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ORIGINAL PAPER

The transpressional connection between Dom Feliciano and Kaoko Belts at 580–550 Ma

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Abstract A new U–Pb SHRIMP age of 551 ± 4 Ma on a mylonitic porphyry that intruded into the Sierra Ballena Shear Zone (Southernmost Dom Feliciano Belt, Uruguay) and a review of relevant published data make possible a more refined correlation and reconstruction of Brasiliano/Pan-African transpressional events. Paleogeographic reconstruction, kinematics and timing of events indicate a connection between the shear systems of the Dom Feliciano and Kaoko Belts at 580–550 Ma. Sinistral transpression recorded in shear zones accommodates deformation subsequent to collision between the Congo and Río de la Plata Cratons. The correlation is strengthened by the similarity of magmatic and metamorphic ages in the Coastal Terrane of the Kaoko Belt and the Punta del Este Terrane of the Dom Feliciano Belt. This post-collisional sinistral transpression brought these units near to their final position in Gondwana and explains the different evolution at 550–530 Ma. While in the Kaoko Belt, an extensional episode resulted in exhumation as a consequence of collision in the Damara Belt, in the Dom Feliciano Belt, sinistral transpression occurred associated with the closure of the southern Adamastor Ocean due to Kalahari-Río de la Plata collision.

Keywords Dom Feliciano Belt · Kaoko Belt · Brasiliano · Pan-African · Transpressional deformation · Shear Zones

Introduction

The Neoproterozoic amalgamation of West Gondwana resulted from the convergence of the Río de la Plata, Kalahari and Congo Cratons (Fig. 1) and the formation of three orogenic belts in southern Africa, the Kaoko, Gariep and Damara Belts, respectively, and the associated Dom Feliciano Belt in the southern part of South America (Porada 1989; Prave 1996; Dürr and Dingeldey 1996). Porada (1979) already suggested a link between the Dom Feliciano Belt of South America and the Kaoko and Gariep Belts of southwestern Africa. In this paper, we present new data that support this link.

Effects of sinistral transpressional deformation during Brasiliano/Pan-African events have been found in the Dom Feliciano as well as in the Kaoko Belt (Fernandes et al. 1992; Dürr and Dingeldey 1996). Transpressional structures and central orogen transcurrent shear zones are major features controlling the architecture and evolution of both belts indicating oblique convergence of the Río de la Plata and Congo Cratons (Dürr and Dingeldey 1996; Fernandes and Koester 1999; Goscombe et al. 2003;

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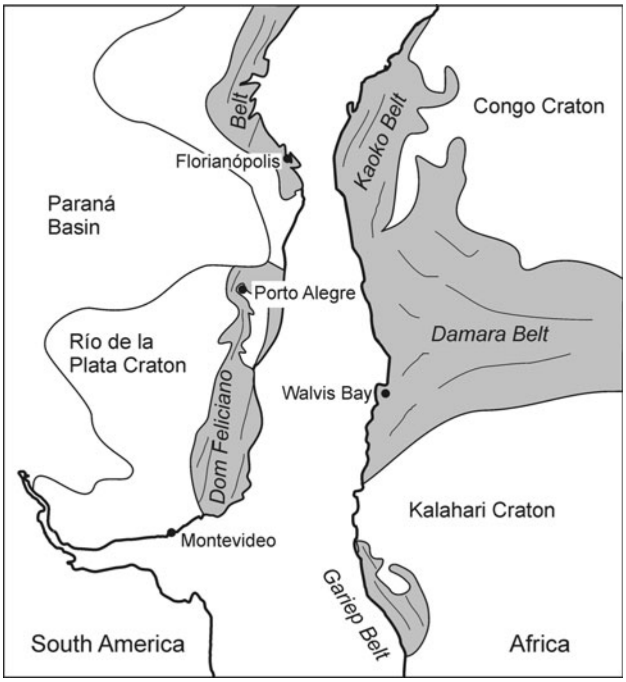


Fig. 1 Tectonic sketch map of Gondwana showing the positions of the cratonic nuclei and orogenic belts

Konopásek et al. 2005; Oyhantçabal et al. 2009a). During the last decade, a considerable amount of new data on both belts has been gathered, so that a better correlation of units and events between South American and African geology is now possible. Several recent structural and geochronological investigations in the southern Dom Feliciano Belt (Basei et al. 2005, 2008; Oyhantçabal et al. 2007, 2009a, b; Gross et al. 2009) and in the Kaoko Belt (Goscombe et al. 2003, 2005; Konopásek et al. 2005, 2008; Goscombe and Gray 2008; Foster et al. 2009) should help to constrain the tectonic evolution. Exhumation in orogens can be related to extrusion of blocks during transpression (Thompson et al. 1997) or to extension (Dewey 2002), therefore, available exhumation data should also be considered when reconstructing the evolution of an orogen.

Oyhantçabal (2005) indicated the possibility of a connection between the shear zones of the Kaoko and Dom Feliciano Belts. Later, de Wit et al. (2008) presented a tectonic map of Brasiliano/Pan-Africano structures in Africa and South America and emphasized the identical Neoproterozoic age and the potential connection or "piercing points" that these major subvertical shear zones represent, being therefore one of the prime targets for further geochronological and structural investigations. The aim of this paper is to discuss the correlation between tectonic events and associated shear zones in the Kaoko and Dom Feliciano Belts. This correlation enhances our understanding of the evolution of the Pan-African/Brasiliano orogenic system.

Geological framework

Dom Feliciano Belt (Uruguay and Southern Brazil)

The Dom Feliciano Belt (DFB) extends for more than 1,200 km from southern Uruguay to Santa Catarina State in Brazil. Several shear zones cross this belt, the most prominent of which are the Sierra Ballena (SBSZ) in Uruguay, and the Dorsal de Canguçu (DCSZ) and Major Gercinho (MGSZ) in southern Brazil (Fig. 2).

Three main geotectonic units are recognized in the Dom Feliciano Belt (Basei et al. 2000) from east to west (Fig. 2):

The Granite Belt comprises high-K calc-alkaline and subordinate peraluminous, and alkaline metaluminous granitoids. Most of the intrusions display a distinct relation with the main shear zones. The geochemical signature of this granitic magmatism suggests a post-collisional setting with slab break-off and lithosphere delamination as possible associated mechanisms (Bitencourt and Nardi 2000; Oyhantçabal et al. 2007). The age of the Granite Belt ranges between 630 and 600 Ma according to available U–Pb ages (SHRIMP and conventional).

