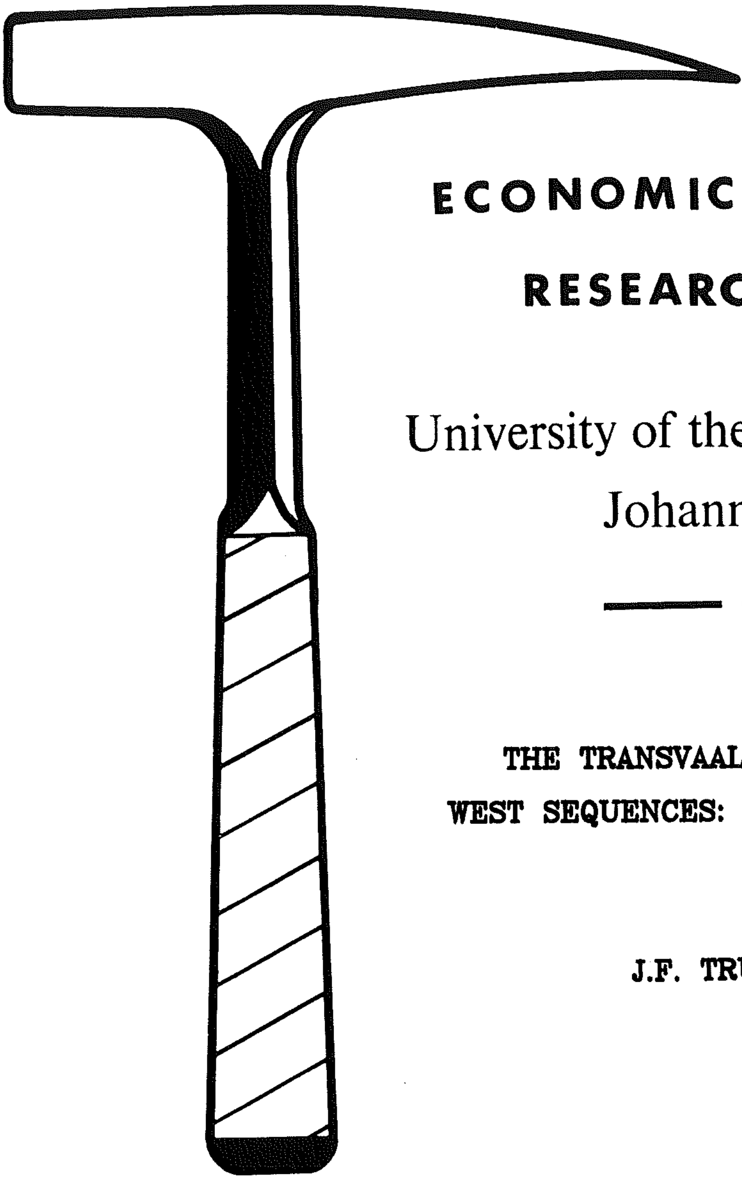

ECONOMIC GEOLOGY

RESEARCH UNIT

University of the Witwatersrand
Johannesburg

THE TRANSVAAL AND GRIQUALAND WEST SEQUENCES: SOME CURRENT ISSUES

J.F. TRUSWELL

INFORMATION CIRCULAR No. 232

UNIVERSITY OF THE WITWATERSRAND

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by

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ABSTRACT

The preserved structural basins in which the Transvaal and Griqualand West Sequences occur lie either side of the complex Vryburg arch, about which the longitudinal axes of the main two occurrences are bent.

The lower part of the thick successions involved are represented by the predominantly dolomitic sediments and associated iron formations, of the Ghaap Group (in the Northern Cape) and the Chuniespoort Group (in the Transvaal). There are significant differences between the overlying Pretoria Group (Transvaal) and Postmasburg Group (Northern Cape). In the Transvaal some underlying strata have been regarded as protobasinal deposits; and uppermost strata, associated with the Rooiberg Felsites, have also been referred to the Transvaal sequence.

The age of these sequences is poorly constrained. In the Transvaal these rocks, together with the underlying uppermost Ventersdorp, accumulated in the period $\sim$ 2700 to 2060 m.y.

Preserved outcrops of the Ghaap and Chuniespoort Groups accumulated in a single basin which occupied, at least, most of the present extent of the Kaapvaal craton.

Over most of this basin deposition took place in a shallow epeiric sea on a vast, ramp-like platform. Southwest of a growth fault at Griquatown a deeper water facies faced open ocean.

Two main stages are distinguished in the development of the Chuniespoort/Ghaap Sea. Both involved NNE transgression away from the Northern Cape, with more complex interactions in detail. Between the two main stages the sea withdrew from the craton altogether.

A number of depositional sequences have been recognized, each represented by genetically related, lithologically similar strata bounded by unconformities. The manner in which the basin formed is less well understood, but the sequential stratigraphy established does call for a simple mechanism of basin formation.

A relationship with earlier Platberg (Ventersdorp) vulcanicity is likely. The basin is thought either to represent subsequent thermal subsidence, with eustasy affecting the vertically stacked sequence; or to the periodic release of compression related to distant plate interactions: no such interactions have been identified as yet, and a thermal subsidence/eustatic model is favoured here.

A number of isolated lithostratigraphic units lie below the Black Reef Quartzite in the Transvaal: in the core of fragments in the Bushveld Complex (Wachteenbeetjie Formation in the Crocodile River Fragment, Groblersdal group in the Dennilton Dome), and at the northwestern (Buffelsfontein Group), northeastern (Wolkberg Group) and eastern (Godwan Formation) margins of the present outcrop.

There is insufficient information for comment on the Wachteenbeetjie Formation or the Groblersdal Group. The Godwan Formation is cut by pre-Transvaal wrench faulting, and is a remnant of a significantly earlier succession.

The Buffelsfontein and Wolkberg Groups have been seen as proto-basinal deposits of the Sequence. This has now been questioned. The earliest (succeeding) carbonate sedimentation was restricted to the Northern Cape - transgression into the northeastern Transvaal took place later. An unconformity has been demonstrated between the Wolkberg and the Black Reef, and a further one within the Wolkberg; further, correlation has been suggested between the Wolkberg and Buffelsfontein and the proposed Platberg and Pniel unconformity-bounded surfaces of the Ventersdorp to the west. Notwithstanding these points, the Buffelsfontein and Wolkberg are still regarded here as being separated by little in a time sense from the overlying Transvaal Sequence; attempts to correlate these units with any other established stratigraphic units may be inappropriate.

A major unconformity developed northeast of the Vryburg arch. Uplift, and very localised folding in the Mhlapitse fold belt took place after Chuniespoort sedimentation, and prior to the deposition of the Pretoria Group. This unconformity is not known in the Northern Cape; uppermost sedimentation in the underlying Ghaap Group at the southwest margin of the craton may in fact be coeval with Timeball Hill sedimentation of the Pretoria Group of the Transvaal.

Pretoria Group sedimentation took place in the littoral and marine zones of an epicontinental sea, although in an alternative suggestion, complex lacustrine basins have been suggested.

Identical lithologies characterise the Pretoria Group, but the outcrops are separated by the lower Proterozoic Rooiberg felsites and Bushveld Granite in the central Transvaal, and by the Gaborone Granite in southeastern Botswana.

Earlier work had indicated that the Gaborone Granite was a $\sim$ 2400 m.y. old; one interpretation of a single outcrop suggested that this granite intruded Black Reef Quartzite. Adjacent to this granite uppermost Transvaal strata have collapsed, and slid under gravity west towards Kanye, eastwards towards the Bushveld; the above relationships could be used to support the view that this catastrophic event related to the forceful, high-level emplacement of the Gaborone granite towards the end of Transvaal sedimentation.

However, field relations show that an equivalent of the 2 700 m.y. Ventersdorp volcanics unconformably overlies the Gaborone Granite. The spatial relationship of this anorogenic granite to the later gravity sliding in Transvaal strata remains to be explained: the northern end of the Kuruman arch may well have been active in some manner at an appropriate, later state.

The view is also supported that Transvaal sedimentation was stripped away from the central Transvaal, probably in post-Magaliesberg times, as this area rose; the mechanism of this is, however, not well understood.

Correlation between the Pretoria and Postmasburg Groups is linked only to coeval volcanics (Hekpoort, Ongeluk), underlain by diamictites; and the surmise that the overlying relatively thin chemical sediments in the northern Cape are a distal facies of the Dwaalheuwel Formation. If subsequent Postmasburg strata were deposited in the Northern Cape they have been removed.

The Rooiberg volcanics, and related sedimentation in the Transvaal, are seen as a later event.

It has been suggested recently that the basic intrusive phase of the Bushveld Complex, rather than cutting across the Pretoria Group on a regional scale, was emplaced along an unconformity. This separated off parts of the distinctive sediments in the Stavoren and Rooiberg fragments, the Rooiberg felsites, overlying red beds of the Loskop and the lower Swaershoek Formations, and the Dullstroom Volcanics into an unconformity-bounded sequence younger than the Pretoria Group.

Such a grouping should be broadened to include all sediments below the Rooiberg felsites in the Rooiberg and Stavoren fragments. More significantly, the Loskop-Wilgerivier unconformity in the Middelburg Basin is regarded as of only local significance. The time of this break does indeed include the intrusion of the Lebowa Granite Suite (Bushveld Granite), but elsewhere, near Nylstroom the shallowly emplaced Bushveld granite was unroofed during the accumulation of similar red-bed sediments.

The grouping envisaged links pre-Rooiberg felsite and post-Lebowa granite continental sediments. The closely related distribution of this overall assemblage has long drawn comment. The suggested grouping would strengthen the concept of petrogenetic and close time linkages between the Rooiberg felsites and the Bushveld Granite Suite.

Current understanding of the Pilbara craton in northern Western Australia and of the Kaapvaal craton supports the hypothesis that the two cratons represented a single crustal fragment through a major part of Precambrian time. Particularly clear similarities have been established between the Transvaal and Hamersley (W.A.) basins: a recent suggestion sees the Pilbara attached to the southwestern portion of the Kaapvaal craton at that time.

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THE TRANSVAAL AND GRIQUALAND WEST SEQUENCES:

SOME CURRENT ISSUES

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INTRODUCTION

The latest Archaean (?) to early Proterozoic Transvaal/Griqualand West Sequences are preserved in two structural basins: the Transvaal Sequence developed in parts of the Transvaal, Orange Free State and adjacent easternmost Botswana; the Griqualand West Sequence in the northern Cape Province, extending into southern Botswana. The two basins lie either side of the complex Vryburg arch, about which the longitudinal axes of the two main occurrences are bent.

The Transvaal Sequence forms a pear-shaped ring around the Bushveld Complex, towards which it dips centripetally; fragments occur in the Complex itself. To the south of this the sequence is also preserved in the Potchefstroom Synclinorium, the south side of which is abruptly upturned against the Vredefort structure. In the northern Cape these rocks occupy a triangular area, the apex of which lies near the Orange River: in this area dips are usually low.

The Transvaal Sequence occurs in three distinct areas: in the eastern and western Bushveld, and the Kanye district of southeastern Botswana; these areas are separated respectively by the Rooiberg felsites and Bushveld Granite of the central Bushveld, and the Gaborone Granite at the northern extremity of the Kuruman arch.

The structural evolution and shape of the basin has been largely controlled by the intrusion of the Bushveld Complex, the emplacement of the Vredefort structure and, probably, by the earlier intrusion of the Gaborone Granite. Other factors operative at various times during or after sedimentation relate to upward movement of granitic basement domes, and more localised ENE-trending structures (Fig. 3).

The Transvaal strata dip inwards below the Rustenburg Layered Suite of the Bushveld Complex. The floor of the complex either cuts across the Transvaal Sequence or, as has recently been suggested, was emplaced concordantly along an unconformity separating off uppermost Pretoria Group sediments and the Rooiberg felsites (Cheney & Twist, 1988).

A large number of basic sills are intruded into the Pretoria Group strata: most of these are related to the Rustenburg Layered Suite.

A number of fragments of Transvaal strata occur within the Bushveld Complex. Some small masses occurring in upper or roof zones are xenolithic: several origins have been suggested for the larger masses such as the Crocodile River fragment in the Western Transvaal, the Moos River fragment in the eastern Transvaal - thrusting, xenolithic, cone-fracturing, diapirism. However, such fragments are now generally considered to be attached to the floor, and domal (Sharpe & Chadwick, 1982; Harzer, 1989).

High-grade metamorphism is associated with the intrusion of the Rustenburg Layered Suite. The metamorphism affects the floor of the complex, and the contained fragments. These fragments frequently have complex structure.

Adjacent to the Gaborone Granite in Botswana upper Transvaal strata collapsed and slid under gravity east and westwards. This is a distinctive feature that will be discussed further.

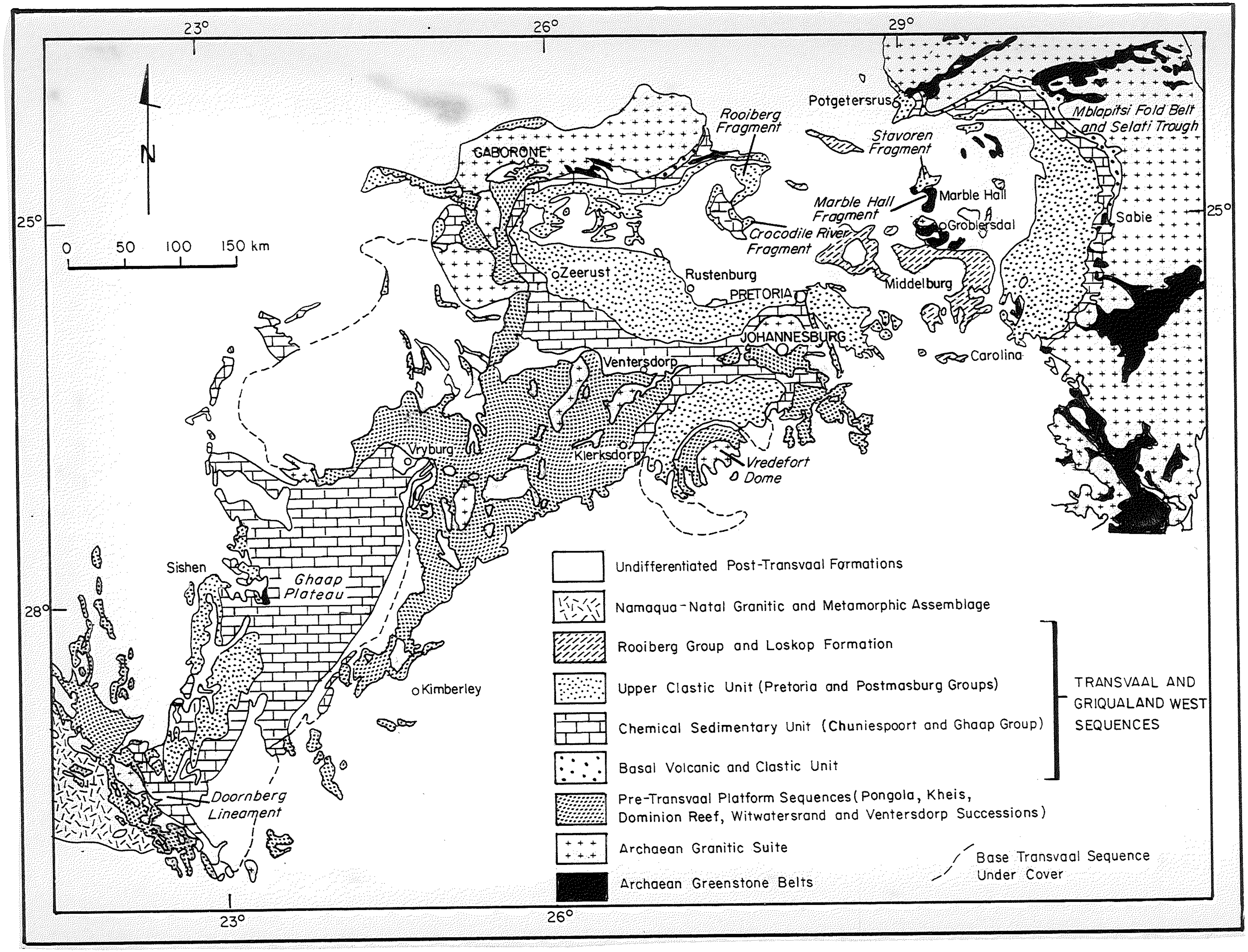

Fig. 1. Geology of the Transvaal and Griqualand West Sequences. (After Button, 1986).

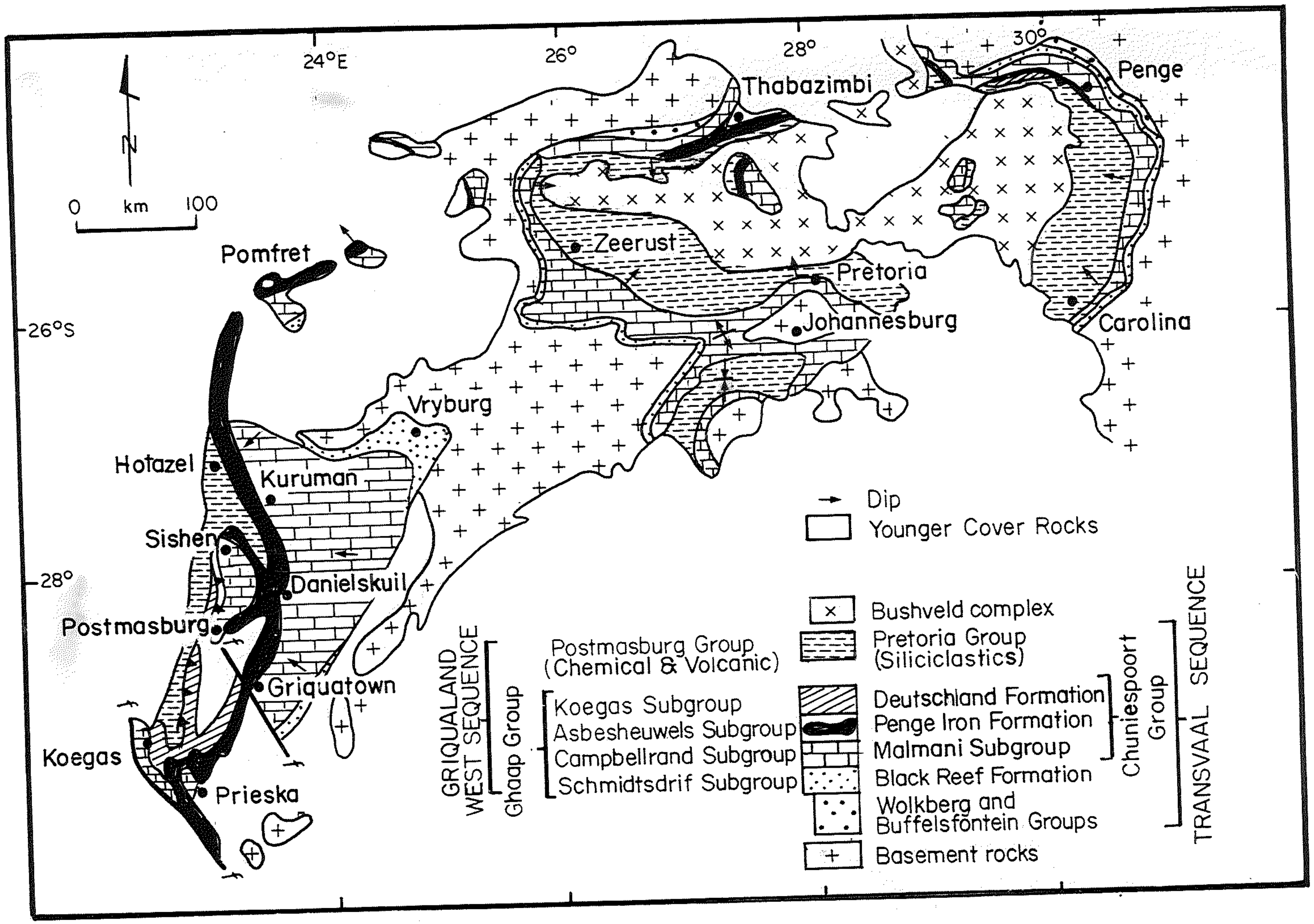

Fig. 2. Simplified geology of the Transvaal and Griqualand West Sequences. (after Beukes, 1987).

Adjacent to the Vredefort structure, Transvaal strata are preserved in a series of folds whose amplitude decreases outwards (McCarthy & Others, 1990). McCarthy & Others (1986) have shown that large and small-scale folds, and penetrative cleavage in Transvaal strata in the area north and west of Vredefort, particularly in the Black Reef Quartzite, are tangential to the Vredefort structure to which they are thought to be genetically related.

In the Northern Cape the dip of the Griqualand West strata is usually very low, to the west.

Westernmost exposures in this region lie at the eastern edge of the Kheis belt, a thrust and fold belt which post-dates younger Olifantshoek red beds. Although it is usually the Olifantshoek that has been crumpled and overthrust eastwards, in the south some Griqualand West strata are affected. Metamorphic grade increases into the belt.

In the extreme south the Griqualand West strata are truncated by later dextral shearing on the Brakbosch and Brulpan Faults.

The Transvaal and Griqualand West sequences fall within the Transvaal System established by Molengraaf in 1901. At the broadest level virtually all of the lower part of each sequence (the Chuniespoort and Ghaap Groups respectively in the Transvaal and the northern Cape) is composed of chemical sediments: of carbonates, and some banded iron formations. For these rocks research since the 70's has confirmed the existence of a single basin extending over at least 500 000 km^2; and has now begun to develop an understanding of the manner in which the overall basin fill accumulated and of how this intracratonic basin may have developed.

In the Transvaal, the Chuniespoort is truncated by a very major unconformity, the significance of which should not be underestimated. Above lies the thick Pretoria Group. Traditionally this group is correlated with the significantly thinner Postmasburg Group in the Northern Cape. But this correlation can only be related to coeval volcanics (Hekpoort, Ongeluk), underlain by diamictites. If the overlying chemical sediments in the Postmasburg are a distal facies of siliciclastics in the Transvaal, then at best they represent only a small part of the succession in the Transvaal.

Whilst the outcrops of the Pretoria Group are, it is believed generally, regarded as structural remnants of a larger basin, it must be noted that in another view they are seen as a chain of smaller basins, of 'Great Lakes'.

Work in the Transvaal in the 70's led to the development of the concept of a protobasinal facies, involving significant vulcanicity, and associated sedimentation, lying below the remainder of the sequence at specific localities; most notably the Wolkberg Group in the eastern Transvaal. Recent studies have tended to

a) indicate that these strata are not conformable with the overlying sequence; and

b) suggest that they may be part of a more widespread than previously thought manifestation of sedimentation and of vulcanicity related to the underlying uppermost Ventersdorp events.

In the central Transvaal the uppermost part of the sequence is represented by the felsites of the Rooiberg Group. In two fragments (Stavoren, Rooiberg) there are distinctive sedimentary units below the felsites, whereas above them lie, conformably, the red beds of the Loskop Formation. The correlation of these units, specifically in relation to the Pretoria Group remains uncertain. There is now some evidence to suggest they may be distinctly younger than the Pretoria Group; such a concept might be expanded to include the time of emplacement of the Bushveld Granite.

Similarities between the Pilbara craton of northwestern Australia and aspects of the Kaapvaal craton have long drawn comment. Such similarities are particularly prevalent in the Transvaal/Griqualand West, and Hamersley strata, and bear on the evolution and siting of these two area.

Figures 1 and 2 illustrate the distribution of units commonly regarded as part of these sequences. Figure 2 is more generalised; that comment would certainly include inferences related to specific correlation shown in the legend. Figure 3 should be seen in the same light: it shows the lithostratigraphic correlations of SACS (1980). These three figures provide background to the ensuing discussion, and do not necessarily reflect current thinking on the grouping of these rocks.

Thicknesses of these sequences are a measure of their significance. The thicknesses of the main units in the Transvaal Sequence are provided in Table 2: thicknesses are greatest in the northeastern Transvaal and approach 10 000 m. In the Griqualand West Sequence thicknesses of the Ghaap Group are comparable to the Chuniespoort Group; the Postmasburg Group is $\sim$ 2000 m thick.

There is an abundant literature on the Transvaal/Griqualand West Sequences. Major works to which reference should be made are the regional theses of Beukes, 1978 (Griqualand West); Button, 1973a (Eastern Transvaal); and Clendenin, 1989 (Chuniespoort/Ghaap Groups). Beukes (1983), as background to consideration of the iron formations, provides much useful bibliographic information. In this he shows how initial sedimentological studies, the beginnings of basin analysis and the introduction of lithostratigraphic terminology date back to the period 1967-1972, and of how such studies accelerated thereafter.

Recent reviews are those of Beukes, 1986 (Griqualand West); Button, 1986 (Transvaal); Eriksson (P.G.) & Clendenin, 1990 (Transvaal). The development of lithostratigraphic terminology is documented by SACS (1980). Tankard & Others (1982) provide, and develop, information on these rocks, in particular laying stress on sedimentary environments and controls.

This circular will not attempt to duplicate existing information, but rather - against a general background - to focus on specific aspects reflecting issues which have already been alluded to above. These include:

- the relationship of underlying volcanics and sediments to the Transvaal Sequence
- the formation of the Chuniespoort/Ghaap intracratonic basin
- the depository or depositories of the Pretoria/Postmasburg Groups
- sediments associated with the Rooiberg felsites, and the Bushveld Granite
- the Transvaal/Griqualand West - Hamersley nexus.

