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THE PONGOLA STRUCTURE OF SOUTHEASTERN AFRICA: THE WORLD'S OLDEST PRESERVED RIFT?

KEVIN BURKE[1], W. S. F. KIDD[2] and T. M. KUSKY[2]

[1] *Lunar and Planetary Institute and Department of Geosciences, University of Houston, Houston, TX 77058, U.S.A.*

[2] *Department of Geological Sciences, SUNY Albany, Albany, NY 12222, U.S.A.*

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ABSTRACT

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Rocks of the Pongola Supergroup form an elongate belt in the Archean Kaapvaal Craton of southern Africa. Because these rocks exhibit many features that are characteristic of rocks deposited in continental rifts, including rapid lateral variations in thickness and character of sediments, volcanic rocks that are bimodal in silica content, coarse, basement derived conglomerates and thick sequences of shallow water sedimentary facies associations, we suggest that the Pongola Supergroup was deposited in such a rift. The age of these rocks (approximately 3.0 Ga) makes the Pongola structure the world's oldest well-preserved rift so far recognized, and comparison of the Pongola Rift with other rifts formed more recently in earth history reveals striking similarities, suggesting that the processes that formed this rift were not significantly different from those that form continental rifts today.

INTRODUCTION

The Pongola Supergroup outcrops in a semi-continuous linear belt in South Africa and Swaziland. Figure 1 shows the location and present outcrop pattern of the Pongola Supergroup, as well as suggested (approximate) margins of the Pongola rift basin. The present extent of the basin is approximately 275 km × 100 km, implying a minimum depositional area of 27,500 square kilometers, although much of its original volume has been removed by erosion, destroyed by granitic intrusions and buried under later cover.

Figure 2 shows a geologic map of the Pongola Structure, with stratigraphic sections of the Supergroup. There are great variations in stratigraphic thickness of the Pongola sediments and a large proportion of volcanic rocks is preserved in the structure. These features suggest to us that the Pongola Supergroup rocks may have been deposited in a continental rift environment.

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Sawkins (1982), expanding on observations by earlier authors, for example Wilson (1968), Dewey and Bird (1971), and Burke (1977), has described characteristics of rock deposited in ancient rifts and our modified list is as follows:

(1) Rift deposits not subsequently incorporated in an Atlantic-type continental margin would not (in general) be highly deformed or metamorphosed.

(2) Lateral thickness variations can occur over short distances and may exceed several kilometers in magnitude.

(3) Volcanic and intrusive igneous rocks are often bimodal in silica content.

(4) Faulted margins and linear rift trends might be discernable.

(5) Subaerial and subaquatic sediments might both occur.

(6) A thick, coarse basal clastic section, in many cases containing volcanics and related intrusive rocks, is overlain by a generally thinner, finer sedimentary section usually poor or lacking in volcanics.

We review the rocks of the Pongola structure in the light of these criteria in order to determine whether or not the Pongola Supergroup was deposited in a rift, and perhaps obtain a better understanding of the nature of the Archean continental rifting process.

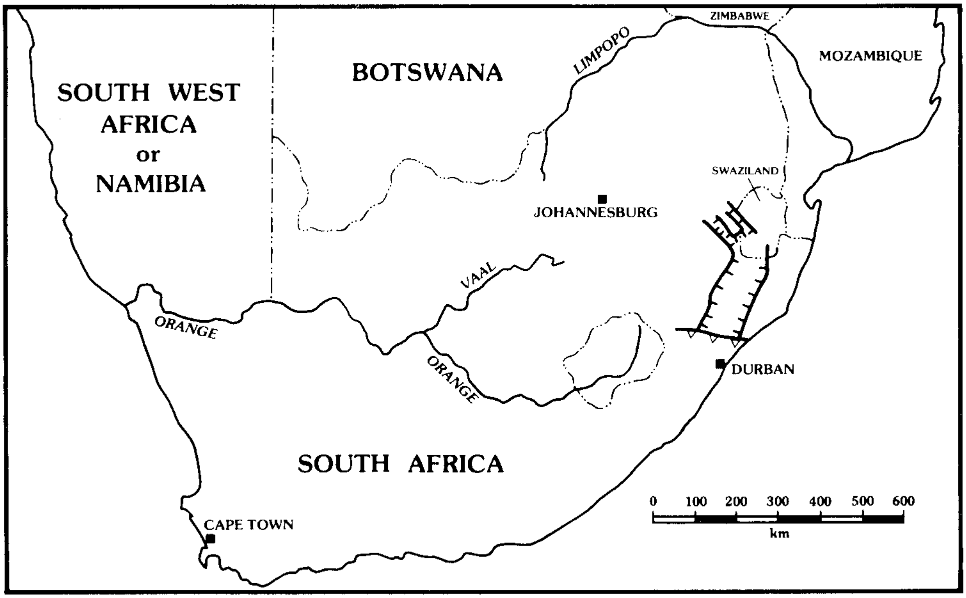

Fig. 1. Southern Africa showing the location of Pongola Group outcrops and the suggested shape of the 3.1 Ga old Pongola Rift in South Africa and Swaziland.

