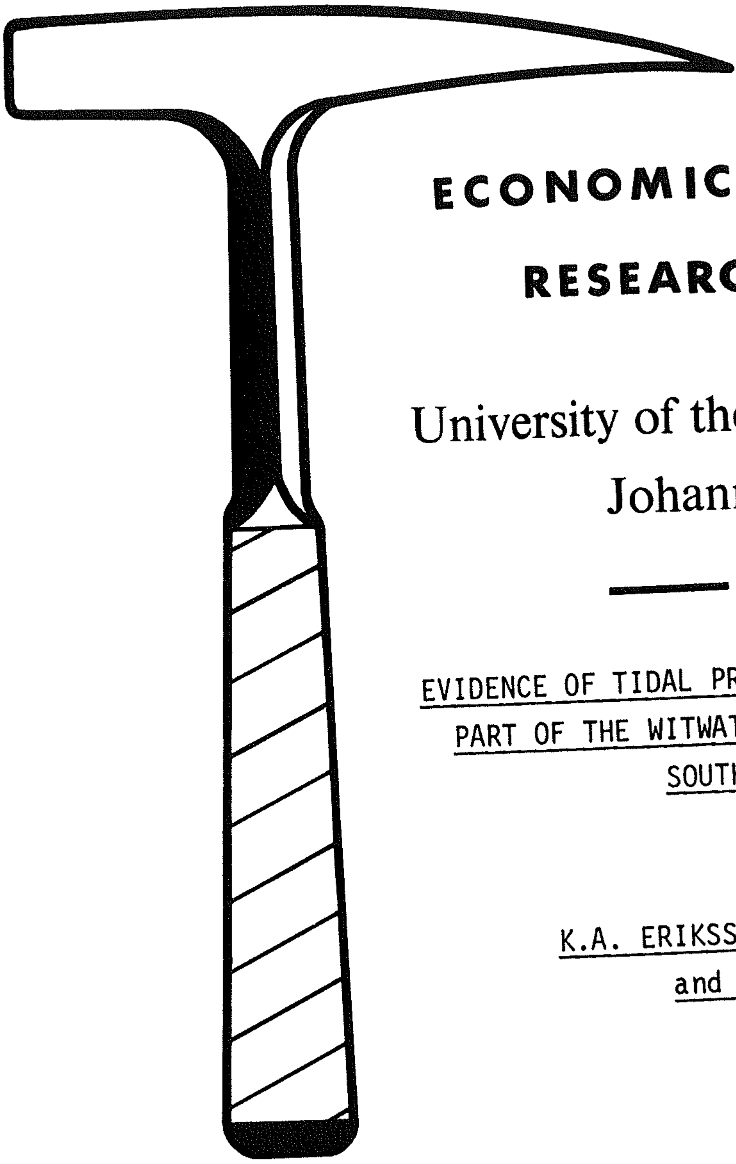

ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

EVIDENCE OF TIDAL PROCESSES FROM THE LOWER PART OF THE WITWATERSRAND SUPERGROUP, SOUTH AFRICA

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INFORMATION CIRCULAR NO. 140

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

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by

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ABSTRACT

A 1 600m succession of quartz arenites and associated shaley deposits comprising the Hospital Hill Subgroup at the base of the Witwatersrand Supergroup is considered to have been deposited largely under the influence of tidal processes. Facies analysis indicates that deposition occurred in the following environments: (1) marine shelf, (2) shallow subtidal to intertidal; (3) intertidal flat; and (4) tidal inlet. The presence of strong tidal currents implies that the Witwatersrand Basin was open to an ocean basin, at least during the early stages of its evolution. Palaeocurrent trends and isopach data suggest that this ocean basin probably lay to the southwest, an area now occupied by the high grade Natal-Namaqua metamorphic belt. The contrast between the supermature quartz arenites of the Hospital Hill Subgroup and the overlying gold-bearing immature subgreywackes, feldspathic quartzites and conglomerates of fluvial origin is believed to be a function of tidal reworking of sediments.