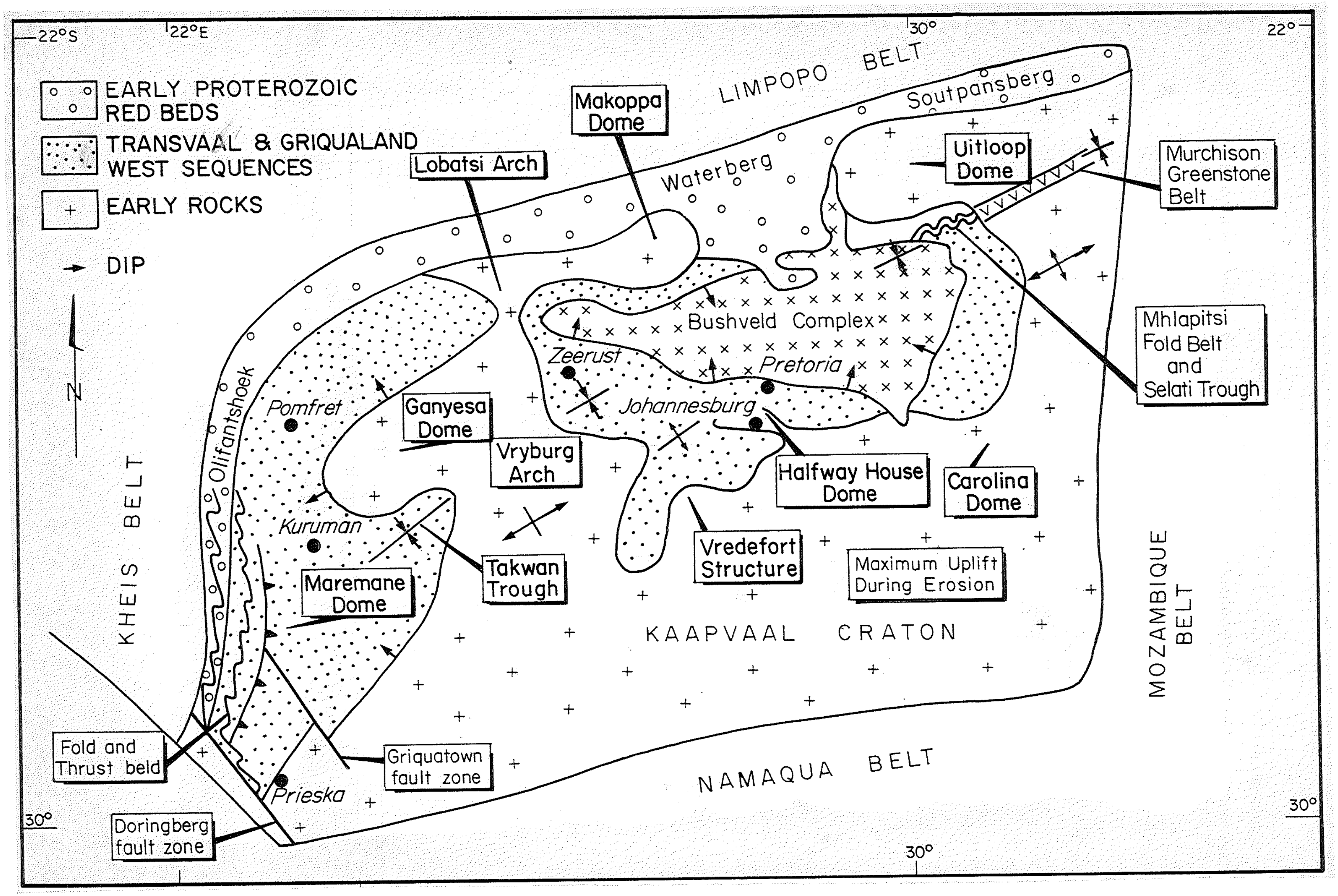

Fig. 3. Tectonic features on the Kaapvaal craton related to the Transvaal/Griqualand West Sequences. (with minor modification after Beukes, 1987).

Group	Subgroup	WESTERN TRANSVAAL	ROOIBERG FRAGMENT	STAVOREN FRAGMENT	Group / Subgroup	EASTERN TRANSVAAL
		Formation	Formation	Formation		Formation
ROOI-BERG GROUP		Schrikkloof				Selons River
ROOI-BERG GROUP		Kwaggasnek				Damwal
PRETORIA GROUP						Dullstroom Basalt
PRETORIA GROUP						Houtenbek
PRETORIA GROUP						Steenkampsberg Quartzite
PRETORIA GROUP						Nederhorst
PRETORIA GROUP		Rayton	Smelterskop Quartzite	Makeckaan Quartzite		Lakenvalei Quartzite
PRETORIA GROUP			Leeuwpoort			Vermont Hornfels
PRETORIA GROUP		Magaliesberg Quartzite				Magaliesberg Quartzite
PRETORIA GROUP		Silverton Shale				Silverton Shale
PRETORIA GROUP		Daspoort Quartzite				Daspoort Quartzite
PRETORIA GROUP		Strubenkop Shale				Strubenkop Shale
PRETORIA GROUP		Droogedal				Dwaalheuwel Quartzite
PRETORIA GROUP		Hekpoort Andesite				Hekpoort Andesite
PRETORIA GROUP		Boshoek				Boshoek
PRETORIA GROUP		Timeball Hill				Timeball Hill
PRETORIA GROUP		Rooihoogte				Rooihoogte
CHUNIESPOORT GROUP						Duitschland
CHUNIESPOORT GROUP		Penge				Penge
CHUNIESPOORT GROUP	MALMANI SUBGROUP	Frisco			MALMANI SUBGROUP	Frisco
CHUNIESPOORT GROUP	MALMANI SUBGROUP	Eccles			MALMANI SUBGROUP	Eccles
CHUNIESPOORT GROUP	MALMANI SUBGROUP	Lyttelton			MALMANI SUBGROUP	Lyttelton
CHUNIESPOORT GROUP	MALMANI SUBGROUP	Monte Christo			MALMANI SUBGROUP	Monte Christo
CHUNIESPOORT GROUP	MALMANI SUBGROUP	Oaktree			MALMANI SUBGROUP	Oaktree
		Black Reef Quartzite				
BUFFELS-FONTEIN GROUP		Tygerkloof Quartzite			WOLKBERG GROUP	Sadowa Shale
BUFFELS-FONTEIN GROUP		Witfonteinrant			WOLKBERG GROUP	Mabin Quartzite
BUFFELS-FONTEIN GROUP		Waterval			WOLKBERG GROUP	Selati Shale
BUFFELS-FONTEIN GROUP		Hampton			WOLKBERG GROUP	Schelem
					WOLKBERG GROUP	Abel Erasmus Basalt
					WOLKBERG GROUP	Sekororo

Table 1. Regional correlation of formations in the Transvaal Sequence; with minor modification but as expressed by SACS (1980).

	EASTERN BOTSWANA (1)	WESTERN TRANSVAAL	PRETORIA	EASTERN TRANSVAAL (2)
PRETORIA	3152	1535	2905 - 3675	3885 - 9305
Above Magaliesberg	1200		1200	1420 - 2985
Base to Magaliesberg	1932	1535	1705 - 2475	2465 - 6320
CHUNIESPOORT	1160	1780	1430	1360 - 2660
Penge & Duitschland	80	320		0 - 1300
Malmani	1080	1780	1430	1360
BLACK REEF	60	25	25 - 30	30 (3)

(1) Section at Lobatsi
(2) Dullstroom volcanics - up to 1600 m (Schweitzer, 1986) not shown.
(3) Clendenin & Others, 1989.

TABLE 2. Thicknesses of the Transvaal Sequence in the Transvaal and Eastern Botswana. Information from SACS (1980) unless indicated.

AGE

The age ascribed to these sequences is somewhat variable. Given their significance, particularly the early carbonate/iron formation succession, it will be as well to document the available data with some care.

The age of the Transvaal can, on present evidence, only be bracketed between ∿ 2700 m.y. and 2061 m.y.

Three samples from the underlying Ventersdorp have now been dated using ion-microprobe techniques on individual zircons (Armstrong & Others, 1990). Zircons from felsic volcanics of the Makwassie Quartz Porphyry are clear, without internal structure and give a mean $^{207}Pb/^{206}Pb$ age of 2709 ± 8 m.y. Data from two basalts from the underlying Klipriviersberg are more problematical: the quantities of zircon are small, the population heterogeneous and it proved difficult to identify a magmatic population; nevertheless, an age of 2724 ± 8 m.y. is indicated.

Armstrong & Others (1990) note that these two ages are not significantly different, indicating that Ventersdorp volcanism, at least between these two stratigraphic horizons, proceeded rapidly. Comparable age measurements are not available from the Pniel Group, that is from the third, and uppermost, major unit in the Ventersdorp.

The Rooiberg Felsites are regarded as the top of the Transvaal. These volcanics have been affected by open-system behaviour of their isotopic systems and the available data are not reliable (Walraven & Others, 1990). These rocks are (thus) dated in relation to the succeeding Rustenburg Layered Suite (RLS) and Lebowa Granite Suite (LGS) of the Bushveld Complex.

The RLS crystallised from magmas with diverse $^{87}Sr/^{86}Sr$ ratios, and magma mixing played an important role in its genesis. However, the Upper Zone of the RLS crystallised from a well-mixed homogeneous magma with a constant initial $^{87}Sr/^{86}Sr$ ratio. Walraven & Others (1990) have combined all concordant whole-rock data from this zone to define an isochron of 2061± 27 m.y. on 33 of 37 points, and regard this as the preferred age.

In the Lebowa Granite Suite there is a range in age of U/Pb zircon dates from the various granite phases, and open-system behaviour has affected the whole-rock Rb-Sr isotope systematics of major parts of the granite so that many of the ages are derived. Walraven (1988) selected a date of 2052 ± 48 for the best age of the Nebo granite, which forms the bulk of the LGS. Beyond this, the multiphase character of the zircons in the LGS dictates that an ion microprobe investigation of the different domains is probably imperative and the only satisfactory method of unravelling the complex crystallisation history, origin and true age.

A good indication of the minimum age of the LGS is now available from consistent information on the Makhutso granite, a final intrusive phase of small isolated stocks and dykes (Walraven, 1988):

2046 ± 55 m.y. (Rb-Sr errorchron on combined dyke and stock samples);
2049 ± 69/-72 (Pb-Pb isochron on dyke samples);
2045 ± 122/-133 (Pb-Pb isochron on stock samples).

The RLS may turn out to be older than presently indicated, but the available evidence now places the upper Ventersdorp (Pniel Group), the Transvaal, and the limited occurrences of pre-Transvaal rocks known from several localities, bracketed between ∿ 2700 and 2061 m.y.

Age dates from within these rocks are given below:

		+	-
1. Dullstroom basalt	2234	2677	1791
2. Hekpoort lava	2224	2245	2203
3. Ongeluk lava	2238	2325	2146
4. Ongeluk lava	2034	2172	1895
5. Timeball Hill shale	2208	2271	2145
6. Vryburg lava	2371	2452	2285
7. Abel Erasmus (Wolkberg) basalt	2138	2184	2091
8. Godwan basic lava	2325	2394	2252
9. Groblersdal granophyric gneiss	2411	2489	2345
10. Groblersdal acid lava	2512	2532	2492

Table 3. Age data from the Transvaal and Griqualand West Sequences

1. Rb-Sr whole-rock errorchron (Walraven, 1987)
2. Rb-Sr isochron (Burger & Coetzee, 1975)
3. Pb-Pb whole-rock isochron (Armstrong, 1987)
4. Rb-Sr errorchron (Armstrong, 1987)
5. Rb-Sr whole-rock errorchron (Hunter & Hamilton, 1978)
6. Pb-Pb whole-rock isochron (Armstrong, 1987)
7. Pb-Pb whole-rock isochron (Armstrong, 1987)
8. Pb-Pb whole-rock isochron (Armstrong, 1987)
9. U-Pb zircon (Coertze & Others, 1978)
10. U-Pb zircon (Faurie, 1977).

Notes:

Walraven & Others (1990) note there is some agreement between measurements in the Pretoria Group (1-5 above) and consider that the

..." preferred age for the Pretoria Group as a whole is... 2224 $\pm$ 21"...

Barton & Hallbauer (1990) provide additional information: lead isotope characteristics suggest that synsedimentary and authigenic pyrite (as distinct from earlier, detrital pyrite) from the Black Reef formed at 2500 m.y.

THE CHUNIESPOORT/GHAAP BASIN

Above a veneer of fluvial conglomerates and quartzites (Black Reef in the Transvaal) and of fluvial and shallow marine conglomerates, quartzites and argillites (Vryburg in the Northern Cape) the strata grade into the dolomitic rocks which make up the bulk of the Chuniespoort and Ghaap Groups, in the Malmani Subgroup and the Campbell Rand Subgroups respectively. Both successions also occur in adjacent southeastern Botswana.

As is typical of Precambrian carbonates the carbonates have the potential for containing more manganese and iron than do younger carbonates, and much chert. As is the case with other early Proterozoic carbonate sequences - in the Pilbara of northwest Western Australia and the Lake Superior District, USA, the dolomite is associated with banded iron formations.

These groups have been extensively studied over the last 20 years. These studies have led to the development of successions in regions and specific areas (Beukes, 1978, 1980; Button, 1973(a); Clay, 1981; Eriksson (K.A.), 1972; Eriksson (K.A.) & Truswell, 1974; Engelbrecht, 1986; Fourie, 1984; Tyler (R), 1989).

Other aspects which have been studied include an understanding of depositional environments, often including stromatolites, of aspects of diagenesis, and of geochemistry. The literature is somewhat interwoven and reference should be made to Beukes (1986), Button, (1986), and Eriksson (P.G.) & Clendenin (1990).

It is now apparent (see in particular Beukes 1978, 1983, 1987; Button, 1973(a); Eriksson (K.A.) & Others, 1976; and Clendenin, 1989, that the successions represented by these two groups accumulated in a vast epeiric sea that covered an area which was probably of greater extent than the present exposure of the Kaapvaal craton.

In arriving at the present knowledge of the epeiric depository four aspects have been of particular significance.

Firstly, relating the lithofacies to three tectonically controlled settings (Beukes, 1978): a very extensive shallow-water environment on the Kaapvaal craton; a hinge-zone marked by the Griquatown growth fault; and a deeper-water basin open to the ocean to the southwest (Fig. 4). The second and third of these settings are mostly covered by the younger Olifantshoek Sequence in the Northern Cape;

Secondly, particularly in relation to the shallower water environment, a number of specific markers, and the application of Walther's Law, has led to the recognition of a number of environmental 'fixes', particularly in the intertidal zone;

Thirdly, an understanding of the banded iron formations (Beukes, 1983; 1984; Button, 1976);

And fourthly, the recognition that the sequence represents a series of vertically stacked, repetitive depositional systems, bounded by unconformities (Clendenin, 1989).

The following general account is taken from Beukes (1987):

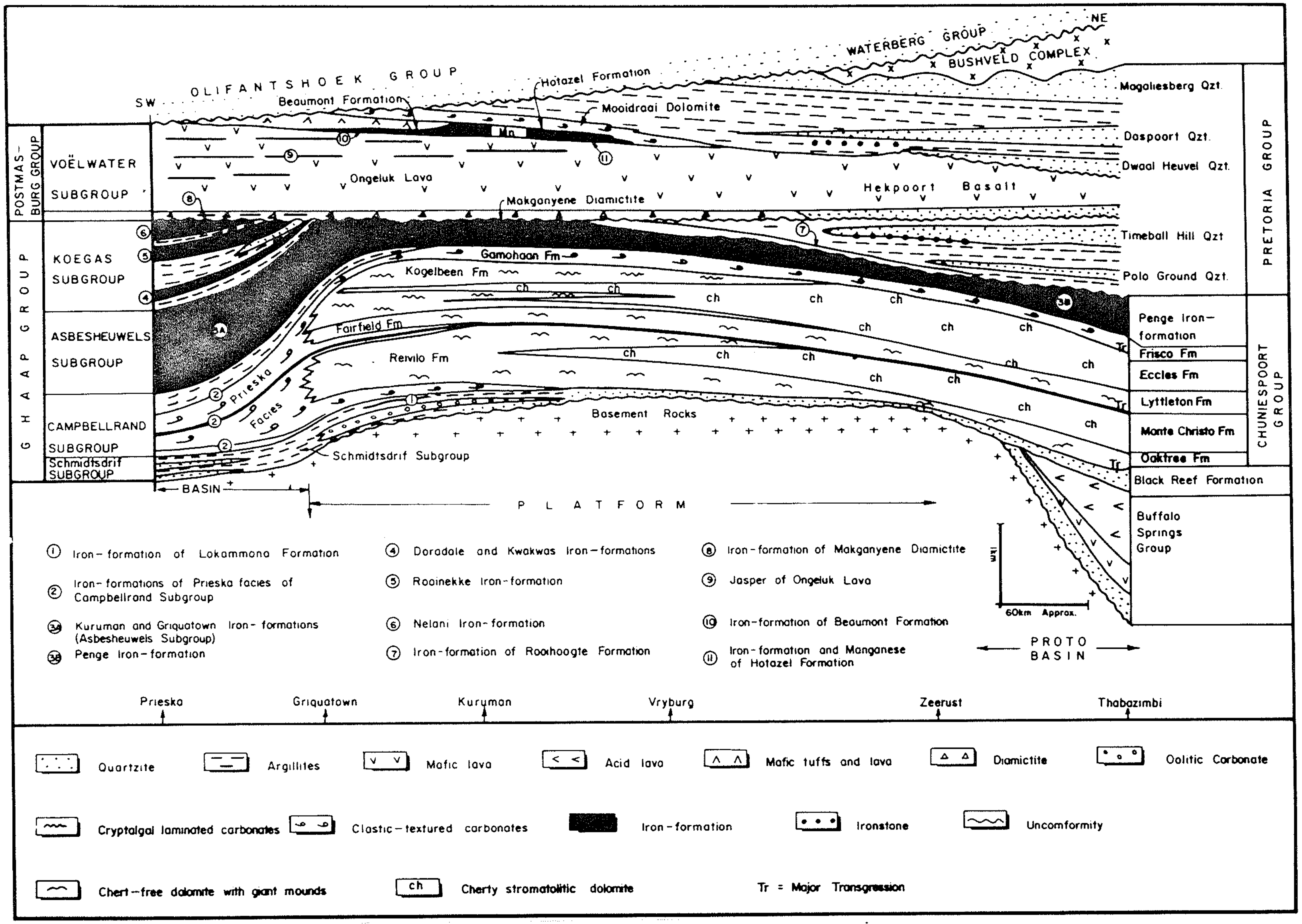

Fig. 4. Regional correlations and sedimentary facies relationships in the Transvaal and Griqualand West Sequences (Beukes, 1986).

The Malmani and Campbell Rand carbonates consist essentially of two major lithofacies: a basinal, non-stromatolitic, laminated carbonate and shale sequence, with minor chert, iron-formation and mafic tuff interbeds off the craton to the west and southwest, and a shallow-water mostly stromatolitic carbonate lying upon the craton. Growth faulting along the southwestern edge of the craton controlled the platform margin: in this setting columnar stromatolites, oolites and carbonate arenite shoal deposits occur. These are flanked seaward by giant subtidal stromatolitic mounds which grade into slope deposits consisting of laminated carbonate, with interbeds of chaotic dolomite breccia and conical (Conophyton) stromatolites. The sediments on the craton consist of dark-coloured, stratified stromatolites interfingering with light grey chert-rich dolomite containing a variety of structures such as domal stromatolites, laminated fenestrae, tepee structures and flat-pebble structures that accumulated intertidally, rarely subtidally.

At the gross level the dolomitic types - light-coloured, chert-rich; and darker, chert-poor represent the major lithostratigraphic units in the succession.

Numerous iron formations occur in the two groups, particularly in the southwest (Beukes, 1983; see Fig. 4). The main iron formations overlie the dolomites: the Kuruman and Penge Iron Formations in the Northern Cape and Transvaal respectively. The banded ferhythmite of the Kuruman Formation is overlain by the clastic-textured Griquatown Iron Formation (these two units from the Asbesheuwels Sub-Group). The Penge Formation is similar in nature, and at a variety of scales the two units can be correlated (Beukes, 1983).

The iron formations represent an integral part of the Transvaal/ Griqualand West sequence. They represent a variable group of chert-bearing iron-rich rocks which are most abundant at the southwest margin of the craton, and are taken to represent either a distal facies of carbonate ramp-like platforms, or, in some cases, volcanic sequences (Beukes, 1983). The iron formations accumulated after a major transgression.

South of the Griquatown fault zone the Kuruman Formation grades upwards into the Koegas Sub-Group, a series of upward-coarsening cycles, from iron formation to chloritic mudstone, siltstone and quartz wacke.

In the northeast Transvaal an assemblage of restricted extent, composed of dolomite and limestone, with some quartzite and shale, of the Duitschland Formation, overlies the Penge Formation. Martini (1979) considers that the Duitschland overlies the Penge unconformity.

Clendenin (1989) has identified four broad depositional situations within a carbonate distally steepened, ramp-like platform. It is relevant to note the distinction between a ramp and a carbonate shelf: in a ramp huge carbonate bodies are built down gentle regional palaeoslopes - without a pronounced break-in-slope (Ahr, 1973; Wilson, 1975). Distal steepening occurs by drowning as a result of rapid sea-level rise, or following flexural downwarping.

Clendenin further distinguishes eight sub-facies and a larger number of lithofacies from more specific positions in the various setting (Table 4).

He has also recognised depositional systems, or synthems within the Chuniespoort/Ghaap Groups. Each of these is bounded by unconformities; the unconformities themselves can be recognised by specific criteria above and/or

Depositional Position	Basin Deep Water →			Ramp ← Shallow Water					Flat			
Facies	Basinal			Periplatform					Peritidal		Shallow Siliciclastic	
Subfacies	Deep Basinal	Shallow Basinal		Submerged Shelf		Shoaled Flat			Emergent Peri-Tidal	Shallow Peri-Tidal	Tidal Flat	Fluvial
Detail Position	Deepest Part of Basin	Shoaled Basin	Toe of Ramp to Shoaled Basin	Lower to Upper Middle Ramp	Upper Middle to Shoaled Ramp	Lower Shoaled Ramp	Lower to Upper Shoaled Ramp	Upper Shoaled Ramp	Emergent Ramp	Ramp Margin	Shoaled to Emergent Ramp	Ramp Margin
Litho-Facies	Banded Iron-Formation	Shale * Mudstone	* Thrombolitic Shale	Tufted Thrombolitic Mound	Columnar Stromatolite	Planar Laminated	Ripple Laminated	Oolitic	Domal Boundstone	* Evaporitic Mudstone	Siliciclastic	
Tidal Range	Subtidal Below Storm Wave Base	Subtidal Below Wave Base and Below Active Current Flow		Subtidal Below Wave Base In Active Current Flow		Subtidal Above Wave Base			Low- to High-Intertidal	High Intertidal to Supra tidal	Subtidal Above Wave Base to High-Intertidal	Supratidal and above

Table 4. Facies classification of the Transvaal sea.
After Clendenin (1989).

below the unconformity surface, such as increased chert to the surface, or a palaeosol; the presence of siliciclastics - or chert-in-shale or chert breccia above the unconformity; or a para-unconformity.

Clendenin distinguishes ten depositional systems. The overall succession defined is a classic example of sequence stratigraphy, in this instance in the Proterozoic (Christie-Blick & Others, 1988): of similar, vertically stacked and genetically related successions, showing similar lateral variations, bounded by unconformities.

The synthems, and their correlation between the Transvaal and Northern Cape, are shown in Fig. 5 .

From the Motiton System a number of shallowing upward cycles, or interthems (Aitken's (1966) so-called grand cycles) can be distinguished (Fig. 6); within them small-scale shallowing upward cycles, the Punctuated Aggradational Cycles (PAC's) of Goodwin & Anderson (1985) also occur.

Clendenin (1989) shows that the Chuniespoort/Ghaap sea has two stages of development.

1. From the Vryburg to the Lower Monte Christo depositional systems. This span is characterised by NNE transgression, and overall depository expansion.

2. From the Motiton to the Duitschland depositional system, in which period the NNE transgression was re-initiated, and within which there was a smaller scale see-sawing regressive-transgressive set of relationships (Figs. 6 and 7).

Between these two stages the sea withdrew from the craton altogether.

Clendenin (1989) interprets the Chuniespoort/Ghaap sea in relation to a number of structurally controlled compartments (Fig. 8). The Vryburg compartment is the first of these to be flooded during the various transgressions; and in this sense is a protobasin. The structural boundaries defined reflect inter-relationships between the underlying Ventersdorp Rift and the Selati Trough.

The (lowest) Vryburg and Boomplaas Systems are not present in the Transvaal; the upper Oak Tree was the first depositional system to extend into the eastern Transvaal compartment, as well as over much of the craton. Thus, fluvial Black Reef quartzite was accumulating in the Eastern Transvaal whilst marine carbonates formed in the Northern Cape.

Clendenin considers that the contact between the Penge and Duitschland depositional systems is transitional, and that the carbonates and other siliciclastics of the Duitschland are time-equivalent to the Griquatown iron formation in the Northern Cape.

Clendenin notes that the

> ..." Rand line (Fig. 7) is most interesting (of the structural boundaries) because at different times during the evolution of the 'Transvaal' sea it acted as a positive arch-like structure, here termed the Ancestral Rand Anticline"...

