal and External Zones, until the area of the future Distrito Federal (Fig. 12b). Furthermore, if nappes propagated ~ 640—635 Ma ago onto the southern paleomargin (Valeriano et al., 2004) the ocean remained opened south of the locking point 1 (Fig. 12b) strongly suggesting control by the irregular margin of the São Francisco paleocontinent about the Distrito Federal latitude (Pimentel et al., 1996b).

A diachronous opening of the Quatipuru ocean towards the south is physically required, since ~750 Ma ago, should the ocean to the south of locking point 1 continues to close (Fig. 12c). This means: despite the Araguaia belt consists of ~630 Ma old tectonites the Estrondo Group (Paixão et al., 2008) should not be a surprise if metamorphism as old as ~ 750 Ma come to be futurely known in rocks of that belt.

Should the ocean close entirely and collision continues to the south, the Quatipuru ocean spreading must reach locking point 1. The Amazon paleocontinent situated west of the Quatipuru ocean is then pulled farther into subduction, moving to point 2 for pushing younger Di—D_2 nappes onto the southern paleomargin, coevally with granulite facies metamorphism of supracrustal rocks carried to depth into the subduction zone.

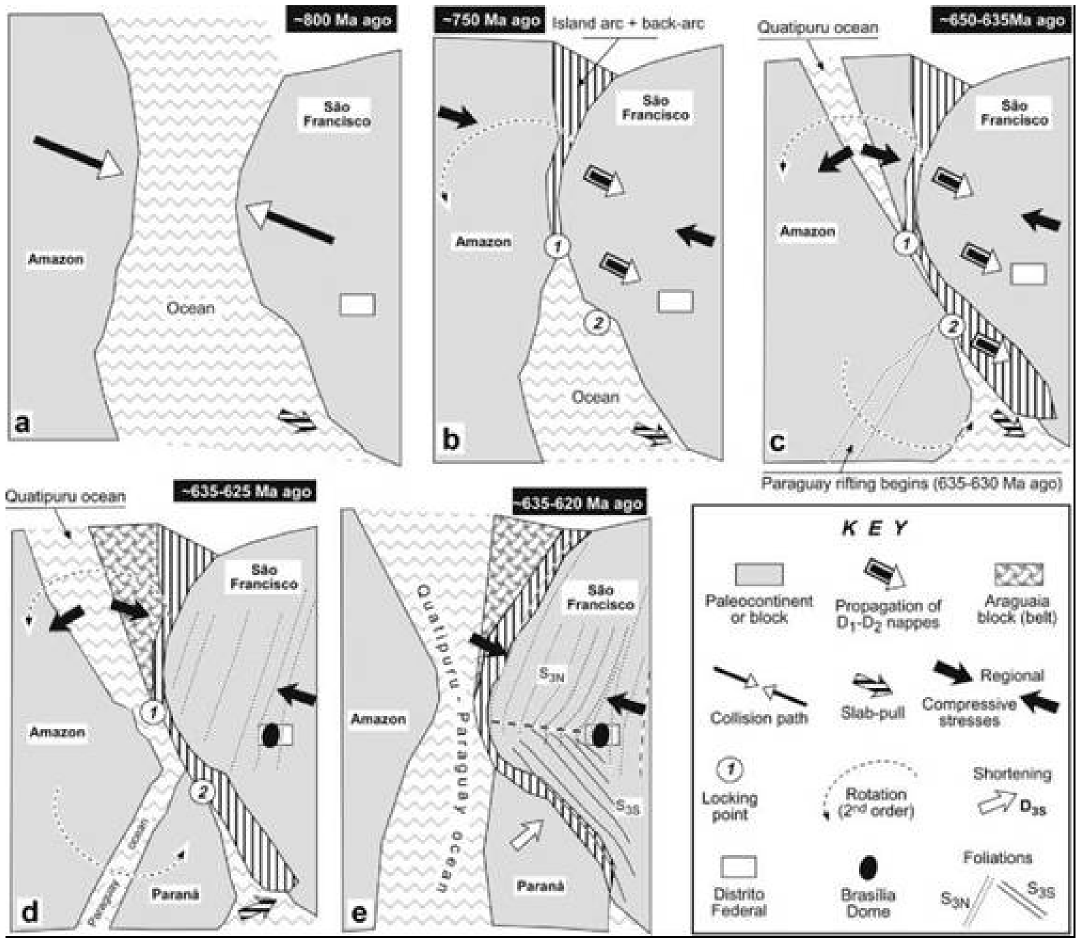

Fig. 12. Largely schematic representation of the evolution of the Brasília Belt due to collision of two irregular continental margins (a—e). The Distrito Federal area is shown for reference. See text for explanation.

