



## TRACKING DOWN THE NEOPROTEROZOIC CONNECTION BETWEEN SOUTHERN AFRICA AND SOUTH AMERICA - A REVISED GEODYNAMIC MODEL FOR SW-GONDWANA AMALGAMATION

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### INTRODUCTION

Previous geodynamic models for the amalgamation of SW-Gondwana along the Pan-African/Brasiliano tectonic belts of southwestern Africa and southeastern South America postulate a wide ocean to have separated Neoproterozoic South America from southern Africa (Adamastor Ocean), with the modern South Atlantic following largely the Pan-African suture. The generally preferred model for the amalgamation for SW-Gondwana cratonic fragments involves the progressive closure of the assumed Adamastor Ocean from north to south. Initial convergence between the Congo and northern Rio de la Plata Cratons, evident in the Kaoko Belt (Dürr and Dingeldey, 1996), was followed by northwesterly subduction of the Kalahari plate (Khomos Ocean) beneath the Congo Craton (Miller, 1983), resulting in the Damara Belt, and eventually subduction of the southern Adamastor oceanic basin to the northwest beneath the South American plate, giving rise to the Gariep Belt (Frimmel et al., 1996). Over the past few years, a great number of new data has emerged from the various Pan-African/Brasiliano belts that flank the modern South Atlantic, which are inconsistent with the above sequence of postulated events and thus require a thorough revision of the existing geodynamic models. These include a much improved geochronological resolution and characterization of tectono-thermal events that shaped the Kaoko Belt (Goscombe et al., 2005), improved age control on and stratigraphic correlation of Neoproterozoic sedimentary units across southwestern Africa (Frimmel et al., 2002; Gaucher et al., 2005; Hoffmann et al., 2004), and a provenance analysis of Neoproterozoic clastic sediments in the Punta del Este Terrane (southern Dom Feliciano Belt) and the Gariep Belt (Basei et al., 2005). While the relationship between the tectonic evolution that is recorded in the various Pan-African/Brasiliano belts in west and central Africa and in eastern Brazil has been well summarized in a recent paper by da Silva et al. (2005), this study focuses on the equivalent belts further to the south, i.e. the Dom Feliciano and Gariep Belts.

### THE AFRICAN AFFINITY OF THE PUNTA DEL ESTE TERRANE

The Punta del Este Terrane, the easternmost tectonic unit of Uruguay, is bordered to the west by the Alferrez-Cordillera-Punta del Este Lineament. Along that shear zone, calc-alkaline granitoids of the Aiguá Batholith were thrust eastwards on top of the Punta del Este Terrane. That batholith has been correlated with the 640 to 590 Ma Pelotas and Florianópolis Batholiths further to the northeast (Babinski et al., 1997; Basei et al., 2000), which represent the deep roots of an extensive volcanic arc along the Dom Feliciano Belt. Other authors consider the Punta del Este Terrane and the Pelotas-Aiguá Batholith as a single tectonostratigraphic unit (Cuchilla Dionisio Terrane, Bossi and Gaucher, 2004). Late-tectonic granite bodies within the Aiguá Batholith yielded slightly younger U-Pb zircon ages between 590 and 570 Ma (Preciozzi et al., 2001), which set a minimum constraint on the juxtaposition of the Punta del Este Terrane and the Aiguá Batholith. The terrane consists of a high-grade metamorphic basement that is overlain by intermediate to felsic metavolcanic rocks (Cerro de Aguirre Formation) and siliciclastic rocks (Rocha Group). In contrast to all other tectonic units in that region of South America, which are dominated by Archaean to Palaeoproterozoic crust, the basement of the Punta del Este Terrane was formed at approximately 1.0 Ga - analogous to the Namaqua-Natal Belt in southern Africa. A high-grade metamorphic overprint of this basement is recorded at approximately 630 Ma (Preciozzi et al., 1999). The overlying volcanic and sedimentary rocks conspicuously lack evidence of this event that corresponds in time with volcanic arc formation in the belt. Thus they must be younger - a relationship that is directly confirmed by a date of  $572 \pm 11$  Ma for the Cerro de Aguirre Formation (Hartmann et al., 2002), and indirectly by the youngest detrital zircon age data reported for the Rocha Group (Basei et al., 2005).