The *Schist Belt* is a fold and thrust belt and comprises pre-collisional Neoproterozoic metavolcanic-sedimentary sequences. The metamorphic grade of these sequences reaches greenschist to lower amphibolite facies. The Lavalleja Group of Uruguay and the equivalent Porongos (Rio Grande do Sul) and Brusque (Santa Catarina) Groups of south Brazil are the lithostratigraphic units defined for this schist belt. Detrital zircon grains gave a maximum Neoproterozoic age for these sequences (Basei et al. 2008).

The *Foreland Belt* consists of several volcano-sedimentary and sedimentary successions of Ediacaran age (Gaucher 2000; Gaucher et al. 2003, 2004 and Pecoits et al. 2008), including marine to continental transition deposits (Arroyo del Soldado and Maldonado Groups in Uruguay and the Itajaí and Camaquã Basins in Brazil).

In the easternmost Dom Feliciano Belt, a pre-Brasiliano Basement Inlier, the Punta del Este Terrane (PET), consists of gneisses, migmatites and granulites of Neoproterozoic age (Oyhantçabal et al. 2009b). East of this basement, the low-grade meta-sedimentary rocks of the Rocha Group (Uruguay) have been associated with the Gariep Belt in Namibia, based on their provenance signature (Basei et al. 2005, 2008). Oyhantçabal et al. (2009b) recently reported new SHRIMP ages for the Punta del Este Terrane indicating a magmatic event at ca. 770 Ma followed by high-grade metamorphism at ca. 640 Ma. These magmatic and metamorphic ages suggest a connection between the Punta del Este Terrane of the Dom Feliciano Belt and the Coastal Terrane of the Kaoko Belt (Oyhantçabal et al. 2009b; Gross et al. 2009). The magmatic ages (850–750 Ma) in the Damara and Kaoko belts have been associated with a

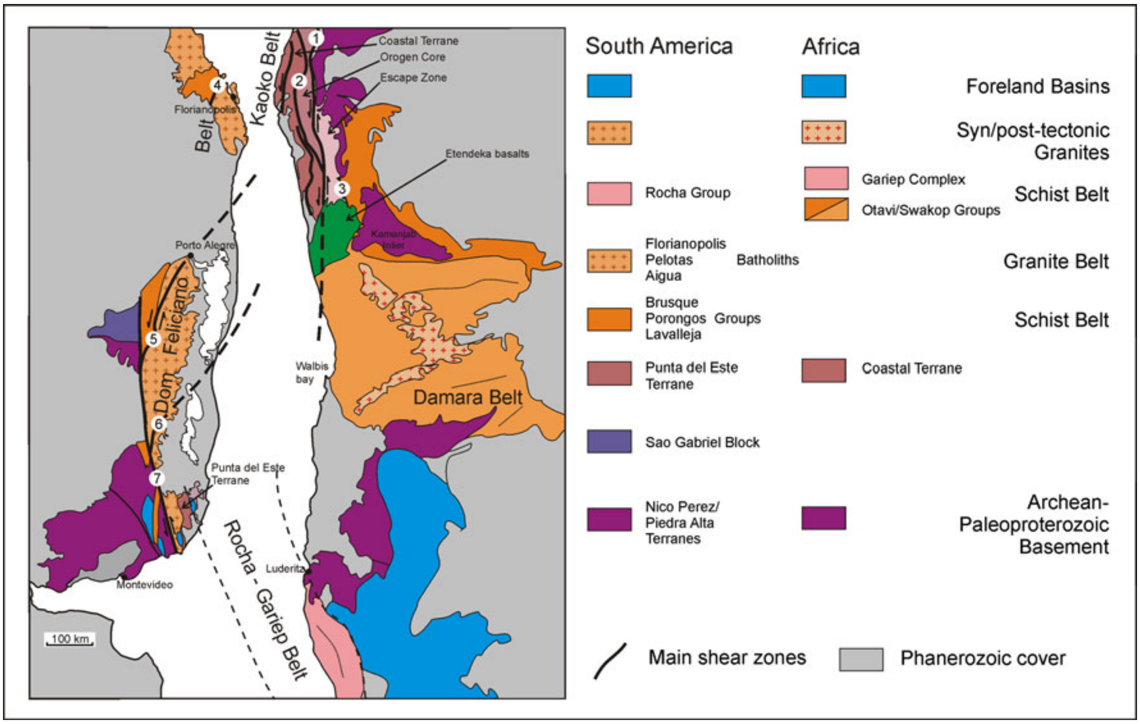


Fig. 2 Sketch map of the main units of the Brasiliano and Pan-African Orogens. South American side based on data from Basei et al. (2000, 2005); Hartmann et al. (2001, 2002); Silva et al. (2005); Philipp and Machado (2005) and Oyhantçabal et al. (2007, 2009a and b). South African side based on data from Gray et al. (2006); Goscombe and Gray (2008) and Gray et al. (2008). Main shear zones: (1) Purros, (2) Three Palms, (3) Sesfontein thrust, (4) Major Gercino, (5) Dorsal de Canguçu, (6) Cerro Amaro, (7) Sierra Ballena

pre-collisional rifting stage (Porada 1989; Prave 1996; Hoffmann et al. 2004; Konopásek et al. 2008).

Kaoko Belt (Namibia and Angola, Southwestern Africa)

The Kaoko Belt is divided into four main NNW-trending zones (Miller 1983; Goscombe et al. 2003; Konopásek et al. 2005; Goscombe and Gray 2008) bounded by three main lineaments, the Three Palms Shear Zone, the Purros Shear Zone and the Sesfontein Thrust (Fig. 2).

