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**CHANGING TECTONO-SEDIMENTARY
SCENARIOS RELEVANT TO THE
DEVELOPMENT OF THE
LATE ARCHAEOAN
WITWATERSRAND BASIN**

I.G. STANISTREET and T.S. McCARTHY

UNIVERSITY OF THE WITWATERSRAND
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BASIN

by

I.G. STANISTREET and T.S. MCCARTHY

*(Economic Geology Research Unit, Department of Geology,
University of the Witwatersrand, P.O. WITS 2050,
Johannesburg, South Africa)*

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ABSTRACT

Recent studies of the Witwatersrand Basin indicate that contrary to earlier proposals the shape and size of the basin and style of sedimentation were very different early and late in basin history. This reflects a geotectonic evolution which may involve an overall Wilson Cycle. Progressive stages prior to, during and after basin development are described in order to map this evolution. Stage 1 saw the structural framework of the Kaapvaal Craton which was to accommodate future basin development. Fault zones representing lineaments and sutures associated with the structural evolution of various greenstone belts of the Kaapvaal Craton were rejuvenated (especially during late stages of Witwatersrand Supergroup deposition) to act as primary synsedimentary fault zones. Stage 2 involved the development of the Dominion Basin which has been interpreted as an extensional basin associated with NNE-trending faults, although volcanic rocks show calc-alkaline affinities. Stage 3 saw widespread deposition over the Kaapvaal Craton of a variety of subtidal sediments of the West Rand Group and its correlatives, including the Pongola Sequence. This epicontinental style of sedimentation was either associated with a thermal cooling phase related to the Dominion Group extension or with the initiation of a foreland basin. The conformable or disconformable relationship between the West Rand Group and the underlying Dominion Group would point to the former. During Stage 4 major changes in sedimentary patterns occurred. Upper Central Rand Group sediments were deposited and draped over compressive basement block-faults, which interacted with the sedimentation, causing reverse faults/monoclines and locally provided sources for coarse gravel. The basin was shrinking considerably in size and fluvial sediments derived from developing pediment areas and uplifted basement interacted with a reduced marine water body. The basin was controlled by NE-SW directed compression which caused a relative tectonic escape of the central part of the Kaapvaal Craton to the southeast. The reason for these changes was the initial orogenesis associated with the subduction history preceding, and the ultimate A-subduction history during, the collision of the Zimbabwe Craton with the Kaapvaal Craton. Stage 5 saw the outpouring of the Klipriviersberg Group flood basalts into the Witwatersrand Basin. Early in this stage the tectonism was similar to that for Stage 4, but late in the extrusive history a change in feeder dyke patterns probably heralded the major extensional tectonics developed during Stage 6, involving the deposition of the Platberg Group. The latter developed in an extensional rift basin caused by the tectonic inversion of faults from their previous reverse state to a normal movement. This has been interpreted as the result of impactogenical rifting. In the aftermath the collapse of the orogen allowed the deposition of the Pniel Sequence and the Wolkberg Group in extensional rift basins and the associated thermal cooling led to the development of the Chuniespoort Group chemical sedimentation. At no time did the Vredefort Dome affect this sedimentary history; in fact this was a post-Bushveld event which was followed by the emplacement of the Johannesburg Dome. The Vredefort Dome did, however, have a major structural impact on the Witwatersrand Basin and may have played a definitive role in its long term preservation up to the present day.

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Basin

INTRODUCTION

The Witwatersrand Basin has been the subject of scientific investigation for more than a century and ideas on its origins have evolved considerably, as documented by Pretorius (1979). In recent years, several models have been erected, however, attempting to explain the sedimentation and related tectonics of the Witwatersrand Basin, and these have resulted in considerable scientific controversy. To some extent the reasons for these controversies may be laid at the door of the many changes which the Witwatersrand Basin itself experienced during its history. It is evident that no single model is adequate to explain all the geological features. It is the purpose of this paper to review these secular changes and so chart basin evolution.

Early basin models emphasized the intracratonic nature of the sedimentation (Pretorius, 1976, 1986, Tankard *et al.*, 1982). However, recent studies showed that even continental interiors over 1000km from a plate margin can be severely deformed by tectonism associated with an adjacent plate margin (e.g. Tapponier *et al.*, 1982). The recognition of the synchronicity of Witwatersrand Basin development and associated basins with adjacent (400km distant Fig.1) Precambrian orogenic activity in the Limpopo Belt (Burke *et al.*, 1985, 1986, Stanistreet *et al.*, 1986) (Fig.1) has therefore led to a re-evaluation of the way basin development and sedimentation responded to its tectonic controls.

In viewing the geology of the "Golden Triad" made up of the Dominion Group; Witwatersrand Supergroup (comprising the West Rand and Central Rand Groups), and the Ventersdorp Supergroup (Fig.2), stages in basin development are recognized from early rifting with bimodal volcanism of the Dominion Group (Bickle and Eriksson, 1982, Tankard *et al.*, 1982) to the late collisional impactogenel rifting of the Platberg Group of the Ventersdorp Supergroup (Burke *et al.*, 1985). It is possible therefore that the development of the Golden Triad experienced the effects of a Wilson Cycle, i.e. rifting, spreading, convergence, and collision of the Kaapvaal Craton with respect to other Precambrian micro-continents. We cannot, however, be sure that the same margin of the craton was involved during the extensional and convergent stages. The following sections track the stages which have thus far been recognized within this spectrum of events. This paper is not so much a review as an extension to results from a research programme undertaken by the Department of Geology of the University of the Witwatersrand and co-workers and published as a Special Issue of the South African Journal of Geology (Vol. 93 No. 1, 1990). For a review of ideas on the Witwatersrand Basin prior to this volume the reader is directed to the work of Pretorius, particularly Pretorius (1979) and Anhaeusser and Maske (1986).

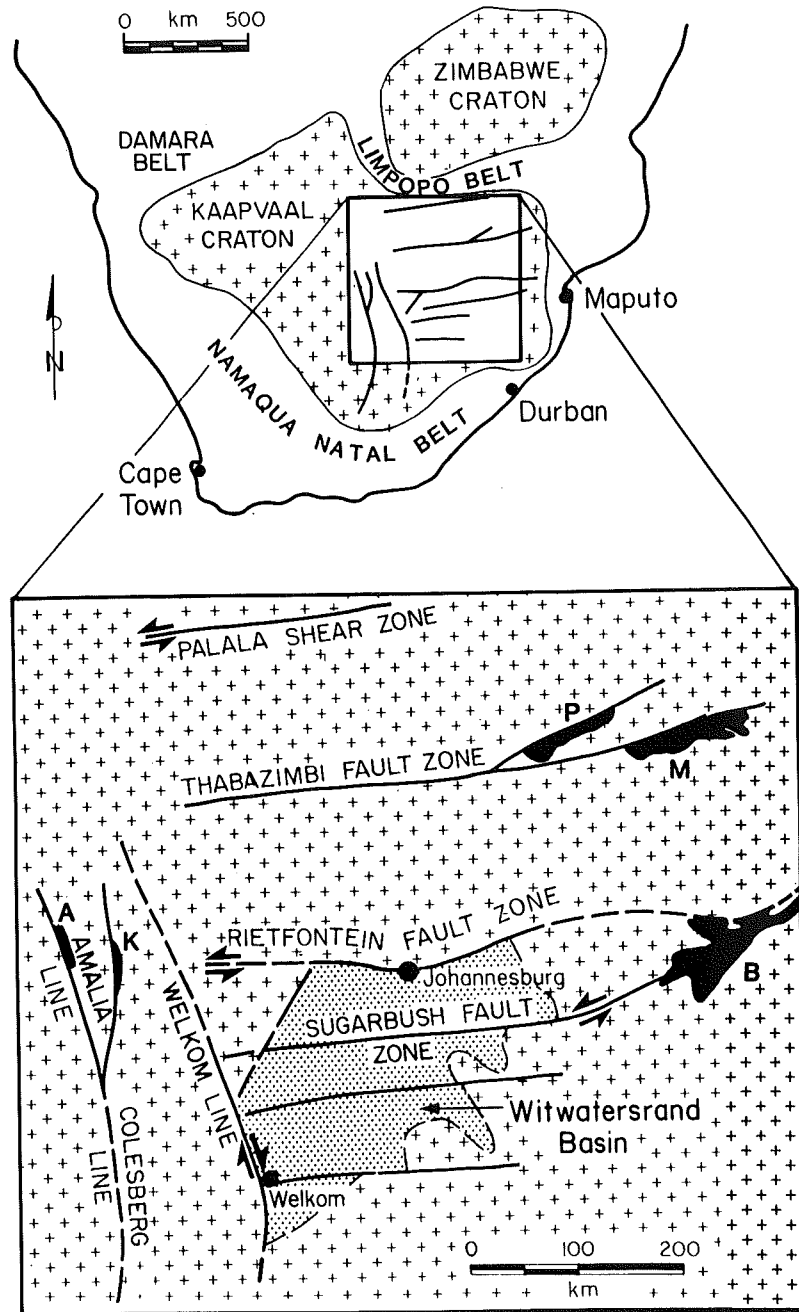


Figure 1: The location of the Witwatersrand Basin and associated syn-sedimentary fault zones with respect to the then contemporary Limpopo Orogenic Belt. Black areas indicate greenstone belts: B = Barberton; M = Murchison; P = Pietersburg; K = Kraaipan; A = Amalia.