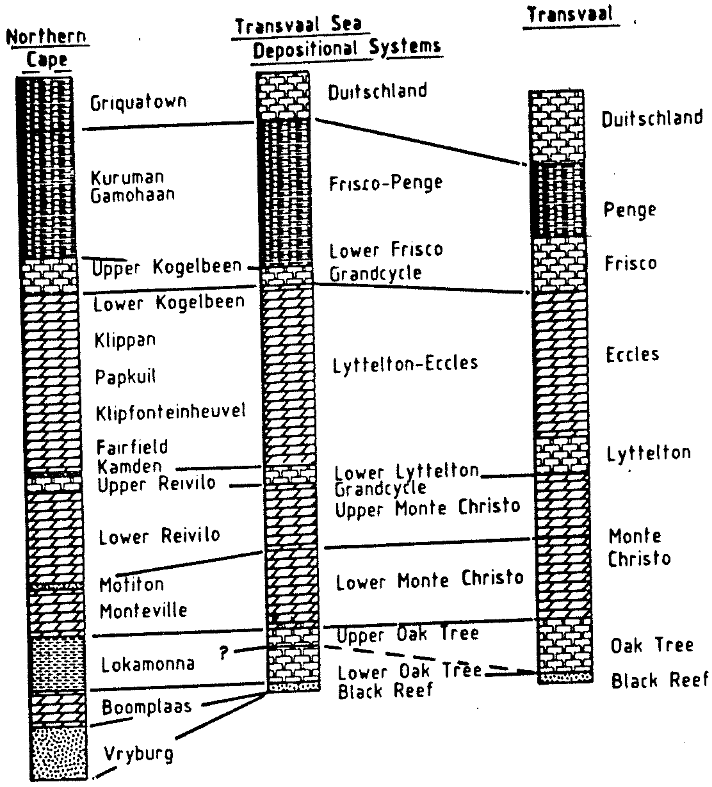

Fig. 5. The relationship of lithostratigraphic units and depositional systems. (Clendenin, 1989).

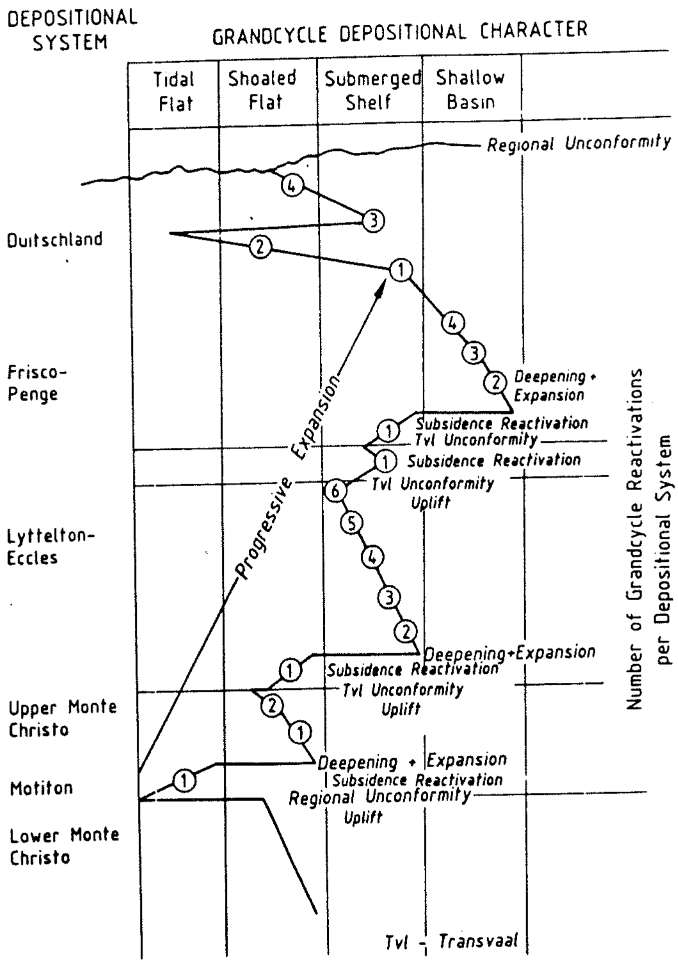

Fig. 6. Depositional systems, and interthems (or grand cycles) from the Lower Monte Christo upwards. (Clendenin, 1989).

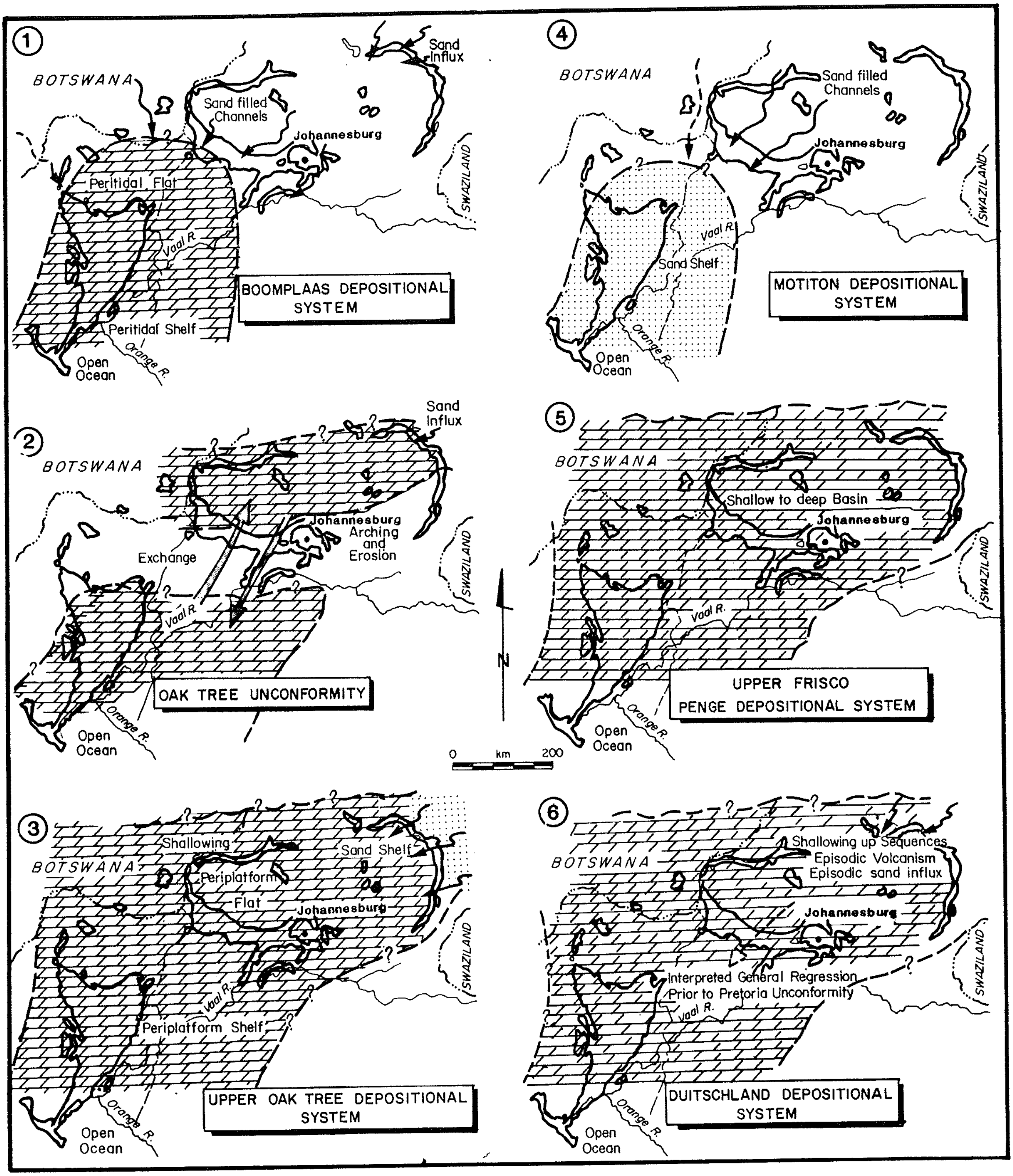

Fig. 7. The distribution of some specific depositional systems from the Chuniespoort/Ghaap Groups.
(From Clendenin, 1989)

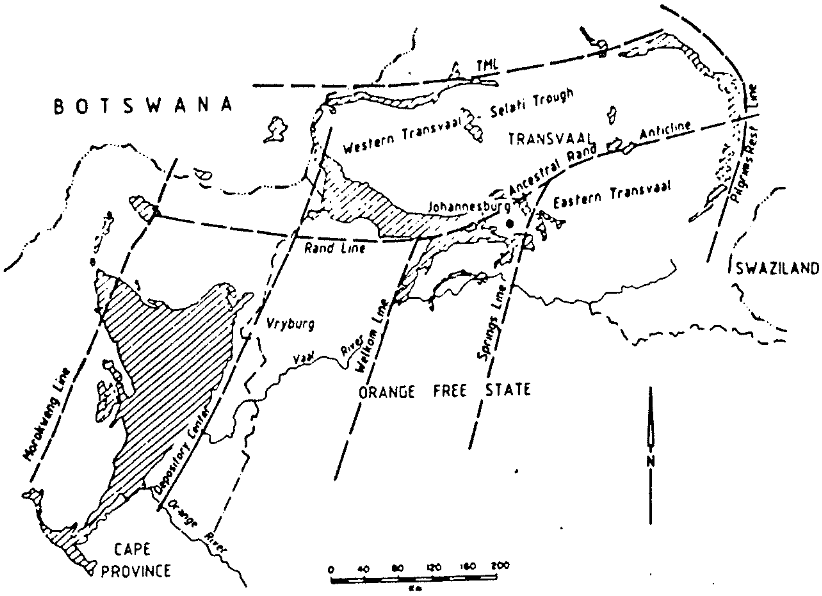

Fig. 8. Suggested structural compartments of the Chuniespoort/Ghaap 'Sea'. (Clendenin, 1989).

As an example of activity on this feature, Clendenin notes that the arch became active towards the end of the Upper Oak Tree. In comparison to the situation north and south of the arch up to 40 m of sediment was either not deposited, or eroded penecontemporaneously.

It remains possible that the arch-like movement need not lie east-west, but might parallel the northwest-trending Kuruman arch.

BASIN FORMATION

Current basin classification lays emphasis on the relationship of preserved sequences to plate tectonic processes. Bally & Snelson (1987) for example, differentiate three families of sedimentary basin:

. those located on rigid lithosphere and not associated with the formation of megasutures;

. perisutural basins on rigid lithosphere associated with, and flanking the compressional megasutures;

. episutural basins located upon and mostly contained within the megasuture.

The manner in which basins located on rigid lithosphere form is less clear than is the case with the remaining basins. Miall (1990) writes

..." We have been discussing what happens at the margin of plates as they drift about at the Earth's surface. However, plate-tectonic theory is at present much less helpful in what is happening in plate interiors. There is a variety of arches, ridges, domes, swells, plateaus and anteclises separating from each other a diversity of basins, troughs, depressions, downwarps, aulacogens and syneclises"...

The process that is most commonly invoked in the formation of continental basins is a thermal one. In a preceding phase a rapid stretching of continental lithosphere leads to crustal thinning and upwelling of hot asthenosphere, and associated rifting. After this thermal uplift, cooling results in thermal contraction, an increase in density, and the subsidence of the plate surface (McKenzie, 1978).

A range of other mechanisms have also been proposed: these include mechanical modification related to the decay of thermal anomalies such as might be produced by subaerial erosion or phase deformations; isostatic equilibration of earlier rift structures underlying continental basins by the application of in-plane lithospheric stress; and mechanical coupling of such basins with adjacent foreland basins (Quinlan, 1987, reviews these mechanisms).

Continental basins are commonly related to arches: subsidence of basins often occurs simultaneously with arch uplift - what is less certain is whether subsidence drives uplift or vice versa, and indeed (again) what relationship such combined structures have to plate movements. Quinlan & Beaumont (1984) argue that both foreland basins and adjacent arches are flexural consequences of a common orogenic driving force - giving rise to a flexured downwarp and a peripheral bulge.

The Chuniespoort/Ghaap Basin covered the Kaapvaal craton as exposed today; thus there is no knowledge of possible structures around its margin. The Vryburg arch lies within the basin; in a broad sense, it was largely negative at this time.

Most sedimentary basins can be readily classified in terms of three criteria (Miall, 1990):

. type of crust on which the basin rests

. position of basin relative to plate margins

. where the basin lies close to a plate margin, the type of plate interaction occurring during sedimentation.

It is as well to realise that all three criteria can change with time; as it is to appreciate that, from the available studies, not all continental basins can be explained by the same model.

In detail, Clendenin's (1989) model is a complex one with a composite origin for the formation of the Chuniespoort/Ghaap Basin.

Clendenin follows Winter (1965) in regarding the Platberg Group Bothaville Formation boundary as a rift unconformity, with the Bothaville and Allanridge Formations (of the Ventersdorp Sequence) accumulating as an initial mechanical subsidence phase of the Chuniespoort/Ghaap sea. There followed a short period of tectonic subsidence representing a readjustment between the earlier mechanical and subsequent flexural thermal subsidence. During tectonic subsidence the driving force of extension is removed prior to thermal subsidence (Houseman & England, 1986). Theoretical models suggest that thermal subsidence began when the first marine sediments appeared, that is within the Boomplaas/Vryburg depositional cycles. Thereafter the sea expanded in a phase of thermal subsidence which was terminated prior to the Motiton depositional system, at which time the sea left the craton (Clendenin, 1989).

Where time relationships can be established in Phanerozoic basins, thermal subsidence tends to follow some 50-60 m.y. after rifting (Quinlan, 1987). If sedimentation can be related simply to thermal subsidence, then that sedimentation will decrease and cease with termination of subsidence; it is on this basis that Clendenin considers that sedimentation related to thermal subsidence ended at this time.

Clendenin considers that, following a period which may have involved uplift, non-deposition and erosion, the ensuing depositional (post-Motiton) cycles reflect reactivated subsidence. This is seen as a shift from extensional to compressional regional stress.

It has been established that the application of horizontal regional stresses caused by distant plate interactions may result in the development of in-plane stresses necessary for reactivation of subsidence (de Rito & Others, 1983); and the potential importance of plate-margin behaviour has been strengthened by the work of Cloetingh (1988) who showed that plate margin stresses could be transmitted for thousands of kilometres controlling stress fields and uplift-subsidence patterns through plate interiors.

Clendenin relates periodic basin expansion (and the development of depositional cycles) to the episodic removal of such compressive stress.

The succession which Clendenin has defined is a classic example of sequence stratigraphy in the Proterozoic (Christie-Blick & Others, 1988): of similar vertically stacked and genetically related successions, showing similar lateral variations, bounded by unconformities.

Carbonate sedimentation is dependent on a number of depositional controls: such as temperature, carbonate saturation, salinity, water depth (and hence rates of relative sea-level change), light penetrations, substrata, water turbidity. The combination is a subtle one, but in a gross sense, key factors are the structural setting, and the interplay between subsidence and sedimentation rates.

Clendenin's model involves an identical setting for the carbonate build up on a south-facing ramp-like platform, in both thermal extensional subsidence and continuing from this, in later periodic release within a compressional environment linked to plate-margin interactions.

To produce the identical stratigraphic sequence under two differing sets of conditions seems unlikely.

It is suggested that the Chuniespoort/Ghaap Basin, in toto, is either related to thermal subsidence of an intracratonic basin, with basinal expansion within the overall sequence reflecting changes in sea level, or is related to compression, and accumulation in a continental basin. Any further comment is speculative but in the first option sea level changes may be eustatic, in the second they are the more likely to be linked to regional tectonics. In the second option isostatic equilibration of the earlier Ventersdorp rift structure could have been delayed until the application of in-plane compressional stress (Quinlan, 1987) so that the basin has a potential for being younger than if it was simply related to the decay of a thermal anomaly.

A number of workers have linked the origins of the Limpopo Belt with the evolution of late Archaean/Early Proterozoic depositories and their resulting fill - the Dominion, Witwatersrand, Ventersdorp and Transvaal Sequences - on the Kaapvaal craton (Light, 1982; Burke & Others, 1985, 1986; Winter, 1987; Clendenin & Others, !988; Clendenin, 1989).

Difficulties in such models at the present time lie in ascribing a specific origin to the Limpopo Belt (see for example van Reenen & Roering, 1990); and as Barton (1990) points out, the detailed structural analyses necessary to prove such linkages have yet to be made. There is also a need to be able to correlate ages from the Limpopo Belt to these depositories. At the present time this is only possible between the Ventersdorp for which ion microproble single zircon U-Pb analyses from lavas of the Klipriviersberg (lower) and Platberg (middle) portions of the Ventersdorp Sequence have yielded ages of $\sim$ 2700 m.y., which are indeed comparable to the main tectonothermal event in the Limpopo belt (van Reenen & Others, 1987).

Clendenin & Others, (1988) and Clendenin (1989) regard the Chuniespoort/Ghaap Group as the third stage in a superimposed model: a pre-graben stage (1) influenced the Dominion, Witwatersrand and Klipriviersberg (lower Ventersdorp); a graben development (2) to which the Platberg (of the Ventersdorp) and the succeeding units of the Ventersdorp (Bothaville, Allanridge) relate; and post-graben subsidence (3), which resulted in the accumulation of the Black Reef and Chuniespoort/Ghaap Groups. The initiating stress is interpreted as having been generated by the oblique collision of the Kaapvaal and Zimbabwe cratons; and the longevity of the overall sequence reflects 'continued convergence' of these cratons following collision. The points just made apply: there is no evidence of this continued convergence.

Until such time as plate-margin interactions have been recognised at the appropriate time in the early Proterozoic, an extensional/eustatic model linked to an early Platberg thermal anomaly appears more plausible for the Chuniespoort/Ghaap Basin.

UNDERLYING SEDIMENTS AND VOLCANICS

A number of successions lie below the Black Reef Quartzites in the Transvaal. In updomed portions within the Bushveld Complex: the Wachteenbeetjie Formation in the Crocodile River Fragment, western Transvaal; and the Groblersdal Group in the Dennilton Dome; and at the margin of the present Transvaal basin: the Godwan Formation at Kaapsehoop; the Wolkberg Group northwards from near Sabie to near Potgietersrus; and the Buffelsfontein Group near and to the southwest of Thabazimbi.

No base has been established for some of these units (Wachteenbeetjie, Groblersdal, Godwan); the others rest on a granite-greenstone floor. There is a potential age range for these often different successions of as much as 500-600 m.y., and it is no great surprise that various relationships, and correlations, have been suggested for the individual sequences (see for example Button, 1973; SACS, 1980). The absolute age data is inadequate.

SACS (1980) considered that

"... The stratigraphic succession of rock units from the Groblersdal and Buffelsfontein groups and the Godwan Formation, through the Wolkberg Group, Black Reef Formation, Chuniespoort, Pretoria and Rooiberg Groups up to the Loskop, Glentig and Rust der Winter Formations is united on the basis of a number of tectonostratigraphic and sedimentary considerations and constitutes a sequence..."

The SACS view is one in which successions represent depositional basins, with smaller outcrops being seen as small separate basins, protobasins or terminal shrinking basins of the larger depositional basins.

Walraven & Others (1990) recognise more than one possible tectonic setting for these units:

"... In relation to the Transvaal Basin there are a number of rock units which SACS (1980) has grouped with the Transvaal Sequence, but which are of uncertain affinity and may either represent protobasinal successions or remnants of largely eroded, previously more extensive, stratigraphic units..."

Cheney & Others (1990; for earlier references refer to this paper) consider that the individual successions are the small and structurally preserved remnants of inter-regional unconformity-bounded surfaces (UBS).

Clendenin & Others (1989) have also defined depositional systems related to UBS's: in this case specifically in the Wolkberg/Black Reef; and suggested relationship of these systems to post-Platberg (Ventersdorp) rifting and the establishment of the Chuniespoort/Ghaap Sea.

An outline of the various successions is presented below. It will be shown that the Godwan Formation is affected by pre-Transvaal wrench-faulting; and that there is insufficient evidence to comment on the Wachteenbeetjie Formation and the Groblersdal Group.

The relationship of the Wolkberg and Buffelsfontein Groups with the Transvaal Sequence, and to Ventersdorp vulcanicity, is discussed in more detail.

Wachteenbeetjie Formation

A pre-Black Reef sequence has been established in the Crocodile River Fragment (CRF), situated in the northwestern part of the Transvaal Basin (Harzer, 1989). Harzer's evaluation of the CRF structure suggests an updomed mode of evolution. Other modes of evolution proposed earlier are that the fragment was a xenolith, resulted from cone-fracturing, or thrusting (see Harzer for earlier references).

Nearly 800 m of this, the Wachteenbeetjie Formation, is known from drilling but information on the lateral extent and overall thickness is uncertain.

The succession consists of carbonaceous claystone and siltstone, with quartz-arenites and dolomite. The Formation is regarded as marine, with deep-water cabonaceous claystones, and marine shelf dolomites and siltstones. The quartz-arenites are graded, and regarded as shelf-edge turbidites.

Harzer considers that this Formation can be compared with other pre-Black Reef successions such as the Wolkberg Group, the Buffelsfontein Group, the Magobane Formation of the Lobatsi Group in Botswana (Key, 1983), the Groblersdal Group or the upper part of the Ventersdorp. No certain correlations have however been established.

Groblersdal Group

The Groblersdal Group (SACS. 1980) forms a structural high in the Dennilton Dome in the eastern Bushveld.

The Group is not well known: a lower Dennilton Formation includes gneiss, and lava, tuff and granophyric schist. Granophyric textures occur locally in the gneisses. Ovelying this formation, apparently conformably, is the Bloempoort Fromation: of blue and yellow banded slate and quartzite, andesite, impure quartzite and shale.

The strata dip south. The thickness of the Dennilton Formation is not known, the Bloempoort Formation is $\sim$ 3000 m thick, and is apparently overlain conformably (SACS, 1980) by the Black Reef Formation.

Ages for the Dennilton granophyric gneiss and acid lava of 2411 + 78/-66 and 2512 $\pm$ 20 have been reported (see Table 3). It is uncertain whether this is an original or a re-setting age.

Godwan Formation

The Godwan Formation is poorly exposed in an area of 250 km^2 at Kaapsehoop in the eastern Transvaal. It overlies the Jamestown schist belt and tonalitic basement, and is unconformably overlain by the Transvaal Sequence.

The northern margin of the present basin is marked by the King Fault, an east-west left-lateral pre-Transvaal wrench fault. The Godwan dips northwest, and is regarded as an asymmetrical graben, with a steep northern edge, a gentler southern edge (Myers, 1986).

Myers has suggested that the Godwan can be divided into a number of tectono-stratigraphic intervals (Fig. 9), defined by basin-wide unconformities following tectonic disturbance in the basin. He comments that

> "...the fact that each interval has an entirely different style of sedimentation indicates that the tectonic adjustments which produced the successive unconformities were more than minor events..."

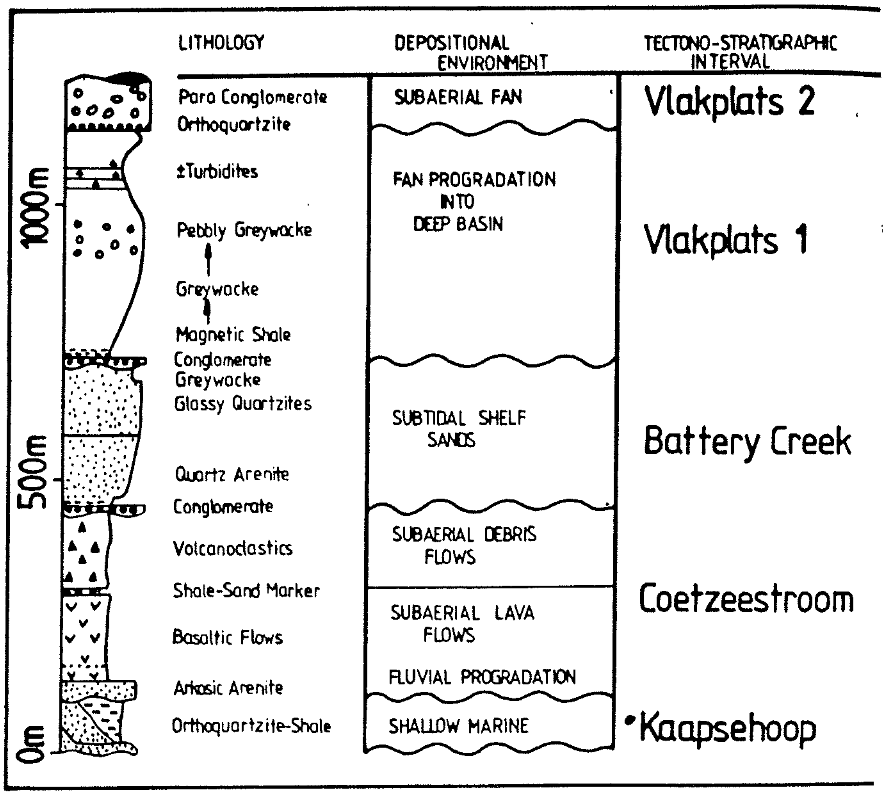

Fig. 9. Generalised lithology and depositional environments of the Godwan. (Myers, 1986).

Basic lava from the Godwan has yielded a whole-rock isochron age of 2325 + 69 - 73 (Table 3).

The recognition of marine environments in the Godwan suggests that this was not an isolated basin, but its correlation has been uncertain; interest in it was stimulated by Button's (1977) tentative correlation with the Witwatersrand.

Studies on the Godwan by R.E. Myers have continued. It is understood that a principal focus of this work has been to develop criteria - tectonic, stratigraphic and in particular others related to the geochemical characgteristics of the volcanics - so as to make comparisons with potential correlative sequences ranging from the Pongola to the Dominion, Witwatersrand, Ventersdorp an Wolkberg. This analysis, indeed its possible further applications, will be of value in the context of this discussion. Myers refers to the Godwan as a Group.