- The Eastern Zone comprises shelf carbonates of a foreland basin with low grade to very low grade metamorphism (Hoffman et al. 1998, cited by Goscombe et al. 2003; Konopásek et al. 2005). Deformation here is simple, with E-directed thrusting and associated folding of the sediments.
- The Central Kaoko Zone (“Escape zone” of Goscombe et al. 2005), west of the Sesfontein Thrust, is an inverted Barrovian metamorphic sequence in a complex alternation of igneous and sedimentary metamorphic rocks. Careful mapping, summarized by Goscombe and Gray (2008), revealed that part of the material is Paleoproterozoic basement, covered with a series of Neoproterozoic sediments. Deformation and metamorphism are intense and hamper separation of basement and cover. The basic structure, however, is one of nappes displaced to the east and separated from the Eastern zone by a low angle low grade to brittle fault zone, the Sesfontein Thrust.
- The Orogen Core (inboard Western Kaoko Zone of Goscombe and Gray 2007), located between Purros and Three Palms shear zones, includes Barrovian style metamorphic sequences and Mesoproterozoic basement inliers (Miller 1983; Seth et al. 1998; Konopásek et al. 2005; Goscombe and Gray 2007) and is dominated by strike slip tectonics.
- The Coastal Terrane comprises meta-sedimentary sequences with low pressure upper amphibolite metamorphism and Neoproterozoic I-type intrusions, indicating an arc-type setting with an age of 660–640 Ma (Konopásek et al. 2005; Goscombe et al. 2005). The coastal terrane and orogenic core are together also referred to as the “Western Zone” (Konopásek et al. 2005). The Coastal Terrane, however, shows evidence of a metamorphic cycle around 655–645 Ma, which is different from any other in the Kaoko Belt, indicating that it is part of an exotic terrain that docked to the developing Kaoko Belt in the latest Neoproterozoic. A

major strike slip shear zone, the Three Palms Shear Zone, separates the coastal terrane from the Central Zone. The suture zone, where the Coastal Terrane docked with the rest of the Kaoko Belt, sometime within the interval of 645–580 Ma, seems to be located between Three Palms and Purros shear zones and is probably masked by granitic intrusions (Goscombe et al. 2005; Konopásek et al. 2008).

The main transpressional event in the Kaoko Belt is associated with collision, transpressional deformation and emplacement of S-type granitoids at ~580–570 Ma. Cessation of transpressional deformation is constrained by post-kinematic pegmatites at ca. 530 Ma (Goscombe et al. 2005).

Main Brasiliano/Pan-African shear zones of the Kaoko and Dom Feliciano Belts

The Sierra Ballena shear zone of the Dom Feliciano Belt

The Sierra Ballena Shear Zone (SBSZ) is part of a high-strain transcurrent system that divides the Dom Feliciano Belt into two different domains. Major associated shear zones (see Fig. 2) are the Dorsal de Canguçu and Major Gercinho systems (in Río Grande do Sul and Santa Catarina of Brazil, respectively). Poor outcrop conditions away from the coast hamper exact reconstruction of the relation between these zones. The SBSZ is a NNW-SSE zone, ca 4 km wide, cropping out for more than 250 km with a steep foliation orientation. Stretching lineations show a shallow plunge to the SSW, and the kinematic regime is a sinistral oblique reverse motion (Oyhantçabal et al. 2009a). Four different kinds of mylonitic rocks have been recognized in the zone.

Granitic mylonites are the most widespread rock type and display a strongly foliated matrix wrapped around alkali feldspar and plagioclase porphyroclasts. Gradual transitions from protomylonite and mylonite to ultramylonite are observed. Syntectonic granites are normally the protolith of these mylonites and solid-state microstructures slightly to completely overprint magmatic features (Oyhantçabal et al. 2009a). Similar microstructures were described by Tommasi et al. (1994) from the Dorsal de Canguçu Shear Zone.

Phyllonites contain small rounded porphyroclasts of feldspar in a very fine-grained and finely banded matrix rich in muscovite and biotite laths. Gradual transitions between granitic mylonite and phyllonite are observed and suggest that these phyllonites were derived from granitic mylonites through comminution of feldspar and retrograde alteration to phyllosilicates due to the influx of water (Oyhantçabal et al. 2009a). Similar alterations are observed in other large shear zones (e.g. Imber et al. 1997).

Quartz mylonite, probably developed from quartz veins emplaced in the SBSZ, is common. Recrystallization in quartz includes subgrain rotation recrystallization and grain boundary migration.

Mylonitic porphyries represent the fourth kind of mylonite in the SBSZ. New chemical and geochronological data are presented in this paper on these porphyries as described in detail in the next section.

The microstructures present in the mylonites of the SBSZ are indicative of recovery and recrystallization in quartz by subgrain rotation and grain boundary migration under upper greenschist to lower amphibolite facies metamorphic conditions. Microstructures in feldspar are typical of deformation at mid to upper greenschist facies metamorphic conditions. A retrograde evolution during deformation is indicated for the SBSZ (Oyhantçabal et al. 2009a) as well as for the Dorsal de Canguçu Shear Zone (Tommasi et al. 1994).

Mylonitic porphyries

Mylonitic porphyries are the most unusual feature of the SBSZ. They were emplaced as dikes in the granitic mylonites and phyllonites and evolved to mylonites during later shearing and associated folding. The texture is porphyritic (Fig. 3) with residual phenocrysts (deformed to porphyroclasts) of alkali feldspar and quartz in a fine-grained and banded matrix. Na-amphibole is the most

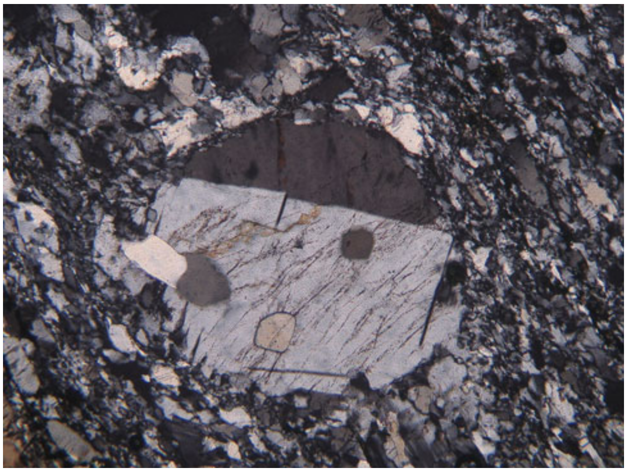


Fig. 3 Microstructural features of the mylonitic porphyries of the SBSZ. Sample UY5-05, section cut perpendicular to foliation and parallel to lineation. Feldspar porphyroclast (residual phenocryst), in foliated matrix. Crossed polarized light, width of view 1.8 mm

Table 1 Whole-rock major and trace element compositions of the mylonitic porphyries of Sierra Ballena shear zone

