PROTEROZOIC TECTONIC EVOLUTION OF SOUTHERN AFRICA

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Introduction

Africa contains some of the world's most extensive exposures of Precambrian crust. These exposures reveal a complex tectonic pattern shown by continental shields worldwide, in which Archean cratonic nuclei stabilized by 2.5 Ga are wrapped by a series of Proterozoic orogenic belts. Orogenesis in the African belts occurred predominantly at 2.0-1.8 Ga, 1.35-1.0 Ga, and 700-500 Ma. Broadly coeval orogenic episodes are recognized in other continents and reflect global patterns of supercontinent assembly and dispersal during the Proterozoic.

Traditionally, the terms "Eburnian," "Kibaran," and "Pan-African" have been used to denote the three Proterozoic orogenic episodes in Africa. I do not use the first two of these terms here because both were originally coined to refer to specific orogenic domains or belts (Eburnian domain in West Africa, Kibaran belt in Central Africa). A consensus appears to be emerging that "Kibaran" should be used only for the belt of that name in Central Africa, and similar arguments can be extended to use of "Eburnian." I continue to use "Pan-African" to encompass Neoproterozoic-Early Paleozoic orogenic activity recognizable over large parts of Africa.

Here I review the Proterozoic tectonic evolution of Africa south of the Equator (Fig. 1), concentrating on the belts formed during the three orogenic episodes mentioned above. Archean cratonic nuclei in this region include the Tanzania craton, and the Zimbabwe and Kaapvaal cratons welded along the Archean Limpopo belt. Archean crust also is exposed on the flanks of the Congo Basin, including the Angola-Kasai craton and parts of the Angola basement farther west. Recent years have seen a pronounced increase in our understanding of the Proterozoic belts that surround and separate these cratons, but there are still many gaps in our knowledge. This is due partly to the fact that critical parts of the orogenic network are blanketed by Phanerozoic deposits in the Congo Basin and Kalahari Desert. Also, precise isotopic age constraints are lacking for many areas. U-Pb zircon ages are emphasized herein whenever possible, but in some regions reliance still must be placed on less reliable geochronometers.

2.0-1.8 Ga Orogenic Belts

Original relations of the Paleoproterozoic crustal elements shown in Figure 1 in many cases are unclear because of plate displacements associated with younger Proterozoic belts. The Ubendian-Usagaran orogen, which wraps the southern margin of the Tanzania craton, formed by oblique collision at 2.0-1.8 Ga between that craton and an unidentified craton to the southeast. In the Usagaran belt, supracrustal rocks of the Usagaran Supergroup along the southeast margin of the Tanzania craton were imbricated in a frontal thrust zone during the collision. West-vergent thrusting was linked to lateral accretion of granulite- and amphibolite-facies gneissic terranes in a dextral shear regime in the Ubendian belt along the southwest craton margin. 2.0 Ga eclogites with MORB affinities and high-pressure granulites are present in both the Usagaran and Ubendian belts, recording subduction of oceanic lithosphere and collisional crustal thickening. In places the high-pressure rocks are juxtaposed with broadly coeval low-pressure granulites, indicating imbrication of tectonic slices from different crustal levels. Emplacement of extensive late-syntectonic felsic volcanic rocks and granitoids at 1.8 Ga on the adjacent Bangweulu block may reflect anatexis of thickened crust during final phases of collision.

A second major Paleoproterozoic orogen is located west of the Zimbabwe and Kaapvaal cratons and is represented by the Magondi and Kheis belts exposed at either end of the Kalahari Desert in Botswana. The Magondi belt contains a thick supracrustal succession (Magondi Supergroup) that forms an east-vergent fold-thrust belt along the Zimbabwe craton margin. Rift-related basalts and terrigenous deposits at the base of the succession pass upward into a passive-margin sequence containing abundant carbonates. These rocks interfinger westward with deeper marine pelites and sandstones. Felsic volcaniclastic intercalations within the deeper marine rocks suggest that the sequence accumulated in a back-arc setting behind a west-facing volcanic arc, remnants of which may be represented by extensive granitoid rocks in the western part of the belt. Archean basement is at least locally present in that region, implying that the arc may have been built on a fragment of older crust. Collisional orogenesis occurred at 2.0-1.9 Ga, based on U-Pb zircon ages for syntectonic granitoids emplaced during granulite-facies metamorphism in the core of the orogen.