High P-T metamorphism soon before 635 Ma ago, under the São Francisco paleocontinental margin, and the fact that the age interval for deformation D_3S in the Brasília belt (~ 630—590 Ma) overlaps the age interval for sedimentary-volcanic infilling of the Paraguay basin (~ 620—550 Ma; Pimentel et al., 1996a) plus the EoPaleozoic emplacement of nappes of high-PT basement rocks onto the southernmost paleocontinental margin (Fig. 4) coevally with both the obduction of the Quatipuru ophiolite and deformation-metamorphism (~ 550—510 Ma; Valeriano et al., 2004) in the Paraguay belt, altogether implies: A - the evolution of the Paraguay belt, Paraná block and the southern segment of the Brasília belt must have been strongly linked; and B - the southeastern part of the Amazon paleocontinent destined to become the Paraná block was very close of the São Francisco margin, or such block moved very fast into collision, most likely both.

Locking point 2 (Fig. 12c) demanded rifting (Paraguay) controlled by an anti-clockwise rotation in the southeastern part of the Amazon paleocontinent, whereas (to the N) the recently- formed Araguaia block (Fig. 12d) was pushed further into A-subduction, promoting D_3N shortening of the northern São Francisco paleomargin. Shortening D_3S was brought to the tectonic scenery since about ~ 635 Ma ago (Fig. 12e) when the Paraná block drifted-apart and followed along a SW—NE path for A-subduction beneath the São Francisco paleomargin.

5.6. Further discussing the timing for deformation D_3S

Despite of the several structural and geological reasons for shortenings D_3N and D_3S co-exist in the ~635—590/580 Ma age interval (previous section) whether the lower limit of age for shortening D_3S is ~590 or ~540 Ma still demands a more detailed analysis.

In fact, the lower limit becomes ~ 540 Ma if new geochrono- logical data come to show this as the best age for post-tectonic granites already dated, or for post-tectonic granites not described yet across the Brasília belt. If so, will be not a surprise if ages futurely obtained directly for the deformation (39Ar/40Ar tech-niques, for example) place in the EoPaleozoic the minimal age for D_3S tectonites. Nevertheless, from the tectonic point of view should not be a surprise if such ages remain >590/580 Ma, either.

Actually, the event of emplacement of the EoPaleozoic nappes to ENE onto the craton margin, although most likely related to further A-subduction of the Paraná block under the São Francisco margin and due to the Amazon-Paraná collision responsible for the Paraguay belt, did not necessarily deform the upper crust further north in the Brasília belt.

This is because, the residual effects of the EoPaleozoic shortening, if any existed there, could have been concentrated mostly in the lower crust of the (overriding) São Francisco plate, facilitated by the higher degree of plasticity of the rocks there, coupled with the difficult for deforming a mechanically stronger upper crust consisting of tectonites with multiply-oriented anisotropies such as: NE-trending axes of F_2 folds; ESE-trending axes of F_2 sheaths; and NNWtrending axes of F_{3S} folds. Moreover, additional A-subduction of the Paraná block could have been accommodated by a ramp of underthrusting inside the block itself and far west of the subduction zone, without deforming the rocks in the Brasília orogen, similarly to what has been recently shown in the Indian continent still A-subducting under Asia (Yin et al., 2010).

5.7. Oroclinal bending, PZHS, Brasília dome and box-junction zone

Among the large variety of mechanisms capable of producing an orocline (Sussman and Weil, 2004) there are four which could be thought as applicable to the Brasília belt. The first three are: rotation on the slip direction around a continent corner; rotation of the grain due to collision of an indented margin; and larger magnitude of rotation closer to a major shear zone. The first two fail to explain the same direction of D_1—D_2—D_{3N} ductile flow on both sides of the PZHS and the delay in the onset of D_3S relative to D_{3N}. The third fails to explain (primarily) why the rotation associated to the PZHS solely affects the Internal and External zones, not the magmatic arc.