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EVIDENCE OF TIDAL PROCESSES FROM THE LOWER PART OF THE WITWATERSRAND SUPERGROUP, SOUTH AFRICA

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EVIDENCE OF TIDAL PROCESSES FROM THE LOWER PART OF THE WITWATERSRAND SUPERGROUP, SOUTH AFRICA

I. INTRODUCTION

The Precambrian Witwatersrand Basin (2 800 to 2 500m.y.) was created by synclinal warping of the Kaapvaal Craton, which forms part of the South African Shield (Minter, 1978). The basin covers an area of about 39 000km^2 and is filled almost entirely by clastic deposits, consisting of quartzites, shales and conglomerates. Associated with the clastics are occasional widespread lava flows. These deposits make up the Witwatersrand Supergroup which overlies Basement complex granites and high grade metamorphics, and is overlain by Ventersdorp lavas and clastic sediments. The Witwatersrand succession is conventionally divided into a lower division and an upper division. The lower division (about 4 500m thick) is finer-grained and consists mainly of sandstones and shales with rare conglomerates, while the coarser-grained upper division (about 3 000m thick) consists mainly of sandstones and conglomerates with one prominent shale horizon, known as the Kimberley shale.

Texturally, and mineralogically, supermature quartz arenites occur in the Hospital Hill Subgroup (1 600m thick) at the base of the Witwatersrand Supergroup (Fig. 1), and contrast with immature subgreywackes and feldspathic quartzites in overlying stratigraphic units (Fuller, 1958). The immature, gold-bearing sandstones and conglomerates are generally interpreted as fluvial deposits (Antrobus, 1956; Pretorius, 1974; Vos, 1975: Minter, 1978). However, no detailed environmental interpretation has been made on the quartz arenites at the base of the Witwatersrand succession.

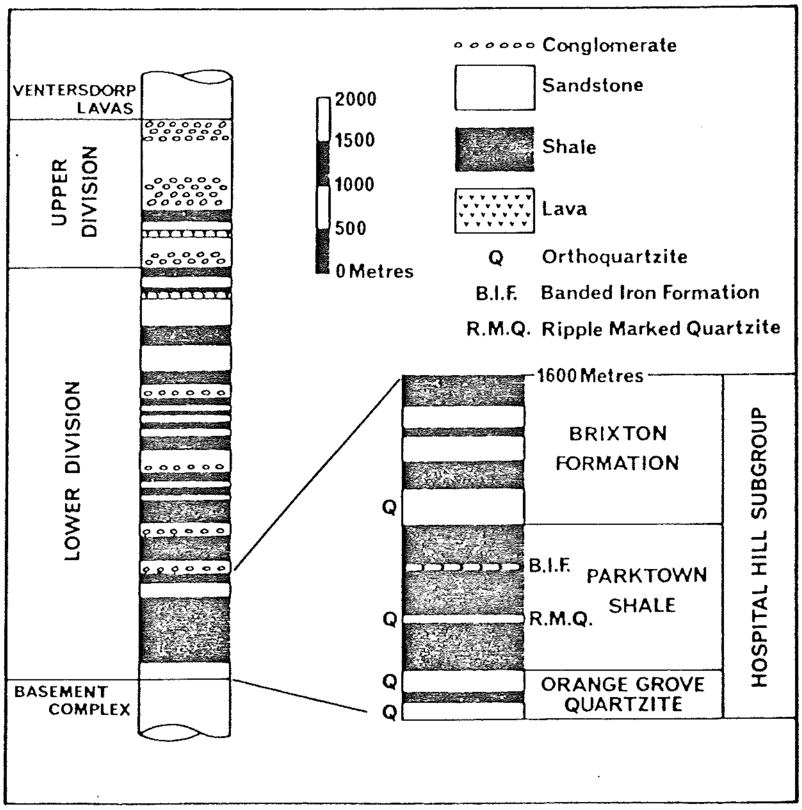

Figure 1 : Generalized stratigraphic section of the Witwatersrand Supergroup showing the finer-grained lower division, coarser-grained upper division and details of the Hospital Hill Subgroup, including stratigraphic names used in the text.

