Proterozoic Crustal Evolution in Parts of Southern Africa and Evidence for Extensive Sialic Crust Since the End of the Archaean

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Proterozoic crustal evolution in parts of southern Africa and evidence for extensive sialic crust since the end of the Archaean

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The Proterozoic mobile belts of southern Africa were subjected to multiphase deformation since the Late Archaean and formed part of an extensive Early Proterozoic crustal segment termed here the Kalahari–Malagasy Protoshield. This shield underwent tectogenesis and differential vertical movement at various times with considerable uplift in the mobile zones and relative stability in the Archaean granite-greenstone terrains. The evolution of the Namaqua, Limpopo and Malagasy mobile segments suggests no large-scale dispersive movements of major continental fragments during the Early and Middle Precambrian.

The basement complex of Angola and northern South West Africa constitutes a mobile zone which includes reworked Archaean sialic crust and a tectonized Early Proterozoic supracrustal cover. This complex may have formed part of another Early Proterozoic segment termed here the Kasai–Angola Protoshield, which was probably connected with the Kalahari–Malagasy Protoshield during the Proterozoic prior to reworking during the Kibaran–Burundian, Rehoboth–Irumide and Pan African tectogenetic cycles.

It is proposed that most, if not all, Proterozoic mobile zones in southern Africa constitute ensialic belts and the widespread occurrence of sialic rock units older than ± 2.5 Ga support the conclusion that a large crustal plate of predominantly granitoid composition and of continental proportions was already in existence since the end of the Archaean.

The Proterozoic evolution of southern Africa is therefore characterized by plate destruction rather than by plate accretion and progressive cratonization, and only some of the granite-greenstone 'nuclei' have escaped this process.

Introduction

The Archaean and Proterozoic crust of southern Africa consists of greenstone/granite terrains and surrounding or cross-cutting mobile belts. The former underwent an evolutionary process which seems to have been characteristic of, and possibly restricted to, the Archaean, involving vertical tectonics, comparatively low grade of metamorphism and the intrusion of enormous volumes of granitoid material (Anhaeusser, Mason, Viljoen & Viljoen 1969; Anhaeusser 1973; Hunter 1974) over a time range of more than 300 Ma and finally led to consolidation of crustal segments now known as the Kaapvaal and Rhodesia Cratons. The mobile belts, in contrast, are characterized by polycyclic deformation, high grade of metamorphism and granitization, and there seems to have been no significant change in their evolutionary pattern since Archaean times. They are, furthermore, predominantly of granitoid composition and appear to be largely of ensialic origin; some of them may constitute at least part of the floor onto which the greenstone belts were deposited (Kröner, in prep.).

Some of the Proterozoic mobile belts of southern Africa are examined in this paper in order to demonstrate that

(i) they evolved on early crust which was predominantly, if not entirely, of sialic composition;
(ii) most, if not all, Proterozoic mobile belts are of ensialic origin and originated through extensive reworking of older shield areas;
(iii) plate tectonics processes as envisaged for the Phanerozoic global evolution are not applicable to the Proterozoic belts of southern Africa up to the Pan-African tectogenesis.

The Archaean Kalahari–Malagasy Protoshield

It is now generally agreed that the Kaapvaal and Rhodesia Cratons are of Archaean age but details about their evolution are still hotly disputed (see, for example, Anhaeusser 1973; Hunter 1974). Although the age of 3.5 Ga for ultramafic rocks of the lower Barberton greenstone sequence (Jahn & Shih 1974) is significantly higher than that for granitoid rocks claimed by Hunter (1974) to constitute the greenstone-floor, there is undisputable field evidence from Rhodesia for a pre-greenstone granitoid basement (Stowe 1971, 1973). A new whole rock Rb-Sr age of ± 3.6 Ga for Rhodesian basement gneisses (Hawkesworth, Moorbath, O'Nions & Wilson 1975) proves a pre-greenstone crustal history in southern Africa and the existence of pre-greenstone sialic crust. Further support for this conclusion comes from east-central Africa where the Early Archaean West Nile mobile belt complex forms the substratum to the Late Archaean or Early Proterozoic Kibalian greenstone belts (Cahen & Lepersonne 1967; Lepersonne 1974; Kröner, in prep.).

The Kaapvaal and Rhodesia Cratons are separated by the Limpopo mobile belt whose ensialic nature is now widely accepted (Mason 1973) and which consists predominantly of reworked shield material of the neighbouring cratons (Graham 1975). The belt suffered its main deformation, including high-stage metamorphism, ± 2.7 Ga ago (van Breemen & Dodson 1792) during a widespread African tectonothermal event which is named here the Limpopo–Liberian tectonogenetic cycle and which caused extensive granite intrusion in the neighbouring shield areas. The Kaapvaal and Rhodesia crustal blocks were only cratonized after this event and since they formed a continuous shield area in pre-Limpopo times it is misleading to regard them as 'cratonic nuclei'.

A comparison of the Malagasy basement with the Archaean complexes discussed above indicates that this island, if placed in its most likely pre-Mesozoic Gondwanic position (King 1973), must have been part of the pre-Limpopo shield complex in southern Africa. The Androyan, Graphite and Vohibory sequences (Besairie 1967) resemble the Dodoman of Tanzania and the Archaean Dharwar Supergroup of southern India (Sarkar 1972) and may constitute remnants of severely tectonized greenstone or schist belts. Their Early Archaean age is indicated by a granite intrusive into the Androyan and dated at 3020 Ma (Hottin 1970). The Antongil granitoid complex north of Tamatave appears to resemble the ancient tonalite massifs of the African mainland and Hottin (1970, p. 17), who regards it as older than the Graphite and Vohibory sequences, reported an (imprecise) common lead age of ± 3.2 Ga for one of its migmatitic gneisses.

There is widespread geochronological evidence for a major tectonogenetic cycle at about 2.6 Ga, which has affected most of the older rocks (Hottin 1970; Besairie 1971) and which is clearly related to the Limpopo event farther west. The formation of high grade metamorphites, including charnockites, during this phase (Razafiniparani 1969) suggests that most of the Early Archaean basement in Malagasy was transformed into a mobile belt during the Limpopo–Liberian cycle. On structural and lithological grounds basement remnants pre-dating the 2.6 Ga event have been recognized throughout Malagasy (Hottin 1970, p. 17; see also figure 1) and it is therefore most likely that the island formed part of the Early Archaean granitoid shield of southern Africa as depicted in figure 1.