Wolkberg Group

Earliest Wolkberg sedimentation was limited to discontinuous bodies of arenaceous sediment deposited in fluvial channel-systems in palaeovalleys. Topographic irregularities were gradually buried by successive periods of deposition and volcanism, by the fluvial systems of the Sekokoro and Schelem Formations, and the Abel Erasmus Volcanics; later sedimentation was on a relatively smooth surface.

The overall pattern of sedimentation is of transgression. The earlier fluvial regimes were covered by sediments deposited lower down the palaeoslope: the Selati, Mabin and Sadowa appear more fluvio-deltaic - with the thick argillaceous units representing deltaic deposits, and the main arenaceous units representing regressive periods. Palaeocurrents show that these deltas built into the basin from the east and north.

Button considered that some of what had been previously referred to the Wolkberg formed a thickened sequence of Black Reef. As defined the Black Reef included Schwellnus & Others (1962)'Main Quartzite' and, in the Selati Trough, the Serala Basalt. Although there was an angular unconformity between the Black Reef Quartzite and the underlying Wolkberg, Button viewed this as being

> "... of local significance only, these units being perfectly and gradational into one another over the majority of their outcrop extent..."

Thicknesses vary in the Wolkberg Group, but an average figure is 835 m (Button, 1973); the Black Reef reached a maximum of 500 m in the ENE-trending Selati Trough. Button regarded the Wolkberg Group as an initial or proto-basinal stage of overall Transvaal sedimentation, thus ruling out correlation with earlier stratigraphic units.

An Pb-Pb whole rock isochron age of 2138 + 46-47 has been determined for the Abel Erasmus volcanics (see Table 3).

Buffelsfontein Group

The Buffelsfontein Group is a sedimentary and volcanic assemblage resting on the basement granite and greenstone remnants of the Makoppa Dome. The occurrence extends for 90 kms at the northwestern margin of the Transvaal Basin, near and to the southwest of Thabazimbi.

The Group is up to 1700 m thick, and starts with braided and meandering fluvial arenites. These inter-tongue with minor intervals of mature quartz-arenite suggesting marine re-working (Tyler, 1979). The remainder of the Group consists of basic volcanics, rhyolitic volcanics and nonclastic sediments. Stromatolitic cherts are sometimes developed between lava flows.

The Hampton Formation has a maximum thickness of 1200 m. It contains numerous lithological members and accumulated in braided stream, meandering stream, and near-shore sedimentary environments.

Above it lie some 200 m of dominantly basaltic lavas of the Waterfall Formation. Overlying the basaltic lavas conformably is an 850 m thick heterogeneous pile of altered acid volcanics, pyroclastics sediment and some basic lavas of the Witfonteinrant Formation. The lavas were extruded subaerially.

Above is a more localised sequence of up to 60 m of arenites and wackes of the Kransberg Quartzite.

The Group, with its sedimentation and intermittent volcanic activity continued almost without interruption. Tyler (1979) considered that this conformity extends upwards into the base of the overlying Black Reef Quartzite; and that only towards the margins does the Black Reef overlap successively older units of the group in a basin-edge unconformity.

THE WOLKBERG AND BUFFELSFONTEIN GROUPS: FURTHER COMMENT

These comments should be read in conjunction with the information already provided on these units.

Button (1973b) showed how the relationship of the Wolkberg to the overlying Transvaal had varied over time.

Up until the war, workers were all agreed on the pre-'Dolomite' succession in the Potgietersrus-Sabie area, and noted the changes in thickness along strike.

In 1949, Truter separated the Wolkberg 'System' (which he correlated with the Witwatersrand) from the Black Reef 'Series'. He referred to evidence suggesting a time-break, although he did not indicate what the evidence was. Truter's separation was supported in the early 60's: Visser and Verwoerd (1960) showed that the Black Reef/Wolkberg contact was unconformable in the Sabie area. Schwellnus & Others (1962), whilst accepting Truter's subdivision, stressed the essentially conformable nature of the Wolkberg and the Black Reef.

Button's studies (1973) in the Wolkberg (referred to earlier) led to its identification at the protobasin of the overall Transvaal Sequence.

Tyler (1979) felt that the Buffelsfontein and Wolkberg Groups were comparable units (Table 5). They have lower and upper sedimentary zonez separated by volcanics. Lithologies and depositional environments are similar. Tyler comments that the Black Reef Quartzite (as defined) is essentially conformable above both, and that the relevant contacts are 'partly gradational'. The only major difference between the two successions is in the thickness of sediment that succeeds the middle volcanics.

On this basis Tyler (1979) suggested tha the two groups were correlatives, and that both constituted a protobasinal phase of the Transvaal basin.

The views of Button and of Tyler continued to be accepted until recently (SACS, 1980; Tankard & Others, 1982).

Two contemporary studies have stressed breaks in the overall sequence under discussion (Clendenin & Others, 1989; Cheney & Others, 1990). Both stress unconformity bounded surfaces and relationships to earlier Ventersdorp volcanics; neither considers those to be the protobasinal phase of the Transvaal Sequence.

Cheney & Others (1990) believe that the succession on the Kaapvaal craton can, tentatively, be subdivided into the unconformity-bounded surfaces (UBS) shown in Table 5. What is suggested is that all the cover sequences on the craton, some of which are isolated and of limited extent, can be correlated in this manner.

	Wolkberg Group	Buffelsfontein Group
Lithology 1. Sediments	Coarse Clastics, quartzites, siltstones, and shale	Similar (coarse clastics dominant)
2. Volcanics	Basic	Basic and acid
Maximum thickness	2 000 m	2 000 m
Depositional environments	Lower sediments: Braided-fluvial Upper sediments: Shallow marine	Braided-fluvial, near-shore
Maximum thickness of volcanic units	Abel Erasmus volcanics over 500 m	Witfonteinrant Formation over 800 m
Average thickness of sediments overlying the volcanic units	565 m	40 m
Contact relationship with the Black Reef Quartzite	Gradational, in part	Gradational, in part

Table 5. A comparison of the Wolkberg and Buffelsfontein Groups.
After Tyler (1979).

Major Sequences	Succession	Constituent groups (GP) or formations (FM) of the major sequences
T3	Transvaal	Granites of the Bushveld complex
T2		Dullstroom to Loskop interval
T1		Pretoria GP below Dullstroom FM; Postmasburg GP; Chuniespoort GP and Black Reef FM; Ghaap GP
V3	Ventersdorp	Pniel GP
V2		Platberg GP
V1		Klipriviersberg GP
R2	Witwatersrand	Central Rand GP; Uitkyk FM?
R1		West Rand GP; Mozaan GP
D	Dominion	Dominion GP; Nsuze GP?; Kanye GP?
	3GT	Basement rocks of Central Kaapvaal craton

Table 6. Pre-2000 m.y. unconformity-bounded sequence on the Kaapvaal Craton (After Cheney & Others, 1990).

Consideration of the units under discussion is focussed on the uppermost Ventersdorp UBS - V3.

In seeking to identify outlers of V3, Cheney & Others (1990) use the following criteria:

. an outlier must be stratigraphically below T1

. the Allanridge or uppermost Pniel lavas have different characteristics to those from underlying V1, V2; the latter are pervasively altered and may contain relatively thick chemical or siliciclastic interbeds

. felsic volcanics, especially those containing quartz megacrysts, are distinctive of D, V2, and T3, but are not known from V3.

That previously identified V3 outliers such as in the Tweefontein borehole; at Ngotwane River and at Mogobane - either side of the Botswana border are V3 seems unassailable.

More problematic is the proposal that the Buffelsfontein and the Wolkberg are, partially, V3; and further that the Godwan Formation, and the Bloempoort Formation in the Dennilton Dome may prove to contain the V3 interval.

Adjacent to the Makoppa Dome in the Buffelsfontein Group, the Witfonteinrant Formation contains felsic volcanics and is correlated by Cheney & Others (1990) with the upper Makwassie lavas of V2. The Tygerkloof Formation is correlated with the Bothaville Formation. Although Tyler (1979) had found no unconformity in the Buffelsfontein formation, Cheney & Others (1990) explain the absence of Rietgat-type volcanics by postulating such a break. They also suggest that the lowest part of the Buffelsfontein may be equivalent to R1 (lower Witwatersrand Sequence) (Fig. 10).

In considering the Wolkberg, Cheney & Others (1990) revert to Schwellnus's (1962) distinction of a lower succession (the Sekokoro Formation and Abel Erasmus basalt of Button, 1973), from the remainder of the Wolkberg with which is included Schwellnus's Main Quartzite and the Serala Basalt. These latter units wedge out, and are regarded as regionally unconformable beneath the Black Reef Quartzite. The suggested relations to proposes UBS's are shown in Fig. 10 .

The writer readily accepts the value of UBS's where appropriate unconformities are demonstrable. It is thus of value within the Ventersdorp sequence, and between the Chuniespoort and Pretoria Groups of the Transvaal Sequence but the application of the concept to these Groups seems no more than long-range lithological correlation and is regarded as speculative. Indeed, only the first of Cheney & Others (1990) three criteria can be applied with certainty.

The knowledge we now have of the Kaapvaal Craton and its late Archaean-lower Proterozoic cover shows that it can no longer be regarded as a granite-greenstone basement stabilised by a particular time, and on which sequences of distinct nature accumulated at specific times.

To illustrate this, not only is it now known that the age range of a suite of hydrothermally altered granites overlaps much of the time in which Witwatersrand sedimentation took place (Robb & Others, 1990) but also that the Pongola Supergroup formed in a distinct tectonic setting at a similar time, but a wider time span, to the lower Witwatersrand (Weilers, 1990).

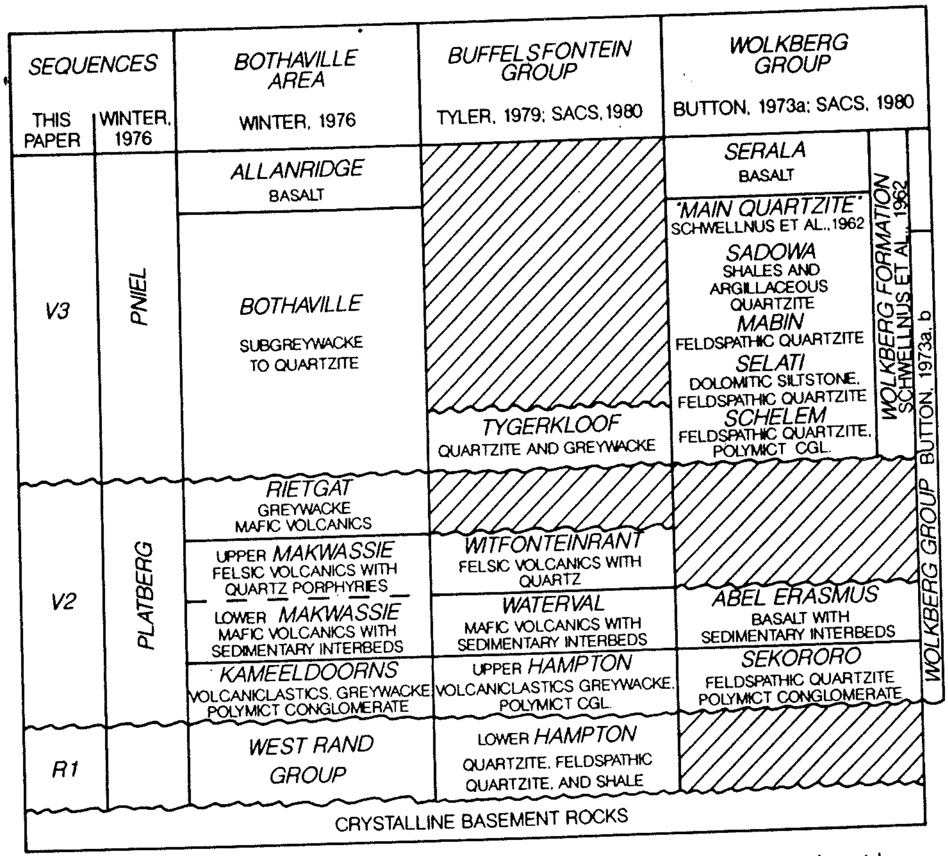

Fig. 10. Suggested correlation of formations in the Buffelsfontein and Wolkberg Groups and UBS's on the Kaapvaal craton.
(Cheney & Others, 1990).

Whilst it remains appropriate to seek to relate the isolated sequences under discussion to other more extensive sequences on the craton, it does not follow that they will be so related: some or all of them may eventually be shown to be quite distinct and separate. It is felt that the UBS concept needs this significant rider.

Miall's note of caution (Miall, 1990) appears warranted. He regards it as premature to establish formal named units for UBS's because

> "...our ideas regarding the origin of unconformity-bounded units, their extent, and whether they can in fact be correlated on an intercontinental scale are still in a considerable state of flux"...

Clendenin & Others (1988) consider that a direct relationship can be demonstrated between the Ventersdorp Supergroup rifting event and the subsequent thermal subsidence which led to the formation of the Chuniespoort/ Ghaap Sea; further, that the depocentre of this sea was along a north-south line east of Vryburg. They regarded the opening of the Selati Trough as being related to the regional extensional stress that gave to the post Platberg (Ventersdorp) rifting, and considered that the Wolkberg Group could be correlated with the 'Ventersdorp Supergroup'.

This is at odds with Button's (1973) concept of a protobasin associated with the east-west trending Selati trough, in which early Transvaal sedimentation and vulcanicity was represented by the Wolkberg. As mentioned previously, Button regarded the Black Reef Formation as being over 500 m thick in the Selati trough, whereas elsewhere it is a very thin veneer.

In further consideration of the issues involved, Clendenin & Others (1989) examined contacts between the Black Reef and underlying and overlying units in the eastern Transvaal. From this study they showed that there are two unconformities with the Wolkberg/Black Reef sequence which, although subtle, are regional in nature. The unconformities define depositional systems. Figure 11 also illustrates relationships of this study to earlier work on these strata.

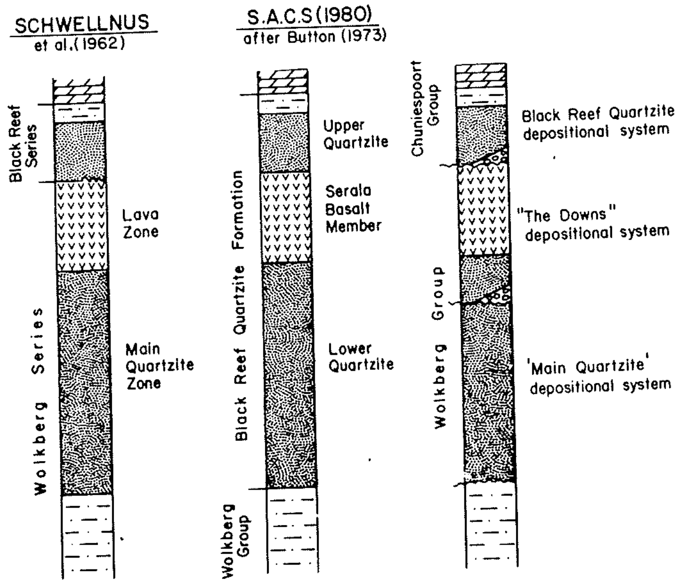

Fig. 11. Stratigraphic sections for the Selati Trough area showing suggested correlations in the Wolkberg and Black Reef. The right-hand column reflects the study of Clendenin & Others (1989).
(Clendenin & Others, 1989).

Clendenin (1989) also commented on the stratigraphic position of the Buffelsfontein Group. Using Tyler's stratigraphic descriptions, Clendenin speculated that the Hampton Formation with its overall upward-coarsening siliciclastics and low-angle discordances can be correlated with the Witwaters-rand 'Supergroup', whilst the remainder of the Group, with its bimodal volcanics, could be tentatively correlated with the Ventersdorp 'Supergroup'. Clendenin also considered that field relationships indicated that there is an unconformity between the Buffelsfontein Group and the overlying Black Reef Quartzite.

Clendenin & Others (1989) suggest a relationship of the depositional systems identified to the Ventersdorp Sequence to the west. There, fluvial siliciclastics of the Bothaville Formation were deposited above the rift unconformity and were succeeded by Allanridge volcanics. Buck (1980) regarded the Bothaville Formation as accumulating on a fluvial plain tilted towards the south.

Clendenin & Others (1989) regard the Downs Depositional System (Fig.11) as representing a mirrored, but very scaled-down succession comparable to the Bothaville/Allanridge; the unconformity below the Downs Depositional System is interpreted as reflecting a similat tilt. An overall basinal modification is thus suggested.

Clendenin & Others (1989) believe that field relations indicate epeirogenic uplift of the southeast portion of the Transvaal took place prior to the deposition of the Black Reef Quartzite; it is a thin unit thickening to a maximum of 30 m in the Selati Trough, which was the axis of subsidence at that time.

Clendenin & Others (1989) see the Selati Trough as a local depocentre, and not as the protobasin to the overall Chuniespoort/Ghaap Sea as proposed by Button (1973); given also Clendenin's (1989) recognition that initial carbonate sedimentation in this sea took place in the Northern Cape, and only later a NNE transgression led to such sedimentation in the eastern Transvaal, this seems clearly established.

What seems less clear is necessarily relating the Wolkberg, and also the Buffelsfontein, to the Ventersdorp. These units may reflect sedimentation which, although localised, may yet be closely related to the succeeding Transvaal Sequence events rather than mirroring events related to the Ventersdorp rift to the north. That the greatest thickness of the Black Reef (as defined by Clendenin & Others, 1989) is, like the underlying Wolkberg, thickest in the Selati trough, certainly suggests some such relationship. It is not always easy to establish the presence of unconformities; once established it is often harder to establish their significance.

THE RELATIONSHIPS OF THE PRETORIA AND POSTMASBURG GROUPS

In the previous section, evidence was led showing the equivalence of the Ghaap and Chuniespoort Groups, and that these sediments formed in an epeiric sea of massive dimensions opening to the ocean in the southwest.

The overlying units of the Transvaal and Griqualand West Sequences are preserved in the same structural basins: the Pretoria Group in the eastern and western Bushveld region, and to the south in the Potchefstroom synclinorium, and as scattered outcrops at the eastern margin of the Kalahari, broadly in the Kanye region; the Postmasburg Group extneding southwards into the northern cape from southernmost Botswana.

The outcrops of the two groups lie either side of the Vryburg arch.

In the Transvaal, and in the Kanye region of easternmost Botswana, lithologies in the Pretoria Group are remarkably similar up to the Magaliesberg Formation; where higher horizons are developed, there are distinct differences, and thicknesses are variable (Table 7.).

The outcrops of the Pretoria Group are separated by lower Proterozoic granitic bodies, associated with felsites and granophyres: the Gaborone Granite at the northern extremity of the Kuruman arch, and the Rooiberg felsites/Bushveld Granite in the central Transvaal.

Correlations between the Groups is based on a coeval thick volcanic sequence (Ongeluk in Griqualand West, Hekpoort in Transvaal), which in both regions is underlain by a diamictite of possible glacial origin. The Makganyene Diamictite represents the base of the Postmasburg Group. Above the Ongeluk volcanics the sequence can only be correlated with a part of the Pretoria Group, and then if a significant facies change is accepted.

Many regard these units as accumulating in a single basin (Button, 1973a;Tankard & Others, 1982).

Others (e.g. Crockett, 1972; Eriksson (P.G.) & Others, 1988; Crockett & Key, 1989) consider that these sediments were deposited in a series of distinct basins; and that subsequent tectonic events were superimposed upon an already existing chain of basins: two, or three (Engelbrecht, 1986) basins in the Bushveld were separate from the Kanye Basin (Crockett, 1972); the Griqualand West occurrence representing a further separate basin.

Pretoria Group

From a regional study in the eastern Transvaal, Button (1973; see also 1986) concluded that the thick Pretoria succession was deposited in the littoral and neritic zones of an epicontinental sea: within the group marine shale, marine shelf sand, prodeltaic muds and silts, intertidal muds, delta-front sands and beach sands are present. This model has continued to be generally accepted.

Excluding the Rooiberg Felsite and Loskop Formation, the Pretoria Group is up to 10000 m thick, the greatest thickness occurring in the eastern Transvaal. It comprises a marginal-marine cyclical assemblage of quartzite and shale, with three carbonate and three volcanic units and minor carbonate units, and, in the north, a number of wedges of fluvial arkose. Within the Pretoria Group, a great variety of depositional environments have been

	EB(1)	WT	Po	CRF	Pr	MHF	DD	ET
Dullstroom								X(4)
Houtenbeck								X
Steenkampberg							X	
Nederhorst								X
Lakenvlei							X	
Vermont	(2)				(3)		X	X
Magaliesberg	X	X	X		X		X	X
Silverton	X	X	X	X	X	X		X
Daspoort	X	X	X	X	X	X	X	X
Strubenkop	X	X	X	X	X	X	X	X
Drogedal/Dwaal Heuwel		X	X			X	X	X
Hekpoort	X	X	X	X	X	X	X	X
Boshoek		X	X		X			X
Timeball Hill	X	X	X	X	X	X	X	X
Rooihoogte	X	X	X	X	X	X	X	X

1. Different nomenclature is used in Botswana (see Key, 1983)
2. Strata above Magalies berg quartzite referred to Woodlands Formation
3. Strata above Magaliesberg quartzite referred to Rayton Formation
4. Cheney & Twist (1988) consider that the Dullstroom overlies the Houtenbeck and the Steenkampsberg unconformably.

EB - Eastern Botswana; WT - Western Transvaal; Po - Potchefstroom; CRF - Crocodile River Fragment; Pr- Pretoria region; MHF - Marble Hall Fragment; DD - Dennilton dome; ET - Eastern Transvaal

TABLE 7. Distribution of lithostratigraphic units in the Pretoria Group.

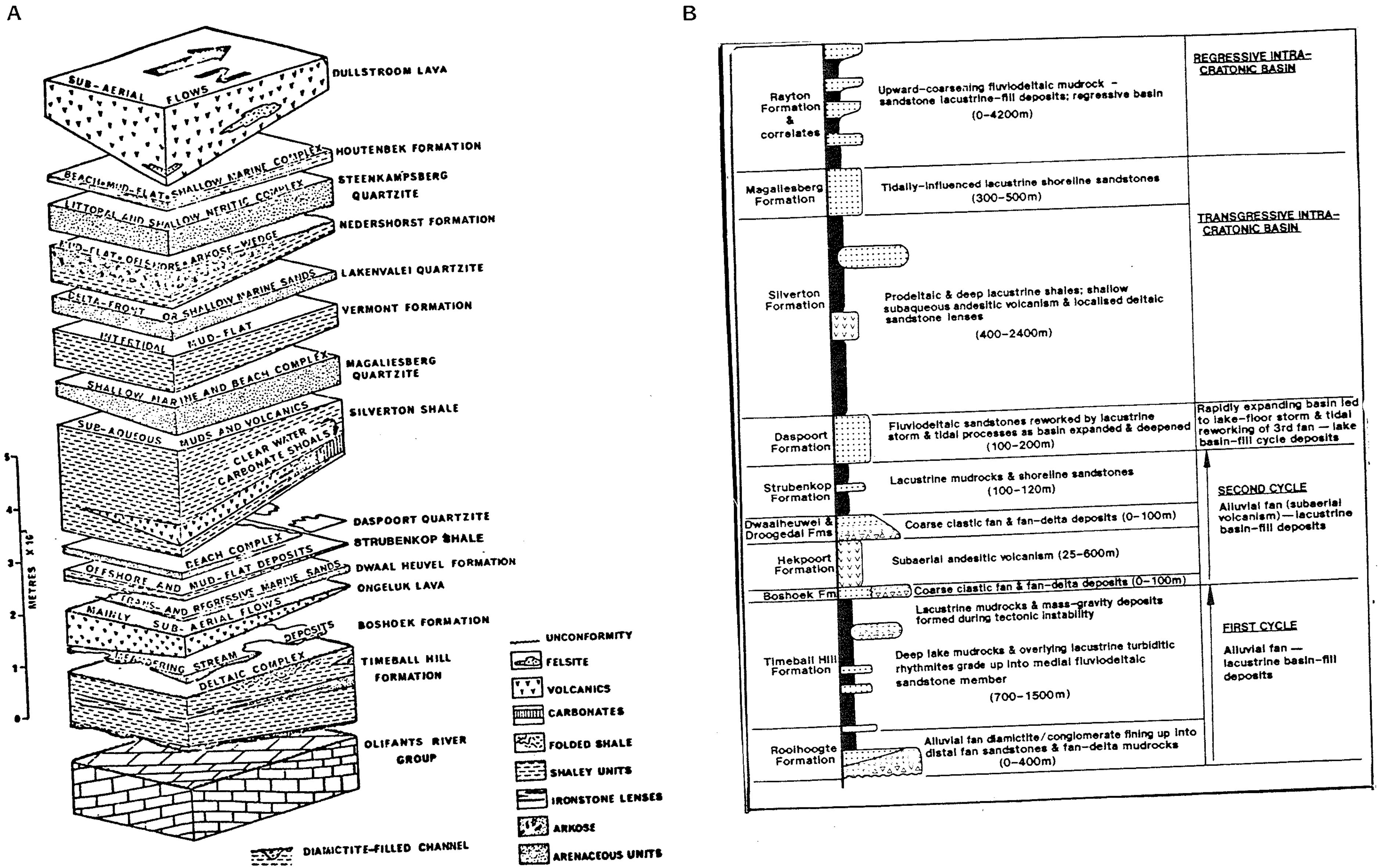

Fig. 12. Depositional environments of the Pretoria Group; (A) after Button (1973); (B) after Eriksson, P.G. (1990).

recognised (Button, 1973; Fig. 12). The distal, clastic-starved submarine shelf is characterized by black carbon-rich shales, sometimes with chert beds. Muddy shelf deposits are very common, formed above wave base, and are lenticular, wavy or graded bedded. They pass upwards into tide-dominated marine shelf deposits, including mature quartz arenites and oölitic iron-stones. Several shelf arenites grade upward to lower and middle tidal flat deposits. The tidal flats were drained by meandering creeks in which arkosic arenites were deposited in fining-upward cycles. Most indications are taken to indicate that the Pretoria Group was deposited on a macrotidal tide-dominated shelf where tidal flats fronted directly on to the marine shelf (Button & Vos, 1977).