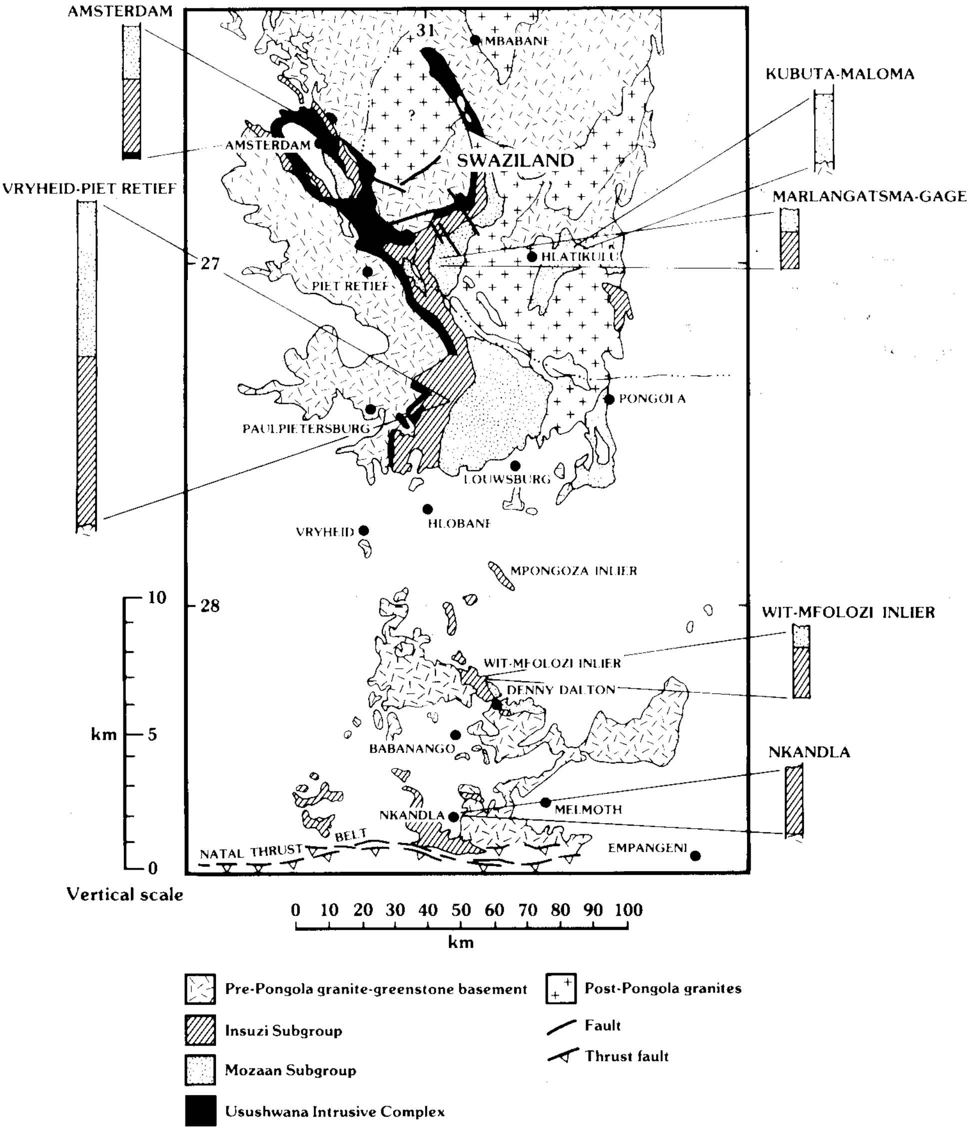

Fig. 2. Geologic map of the Pongola structure with stratigraphic sections from various localities. The rift is bounded by thrusts in the south and splits in two around basement horsts in the north (based in part on the work of Button, 1981).