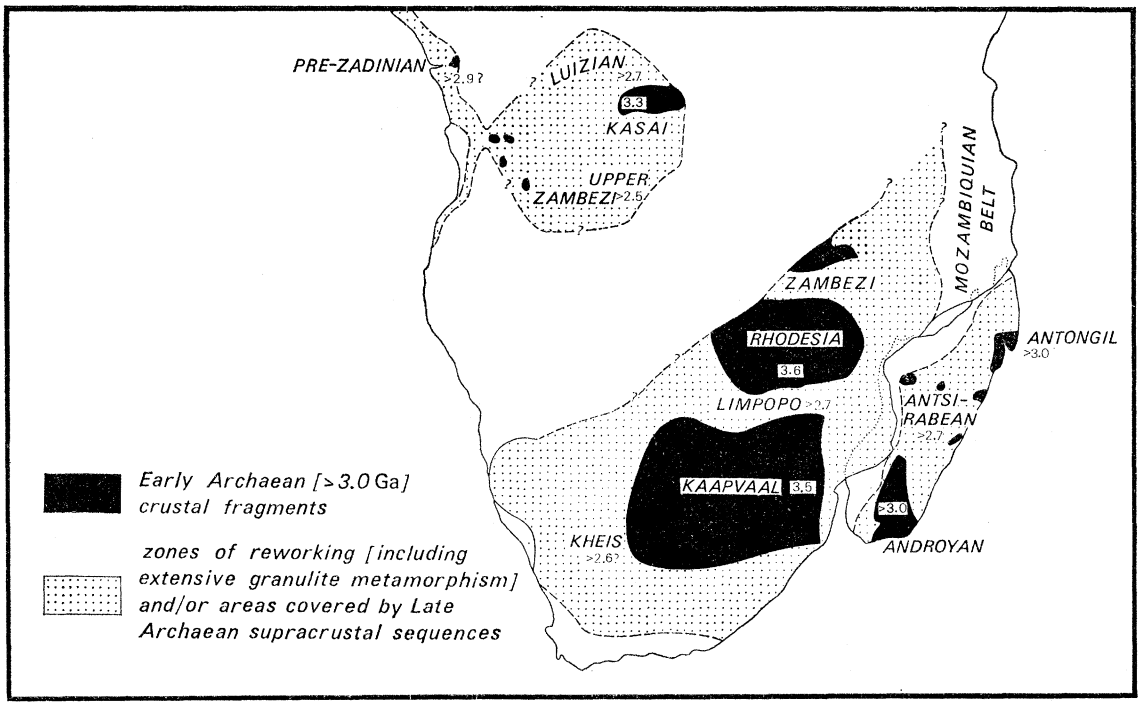

FIGURE 1. The distribution of presently known Early Archaean protoshield fragments in southern Africa and surrounding mobile zones probably containing reworked Archaean crust. Numbers give measured ages and the symbol > indicates that crust was in existence at this locality prior to the event reflected by the given age.

The true significance of the Limpopo reactivation in Malagasy and its relation to the mainland mobile belt is still poorly understood and much of the Archaean record was destroyed during the Pan-African reworking when the area formed part of the Mozambique belt.

The Kaapvaal Craton is fringed in the south and southwest by the Namaqua–Natal Metamorphic Complex which has yielded widespread ages between 900 and 1250 Ma (Nicolaysen & Burger 1965). This areally very extensive terrain forms a mobile belt and consists of medium to high grade gneisses and granitoids showing polyphase deformation (Joubert 1971; Kröner, Anhaeusser & Vajner 1973). It was regarded by Clifford (1970) as a 'vestigeosyncline' of the Kibaran orogenic zone. Joubert (1971) and Vajner (1974*a*) correlated part of the Namaqua gneissic sequence and associated metaquartzites with the Kheis Group which occupies a marginal position to both the Namaqua Complex and the Kaapvaal Craton and is regarded as older than 2.9 Ga (Kröner *et al.* 1973; Vajner 1974*a*).

The previous correlation of the Kheis and Swaziland sequences (Du Toit 1954; van Eeden 1972) appears doubtful, however, since the Kheis evolution indicates a crustal thickness significantly greater than that during the evolution of the Barberton greenstone belt farther east. Kröner *et al.* (1973) proposed a correlation of the Kheis with the Pongola sequence which was deposited on the Kaapvaal greenstone/granite complex approximately 3.1 Ga ago (van Eeden 1972, p. 13). This correlation and the fact that the lithology of the Kheis indicates deposition into one or several intracratonic basins on an extensive sialic crust which must have been older than about 3.0 Ga (Kröner *et al.* 1973), makes it likely that the Kheis and Namaqua provinces may have formed part of the Kaapvaal Craton prior to remobilization during the Limpopo tectogenesis.

Pretorius (1974, p. 26) concluded from a gravity survey over the Namaqua–Kaapvaal boundary zone that 'the two provinces were parts of the same crustal fragment during Archaean and Early Proterozoic times' and that continued uplift in the west has brought the deep crustal level Namaqua Complex in juxtaposition with the high level Kaapvaal Craton. No Early Precambrian ages have yet been reported from the Namaqua–Natal belt but the following structural relations support the conclusion that the first tectogenetic event dates back to the Early Precambrian.

The Kheis sequence and its possible correlates in Namaqualand suffered intensive isoclinal folding and high grade metamorphism prior to the deposition of the Ventersdorp sequence (Vajner 1974*a*) dated at about 2.3 Ga (Burger & Coertze 1973). According to Vajner (1974*a*) this tectogenesis was accompanied by widespread granitoid intrusions and a post-tectonic granite yielded a U-Pb zircon minimum age of 2.5 Ga (Burger & Coertze 1973). It is thus likely that the main Kheis deformation is time-equivalent to the Limpopo event farther east (Kröner *et al.* 1973).

Both Joubert (1974, p. 28) and Vajner (1974*a*, *b*) correlated the early structures found in the Kheis sequence with the widespread (F_1–F_2) isoclinal fabric in the Namaqualand Metamorphic Complex and the regional extent of these structures indicates that the above tectonism represents one of the most important stages in the Archaean evolution of the area west of the present Kaapvaal Craton. It was probably during this episode, 2.5–2.9 Ga ago, that the Early Archaean granitoid crust was remobilized and tectonized together with its Kheis cover by evolving into a mobile belt. The situation is thus similar to the reworking of older crust and cover in the Limpopo belt and in Malagasy.