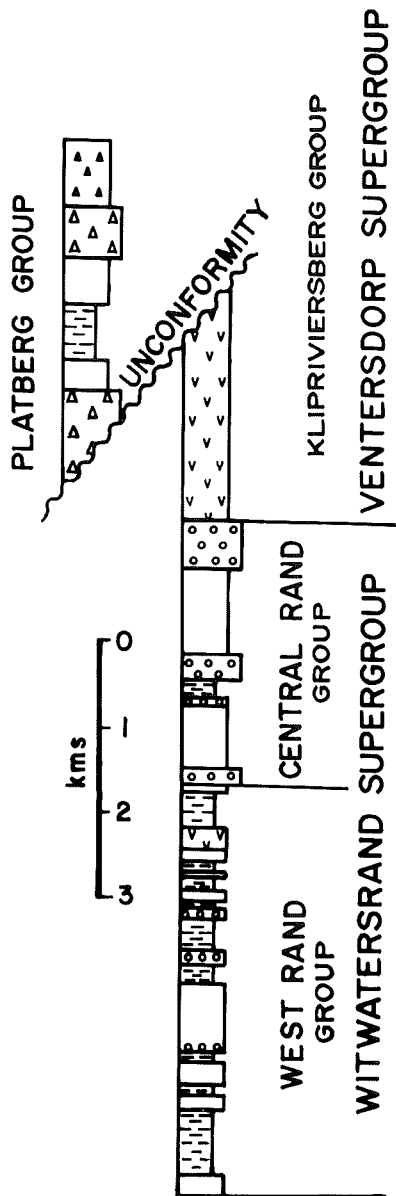


Figure 2: Stratigraphy of the Witwatersrand and Ventersdorp Supergroups

STAGE 1 : THE STRUCTURAL FRAMEWORK

As with most of the supracrustal Precambrian basins of southern Africa (e.g. Stanistreet *et al.*, 1991) the fault zone framework which accommodated the Witwatersrand and associated basins was "pre-programmed" within the pre-3,100Ma basement rocks. In particular, the greenstone belts and their associated lineaments define fundamental ancient suture zones (Fig. 1 inset), representing planes of weakness, which were reactivated during Witwatersrand Basin development (Stanistreet *et al.*, 1986) as well as during the development of many subsequent basins (e.g. McCarthy, *et al.*, 1990c, Stanistreet and McCarthy, 1990, Myers, J. *et al.*, 1990). Two sets of these lineaments are evident, one trending ENE (exemplified by the Pietersburg, Murchison and Barberton greenstone belts) and the other trending NNW (exemplified by the Kraaipan and Amalia Greenstone Belts).

Figure 1 shows the structural framework on top of which the Witwatersrand Basin formed. This later gave rise to syn-sedimentary fault zones which have lateral equivalents in the greenstone-related lineaments (e.g. Stanistreet *et al.*, 1986) and played a major role in the evolution of basins which followed. These included both the Witwatersrand and post-Witwatersrand Basins (e.g. McCarthy, *et al.*, 1990c, Stanistreet and McCarthy, 1990, Clendenin *et al.*, 1988b; Du Plessis, 1987).

STAGE 2: THE DOMINION BASIN

The Dominion Basin is a structural remnant of a larger basin dated at 3074 Ma (Armstrong *et al.*, 1990) and was filled with a bimodal volcanic suite and lesser fluvial sediments. This is consistent with the style of an extensional, failed, rift basin (Bickle and Eriksson, 1982, Tankard *et al.*, 1982). Clendenin *et al.* (1990) suggested that the NNE-trending Platberg Fault was initiated as an extensional fault during the development of the Dominion Basin. This parallels other faults which control the preservation of the Dominion Group, such as a fault margin exposed on the northern edge of the Vredefort Dome. The status of the Dominion Group is, however, far from certain, as the volcanic rocks are calc-alkaline in character (for a discussion see Crow and Condie, 1987) and closely resemble Andean arc-type rocks (Burke *et al.*, 1986).

It is important to note that the Dominion Group sequence is only preserved where it is overlain with at least apparent conformity or disconformity by West Rand Group rocks. This indicates that it was covered by the geographically more extensive West Rand Group prior to its deformation during the subsequent development of the Witwatersrand and Lichtenburg (Platberg Group) Basins.

STAGE 3: WEST RAND GROUP SEDIMENTATION

Button (1977) was followed by Stanistreet *et al.* (1986) in suggesting that the Godwan Group represented a lateral correlative of the Witwatersrand Basin. U/Pb dating of zircons from the volcanics of the Nsuze Group of the Pongola Sequence yielded dates of 2940 ± 22 Ma (Hegner *et al.*, 1984). This places the Nsuze succession within the presently defined age range for the West Rand Group (Armstrong *et al.*, 1990). The cyclic facies style of the overlying Mozaan Group of the Pongola Sequence is similar to that of the upper portion of the West Rand Group. A geomagnetic analysis of the Witwatersrand Basin (Corner *et al.*, 1986) recognizes outliers of West Rand Group rocks not only far to the north of the presently perceived Basin, but also eastwards to northern Natal. There is thus little doubt that the Pongola Sequence is also correlative with the Witwatersrand Supergroup. Figure 3 shows these West Rand Group suboutcrops and their correlatives plotted on a map and indicates that the West Rand Group overlying the Dominion Group represented a large-scale epicontinental cover sequence (albeit on a micro-continent). Widespread quartz-rich sand bodies contained within the sequence are analogous with other extensive storm or tidally dominateds and sheets which developed on platforms at various times throughout the Precambrian, particularly well recognized in the Late Proterozoic (e.g. Johnson and Baldwin, 1982).

Eriksson *et al.* (1981) proposed shoreline, shoreface, and subtidal settings for the Hospital Hill Subgroup of the West Rand Group under the influence of tidal ranges varying from meso- to macro-tidal. Coarsening-

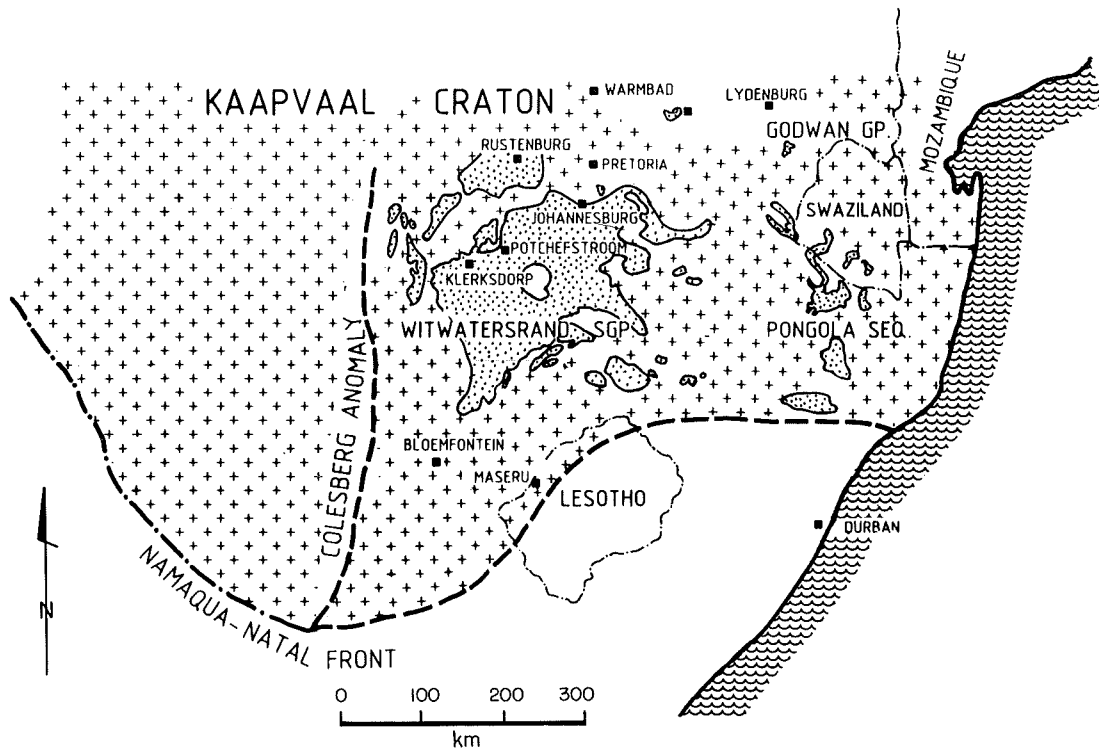


Figure 3: Preserved extent of West Rand Group rocks and their correlatives.

upward progradational cycles are parasequences (terminology of Van Wagoner *et al.*, 1988) similar to those developed in the Orange Grove Quartzite at the base of the Hospital Hill Subgroup (Fig. 4). This is in contrast with the measured section of Eriksson *et al.* (1981). The paucity of true shoreline sediments in the Hospital Hill Subgroup suggests that these tidally dominated subtidal sands are analogous with those developed at the present day within the North Sea Basin (Kenyon and Stride, 1970). In the latter, the passage of the tidal maximum in an anti-clockwise direction around the basin creates shore-parallel tidal currents which develop supermature blanket sands in lesser shelf depths and allows the deposition of fine-grained sediments in the basin centre.

