NEOPROTEROZOIC EVOLUTION OF SOUTHWESTERN GONDWANA

[1]GRESSE, P.G., [2]SILVA, L.C. da, [3]GERMS, G.J.B. [4]HARTMANN, L.A. AND [5]ROZENDAAL, A. [1]Council for Geoscience, Bellville, South Africa; Geological Survey of Brazil-PRM, Belo Horizonte, Brazil; [3]P.O. Box 4043, Helikonpark, South Africa; [4]UFRGS, Porto Alegre, Brazil; [5]University of Stellenbosch, Stellenbosch, South Africa.

Summary

The Pan-African/Brasiliano belts and foreland basins of southern Africa and southern Brazil are ancient global scars left by the coalescence of the southwestern Gondwanan cratons, following breakup of Rodinia. Southern African and South American cratons apparently constituted corresponding opposing margins from breakup to reconstruction. The continents that rifted and drifted away from the southern African margin are unknown and the ones that took their place in Gondwana are speculative. On the southern African plate the western Pan-African belts are represented by overthrusted, interleaved remnants of the rifted margin successions, containing representatives of two global Neoproterozoic glaciogenic events, oceanic crust and reactivated basement. The southern belt constitutes accreted terranes overprinted by late- to post-orogenic strike-slip related magmatism, ranging from ~550-510 Ma, and derived from juvenile Pan-African and reworked Mesoproterozoic crust. In southern Brazil the Brasiliano belts constitute minor juvenile and major crustal orogenic magmatism from ~ 780-590 Ma. Post-orogenic magmatism is associated with the foreland basins and ranges in age between ~540 Ma and ~500 Ma. Age differences of up to 80 Ma between the syntectonic Dom Feliciano magmatism (~630 Ma) and the Cape Granite Suite (~550 Ma) in the Saldania Belt militate against a direct link between the two belts (Silva, 1999) as thought before. Foreland basins on the African side contain well preserved records of Ediacaran soft body fossils and Cambrian trace fossil fauna. The geotectonic development of these belts and their forelands can be linked to simultaneous transpressive subduction processes in the paleo-Atlantic and -Southern Oceans driven by the opening of Iapetus.

Introduction

In southern Africa the Damara, Kaoko, Gariep and Saldania collision/accretion orogens, have been thrust onto the western and southern margins of the Kalahari and Kongo cratons. They are craton-verging thrust-and-fold belts and strike-slip transpressive orogens containing mixed tectonostratigraphic successions of rifted margin deposits, Mesoproterozoic basement and juvenile oceanic crust. Cratonward of these belts, late Neoproterozoic to Cambrian foreland deposits such as the Mulden, Nama, Vanrhynsdorp and upper Kango Groups reflect the late- to synorogenic sedimentary response to crustal shortening in the mobile belts and thrust loading of the craton margins.

In southern Brazil, the Neoproterozoic belts record an early thrust movement toward the eastern Kalahari Craton, in the western Vila Nova Terrane (São Gabriel Orogeny), and a younger northwestward movement, towards the Rio de La Plata Craton, as in the eastern Dom Feliciano Belt. These orogenic events were succeeded by the deposition of the late-to post-tectonic foreland deposits of the Itajaí and Camaquã basins.

Pan-African/Brasiliano Cycle in southern Africa and southern Brazil

With the breakup of the supercontinent Rodinia an interconnected complex of rift basins developed between 780-750 Ma. They became the depositional loci for Pan-African and Brasiliano sedimentary successions. In southern Africa the Damara and Gariep Supergroups and the Malmesbury and Kango Groups, among others, were deposited. In southern Brazil these deposits are represented by the Porongos Group and Vacacaí Supergroup. Subsequently, during the construction of Gondwana in the Late Neoproterozoic to Early Cambrian, closure and inversion of these oceans occurred to produce orogenic mountain belts flanked by foreland basins.

Rifting

Rifting between the southern African and southern American cratons apparently proceeded in the form of a series of stepped pull-apart basins defined by northwest-trending, dextral transtensional margins and north-northeast-trending normal rift margins (Gresse, 1995). The zig-zag shape of the southern African coast line, following the sinuous onshore-offshore exposure patterns of the Pan-African belts from Gabon to Cape Town, reflect the original rift-basin morphology. Northwesterly-trending transtensional basin margins coincided with transform faults offsetting the northerly trending proto-Atlantic (Adamastor) spreading ridge. The configuration and age of rifting is well constrained in the northern Damara and Gariep belts. Rift volcanics in the Port Nolloth Group of the Gariep Belt have been dated at 743±6 Ma (Frimmel *et al.*, 1996), conforming to an age of 741±6 Ma for similar volcanics in the Damara Belt of northern Namibia (Hoffman *et al.*, 1994).