There is no doubt that the Namaqua belt remained mobile for a considerable period of time through the Proterozoic as will be detailed below, but the first (Archaean) event was most severe and the accompanying high grade of metamorphism has completely obliterated the original basement–cover relations. It is significant that charnockites are widespread within a central zone of the Namaqua belt (Blignault, Jackson, Beukes & Toogood 1974) and are clearly related to a very early phase of the tectonic evolution. Clifford (1973) and Clifford, Gronow, Rex & Burger (1975) proposed from geochronological studies in the Okiep area that the granulite metamorphism in Namaqualand is part of the Kibaran reactivation but this is at variance with the conclusions presented here. According to Clifford (1973) all African charnockites, with the exception of those in the Namaqua belt, are of Archaean age and either reflect the 2.7 ± 0.2 Ga old Limpopo–Liberia tectogenesis (Kröner, in prep.) or a still earlier event at about 3.0–3.3 Ga (Caby 1972; Allègre & Caby 1972). It is tentatively concluded that the Namaqua charnockites also originated during the Late Archaean continent-wide diastrophism but that these rocks remained at deep crustal levels and thus remained isotopically open systems until they were sufficiently elevated during the Kibaran uplift to record a cooling rather than a metamorphic age.

The data so far presented provide evidence for the existence of a large Early Precambrian sialic crustal fragment in southern Africa which included most of South Africa, southern South West Africa, Rhodesia and Malagasy and for which the name Kalahari–Malagasy Protoshield is proposed. This shield underwent partial remobilization and thus destruction with the generation of mobile belts during the Late Archaean Limpopo–Liberian tectogenesis whereas parts like the Kaapvaal and Rhodesia regions retained their cratonic character.

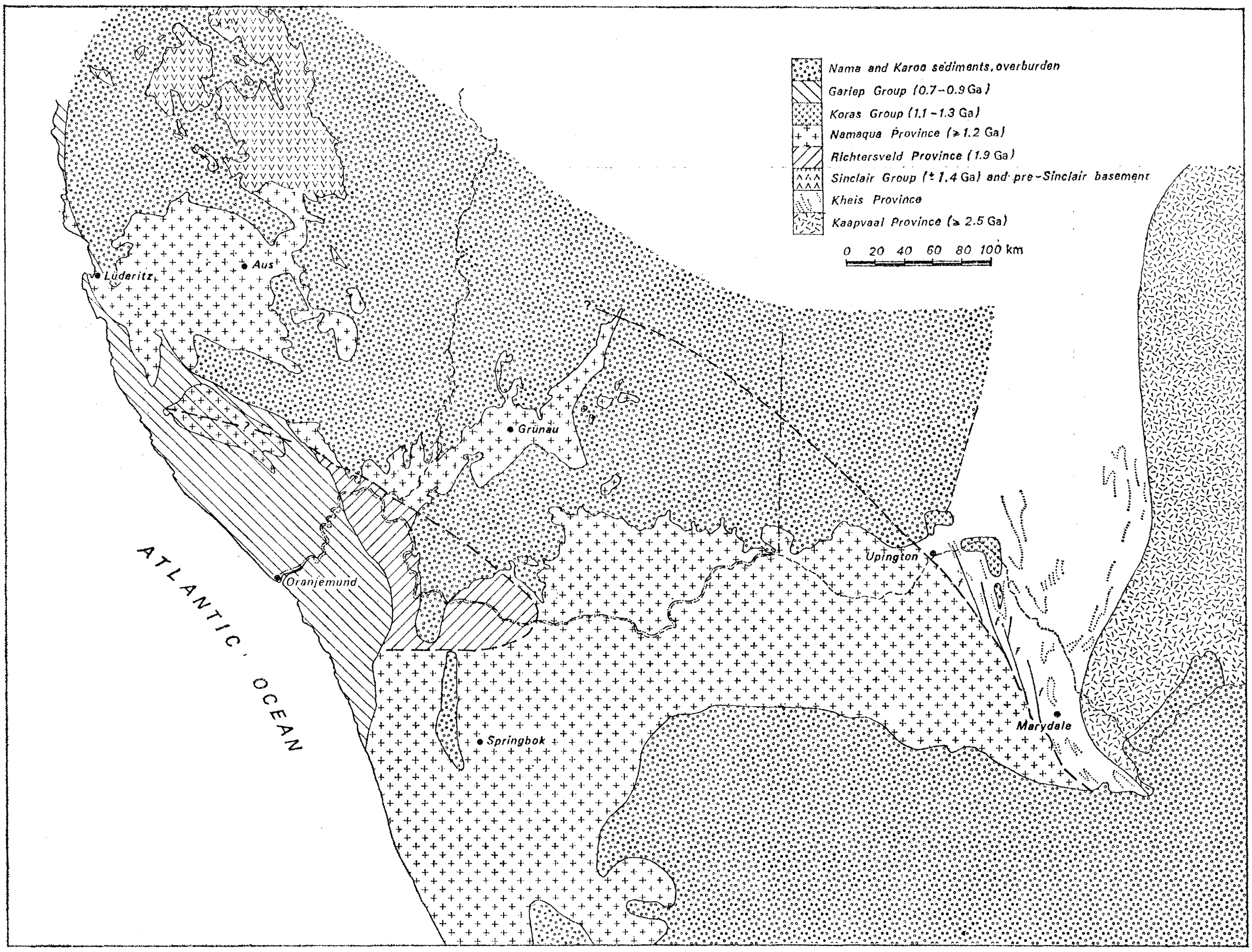

FIGURE 2. The Namaqua tectonic province and neighbouring domains (modified after Blignault *et al.* 1974).

PROTEROZOIC EVOLUTION OF THE NAMAQUA MOBILE BELT

The Namaqua Mobile Belt is defined here as the whole domain west of the Kaapvaal Craton which was affected by a series of tectono-metamorphic events beginning with the Kheis tectogenesis and ending with the late Namaqua or Kibaran tectogenesis (Kröner *et al.* 1973). The Kheis domain or province is therefore part of the mobile belt (figure 2).