Carbonates, formed during a period of, or in local areas of, reduced clastic input, are stromatolitic, and were deposited both inter- and sub-tidally (Button & Vos, 1977). Sediments interpreted as glaciomarine and fluvioglacial are developed in the Timeball Hill Formation (Visser, 1971: de Villiers & Visser, 1977).

The lavas, which are basaltic or intermediate in composition, are usually associated with some pyroclasts. They were extruded on land (Hekpoort and Dullstroom units) and in a submarine setting (Machadodorp Volcanic Member) (Button, 1974). A very widely developed palaeosol is developed at the top of the Hekpoort Basalt (Button, 1979), and consists of a sericite-rich upper zone overlying a chlorite-rich lower zone.

A different style of sedimentation is developed in the uppermost parts of the Transvaal Sequence in the Stavoren fragment (north of Marble Hall), and in the Rooiberg fragment. Here predominantly arkosic sediments occur. As will be seen, it is thought possible that these sediments are younger than the Pretoria Group: they are discussed separately in the following section.

Whilst accepting that the littoral/neritic model for the formation of the Pretoria Group is an appropriate one, Eriksson (P.G.)(1988) considers that the lithologies and sedimentary structures can also be accommodated in an intra-cratonic or complex lacustrine basin, somewhat comparable to the current Great Lakes in the U.S.A. Two cycles of alluvial fan - lacustrine fill deposits (Fig. 13) are succeeded by the Daspoort formation,

> ..."interpreted as representing the deposits of a third such cycle, subsequently re-worked by high-energy lake bottom processes, as the basin expanded and deepened rapidly. A transgressive phase is represented by the overlying Silverton and Magaliesberg Formations. Fluviodeltaic lake-fill sedimentation (Rayton Formation and correlates) terminated the Pretoria Group sedimentation"...
>
> (Eriksson, P.G. ,1988)

Eriksson (P.G.) & Others (1988); Eriksson (P.G.)(1990) believe that the Pretoria Group was laid down in two sub-basins (eastern and western Transvaal) which were linked by a smaller but higher energy and presumed shallower palaeohigh (Fig. 13), which shed detritus east and west. Pretoria Group sediments in the Potchefstroom synclinorium may represent a third sub-basin (Eriksson (P.G.) & Others, 1988).

In Botswana, west of the Transvaal Basin or western Transvaal sub-basin, there are occurrences of Transvaal sequence strata. Those at Segwagma and Dikgomo di Kae contain a partial and more complete Pretoria Group assemblage respectively. In these occurrences quartzites are exposed in low escarpments,

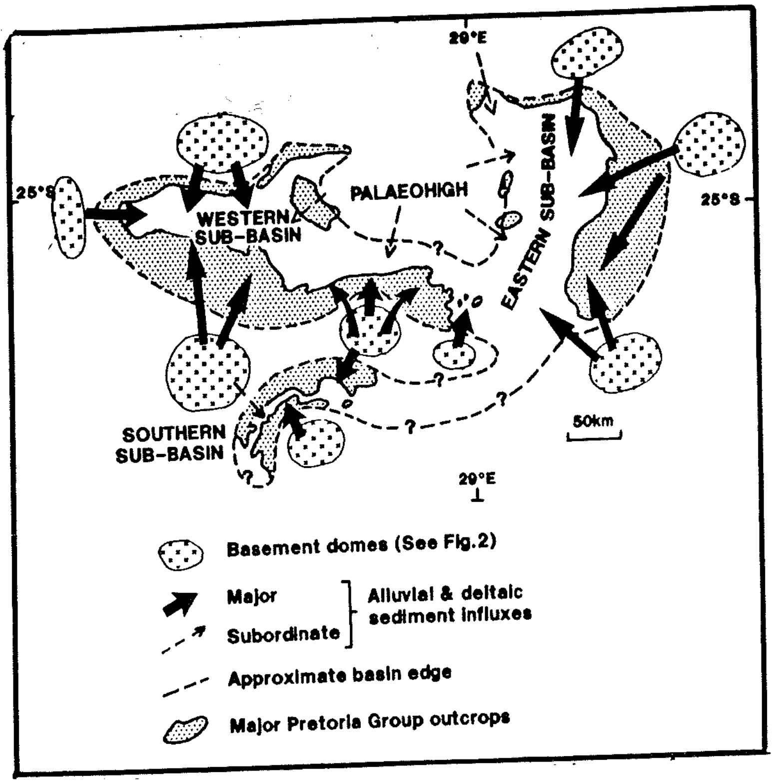

Fig. 13. Palaeogeography during initial alluvial-lacustrine cycles postulated for the Pretoria Group.
(Eriksson,P.G. 1990).

argillaceous and volcanic rocks are known only from rare wells or borehole information. Although there are differences in detail, the rock types are those to be found in the Bushveld region.

Crockett (1972) considers that these occurrences along the eastern fringes of the Kalahari were laid down in a separate, Kanye Basin. Crockett & Key (1989) reinforced that view, considering that the Transvaal sediments were originally deposited in a series of distinct basins and that

..." tectonic effects dating from the end of Transvaal time onwards were superimposed upon an already existing chain of basins." ....

Crockett (1972) records some evidence from boreholes and rare outcrops between Dikgomo di Kae and Segwagwa, and Molopo to the south, that these dolomitic (Chuniespoort/Ghaap) rocks may have been continuous across this region, thus that post-Chuniespoort/Ghaap uplift may have been responsible for the distinction that exists between the overlying Pretoria and Chuniespoort Group rocks; with the presumed implication that the Ghaap and Chuniespoort basis did accumulate in a single basin. This is in accord with the discussion in the previous section.

Possible supportive evidence for non-deposition in the central Transvaal is provided by the reduced thickness of the Pretoria Group in the Marble Hall fragment (Kleywegt & du Plessis, 1986), and in the Crocodile River fragment (Harzer, 1989). A similar reduction occurs towards the Vryburg arch from the Northern Cape and the Transvaal. This is evidence at least of some differential movement in Pretoria times, if not of non-deposition in areas such as the central Transvaal.

The postulate of Eriksson (P.G.) & Others (1988), and the earlier work of Crockett (1972) is that the present outcrops of the Pretoria Group reflect original (separate) depositories.

This is at odds with the identical lithologies found throughout the Group, up to and including the Magaliesberg quartzite; a number of recognised facies changes - for example the southward changes in the Timeball Hill in the eastern Transvaal, with decreasing quartzite thicknesses and complementary increases in ironstones (Button, 1973), and similar changes in the Potchefstroom area (Eriksson, K.A., 1973) (See Figs. 14 and 15), and the structural control of the present sedimentary pattern by the Bushveld Complex, the Gaborone Granite and the Vredefort Dome.

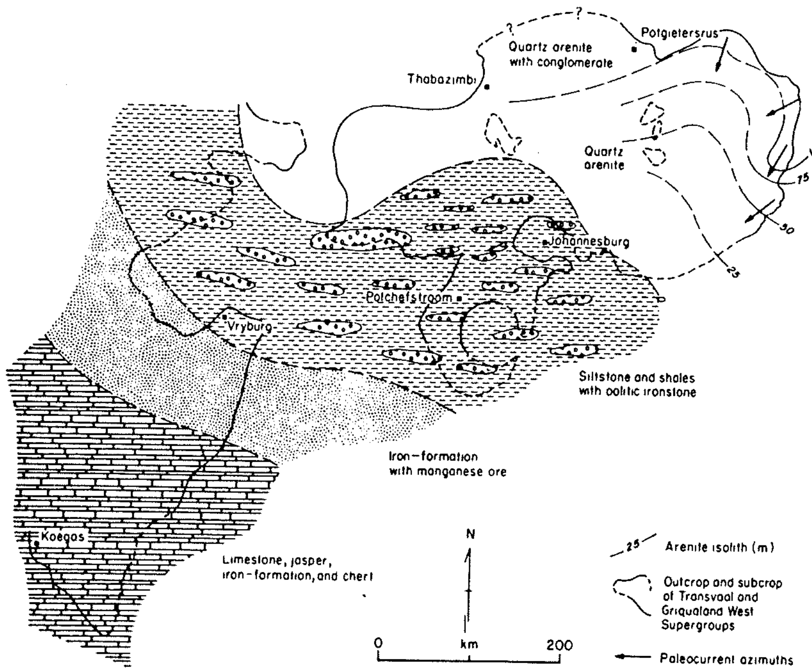

Fig. 14. Facies patterns in the Dwaalheuwel (Transvaal) and Voelwater Jasper (Griqualand West). (Tankard & Others, 1982, based on the work of Button)

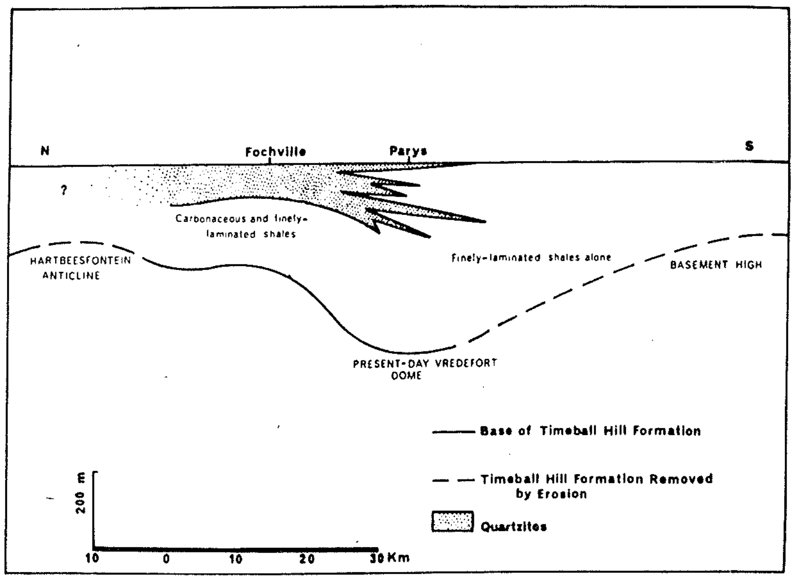

Fig. 15. The Lower Timeball Hill Formation facies in the Potchefstroom district (Eriksson, K.A., 1973).

The evidence surely supports the concept that the Pretoria Group, at least until Magaliesberg times, accumulated in a single basin. Subsequently, the history of the basin became more complicated as will be discussed, and the separation of the present structural basins was completed by the time that the Bushveld Granite was emplaced; prior to these separations it is likely that the sedimentation followed more individual patterns in distinct areas.

Postmasburg Group

The Postmasburg Group overlies the Griquatown and Koegas Sub-Group disconformably in the north and south respectively; on the Maremane Dome the contact with the underlying but younger Gamagara Formation is a thrust surface (Beukes & Smit, 1987 ; Fig. 16).

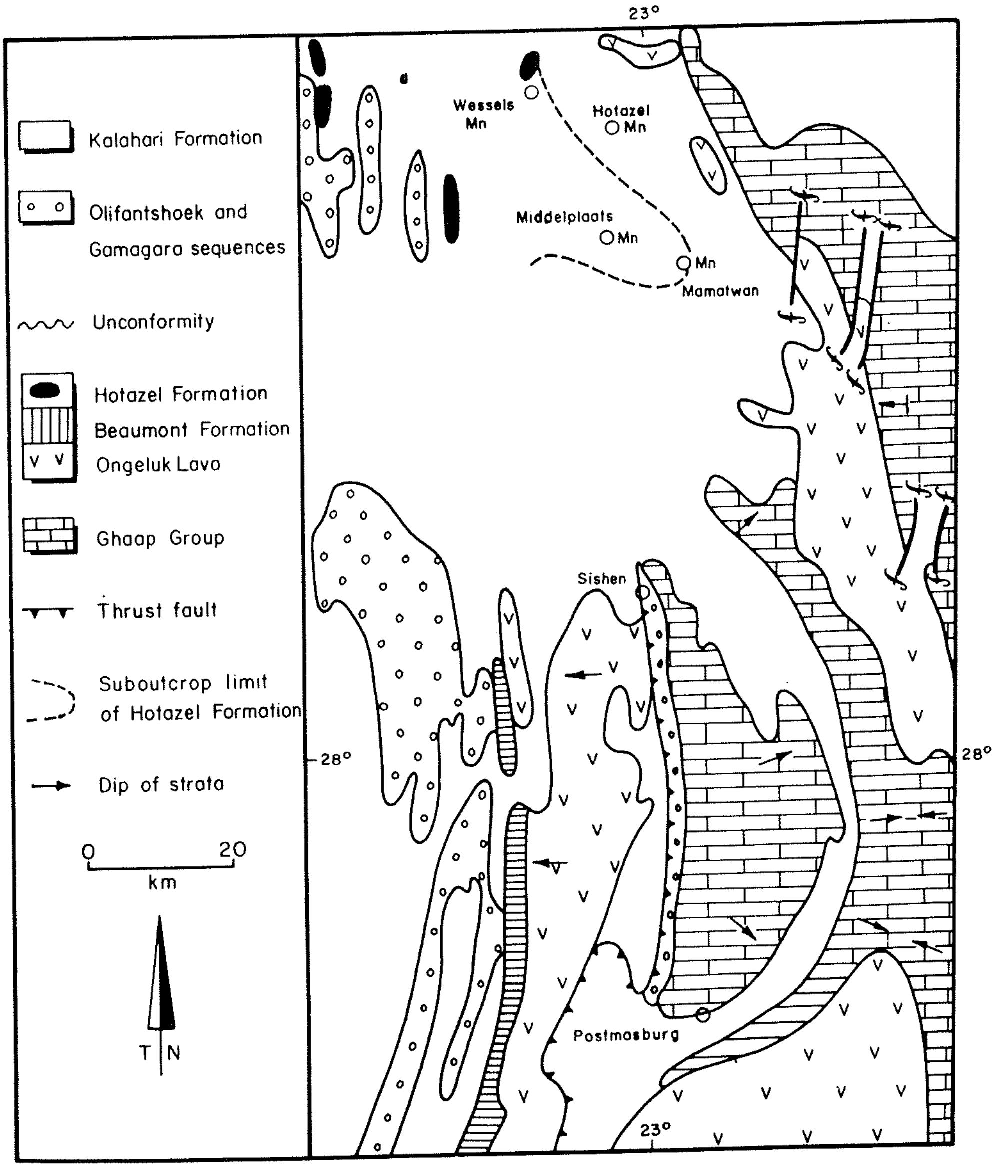

Fig. 16. The distribution of the Postmasburg Group in Griqualand West (Beukes, 1983).

Uplift and erosion preceded deposition of the Makganyane Formation. The diamictites of this unit cut deeper into the platform facies than into the basinal facies south of the Griquatown fault zone (Beukes, 1986).

The Group may be as much as 2000 m thick. Sediments of the Makganyane Formation lie below the thick Ongeluk Volcanics; above the volcanics lie the Hotazel, Beaumont and Mooidraai Formations. Among features that unify the sequence are that volcanic ash and fragments become most abundant towards the top of the Makganyane; that jasper-rich rocks are found in all of the above units, including the volcanics; and that dolomitic rocks occur in the Makganyane and Mooidraai Formations.

The Makganyane Formation contains a number of diamictites: these occur in a sandy matrix lower in the sequence, are more argillaceous towards the top. Some striated clasts have been found on the surface, and have led to the suggestion that the diamictites involve a glacial origin with clasts being deposited from floating ice into muds, or occurring in turbidite sands (Visser, 1971; de Villiers & Visser, 1977).

The information from units above the Ongeluk comes from the subsurface. As mentioned above, jasper-rich units are interbedded in the andesitic lavas which are overlain jasper, jaspilite and bedded sedimentary manganese deposits of the Hotazel Formation; this in turn by clastic-textured dolomite, and stromatolitic dolomite of the Mooidraai Formation. The Hotazel Formation interfingers laterally with jaspilite, jasper, dolomite, tuff and lava of the Beaumont Formation.

Gaborone Granite

Hunter (1974) noted that the lower Proterozoic granitic bodies (of Bushveld age or older) on the Kaapvaal craton tend to be mushroom-shaped, to be anorogenic, and associated with felsites and granophyres. All were emplaced at high crustal levels, at depths of 10 km or less. When compared to older granitic bodies representing an integral part of the craton as such, these somewhat younger bodies are chemically distinctive: they have high Rb, Ti, Sc, and high ratios of Fe/Mg and Ba/Sr. They are considered to have been derived from mantle and crustal sources.

The Gaborone Granite is such a body, although a late Archaean age is now suggested. It is large, with a surface area exceeding 5 000 sq kms. A central core of rapakivi granite (Thamaga Granite) is surrounded by successive shells of equigranular leucocratic granite (Kgale Granite), porphyritic granophyre or microgranite (Ntlhantlha Microgranite). Around these shales lies a zone of felsite (Kanye Volcanics).

Either side of the Gaborone Granite lie exposures of the Transvaal sequence: the main outcrop to the east through the Bushveld region, smaller occurrences from Kanye westwards into the Kalahari (Fig. 17).

Given its setting, it follows that the age of this granite, and its relations to the Transvaaal sequence, are of significance, as are the possible relationships of the granite to structures within the Transvaal Sequence.

The Gaborone Granite was emplaced parallel to essentially north-south fractures, but in the north spread laterally parallel to the ENE-trending Molepolele and Moshaneng lineaments. The emplacement appears to have been violent. Key (1983) envisaged a complex cooling history with lithological

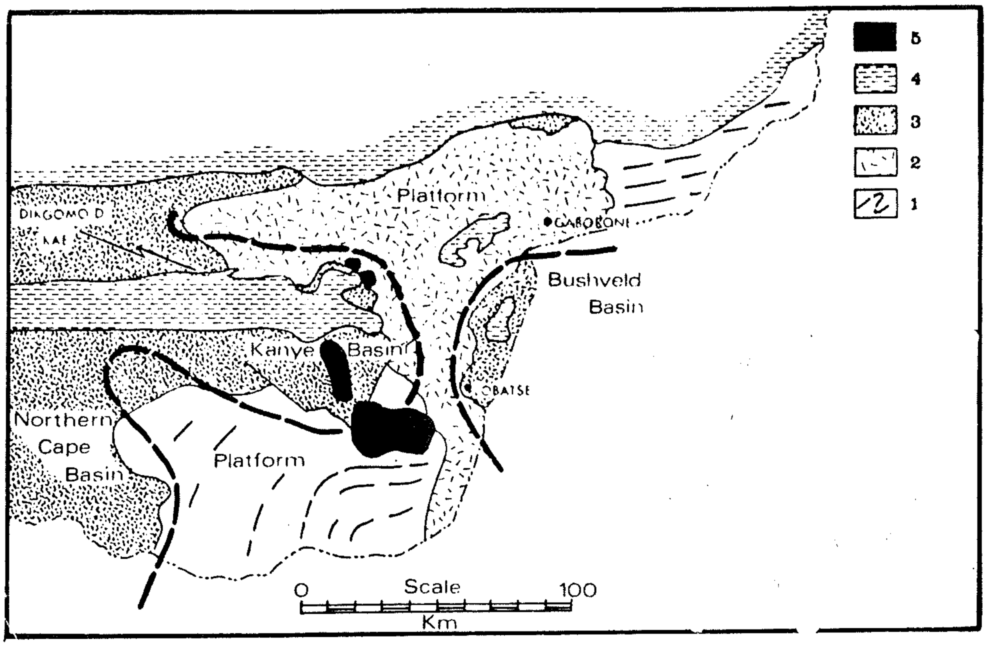

Fig. 17. Simplified geological map of southeastern Botswana showing the setting of the Gaborone Granite
1. Basement; 2. Gaborone Granite;
3. Ventersdorp and Transvaal; 4. Waterberg
5. post-Waterberg syenite and granite.
(Crockett, 1972)

zoning paralleling the shape of the intrusion. He considered that the outer crust quenched rapidly to form the unit referred to as the Kanye Volcanics; there was evidence that locally magma reached the surface to form banded rhyolites and agglomerates.

Aldiss & Others (1989) regard the Kanye Volcanics not as carapace to the granite, but as ash-flow tuffs representing an extrusive precursor to the granite.

The Kgale granite extends in places through the microgranite-granophyre and has intrusive contacts with the Kanye Volcanics. At one locality, Tsele hill west of Mochudi, the granite is in contact with Black Reef quartzites. Key & Wright (1982) and Key (1983) consider this to be an intrusive contact, with limited thermal metamorphism. Aldiss (1985), however, considers that the Black Reef overlies the granite unconformably, and comments as follows:

"... in one part of the section detrital arkoses have recrystallised to resemble igneous rocks, and fault bounded blocks of sediment within the granite resemble xenoliths..."

Key & Wright (1982) considered that the age of the overall Gaborone Granite body is 2394 ± 26 m.y., but if the volcanics are excluded from consideration and only the granitic rocks are regressed, then the age is 2428 ± 55 m.y.; they conclude that the Gaborone Granite was emplaced in toto at about 2400 m.y.

Aldiss & Others (1989) note that the Kanye Volcanics are overlain by the Lobatse volcanics: the latter is an equivalent of the Makwassie Formation within the Ventersdorp Sequence in South Africa to the south. An age of 2709 ± 8 m.y. has been determined for this unit (Armstrong & Others, 1990). The Lobatse Volcanics usually follow around the outcrop of the Kanye Volcanics but in a few places overstep these volcanics to lie unconformably on the Gaborone Granite.

With this interpretation the Gaborone granite is > 2700 m.y., and the younger age referred to earlier represents some later regional event.

To the east and to some extent to the southwest of this granite the upper parts of the Transvaal Sequence show intense faulting interpreted as resulting from gravity sliding following marked subsidence in unstable basins relative to and adjacent to a more stable platform (Crockett, 1969; 1971). Crockett distinguished an eastern basin province, which collapsed during the deposition of the Woodlands Formation, from a stable shelf province lying west of Gaborone and Lobatse; and infers similar unstable conditions west of Kanye, notably near Segwagwe.

The collapse gave rise to

- tilting of lower Transvaal strata at angles of up to 45°; the zones affected, although intensely folded, remained autochthonous (Fig. 18).
- to the east, gravity sliding eastwards of higher horizons in the Transvaal sequence in two stages (Slides 1-2, 3-5; see Fig. 18). Individual slide phases are shallow, and are defined by mylonites and brecciation. The slides flatten out eastwards in toe zones and present little or no evidence in adjacent South Africa.

The gravity-related decollement structures are not known anywhere else in the Transvaal occurrences. As mentioned, Crockett saw the structures as resulting from a collapse in the basin, but Key & Wright (1982) and Key (1983), noting that these structures are adjacent to the Gaborone Granite, have suggested that the intrusion of this major body

> "... initiated the catastrophic uplift of the Shelf Province relative to the Basin Province..."

Dietworst (1988) relates the above structures to a period of post-Transvaal folding, involving basement uplift, fragmentations of the Transvaal depository and 'block-faulting'. This contribution is inimical to Crockett's observations, and has been rebutted (Crockett & Key, 1989).

Key (1983) considered that the localised sliding was related to the forceful high-level emplacement of the Gaborone Granite; with the implication that this intrusion took place during the deposition of the Woodlands Formation, thus Transvaal sedimentation would have ended by ~ 2400 m.y. (Key & Wright, 1982).

This view is negated by the field relations and age correlations of Aldiss & Others (1989).

However it does remain to be seen what relationship there is between the late Transvaal gravity sliding and the northern margin of the Kuruman arch in the region of the Gaborone Granite: a more complex history may yet emerge.