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	CO_2	H_2O	Total
Major elements													
SB091	75.8	0.20	10.5	3.93	0.007	0.17	0.34	2.90	4.88	0.05	0.39	<0.01	99.17
SB111	75.3	0.14	11.1	2.97	0.04	0.11	0.30	2.82	6.13	0.03	0.40	0.16	99.50
SB030	71.2	0.20	15.4	1.43	0.01	0.46	1.32	5.37	3.07	0.15	0.55	0.04	99.20
SB171	73.3	0.09	14.8	1.25	0.03	0.31	1.15	4.24	3.05	0.10	0.87	0.01	99.20

Sample	Ba	Cr	Ga	Nb	Rb	Sc	Sr	V	Y	Zn	Zr
Trace elements											
SB091	138	426	31	115	187	10	10	12	170	224	1,807
SB111	12	531	34	99	382	10	12	10	168	250	963
SB030	2,628	44	23	10	46	11	1,711	21	10	53	147
SB171	946	39	19	15	109	10	270	10	10	51	82

frequent mafic mineral, occurring as fine needles (about 0.02 mm in length), occasionally associated with aegirine-augite.

The fine-grained matrix of these dikes indicate subvolcanic emplacement. Evidence of dynamic recrystallization in feldspar, together with the occurrence of aegirine-augite in pressure shadows, suggest that deformation of these mylonitic porphyries began in the magmatic stage and continued in the solid state.

Geochemistry of the mylonitic porphyries

Analysis of major and trace elements for 4 samples of the mylonitic porphyries is presented in Table 1. Major element concentrations were determined by X-ray fluorescence (XRF), while the trace element concentrations were determined by ICP-MS at the laboratories of the Geoscience Centre of the University of Göttingen (Germany). The samples show high silica contents ranging from 71 to 76 wt%, suggesting the possibility of silica enrichment during mylonitization. K contents are high ($K_2O = 3.1$–4.9 wt%), and the rocks plot in the transalkaline field of Middlemost (1997). Shand's (1943) alumina and alkali saturation molar ratios indicate compositions in the transition between the metaluminous and peralkaline fields.

Using immobile elements, these rocks classify as trachyte and alkali rhyolite in the Nb/Y versus Zr/Ti diagram (Pearce 1996), and the Nb/Y ratio (ca. 1) indicates a transitional affinity between alkaline and subalkaline series (Fig. 4). Despite these few samples are not conclusive, the geochemical affinity is compatible with a post-collisional alkaline suite. In the Rb versus Y + Nb and Nb versus Y diagrams of Pearce et al. (1984), devised for granitoid rocks, the mylonitic porphyries plot in a scattered region, two in VAG field and two in WPG field (Fig. 5).

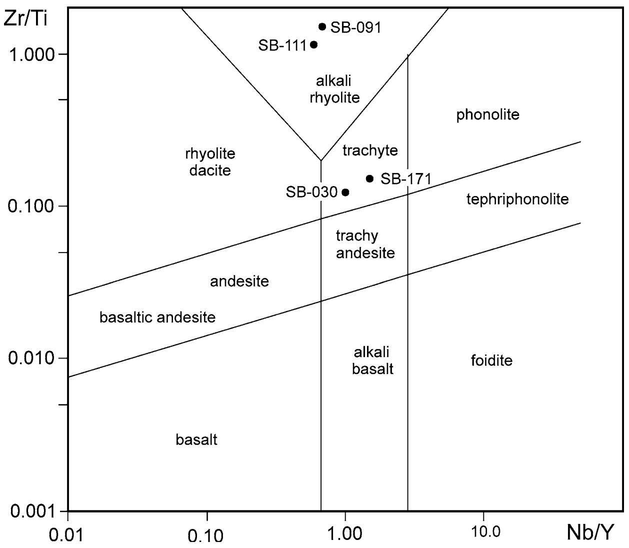


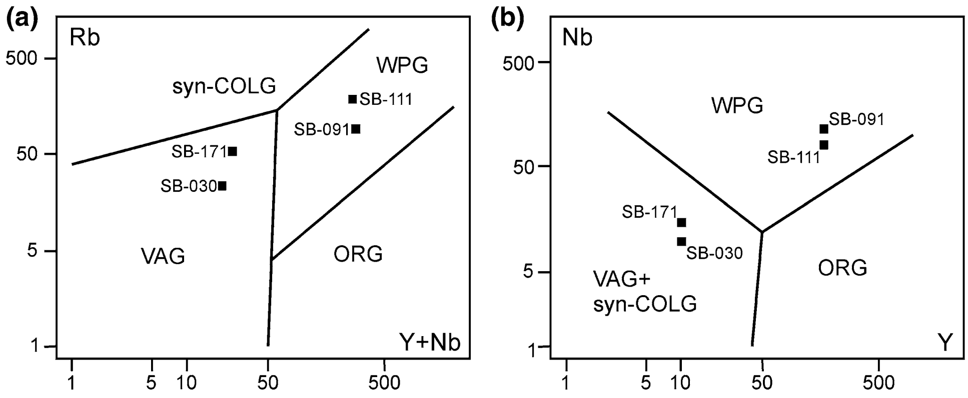
Fig. 4 Nb/Y versus Zr/Ti diagram (Pearce 1996) for the mylonitic porphyries

U–Pb SHRIMP geochronology of the mylonitic porphyries

U–Pb analyses of zircon grains from mylonitic porphyry were made using the SHRIMP II instrument at the Research School of Earth Sciences, ANU, Australia. The coordinates of the sample locality are 32°36′27.60″ S and 54°14′7.43″ W (datum WGS84), and the geological location is shown in Fig. 6. Ages are reported with their two-sigma uncertainties (95% confidence level). Results are given in the Table 2.