Geophysical and borehole evidence shows the Magondi belt to continue to the south beneath extensive cover in the Kalahari Desert. Small exposures of 2.05 Ga granite, metarhyolite, and gneiss protruding locally through the Kalahari sands help to delimit the largely buried Paleoproterozoic orogen in this region. Farther south, the Kheis belt exposes another thick supracrustal succession (Olifantshoek Supergroup), which is thrust eastward onto the Kaapvaal craton margin. Rift-related volcanic rocks in the lower part of the supergroup were erupted at 1.9 Ga. Orogenesis in the Kheis belt is not well dated but ended by 1.75 Ga. Basin initiation in the Kheis belt occurred at the same time as contractional deformation in the Magondi belt to the north, indicating that parts of the Kheis-Magondi orogen evolved diachronously along strike.

The central part of the Archean Limpopo belt underwent granulite-grade transpressional shearing and syntectonic granite intrusion at 2.0 Ga, in the same time frame as Kheis-Magondi orogenesis. Hence, a buried triple junction must connect Paleoproterozoic elements of the Limpopo belt with the Kheis-Magondi orogen to the west (Fig. 1). Shearing in the Limpopo belt is inferred to represent reactivation of Archean lines of weakness during orogenesis along the convergent margin to the west. The enormous Bushveld and Molopo Farms layered mafic intrusions were emplaced in adjacent parts of the Kaapvaal craton at 2.05 Ga, and possible relations between this within-plate magmatic episode and evolution of the Kheis-Magondi-Limpopo system require further investigation.

Another, more poorly understood Paleoproterozoic orogenic province occurs in the northwestern part of the area shown in Figure 1. This province includes 2.0 Ga basement in the Pan-African West Congo belt, as well as extensive basement exposures in western Angola. It can be traced south into northern Namibia, where it forms 2.0-1.7 Ga basement inliers in the Kaoko and Damara belts. Limited outcrops of 2.05 Ga granite gneiss along the Namibia/Botswana border in the Kalahari Desert represent a similar inlier, and parts of the Angola-Kasai craton record tectonothermal activity in this time frame. This unnamed Paleoproterozoic province is separated from the broadly coeval Kheis-Magondi orogen to the southeast by younger Proterozoic belts and should be considered separate from it.

1.35-1.0 Ga Orogenic Belts

Mesoproterozoic orogenic belts in southern Africa record accretion of juvenile arc terranes and microcontinents leading to final assembly of the Rodinia supercontinent by 1.0 Ga. In South Africa, the Namaqua and Natal belts are exposed segments of a single, continuous orogenic province that can be traced geophysically along the southern margin of the Kaapvaal craton. Deformed Mesoproterozoic supracrustal rocks in this orogen include a passive margin sequence in Natal and volcano-sedimentary sequences farther west (Bushmanland Group, etc.) that accumulated in rift basins on older continental crust, probably in convergent-margin settings. The Namaqua belt contains extensive amounts of reworked, 2.0-1.8 Ga basement (including the large Richtersveld terrane), but accreted, ~1.3 Ga juvenile arc crust also is present. In the Natal belt, an ophiolitic slab with a complex pre-obduction history of arc plutonism and deformation structurally overlies the Kaapvaal craton margin and is succeeded outboard by accreted juvenile arc terranes. Orogenesis in both the Namaqua and Natal belts involved polyphase ductile deformation, regional metamorphism at amphibolite to granulite grade, and emplacement of diverse plutonic suites. The main orogenic activity is dated at 1.2-1.0 Ga, but there is evidence for earlier tectonothermal events back to ~1.35 Ga. Late, steep transcurrent shear zones show a regionally consistent kinematic pattern around the convex southwest margin of the Kaapvaal craton, which appears to have acted as an indentor in an overall contractional regime.