A distinct difference in the nature of the underlying Precambrian crust between the west and the east of the

Dom Feliciano magmatic arc has been noted previously, based on the distribution of Nd model ages (Basei et al., 2001; Bossi and Gaucher, 2004). The mean  $T_{DM}$  model age in the metamorphic belts and foreland basins to the west of the Dom Feliciano granite belt are 1.91 Ga with an age group around 2.1 Ga dominating, that of the adjacent cratonic basement is 2.51 Ga and there the distribution is skewed towards older Archaean ages. In contrast, the mean model ages in the granite belt and in the metamorphic belts and corresponding foreland basins in southern Africa are with respectively 1.62, 1.59 and 1.58 Ga significantly younger. In contrast to the domains west of the granite belt, the Nd model ages of the granite belt and the metamorphic belts of southern Africa are marked by Mesoproterozoic as opposed to Palaeo-proterozoic data. This difference has led Basei et al. (2001) to suggest that the Punta del Este Terrane forms part of the African crust and furthermore that the Dom Feliciano magmatic arc is related to the accretion of that African crust to the South American side during the amalgamation of Gondwana.

Recently acquired provenance data from Neoproterozoic siliciclastic successions in the uppermost parts of the Pan-African Gariep Belt (Oranjemund Group in the allochthonous, largely oceanic Marmora Terrane) in southwestern Africa, as well as in the Rocha Group revealed a strong similarity between the Rocha and Oranjemund groups (Basei et al., 2005). Both groups bear not only strong lithological similarities, but also share a common metamorphic (low-grade) and structural history. Age spectra obtained by SHRIMP U-Pb analyses of detrital zircon grains from arenite samples of the Oranjemund and the Rocha Groups are very similar. In both units, zircon grains of 1.0 to 1.2 Ga dominate, with a further peak in the age distribution between 1.7 and 2.0 Ga. These ages compare well with the pre-Gariep basement geology in southwestern Africa, where the former age range corresponds to magmatic and high-grade metamorphic activity in the Mesoproterozoic Namaqua-Natal Belt and the latter to an extensive Palaeoproterozoic Andean-type volcanic arc (Richtersveld Terrane). Comparable ages are conspicuously absent in the basement of the Rio de la Plata Craton in South America. A minor age group around 800 Ma in both units can be explained by the erosion of equivalents to 762 Ma granite in the pre-Rocha basement (Hartmann et al., 2002), as well as 830 and 771 Ma granite and syenite in the pre-Gariep basement in South Africa (Frimmel et al., 2001). The youngest detrital zircon grains in both groups have an age of approximately 600 Ma. Derivation of the Rocha Group sediments from a similar source as the apparently contemporaneous Oranjemund Group sediments is therefore suggested. The most likely source of the youngest detrital zircon grains in these two stratigraphic units is the 640 to 590 Ma magmatic arc of the Dom Feliciano Belt, thus further corroborating the suggestion of an African affinity of the Punta del Este Terrane.

## MAGMATISM IN THE GARIEP BELT

The tectono-thermal evolution of a geological terrain is typically a reflection of its tectonic setting. A generally low metamorphic grade across the Gariep orogenic belt is not very diagnostic, although the absence of a proper high-P/low-T metamorphic belt is noteworthy. Consequently, the type of magmatism in that orogen might be more revealing. Of prime importance is the absence of any syn-tectonic calc-alkaline magmatism. Three stages of magmatic activity are recognised: (i) pre-tectonic alkaline felsic magmatism during the pre-rift and rift stage, (ii) predominantly mafic magmatism at the continental break-up stage and subsequent oceanic crust formation, and (iii) post-orogenic alkaline magmatism. Of significance for the topic of this study are the first two stages.