Sample UY5-05 is a fine-grained, dark-colored mylonite with small pyroxene and amphibole porphyroclasts. At the microscopic scale, a fine-grained banded matrix (0.1–0.2 mm) composed of quartz, perthitic orthoclase and

Fig. 5 Rb versus Y + Nb (**a**) and Nb versus Y (**b**) diagrams of Pearce et al. (1984) for the mylonitic porphyries



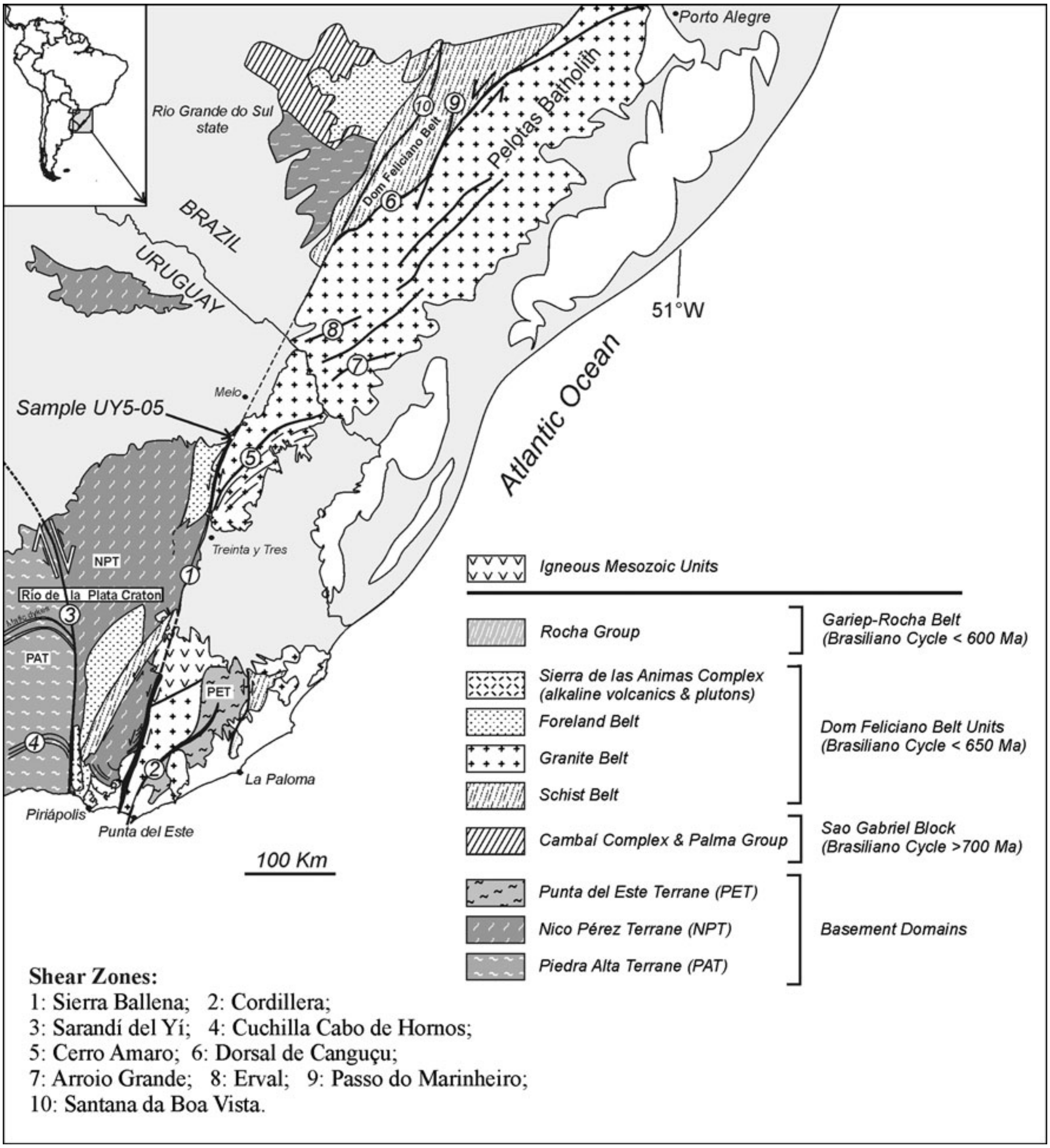


Fig. 6 Location of sample UY5-05 on a regional geological map of the southern Dom Feliciano Belt (modified from Oyhantçabal et al. 2009a)

Table 2 Summary of SHRIMP U–Pb zircon data for sample UY5-05

Grain spot	$\%^{206}Pb_c$	U ppm	Th ppm	$^{232}Th/^{238}U$	ppm $^{206}Pb^*$	$(1)^{206}Pb/^{238}U$ age	$(1)^{207}Pb/^{206}Pb$ age	% Discordant	$(1)^{207}Pb^*/^{206}Pb^*$	±%	$(1)^{207}Pb^*/^{235}U$	±%	$(1)^{206}Pb^*/^{238}U$	±%	Err. corr.
1.1	0.12	211	50	0.24	15.6	529 ± 5.8	539 ± 35	2	0.05824	1.6	0.687	2	0.08552	1.2	0.583
2.1	0.15	925	104	0.12	66.9	520.5 ± 5.2	531 ± 20	2	0.05804	0.89	0.673	1.4	0.0841	1	0.759
2.2	0.07	344	37	0.11	26	542.3 ± 5.8	557 ± 25	3	0.05874	1.1	0.711	1.6	0.08777	1.1	0.699
3.1	0.22	463	196	0.44	32.9	511.5 ± 5.3	521 ± 26	2	0.05776	1.2	0.658	1.6	0.08258	1.1	0.669
4.1	0.16	361	66	0.19	28.3	563 ± 6.1	533 ± 33	−6	0.05808	1.5	0.731	1.9	0.0913	1.1	0.602
5.1	0.49	153	9	0.06	11.6	539 ± 6.5	457 ± 69	−18	0.0561	3.1	0.675	3.4	0.0872	1.3	0.376
6.1	0.09	321	25	0.08	22.1	495.7 ± 5.5	563 ± 28	12	0.0589	1.3	0.649	1.7	0.07993	1.1	0.664
8.1	0.00	265	55	0.22	20.1	545.8 ± 7.3	574 ± 27	5	0.05918	1.2	0.721	1.9	0.0884	1.4	0.750
9.1	0.26	187	64	0.35	14.7	562.9 ± 6.9	573 ± 43	2	0.0592	2	0.744	2.4	0.0912	1.3	0.542
9.2	4.73	175	112	0.66	13.4	524.5 ± 9.2	529 ± 500	1	0.058	23	0.68	23	0.0848	1.8	0.079
10.1	0.00	166	32	0.20	12.9	558 ± 6.7	520 ± 38	−7	0.05774	1.7	0.72	2.1	0.0904	1.3	0.589
11.1	0.17	212	12	0.06	16.1	546.3 ± 7.3	534 ± 42	−2	0.0581	1.9	0.709	2.4	0.0884	1.4	0.585
12.1	0.97	413	66	0.17	30.1	520.2 ± 5.5	557 ± 58	7	0.0587	2.7	0.681	2.9	0.08404	1.1	0.382
13.1	0.21	220	11	0.05	16.9	549.2 ± 6.4	517 ± 39	−6	0.0577	1.8	0.707	2.2	0.0889	1.2	0.564
14.1	0.10	1,078	222	0.21	88.1	585 ± 6	523 ± 18	−12	0.05783	0.8	0.758	1.3	0.095	1.1	0.801
14.2	1.99	242	59	0.25	19	554 ± 7.5	595 ± 120	7	0.0598	5.3	0.739	5.5	0.0897	1.4	0.255
15.1	0.41	258	497	1.99	18.9	526 ± 5.9	518 ± 53	−2	0.0577	2.4	0.676	2.7	0.08502	1.2	0.440
15.2	0.05	622	82	0.14	45.9	531.3 ± 5.5	542 ± 20	2	0.05831	0.93	0.6907	1.4	0.08591	1.1	0.758
16.1	1.02	789	237	0.31	62	558.7 ± 5.8	536 ± 50	−4	0.0582	2.3	0.726	2.5	0.09054	1.1	0.427
17.1	0.19	230	14	0.06	15.6	487.1 ± 5.7	500 ± 46	3	0.0572	2.1	0.619	2.4	0.07849	1.2	0.505
18.1	0.24	1,168	145	0.13	88.3	542.3 ± 5.5	537 ± 22	−1	0.0582	1	0.704	1.5	0.08777	1.1	0.717