STRATIGRAPHY AND SEDIMENTARY ASSOCIATIONS OF THE PONGOLA SUPERGROUP

The Pongola Supergroup (Humphrey, 1912) has been divided into two subgroups; the Nsuzi (formerly Insuzi, S.A.C.S., 1980) which rests nonconformably on older Archean granites and greenstones, and the Mozaan Subgroup which oversteps successively lower units of the Nsuzi Subgroup towards the southeast (Button, 1981). Locally, in the northern outcrop area, a paleoregolith up to 7.5 meters thick is developed between the older granites and the Nsuzi Subgroup (Matthews and Scharrer, 1968). This soil is thought to have formed by *in situ* subaerial chemical weathering of the underlying biotite-microcline granite. The paleoregolith is now composed of sericite, quartz and vermiculite, with the amount of sericite diminishing towards the top which, along with the development of a crude stratification may suggest incipient reworking of the soil (Button *et al.*, 1981).

THE NSUZI SUBGROUP

The Nsuzi Subgroup consists predominantly of interfingering basalts and rhyolites, basaltic andesites and dacites, along with minor sedimentary intercalations. These volcanic rocks have been interpreted as showing both tholeiitic and calc-alkaline affinities (Tankard *et al.*, 1982) and are bimodal in silica content. The Nsuzi Subgroup is best developed in the north along the Pongola River (Fig. 2) where it attains a thickness of 6100 m (Fig. 3). It thins towards the south to a thickness of 1800 m in the Wit Mfolozi inlier (Figs. 2 and 3). This substantial variation in along strike thickness can be attributed to differential subsidence during deposition, although the relatively thin nature of the Nsuzi Subgroup farther south in such localities as Nkandla (Figs. 2 and 3) may, at least in part, be attributable to erosion that may also have removed the entire Mozaan Subgroup, which is absent in this area. The base of the Nsuzi Subgroup is marked by an up to 850 m thick series of rapidly alternating argillaceous, arenaceous and arkosic grits, quartz arenites, conglomerates and breccias (Button, 1981). The immature nature of some of these fluvial sands and the presence of feldspars indicates that they were derived, at least in part, from a local, uplifted, probably granitic source terrane. These sediments resemble fanglomerates and are derived from older Archean basement that perhaps formed shoulders to an active rift. Some of the more mature quartz-arenite and granule-conglomerate sediments that occur in the upper part of this lower unit (Matthews and Scharrer, 1968) may have been transported along the rift axis in an internal drainage network, as is common in the early stages of rift development (for example: as in the Awash valley of the Ethiopian Afar). Hobday and Von Brunn (1976) have