During the first event a tectonic banding (regional foliation) and accompanying penetrative mineral lineation were generated and these structures are identifiable almost throughout the entire belt. Later events during the Proterozoic have modified the geometry of these early structures and locally resulted in extensive overprinting. The differences in tectonic style of consecutive deformational phases resulted from the increasing rigidity of the rocks during their tectonic evolution (Joubert 1974, p. 28).

The intense Kheis tectogenesis was followed by the generation of basin and dome structures and the beginning of extensive shearing. On geometrical grounds Vajner (1974*a*) correlated this deformation, here named the Early Namaqua Tectogenesis, with gravity folding affecting the Transvaal and Matsap–Waterberg sequences along the margin of the Kaapvaal Craton

TABLE 1. PROPOSAL FOR A SUBDIVISION OF THE TECTONIC HISTORY IN THE NAMAQUA MOBILE BELT (MODIFIED AFTER KRÖNER, AUHAEUSSER & VAJNER 1973)

age Ma	supracrustal deposits	cycles	tectonism
900	Gariep		East–west tensional movements accompanied by intrusion of Richtersveld Igneous Complex and basic dykes of the Gannakouriep-type. Deposition of 'molasse' (Stinkfontein Formation) into newly formed marginal Gariep trough.
1000			*Late Namaqua tectogenesis* (2. Event, F$_4$-F$_7$, ± 1400–950 Ma) Strong penetrative NW-shearing along margin of Kaapvaal Craton, in the NMC and along margin with Richtersveld Province. Open flexures, also in supracrustals of the eastern foreland
1100	Koras	Late Precambrian	Strong thermal event with intrusion of granitoids, charnockites and pegmatites Late tectonic shear zones ('steep structures') and brittle shear deformation along the margin of the Kalahari Craton, accompanied by strong uplift and pegmatite intrusion and representing the final stages of the Namaqua 'Orogeny'
1200			Closing of Rb-Sr and U-Pb isotopic systems. Consolidation into shield area
1300			
1400			
1500			
1600			
1700	Matsap–Waterberg		*Early Namaqua tectogenesis* (1. Event, F$_3$, 2300–1650 Ma) Gravity deformation on the Kaapvaal Craton. Intensive folding in the Namaqua Belt with formation of basin and dome structures and some shearing. Intrusion of the Vioolsdrif suite of granitoids and associated formations of the Orange River Group. Amphibolite facies metamorphism.
1800		Middle Precambrian	
1900			
2000			
2100	Transvaal		
2200			
2300	Ventersdorp		
2400			
2500			
2600			*Kheis tectogenesis* (F$_1$–F$_2$, 3000–2500 Ma) Two phases of isoclinal folding with generation of tectonic banding (regional foliation) and penetrative mineral lineation. Strong metamorphism with zoning up to granulite facies and accompanied in the eastern foreland by intrusion of two generations of granitoids (± 2600 Ma and ± 2900 Ma)
2700			
2800			
2900			
3000	Kheis-Pongola		
		Early Precambrian	Consolidated Archaean sialic crust (Kaapvaal Craton and environs after greenstone-belt evolution)

(see table 1). Crustal instability of the early Namaqua event has therefore extended over a period of 200–300 Ma and may have come to an end some 1700–1800 Ma ago. It was thus time-equivalent with the widespread Eburnian tectogenesis and the reactivation of the Limpopo belt. First preliminary U-Pb zircon analyses from mafic gneisses indicate an age of about 1750–1800 Ma and this age is presently interpreted as reflecting the early Namaqua tectogenesis.

In the west the Namaqua belt was intruded by the batholithic Vioolsdrif granitoid suite dated at 1750–1900 Ma (Welke *et al.*, in prep.). This suite represents a fully differentiated igneous sequence ranging from gabbroid phases through diorites, granodiorites, adamellites to leucogranites with the more acid types predominating areally (Blignault 1974). This suite, together with older, though genetically associated, volcanics comprises a geographically distinct domain which was only marginally affected by subsequent deformation in the mobile belt and is known as the Richtersveld Province (Blignault *et al.* 1974; Kröner & Blignault, in prep.; see also figure 2).

It is seen as significant that the isotopic U-Pb data of the gneisses mentioned above plot very close to or even on the chord defined by more than 6 samples of the Vioolsdrif granodiorites on a concordia diagram and a close association between the Vioolsdrif igneous activity and the early Namaqua event is therefore postulated.

The Namaqua mobile belt was subjected to very extensive thermal rejuvenation during Kibaran times (1100 ± 200 Ma) which was accompanied by strong, penetrative northwest shearing and flexural slip folding along the margin of the Kaapvaal Craton, in distinct zones within the Namaqua Metamorphic Complex, and along the margin of the Richtersveld Province. This movement resulted in considerable uplift and also affected the supracrustal sequences in the eastern foreland of the belt (e.g. Matsap Formation). It was during this event, here termed the Late Namaqua Tectogenesis, that much of the presently observed regional structural grain was superimposed on earlier structures and the enormous uplift caused closing of the isotopic systems so that Kibaran ages are obtained from almost all parts of the belt (Nicolaysen & Burger 1965; Burger & Coertze 1973; Clifford *et al.* 1975). The significance of the thermal event is underlined by widespread granitoid intrusions and a distinct 30–60 km wide pegmatite belt which is interpreted by Joubert (1971) as the margin of a large thermal dome.

The Kibaran igneous activity and late-tectonic shear zones ('steep' structures of the Okiep area) represent the final stages of the Namaqua tectonism in the central and eastern parts of the mobile belt (Joubert 1971; Vajner 1974*a*) and led to consolidation into a shield area. In the west, however, pronounced shearing continued and resulted in the formation of a north–south trending basin into which the Late Precambrian geosynclinal deposits of the Gariep Group were laid down (Kröner 1974).

The basal Gariep strata (thick conglomerates, arkoses, grits and quartzites) were deposited as a direct result of strong uplift in the Namaqua belt and can thus be regarded as a late Namaqua 'molasse'. This situation is remarkably similar to the Kibaride–Katangide relation in south-central Africa where Cahen (1970) demonstrated the basal Katangan sequences to be a Kibaran molasse.