North of the Namibia-South Africa border, the low-grade, 1.2 Ga, arc-related Sinclair Sequence is exposed between the coast and younger cover to the east. These rocks overlie 1.38 Ga gneissic basement that records early Namaqua orogenic activity. They represent a volcano-plutonic complex preserved at higher crustal levels than coeval, high-grade parts of the Namaqua belt to the southeast.

The Namaqua belt is separated from the Kaapvaal craton by the 2.0-1.8 Ga Kheis belt. An analogous tectonic pattern occurs on the other side of the Kalahari Desert, where the Magondi belt occurs between the Zimbabwe craton and the Choma-Kalomo block to the west. Amphibolite-facies supracrustal rocks in the Choma-Kalomo block were deformed along northeast trends and intruded by syn- to post-tectonic granitoid plutons at 1.35-1.2 Ga. Subsurface data indicate that structural trends in the Choma-Kalomo block continue beneath Kalahari cover into Botswana. Limited exposures of 1.1 Ga bimodal magmatic rocks in Botswana directly along strike from the Choma-Kalomo block are inferred to represent a late-orogenic rift developed on a buried connection between the block and the Namaqua belt. These bimodal magmatic rocks can be traced into the southern foreland of the younger Damara belt. They form parts of the Umkondo igneous province that was emplaced at 1.1 Ga over a wide area behind segments of the Namaqua-Natal belt undergoing culminating phases of orogenesis in the same time frame. Formation of this within-plate igneous province during Rodinia assembly appears to reflect an interplay between an uprising mantle plume and stresses transmitted inboard from the convergent plate boundary.

An extensive region affected by 1.35-1.0 Ga orogenesis also occurs in the northeastern part of the area shown in Figure 1, west and south of the Tanzania craton. The Kibaran and Irumide belts both contain thick, dominantly terrigenous successions (Kibaran and Muva Supergroups, respectively) that underwent thrusting at variable metamorphic grades, together with intrusion by syn- to post-tectonic granitoid plutons. The main orogenic pulse in the Kibaran belt occurred at 1.37 Ga and was followed by transcurrent shearing at 1.25 Ga, but the timing of orogenesis in the Irumide belt is less well constrained. Emplacement of widespread tin granites in the Kibaran belt at 1.0 Ga was associated with domainal shearing, and late syn- to post-tectonic plutons were intruded in the Irumide belt in the same time frame. The two belts are separated by the Bangweulu block, which is affected by west-vergent thrusting linked to orthogonal contraction in the Irumide belt. Some workers have suggested that Irumide contraction is accommodated northward by transcurrent shearing along reactivated parts of the Ubendian belt. Although structural relations at the northern end of the Irumide belt presently are controversial, it seems likely that deformation in the Irumide and Kibaran belts was kinematically linked on a large scale.

Recent interpretations suggest that the Muva Supergroup in the Irumide belt in Zambia passes laterally eastward into a highly deformed continental shelf/slope assemblage in Malawi. Reworked Paleoproterozoic and Archean (?) massifs in southeast Zambia and parts of Malawi (e.g., Champira dome) may represent parautochthonous basement to these supracrustal rocks. Eastern Malawi and adjacent parts of Mozambique are underlain by amphibolite- and granulite-facies rocks that represent Mesoproterozoic crust overprinted to various degrees by Pan-African orogenesis. Extensive calc-alkaline meta-igneous rocks with low initial Sr isotopic ratios and protolith ages of 1.1-1.0 Ga in this region are reasonably interpreted as juvenile arc crust accreted, at least in part, during Mesoproterozoic orogenesis. Similar basement is present in portions of the Pan-African Zambezi belt along the northern margin of the Zimbabwe craton, where a dismembered 1.4 Ga ophiolite recently has been documented.

The Kibaran and Irumide belts and associated juvenile arc crust in the area between the Tanzania and Zimbabwe cratons appear to represent a single, long-lived Mesoproterozoic orogenic province that is likely to have played an important role in assembly of the Rodinia supercontinent. A major problem in delimiting the original extent of the province is the strong Pan-African overprint in the eastern part of this region. 1.1-1.0 Ga juvenile arc crust extends all the way to the coast in Mozambique, but a significant portion of that material may have been accreted or displaced laterally during Pan-African collisional orogenesis in the Mozambique belt.