The fourth mechanism consists of perpendicular shortenings, such as D_{3S} and D_{3N}. Moreover, the tectonic model (Fig. 12) highlights the role of irregular continental margins in the generation of a third continental block capable to produce coeval crossed shortenings in the Brasília belt, emphasizing that such margins may strongly control the geometry-evolution of collision zones in time (such as in Coward and Dietrich, 1989). More recently, Ghiglione and Cristalline (2007) used geophysical and structural evidence supporting the Patagonian orocline as formed in consequence of rotation of a small block. Contrarily to the Paraná-São Francisco scenery of collision, however, these authors reported two differently oriented deformation phases attributed to the small block moving in different directions, at different times, all consistent with a change in the direction of convergence of Farallon-Nazca plate, ca. 27 Ma ago.

Three factors justifies the bending and the PZHS along the interface between the Barro Alto and Anápolis-Itauçu complexes (Fig. 3): (1) - the different rock compositions in these complexes likely implied a zone of crustal weakness; (2) - the Box-Junction Zone and its continuation to the west represented a zone of relative enhancement in crustal strength, not suitable for bending; and (3) - the uniqueness of shortening D_{3N} or D_{3S} implied lack of reasons for bending at any other site respectively north of the PZHS or south of the Box-Junction Zone.

Sub-horizontal normal and sub-horizontal shear components of D_{3N} and D_{3S} stresses (relative to the PZHS) explain the strong N—S shortening of D_1—D_2 nappes nearby or inside the eastern PZHS (see spoons by Araújo Filho, 2000; Fig. 3) and rotation of the lithos-tructural grain along its northern and southern sides. The normal components account also for a non penetrative spaced cleavage (S_3- late foliation; stereogram in Fig. 5i) found locally in this study area. D'el-Rey Silva et al. (in preparation) emphasize that both the N—S shortening across and the rotation along the PZHS' eastern half fit the expected shrinking in the inner arc of the Brasília bend, whereas the series of WNW-trending dykes which characterizes the western half (through the magmatic arc; Moreira et al., 2008) record the extension expected for the outer arc.

During a short time interval (15 million years) the granulitic rocks exhumed from a depth of ~35 km along the Rio Maranhão Thrust (RMT), cut through the blanket of nappes and reached the crustal level currently exposed by the same time of oroclinal bending and formation of the PZHS, ~ 625—620 Ma ago, according to abundant structural and mapping data, plus data on Sm-Nd isotopes relative to metasediments in the hangingwall and footwall of the RMT (area J; Fig. 1b; D'el-Rey Silva et al., 2008). All this means oroclinal bending assisted by a suitably elevated temperature and matches the concept of hot orogen recently postulated for the Brasília belt at that time (Della Giustina, 2010).

The Brasília dome and the D_{3N} structures must have evolved (Fig. 12d) lately in the ~ 630—625 Ma age interval, coevally with granulite exhumation but before the PZHS' onset, whereas the Box- Junction Zone (Fig. 2) evolved in the 625—620 Ma age interval, shortly after the dome's uplift and shortly before orocline bending and the PZHS (Fig. 12e).

6. Conclusions

The Brasília belt is an orocline comprised of N—S longitudinal domains (magmatic arc; Internal and External zones) and divided into a NE-trending northern segment and a SE-trending southern segment. It forms, together with the Araguaia and Paraguay belts, the Tocantins province. This province results from Neoproterozoic- Cambrian collision events involving the Amazon and São Francisco paleocontinents and the Paraná block of central Brazil.

Within the Distrito Federal (DF) area, the Brasilia dome is a structural window demonstrating stratigraphy and structural (D_1—D_2—D_{3N} events of WNW—ESE shortening) continuity across the External Zone of the Brasília belt. The eastern tip of the Pirineus Zone of High Strain (PZHS) rests few kilometers west of the dome. Abundant structural data have shown deformation of the northern segment due to WNW—ESE shortenings D_1—D_2 and D_{3N}, and the southern segment due to WNW—ESE D_1—D_2, overprinted by shortening SW—NE (D_3S). Moreover, in the area close to the SW margin of the dome, D_{3S} structures shorten D_{3N} structures in a narrow Box-Junction Zone.