It is obvious from the above discussion that the late Namaqua tectogenesis does not have orogenic character and there is no evidence for a direct link between the Namaqua belt and the Kibaran chains as was first suggested by Holmes (1951). The late Namaqua deformation has affected rocks which were already sufficiently elevated and cooled down to react by brittle failure. Quartz-porphyry dykes with a Pb-Pb age of 1280 ± 50 Ma (Van Niekerk & Burger 1967) cut shear zones of the Namaqua event near Upington and a pronounced high-level shear belt in southern South West Africa has a minimum K-Ar age of 1127–1143 ± 45 Ma (Watters 1974). It is therefore certain that the rocks now exposed on surface were already situated at high crustal levels (as also documented by retrograde metamorphism) some 1200–1300 Ma ago and could not have suffered extensive granulite metamorphism during that time.

Kröner (1974) suggested that much of the late Namaqua shearing along the western margin of the metamorphic complex is related to east–west tensional movements as documented by a broad swarm of basic dykes and the intrusion of granitoids. This movement may have initiated continental rupture and eventual breakup of a Kalahari–Brazil Craton, resulting in deposition of the Late Precambrian Gariep sequence along a plate margin (see Kröner *et al.* 1973; Kröner 1974).

This model stresses the continuous crustal instability in southern Africa from Kibaran into Pan-African times which has also been reported from other parts of the continent as shown, for instance, by the Kibaride–Katangide relation (Cahen 1970) and the evolution of the Hoggar Massif in the central Sahara (Bertrand 1974).

The suggested tectonic history of the Namaqua mobile belt is shown schematically in table 1. There has been polycyclic deformation during the Proterozoic but this affected an already 'established' mobile belt which evolved on a pre-existing Archaean crust and was finally consolidated during Late Precambrian times.

The Proterozoic of South West Africa and Angola

Outcrops of basement complexes older than the Late Precambrian Damara Supergroup are comparatively small in central and northern South West Africa and their interrelation is still poorly known. The pre-Kibaran granitoids, metamorphites and basic intrusives north of the Namaqua belt in the Maltahöhe and Rehoboth Districts have apparently not undergone much deformation since the deposition of the 1350–1400 Ma old mixed volcano-sedimentary Sinclair Group (Watters 1974) and may thus occupy a similar position as the ± 2.0 Ga old Richtersveld Province farther south. No radiometric data are available from this basement whose structure and metamorphism remains to be studied.

To the north a narrow northeast trending basement ridge separates the Rehobothian belt of Kibaran age from the Pan-African Damarides. This basement consists of high grade metamorphites with prominent metavolcanics which were intruded repeatedly by granitoids prior to a distinct event leading to widespread migmatization and formation of amphibolite. A single Pb–Pb age of 1900 Ma from a cross-cutting galena-bearing quartz vein (Nicolaysen, quoted in Martin 1965, p. 13) may reflect the late phases of this event which appears to belong to the continent-wide Eburnian tectogenesis. The basement occurrences are too isolated to determine their overall structural pattern.

There is no doubt that all the basement rocks described here belong to the Kalahari Craton which was consolidated during the Kibaran event but existed already as part of a much larger shield in pre-Kibaran times.

The rocks occupying the Rehobothian belt occur within a zone of intracontinental subsidence in the strike continuation of the Irumide belt and consist of thick metasediments as well as considerable basic to acid metavolcanics which were deposited 1300–1700 Ma ago and suffered comparatively mild deformation during the Kibaran event. Intrusive granites so far dated range in age between 1380 and 1100 Ma. The Rehoboth belt together with the virtually undeformed Sinclair Group along the Namib Desert constitute a prominent magmatic arc which Watters (1974) interpreted as an ancient island arc developed along the margin of the Kalahari Plate as a result of active consumption of an oceanic crustal plate during the Kibaran tectogenesis. This model is based on the recognition of shoshonitic basic lavas within the Sinclair Group, and it would appear that the Rehoboth arc constitutes one of the major shoshonitic magma provinces that have so far been recognized in the Precambrian. There are, however, inherent structural, stratigraphic and geotectonic difficulties resulting from the plate tectonics model and the author prefers to relate the Rehoboth magmatism to incipient intracontinental rifting of Rhine- or East African Rift Valley-type since remnants of pre-Rohoboth basement can be recognized throughout the belt. It is therefore argued that the occurrence of shoshonites *per se* is not necessarily proof for subduction processes as often claimed from geotectonic analyses of modern island arcs. The recent discovery of pillow lavas with an oceanic tholeiite chemistry in the Transvaal sequence (Button 1974) of the intracratonic Transvaal basin also shows that great care should be taken in using chemical data for the interpretation of geotectonic processes.

The rocks of the Kalahari Craton are separated from the basement of northern South West Africa by the Pan-African Damara Belt which is most probably of ensialic origin as shown by several basement inliers and an apparent continuity of specific lithologies such as carbonates and glaciogenic strata from one margin of the belt to the other (Martin 1965; Kröner & Rankama 1973).

To the north of the Damarides Proterozoic basement is again exposed in the Outjo District and in the Kaokoveld of South West Africa as well as in a vast area of southern and central Angola. These rocks belong to the southern portion of what Clifford (1970) called the Angola–Kasai Craton, a large Proterozoic crustal segment which was probably connected with the Kalahari Craton farther south to form a huge protocontinental shield in pre-Kibaran and pre-Pan-African times (Kröner, in prep.).

Although there is clear structural and geochronological evidence that the basement formations of northern South West Africa and southern Angola were affected by the Eburnian tectogenesis (Huabian episode of Clifford 1970), these rocks are probably considerably older and may date back to the Archaean (Carvalho 1972). The strongly tectonized migmatitic Epupa Formation of the Kunene River area is intruded by granitoids and by the southern extremity of a huge gabbro-anorthosite massif, which is now dated at 2157 ± 43 Ma (da Silva 1974). Farther south the Huab sequence, a probable correlate of the Epupa rocks (Martin 1965), was tectonized prior to the deposition of the largely volcanic Khoabendus Formation which, in turn, is intruded by the Fransfontein granitoid suite (Guj, quoted in Porada 1974), now dated at up to 2070 Ma (Burger & Coertze 1973).