The Kibaran belt disappears beneath cover in easternmost Angola but may connect with poorly understood rocks of similar age exposed in the Angola basement to the southwest. In contrast, the Irumide belt and Mesoproterozoic terranes farther east abut against the Pan-African Zambezi belt and Lufilian arc. It has been suggested that the Choma-Kalomo block in southern Zambia is the direct continuation of the Irumide belt on the other side of the Zambezi belt. This requires further testing but, if true, would mean that only limited displacements occurred along the Zambezi belt/Lufilian arc during the Pan-African event and would imply that a major part of southern Africa was assembled during 1.35-1.0 Ga orogenesis.

Pan-African Belts

On a global scale, the Neoproterozoic Era records a profound episode of plate reorganization linked to the supercontinent cycle. Initial stages of rifting began to affect parts of Rodinia shortly after its formation and led to progressive fragmentation of the supercontinent at 750-550 Ma. Reassembly of the component cratons into the younger Gondwana supercontinent created a plexus of mountain belts that can be traced throughout the southern continents, including the widespread Pan-African orogenic network in Africa.

Crust stabilized in southern Africa after Rodinia assembly at 1.0 Ga occupies two major cratonic blocks, the Congo and Kalahari cratons, which are separated by the transcontinental Pan-African Damara-Lufilian-Zambezi orogenic system. These cratons represent two of the main building blocks of the Rodinia and Gondwana supercontinents. Their relative positions prior to final assembly of Gondwana are controversial, but arguments mentioned above, if correct, would imply that the two cratons were not displaced substantially from each other during Rodinia breakup and subsequent formation of Gondwana.

Early stages in the evolution of the Pan-African orogenic network in southern Africa are represented by rifting and within-plate magmatism associated with Rodinia fragmentation. Emplacement of alkaline plutons (e.g., Richtersveld Intrusive Suite) at 920 Ma in parts of the Namaqua belt provides some of the earliest evidence for this change in tectonic regime. Bimodal igneous rocks in the West Congo belt, which have recently yielded U-Pb zircon ages of 920 Ma, also reflect extensional tectonism in this time frame. Rift-related rhyolites near the base of thick supracrustal sequences in the Gariep and Damara belts were extruded at 760-740 Ma, and bimodal magmatic assemblages in the Lufilian arc and Zambezi belt inferred to have been emplaced in rift environments range in age from 880 to 740 Ma. In the Ubendian and Kibaran belts, a series of 800-740 Ma alkaline plutonic centers reflect uprise of mantle-derived magmas along older lines of structural weakness. These alkaline centers were emplaced in a similar time frame to extrusion of basalts within the Malagarasian/Bukoban Supergroup along the southwest margin of the Tanzania craton.

All of the Pan-African belts contain sequences representing the fill of Neoproterozoic basins destroyed during Pan-African orogenesis (e.g., Damara Sequence in the Damara belt, Katangan in the Lufilian arc). Where best preserved, these sequences generally record deposition in subaerial, shallow-marine platform, and deep-marine environments, and at least two separate glacial horizons are recognized in some belts. Associated foreland-basin deposits on the craton margins are only partly preserved but include the Nama Group in Namibia, the West Congo Supergroup, parts of the Kundelungu in the Lufilian arc, and the Sijarira Group in Zimbabwe.

The Mozambique belt joins with the Arabian-Nubian shield to the north to form the East African orogen, which represents one of the main destructive plate margins active during Gondwana assembly. In the Arabian-Nubian shield, well-preserved juvenile arc terranes and ophiolites record prolonged subduction of oceanic lithosphere prior to final continent-continent collision. Metamorphic grade increases southward in the Mozambique belt, and the position of the main Pan-African suture zone (or zones) in the southern part of the belt is conjectural. Metasedimentary assemblages in the belt in Kenya and Tanzania are inferred to represent passive-margin sequences that faced an open ocean to the east, but there is isotopic evidence for involvement of older basement in much of the belt in Tanzania. Farther south in Mozambique, Pan-African orogenesis overprints 1.1-1.0 Ga basement, as discussed previously.