In Brazil, new well-constrained isotopic ages of the volcanic-plutonic felsic sequence in the Porongos Group, dated at ~780 Ma (Silva, 1999; Porcher *et al.*, 1999) points to earlier rift initiation along the Brazilian margin, perhaps before opening of the Adamastor Ocean proper. Glacial deposits of Sturtian age (~760-700 Ma) associated with the rift successions of the northern Damara basin (Khomas Sea, Chuos tillite), Kaoko basin (Chuos and Gaub formations) and the Gariep basin (Kaigas Formation) agree with the volcanic ages. In the south, rifting along the northern margin of the Saldania Belt (southern margin of the Kalahari Craton) was constrained by the same plate movements and, by inference, must have occurred at about the same time.

Similarities between the WPB-MORB chemistry of juvenile Pan-African, alkaline oceanic crustal fragments (Bridgetown Formation of the Saldania Belt, and the Schakalsberg and Chameis Complexes of the Gariep Belt) support a common source and possibly similar age (>600 <700 Ma) for oceanic spreading in these two belts. The Matchless amphibolite represents spreading in the Damara Belt and in southern Brazil the Cerro Mantiqueira ophiolitic remnants in the far west (Vila Nova Belt) indicate slightly older oceanic spreading between ~780 Ma (rifting) and ~730 Ma (peak of first collisional metamorphism) in an older, westerly situated oceanic basin. Subsequently, another oceanic basin, bordering the African cratons, opened to the east. Rift models suggest that the orthogonally stepped semi-pull-apart basins along the western rift-margin of the Congo and Kalahari cratons developed sequentially from south to north. They were most likely interconnected, but their deposits were perhaps slightly diachronous, each characterized by rapid facies variations along the active strike-slip and normal-faulted margins.

Oceanic closure

Reversal of spreading in the western (Vila Nova) ocean occurred prior to intra-oceanic collision at ~730 Ma. In the eastern Dom Feliciano and Ribeira belts collisional magmatism extend from 650 Ma to ~630 Ma. This agrees roughly with the age of reversal in the Adamastor Ocean as recorded in parts of the Pan-African belts, namely from 750-600 Ma in the Kaoko Belt, compared to 600-570 Ma in the Damara and Gariep belts. Orogenic vergence directions in the Kaoko, Damara and Gariep orogens are to the southeast. After initial convergence between the Congo and northern Rio de La Plata cratons (Kaoko and Dom Feliciano belts) between 750 Ma and 600 Ma (Dürr and Dingeldey, 1996), the southern African (Kalahari) plate was subducted in a northwesterly direction underneath the Congo Craton, colliding between 590-550 Ma. In the Gariep Belt, northwesterly subduction and collision with the South American plate (Frimmel *et al.*, 1996) occurred at around 545 Ma. This movement vector caused sinistral transpressional reactivation of the northeastern Gariep rift margin. Lateral ramp-style deformation along this margin merges with frontal ramp conditions along the orthogonal north-northeast-trending basin edge in the resultant Gariep Arc. The northeastern Saldanian margin, was reactivated in the same way and parallel terrane/accretion boundaries inside the Saldania Belt also exhibit evidence of early sinistral (ductile) shearing followed by later dextral and repeated sinistral movement. There does not appear to be a proper collision orogen developed in the Saldania Belt. This, together with the nature and age of late tectonic granite intrusions and the very young age of detrital zircons (~560 Ma), suggest that the southern terranes of the Saldania Belt represent allochthonous crustal fragments accreted laterally to the southern Kalahari margin. The metavolcanic Bridgetown Formation, which displays WPB/MORB characteristics, apparently forms the northern suture boundary of these terranes, possibly rafted off the Ross orogenic belt of the Transantarctic Mountain Range.