This study documents particular associations of lithologies and sedimentary structures from the Hospital Hill Subgroup on the Central Rand, West Rand, and at Zwartkops, (Fig. 2) and suggests that deposition and reworking of sediments took place largely under the influence of tidal processes. A generally southwest-northeast orientated shoreline and southeasterly palaeoslope are implied from isopach maps.

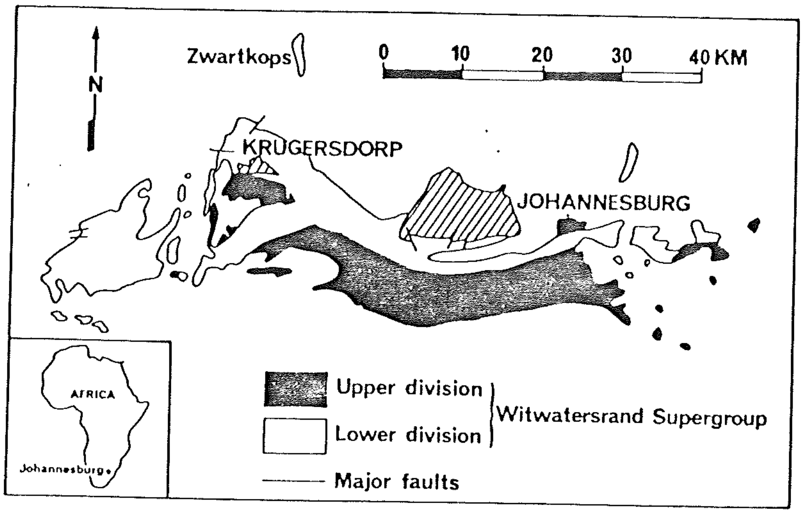

Figure 2 : *Locality map showing outcrop of the Witwatersrand Supergroup*

II. DEPOSITIONAL ENVIRONMENTS

Two broad environmental settings are recognized for the Hospital Hill Subgroup; a tidal inlet environment developed along a mesotidal coastline (tidal range 2 to 4m) and a subtidal to intertidal setting developed along a macrotidal coastline (tidal range greater than 4m).

A. Tidal Inlet Depositional Environment

This environment was observed only in the Orange Grove Quartzite at Zwartkops (Fig. 3), and comprises stacked upward-fining conglomerate to sandstone sequences. Four distinct subenvironments or facies are recognized.

1. *Conglomerate Facies*

This facies consists of well-rounded and sorted quartz pebbles (average diameter 1cm) set in a coarse-grained quartz arenite sandstone matrix (Plate 1A). Two conglomerate layers up to 1,5m in thickness are present. These layers are laterally persistent and occupy the base of upward-fining sequences. This facies is interpreted as a tidal inlet channel floor lag gravel.

2. *Cross-bedded Quartz Arenite Sandstone Facies*

This facies consists mainly of medium-to coarse-grained and well-sorted quartz arenite and occurs as 1,5 to 5m units directly overlying conglomerate layers described above. Trough cross-bedding is the dominant sedimentary structure with foresets directed to the southwest (Fig. 3, rose diagram). These cross-beds are arranged in 1,3m thick depositional units which show an upward decrease in set thickness. These units are usually capped by a thin siltstone-shale parting (Fig. 3).

This facies is considered to have developed in a tidal inlet channel. Megaripple migration occurred in response to waning ebb currents with no sand movement during flood inflow. A similar phenomenon has been observed for tide-dominated (as opposed to wave-dominated) inlets along the east coast of the U.S.A. (Hubbard, 1977). Thus a mesotidal coastline can be invoked for this facies, with the occasional siltstone and shale partings accumulating during a period of prolonged tidal stillstand, which may be of 4 hours duration (Green, 1975).