Pan-African deformation in the Mozambique belt involved west-vergent thrusting along the margins of the Congo and Kalahari cratons. The core of the orogen contains highly deformed supracrustal rocks, migmatitic gneisses, and granulites characterized by recumbent to east-dipping ductile structures. High-pressure granulites in Tanzania provide evidence of significant crustal thickening during thrusting.

A second major collisional belt active during Gondwana assembly is discontinuously exposed along the western and southern margins of Africa and is represented by the West Congo, Kaoko, Gariep, and Saldania belts. Prior to Mesozoic breakup of Gondwana, the Congo craton joined with the São Francisco craton in South America. The West Congo belt projects into an embayment within the restored Congo-São Francisco craton to the north and hence can have involved only limited amounts of true oceanic crust. Farther south in the Gariep and Saldania belts, however, fragments of accreted ocean-floor material (including a seamount assemblage in the Gariep belt) record destruction of an ocean basin. Associated volcanic arc assemblages occur in originally continuous belts wrapping the southern margin of the São Francisco craton in South America. Oblique closure of the ocean basin led to sinistral transpressional deformation in the Kaoko, Gariep, and Saldania belts, with emplacement of the Cape Granite Suite in transcurrent shear zones in the Saldania belt.

Pan-African orogenesis along the transcontinental Damara-Lufilian-Zambezi system involved contractional and transpressional deformation of Neoproterozoic supracrustal sequences, extensive reworking of underlying basement, and, in some areas, emplacement of crustally derived, syn- to post-tectonic granitoid batholiths. Some authors have argued that this transcontinental system formed by closure of a major Neoproterozoic ocean separating the Congo and Kalahari cratons. Based on the nature of preserved lithotectonic assemblages in the transcontinental system, and the evidence noted above that the Zambezi belt may cut directly across older basement trends, other workers (including myself and colleagues) have argued that this system records closure of linked intracontinental rift basins or relatively narrow, Red-Sea-type ocean basins. Significant crustal thickening during contractional deformation and basin closure is required to explain discontinuous eclogites and whiteschists present in parts of the Lufilian arc and Zambezi belt.

Robust age constraints throughout the combined West Congo-Kaoko-Gariep-Saldania and Damara-Lufilian-Zambezi orogenic systems indicate that culminating phases of Pan-African orogenesis affected these regions at 570-510 Ma, with late-stage magmatism extending in places to 450 Ma. Rb-Sr and K-Ar mineral ages as young as 450-420 Ma are found in many areas and record final stages of uplift and cooling. In the Mozambique belt in Tanzania and Mozambique, widespread granulite-facies metamorphism occurred at 700-620 Ma. Many of these granulites formed at high pressures and probably record magmatic underplating in volcanic arc settings, and/or early collisions of arcs or microcontinents with the continental margin. I follow many authors in inferring that final stages in collisional suturing along the Mozambique belt are marked by widespread isotopic ages of 580-520 Ma for high-grade terranes in originally contiguous parts of East Africa, Madagascar, Sri Lanka, southern India, and East Antarctica. All of these data point to assembly of the central part of Gondwana near the end of the Neoproterozoic, with Himalayan-style belts along the eastern and western margins of southern Africa representing sites where major ocean basins were consumed. Orogenesis along the Damara-Lufilian-Zambezi trend may reflect closure of linked basins in response to stresses transmitted inboard from the convergent margins.