The basement granites and metamorphites of southern Angola are still poorly studied and their true age is unknown. Mendes (1968) reported Eburnian and younger ages from this region without giving details of the geology but systematic mapping by the Angolan Geological Survey now reveals that ‘geosynclinal’ deposition of sedimentary and acid volcanic rocks took place on an older granitoid substratum in restricted zones of subsidence and these rocks were tectonized together with their floor between about 2000 and 2250 Ma ago (da Silva 1974). This pre-Eburnian basement has also been identified in the Chamza River area of central Angola (A. T. S. F. da Silva, private communication) and in a narrow belt along the Atlantic coast south of the pre-Zadinian (and possibly Archaean) Mpozo–Tombagido Complex of Zaire where metamorphic ages of 2650–2700 Ma were obtained by Mendes & Vialette (1972).

The oldest basement remnants in central Angola consist of granulites and associated charnockite-gabbroid complexes (A. T. S. F. da Silva, private communication) which are almost certainly related to the ± 2.9 Ga old Kasai–Lomami granulites of southwestern Zaire. These high grade rocks are found within a granitoid-gneiss-migmatite unit (A. T. S. F. da Silva, private communication) which, on lithological and structural grounds, resembles the Dibaya complex of the Kasai Craton whose migmatization and granitization was dated at between 2.5 and 2.7 Ga (Cahen & Lepersonne 1967; Lepersonne 1974).

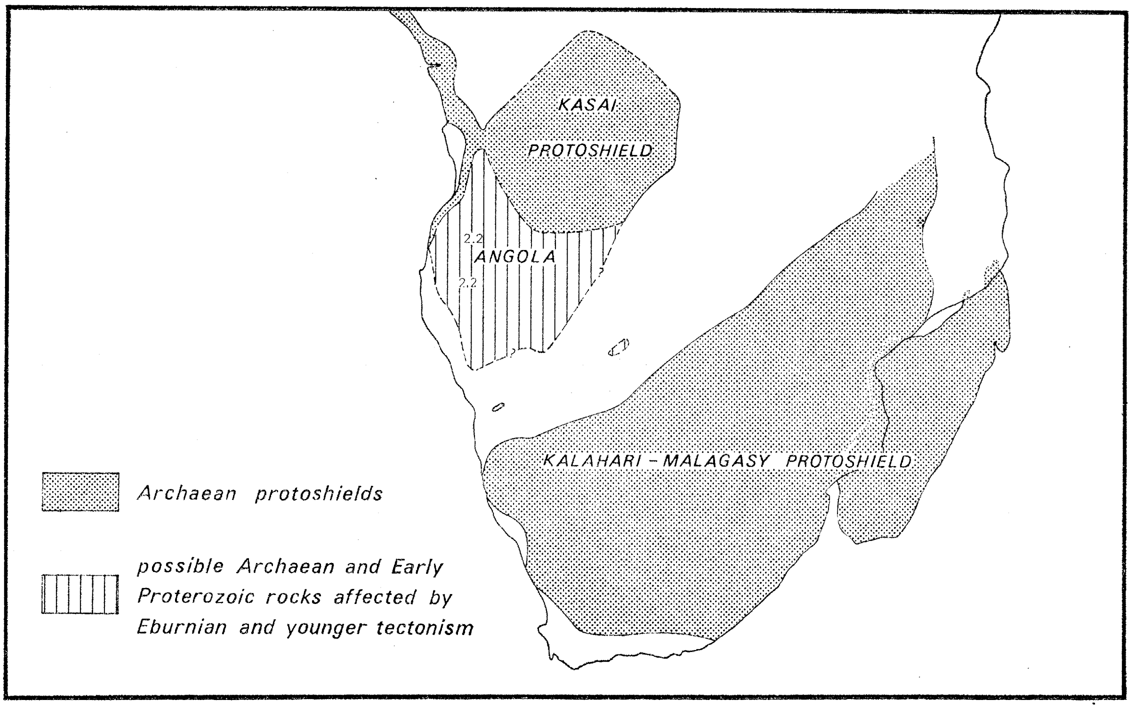

Figure 3. Archaean protoshield complexes in southern Africa and zones of rejuvenation during the Eburnian tectogenetic cycle (2000 ± 200 Ma). Meaning of numbers as in figure 1.

The Chamza River migmatitic gneisses are probably also equivalent to the north–south trending metamorphites of the upper Zambezi River for which Mendes & Vialette (1972) reported a metamorphic age of ± 2.5 Ga.

It is of particular interest to note here that the pronounced north–south trend of the upper Zambezi gneisses seems to find its continuation on the southern side of the Damarides in western Botswana, as shown by new gravity data (Reeves & Hutchins 1975), and in the Kheis fold belt of the northern Cape Province whose early tectogenesis correlates well in time with the metamorphic ages from eastern Angola.

The data presented here lead to the conclusion that much, if not all, of the granitoid basement of central Angola is of Archaean age and belonged to the once very extensive Early Precambrian Kasai Protoshield which was largely destroyed during subsequent Proterozoic tectogenetic events.

CONCLUSIONS

The Late Archaean and Proterozoic mobile belts of southern Africa developed on a pre-existing older crust which was predominantly of granitoid composition. This is shown by the ensialic nature of most cover sequences (e.g. Kheis and its correlates in Namaqualand; Messina sequence in the Limpopo belt) which were tectonized together with their Archaean substratum. High grade metamorphites, including charnockites, and tight isoclinal folding appear to be characteristic of the widespread Limpopo–Liberian tectogenesis 2700 ± 200 Ma ago, during which much of the earliest record in the affected rocks has been wiped out so that the impression of extensive consolidation into a protoshield of subcontinental proportions is created. It is argued however, that older crustal segments of equal or even larger size may have been present in pre-Limpopo times. This conclusion is not in agreement with Burke & Dewey (1973) who emphasized the absence of continental areas larger than about 10^5 km^2 during the Archaean.

All pre-Pan-African Proterozoic mobile belts of southern Africa are of ensialic origin and some of them had a more than 1500 Ma long history of polycyclic deformation and metamorphism (e.g. the Namaqua Mobile Belt).

Acceptance of the ensialic and intracontinental nature of these belts means that no new crust was added to the southern part of Africa in Archaean times, thus none was probably consumed. This evolution is incompatible with Phanerozoic plate tectonic processes and it is therefore concluded that large-scale plate movement has not taken place. There is also no evidence for assuming the existence of several microplates in the Early Precambrian which, through repeated collision and subduction, should have grown onion-skin type orogenic belts around them and were finally 'welded' together as was proposed by Burke & Dewey (1973).