The Ross Orogen displays contrasting characteristics along strike. Early-stage granite intrusion into unfossiliferous sediments, related to west-directed transpressive subduction, occurred at about 540 Ma. I- and S-granites with ages of 500-470 Ma form a linear belt west of the suture zone, defined by ultramafic lenses. Orogenic contraction in the belt lasted until about 460 Ma. No conclusive fossil or isotopic evidence for Cambrian sediments has been found in the main part of the belt to date, although these are present in the Delamarian Orogen in the Australian segment of the belt and in the Ellsworth-Whitmore Mountains terrane. The sedimentary, tectonic and magmatic history of the Heritage Range corresponds in many respects to that of the Saldania Belt. Sinistral transpressive contraction and subduction in the Ross Orogen have been related to the opening of Iapetus (Grunow *et al.*, 1996), also responsible for the almost coeval closure of the Adamastor Ocean.

Magmatism

Multiphase S-, I- and A-type granites intruded the Damara, Gariep and Saldania belts. The Saldanian Cape Granite Suite intruded in a pervasive transpressive regime, resulting in prominently northwest-elongated late- to post-orogenic plutons. Only some of the older S-type intrusions display syn-intrusive ductile shearing and foliation development. Sequential intrusion of early S-type, crustal-derived granites followed by later I- and A-types with increasing juvenile mixing, indicates increased tectonic evolution of the controlling strike-slip zones. Granite ages range from 550-510 Ma and intrusion clearly post-dates peak metamorphism (Silva *et al.*, 1997). This is slightly younger than the peak of voluminous syntectonic granitoid intrusion in the Damara Belt between 580-535 Ma but compares reasonably well with the 545 Ma age of peak metamorphism in the Gariep Belt (Frimmel*et al.*, 1996).

The Cape Granite Suite is considerably younger than the collision-related granites of the Dom Feliciano Belt, the apparent counterpart of the Gariep and Kaoko belts on the South American continent. The southeastern Brazilian granites display a more complex history (Silva, 1999) including two collisional peaks: at ~ 730 Ma, the São Gabriel Orogeny (Early Brasiliano/Pan-African) and at ~ 630 Ma Dom Feliciano (and Ribeira) Orogeny (Middle Brasiliano/Pan-African). The former involves early ~780 Ma rifting and oceanic opening), followed by intra-oceanic subduction-related orogen development and collision at ~730-700 Ma. The younger Dom Feliciano/Ribeira belts are short-lived, collision-controlled orogens, marked by widespread crustal magmatism extending from 650 to 590 Ma. Based on this age discrepancy, Silva (1999), proposed that the Saldania Belt is unrelated to the Dom Feliciano Belt and represent accreted segments of, for example, the Ross Orogen or the basement of the Sierras Australes of Argentina. The presence of alkali volcanics that are chemically distinct from oceanic basalts of the Bridgetown Formation, in the accreted Saldanian terranes, support this model.

Late- to post-orogenic, metaluminous to peraluminous S- and I-type plutons of comparable age in the Ross Orogen, are also elongated in the dominant structural grain. They intrude unfossiliferous deposits (greywackes, etc.) of late Neoproterozoic age. These events occurred roughly coevally with closure of the Gariep-Damara-Dom Feliciano belts and must correspond to a common plate tectonic model that can accommodate simultaneous sinistral transpressive subduction in both belts. The rifting of Laurentia from South America and opening of the Iapetus Ocean provide a common driver for the formation of these orogens.

Foreland basins

Loading and depression of the southwestern Congo Craton led to foreland deposition in the upper Otavi and Mulden basins well before foreland activity started on the southern Kalahari Craton. Otavi Group glaciogenic sediments are 750-600 Ma old. Deposition in the Nama and Vanrhynsdorp peripheral foreland basins on the Kalahari Craton only started at about 570-560 Ma. An extensive unconformity, coinciding with peak metamorphism and collision at about 545 Ma (Precambrian-Cambrian boundary) in the Damara and Gariep belts, developed in the Nama foreland basin. The unconformity is overlain by coarse molasse deposits derived from the collision orogens (Nomtsas Formation and Fish River Group). The Nama Group is well known for its Ediacaran fauna (Germs, 1983). Recent discoveries of *Swartpuntia germsi* and *Pteridinium carolinaense* in the upper Schwarzrand Subgroup indicate that the Ediacaran fossils had a substantial age range until approximately 6 million years prior to the Precambrian-Cambrian boundary, i.e near the beginning of the Cambrian explosion (Grötzinger *et al.*, 1995). “Cambrian” trace fossils such as *Phycodes/Trichophycus pedum*, *Oldhamia*, *Curvolithos*, *Treptichnus* and *Monomorphichnus* are particularly common in the Vanrhynsdorp Group.