Cycles in the Witwatersrand Supergroup were recognized long ago by Sharpe (1949). Now they may be differentiated. The asymmetric progradational parasequences tens of metres thick represent responses to minor eustatic fluctuations of sea level which also produce parasequences in a similar manner in Phanerozoic shelf sequences (e.g. Vail *et al.*, 1984). The larger symmetric cycles hundreds of metres thick, e.g. causing facies sequence repeats such as the Brixton Formation following the Orange Grove Quartzite Formation, are possibly also related to eustatic sea level changes of a much lower frequency. At times of transgressive maxima during these lower frequency cycles (Fig. 4) parasequences incorporated pelagic deposits at their base, represented by the accumulation of iron oxide precipitates to form ironstones or banded iron formations (Eriksson *et al.*,

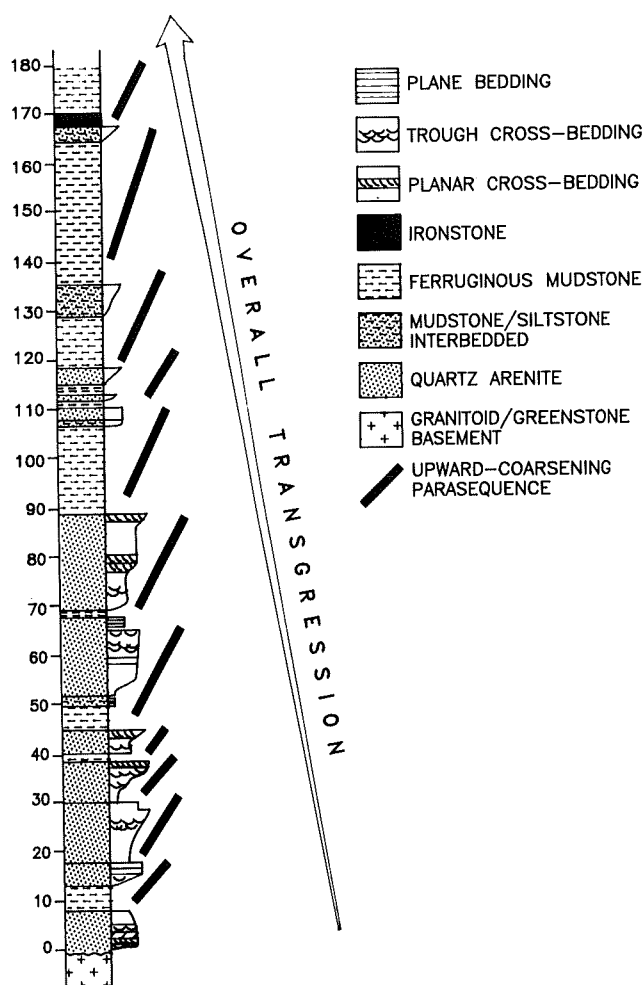


Figure 4: Measured section through the Orange Grove Quartzite exposed in a road cutting on the Krugersdorp/Pretoria highway, 5km northwest of Krugersdorp.

1981, Eriksson, 1982) such as the Water Tower Slate (Fig.4) and Contorted Bed. These represent the Precambrian equivalent of Phanerozoic marine condensed sequences (e.g. Van Wagoner et al., 1988). Only one volcanic event occurred during the deposition of the West Rand Group. The Crown Lava is a laterally extensive dacite unit (Myers, R.E. 1991) extruded during the deposition of the Jeppeshtown Subgroup shales.

Two models have been proposed for the spreading over the Kaapvaal Craton of the sea which incorporated the West Rand Group. Burke et al. (1986) suggested that the transgression was associated with the development of a foreland basin during the initial phases of the Limpopo Orogeny, while Clendenin et al. (1988) suggested that thermal subsidence following the extension of the Dominion Basin caused this transgression. The former model would make the basin analogous perhaps with the Jurassic Cretaceous

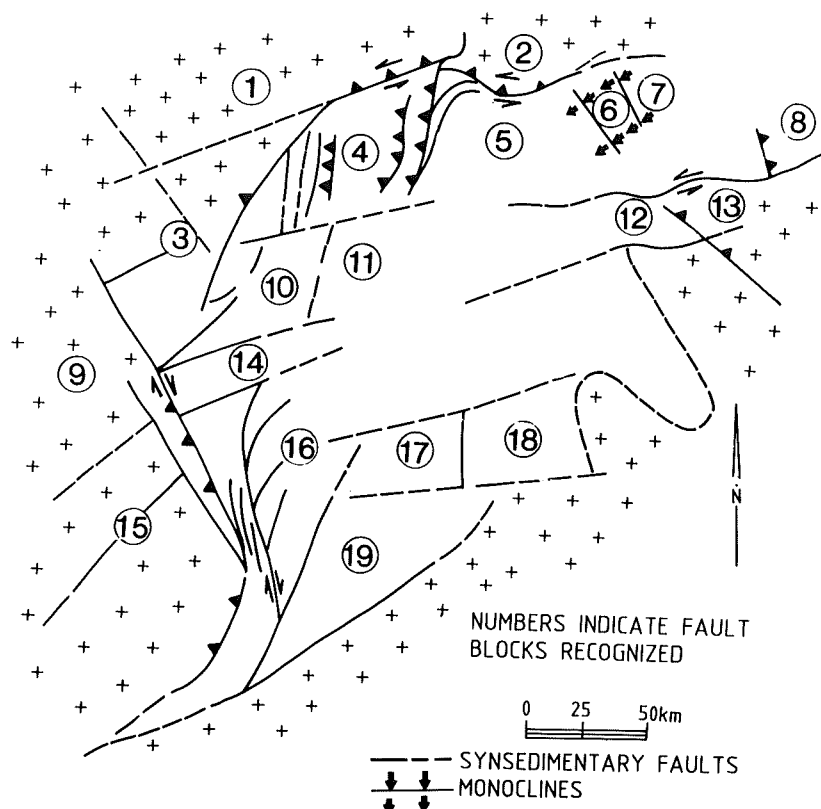
seaway of the western U.S.A (e.g. Spearing, 1975), while the latter model would make it analogous with failed rift basins during their thermal cooling phase such as the North Sea Basin (e.g. Sclater and Christie, 1980). The fact mentioned earlier that the Dominion Group, where preserved, is always mapped immediately beneath the Orange Grove Quartzite with apparent conformity (and particularly well displayed around the collar of the Vredefort Dome) suggests that the Hospital Hill Subgroup has close affinities with the Dominion Group in terms of basin development and it may well have been initiated by a transgression associated with thermal subsidence.

A comparison of the West Rand Group characteristics with those of the Central Rand Group described in the following section show that both the style of sedimentation and basin size for these two groups are considerably different. Consequently attempts to place both groups into a single mode of basin development are incorrect.

STAGE 4 : CENTRAL RAND GROUP SEDIMENTATION; THE DEVELOPMENT OF THE WITWATERSRAND BASIN (*sensu stricto*)

The later stages of the deposition of the Witwatersrand Supergroup reflect major changes in the style, size, and shape of the depository. Pretorius (1976) recognized that the basin shrank at this stage; Pretorius (1986) also realized that this end-phase basin was triangular in shape. Brock and Pretorius (1964) first recognized the importance of syn-sedimentary faults bounding the Central Rand Group basins. These structures were further investigated by Stanistreet and McCarthy (1986) and Stanistreet *et al.* (1986) who recognized the strike-slip character of the synsedimentary fault zones (Rietfontein, Ireton, Sugarbush, and Border) and the manner in which they control sedimentation within the basin throughout the deposition of the entire Central Rand Group (Myers, R. *et al.*, 1990a). Using changes in stratigraphic thickness and facies adjacent to the boundary faults, Myers, R. *et al.* (1990a) were able to demonstrate that movement of basement fault-blocks affected sedimentation and were a major feature (Fig. 5) throughout the evolution of the Central Rand Group.

It is not known how early in the basin history basement block-faulting became a major feature, but they were operating by at least the start of Central Rand Group sedimentation. Stanistreet *et al.*, (1988) traced the style of major cycles developed within the Central Rand Group back to the base of the Government Subgroup (Fig. 6). The Government and Jeppestown Subgroups may therefore be visualized as transitional between the epicontinental style of sedimentation typified by the Hospital Hill Subgroup and the restricted, localized, fault-controlled sedimentation which became dominant in the later phases of basin development particularly during the deposition of the Turffontein Subgroup. In the exposed northern portion of the Basin, major transport directions during this transitional phase were to the south initially (e.g. Tainton and Meyer; 1990 Promise Formation) 1990) and later swung towards the southeast. This swing is detected initially in the NW-SE trending bimodal bipolar palaeocurrent pattern in the southern outcrop of the Florida Formation of the Jeppestown Subgroup (Watchorn, 1981), which heralds the unimodal SE directed fluvial palaeocurrents of the lowermost Johannesburg Subgroup.



- | | |
|-----------------------|---------------------|
| 2 HALFWAY HOUSE BLOCK | 8 EVANDER BLOCK |
| 4 CARLETONVILLE BLOCK | 10 KLERKSDORP BLOCK |
| 5 MEYERTON BLOCK | 11 PARYS BLOCK |
| 6 EAST RAND BLOCK | 16 WELKOM BLOCK |

Figure 5: Structural fault zones or lineaments which are thought to have affected Witwatersrand sedimentation. They define the edges of basement fault blocks. Named blocks are indicated.