The large database allows understanding the Tocantins Province in terms of the collision of irregular continental margins. The Amazon-São Francisco collision produced the Brasília-Araguaia belt, and resulted in D_1—D_2 and D_{3N} WNW—ESE shortenings (respectively ~ 750—640 Ma and ~ 640—590 Ma ago) in the Brasília belt until the southernmost latitude of the Box-junction Zone. The Paraná block rifted/drifted-apart from the Amazon paleocontinent and shortened SW-NE the southern segment of the belt ~ 630—590/580 Ma ago, as indicated by D_{3S} structures up to the northernmost latitude of the Box-Junction Zone. Shortening D_3 (D_{3N} + D_3S) accounts for exhumation of granulites in the Brasília belt, for oroclinal bending and the PZHS. The Amazon-Paraná collision accounts for both the Paraguay belt and Cambrian nappes in the southernmost Brasília belt.

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References

Almeida, F.F.M., Hasui, Y., de Brito Neves, B.B., Fuck, R.A., 1981. Brazilian structural provinces: an introduction. Earth Sciences Reviews 17,1—29.

Araújo Filho, J.O. de, 2000. The Pirineus Syntaxis: an example of the Intersection of two Brasiliano fold-thrust belts in Central Brazil and its implications for the tectonic evolution of Western Gondwana. Revista Brasileira de Geociências 30 (1), 144—148.

Blum, M. de L.B., 1995. Superficies Curie da região central de Goiás e relações com geologia, geotectônica e Recursos Minerais. MSc Dissertation 96, Universidade de Brasília.

Campos Neto, M.da C., Caby, R., 1999. Neoproterozoic high-pressure metamorphism and tectonic constraint from the nappe system south of São Francisco Craton, southeast Brazil. Precambrian Research 97 (1—2), 3—26.

Coward, M.P., Dietrich, D., 1989. Alpine Tectonics — an overview. In: Coward, M.P., Dietrich, D., Park, R.G. (Eds.), Alpine Tectonics, 45. Geological Society London Special Publication, pp. 1 —29.

D'el-Rey Silva, L.J.H., Barros Neto, L. de S., 2002. The Santa Terezinha-Campos Verdes Emerald district, central Brazil: structural and Sm/Nd data to constrain the tectonic evolution of the Neoproterozoic Brasília belt. Journal of South American Earth Sciences 15 (6), 693—708. doi:10.1016/$S_0$895-9811(02)00087-1.

D'el-Rey Silva, L.J.H., Klein, P.B.W., Walde, D.H.G., 2004. The Caldas Novas dome, central Brazil: structural evolution and implications on the evolution of the Neoproterozoic Brasília belt. Journal of South American Earth Sciences 17 (1), 163—179. doi:10.1016/j.sames.2004.03.001.

D'el-Rey Silva, L.J.H., Vasconcelos, M.A.R., Gonçalves, D.V., 2008. Timing and role of the Maranhão River thrust in the evolution of the Neoproterozoic Brasília belt and Tocantins province, central Brazil. Gondwana Research 13 (3), 352—372. doi:10.1016/j.gr.2007.09.004.

D'el-Rey Silva, L.J.H., Lemos, M.V.F., Martins-Ferreira, M.A.C., Nascimento, B.M., Pereira, K.M.daS., Carreiro, S.A.deA., Lopes, G.deC., Oliveira, F.C.de, Queiroz, H.V., Perin, D.H.de, Silva, H.L., Koth, L.B., Lemos, A.deS., Freitas, L.L. The Neoproterozoic Brasília Dome, Central Brazil: A structural window highly relevant for better understanding the build-up ofWestern Gondwana, in preparation.

D'el-Rey Silva, L.J.H., Pohren, C.B., Oliveira, I.L.de, 2011. The role of irregular continental margins in the evolution of the Brasília belt, Central Brazil. In: Tectonic Studies Group Meeting 2011 (TSG2011), Durham University, UK, January, 5th- 7th, 2011. TSG2011 Programme and Abstracts, p. 25.