The Nama and Vanrhynsdorp foreland deposits were deformed by sinistral transpressive movements rooted in the marginal orogens between 534 and 495 Ma. Biotite cooling ages ranging from 485 to 495 Ma correspond to the timing of tectono-metamorphic events in the Ross Orogeny (Goodge and Dallmeyer, 1995). Along the southern Kalahari Craton, molassic deposits of the upper Kango Group contain ~519 Ma old detrital zircons, probably derived from the Cape Granite Suite or other magmatic rocks of similar age. We therefore propose deposition of the upper Kango Group in a syn- to post-orogenic intra-orogen or marginal pull–apart basin around 510 Ma, possibly related to collision/accretion in the Ross-Saldania orogen to the south. The marked younging of foreland deposits from about ~700 Ma in the north to about ~520 Ma in the south reflects sequential closure of the Adamastor Ocean from north to south.

Foreland and molasse basins in Brazil developed in retro-arc environments cratonward of back-arc fold-thrust belts. Present day exposures of the Camaquã and Itajaí basins are bounded by NE-striking faults along their southeastern and mostly also their northwestern margins. These faults are characterized by post-collisional, sinistral and dextral strike-slip reactivation. The voluminous volcanic and volcaniclastic component in the basin fills, as well as the related plutonism, in general support a proximal arc (retro-arc) setting.

The Camaquã basin contains an older deformed succession (>570 Ma) and a younger undeformed “molasse” succession (< 530 Ma). It is inferred that the last pulses of deformation in the bordering Dom Feliciano Belt advanced into the Camaquã basin, causing west-verging thrust and fold deformation in the older successions (Maricá and Bom Jardim groups), along the eastern margin. The upper Camaquã basin deposits (Santa Bárbara and Guarites groups) represent post-orogenic facies that may have been shed into the basin from the uplifted Dom Feliciano Belt during intrusion of the youngest granitic phases (post ~520 Ma) and transpressional strike-slip basin modification. The intrusive shoshonitic to alkaline granitoids has been dated at 568 ± 6 Ma (Rb-Sr wr - Lavras Granite), 519 ± 8 Ma (Rb-Sr wr - Sao Sepé Granite) and 539 ± 20 Ma (Jaguari Granite). The age of northwest-verging folding and thrusting in the Itajaí basin is loosely constrained by the intrusive Apiúna (Campo Alegre) rhyolites and the Subida granites with ages ranging from 600 to 580 Ma, representing the opening stages of the basins . These dates suggest that the Itajaí sediments were deformed after ~580 Ma coeval to the early stages of deformation like the lower Camaquã successions.

Conclusions

A semi-connected complex of rift basins constituted the Adamastor Ocean as it opened sequentially from south to north. These basins became the loci for Pan-African and Brasiliano volcano-sedimentary successions, such as those comprising the Kaoko, Damara, Gariep and Saldania belts on the southern African plates. Fragments of chemically similar, juvenile alkaline oceanic crust in the latter two belts, attest to spreading of a common ocean floor and evolving of marginal basins. In Southern Brazil an early rifting phase, (~800-730 Ma) culminated with ocean floor spreading (Cerro Mantiqueira ophiolitic remnants). This small, short-lived, segment of the Adamastor Ocean was recycled (subducted), generating the Cambaí TTG accreted association and the calc-alkaline dacitic Vacacaí arc volcanism, recording a collisional metamorphic peak at ~730 Ma.

After reversal of spreading in the Adamastor Ocean and initial convergence between the Congo and northern Rio de La Plato cratons, the Kalahari Craton was subducted to the northwest underneath the Congo and Rio de La Plata plates. This caused extrusion of the Congo Craton to the northeast and sinistral shear in the Kaoko Belt. The absence of a proper collision orogen, the presence of a suture zone of accreted oceanic crust and the strong northwesterly trending structural grain, support either low-angle oblique collision or strike-slip transpressional tectonics in the Saldania Belt. The spatial distribution of the late- to post-orogenic Cape Granite Suite in low-strain areas bordering zones of extensive strike-slip suggests generation and intrusion of magma within such a tectonic regime.