Figure 6 shows that the major cycles in the Central Rand Group sequence and below may be characterized as overall fining-upward sequences over 1000m thick, which tended to develop conglomeratic (reefs) and associated diamictites early in their history (Martin *et al.*, 1988, 1989, Stanistreet *et al.*, 1988) and a predominance of shales and/or basic lavas late in their history. Within these cycles medium-scale, conglomerate-based, fining-upward cycles hundreds of metres thick are developed e.g. the Promise Quartzite and Coronation Shale from the lower cycle (Tainton and Meyer 1990); the Main Conglomerate and Langlaagte Quartzite from the middle cycle (Beneke, in prep); and the Kimberley Conglomerate and half the overlying Elsburg Quartzite (Holland *et al.*, 1990). These medium-scale cycles, when developed in full and not truncated at the top, comprise

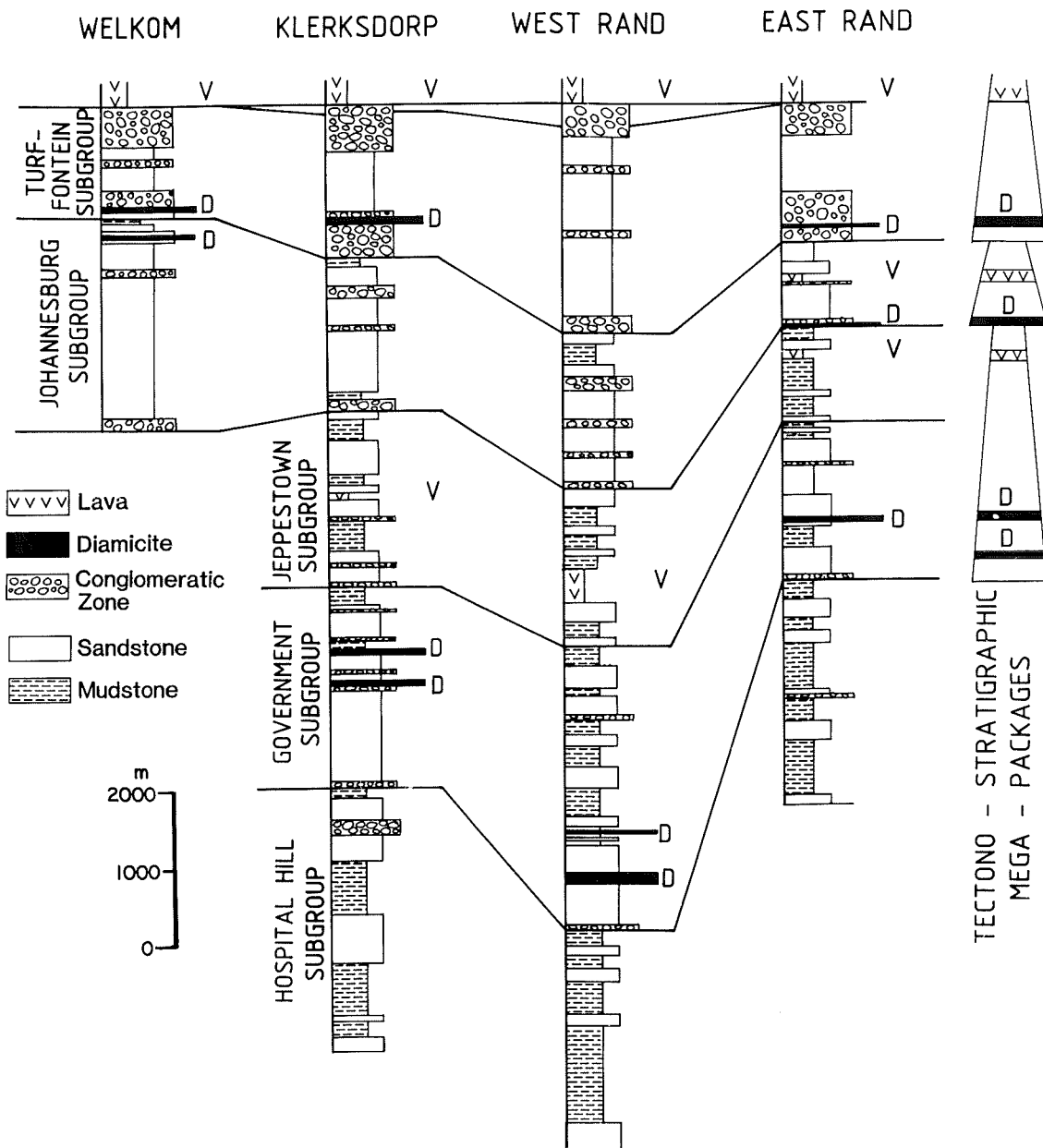


Figure 6: Major fining-upward cycles in the Witwatersrand Supergroup. They have conglomerates with associated mud flow diamictites towards the base. Shales and/or lavas tend to develop towards the top (measured sections are modified from Tankard *et al.*, 1982).

erosively based fluvially dominated sequences overlain by transgressive marine quartz arenites and finally a mudstone unit. Within these are small scale erosively-based cycles starting with individual conglomerate units. Close to synsedimentary faults and folds even these small-scale cycles may lie on unconformities which erode deeply into the footwall sequence.

Previous sedimentary models have emphasized the development of alluvial and fluvial fan sedimentation during the deposition of the Central Rand Group (e.g. Pretorius, 1976, Tankard *et al.*, 1982) although a bajada model was proposed as an alternative by Vos (1975). The uppermost conglomerate reef developed during basin evolution, the Venterspost Placer (V.C.R.), becomes more conformable towards thicker sequences of the basin centre in a manner similar to lower reefs. Proximally, this conglomerate lies on an extremely erosive unconformity (Krapez, 1980). Turner (1979) proposed a pediment surface for this sub-V.C.R. unconformity. This and the V.C.R. were preserved by the later extrusion of the Klipriviersberg flood basalts. It is reasonable to assume that earlier conglomerates also had proximal pediments associated with them, in a fashion described for the Composite Reefs of the West Rand by Tucker and Viljoen (1986). Earlier pediments did not, however, have the advantage of later volcanic extrusions to preserve them and would have been preferentially eroded to form younger pediments. Recent work by Holland (1990) indicated that, within the centre of the Witwatersrand Basin, conglomerate-based fluvial sequences even as young as the Kimberley Formation interacted with tidal marine processes. These aspects are synthesized (Fig. 7) in a block diagram across a typical faulted basin margin late in the Basin's history. The erosion surface in the upfaulted hinterland passes downslope into a fluvial bajada which interacted towards the Basin centre with a marine waterbody.

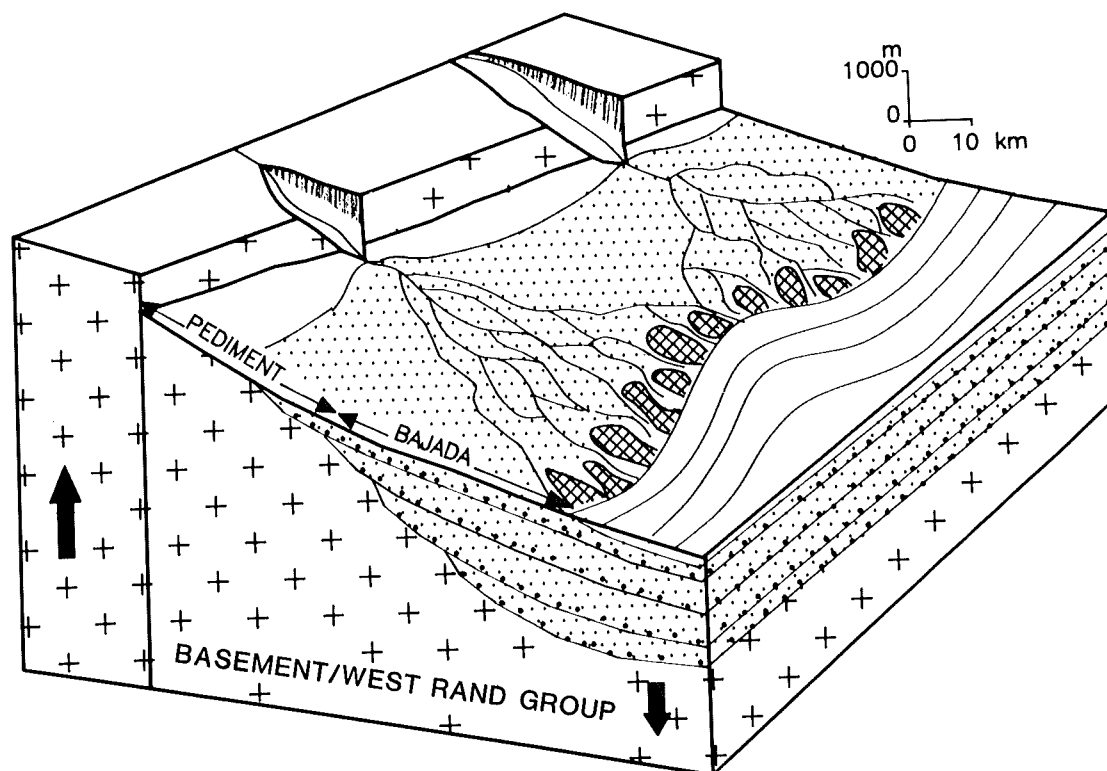


Figure 7: Relationship between sedimentary palaeoenvironments and fault zones defining the basin margin late in Central Rand Group sedimentation. The scale is approximate.

The stratigraphic correlation programme, undertaken by the Sedimentology Division of the Geological Society of South Africa in 1984 from Evander around the margin of the Witwatersrand Basin to Welkom (reported by Camden-Smith *et al.*, 1986) concluded that the thicker, reef-based, unconformity-bound packages could be correlated all the way around the basin margin. Holland *et al.* (1990) have shown that sedimentary packages in the Turffontein Subgroup at the Basin centre around Vredefort can also be correlated with this profile. This implies that at the closing stages the Basin palaeogeography would have looked like the map indicated in Figure 8 as superimposed on top of the structural reconstruction of Myers, *et al.* (1990a) as shown in Figure 5.