Dardenne, M.A., 2000. The Brasília Fold Belt. In Cordani, U. G., Milani, E.J., Thomaz Filho, A., Campos, D. A. (Ed.) Tectonic Evolution of South America, 31 International Geological Congress, Rio; 231—264.

Della Giustina, M.E.S., 2010. Geocronologia e significado tectônico de rochas máficas de alto grau metamórfico da Faixa Brasília. Unpublished PhD thesis, 101, University of Brasília, p. 121.

Faria, A., 1995. Estratigrafia e sistemas deposicionais do Grupo Paranoá nas áreas de Cristalina, Distrito Federal e São João d'Aliança-Alto Paraiso de Goiás. Unpublished PhD thesis, Universidade de Brasília, p. 199.

Faria, A., Guimarães, E.M., Figueiredo, A.N., 1997. Programa Cartas de Síntese e Estudos de Integração Geológica. Mapa geológico escala 1:100.000 do Distrito Federal. DNPM/UnB.

Freitas-Silva, F.H., Campos, J.E.G., 1995. Geologia do Parque Nacional de Brasília/DF. SBG. Boletim de Geociências do Centro-Oeste 18 (1/2), 32—43.

Freitas-Silva, F.H. and Campos, J.E.G., 1998. Geologia do Distrito Federal. In: Inventário Hidrogeológico e dos Recursos Hídricos Superficiais do Distrito Federal. Brasília. IEMA/SEMATEC/UnB. Parte I.p. 86.

Fuck, R.A., Pimentel, M.M., D'el-Rey Silva, L.J.H., 1994. Compartimentação Tectônica na Porção Oriental da Província Tocantins. In: XXXVIII Congresso Brasileiro de Geologia, Camboriú, SBG, Boletim Resumos Expandidos SBG, 1; 215—217.

Fuck, R.A., Pimentel, M.M., Soares, J.E.P., Dantas, E.L., 2006. Faixa Brasília: Uma revisão. In: XLIII Congresso Brasileiro de Geologia, Aracaju, Anais SBG, SO4:AO-073; p. 27.

Ghiglione, M.C., Cristalline, E.O., 2007. Have the southernmost Andes been curved since Late Cretaceous time? An analog test for the Patagonian Orocline. Geology 35 (1), 13—16. doi:10.1130/G22770A.1.

Lemos, M.V.F., Morais, B.M., Lopes G.C., Pereira, K.M. da S., Perin, D.H.N., Silva, H.L., Freitas, L.L., D'el-Rey Silva, L.J.H., Carreiro, S.A. de A., Silva, H.Q.V., Oliveira, F.C. and Koth, L.B., 2008. Evolução Estrutural da área do Distrito Federal (Parte II): Relativa simplicidade e implicações tectônicas adicionais na evolução tectônica da Faixa Brasília, Brasil Central. 440 Congresso Brasileiro de Geologia, Curitiba, Outubro de 2008, Abstract also in CD-ROM.

Lister, G.S., Snoke, A.W., 1984. S-C mylonites. Journal of Structural Geology 6, 617—638.

Mantovani, M.S.M., Brito Neves, B.B. de, 2005. The Paranapanema lithospheric block: its importance for Proterozoic (Rodinia, Gondwana) supercontinent Theories. Gondwana Research 8 (3), 303—315.

Marini, O.J., Fuck, R.A., Dardenne, M.A., Danni, J.C.M., Almeid, F.F.M. de, Hasui, e Y., 1984. Província Tocantins, Setores Central e Sudeste. In: O Precambriano Do Brasil. Editora Edgard Blucher, pp. 205—264.

McClay, K.R., 1992. Thrust Tectonics. Chapman & Hall, London. 447 p.

Moreira, M.L.O., Moreton, L.C., Araújo, V.A. de, Lacerda Filho, J.M. de, Costa, H.F. da, 2008. Geologia do Estado de Goiás e Distrito Federal, Escala 1:500.000. CPRM/ SIC — FUNMINERAL, ISBN 978-85-7499-058-3.