Although the timing of collision and peak metamorphism in the Gariep Belt coincides with the intrusion of this suite between 550-510 Ma, this setting contrasts sharply with that of collisional granites in the Dom Feliciano Belt, the apparent counterpart of the Gariep Belt on the South American continent. Furthermore, an age discrepancy of approximately 70 Ma between these two granitoid suites, favours correlation with comparable events in the Ross orogen. These differences notwithstanding, sequential north to south closure of the Kaoko-Damara-Gariep-Dom Feliciano belts and sinistral transpressive deformation in the Delamarian-Ross-Saldania orogenic chain are kinematically related and must fit a common plate tectonic model, possibly involving opening of the Iapetus Ocean in the Latest Vendian and Cambrian.

Syn- to post-orogenic sedimentary basins, hosting the Mulden, Nama and Vanrhynsdorp Groups and the upper Kango Group on the African side, and Camaquã, Itajaí and Guaratubinha basins in Brazil, developed in response to loading and pull-apart deformation of the Kongo, Kalahari and Rio de La Plata Craton margins and tensional or strike-slip sudsidence within the orogens themselves. Foreland basins on the Kongo and Rio de La Plata cratons developed earlier in response to orogenic events older than those reflected by basins on the Kalahari Craton. They were nonetheless deformed by events that can be matched with late Pan-African orogenesis along the Kalahari Craton margins. Upper sequences in the older basins are roughly coeval with deposits of the Kalahari basins, spanning the Precambrian-Cambrian boundary.

References

Dürr, S.B. and Dingeldey, D.P., 1996. The Kaoko belt (Namibia): Part of a late Neoproterozoic continental-scale strike-slip system. *Geology*, 24, 503-506.

Frimmel, H.E., Hartnady, C.J.H. and Koller, F., 1996. Geochemistry and tectonic setting of magmatic units in the Pan-African Gariep Belt, Namibia. *Chem. Geol* .,130, 101-121.

Germs, G.J.B., 1983. Implications of a sedimentary facies and depositional environmental analysis of the Nama Group in South West Africa/Namibia. *Spec. Publ. Geol. Soc. S. Afr*., 11, 89-114.

Goodge, J.W. and Dallmeyer, R.D., 1995. Contrasting basement kinematics and cooling histories within the Ross Orogen, Antarctica. *Abstract VII International Symposium on Antarctic Earth Sciences*, Siena (Italy), 162.

Gresse, P.G., 1995. Transpression and transection in the late Pan-African Vanrhynsdorp foreland thrust-fold belt, South Africa, *J. Afr. Earth. Sci.*, 21, 91-105.

Grötzinger, J.P., Bowring, S.A., Saylor, B.Z. and Kaufman, A.J., 1995. Biostratigraphic and geochronologic constraints of early animal evolution: *Science*, 270, 598-604.

Grunow, A., Hanson, R. and Wilson, T., 1996. Were aspects of Pan-African deformation linked to Iapetus opening?. *Geology*, 24, 1063-1066.

Hoffmann, P.F., Bowring, S.A. and Isachsen, C.E., 1994. New U-Pb zircon ages for the early Damaran Oas syenite (Welwitschia inlier) and upper Naauwpoort volcanics (Summas Mts), Namibia. *Abstracts Proterozoic Crustal & Metallogenic Evolution, Windhoek, 29 August - 1 September 1994, 30.*

Porcher, C.C., McNaughton, N.J., Leite, J.A.D., Hartmann, L.A., Fernandes, L.A.D. (1999). Geochronology of Proterozoic basement-cover relationships in the southern Brazilian Porongos Belt. *Precambrian Res.* (submitted).

Silva, L.C. da, 1999. *Geocronologia U-Pb SHRIMP e Sm-Nd na província Mantiqueira meridional, no Cinturão Saldania (África do Sul) e a evolução do Ciclo Brasiiliano/Pan-Africano.* (Ph.D. thesis, unpubl.). Universidade Federal do Rio Grande do Sul, Porto Alegre, 243p.

Silva, L.C. da, McNaughton, N.J., Hartmann, L.A., Flechter, I.R., Gresse, P.G. and Scheepers, R., 1997. U-Pb (SHRIMP) isotopic constraints for the evolution of southern Brazilian granitic province, and some correlated South African, Pan-African plutons: *Second International Symposium on Granites and Associated Mineralizations*, Salvador, 1997, 276-277.