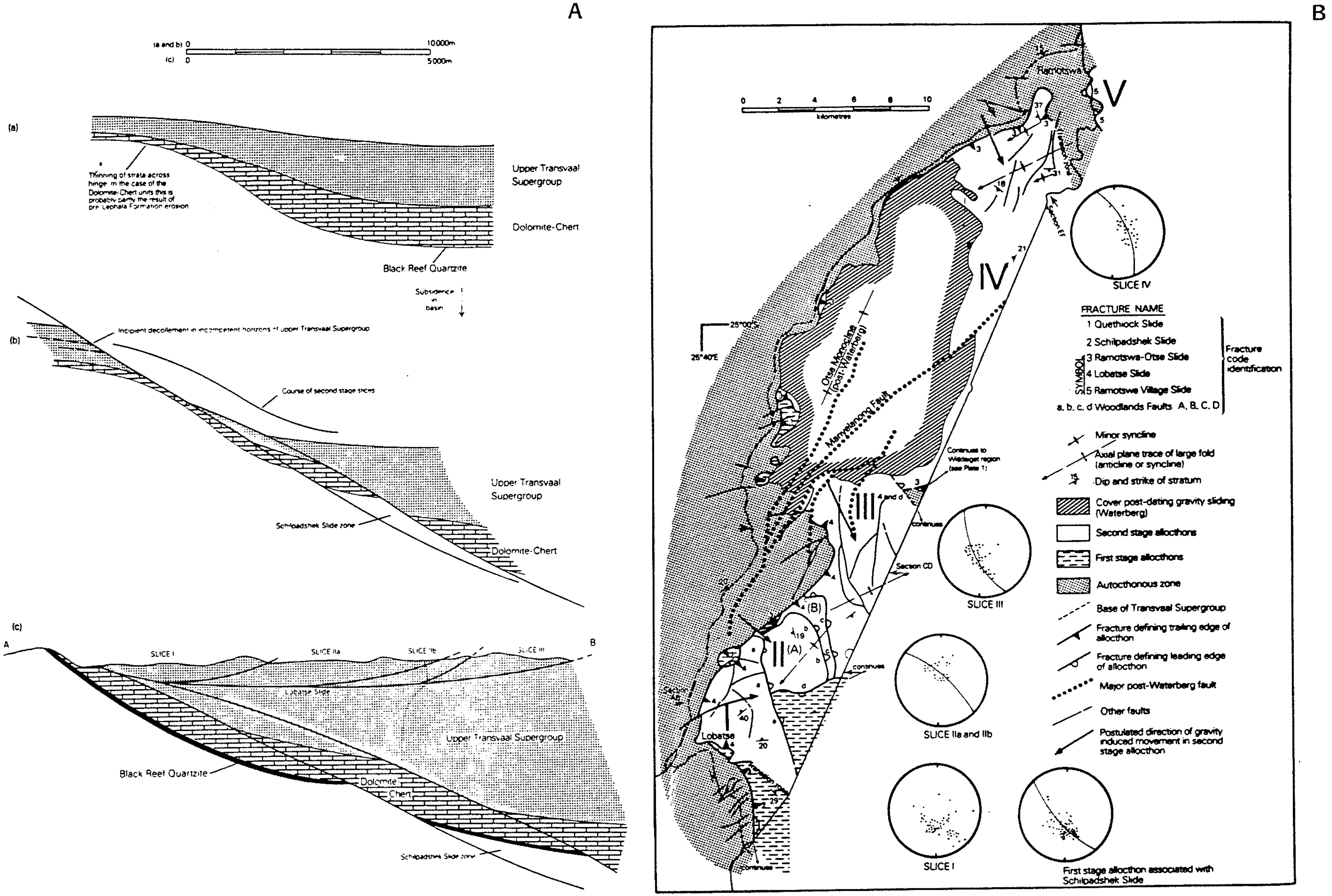

Fig. 18. The structure in the Transvaal Sequence, Lobatse-Ramotswa area, southeastern Botswana
(A) Showing the structural evolution
(B) Structural elements, including individual gravity slides.
(Crockett, 1971).

Rooiberg Felsites and the Bushveld Granite

The central part of the Bushveld is occupied largely by Rooiberg felsite and granite and granophyre of the Bushveld Complex. Transvaal strata are not exposed in this region, and gravity and resistivity information indicates that neither it, nor the Rustenburg Layered Suite, occurs here (Eriksson (P.G.) & Others, 1988; Kleywegt & du Plessis, 1986; Smit, 1961). du Plessis & Levitt, (1987) and Visser, (1970) suggested that the Transvaal Sequence was laid down in this zone, but subsequently removed by erosion following on uplift.

The Rooiberg felsites have long been held as the terminal phase of the Transvaal Sequence (Hall, 1932), with the major uncertainty being whether or not there is some genetic linkage between these volcanics and the later Lebowa Granite Suite (the Bushveld Granite). But whether or not the Rooiberg felsites represent such a terminal phase is far from clear. The felsites are only underlain by sediments at Stavoren and Rooiberg, and these occurrences are not necessarily part of the Pretoria Group.

There are different views on the relationship of the Rooiberg Felsite and the Bushveld Granite. Hunter (1973) considered that the trace-element data can be interpreted as a fractionating series from felsite to granite; whereas Rhodes (1974) felt that the major element chemistry demonstrates no genetic linkage. Twist & Others (1986) note that on most element variation plots the granites exhibit evolutionary trends that differ radically from those of the felsites, and conclude that the granites were evidently derived by melting of different source materials, and the granite magmas recrystallised in fundamentally different ways to the felsite liquids.

Twist (1985) comments that further isotopic analyses are essential so as to evaluate this relationship. Given the close spatial relationship of the felsites and the Bushveld Granite, and that no significant time difference between them is demonstrable on available age data, the burden of proof would appear to rest with those who see no genetic linkage between these suites.

At Rooiberg a northwest-trending fault separates the more deformed upfaulted Crocodile River fragment from the Rooiberg Fragment (Harzer, 1989). At Stavoren a similar relationship exists betwen the Moos River - Marble Hall fragment and the Stavoren fragment. Thus, it cannot be demonstrated that the Rooiberg Felsites cap the Pretoria Group. The sediments overlying and underlying the Rooiberg Felsites, and the relationships with the Lebowa Granite Suite, will be discussed in the following section.

Visser (1970) suggested that Transvaal rocks were stripped away over rising domes in this central Bushveld region. Kleywegt & du Plessis (1986) regard the two large areas of defined gravity low as topographic highs at the close of Magaliesberg times,(see Fig. 19). Continuing differential movement led to the stripping away of the Transvaal sedimentation. The extrusion of the felsites represented a culmination of the overall processes involved.

It is possible that granite domes, additional to those related to the Kuruman arch to the west (Fig. 20) may have developed in the central Bushveld region in late Transvaal times.

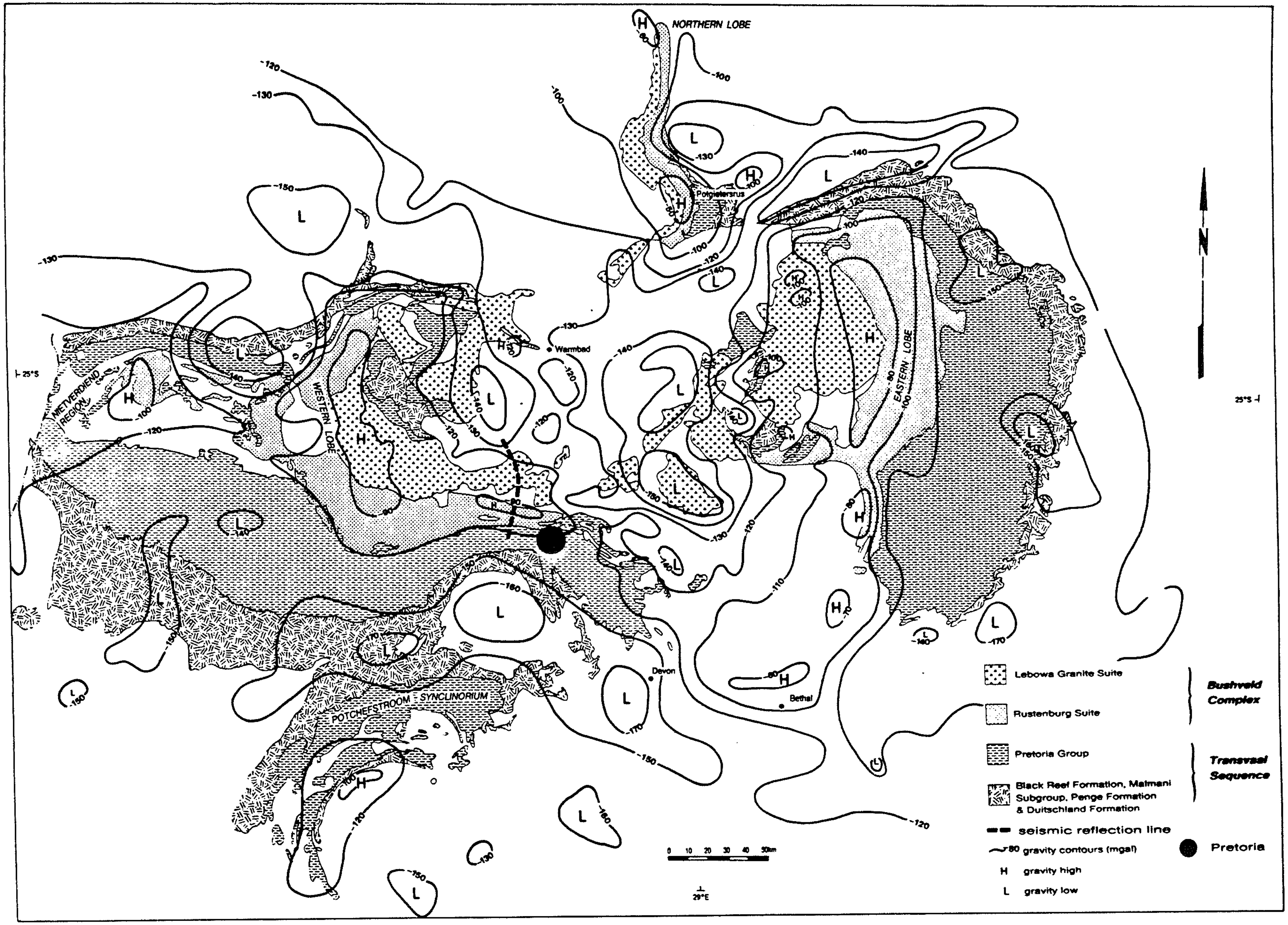

Fig. 19. General geology and Bouguer anomaly map of the Transvaal Basin.
(from Eriksson, P.G. & Others, 1988).

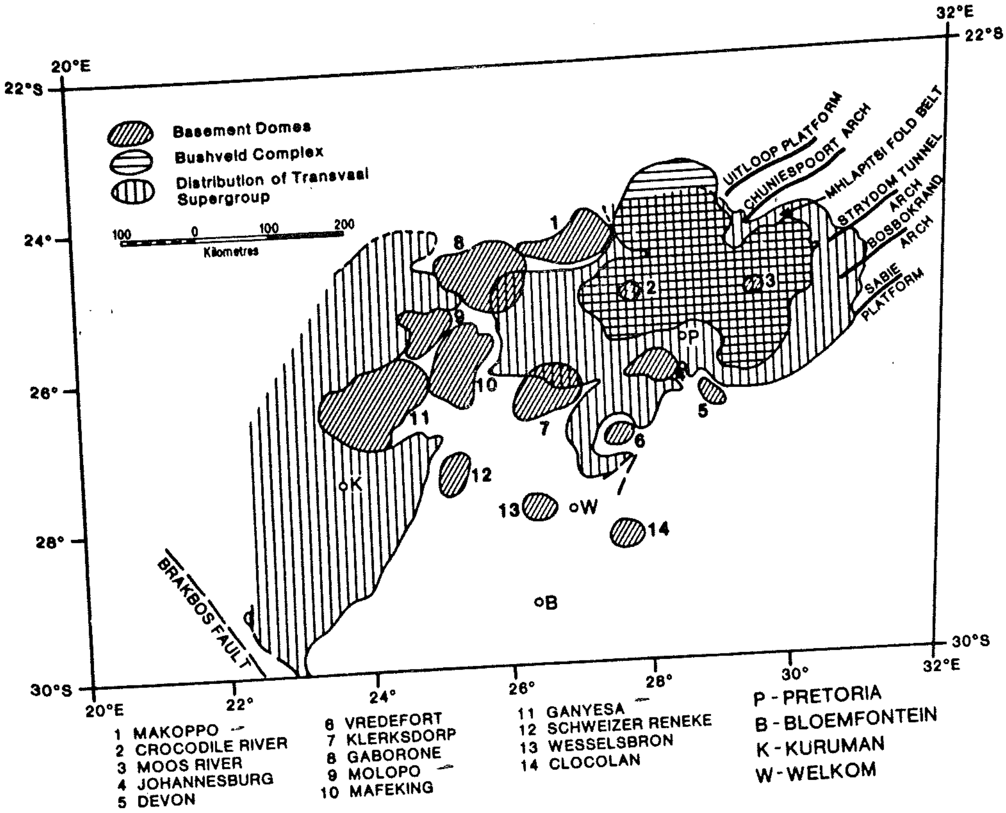

Fig. 20. Basement domes in relation to the Transvaal and Griqualand West Sequences. (Hunter & Hamilton, 1978)

In contrast to suggested catastrophic uplift related to the intrusion of the Gaborone Granite, the emplacement of the Bushveld granite followed a slow uplift, post-dating the extrusion of the Rooiberg felsites. In such a model the Rooiberg Felsites, and related local sedimentation, would be younger than the Pretoria Group. By how much this might be is uncertain.

Correlation

The only clear basis of correlation between the Postmasburg and Pretoria Groups is that the thick subaerial Hekpoort volcanics of the Transvaal (Button, 1973a; Klopp, 1978) are coeval with the subaqueous Ongeluk volcanics in Griqualand West (Grobler & Botha, 1976).

Other aspects of correlation are more speculative.

There are diamictites below each of the above volcanics. The Makganyane diamictite in Griqualand West contains striated chert fragments; a glacial origin is predicated on this observation (Visser, 1971; de Villiers & Visser, 1977). In the eastern Transvaal diamictites have been interpreted as density flow deposits, not necessarily derived from glacial debris (Button, 1973). Beukes (1983) comments that a glacial origin for the Makganyane diamictite

"... most probably needs critical re-examination...".

Thus there is no certainty in correlating these diamictites.

The Postmasburg sediments have been regarded as distal facies equivalents of the Pretoria Group (above and below the Hekpoort volcanics) (Button, 1976)'; illustrated respectively by the Gamagara Shale - Timeball Hill Formation, and the Hotazel - Dwaalheuvel Formation.

Prior to 1967, it was generally accepted that the Gamagara Formation could be correlated with the Olifantshoek Sequence, and that Griqualand West Sequence strata were thrust over it from the west (see for example Strauss, 1964). Thereafter, it was suggested (de Villiers, 1967; Wessels, 1967) that no thrusting had taken place across the Maremane Dome and that the Gamagara formed part of the Griqualand West Sequence.

On the basis of determined major stratigraphic relations and structural dislocations, Beukes & Smit (1987) have re-established that the Gamagara Formation has been thrust over a part of the Griqualand West Sequence. The Gamagara Formation is now regarded as an equivalent of the lower part of the Mapedi Formation; and as a part of the younger Olifantshoek Sequence the correlation of the Gamagara with the Timeball Hill Formation is no longer appropriate.

In the Dwaalheuvel Formation coarse clastics interfinger to the south with finer clastics and oölitic ironstones, and a gradation is inferred with non-clastics in Griqualand West (Button, 1976; Fig.). Precise correlation is made more difficult by a period of erosion, marked by a pronounced palaeosol, capping the underlying Hekpoort Volcanics in the Transvaal (Button, 1979; Button & Tyler, 1981).

There is a major unconformity above the Chuniespoort Group. This may be measured by

- the existence and variable thickness of chert rubble lying on this surface
- the truncation, to differing extents, of underlying units in the Transvaal. The greatest uplift is in the central part of the craton (Beukes, 1983).

Locally in the northeastern Transvaal the deformation of the Duitschland Formation was along the line of the Murchison lineament to form the Mhlapitsi Fold Belt (Button, 1973); a significant phase of this deformation pre-dating the accumulation of the Pretoria Group (Potgieter, 1988).

Southwards from the northeastern Transvaal the Duitschland, Penge, and Frisco, Eccles and part of the Lyttelton Formations have successively been removed (Button, 1973). Assuming full development of the succession, a very considerable part of the sequence was stripped away prior to deposition of the Pretoria Group. In the western Transvaal the Penge Formation, then the Frisco Formation, are truncated westwards; whereas at Zeerust these two units are truncated eastwards. To the northwest of Johannesburg (Swartkops) and in the Potchefstroom synclinorium, the erosion cuts down into the Eccles (Eriksson, (K.A.) & Others, 1976). Pre-Pretoria erosion is thus greatest in the centre of the craton.

Given the correlation between the Asbesheuwels Subgroup and the Ongeluk Volcanics, and the Penge Formation and the Hekpoort volcanics, the varied intervening events in the two areas must have time equivalence.

The events in the interior of the craton are: the (local?) unconformity between the Penge and Duitschland Formations; the accumulation of the Duitschland Formation; uplift and very extensive erosion; re-working of the resulting chert rubble and the accumulation of the Rooihoogte and Timeball Hill Formations.

On the southwest margin of the Kaapvaal craton the same time period is represented by the Koegas Subgroup, and the unconformity below the Makganyane diamictite. The time significance of the unconformity below the Makganyane Formation is not known.

Beukes (1983) contends that a correlation of the Timeball Hill Formation with the upper iron formations of the Koegas Subgroup

"... seems not to be too unreasonable a suggestion..."

In Griqualand West there are no Griqualand West sequence strata above the Mooidraai Formation. It is not known whether any such strata were deposited, and subsequently removed.

SEDIMENTS ASSOCIATED WITH THE ROOIBERG FELSITES AND THE BUSHVELD GRANITE

There is a distinction amongst the fragments lying within the Bushveld Complex between those, such as at the Crocodile River and Marble Hall, that contain strata that can be readily correlated with units up to the Magaliesberg; and those at Stavoren and Rooiberg.

In the latter the sediment is different, often arkosic, is less deformed and is overlain by the thick felsitic volcanics of the Rooiberg. The relevant contacts are faulted. The Rooiberg is widely developed through the central zone of the Bushveld and, in the Middelburg basin is overlain by the red beds of the Loskop Formation.

Traditionally the sediments in the Stavoren and Rooiberg fragments have been regarded as a part of the Pretoria Group. In addition, the Loskop is seen as the last stage of overall activity in a shrinking Transvaal basin (Coertze & Others, 1977; SACS, 1980; Jansen, 1982).

Both these points require comment: in this section outline descriptions are provided of the relevant rocks. Thereafter the position of these rocks is discussed more fully.

Stavoren Fragment

In the Stavoren fragment the total thickness of sediment in the Makechaan Formation exceeds 410 m (Rhodes, 1972); the sediments are litte deformed, completely surrounded by Bushveld Granite and overlain by felsite. Much of the sediment is felspathic sandstone: detailed environmental studies have not been carried out, but a fluvial origin is inferred. Some associated quartzitic beds represent re-worked sediments. The uppermost sediments occur above a sand-covered contact: these are felspathic greywackes, with some vesicular basalt. Rhodes considered that the above sand-covered contact may be 'tectonic', but presented no specific evidence in support of this contention.

Rooiberg Fragment

The Leeuwpoort and Smelterskop Formations in the Rooiberg Fragment have been studied by Stear (1977), Phillips (1982), Richards (1987) and Richards & Eriksson (1988). The total thickness is $\sim$ 2000 m. The upward-fining Leeuwpoort is subdivided into the thick, Boshoffsberg member, interpreted as a braided stream deposit, and the Blaauwhoek Member, regarded as a sequence of upward-fining point bars passing into floodplain deposits (Richards & Eriksson, 1988). This unit is overlain conformably by the Smelterskop Formation, in which quartzites are predominant, other rock types are arkose, conglomerate, basic lavas, pyroclastic rocks and minor greywackes, and is interpreted as a more proximal fluvial deposit. The Smelterskop is in turn overlain, disconformably, by the Rooiberg felsites (Richards, 1987; Fig. 21).

Rooiberg Group

The felsites of the Rooiberg Group constitute the volcanic precursor to the succeeding plutonism of the Bushveld Complex (Twist, 1985). They form the roof of the Rustenburg Layered Suite and Lebowa Granite Suite (the Bushveld Complex). Based on the present outcrop, in a northeast-trending belt from Vila Nora in the north to south of the Middelburg in the south in a central zone of

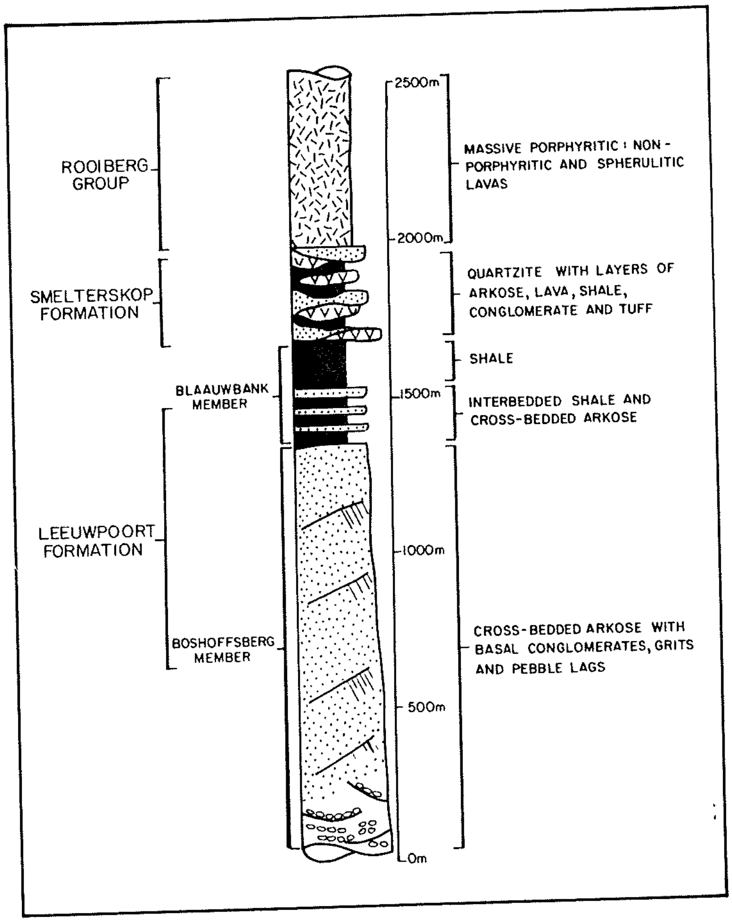

Fig. 21. Section illustrating the sediments, and related Rooiberg felsites in the Rooiberg Fragment.
(Richards & Eriksson, 1988).

the Bushveld Complex, this represents one of the largest known masses of acid volcanism (Twist & French, 1983).

Great thicknesses are common. Where best known, in the Loskop Dam area, these are up to 5000 m. In this region thick sequences of lavas are usually separated by, and sometimes contain thinner volcaniclastic sequences (Twist, 1985). Clubley-Armstrong (1977) recognised a thick quartzite marker which separates off a lower, darker-coloured Damwal Formation from a reddish coloured Selons River Formation. This distinction is thought to be significant in terms of the timing of the development of any oxygen-rich atmosphere (Twist & Cheney, 1986), reflecting increased oxygen in the atmosphere at this specific time horizon. Succeeding continental sediments (Loskop Formation, Waterberg Group) are classic red beds.

A 250 m-zone near the top of the sequence includes numerous pyroclastic and sedimentary rocks.

The sequence of lavas contains some silicic andesites near the base, but overall rhyolitic lavas dominate.

Twist has distinguished three magma types in the felsites: the two major ones - a high Mg (> 1.7% MgO) and low-Mg (< 1.0% MgO) have calc-alkaline and tholeiitic affinities respectively, and are thought to have erupted intermittently but in close succession from different magma chambers. The high-Mg felsites are geochemically similar to volcanic-arc granites (Hatton, 1988); Hatton & Sharpe (1990) have suggested a model in which the felsites, and the plutonic phases of the Bushveld Complex result from the collision of a spreading centre with the northern edge of the Kaapvaal craton: there is, however, as yet no tectonic evidence to support such a model.

Loskop Formation

In the Middelburg Basin the Selons River Formation (of the Rooiberg felsites) is conformably overlain by the Loskop Formation. Further evidence of a continuous succession between these units is provided by the increasing number of sedimentary (and pyroclastic) intercalations in the felsites towards the top of the sequence.

The Loskop consists of ∿ 1200 m of red-bed sediments, with limited interbedded lavas and pyroclasts near the base. In addition to shale and siltstone, sandstones, quartzites, felspathic sandstones, conglomerates and breccias occur (Coertze & Others, 1977). There is a prominent conglomerate at the base. Not only acid lavas, but also epidotised intermediate to basic lavas occur near the base of the Formation.

Near Loskop Dam a porphyritic Bushveld Granite intrudes basal Loskop strata (Rhodes, 1972). The contact with the overlying Wilgerivier Formation is in general disconformable, but at several localities an angular unconformity is seen; the Wilgerivier is not intruded by the Bushveld Granite. Different interpretations have been placed on these relationships over the years but (SACS, 1980) regards the Loskop as the top of the Transvaal sedimentation, the Wilgerivier as the start of Waterberg sedimentation.

ARE THESE SEDIMENTS YOUNGER THAN THE PRETORIA GROUP?

As part of consideration of possible correlatives to the units of the Transvaal sequence in the Eastern Transvaal, Button (1973a) felt that on the evidence available that the arkosic fluvial sediments below the Rooiberg felsites at Rooiberg, and at Stavoren, were broad time equivalents of the similarly arkosic Nederhorst Formation of the Pretoria Group; he suggested that these three units were part of an arkosic wedge shed into the Transvaal Basin from the north.

Stear (1977) regarded the Smelterskop at Rooiberg as indicative of tectonically interrupted sedimentation, and goes on to speculate that the Rooiberg Fragment is located on the extrapolation of the westward extension of the ENE-trending Murchison lineament. Stear went on to make the following comment, which appears to be prescient:

> ..."The Rooiberg fragment undoubtedly holds an important stratigraphic position. Had the succession not have been capped by felsite, and had the sediments not been the host to tin deposits related to the Bushveld Complex, the rocks might easily have been correlated with the Waterberg" ...

Cheney & Twist (1988) have suggested that a major, previously unrecognosed gentle angular unconformity occurs within the upper part of the Pretoria Group; and that the Rustenburg Layered Suite (of the Bushveld Complex), rather than cutting across the rocks of the Pretoria Group on a regional scale as commonly supposed, was emplaced concordantly along this unconformity.