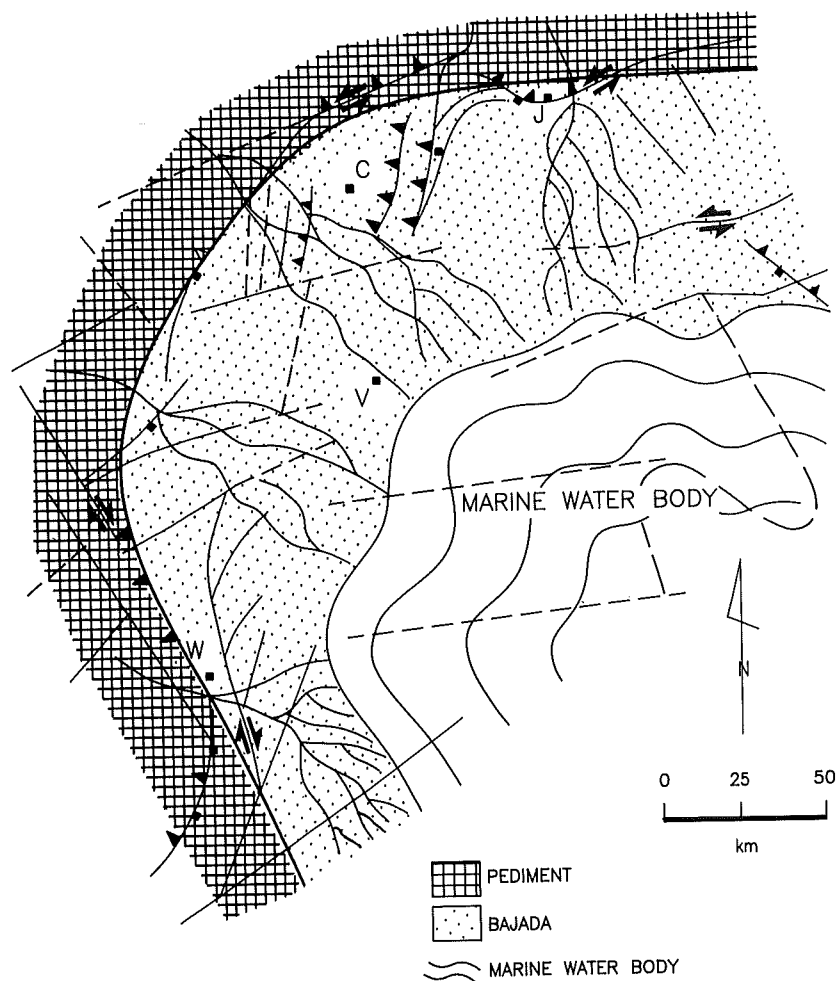


Figure 8: Schematic palaeogeographic map of the Witwatersrand Basin close to the end of sedimentation.

Turning in more detail to the structural disruption of the basement during deposition of the Central Rand Group, syn-sedimentary faults and various fault-blocks are individually identified in Figure 5 with some already named from Myers, R. *et al.* (1990b). These blocks developed under a compressive regime with principal stresses directed from the NE and SW. This can be determined from two perspectives: (1) syn-sedimentary folds developed orthogonally to this compression direction trending in a north-westerly orientation (e.g. Antrobus and Whiteside, 1964); and (2) faults trending sub-parallel to E-W had a left-lateral oblique-slip component where this can be determined (e.g. Stanistreet *et al.*, 1986; Booth, 1985; Vermaak, 1986; Myers, J. *et al.*, 1987) and syn-sedimentary faults trending sub-parallel to N-S apparently had a right-lateral oblique-slip component (e.g. Myers, R., 1985; Stanistreet *et al.*, 1986; Stanistreet and McCarthy, 1990; right-lateral offset of green bar channel shown in Engelbrecht *et al.*, 1986 - their Fig.4). If the components of movement on these faults are taken together, the overall effect was that the area of the Witwatersrand Basin was in the process of being "squeezed out" of the Kaapvaal Craton towards the southeast (Fig 9) (Stanistreet, 1990). Other fault systems external to the Basin also probably acted in a complementary fashion. The Palala Shear Zone acted in a left-lateral sense during the Limpopo Orogeny (McCourt and Vearncombe, 1987, Van Reenen *et al.*, 1987) and the Thabazimbi-Murchison Lineament would also probably have acted in a similar fashion. The northerly striking faults also had their probable counterparts to the west of the Basin. Fault zones associated with the Amalia and Kraaipan Lineaments (Fig.1) may have acted with a right-lateral component. The implied reverse oblique-slip movement could explain the Colesberg anomaly, which is regarded as a deep crustal feature (Corner *et al.*, 1986) and has been related to upthrow of lower levels of the crust in this region (Corner *et al.*, 1986; Drennan *et al.*, 1990).

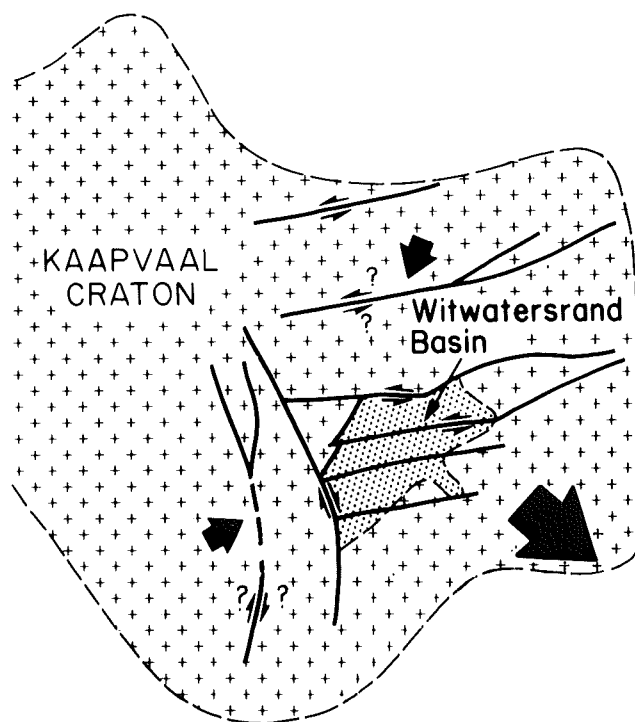


Figure 9 : Map showing the relative movement outward from the Kaapvaal Craton during syn-Witwatersrand compression.

Such a "tectonic escape" of continental crust from continental interiors occurs during continental collision. Molnar and Tapponier (1975) were the first to identify this process associated with the modern collision of the Indian sub-continent with the Eurasian Plate. There the Tibetan Plateau is escaping eastwards. A similar effect has been proposed by McKenzie (1978) involving the tectonic escape westwards of a major proportion of Turkey and the Aegean area into the Mediterranean remnant ocean basin. An interesting feature of the latter is the intrusion of tholeiites into the oceanward area of this plate associated with a 50% extension of the attenuated continental crust (Burke and Sengör, 1986). In these two areas, however, there is no basin developing which is directly comparable with the Witwatersrand Basin. In Venezuela and Columbia, however, Burke and Sengör (1986) have ascribed the Cainozoic tectonic escape northwards of the Bonaire Block from the South American continent into the Caribbean Sea to the collision of the Panama Arc with South