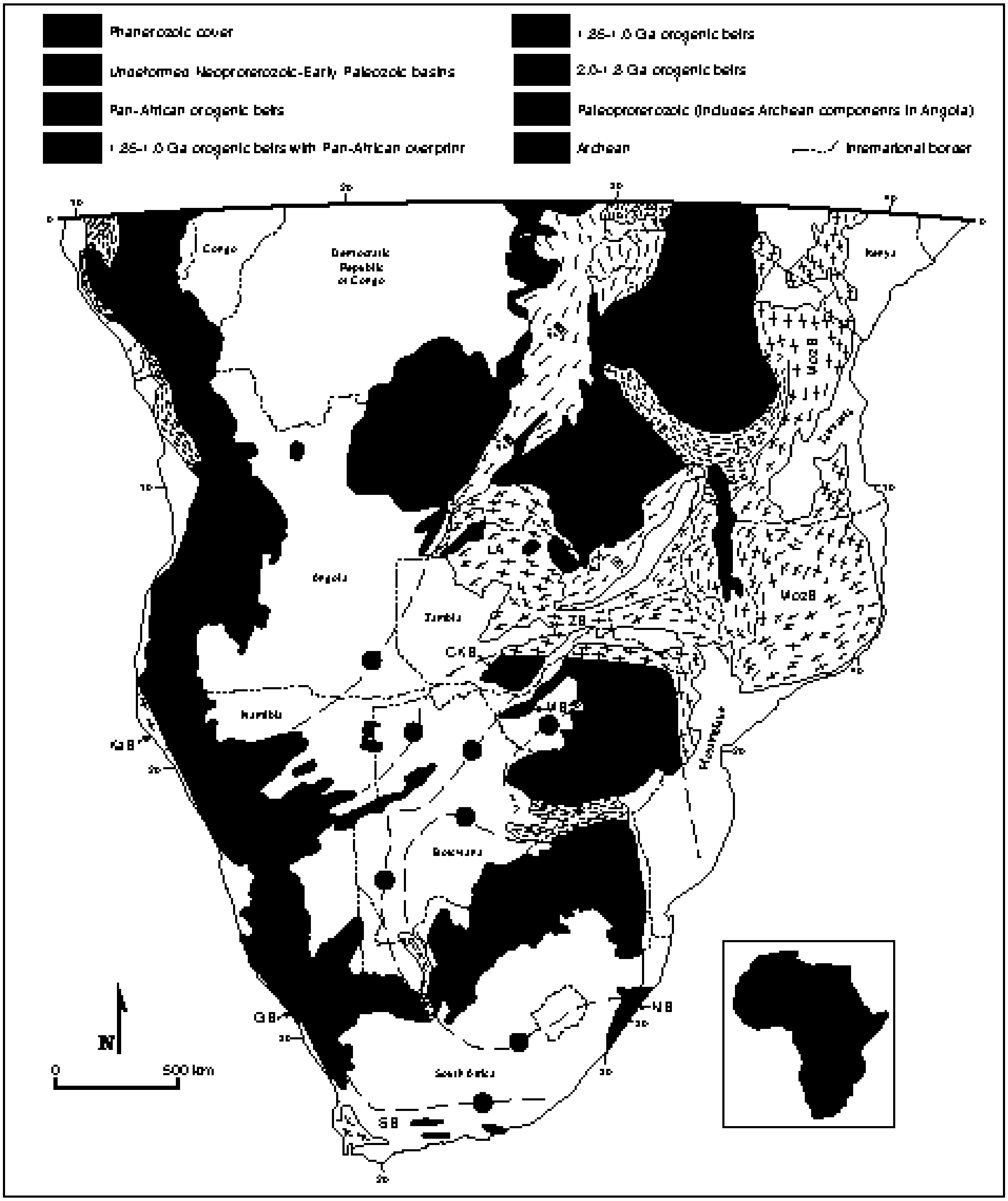

Figure 1. Precambrian tectonic framework of southern Africa. Transcurrent shear zones and many basement inliers within younger belts are not shown. 2.0-1.8 Ga belts: UsB = Usagaran belt; UB = Ubendian belt; BB = Bangweulu block; MB = Magondi belt; KhB = Kheis belt; R = Richtersveld terrane; LB = reactivation in Archean Limpopo belt. 1.35-1.0 Ga belts: KB = Kibaran belt; IB = Irumide belt; CKB = Choma-Kalomo block; NaqB = Namaqua belt; NB = Natal belt. Pan-African belts: MozB = Mozambique belt; ZB = Zambezi belt; LA = Lufilian arc; DB = Damara belt; WCB = West Congo belt; KaB = Kaoko belt; GB = Gariep belt; SB = Saldania belt. Inferred boundaries beneath cover: 1 = eastern margin of Kheis-Magondi belt; 2 = boundary between Kheis-Magondi belt and 1.35-1.0 Ga belt to west; 3 = boundaries of Damara-Lufilian-Zambezi system; 4 = boundaries of Namaqua-Natal belt.