As defined, rocks above the unconformity represent the youngest UBS - T3 or the Bothasberg Sequence in the Transvaal Megasequence (Cheney & Winter, 1990); this unit is a thick volcano-sedimentary sequence represented by the Dullstroom Volcanics to the west of Dullstroom; the Rooiberg Felsites occupying extensive areas in the central Bushveld; the Smelterskop Formation, and a part of the Mackekaan Formation below the Rooiberg Felsites in, respectively, the Rooiberg and Stavoren fragments; the Loskop Formation conformably overlying the Rooiberg in the Middelburg Basin; and a suggested correlative of the Loskop Formation, the Lower Swaershoek Formation in the Nylstroom Basin (Cheney & Twist, 1986; See Fig. 22, Table 8A)

Cheney & Twist (1988) consider that the grouping of these rocks is supported by

(a) petrogenetic similarities between the Rooiberg and Dullstroom volcanics, and

(b) unconformities at the base of the Dullstroom volcanics, and within the sediments at Stavoren and Rooiberg.

(a) The Dullstroom and Rooiberg Volcanics are not in contact, but geochemical work (Schweitzer, 1987) supports the view of Sharpe & Others (1983) that these two originally formed a continuous unit, a unit which becomes more silicic upwards. Lavas with high TiO_2 contents are common to both volcanic sequences (Schweitzer, 1986); trace and major-element data from these suites suggest that they are related by fractional crystallisation along a common, but punctuated liquid line of descent, indicating episodic breaks during the magmatic history in this overall region.

Similarities have also been noted between the minor andesitic layers in the Smelterskop Formation and those in the Dullstroom and Lower Rooiberg (Damwal Formation) : all have similar calc-alkaline characteristics (Schweitzer, 1987; Richards, 1987).

(b) The Dullstroom volcanics overlie the Houtenbek, and the Steenkampsberg Formation of the Pretoria Group. In the overall sequence in the eastern Transvaal, the Houtenbek overlies the Steenkampsberg, thus an unconformity with the Dullstroom must be inferred. In addition, probable depressions at the base of the Dullstroom are thought to represent palaeovalleys carved into the underlying rocks.

At Rooiberg, the Smelterskop Formation generally seems to overlie the Blaauwhoek Shale (of the Leeuwpoort Formation) conformably, but north of Rooiberg itself the basal conglomerate of the Smelterskop truncates the upper portion of the shale (Fig. 9). Channel-fill deposits occur along this contact (Richards, 1987).

In the Stavoren fragment felspathic sandstone, and succeeding more varied clastic sediments and andesites are overlain by the Rooiberg felsites. Rhodes (1972) regarded the unexposed contact between the felspathic sandstones and the overlying sediments as possibly 'tectonic'; Cheney & Twist (1988) equate this contact with the unconformity noted above to the north of Rooiberg

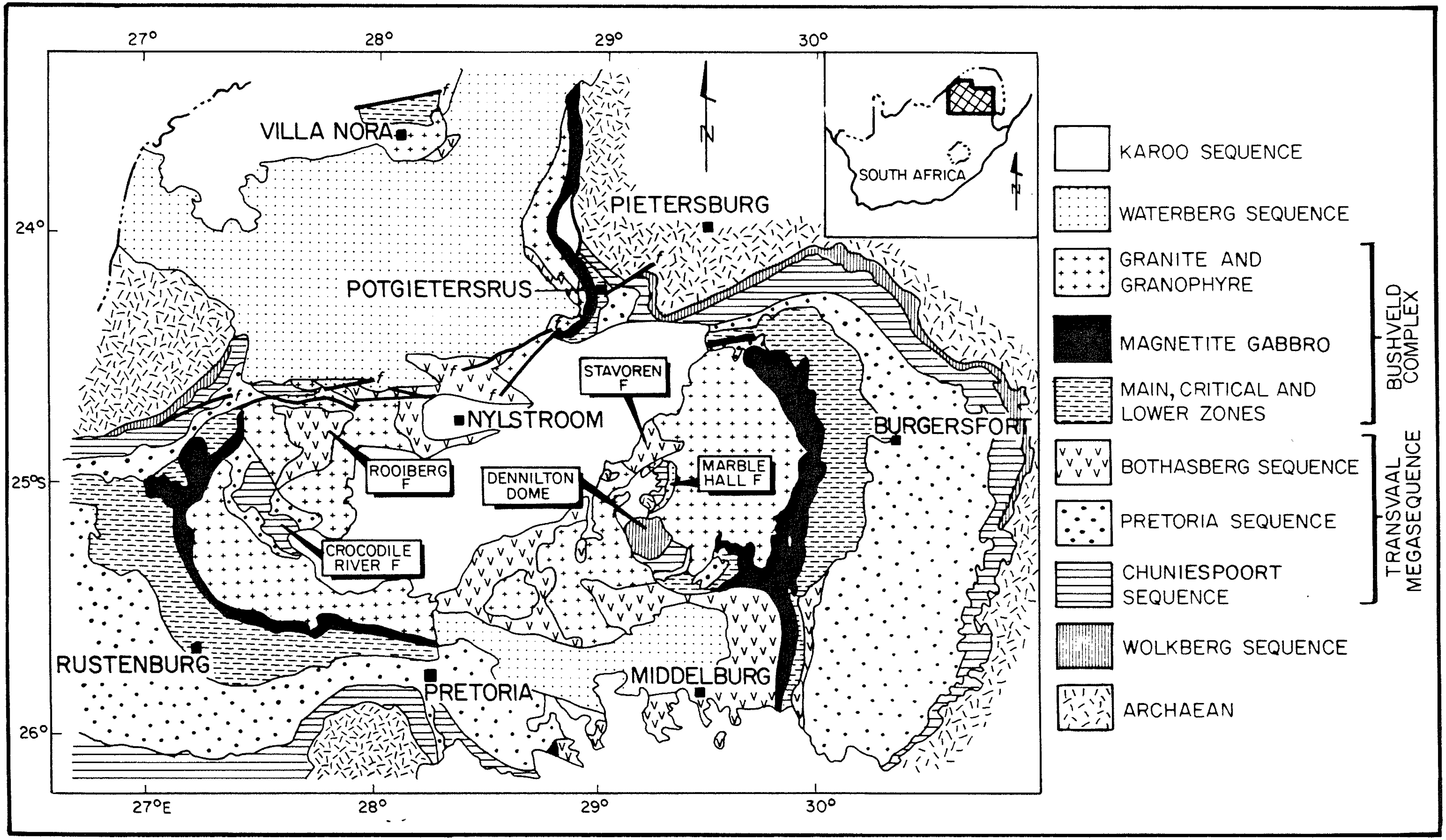

Fig. 22. Suggested unconformity-bounded sequences (UBS) in the Transvaal Basin - Bushveld Complex region. (With minor modification, after Cheney & Twist, 1988).

That the units described can be grouped is accepted. What does appear to be more difficult to accept is that the lower surface of an UBS has been defined, or as will become apparent, that an upper surface, defined by the unconformity above the Loskop Formation is a regional feature.

At Stavoren the 'tectonic' contact within the sediments underlying the Rooiberg has yet to be shown to be an unconformity; at Rooiberg the unconformity suggested may only be a local diastem. Additionally, at Rooiberg a disconformity has also been suggested below the Rooiberg felsites (Richards, 1987). There do not, at present, appear to be grounds for separating off any of the sediments below the felsites at either Stavoren or Rooiberg.

The relationships in the Middelburg Basin have already been described: the Loskop Formation is intruded by Bushveld Granite; it is overlain, at times unconformably, by the Wilgerivier Formation (which is not intruded by the Bushveld Granite). SACS (1980) regards the Loskop, and the lower part of the Swaershoek in the Nylstroom area as the top of the Transvaal Sequence, the overlying Wilgerivier as the start of Waterberg sedimentation after a very long break (Walraven & Others, 1990); a break that is not entirely separated by the emplacement of the Bushveld Complex. That time break was felt to be at least 180 m.y. (Coertze & Others, 1977).

The South African Committee for Stratigraphy still holds the view that there is a major break between the termination of sedimentation (and volcanism) in the Transvaal and the commencement of Waterberg sedimentation. Johnson & Others (1989) allude to the figure of 180 m.y. between the respective units, but there is little evidence today to quantify this figure. The Rooiberg can only be said to be older than the intrusive Bushveld Complex. The basic suite of this complex is well dated at ∿ 2060 m.y., as are the later granites at ∿ 2050 m.y. (Walraven & Others, 1990). All that can be said of the age of the basal Waterberg (as defined) is that it is younger than 2050 m.y. The concept of a major time gap can no longer be sustained.

Cheney & Twist (1986) have questioned the concept of Waterberg sedimentation as an evolution from an original protobasin through a major phase of expansion to a terminal shrinking basin.

Rather than seeing a relationship between patterns of deposition and present preservation, these authors consider that the extent of the Waterberg may have been considerably greater in the past, and that the thickest remaining parts of the sequence were not necessarily depositional centres.

Cheney & Twist consider that the overall succession consists of five unconformity-bounded sequences: the oldest sequence is equivalent to the Loskop Formation, the remainder represent the Waterberg Group as defined.

Whereas Jansen (1982) had considered most unconformities in the Waterberg Group to be of local extent, Cheney & Twist regard them to be of much greater significance. In total they feel these red beds may have accumulated over a very long time span.

This examination is of the Transvaal sequence, and not of the overlying Waterberg. The different approaches noted above highlight the difficulty in defining the top of the Transvaal Sequence.

It is appropriate to examine two relationships at this point:

Firstly, the position of the Swaershoek Formation in the Nylstroom area in the sequence:

Its relationship with the underlying Rooiberg Felsites has been commented on variously. It was considered that the Swaershoek was part of the Rooiberg (Coetzee, 1969). Jansen (1969) provided evidence of a locally irregular pre-Swaershoek topography in the Rooiberg. However, over large areas the contact between the felsite and the basal Swaershoek is a disconformity (du Plessis, 1972). Note however, that there is some confusion on this point: Coertze & Others (1977) refer to a conformable or disconformable contact; Callaghan (1987) quotes du Plessis as showing that the lower Swaershoek is conformable with the Rooiberg felsites. Overall no major break has been demonstrated.

du Plessis (1972) has shown broad conformity of the lower Swaershoek with the Rooiberg felsites, and that this 'conformity' extents to the Bushveld Granite in structures such as the Swartkloof anticline southwest of Nylstroom. du Plessis considers that the granite was still pliable during the deformation of the lower Swaershoek, and that the deposition of this unit is penecontemporaneous with the emplacement of the Bushveld Granite.

Relevant to the above, the lower Swaershoek sediments contain no Bushveld Granite clasts, whereas the upper Swaershoek, and the overlying Alma Formation, do. It seems likely then that the shallowly emplaced Bushveld Granite was unroofed during the overall accumulation of the Swaershoek.

The point needs to be emphasised that this sedimentation took place at the same time as the granite was being emplaced, not only here but presumably also in the Middelburg Basin.

Secondly, the tectonic setting of the overlying Alma Formation to the north of Nylstroom:

Callaghan (1986) interpreted the Alma Formation as a series of alluvial fans

> ... " caused by the uplifted block on the south side of the Murchison strike-slip fault system".....

du Plessis (1987) re-interpreted the structure at Gatkop to the east of Thabazimbi: previously regarded as an area of northerly directed thrust-faulting, in which older Transvaal strata were carried over Waterberg red beds, du Plessis shows, on the basis of slickensides and the identification of a positive flower structure that

> ..."faulting is related to early Waterberg basin-forming processes and that strike-slip-controlled sedimentation (on the Thabazimbi-Murchison lineament) is indicated by pebble mis-matching".....

Callaghan (1987) considered that the Alma Formation represents the base of the Waterberg. Following a review of all the early Proterozoic red beds it is felt that all succeeding (Waterberg) sedimentation is related to strike-slip movement on ENE-trending lineaments. Initially sediment was shed northwards from the Thabazimbi-Murchison fault-zone, but it appears that major side-stepping took place, with the left-lateral movement being carried on by the Zoetfontein fault to the north: the bulk of the Waterberg red beds were shed from this northern fault zone (Truswell, 1990). By the very nature of strike-slip belts unconformities are bound to be limited in extent and in fact continuous with nearby sedimentation. In such terranes correlations involving the supposed synchroneity of unconformities are thus of doubtful value (Reading, 1980).

Given that no significant breaks have been established in the Swaershoek-Alma sequence, it seems likely that the unroofing of the Bushveld Granite during Swaershoek time involved rapid vertical (dip-slip) movement on the plane of the strike-slip zone of the Murchison-Thabazimbi fault.

Below the Alma Formation there may be some tectonic control on sedimentation, but overall the depositories of these red beds can be related to upwelling and other crustal adjustments linked to the Rooiberg Felsites and the Bushveld Complex.

The Loskop-Wilgerivier unconformity is regarded as a local feature. On a broader scale it is contended that no regional unconformity has been documented in the sediments lying below the Rooiberg Felsites at Stavoren and at Rooiberg, or in any of the red beds which overlie the felsites, that is through the Loskop and the Waterberg. Table 8B groups the package of sediments linked to the Rooiberg Felsites and the Bushveld Granite. The age of this grouping in relation to the underlying Pretoria Group is not known, but the hypothesis put forward suggests that it may well turn out to be significantly younger. The grouping supports close petrogenetic and time linkages between the Rooiberg Felsites and the Bushveld Granite.

The definition of the base of the Waterberg at the Alma Formation relates to a change in process rather than a significant break. It would be possible to suggest that the package defined here did in fact continue to include the Waterberg Group sedimentation.

Rooiberg	Nylstroom	Stavoren	Loskop	Dullstroom
	'Lower' Swaershoek		Loskop	
Rooiberg G	Rooiberg G	Rooiberg G	Rooiberg G	Dullstroom F
Smelterskop F Blaauwhoek Shale M		Upper part of Makeckaan F		

A. The Bothasberg UBS (Cheney & Twist, 1988)

Rooiberg	Nylstroom	Stavoren	Loskop	Dullstroom
	Alma F *			
	'Upper' Swaershoek F		Wilgerivier F	
	'Lower' Swaershoek F	Bushveld Granite	Bushveld Granite	
Rooiberg G	Rooiberg G	Rooiberg G	Rooiberg G	Dullstroom F
Smelterskop F		Makeckaan F		
Leeuwpoort F				

* In the Nylstroom structure, not to the north

B. A broader grouping, linking sedimentation to the Rooiberg felsites and the emplacement of the Bushveld Granite

TABLE 8. Sediments associated with the Rooiberg felsites and (B) the Bushveld Granite.

THE HAMERSLEY - TRANSVAAL NEXUS

There are opposing views on the disposition of continental masses through the Proterozoic era, in particular during the earlier part of that era.

The one holds that a single supercontinent existed from ∿ 2600 to 570 m.y., and that within this mass, as represented by the current cratonic areas, any movements were intracontinental or ensialic. This view has been held quite strongly in Australia, and in Africa (Kröner, 1977); Pretorius, 1984). The other is that the plate tectonic cycle involving the opening and closing of oceans is not only applicable to the Phanerozoic but also throughout the Proterozoic.

A complex issue grows no simpler when the same data may be interpreted in different ways.

Piper (1976, 1982) has contended that the Precambrian Shields collectively formed a lens-shaped body of crust (Fig. 23).; and that the available palaeomagnetic data indicates that the palaeopole positions from the major shields are accommodated in a single, narrow apparent wander curve for the time period referred to above, with only some minor adjustments necessary to peripheral shields at 1100 m.y.

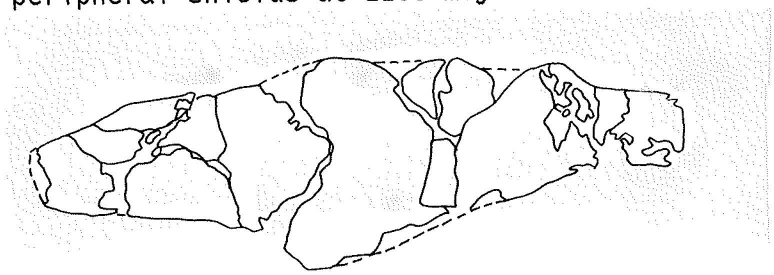

Fig. 23. The proposed reconstruction of a Proterozoic supercontinent. (Piper, 1982).

Burke & Others (1976) consider that sutures marking zones along which continental blocks have collided can be recognised in rocks with ages from Archaean onwards; and take this to indicate that plate tectonic cycles have been in operation since these times. They use available palaeomagnetic data to test their conclusion: plotting APW paths for suture-bound blocks they find that

> ... "APW paths produced in this way fit the palaeomagnetic data better than APW paths for present-day continents, or Pangea" ...

The above comments have particular significance given the striking similarities of the Transvaal rocks of the Kaapvaal craton and equivalent rocks, including the Hamersley Group, in the Pilbara, Western Australia (Button, 1976), and both underlying rocks - Ventersdorp in the Kaapvaal, Fortescue in the Pilbara (Grobler & Meakins, 1988), and in some measure younger Proterozoic sequences.

Button (1976) provides very detailed comment on the Transvaal and Hamersley Basins. His summary is that

> ... "They are roughly the same age. They have the same geotectonic setting. Each is divided into a basal volcanic and clastic unit, and an upper clastic unit. Stratigraphic relations, lithologies, and depositional environments within each of these divisions are similar. The basins have a number of important mineral deposits in common" ...

It will be as well to view the relevant successions in the Pilbara in their regional setting: recent work has been taken to show that south-western Australia had a complex Precambrian history of crustal fragmentation and aggregation by continental collision and accretion. This interpretation

> ... "contrasts with the widely held belief that most of Australia was part of a supercontinent in which all tectonic, magmatic, and metamorphic activity was intracontinental"... (Myers, 1990).

Myers considers that the Pilbara and the Yilgarn (to the south) had distinctive geological histories. The Pilbara was established as a craton at about 2800 m.y. Most of the rocks were then deformed and metamorphosed at low grade. After erosion, this granite-greenstone terrane was overlain by flood basalt at 2800-2700 m.y., reflecting a major period of rifting, and then by banded iron formation at 2500-2400 m.y.

Myers suggests that the Pilbara and Yilgarn cratons collided, giving rise to the intervening Capricorn orogen, between 2000 and 1600 m.y. (Fig.24). Subsequently, this joined block was truncated to the west, south and southeast by the Pinjarra and Albany-Fraser orogens; both were active at 1800 and 1100 m.y., with the main activity in the latter orogeny between 1300 and 1000 m.y. Rifting removed the northeastern part of the overall block. Subsequent continental collision along this rifted margin formed the Paterson orogeny at 700-600 m.y. Myers considers that it was only at this time that this significant part of Gondwanaland was assembled.

Cheney & Others (1988) consider that the long list of similarities between the Kaapvaal and Pilbara cratons requires that they were part of the same plate, which they call Vaalbara, up until $\sim$ 1600 m.y.

They note the following specific information:

. the lithofacies of the Jeerimah in the Pilbara match those of the Schmidsdrif

. the correlative Wittenoom and Carawine dolomites of the Hamersley Group match the Prieska (basinal) and Ghaap Plateau (platform) facies of the Ghaap Group

. the Pniel Group (UBS V3) is best preserved below T1 and is 'more' nearly conformable with V3 in the western parts of the two cratons

. the predominantly volcanic assemblage T3 (represented in the Kaapvaal particularly by the Rooiberg felsites) is not present in the Pilbara

. gregarious Archaean batholiths occur in the northern part of the Pilbara,

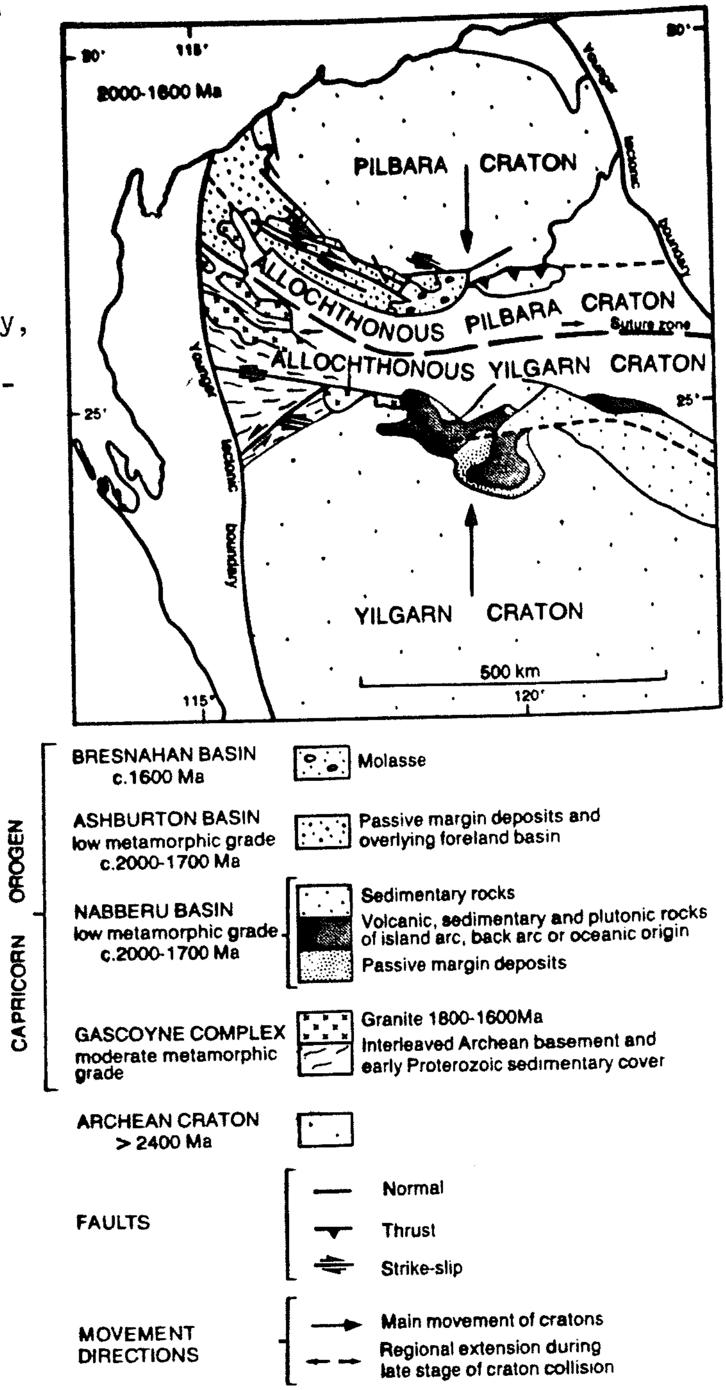

Fig. 24. The Capricorn orogeny, resulting from collision of the Pilbara and Yilgarn cratons (Western Australia) between 2000 and 1600 m.y. (Myers, 1990).

and comment that the Pilbara cannot be fitted, that is in a geological sense, to the northern half of the Kaapvaal craton, but believe that it was attached to the southwestern, Griqualand West, portion of the Kaapvaal craton. Such a reconstruction, which would involve significant rotation, would see the Ashburton Fold Belt (now striking broadly east-west) and the northern zone of the Gascoyne metamorphic province striking into the north-south trending Kheis belt at the western margin of the Kaapvaal craton.

These facts continue to suggest that the Hamersley and Transvaal basins either formed contiguously or at least developed near to one another on a single cratonic unit. Button's (1976) comment

> ..."continental reconstructions that place the western margin of Australia against the African-Madagascan unit are favoured on geological grounds"...

remains valid in the sense of Gondwana fragmentation, but current understanding of the Pilbara/Kaapvaal cratons supports the view that they represented a single crustal fragment through a major part of Precambrian time.

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REFERENCES

ALDISS, D.T., 1985. The Geology of the Phitshane area. Bull. Geol Surv. Botswana, 28.

ALDISS, D.T., TOMBALE, A.R., MAPEO, R.B.M. and CHIEPE, M., 1989. The Geology of the Kanye area. Bull. Geol. Surv. Botswana, 34.

AHR, W.M., 1973. The carbonate ramp - an alternative to the shelf model. Trans Gulf West Assoc. Geol. Societies, 23, 221-225.

AITKEN, J.D.,1966. Middle Cambrian to Middle Ordovician cyclic sedimentation, southern Rocky Mountains of Alberta. Bull. Can. Petrol. Geol., 14, 405-441.

ARMSTRONG, R.A., 1987. Geochronological studies on Archaean and Proterozoic formations of the foreland of the Namaqua Front and possible correlates on the Kaapvaal craton. Unpubl. Ph.D. Thesis, Univ. Witwatersrand.

ARMSTRONG, R.A.,RETIEF, E., COMPSTON, W.S. and I.S. WILLIAMS, 1990. Geochronological constraints on the evolution of the Witwatersrand basin, as deduced from single zircon U/Pb ion microprobe studies. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 24-27.

BALLY, A.W. and SNELSON, S., 1987. Realms of subsidence. In:Foster, N.H. and Beaumont, E.A., Geologic Basins 1 : Classification, modelling and predictive stratigraphy. Treatise on Petroleum Geology, Reprint Series No. 1, 1-86.

BARTON, E.S. and HALLBAUER, D.K., 1990. U-Pb isotope and trace element compositions of pyrites in the Black Reef: implications on their age and origin. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 36-39.

BARTON, J.M., 1990. The Limpopo belt: an historical perspective. In: Van Reenen, D.D. and Roering, C. (compilers),The Limpopo Belt: a Field Workshop on granulites and deep crustal tectonics. Dept. of Geol., Rand Afrikaans Univ.,1-4.

BEUKES, N.J., 1978. Die Karbonaatgesteentes en ysterformasies van die Ghaap-groep van die Transvaal Supergroup in Noord Kaapland. Unpubl. Ph.D. Thesis, Rand Afrikaans Univ.