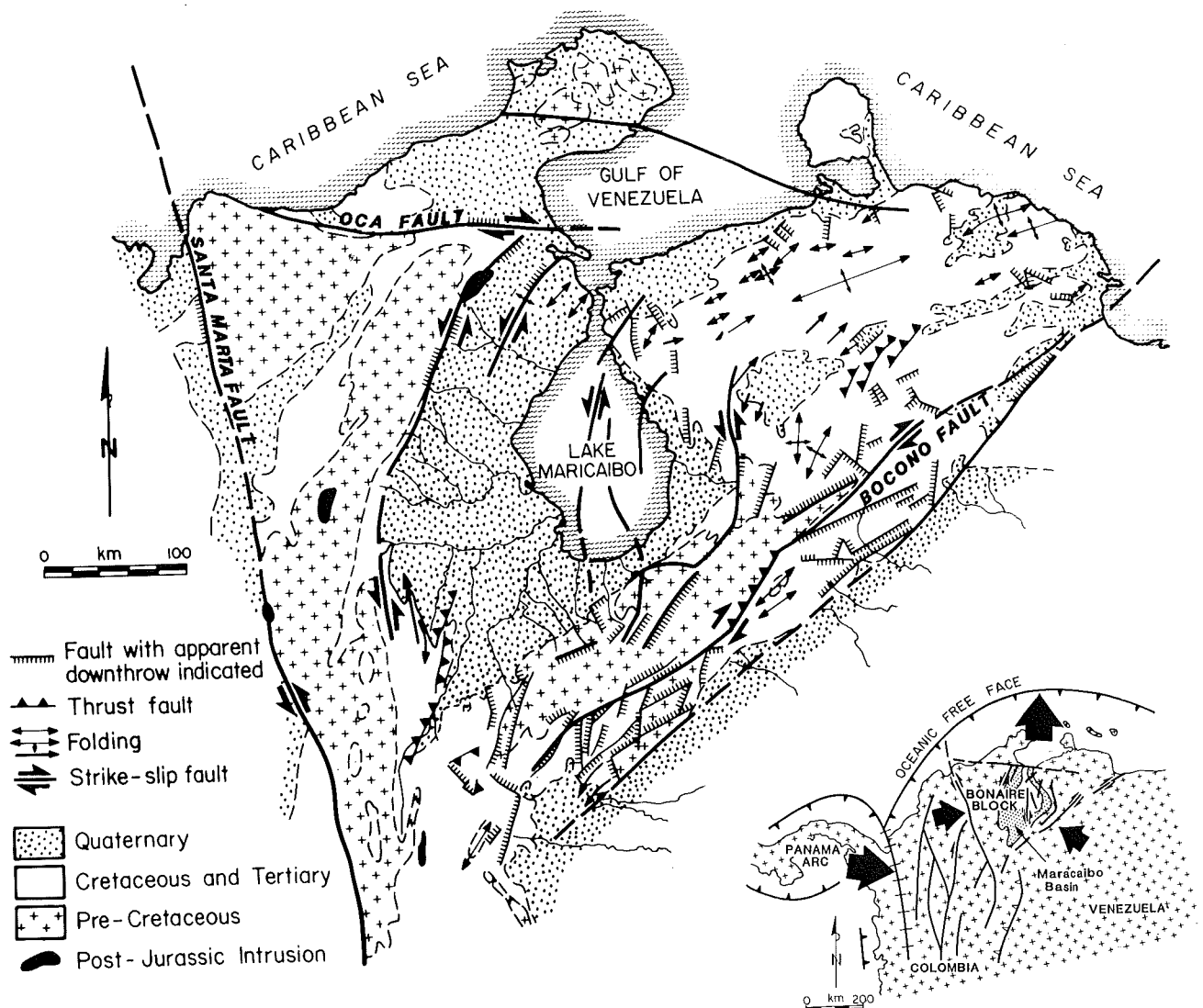


Figure 10: Geology of the Maracaibo Basin and with the inset showing the interpretation of Burke and Sengör (1982) of the basin as a result of collisional tectonic escape.

America (Fig.10 inset). On top of the Bonaire Block the Cainozoic Maracaibo Basin has evolved under the influence of the tectonic escape process. The basin has a brackish (previously marine) waterbody at its centre surrounded by a fluvial sedimentary apron (Fig.10) which drains uplifted basement areas to the west and the east. Much of the basin is severely affected by fault-block tectonics and synsedimentary folding is developed orthogonally to the major compressive stress, making features of the present Maracaibo Basin a close modern analogy (Stanistreet, 1990) with the features described from the Witwatersrand Basin. Figure 11 shows how the process of tectonic escape is comparable not only in terms of geometry, but also in terms of scale.

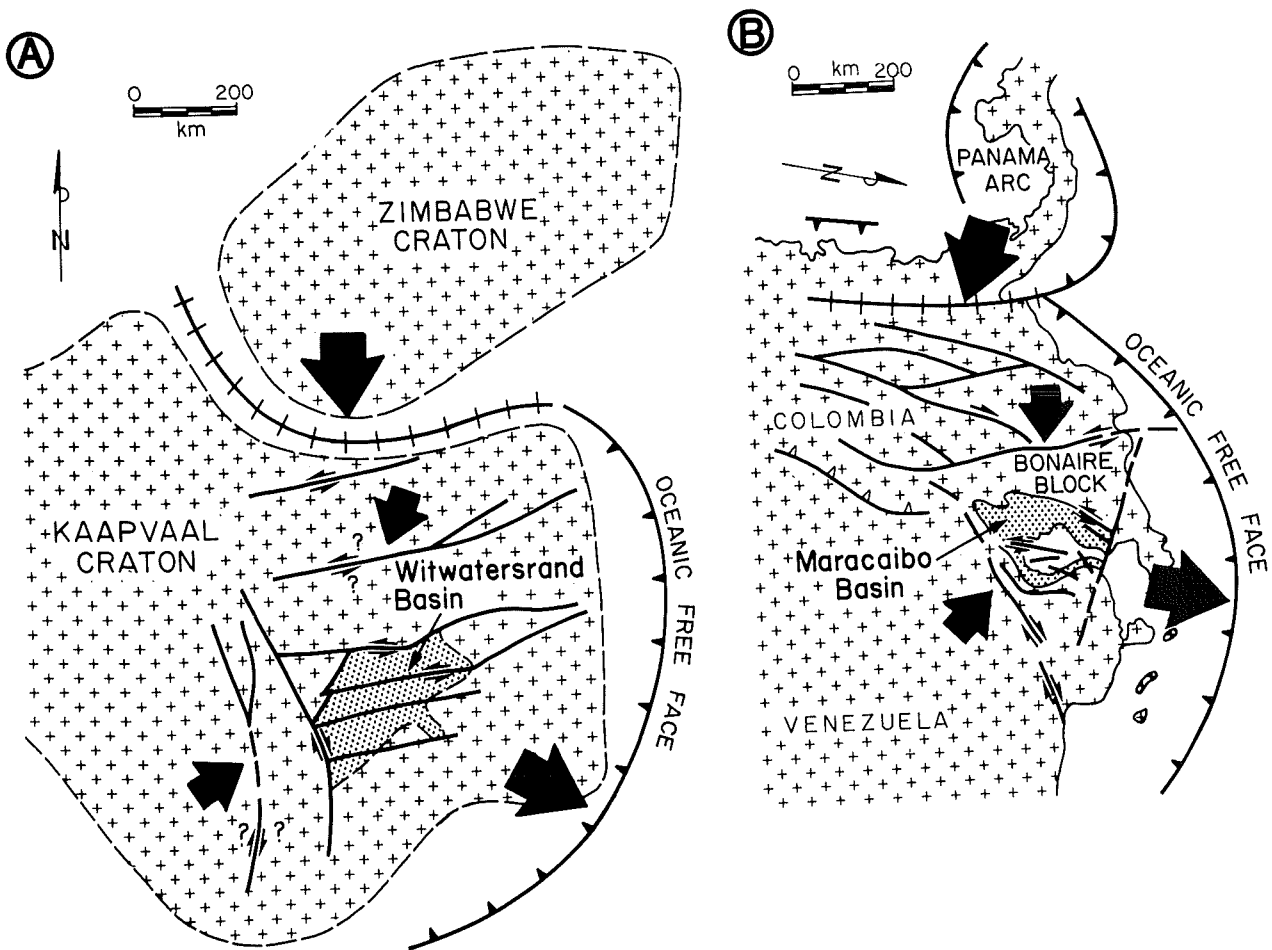


Figure 11: (A) The origin of the Witwatersrand Basin as a result of tectonic escape due to the collision of the Zimbabwe Craton. (B) Comparison with the tectonic escape of the Maracaibo Basin. This map has been rotated clockwise by nearly 90° to facilitate comparison.

STAGE 5: THE OUTPOURING OF THE FLOOD BASALTS

The origins of the Klipriviersberg Group flood basalts have remained an enigma since they were first recognized. Recent U-Pb zircon dates indicate that the 60000 km³ of continental tholeiitic lava were extruded in a short period of time, probably less than 10Ma (Armstrong *et al.*, 1990). Three aspects of the lavas help, however, to constrain the style of tectonism associated with this unit.

Firstly, as was originally alluded to by Winter (1976), this large volume of lavas was extruded within the area of the Witwatersrand Basin, in contrast to the remainder of the Ventersdorp Supergroup which was deposited in a new basin referred to here as the Lichtenburg Basin (this, in fact, brings into question the designation of the various units of the Ventersdorp as a valid supergroup).

Secondly, the fault systems which were operating during the sedimentation of the Witwatersrand Supergroup were still operating with the same reverse sense of movement during the outpouring of the lower half, at least, of the Klipriviersberg Group. In the case of both the Border Fault in the Orange Free State Goldfield (Tweedie, 1984) and the Rietfontein/Ireton Fault Zone of the Central Rand Goldfield (Stanistreet and McCarthy, 1990; McCarthy *et al.*, 1990c) the basalt stratigraphy continues to thin across the fault/monocline structures in a similar fashion to the underlying sedimentary formations (Fig. 12).

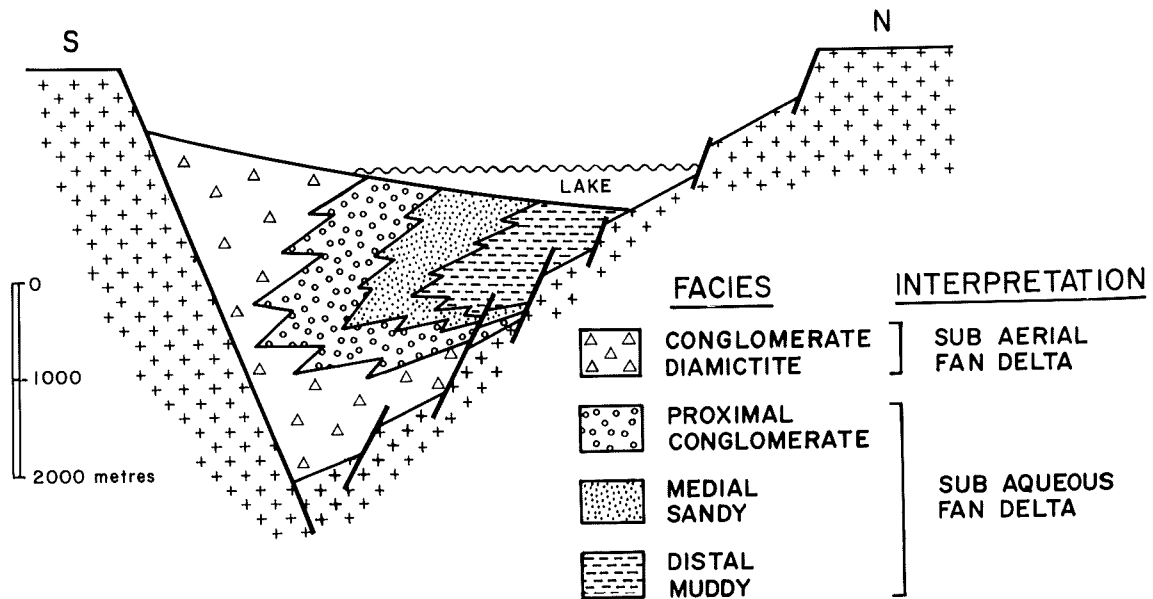


Figure 12: The structural relationship along the northern margin of the Witwatersrand Basin between end-Witwatersrand Supergroup sedimentation (A), and the subsequent outpouring of the Klipriviersberg Group basalts (B). Compressive block fault tectonics continued throughout this change in basin-fill.