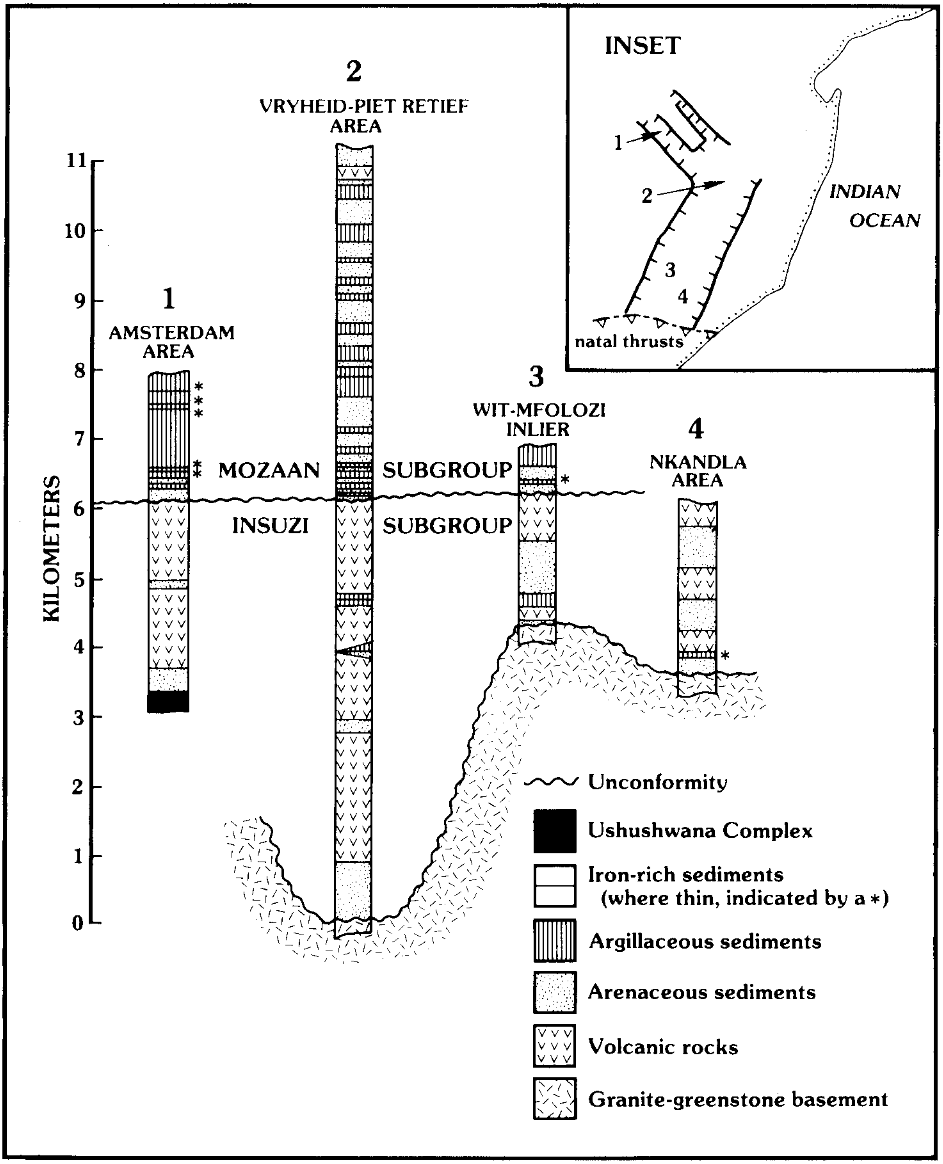

Fig. 3. Stratigraphic columns for the Pongola Group (modified from Button, 1981). Inset shows the approximate locations of these columns, which show features typical of rift stratigraphy.

demonstrated a dominantly granitic source for the arenites and argillites interbedded with the Nsuzi lavas and have suggested, as a result of applying a model by Klein (1971), that they were deposited by tidal currents under a high tidal range. In some places the arenites wedge out against paleotopographic basement highs (Matthews, 1967) that may have been induced by syndepositional basement faulting (Button, 1981). Basalts of the Nsuzi Subgroup are of both tholeiitic and high magnesium varieties (unpublished analyses of Matthews, mentioned in Burton, 1981). The basalts have been deuterically altered to an assemblage of turbid plagioclase, chlorite, epidote, calcite, leucoxene and opaque phases, and contain amygdules of chlorite, quartz, calcite, epidote and pyrite (Matthews, 1967). Rhyolitic horizons are abundant in the Nsuzi Subgroup with thicknesses of individual flows typically less than 10 meters. Flow top and gas streaming structures are common (Tankard *et al.*, 1982). DuToit (1954) described abundant amygdaloidal andesites and tuffs from the lower Nsuzi valley. The Nsuzi volcanics have been interpreted as showing greenschist facies metamorphism and deuteric alteration and the mobility of those elements used to discriminate between calc-alkaline, and any other igneous rock series, suggests that the present composition of the Nsuzi volcanics does not necessarily closely correspond to their original chemistry. This conclusion is supported by the large scatter of Sr, Ba, and Fe_2O_3 on Larsen and crystallisation index diagrams (Tankard *et al.*, 1982). The calc-alkaline affinities are in any case not strongly developed; on the basis of current data we do not regard the composition of the volcanics as incompatible with the interpretation of the Pongola structure as a rift.

A banded shale zone locally interbedded with the Nsuzi lavas (Fig. 3) was considered by Matthews (1967) to be a tidal flat deposit. The presence of these shallow water deposits about 4 km stratigraphically above the alluvial facies of the basal sand (see Vryheid-Piet Retief section, Fig. 3) indicates a minimum value for the subsidence that must have occurred in the Pongola basin. The tidal facies contains graded beds with small scale ripple drift, cross-laminated siltstone, shale, and lenticular channel deposits that display basal lag concentrates and fining upwards sequences. Another tidal or shallow marine deposit occurs in the Nsuzi Subgroup above another zone of bimodal volcanics. It contains carbonate cemented quartz arenites (Matthews, 1967), various other carbonates including aphanitic, oolitic and pisolitic dolomites, shales, tuffaceous sandstones, breccias and lenses of granule conglomerates. Also present are some shale clasts, partially silicified intraclast dolomites, sandstones with herrigbone cross-laminations, fenestral textures in dolomites and domical stromatolites (Von Brunn and Mason, 1977; Mason and Von Brunn, 1977) which have been interpreted a representing a tidal flat environment of deposition. Cycles with sand and mudstone are present throughout the Nsuzi Subgroup and have been interpreted to have formed from muddy tidal flats prograding over shallow water sands (Hobday and Von Brunn, 1976; Von Brunn and Hobday, 1976; Von Brunn, 1974).