BEUKES, N.J., 1980. Suggestions towards a classification of and nomenclature for iron-formations. Trans. geol. Soc. S. Afr., 83, 285-290.

BEUKES, N.J., 1983. Palaeoenvironmental setting of iron-formations in the depositional basin of the Transvaal Supergroup, South Africa. In: Trendall, A.F. and Morris, R.C. (Eds.). Iron formations: Facts and Problems. Elsevier, Amsterdam, 131-209.

BEUKES, N.J., 1984. Sedimentology of the Kuruman and Griquatown Iron-Formations, Transvaal Supergroup, Griqualand West, South Africa. Precambrian Research, 24, 47-84.

BEUKES, N.J., 1986. The Transvaal Sequence in Griqualand West. In: Anhaeusser, C.R. and Maske, S. (Eds), Mineral Deposits of Southern Africa, Geol. Soc. S. Afr., Johannesburg, 1, 819-828.

BEUKES, N.J., 1987. Facies relations, depositional environments and diagenesis in a major early Proterozoic stromatolitic carbonate platform to basinal sequence, Campbellrand Subgroup, Transvaal Supergroup, Southern Africa. Sed. Geol., 54, 1-46.

BEUKES, N.J. and SMIT, C.A., 1987. New evidence for thrust faulting in Griqualand West, South Africa: implications for stratigraphy and the age of red beds. S. Afr. J. Geol., 90, 378-394.

BUCK, S.G., 1980. Stromatolite and ooid deposits within the fluvial and lacustrine sediments of the Precambrian Ventersdorp Supergroup of South Africa. Precambrian Res., 12, 311-330.

BURGER, A.J. and COERTZE, F.J., 1975. Age determinations - April 1972 to March, 1974. Ann. Geol. Surv. S. Afr., 10, 135-141.

BURKE, K., DEWEY, J.F. and KIDD, W.S.F., 1976. Precambrian palaeomagnetic results compatible with contemporary operation of the Wilson cycle. Tectonophysics, 33, 287-299.

BURKE, K., KIDD, W.S.F. and KUSKY, T., 1985. Is the Ventersdorp rift system of Southern Africa related to a continental collision between Kaapvaal and Zimbabwe Cratons 2.64 b.y. ago? Tectonophysics, 115, 1-24.

BURKE, K., KIDD, W.S.F. and KUSKY, T.M., 1986. Archaean foreland basin tectonics in the Witwatersrand, South Africa. Tectonics, 5, 439-456.

BUTTON, A. , 1973(a). A regional study of the stratigraphy and development of the Transvaal Basin in the eastern and northeastern Transvaal. Johannesburg, Unpubl. Ph.D. Thesis, Univ. Witwatersrand.

BUTTON, A., 1973(b). The depositional history of the Wolkberg Proto-Basin, Transvaal. Trans. geol. Soc. S. Afr., 76, 15-25.

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

BUTTON, A., 1976. Transvaal and Hamersley Basins - review of basin development and mineral deposits. Minerals Sci. Engineering, 8, 262-293.

BUTTON, A., 1979. Early Proterozoic weathering profile on the 2200 m.y. old Hekpoort Basalt, Pretoria Group, South Africa: preliminary results. Econ. Geol. Research Unit, Univ. Witwatersrand, Inf. Circular 133.

BUTTON, A. 1986. The Transvaal Sub-Basin of the Transvaal Sequence. In: Anhaeusser, C.R. and Maske, S. (Eds.) Mineral deposits of Southern Africa, 1, Geol. Soc. S. Sfr., Johannesburg, 811-817.

BUTTON, A. and TYLER, N., 1981. The character and economic significance of Precambrian palaeoweathering and erosion surfaces in Southern Africa. Econ. Geol., 75th Anniv. Vol., 686-709.

BUTTON, A. and VOS, R.G., 1977. Subtidal and intertidal clastic and carbonate sedimentation in a macrotidal environment: an example from the Lower Proterozoic of South Africa. Sed. Geol., 18, 175-200.

CALLAGHAN, C.C., 1986. The Waterberg Basin: its evolution, sedimentation and mineralization. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 759-762.

CALLAGHAN, C.C., 1987. The Geology of the Waterberg Group in the southern part of the Waterberg Basin. Unpubl. M.Sc. Thesis, Univ. Pretoria.

CHENEY, E.S., ROERING, C. and STETTLER, E., 1988. Vaalbara. Geol. Soc. S. Afr., Geocongress Extended Abstracts., 85-88.

CHENEY, E.S., ROERING, C. and WINTER, H. de la R., 1990. The Archaean-Proterozoic boundary in the Kaapvaal Province of southern Africa. Precambrian Research, 46, 329-340.

CHENEY, E.S. and TWIST, D., 1986. The Waterberg 'basin' - a reappraisal. Trans. geol. Soc. S. Afr., 89, 353-360.

CHENEY, E.S. and TWIST, D., 1988. The conformable emplacement of the Bushveld mafic magmas along a regional unconformity; Inst. Geol. Research Bushveld Complex, Univ. Pretoria, Research Rpt. 78.

CHRISTIE-BLICK, N., GROTZINGER, J.P. and VAN DER BORCH, C.C., 1988. Sequence stratigraphy in Proterozoic successions. Geology, 16, 100-104.

CLAY, A.N., 1981. The geology of the Malmani Dolomite Subgroup in the Carletonville area, Transvaal. Unpubl. M.Sc. Thesis, Univ. Witwatersrand.

CLENDENIN, C.W., 1989. Tectonic influence on the evolution of the early Proterozoic Transvaal Sea, Southern Africa. Unpubl. Ph.D. Thesis, Univ. Witwatersrand.

CLENDENIN, C.W., CHARLESWORTH, E.G. and MASKE, S., 1988. An early Proterozoic three-stage rift system, Kaapvaal craton, South Africa. Tectonophysics, 145, 73-96.

CLENDENIN, C.W., HENRY, G. and CHARLESWORTH, E.G., 1989. Characteristics of and influences on the Black Reef quartzite stratigraphic package in the eastern Transvaal. Econ. Geol. Research Unit, Univ. Witwatersrand, Inf. Circular 214.

CLOETINGH, S., 1988. Intraplate stresses: a tectonic cause for third order cycles in apparent sea level? In: Wilgus, C.K. and Others (Eds.), Sea Level changes: an integrated approach. Soc. Econ. Miner. Pal., Spec. Pub. 42, 19-29.

CLUBLEY-ARMSTRONG, A.R., 1977. The geology of the Selonsrivier Area, north of Middelburg, Transvaal, with special reference to the structure of the region southeast of the Dennilton Dome. Unpubl. M.Sc. Thesis, Univ. Pretoria.

COERTZE, F.J., JANSEN, H., and WALRAVEN, F. 1977. The transition from the Transvaal sequence to the Waterberg Group. Trans. geol. Soc. S. Afr., 80, 145-156.

COERTZE, F.J., BURGER, A.J., WALRAVEN, F., MARLOW, A.G. and MACCASKIE, D.R., 1978. Field relations and age determinations in the Bushveld Complex. Trans. geol. Soc. S. Afr., 81, 1-11.

COETZEE, G.L., 1969. The Rooiberg felsite series north of Nylstroom. In: Visser, D.J.L. and Von Gruenewaldt, G. (Eds.), Symposium on the Bushveld Igneous Complex and other layered intrusions. Spec. Pub. geol. Soc. S. Afr., 1, 312-325.

CROCKETT, R.N., 1969. The geological significance of the margin of the Bushveld Basin in Botswana. Unpubl. Ph.D. Thesis, Univ. London.

CROCKETT, R.N., 1971. Some aspects of post-Transvaal system tectogenesis in southeastern Botswana with particular reference to the Lobatse and Ramotswa area. Trans. geol. Soc. S. Afr., 74, 211,235.

CROCKETT, R.N., 1972. The Transvaal System in Botswana: its geotectonic and depositional environment and special problems. Trans. geol. Soc. S. Afr., 75, 275-291.

CROCKETT, R.N. and KEY, R.M., 1989. Early Precambrian Basement uplift and block faulting along the western margin of the Bushveld Complex, southeastern Botswana: Commentary on paper by E.J.L. Dietworst. J. Afr. Earth Sci., 8, 127-129.

DeRITO, R.F., COZZARELLI, F.A., and HODGE, D.S., 1983. Mechanisms of subsidence of ancient cratonic rift basins. In: Morgan, P. and Baker, G.H. (Eds.), Processes of continental rifting, Tectonophysics, 94, 141-148.

de VILLIERS, P.R. and VISSER, J.H.J., 1977. The glacial beds of the Griqualand West Supergroup as revealed by four deep boreholes between Postmasburg and Sishen. Trans. geol. Soc. S. Afr., 80, 1-8.

de VILLIERS, S.B., 1967. Aanvoerrigtings van sedimente van die sisteme Loskop en Waterberg in Noord-Transvaal soos weerspieël deur kruisgelaagdheid. Ann. geol. Surv. S. Afr., 6, 63-67.

DIETWORST, E.J.L., 1988. Early Precambrian Basement uplift and block faulting along the western margin of the Bushveld Complex, southeastern Botswana. J. Afr. Earth Sciences, 7, 641,651.

du PLESSIS, A. and LEVITT, J.C., 1987. On the structure of the Rustenburg Layered Suite - insight from seismic reflection data. Abstr. Indaba on the Tectonic setting of layered intrusions, Pretoria, 14-15.

du PLESSIS, C.P., 1987. New perspectives on early Waterberg Group sedimentation from the Gatkop area, northeastern Transvaal. S. Afr. J. Geol., 90, 395-408.

du PLESSIS, M.D., 1972. The relationship between the Bushveld Complex and the Waterberg System in the area between Loubad and Warmbad. Ann. Geol. Surv. S. Afr., 9, 85-87.

ENGELBRECHT, J.P., 1986. Die Bosveld Kompleks en sy vloergesteentes in die omgewing van Nietverdiend, Wes-Transvaal. Unpubl. Ph.D. Thesis, Univ. Pretoria.

ERIKSSON, K.A., 1972. Cyclic sedimentation in the Malmani Dolomite, Potchefstroom Synclinorium. Trans.geol. Soc. S. Afr., 75, 85-97.

ERIKSSON, K.A., 1973. The Timeball Hill Formation - a fossil delta. J. Sediment. Petrol., 43, 1046-1053.

ERIKSSON, K.A. and TRUSWELL, J.F., 1974. Stratotypes from the Malmani Subgroup north-west of Johannesburg, South Africa. Trans. geol. Soc. S. Afr., 77, 211-222.

ERIKSSON, K.A., TRUSWELL, J.F. and BUTTON, A., 1976. Palaeoenvironmental and geochemical models from an early Proterozoic carbonate succession in South Africa. In: Walter, M.R. (Ed.) Stromatolites: Developments in Sedimentology, Elsevier, Amsterdam, 20, 635-643.

ERIKSSON, P.G., 1988. A palaeoenvironmental review of the Pretoria Group, Transvaal Sequence. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 187-190.

ERIKSSON, P.G., 1990. Rift-controlled sedimentation in the floor rocks of the Bushveld Complex. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 149-152.

ERIKSSON. P.G. and CLENDENIN, C.W., 1990. A review of the Transvaal sequence, South Africa. In: Hogte, C.A., Klitzsch, E. and Land, J. (Eds.) Grands Complexes Continentaux Phanerozoiques d'Afrique et dynamique de la sedimentation. J. Afr. Earth Sciences, 10, 101-116.

ERIKSSON, P.G., MEYER, R. and BOTHA, W.J., 1988. A hypothesis on the nature of the Pretoria Group Basin. S. Afr. J. Geol., 91, 490-497.

FAURIE, J.N., 1977. Uraan-lood-ouderdoms bepalings op granitiese gesteentes van die oostelike Bosveldkompleks. Unpubl. M.Sc. Thesis, Univ. Pretoria.

FOURIE, E.T., 1984. Die stratigrafie en sedimentologie van die Chuniespoort-Groep in noordwes-Transvaal. Unpubl. M.Sc. Thesis, Rand Afrikaans University.

GOODWIN, P.W, and ANDERSON, E.I., 1985. Punctuated aggradational cycles: a general hypothesis of episodic stratigraphic accumulation. J. Geology, 93, 515-533.

GROBLER, N.J. and BOTHA, B.J.V., 1976. Pillow lavas and hyaloclastite in the Ongeluk Andesite Formation in a road cutting west of Griquatown, S. Africa. Trans. geol. Soc. S. Afr., 79, 53-57.

GROBLER, J.N. and MEAKINS, A. 1988. Comparison between the Fortescue Group and the Ventersdorp Supergroup, Geol. Soc. S. Afr., Geocongress Extended Abstracts, 211-214.

HALL, A.L., 1932. The Bushveld Complex of the central Transvaal. Geol. Surv. S. Afr., Mem. 28.

HARZER, F.J., 1989. Stratigraphy, structure and tectonic evolution of the Crocodile River Fragment. S.Afr. J. Geol., 92, 110-124.

HATTON, C.J. , 1988. Formation of the Bushveld Complex at a plate margin. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 251-254.

HATTON, C.J. and SHARPE, M.R., 1990. Genesis of Bushveld magmas at an early Proterozoic plate margin. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 762-765.

HOUSEMAN, G. and ENGLAND, P. , 1986. A dynamic model of lithosphere extension and sedimentary basin formation. J. Geophys. Res., 91, 719-729.

HUNTER, D.R., 1973. Geochemistry of granitic and associated rocks in the Kaapvaal craton. Econ. Geol. Research Unit, Univ. Witwatersrand, Inf. Circular 81.

HUNTER, D.R., 1974. Crustal development in the Kaapvaal craton, II. The Proterozoic. Precambrian Research, 1, 295-326.

HUNTER, D. and HAMILTON, P.J., 1978. The Bushveld Complex. In: D.H. Tarling (Ed.), Evolution of the Earth's crust. Academic Press, London, 107-173.

JANSEN, H.,1969. The structural evolution of the southern part of the Waterberg Basin. Ann. Geol. Surv. S. Afr., 7, 57-62.

JANSEN, H.,1982. The geology of the Waterberg Basin in the Transvaal, Republic of South Africa. Mem. Geol. Surv. S. Afr., 71.

KEY, R.M., 1983. The geology of the area around Gaborone and Lobatse, Kweneng, Kgatleng, southern and southeast districts. Geol. Surv. Botswana, District Mem. 5.

KEY, R.M. and WRIGHT, E.P., 1982. The genesis of the Gaborone rapativi granite complex in southern Africa. J. Geol. Soc. London, 139, 109-126.

KLEYWEGT, R.J. and du PLESSIS, A., 1986. On the structure of the Bushveld Complex and the Central Transvaal Basin. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 603-607.

KLOP, A.A.C., 1978. The metamorphosed sediments of the Pretoria Group and the associated rocks northwest of Zeerust, Western Transvaal. Unpubl. M.Sc. Thesis, Univ. Pretoria.

KRÖNER, A., 1977. Precambrian mobile belts of southern and eastern Africa - ancient sutures or sites of ensialic mobility? A case for crustal evolution towards plate tectonics. Tectonophysics, 40, 101-135.

LIGHT, M.P.R., 1982. The Limpopo Mobile Belt: a result of continental collision. Tectonics, 1, 325,342.

MARTINI, J.E.J., 1979. A copper-bearing bed in the Pretoria Group in northeastern Transvaal. In: Anderson, A.M. and van Biljon, W.J. (Eds.), Spec. Publ. 6, Geol. Soc. S. Afr., 65-72.

MIALL, A.D., 1990. Principles of sedimentary basin analysis. 2nd ed. Springer-Verlag, New York.

MYERS, J.S., 1990. Precambrian tectonic evolution of part of Gondwana, southwestern Australia. Geology, 18, 537-540.

MYERS, R.E., 1986. Stratigraphy and depositional environments of the Godwan Group: Kaapsehoop area, eastern Transvaal. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 903-906.

McCARTHY, T.S., CHARLESWORTH, E.G., and STANISTREET, I.G., 1986. Post-Transvaal structural features of the northern portion of the Witwatersrand Basin. Trans. geol. Soc. S. Afr., 85, 189-201.

McCARTHY, T.S., STANISTREET, I.G. and ROBB, L.J., 1990. Geological studies related to the origin of the Witwatersrand Basin and its mineralization - an introduction and a strategy for research and exploration, S.Afr. J. Geol., 93, 1-4.

McKENZIE, D., 1978. Some remarks on the development of sedimentary basins. Earth Planet. Sci. Lett., 40, 25-32.

PHILLIPS, A.H., 1982. The geology of the Leeuwpoort tin deposit and selected aspects of its environs. Johannesburg, Unpubl. M.Sc. Thesis, Univ. Witwatersrand.

PIPER, J.D.A., 1976. Palaeomagnetic evidence for a Proterozoic supercontinent. Philos. Trans. R. Soc. London, Ser. A, 280, 469-490.

PIPER, J.D.A., 1982. The Precambrian palaeomagnetic record: the case for the Proterozoic supercontinent. Earth Planet. Sci. Lett., 59, 61-89.

POTGIETER, G., 1988. The structural evolution of the Transvaal rocks in the area between Potgietersrus and the Murchison range. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 465-467.

PRETORIUS, D.A., 1984. The Kalahari Foreland, its Marginal troughs and Overthrust Belts, and the regional Structure of Botswana. Econ. Geol. Research Unit, Univ. Witwatersrand, Inf. Circular 169.

QUINLAN, G. , 1987. Models of subsidence mechanisms in intracratonic basins, and their applicability to North American examples. In: Beaumont, C. and Tankard, A.J., (Eds.), Sedimentary basins and basin-forming mechanisms, Can.Soc. Petrol. Geologists., Mem. 12, 463-481.

QUINLAN, G.M. and BEAUMONT, C., 1984. Appalachian thrusting, lithosphere flexure, and the Paleozoic stratigraphy of the eastern interior of North America. Can. J. Earth Sci., 211, 973-996.

READING, H.G., 1980. Characteristics and recognition of strike-slip fault systems. Spec. Publ. Int. Ass. Sediment., 4, 7-26.

RHODES, R.C., 1972. Granite intrusive into Waterberg sediments at Loskop Dam, Transvaal. Ann. Geol. Surv. of S. Afr., 9, 95-96.

RHODES, R.C., 1972. Palaeocurrents in the Pretoria Group north of Marble Hall, Transvaal. Ann. Geol. Surv. S. Afr., 9, 119-122.

RHODES, R.C., 1974. Petrochemical characteristics of Bushveld Granite and Rooiberg Felsite. Trans. geol. Soc. S. Afr., 77, 93-98.

RICHARDS, R.J., 1987. A geological investigation of upper Transvaal sequence rocks in the northern portion of the Rooiberg Fragment. Unpubl. M.Sc. Thesis, Univ. Pretoria.

RICHARDS, R.J. and ERIKSSON, P.G., 1988. The sedimentology of the Pretoria Group in selected areas of the northern portion of the Rooiberg Fragment. S. Afr. J. Geol., 91, 498-508.

ROBB, L.J., DAVIS, D.W. and KAMO, S., 1989. U-Pb ages on single detrital zircon grains from the Witwatersrand Basin: constraints on the age of sedimentation and the evolution of granites adjacent to the depository. Econ. Geol. Research Unit, Univ. Witwatersrand, Inf. Circular 208.

SCHWEITZER, J.K., 1986. Field and geochemical investigations of the Dullstroom and Rooiberg Volcanic rocks. Geol. Soc. of S. Afr., Geocongress Extended Abstracts, 885-888.

SCHWEITZER, J.K., 1987. The transition from the Dullstroom Basalt Formation to the Rooiberg Felsite Group, Transvaal sequence: a volcanological, geochemical and petrogenetic investigation. Unpubl. Ph.D. Thesis, Univ. Pretoria.

SCHWELLNUS, J.S.I., ENGELBRECHT, L.N.J., COERTZE, F.J., RUSSELL, H.D., MALHERBE, S.J., VAN ROOYEN, D.P., and COOKE, R., 1962. The Geology of the Olifants River Area, Transvaal. Geol. Surv. S. Afr., Explan. Sheets 2429B (Chuniespoort) and 2430A (Wolkberg).

SHARPE, M.R., BRITS, R., and ENGELBRECHT, J.P., 1983. Rare earth and trace element evidence pertaining to the petrogenesis of 2.3 Ga old continental andesites and other volcanic rocks from the Transvaal sequence, South Africa. Inst. geol. Res. Bushveld Complex, Univ. Pretoria, Research Rept. 40.

SHARPE, M.R. and CHADWICK, B., 1982. Structures in Transvaal sequence rocks within and adjacent to the eastern Bushveld Complex. Trans. geol. Soc. S. Afr., 85, 29-41.

SMIT, P.J., 1961. Interpretation of gravity anomalies in the gravity survey of the Republic of South Africa (Part 3). Open File Rpt., Geol. Surv. S. Afr., 330.

SOUTH AFRICAN COMMITTEE FOR STRATIGRAPHY (SACS), 1980. Stratigraphy of South Africa, Part 1, comp. L.E. Kent: Lithostratigraphy of the Republic of South Africa, Southwest Africa/Namibia, and the Republics of Bophuthatswana, Transkei and Venda. Handbook Geol. Surv. S. Afr., 8.

STEAR, W.M., 1977. The stratigraphy and sedimentation of the Pretoria Group at Rooiberg, Transvaal. Trans. geol. Soc. S. Afr., 80, 53-65.

STRAUSS, C.A., 1964. The iron ore deposits in the Sishen area, Cape Province. In: Haughton, S.H. (Ed.) The Geology of some ore deposits in Southern Africa, 11, Geol. Soc. S. Afr., Johannesburg, 393-403.

TANKARD, A.J., JACKSON, M.P.A., ERIKSSON, K.A., HOBDAY, D.K., HUNTER, D.R., and MINTER, W.E.L., 1982. Crustal evolution of Southern Africa: 3.8 billion years of earth history. Springer Verlag, New York.

TRUSWELL, J.F., 1990. Early Proterozoic red beds on the Kaapvaal craton. Econ. Geol. Research Unit, Univ. Witwatersrand, Inf. Circular 223.

TRUTER, F.C., 1949. A review of volcanism in the geological history of South Africa. Proc. geol. Soc. S. Afr., 52, xxix-lxxxix.

TWIST, D., 1985. Geochemical evolution of the Rooiberg silicic lavas in the Loskop Dam area, southeastern Bushveld. Econ. Geol., 80, 1153-1165.

TWIST, D. and CHENEY, E.S., 1986. Evidence for the transition to an oxygen-rich atmosphere in the Rooiberg group, South Africa: a note. Precambrian Res., 33, 255-264.

TWIST, D. and FRENCH, B.M., 1983. Voluminous acid volcanism in the Bushveld Complex: a review of the Rooiberg Felsite. Bull. Volcanol., 46, 225-242.

TWIST, D., HARMER , R.E., and FARROW, D., 1986. Petrogenesis of the Rooiberg silicic lavas, Bushveld Complex. Geol. Soc. S. Afr., Geocongress Extended Abstracts, 885-888.

TYLER, N., 1979. The stratigraphy of the Early-Proterozoic Buffalo Springs Group in the Thabazimbi area, west-central Transvaal. Trans. geol. Soc. S. Afr., 82, 215-226.

TYLER, R., 1989. Cyclic sedimentation and gold mineralization in the Malmani Dolomite Subgroup, Pilgrims Rest - Sabie area, eastern Transvaal. Unpubl. M.Sc. Thesis, Univ. Witwatersrand.

VAN REENEN, D.D., BARTON, J.M., ROERING, C., SMITH, C.A. and VAN SCHALKWYK, J.F., 1987. Deep crustal response to continental collision: the Limpopo Belt of southern Africa. Geology, 15, 11-14.

VAN REENEN, D.D. and ROERING, C. (Compilers), 1990. the Limpopo Belt: a Field Workshop on granulites and deep crustal tectonics. Dept. of Geology, Rand Afrikaans Univ.

VISSER, H.N. and VERWOERD, W.J., 1960. The geology of the country north of Nelspruit. Geol. Surv. S. Afr., Explan. Sheet 22.

VISSER, J.N.J., 1970. The Transvaal basin - a new sedimentary model? Ann. Geol. Surv. S. Afr., 8, 75-86.

VISSER, J.N.J., 1971. The deposition of the Griquatown glacial member in the Transvaal Supergroup. Trans. geol. Soc. S. Afr., 74, 187-199.

WALRAVEN, R., 1987. Textural, geochemical and genetical aspects of the granophyric rocks of the Bushveld Complex. Mem. Geol. Surv. S. Afr., 72.

WALRAVEN, F. , 1988. Notes on the age and genetic relationships of the Makhutso Granite, Bushveld Complex, South Africa. Chem. Geol. (Isot. Geosc. Sect.), 72, 17-28.

WALRAVEN, F., ARMSTRONG, R.A. and KRUGER, F.J., 1990. A chronostratigraphic framework for the north-central Kaapvaal craton, Bushveld Complex and Vredefort Structure: a review. Tectonophysics, 171.

WEILERS, B.F., 1990. A review of the Pongola Supergroup and its setting on the Kaapvaal craton. Econ. Geol. Research Unit, Univ. Witwatersrand, Inf. Circular 228.

WILSON, J.L., 1975. Carbonate facies in geologic history. New York, Springer-Verlag.

WINTER, H. de la R. , 1965. The stratigraphy of the Ventersdorp System in the Bothaville District and adjoining areas. Unpubl. Ph. D. Thesis, Univ. Witwatersrand.

WINTER, H. de la R., 1987. A cratonic foreland model for Witwatersrand Basin development in a continental back-arc, plate-tectonic setting. S. Afr. J. Geol., 90, 409-427.