Thirdly, the same (i.e. NE-SW compressive) system which is thought to have operated during the deposition of the Central Rand Group (Fig. 9) is also concluded by McCarthy *et al.* (1990b) to have operated during the outpouring of the Klipriviersberg flood basalts. This is because feeder dykes to the individual lava formations are intruded into NE-SW trending fractures which were opened up by the continuing deformation. Extrusion was initially related to the left-lateral oblique-slip Rietfontein Fault (Myers, R. *et al.*, 1990c).

It can therefore be deduced that the Klipriviersberg lavas were extruded into a still shrinking and compressive Witwatersrand Basin. McCarthy *et al.* (1990b) also recorded a change in dyke orientation in the upper half of the Klipriviersberg Group when the NE-SW trending dykes were joined by WNW-ESE trending dykes. They suggested that this change may mark the start of the change in cratonic stresses which resulted in the extensional rift basin that later accepted the Platberg Group.

When the three aspects described above are considered together it can be deduced that:

- 1) basalt extrusion was mainly associated with overall compressive not extensional tectonics;
- 2) previous models which view the Central Rand Group as deposited in a simple foreland basin (Burke *et al.*, 1986, Winter, 1987) fail to explain the massive extrusion of lavas into what should normally be very much a non-magmatic setting; and
- 3) a viable model is one of a tectonic escape basin, developed in the previous section, in which collisional compression and extension take place orthogonally to one another. A possible comparison is the basaltic magmatism associated with extension in the Aegean block as it is expelled laterally into the Mediterranean by the collision of the Arabian micro-continent with the Eurasian Plate (Burke and Sengör, 1986). The gradual movement of areas of extrusion from east to west along the Rietfontein Fault is also explained as the Witwatersrand "block" continued to be expelled eastward by the tectonic escape process.

In relating the Klipriviersberg basalts to the evolution of the Witwatersrand Basin, the Crown and Bird lavas of the Witwatersrand Supergroup act as important precedents. These may reflect the initial development of tectonic escape-related volcanism. Figure 6 shows that the Crown and Bird lavas developed at the top of the lower two major tectonic cycles, which developed in the Witwatersrand Basin, representing extensional phases of tectonic escape perhaps analogous with the aforementioned Late Neogene basaltic intrusion (Burke and Sengör, 1986) into the tectonically escaping Aegean Plate (McKenzie, 1978). Similarly, the Klipriviersberg Group can be viewed as the chronic end point of this magmatic tendency in which the tectonic escape process reached its climax.

STAGE 6: IMPACTOGENAL RIFTING : THE END PHASE OF COLLISION

As Buck (1980) has pointed out the Platberg Group was deposited in an extensional rift basin. Sedimentation associated with this extension (Buck, 1980; Stanistreet and McCarthy, 1984; 1990; Karpeta, 1989, 1990; Myers, R. *et al.*, 1990b; McCarthy *et al.*, 1990c) involved alluvial fans prograding into lacustrine environments (Fig. 13) and this was associated

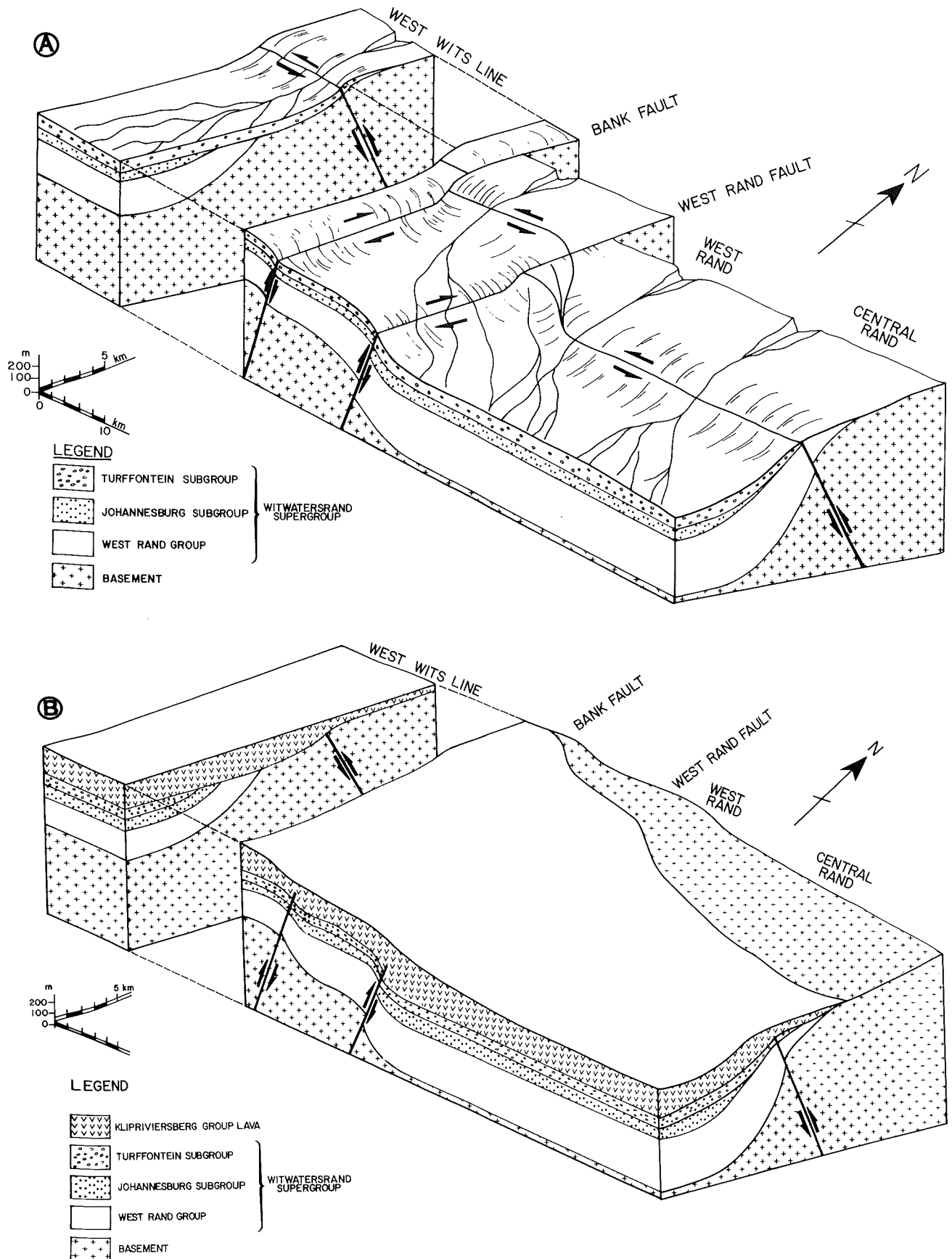


Figure 13: Alluvial fan and lake sedimentation typical of the Platberg Group. This was controlled by extensional and associated transfer faults during the development of the Lichtenburg Basin.

with classic rift-related bimodal volcanism (Myers, J.M. *et al.*, 1990). As Burke *et al.* (1985) recognized, the rift basin developed orthogonally to the Limpopo Orogenic Belt as an impactogenical rift, analogous with the Baikal rift associated at the present day with the Himalayan Orogeny (Tapponier *et al.*, 1982). The writers view this impactogenical rift, however, as the end stage in a far more extensive collisional phase involving the uppermost Central Rand, the Klipriviersberg, and the Platberg Groups. This also explains why these various groups were developed under a relatively short time span (Klipriviersberg - 2714 ± 8 Ma; Makwassie - 2709 ± 4 Ma; Armstrong *et al.*, 1990). Extension of the Lichtenburg Trough was accommodated by transfer faults. Stanistreet *et al.* (1985) and Clendenin *et al.* (1988b) suggested that the Rietfontein Fault acted in this way as a left-lateral transfer fault along which the Ireton and Bezuidenhout Valley pull-apart half grabens developed (Stanistreet and McCarthy, 1990, McCarthy *et al.*, 1990c). Karpeta (1990) showed, however, that right lateral transfer faults (Fig. 14d) were also operative and that these may have been the major set. His easternmost transfer fault branches from the Platberg Fault which was a locus of volcanism of the Klerksdorp Townlands type (Myers, J.M. *et al.*, 1990). His western transfer fault is an extension of the Welkom Border Fault as indicated by Myers, R. *et al.* (1990a). This illustrates how the oblique-slip reverse faults controlling the Witwatersrand Basin (Fig. 14c) during collisional tectonic escape converted into oblique-slip normal faults with the same sense of strike-slip component movement during the impactogenical rift stage (Fig. 14d).