The persistence of shallow water sedimentary environments throughout the eruption and deposition of the Nsuzi Subgroup volcanic rocks indicates that subsidence was penecontemporaneous with depositon. The subsidence was accomodated by normal faulting, which has been locally demonstrated to be of pre-Mozaan age in the Nkandla area (Matthews, 1967). We suggest that the Nsuzi Subgroup represents a rapid initial phase of subsidence and filling of the Pongola rift basin because it has characteristics similar to those of many more recent initial phase rift deposits, including: bimodal volcanic rocks, rapid variations in thickness and extent of sedimentary facies, syndepositional basement faulting and irregular basement topography, linear outcrop trends and (at least locally) faulted margins, thick sequences of shallow water facies deposits and immature basement derived fanglomerates.

THE MOZAAN SUBGROUP

The Mozaan Subgroup consists predominantly of alternating shales, quartz arenites, conglomerates and minor iron formation. The interaction of three sedimentary environments; braided alluvial plain, tidal flat and offshore shelf, has been discerned in the deposition of the Mozaan sequence (Watchorn, 1980) which is over 4600 m thick in its northern outcrops (Figs. 2 and 3; see also Matthews and Scharrer, 1968). Only 700 m are preserved towards the south, but much of the original thickness of the southern sections appears to have been removed by erosion, possibly during uplift associated with the Natal collision (see below).

The unconformity at the base of the Mozaan Subgroup truncates successively lower units of the Nsuzi Subgroup towards the southeast, and in general the area of Mozaan outcrop extends considerably farther east than the outcrop area of the Nsuzi Subgroup (Fig. 4). Tankard *et al.*, (1982) have inferred that the Mozaan sediments may also extend a considerable distance westward of the area of Nsuzi outcrop (Fig. 4), but in that area they are now covered by Karoo rocks. The geometry of the Pongola Supergroup shows some resemblance to the Steers Head, or Texas Longhorn condition, a feature that typifies the two stage stretching, and thermal recovery development of a rift system (Burke, 1979; McKenzie, 1978). Bickle and Eriksson (1982) have suggested that the Mozaan sediments represent the thermal subsidence phase of the Pongola basin. Sediments deposited during the thermal subsidence phase are expected to differ from those of the initial stretching phase by slower accumulation (and subsidence) rates, a lack or scarcity of volcanics, and a larger area of deposition.

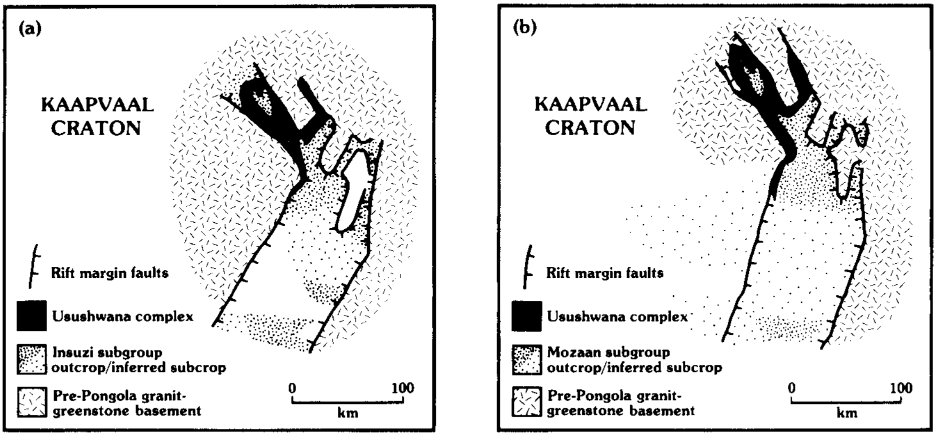

Fig. 4. Sketch map showing the distribution of Nsuzi sediments in the Pongola structure which are interpreted as rift-fill (Fig. 4a). Also shown are our suggested rift margins, which probably joined an Atlantic-type continental margin. The Mozaan sediments are distribution more widely than the Nsuzi Group rocks and have been interpreted as thermal subsidence phase deposits (Fig. 4b). (Based on work of Tankard *et al.*, 1982).