Errors are 1-sigma; Pb_c and Pb^* indicate the common and radiogenic portions, respectively

Error in Standard calibration was 0.35% (not included in above errors but required when comparing data from different mounts)

(1) Common Pb corrected using measured ^{204}Pb

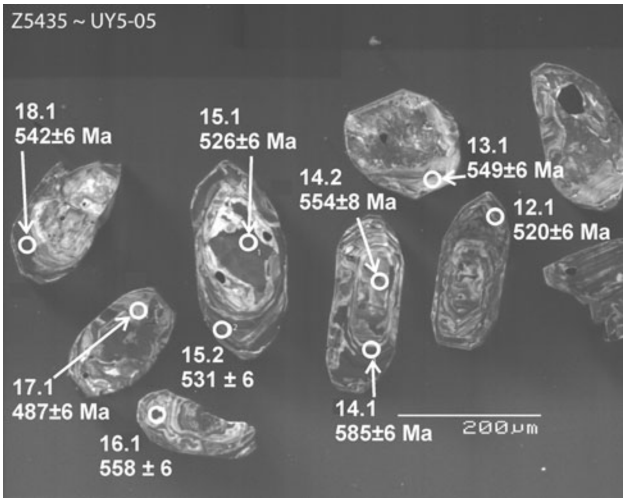


Fig. 7 Cathodoluminescence image of representative zircon grains form the sample UY5-05

dark-green blue amphibole needles is observable. The porphyroclasts are relictic phenocrysts of orthoclase, aegirine-augite and hornblende (about 1.0–1.5 mm), rounded and flattened (Fig. 3).

The zircon crystals of sample UY5-05 are euhedral, normal prismatic to stubby and brown. The length/width ratio is rather constant (ca. 3:1). Spectacular oscillatory zoning typical of magmatic crystallization and complex swirling zoning and patchy development of bright and dark zones is observable in cathodoluminescence images (Fig. 7).

A total of 21 points in 18 grains were measured. The data yield a near-concordant, upper intercept age of 537 ± 12 Ma (MSWD = 0.43, probability of fit = 0.98, $n = 21$; Fig. 8a). The points also yielded an identical weighted mean ^{207}Pb–^{206}Pb age of 537 ± 13 (95% conf.; MSWD = 0.44, probability = 0.98, $n = 21$). Assuming that Pb-loss gives the spread down of points along the concordia, after rejection of 10 points, a concordia age of 551 ± 4.4 Ma (95% conf.; MSWD = 1.18, probability = 0.28, $n = 11$) is obtained (Fig. 8b). This is the preferred age for the crystallization of these porphyries.

Age constraints for Sierra Ballena shear zone

Nucleation of the shear zones and the onset of the transpressional deformation are estimated based on the ages of associated syntectonic intrusions at 658 to 605 Ma (Frantz et al. 2003 and Oyhantçabal et al. 2007, 2009a).

After an extensional or transtensional episode (at ca. 590 Ma), a second transpressional episode is constrained by the ^{40}Ar/^{39}Ar cooling age of muscovite from quartz mylonite (586 ± 2 Ma; Oyhantçabal et al. 2009a) and the age of the syntectonic Maldonado granite (564 ± 7 Ma; U–Pb SHRIMP on zircon; Oyhantçabal et al. 2009b). The age of the alkaline magmatism associated with the mylonitic porphyries is 551 ± 4 Ma (U–Pb on zircon, this investigation). Quartz mylonites and mylonitic porphyries are spatially associated along the SBSZ. These data indicate cooling and closure of muscovite in the quartz mylonites occurred before the emplacement of the porphyries, and therefore, an exhumation episode older than 551 Ma is suggested.

For a review of the other major shear zones of the Dom Feliciano Belt, the reader is referred to Passarelli et al. (2010, this volume).

The shear zones of the Kaoko Belt

The Sesfontein, Purros (PSZ) and Three Palms shear zones (the last one equivalent to the Village Mylonite Zone of Goscombe et al. 2003 and Konopásek et al. 2005) are the main structures of the Kaoko transpressional belt (Fig. 2). All three structures are crustal scale shear zones of localized flow, although some branching is observed.