The concept of successive cratonization of the African continent through time as proposed by Clifford (1968, 1970) needs revision. There is no evidence for small 'nuclei' having grown to a continental craton during the Proterozoic, it would appear, rather, that early shield areas were successively destroyed during crustal reworking in ensialic belts and even the mobile belts were often not consolidated after their main deformation but suffered rejuvenation and overprinting during later events as demonstrated for the Namaqua belt.

Cratonization is limited to times between the major African tectogenetic cycles and it is not evident that younger events have affected successively larger crustal segments as proposed by Clifford (1970). The data presented here show for instance that the Kalahari–Malagasy Protoshield was probably not substantially smaller during the Limpopo, Eburnian and Kibaran events than during the end-Precambrian Pan-African tectonism. Cratonization, therefore, should not be interpreted as *final* consolidation but rather as temporary consolidation of crust.

REFERENCES (Kröner)

Allègre, C. J. & Caby, R. 1972 Chronologie absolue du Précambrien de l'Ahaggar occidental. *C. r. hebd. Séance. Acad. Sci. Paris* D **275**, 2095–2098.

Anhaeusser, C. R. 1973 The evolution of the early Precambrian crust of southern Africa. *Phil. Trans. R. Soc. Lond.* A **273**, 359–388.

Anhaeusser, C. R., Mason, R., Viljoen, M. J. & Viljoen, R. P. 1969 A reappraisal of some aspects of Precambrian shield geology. *Geol. Soc. Am. Bull.* **80**, 2175–2200.

Bertrand, J. M. L. 1974 Evolution polycyclique des gneiss précambriens de l'Aleksod (Hoggar Central, Sahara Algerien). *C.N.R.S., Centre Rech. Zones Arides, Sèrie Geol. No.* **19**, 307 pp.

Besairie, H. 1967 The Precambrian of Madagascar. In *The Precambrian* **3**, (ed. K. Rankama), 113–142. London: Interscience.

Besairie, H. 1971 Madagascar. In *Tectonique de l'Afrique. UNESCO Earth Sciences* **6**, Paris, 549–558.

Blignault, H. J. 1974 Aspects of the Richtersveld Province. In *Contributions to the Precambrian geology of southern Africa* (ed. A. Kröner). *Precambrian Res. Unit, Univ. Cape Town, Bull.* **15**, 49–56.

Blignault, H. J., Jackson, M. P. A., Beukes, G. J. & Toogood, D. J. 1974 The Namaqua tectonic province in South West Africa. In *Contributions to the Precambrian geology of southern Africa* (ed. A. Kröner). *Precambrian Res. Unit, Univ. Cape Town, Bull.* **15**, 29–48.

Burke, K. C. & Dewey, J. F. 1973 An outline of Precambrian plate development. In *Implications of continental drift to the earth sciences*, **2** (ed. D. H. Tarling & S. K. Runcorn), 1035–1045. London: Academic Press.

Burger, A. J. & Coertze, F. J. 1973 Radiometric age measurements on rocks from southern Africa to the end of 1971. *Geol. Surv. S. Afr., Bull.* **58**, 46 pp.

Button, A. 1974 Low-potash pillow basalts in the Pretoria Group, Transvaal Supergroup. *Trans. geol. Soc. S. Afr.* **77**, 99–104.

Caby, R. 1972 Evolution préorogénique, site et agencement de la chaine pharusienne dans le NW de l'Ahaggar (Sahara algérien): sa place dans l'orogèse pan-africaine en Afrique occidentale. *Notes et Mem. Serv. Geol. Maroc.* **236**, 65–80.

Cahen, L. 1970 Igneous activity and mineralization episodes in the evolution of the Kibaride and Katangide orogenic belts of central Africa. In *African magmatism and tectonics* (ed. T. N. Clifford & I. G. Gass), 97–117. Edinburgh: Oliver & Boyd.

Cahen, L. & Lepersonne, J. 1967 The Precambrian of the Congo, Rwanda and Burundi. In *The Precambrian*, **3**, (ed. K. Rankama), 143–290. London: Interscience.

Carvalho, H. de 1972 Chronologie des formations géologiques Précambriennes de la région centrale du sud-ouest de l'Angola et essai de corrélation avec celles du Sud-Ouest Africain. *24th Int. Geol. Congr. Montréal* **1**, 187–194.

Clifford, T. N. 1968 Radiometric dating and the pre-Silurian geology of Africa. In *Radiometric dating for geologists* (ed. E. I. Hamilton & R. M. Farquhar), 299–416. London: Interscience.

Clifford, T. N. 1970 The structural framework of Africa. In *African magmatism and tectonics* (ed. T. N. Clifford & I. G. Gass), 1–26. Edinburgh: Oliver & Boyd.

Clifford, T. N. 1973 African granulites and related rocks: a preliminary note. In *Symposium on granites, gneisses and related rocks* (ed. L. A. Lister). *Geol. Soc. S. Afr. Spec. Publ.* **3**, 17–24.

Clifford, T. N., Gronow, J., Rex, D. C. & Burger, A. J. 1975 Petrochemistry and whole rock Rb-Sr and mineral U-Pb ages of high-grade metamorphic rocks and intrusives in Namaqualand, South Africa. *J. Petrol.* (In the Press.)

Da Silva, A. T. S. F. 1974 Nota prévia sobre o geossinclinal eburneano assinalado na regiao de Caluqueme (Angola). *Serv. Geol. Min. Angola, Mem.* **13**, 12 pp.

Du Toit, A. L. 1954 *The geology of South Africa*, 3rd ed. Edinburgh: Oliver & Boyd.

Graham, R. H. 1975 A structural investigation of the southern part of the Limpopo belt and the adjacent Kaapvaal Craton, South Africa. 18th Ann. Rep. *Res. Inst. Afr. Geol. Univ. Leeds*, 63–69.

Hawkesworth, C. J., Moorbath, S., O'Nions, R. K. & Wilson, J. F. 1975 Age relationships between greenstone belts and 'granites' in the Rhodesian Archaean craton. *Earth planet. Sci. Lett.* **25**, 251–261.