Pyritic conglomerates are developed near the base of the Mozaan group (Button, 1981) and similar conglomerates persist as well-defined thin horizons throughout the entire thickness of the subgroup. DuToit (1954) described conglomerates from the Denny Dalton area that are auriferous and uraniferous, also containing clasts of vein quartz, striped and black cherts, green quartzite, lava and pyrite. Near the base of the Mozaan Subgroup in Swaziland quartzite greatly exceeds shale in abundance, while throughout most of the subgroup they occur in nearly equal amounts (Hunter, 1963). Fourteen quartzite-shale cycles have been recognized from the northern outcrop areas (Button, 1981). Many of the shales are ferruginous and in some cases iron formations have developed, typically consisting of magnetite + tremolite + actinolite + quartz + chlorite with or without spessartine assemblages (Hunter, 1963). Banded iron formations consists of: (1) alternating iron oxide and red jasper mesobands (Strauss and DuPlessis, 1956); (2) oolites with chert nucleii surrounded by siderite (Beukes, 1973) or, (3) magnetite rich shales alternating with chlorite rich mesobands (Hunter, 1961; Beukes, 1973). The banded iron formations sometimes display intricate sedimentary slump fold structures (Beukes, 1973) which may indicate tectonic instability of the environment during deposition. Van Vuuren (1965) has noted some low grade manganese deposits associated with the iron rich parts of the Mozaan Subgroup, concluding that the manganese enrichment is most pronounced along faults.

In general, the shales of the lower Mozaan Subgroup typically containing an andalusite + pyrophyllite assemblage are more aluminous than are the upper, iron rich shales. Local contact metamorphic effects in the lower Mozaan Subgroup may have accentuated the apparent alumina concentration, locally forming andalusite – sericite or pyrophyllitic phyllites and sillimanite bearing quartzites (Beukes, 1973; Hunter, 1963).

Von Brunn and Hobday (1976) have attributed patterns of cyclic sedimentation in the Mozaan Subgroup to tidal flat deposition on a east-west trending shoreline. The orientation of the shoreline, which could possibly be related to the progradation of a shallow marine "delta" down an elongate (rift valley) depression, is indicated by the southeast directed through cross-beds and the east-west preferred orientation of pebble long axes and ripple crests. The shallow tidal environment was hypothesized by Von Brunn and Hobday (1976) because of the presence of herringbone cross-strata, double crested and flat topped ripples. Cyclic sedimentation patterns between lower, middle and upper tidal flat sediments were noted by these authors. The lower tidal flat deposits consist of cross-laminated arenites that grade up into an alternating arenite-argillite mid tidal flat facies. The middle tidal flat deposits commence with flaser bedded arenites which are succeeded by wavy and lenticular bedded arenite-argillite alternations. These contain numerous dessication cracks, ripple marks and mud clasts indicative of tidal reworking. The upper tidal flat deposists consist of mudstones and graded siltstones displaying abundant mudclast microbreccias and dessication features. Locally associated with the upper tidal flat deposits are jaspillitic iron formations that may have accumulated in small episodically flooded depressions (Button, 1981).

THE USUSHWANA INTRUSIVE SUITE

The Usushwana Intrusive Suite was named by Hunter (1950) and has recently been dated at 2871 +/– 30 Ma (Sm-Nd mineral/whole rock isochron, Hegner *et al.*, 1984). In the Mhlambanyatsi area (Fig. 2) the Usushwana complex occurs as a northwest striking 40 km long × 6.5 km wide steep sided dike that parallels major faults in the granitic basement (Tankard *et al.*, 1982; gravity data of Burley *et al.*, 1970). This large dike is linked by a sheetlike mass that extends along the base of the Pongola Supergroup to a second northwest striking large steep sided dike complex that is also paralleled by major faults in the basement. Both the dikes and sheet contain xenoliths of Pongola rocks.

The Usushwana complex is composed of various mafic phases including hypersthene gabbro, quartz gabbro, olivine pyroxenite and serpentinised ultramafic rocks. A compositional layering in locally displayed. The earliest phase is a coarse grained olivine pyroxenite that was intruded by quartz gabbro, disrupting the compositional layering (Tankard *et al.*, 1982). A thick granophyre layer commonly overlies the quartz gabbro, and can be observed northeast of Piet Retief (Fig. 2). Granitic dikes up to 20 meters wide containing plagioclase, quartz, epidote and biotite commonly fill joint planes in the gabbroic rocks. Although no economic grade mineral occurrences are known from the Usushwana complex, some disseminated chalcopyrite and pyrrhotite layers are fairly well developed near Mhlambanyatsi (Tankard *et al.*, 1982).