Pulses of pre-rift shallow-level granite and syenite intrusions have been dated at 830, 800 and 771 Ma and can be explained by thinning of continental crust (Frimmel et al., 2001). The latter age provides the maximum age limit for sedimentation in the Gariep Basin. Syn-rift magmatism is recorded in two stratigraphic positions, the c. 750 Ma Rosh Pinah Formation and the slightly older Vredefontein Formation. The former bears all the petrological and geochemical hallmarks of bimodal (rhyolitic and basaltic melts) continental rift-magmatism, but the latter is different by spanning a wide range in composition with predominance of trachyandesite. Compared to the nearby, only slightly older pre-rift Richtersveld Suite, whose trace element distribution is in accordance with continental within-plate granite, the metavolcanic rocks of the Vredefontein Formation are depleted in Ta, similar to ocean-ridge granite, but conform in other trace element ratios to melts derived from the lower crust. A large mafic dyke swarm of tholeiitic composition (Gannakouriep Suite) was emplaced at the advanced stage of rifting and delineates the palaeo-stress field during continental break-up.

Oceanic crustal material is well preserved in the Marmora Terrane in the form of metabasalt, metagabbro and to a lesser extent metasomatised ultramafic rocks and various submarine pyroclastic deposits (Bakers Bay Suite, Dernburg and Grootderm Formations). Geochemically, these rocks are largely comparable with oceanic islands and to a lesser extent mid-ocean-ridge basalt, MORB (Frimmel et al., 1996). Their age is not well dated but is estimated to be between 620 and 580 Ma. Of note are relatively high  $\epsilon_{Nd}(t)$  values between +3.1 and +6.1 that were calculated not only for the mafic rocks in the Marmora Terrane but also for those in the continental syn-rift Rosh Pinah Formation and Gannakouriep Suite dykes. Calculated Nd model ages are far too low for oceanic island basalt in the Marmora Terrane and the Gannakouriep Suite dykes, indicating derivation from melting of a depleted mantle, whereas those for the mafic rocks with MORB-affinity are Palaeoproterozoic (2.1 - 2.3 Ga). The mafic rocks of the Rosh Pinah Formation yielded Nd model ages between 1.0 and 1.1 Ga, analogous to their Pb model ages, which

reflect the late Mesoproterozoic basement (Bushmanland Terrane) there.

## IMPLICATION FOR THE GEODYNAMIC EVOLUTION

In the light of the above Nd model ages, differences in the tectono-thermal history of the Palaeo- to Mesoproterozoic basements, the recent provenance data, as well as the distribution and timing of Neoproterozoic magmatic units and metamorphic field gradients across the Pan-African/Brasiliano belts in southeastern Brazil and Uruguay and in southern Africa, the existing model of a wide Adamastor Ocean having separated Neoproterozoic South America from Africa has to be abandoned. As suggested by Bossi and Gaucher (2004), the main suture between the two palaeocontinents is suspected to be west of the Dom Feliciano magmatic arc (Major Gercino – Sierra Ballena Shear Zone), with the Punta del Este Terrane forming the westernmost part of the Kalahari Craton, which consolidated at the end of the Mesoproterozoic. Consequently, the main oceanic basin that separated palaeo-South America from southern Africa (Adamastor Ocean) must have been located between today's granite belt and the Río de la Plata Craton (Nico Pérez Terrane, Fig. 1). Following this conclusion, a two-stage basin evolution is suggested for the "Gariép Basin", which is now understood as a successor basin: first, opening of a failed continental rift basin (770 - 740 Ma), and then, separated by a major break in sedimentation, the re-activation of that older basin to a back-arc basin in response to the formation of the 640 to 590 Ma magmatic arc in the Dom Feliciano Belt.

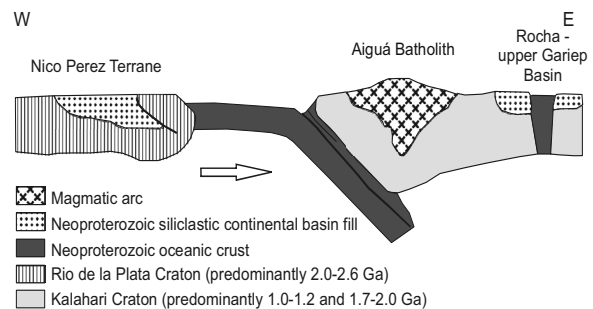
Rifting was most likely not a far-distance effect of contractional tectonic activity in palaeo-South America, but rather related to a long-lasting thermal anomaly in the mantle beneath the Kalahari Craton. The signature of that anomaly can be traced over more than 200 myr from pre-rift (Richersveld Suite) to late-rift magmatism (Gannakouriep Suite) and to the formation of oceanic islands in the younger back-arc basin. Melts not related to that mantle anomaly show strong contamination with older crustal material that reflects regional differences in the make-up of the basement.