DISCUSSION AND AFTERMATH

Tankard *et al.* (1982) pointed out that the Dominion Group is almost entirely restricted to what later was to become the area of the Lichtenburg extensional basin. The reasons for this may now be resolved. The extensional rift basin which received the Dominion Group was reactivated during the later collision phase to become the Lichtenburg Trough. There is a direct reason why the Dominion Group is preserved in such a restricted part of the younger rift. During the evolution of the Witwatersrand Basin, Dominion Group sequences to the northeast and southwest of its presently preserved area were eliminated by erosion as areas to the west of the Welkom (Border) Fault Zone and north of the Ireton/Rietfontein Fault Zones were gradually thrown upwards to provide a source area to the evolving Witwatersrand Basin. This explains the old conundrum of why Platberg Group rocks external to the Witwatersrand Basin tend to lie on basement, whereas internally to the basin, Platberg Group sequences lie on a variety of underlying stratigraphic units.

The tectonic record of the Lichtenburg Trough is not, however, complete. Buck (1980) showed that it was succeeded by further extension leading to the deposition of the Pniel Sequence, which Winter (1976) had already recognized as the forerunner of the Transvaal Basin. The writers relate this extension to the gravitational collapse of the Limpopo Orogeny which led not only to the deposition of the Pniel Sequence, but also the Wolkberg Group. The Chuniespoort Group represents the thermal cooling phase (Clendenin *et al.*, 1988b) associated with this extension and continental re-equilibration.

The Vredefort Structure occupies a central position in the Witwatersrand Basin and is associated with intense and complex deformation (Roering *et al.*, 1990). Its status in the basin evolutionary models is controversial. Although this structure is clearly post-Transvaal Sequence

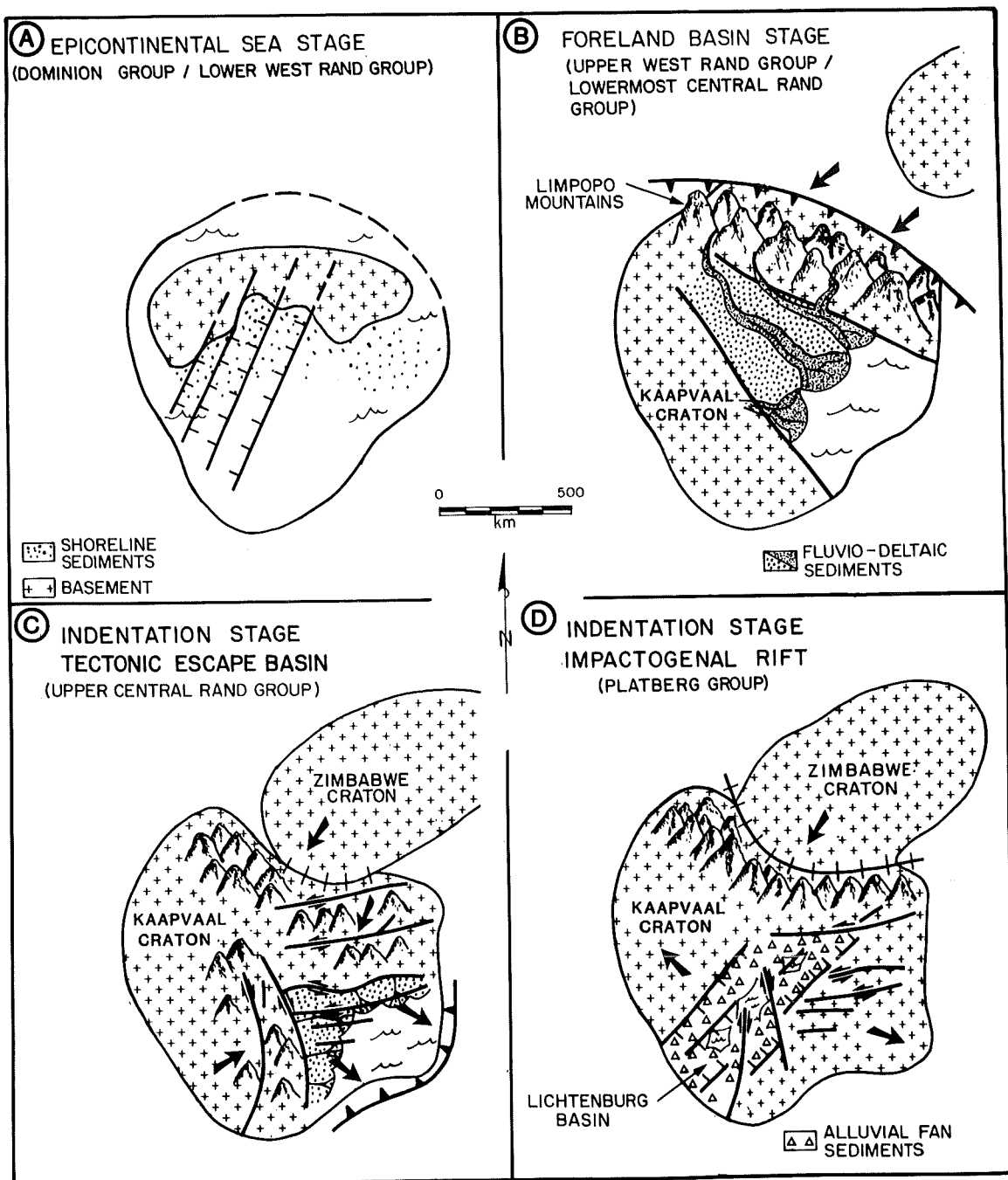


Figure 14: Stages in the evolution of the Witwatersrand Basin. (A) The Dominion Group developed in an extensional basin with the West Rand Group representing the associated thermal subsidence sedimentation. (B) Subduction under the northeast margin of the craton creates a retroarc basin in which upper West Rand Group and lowermost Central Rand Group sediments were deposited. (C) Collision of the Zimbabwe Craton during Central Rand Group sedimentation causes tectonic escape. (D) Ultimate indentation creates an impactogenic rift in which Platberg Group sediments were deposited.

in age many workers regard this merely as the manifestation of continued deformation in this area. Corner and Wilshire (1986) argued, on geophysical grounds, that the Vredefort Structure lies on a fundamental symmetry axis through the Witwatersrand Basin. Pretorius (1986), on the other hand, considered the Vredefort Structure to form part of a regular pattern of domes and basins which controlled the distribution of the Witwatersrand Basin sediments.

Recent sedimentological studies by Mayer and Albat (1988) and Holland *et al.* (1990) in the collar rocks show no indication that this structure was operative during Witwatersrand sedimentation. No terrigenous input into the carbonate sediments of the Chuniespoort Group is evident from the Vredefort Dome (Beukes, 1978) and Eriksson (1973) has shown that during deposition of the lower Pretoria Group the area presently occupied by the Vredefort Structure was a topographic low with facies prograding into the area. It thus appears that the Vredefort Structure is entirely post-Transvaal in age. McCarthy *et al.* (1986) have shown that the Johannesburg Dome was emplaced after the Vredefort Dome and therefore also did not affect sedimentary basins described in this paper.

The Vredefort event did, however, have a major structural impact on Witwatersrand age rocks (McCarthy *et al.*, 1986). The reasons for its central position in the Witwatersrand Basin have been addressed by McCarthy *et al.* (1990a). It appears that the large, marginal syncline associated with this structure caused the infolding of Witwatersrand strata and has protected them from later erosion. The coincidence of the Witwatersrand Basin with the Vredefort Structure may therefore be an artifact of this erosional protection and has no primary significance for the evolution of the Witwatersrand Basin *per se*.

CONCLUSIONS

The Late Archaean geological history of the Kaapvaal Craton records a variety of basin styles, all of which are responses felt internally by this micro-continent during the Wilson Cycle within which the Limpopo Orogeny developed. These basinal responses were: (1) an extensional rift basin which received the Dominion Group, established during a possible spreading phase; (2) thermal subsidence which led to transgression and the deposition of the Hospital Hill Subgroup epicontinental sequence (Fig. 14a); (3) a foreland basin in which the upper West Rand Group and lowermost Central Rand Group was deposited, associated with oceanic subduction beneath the northern margin of the Kaapvaal Craton (Fig. 14b); (4) collisional stage tectonic escape which led to the development of the Witwatersrand Basin *sensu stricto* and which received the upper part of the Central Rand Group (Fig. 14c); (5) through tectonic-escape-related extension and oblique-slip faulting the Klipriviersberg flood basalts were extruded into the Witwatersrand Basin (this stage was already impactogenic and hence the apparent enigma that the Klipriviersburg is at once both compressional and extensional); and (6) indentation of the Zimbabwe Craton into the Kaapvaal Craton resulted finally in the formation of an impactogenical extensional rift basin (Lichtenburg Basin) which received the Platberg Group.

The complete cycle was followed by gravitational collapse and erosion of the mountain belt leading to the extensional phase in the Lichtenburg and Selati Troughs which received the Pniel Sequence and Wolkberg Group. This was followed by thermal cooling leading to the

epicontinental sea setting in which the Chuniespoort Group was deposited. The latter represented the final re-equilibration of the now newly accreted Kalahari Craton (Kaapvaal + Zimbabwe Cratons - then also probably including the Pilbara Craton; Cheney et al., 1988), following the Wilson Cycle which contained the Limpopo Orogenic episode.

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