The Three Palms shear zone is 1 to 2 km wide and dominantly vertical. Stretching lineations show a shallow plunge to SSE indicating oblique extensional strike slip. The deformation conditions are typical exhumation during shear, and PT estimates show an evolution form

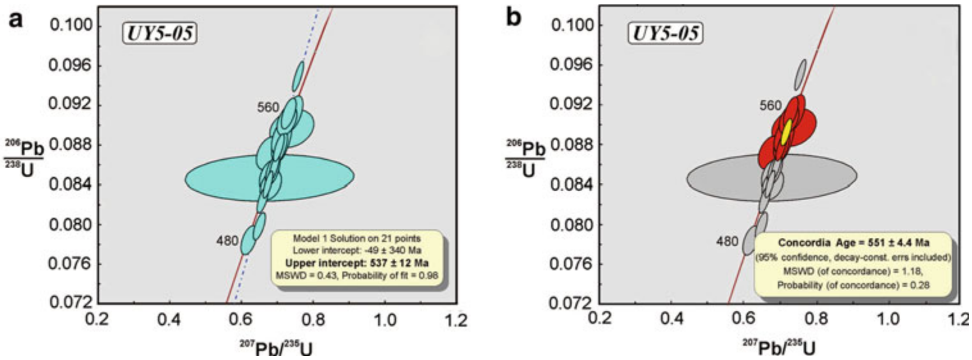


Fig. 8 U-Pb Concordia plots of SHRIMP data on zircon for sample UY5-05: **a** Model 1 solution on 21 points; **b** Concordia age on 11 points. Data symbolized with *gray ellipses* were rejected in age calculation. Ellipses represent 1σ errors

555–545°C, 4–4.8 kb through 580–450°C and finally brittle overprint under 290°C (Foster et al. 2009).

The Purros shear zone is 1 to 5 km wide and seems to have a west-dipping listric shape, with steep orientations in the north and shallower orientations in the south (Goscombe et al. 2005). Stretching lineations plunge to NNW, and therefore, kinematics is oblique reverse. The deformation conditions do not show contrast with the country rock, and overprinting by low-temperature deformation is very scarce. PT estimates for deformation are 640°C–8.8 kb, 620–580°C, 4.4–4.6 kb (Foster et al., 2009). The Sesfontein shear zone is west dipping with dominantly shallow dip and low-grade mylonitic to brittle deformation structures.

The kinematics of the three shear zones as indicated by the orientation of aggregate lineations and shear sense indicators is laterally variable. The Sesfontein shear zone operated by thrusting to the east toward the foreland at low grade. The oldest fabrics in the belt are gently plunging foliations and lineations, presumably associated with west-dipping subduction that caused docking of the coastal terrane after 600 Ma (Goscombe et al. 2005). The suture, located between the Three Palms and Purros shear zones, is probably masked by the Boundary Igneous Complex (Konopásek et al. 2008). The Purros and Three Palms shear zones overprint this fabric and were established later and are now dominantly sinistral strike slip shear zones with a component of thrusting in the Purros shear zone, based on gently N-plunging lineations, and a extensional component in the Three Palms shear zone, with gently south-plunging lineations.

Foster et al. (2009) point out that structures and metamorphic assemblages show evidence of retrograde juxtaposition of HT-medium P in the Orogen core and HP-moderate T inverted Barrovian metamorphism in the Central Zone and therefore favor differential exhumation during oblique extension instead of the extrusion of the Orogen Core during transpression as suggested previously by Goscombe and Gray (2008). Ar–Ar data in the Three Palms, Khumib and Village shear zones indicate this differential exhumation occurred at 530–520 Ma and is probably associated with the final closure of the Damara Belt (Foster et al. 2009).

Tectonic evolution and the transpressional connection between Dom Feliciano and Kaoko Belts

Pre-collisional magmatism and HT metamorphism in the Coastal terrane of the Kaoko Belt and in the Punta de Este Terrane of the Dom Feliciano Belt

In the reconstruction of the Pre-Atlantic ocean, the present Dom Feliciano Belts of Uruguay and the Kaoko Belt of Namibia are opposite and close together, separated by an obscured zone of possibly several hundred km wide, presently below the shelves of South America and Africa. Magmatism at 850–750 Ma has been indicated in the Punta del Este Terrane of the Dom Feliciano Belt and in the Coastal Terrane of the Kaoko Belt, suggesting a connection between both Terranes (Oyhantçabal et al. 2009b). This range of magmatic ages has been associated with pre-collisional rifting in Damara and Kaoko belts (Porada 1989; Prave 1996; Hoffmann et al. 2004; Konopásek et al. 2008). High-temperature metamorphism at 650–600 Ma confirms the suggested connection (Gross et al. 2009; Oyhantçabal et al. 2009b).

Calc-alkaline magmatism with arc affinity, recorded between 660 and 650 Ma in the Coastal Terrane (Masberg et al. 2005; Goscombe et al. 2005) and between 650 and 600 Ma in the Granite Belt of the Dom Feliciano Belt (Frantz et al. 2003; Oyhantçabal et al. 2007, 2009b), supports westward subduction and suggests the above-mentioned HT metamorphism probably occurred in the root of a magmatic arc. In this tectonic scenario, the Schist Belt of the DFB (Fig. 2) can be interpreted as the back arc, as suggested by Jost and Bitencourt (1980) and Sánchez-Bettucci et al. (2001).

Exhumation and deposition of molasse deposits in the DFB

Available cooling ages on muscovite from pegmatite dikes of the Punta del Este Terrane indicate cooling below 300–400° at ca. 620 Ma (Oyhantçabal et al. 2009b). This early exhumation in the South American side is consistent with the deposition of the Ediacaran sedimentary sequences of Arroyo del Soldado and Maldonado Groups (Gaucher et al. 2003; Pecoits et al. 2008) and is probably related to exhumation after the collision of the magmatic arc with the Rio de la Plata Craton. There is no record up to now of this event on the African side.

Post-collisional transpressional magmatism and deformation in the Kaoko and Dom Feliciano Belts

Magmatism related to transcurrent transpressional tectonics at 580–550 Ma is well documented in both belts. In the Solís de Mataojo granite of Uruguay (584 ± 13 Ma; Pb–Pb on titanite; Oyhantçabal et al. 2007), meso and microstructures, formed during transitions from magmatic to solid-state, are evidence of flattening and sinistral shearing (Oyhantçabal et al. 2001). Similar flattening structures, but with evidence for east-side up kinematics, were observed in the Maldonado Granite (564 ± 7 Ma; U–Pb SHRIMP on Zircon; Oyhantçabal et al. 2009b), on the eastern side of the Sierra Ballena Shear Zone (Figs. 2 and 6).

Syn- to post-kinematic S-type granites, with ages in the range 580–550 Ma, are frequent in the Coastal Terrane and the westernmost Orogen Core (Seth et al. 1998; Franz et al. 1999; Kröner et al. 2004; Goscombe et al. 2005). The age of this magmatism corresponds to the post-collisional transpressional stage (580–550 Ma; Goscombe and Gray 2008; Konopásek et al. 2008).