The Rocha and Oranjemund Groups on either side of the modern South Atlantic are considered equivalent and their upper parts related to sedimentation in a foredeep subsequent to tectonic inversion at approximately 580 Ma and prior to continental collision at 550 to 545 Ma. Such a two-stage basin evolution model also helps to overcome a fundamental problem in our understanding of the Gariépien rock record. Previously, assuming a Wilson-Cycle model for the Gariép Belt, a conspicuous lack of sediment was noted for the passive margin stage (Frimmel, 2004). In the meantime, a major hiatus in sedimentation has been recognized across the continental part of the Gariép Belt at the base of the Wallekraal Formation within the Hilda Subgroup. The new geodynamic model proposed here would explain the lack

of progressive basin subsidence and thus the lack of sedimentation after rifting. Most probably, the area around the Gariép Belt was land at that time, which would explain the conspicuous absence of the global Marinoan glacial deposits in the Gariép Belt as revealed by recent micropalaeontological data (Gaucher et al., 2005). Sedimentation only commenced again, after a break of more than 100 myr, during the back-arc stage. The limited amount of oceanic crust formed in that basin was insufficient to sink below the adjacent continental fragments and, in the absence of any subduction, remained well preserved in thrust slices of the Marmora Terrane.

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**Fig. 1.** Schematic proposed geodynamic setting of eastern Uruguay relative to southwestern Africa at 600 Ma.

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## RESUMO

Dados recentes sobre a proveniência das sucessões siliciclásticas Neoproterozóicas das porções estratigráfica e tectonicamente basais e superiores do cinturão Pan-africano Gariep (Sub-grupo Stinkfontein, sedimentos continentais da zona para -alóctone de Port Nolloth e o Grupo Oranjemund da porção predominante oceânica do Terreno Marmora) no sudoeste da África, bem como no Grupo Rocha do Terreno Punta del Este (Cinturão Dom Feliciano) no Uruguai, dados isotópicos Sm-Nd em rocha total, como também a distribuição e idade das unidades magmáticas Neoproterozóicas e os gradientes metamórficos através desses Cinturões, requerem uma revisão dos modelos geotectônicos precedentes para a amalgamação da porção SW do Gondwana. O modelo existente implicando em um vasto oceano Adamastor separando América do Sul da África tem que ser abandonado. Adicionalmente, é sugerido que a principal sutura entre os dois paleocontinentes esteja posicionada a oeste das raízes do arco-vulcânico do Cinturão Don-Feliciano, com o Terreno Punta Del Este, cujo embasamento consolidou-se ao final do Mesoproterozóico, representando a porção mais ocidental do Craton do Kalahari. Para a paleobacia do Cinturão Gariep, é proposta uma evolução em dois estágios: primeiramente abertura de uma bacia de rifte- continental abortada (770-740 Ma), a seguir após por uma grande interrupção na sedimentação (provavelmente ocupando todo o tempo da glaciação global Marinoana), teria ocorrido a reativação dessa bacia para uma bacia do tipo back-arc em resposta a formação do arco magmático do Cinturão Dom Feliciano (640 a 590 Ma). Uma limitada geração de crosta oceânica formou-se nesse estágio, agora preservada no Terreno Marmora. O Grupos Rocha e Oranjemund em ambos lados do atual Oceano Atlântico são considerados equivalentes e, suas porções superiores relacionadas a sedimentação em uma bacia de ante-país subsequente a inversão tectônica (ca. 580Ma) e anterior a colisão continental ocorrida entre 550-545Ma.