Intrusives of the Usushwana complex also occur as numerous dikes and sills throughout the entire thickness of the Pongola Supergroup. Humphrey and Kriege (1932) recognized 10 diabase sills that intrude the Mozaan Subgroup preferentially along quartzite-shale contacts. Hunter (1963) notes that the amygdaloidal "basalt" in Swaziland is very similar to the amygdular diabase sills east of Piet Retief. Since these sills are part of the Usushwana complex, it is possible that the "basalt" in Swaziland may be the extrusive equivalent of the Usushwana complex, or alternatively it may be a large sill from which the cover has been eroded.

A postulated evolution for the Usushwana complex is (Hunter, 1970) that magmas appear to have preferentially intruded along faults that were formed during the initial rifting episode. Numerous diabase dikes lithologically similar to the main Usushwana complex intrude the basement complex, and are commonly oriented subparallel to the basin margins. The Usushwana intrusions have destroyed much of the original contact relationship between the granitic basement and the Pongola Supergroup. Tankard *et al.*, (1982) note the many striking similarities of the Usushwana complex to the Great Dike of Zimbabwe, which is considered to represent an outcropping example of "the axial dike" of a continental rift (Burke and Whiteman, 1973). If the Usushwana igneous complex is related to the Pongola structure, we may be seeing an episode of renewed rifting postdating a thermal subsidence event recorded in the Mozaan sequence. Such an event might make tectonic interpretation of stratigraphic thicknesses difficult.

AGE OF THE PONGOLA STRUCTURE

Rocks of the Pongola Supergroup have recently yielded isotopic ages of 2940 +/− 22 Ma (U-Pb zircon concordia intercept, Hegner *et al.*, 1984) and 2934 +/− 114 Ma (Sm-Nd whole rock isochron from basalt-rhyolite suite, Hegner *et al.*, 1984). These dates are slightly younger than earlier reported ages of 3083 +/− 150 Ma (Rb-Sr whole rock method, Burger and Coertze, 1973) and 3030 +/− 90 Ma (U-Pb from zircons, recalculated from Burger and Coertze, 1973).

Granitic basement to the Pongola Supergroup has been reported to have yielded a Rb-Sr whole rock isochron of 2995 +/− 140 Ma (eg., Hunter, 1974 "quoting" data of Allsop *et al.*, 1962). However, Allsop *et al.*, (1962) ascribe this isochron to a Swaziland G4 granite that intrudes the Mozaan sediments in southwestern Swaziland (Hunter, 1957, 1963), providing a minimum rather than a basement age for the Pongola Supergroup. It is therefore likely that the basement to the Pongola Rift is of an older age, possibly that of the "older" granites and gneisses in Swaziland which have yielded a Rb-Sr isochron of 3367 +/− 300 Ma (Allsop *et al.*, 1962). Until future studies resolve relative ages of Pongola rocks and the Swaziland G4 granites, it is only possible to state that the time of initial Pongola deposition and rifting was approximately 3.0 Ga ago.

The Usushwana Intrusive Suite, which we suggest represents a renewed rifting event in the Pongola Structure, has yielded a Sm-Nd mineral/whole rock isochron of 2871 +/− 30 Ma (Hegner *et al.*, 1984), which is in fair agreement with an earlier age determination of 2813 +/− 30 Ma (Rb-Sr whole rock, Davies *et al.*, 1969). Ages quoted in this section have been recalculated (where necessary) using the decay constants of Steiger and Jager, 1977.

METAMORPHISM AND CONVERGENT TECTONICS

The Pongola Supergroup has been metamorphosed to greenschist facies and is only mildly defomed, except in the south, where it was involved in at least two orogenic episodes. In the Vryheid-Piet Retief area just south of Swaziland Pongola beds are gently folded producing dips of 0 to 30 degrees and a dominant west-northwest fold trend direction (Button, 1981). Although