Extension and exhumation in the Kaoko Belt

According to Foster et al. (2009), exhumation and juxtaposition of high- and low- pressure domains in the Kaoko Belt occurred between 530 and 525 Ma, after the main transpressive event, by oblique extension associated with the closure of the Damara Belt. A correlative extensional event on the South American side was not reported. The U–Pb SHRIMP age of the mylonitic porphyries presented in this investigation could represent the record of this event, considering the suggested within-plate affinity, but further investigation is necessary. A possible explanation of the difference observed between Kaoko and southern Dom Feliciano Belts at 530–520 Ma is that the main sinistral transpressional phase (580–550 Ma) had already brought the units near to their final position in the Gondwana supercontinent, and therefore, the far-field effect of the closure of the Damara Belt was different.

In the southern Dom Feliciano Belt, the final amalgamation of Gondwana resulted in the closure of the Rocha-Gariep Basin in Ediacaran times, as a consequence of the collision of Kalahari and Río de la Plata Cratons (Frimmel and Frank 1998; Frimmel and Fölling 2004; Basei et al. 2005). This late event in the evolution of the Brasiliano Cycle probably represents a second orogenic event, younger than the Dom Feliciano orogeny. The closure of the Rocha-Gariep Belt (550–540 Ma; Frimmel and Frank 1998; Basei et al. 2005, 2008) should be responsible of the folding observed in the mylonitic porphyries of Sierra Ballena Shear Zone and in the final structure of SBSZ (Oyhantçabal et al. 2009a). For a sketch of the proposed evolution, see Fig. 9. Schmitt et al. (2008) reported a 530–490 Ma tectono-metamorphic event, the Búzios Orogeny, in the Cabo Frio tectonic domain of Rio de Janeiro (Brazil). This event is a late collision associated with the final assembly of Gondwana and is probably coeval with the extension recorded in the Kaoko Belt and the closure of Damara, taking into account the different trends of these orogens (Fig. 1 in Schmitt et al. 2008).

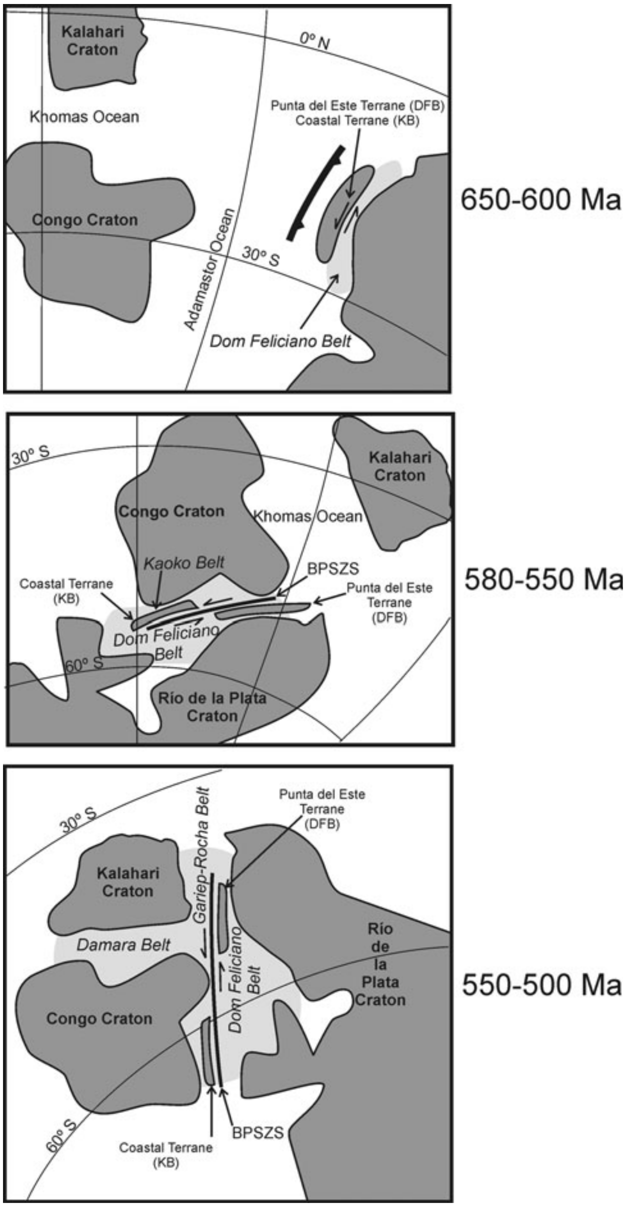


Fig. 9 Proposed evolution. Schema based on Figs. 8 to 10 of Gray et al. (2008) slightly modified to show the Punta del Este Terrane of the Dom Feliciano Belt and the Coastal Terrane of the Kaoko Belt. BPSZS, Ballena-Purros Shear Zone System

Conclusions

A review of recently published data for Dom Feliciano and Kaoko Belts reveals the following main points:

1. Magmatic ages at 850–750 Ma and metamorphic peak at ca. 650 Ma indicate a connection between the Coastal Terrane of the Kaoko Belt and the Punta del Este Terrane of the Dom Feliciano Belt. Both terranes were probably part of one single continental magmatic arc that collided with the Río de La Plata Craton closing the back arc basin of the Schist Belt (Lavalleja, Porongos and Brusque groups). The age of this collision is poorly constrained between 650 and 600 Ma, based on high T metamorphic peak.

2. Collision of the Río de la Plata Craton (including the Schist and Granite Belts, and the Punta del Este Terrane of the Dom Feliciano Belt) with the Congo Craton resulted in post-collisional transpression at 580–550 Ma in the Kaoko and Dom Feliciano Belts.
3. The post collisional sinistral transpression at 580–550 Ma brought the units near to their final position in Gondwana, and therefore, the influence of Damara and Gariep orogenies was different. This sinistral transpression and separation of the Coastal Terrane of the Kaoko Belt and the Punta del Este Terrane of the Dom Feliciano imply that the Sierra Ballena-Purros system produced a final displacement over several 100 km. While in the Kaoko Belt, an extensional episode resulted in exhumation between 520 and 524 Ma as a consequence of collision in the Damara Belt (Foster et al. 2009), in the Dom Feliciano Belt, sinistral transpression occurred associated with the closure of the southern Adamastor Ocean.

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