Paixão, M.A.P., Nilson, A.A., Dantas, E.L., 2008. The Neoproterozoic Quatipuru Ophiolite and the Araguaia fold belt, central-northern Brazil, compared with correlatives in NW Africa. Geological Society London Special Publications 294, 297—318. doi:10.1144/SP294.16.

Pimentel, M.M., Fuck, R.A., Alvarenga, C.J.S., 1996a. Post-Brasiliano (Pan-African) high-K granitic magmatism in central Brazil: the role of late Precambrian-Early Paleozoic extension. Precambrian Research 80, 217—238.

Pimentel, M.M., Fuck, R.A., D'el-Rey Silva, L.J.H., 1996b. Dados Rb-Sr e Sm-Nd na região de Jussara-Goiás-Mossâmedes (GO), e o limite entre terrenos antigos do Maciço de Goiás e o Arco Magmático de Goiás. Revista Brasileira de Geociências 26 (2), 61—70.

Pimentel, M.M., Fuck, R.A., Botelho, N.F., 1999. Granites and the geodynamic history of the Neoproterozoic Brasília belt, Central Brazil: a review. Lithos 46, 463—483.

Pimentel, M.M., Dantas, E.L., Fuck, R.A., Armstrong, R.A., 2003. Shrimp and conventional U-Pb age, Sm-Nd isotopic characteristics and tectonic significance of the K-rich Itapuranga suite in Goiás, Central Brazil. Anais da Academia Brasileira de Ciências 73 (3), 97—108.

Ramsay, J.G., 1967. Folding and Fracturing of Rocks. McGraw-Hill Book Company. 568 p.

Sengupta, S., Ghosh, S.K., 2007. Origin of striping lineation and transposition of linear structures in shear zones. Journal of Structural Geology 29, 273—287. doi:10.1016/j.jsg.2006.08.012.

Silva, K.M. da, Carreiro, S.A., Lemos, M.V.F., Koth, L.B., Valente, H.Q., Perin, D.H.N., Freitas, L.L., Calacia, F.O., D'el-Rey Silva, L.J.H., Nascimento, B.M., Lopes, G. de C., Silva, H.L., 2008. Evolução Estrutural da área do Distrito Federal (Parte I): Complexidade e implicações na Evolução Tectônica da Faixa Brasília, Brasil central. Poster presented In: 440. Congresso Brasileiro de Geologia, Curitiba, Anais SBG, Abstract in p.762, also in CD-ROM.

Sussman, A.J., Weil, A.B. (Eds.), 2004, Orogenic Curvature: Integrating Paleomag-netic and Structural Analysis, vol. 383. Geological Society of America Special Paper, ISBN 0-8137-2383-3, p. 271.

Trompette, R., 1994. Geology of Western Gondwana. A.A. Balkema, Rotterdam. p350.

Twiss, R.J., Moores, E.M., 1992. Structural Geology. W.H. Freeman & Co., p. 532.

Valeriano, C. de M., Teixeira, W., Heilbron, M., Simões, L.S.de A., 2000. Southern

Brasilia belt (SE Brazil): tectonic discontinuities, K-Ar data and evolution during the Neoproterozoic Brasíliano orogeny. Revista Brasileira de Geociências 30 (1), 195—199.

Valeriano, C.M., Dardenne, M.A., Fonseca, M.A., Simões, L.S.A., e Seer, J.H., Mantesso- Neto, V., Bartorelli, A., Carneiro, C.D.R., Brito Neves, B.B., 2004. Capítulo XXXII - Evolução Tectônica da Faixa Brasília. In: Geologia do Continente Sul-Americano. Evolução da Obra de Fernando Marques Flávio de Almeida. Beca Produções Culturais, São Paulo, pp. 575—593.

Yin, A., Debey, C.S., Webb, A.A.G., Kelty, T.K., Grove, M., Gebrels, G.E., Burgess, W.P., 2010. Geologic correlation of the Himalayan orogen and Indian craton: part1. Structural geology, U-Pb zircon geochronology, and tectonic evolution of the Shillong Plateau and its neighboring regions in NE India. GSA Bulletim 122 (3/4), 336—359. doi:10.1030/B26460.1.