Holmes, A. 1951 The sequence of Precambrian orogenic belts in south and central Africa. *18th Int. Geol. Congr., London* 1948, **14**, 254–269.

Hottin, G. 1970 Geochronologie et stratigraphie Malagaches – essai d'interpretation. *Serv. Géol. Malagasy, Docum. Bur. Géol.* **182**, 21 pp.

Hunter, D. R. 1974 Crustal development in the Kaapvaal Craton, Part I. The Archaean. *Precambrian Res.* **1**, 259–294.

Jahn, B. & Shih, C. 1974 On the age of the Onverwacht Group, Swaziland Sequence, South Africa. *Geochim. Cosmochim. Acta.* **38**, 873–885.

Joubert, P. 1971 The regional tectonism of the gneisses of part of Namaqualand. *Precambrian Res. Unit, Univ. Cape Town, Bull.* **10**, 220 pp.

Joubert, P. 1974 Geological survey of Namaqualand and Bushmanland. In *10th and 11th annual reports*: 1972–1973 (ed. A. Kröner). *Precambrian Res. Unit, Univ. Cape Town*, 24–30.

King, L. C. 1973 An improved reconstruction of Gondwanaland. In *Implications of continental drift to the earth sciences*, **2** (ed. D. H. Tarling & S. K. Runcorn), 851–864. London: Academic Press.

Kröner, A. 1974 The Gariep Group, part I: Late Precambrian formations in the western Richtersveld, northern Cape Province. *Precambrian Res. Unit, Univ. Cape Town, Bull.* **13**, 115 pp. Also in *Trans. r. Soc. S. Afr.* **41**, 375–433.

Kröner, A. 1976 The precambrian geotectonic evolution of Africa: plate accretion versus plate destruction. (In preparation.)

Kröner, A. & Rankama, K. 1973 Late Precambrian glaciogenic sedimentary rocks in southern Africa: a comparison with definitions and correlations. *Geol. Soc. Finland Bull.* **45**, 79–102.

Kröner, A., Anhaeusser, C. R. & Vajner, V. 1973 Neue Ergebnisse zur Evolution der präkambrischen Kruste im südlichen Afrika. *Geol. Rundschau* **62**, 281–309.

Kröner, A. & Blignault, H. J. 1976 Towards a definition of some tectonic and igneous provinces in western South Africa and southern South West Africa. (In preparation.)

Lepersonne, J. 1974 Carte géologique du Zaïre au 1/2000000 avec note explicative. *Rep. Zaïre, Dept. des Mines, Dir. Géol.*, 67 pp.

Martin, H. 1965 The Precambrian geology of South West Africa and Namaqualand. *Precambrian Res. Univ. Cape Town*, 159 pp.

Mason, R. 1973 The Limpopo mobile belt – southern Africa. *Phil. Trans. R. Soc. Lond.* A **273**, 463–485.

Mendes, F. 1968 Mesures géochronologiques en Angola. D.Sc. thesis, Univ. Clermont-Ferrand, France, 23 pp.

Mendes, F. & Vialette, Y. 1972 Le Précambrien de l'Angola. 24*th Int. Geol. Congr. Montréal* **1**, 213–220.

Nicolaysen, L. O. & Burger, A. J. 1965 Note on an extensive zone of 1000 million-year old metamorphic and igneous rocks in southern Africa. *Sci. de la Terre.* **10**, 497–516.

Porada, H. R. 1974 The Khoabendus Formation in the area northwest of Kamanjab and in the southeastern Kaokoveld, South West Africa. *Geol. Surv. S. Afr., Mem.* **4**, (South West Africa series), 23 pp.

Pretorius, D. A. 1974 The structural boundary between the Kaapvaal and Sonama crustal provinces. *Econ. Geology Res. Unit, Univ. Witwatersrand, Johannesburg Inf. Circ.* no. 88, 27 pp.

Razafiniparani, A. 1969 Les charnockites du socle Précambrien de Madagascar. *Serv. Géol. Rep. Malagasy, Docum. Bur. Géol.* **179**, 289 pp.

Reeves, C. V. & Hutchins, D. G. 1975 Crustal structures in central southern Africa. *Nature, Lond.* **254**, 408–409.

Sarkar, S. N. 1972 Present status of Precambrian geochronology of peninsular India. 24*th Int. Geol. Congr. Montréal* **1**, 260–272.

Stowe, C. W. 1971 Summary of the tectonic development of the Rhodesian Archaean craton. In *Symposium on Archaean rocks* (ed. J. E. Glover). *Geol. Soc. Australia, Spec. Publ.* **3**, 337–383.

Stowe, C. W. 1973 The older tonalite gneiss complex in the Selukwe area, Rhodesia. In *Symposium on granites, gneisses and related rocks* (ed. L. A. Lister). *Geol. Soc. S. Afr. Spec. Publ.* **3**, 85–96.

Vajner, V. 1974*a* The tectonic development of the Namaqua mobile belt and its foreland in parts of the northern Cape. *Precambrian Res. Unit, Univ. Cape Town, Bull.* **14**, 201 pp.

Vajner, V. 1974*b* Crustal evolution of the Namaqua mobile belt and its foreland in parts of the northern Cape. In *Contributions to the Precambrian geology of southern Africa* (ed. A. Kröner). *Precambrian Res. Unit, Cape Town, Bull.* **15**, 1–16.

Van Breemen, O. & Dodson, M. H. 1972 Metamorphic chronology of the Limpopo belt, southern Africa. *Geol. Soc. Am. Bull.* **83**, 2005–2018.

Van Eeden, O. R. 1972 The geology of the Republic of South Africa. An explanation of the 1:1000000 map, 1970 edition. *Geol. Surv. S. Afr., Spec. Publ.* **18**, 85 pp.

Van Niekerk, C. B. & Burger, A. J. 1967 Radiometric dating of the Koras Formation. *Ann. geol. Surv. S. Afr.* **72**, 37–45.

Watters, B. R. 1974 Stratigraphy, igneous petrology and evolution of the Sinclair Group in southern South West Africa. *Precambrian Res. Unit. Univ. Cape Town, Bull.* **16**, 235 pp.

Welke, H. J., Burger, A. J., Corner, B., Kröner, A., Blignault, H. J. & Beukes, G. J. 1976 Geochronological results from the Richtersveld Province. (In preparation.)