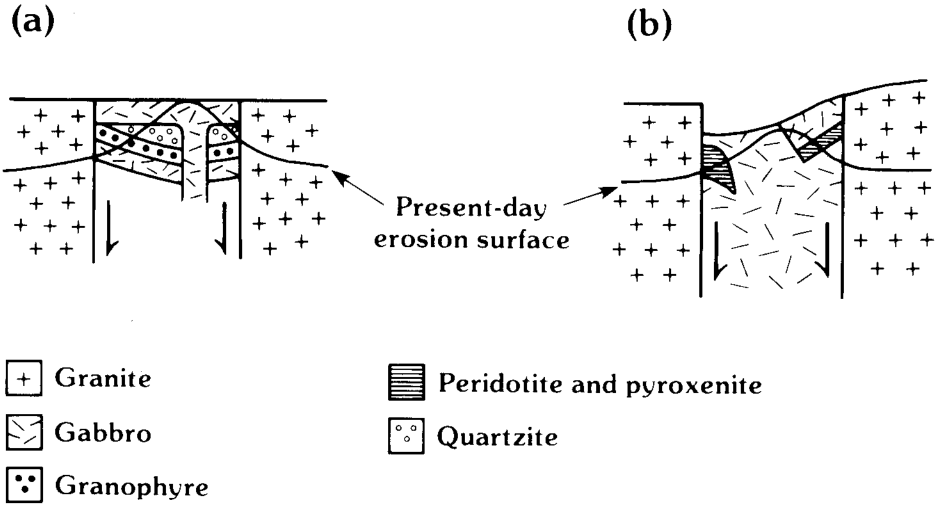

Fig. 5. Sketch cross-sections of the Pongola rift and Usushwana intrusive suite (a) S.W. of and (b) N.W. of Mhlambanyatsi in Swaziland modified after Hunter (1970).

another episode of gentle folding has produced mild basin and dome structures (DuToit, 1954; Button, 1981); each of the folding episodes was only associated with a minor amount of shortening and no complex structural relationships appear to have formed. In the Amsterdam and Mhlambanyatsi areas the general structural disposition of Pongola strata is a synclinal form, trending and plunging to the southeast, and intruded by steep sided mafic Usushwana dikes (Fig. 5). Pongola rocks in the southern inliears around Nkandla are strongly folded and metamorphosed, with the amount of deformation increasing southward towards the Natal-Ntingwe thrust front, which marks the boundary between the Kaapvaal and Natal crustal provinces (Matthews, 1959). The Natal Province is an allochthonous terrane emplaced upon the southern portion of the Kaapvaal Craton as a series of nappes at a suture zone about 1.0 Ga years ago (Matthews, 1981). The Tugela and Mfongosi suites of the Natal Province represent, respectively, the lower and upper parts of an ophiolite suite obducted northward onto the Kaapvaal Craton along the Makasana basal decollement zone (Tankard *et al.*, 1982). The truncated nature of the rocks of the Pongola structure at the Natal thrust front suggests that the Pongola rift originally continued farther southward, and may now be partly buried under the Natal allochthons.

DISCUSSION

The Pongola Supergroup shows many features that are typical and diagnostic of rocks deposited in continental rifts. Its age ranges from approximately 3.0 to 2.87 Ga, making it the world's oldest well-preserved rift so far recognized. This identification extends the occurrence of rifts considerably further back in time than recognised by Burke *et al.* (1976) and Burke (1977) and suggests that it is more likely that the scarcity of old rifts is an accident of preservation rather than indicative of a radical secular change in planetary tectonic behavior from the Archean to younger times. Linear outcrop trends along with locally faulted margins enable the original width of the rift to be roughly estimated at 50–70 km. In numerous places where the basin margins are not observed to be faulted, the contact between Pongola strata and older basement is the site of mafic intrusions (Usushwana Suite). These dikes (and sills) have been preferentially intruded in places that are inferred to have been zones of weakness developed during the initial stages of Pongola rifting. Bickle and Eriksson (1982) have estimated a stretching factor of 1.4 to 2.2 for the Pongola basin using thicknesses for the sediments and volcanics deposited during postulated initial stretching and thermal subsidence phases. Intrusion of the Usushawana rocks late in the rifting episode indicates additional extension. Because of difficulties in quantifying the amount of Ushushwana related extension and because the lithospheric thickness before any Pongola rifting remains unknown we prefer not to make a numerical estimate of extension or stretching. However, the overall thicknesses and size of the Pongola structure are quite typical of Phanerozic continental rifts, for which a stretching factor of about 2 is often appropriate. The evidence from the Pongola rift suggests that Archean rifting was not significantly different from continental rifting later in the earth's history. There is persuasive evidence of an ocean closing event about 1 Ga ago in the Namaqualand orogen at the southern end of the Pongola rift, but it is not yet clear whether the initiation of the Atlantic-type continental margin on the southern edge of the Kaapval Craton (which forms the northern side of the Namaqua orogen) was contemporary with or much younger than the Pongola rifting event.

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