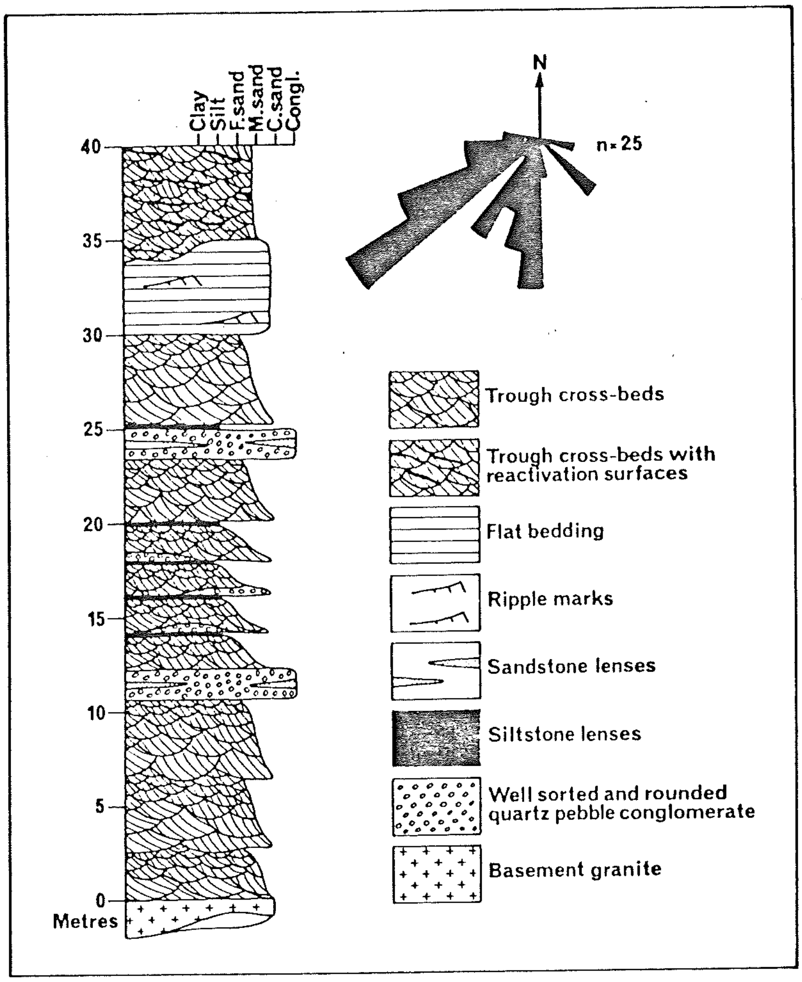

Figure 3 : *Measured stratigraphic section through the Orange Grove Quartzite at Zwartkops. The rose diagram shows sediment transport directions for the uppermost trough cross-bedded unit.*

3. *Plane-bedded Quartz Arenite Sandstone Facies*

This facies consists of plane-bedded fine-to medium-grained quartz arenite and occurs overlying the cross-bedded quartz arenite facies (Fig. 3 and Plate 1B). Plane-bedded sequences up to 5m in thickness are present as well as rare asymmetric ripples.

This facies is interpreted as upper flow regime swash-generated deposits which developed on channel margin bars in the tidal inlet setting. These are characteristically developed on the margins and seaward of tide-dominated inlets. They are orientated at right angles to the coastline and subject to intense swash reworking (Hubbard, 1977).

4. *Trough Cross-bedded Quartz Arenite Sandstone Facies*

The upper 4m of the Orange Grove Quartzite at Zwartkops comprises small- and medium-scale trough cross-beds with a dominant southwesterly palaeocurrent mode (Fig. 3). This facies rests on the underlying plane-bedded sandstones with an erosional contact having an observed relief of 1,5m.

This facies possibly originated by channelling into swash bars on the ebb tidal delta fronting the tidal inlet. Similar incision into channel margin swash bars is observed on present day tidal deltas (Oertel, 1975).

B. Facies Stacking

Vertical stacking of the previously described facies probably resulted from longshore migration of tidal inlets. The upper cycle (Fig. 2; 22-28m) is best preserved and indicates swash bar migration across the inlet channel complex. In the underlying cycle, by contrast, only the channel floor and shallow-to deep-channel facies are preserved, probably as a result of erosion by younger migrating inlets. Similar processes are observed along the North Carolina coast where inlets migrate parallel to the shoreline for up to 6km before reopening at the original position of the inlet (Kumar and Sanders, 1974, quoting Pierce, 1970). In this way, and especially if associated with a transgressive coast-line, superimposition of tidal inlet sequences results.

Tidal inlet sequences may rest on deeper marginal marine deposits or even on older basement rocks (Kumar and Sanders, 1974). The lowermost tidal inlet sequence in the Orange Grove Quartzites is underlain by trough cross-bedded quartz arenite sandstones devoid of pebble lags and siltstone-shale partings (Fig. 3). These sandstones are interpreted as shoreface sediments.

C. Macrotidal Coastline Depositional Environment

This environment was observed in the middle and upper Orange Grove Quartzite and lowermost Brixton Quartzite on the Central Rand (Fig. 1). Four facies are recognised, based on associations of lithologies and sedimentary structures:

1. *Banded Iron-Formation-Shale Facies*

The contorted bed in the Parktown Shale occurs at the base of an upward-coarsening sequence (Figs. 1 and 4). This horizon is a tectonically deformed banded iron-formation (Fig. 8; Fripp and Gay, 1972) which consists of inter-laminated chert, jasper, magnetite and shale. The proportion of shale increases upwards until thin (± 1cm) chert bands constitute the only chemical sediments. Siltstones eventually appear at the expense of chert (Fig. 4). Both the shales and siltstones are horizontally laminated.

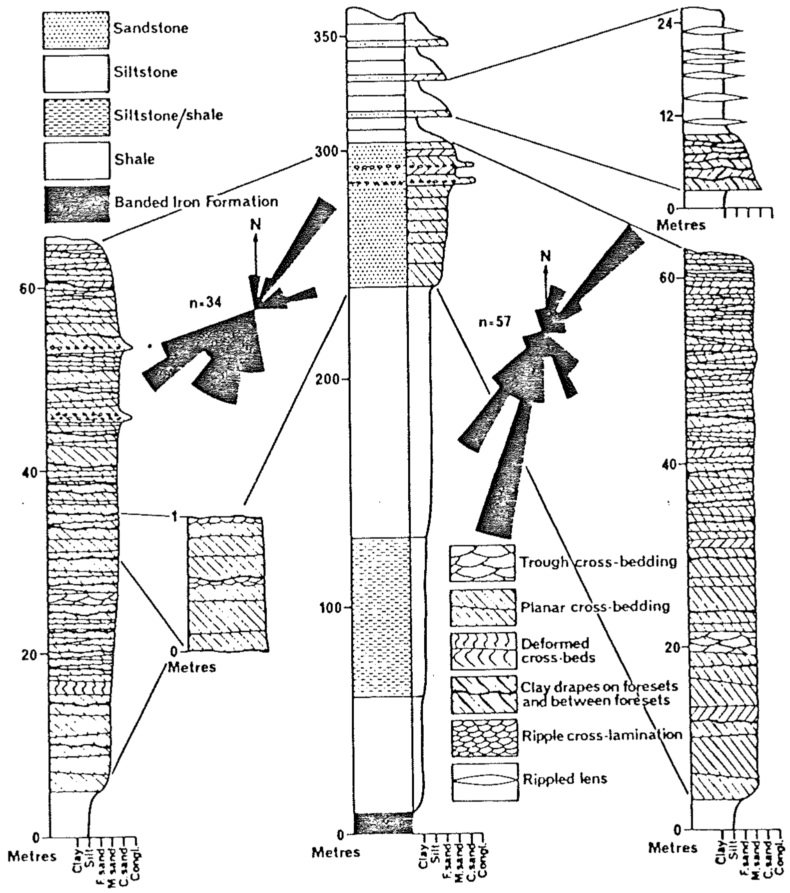

Figure 4 : Generalized stratigraphic column of the Hospital Hill Subgroup showing the lower Brixton Quartzite on the West Rand.

Horizontal lamination probably indicates a depositional environment near to or below wave base. The most likely setting is an offshore shelf on which chemical and suspension sedimentation predominated. Suspension settling of clays and rare silts occurred on the more proximal reaches of the offshore shelf whereas in deep waters, beyond clastic input, chemical precipitation of iron and silica was enhanced. The rhythmic interlayering of siliceous and ferruginous layers reflects fluctuating Eh and pH conditions which may have been seasonal (Govett, 1966; Eugster, 1969) or diurnal due to photosynthesis (Walter, 1972).

2. *Siltstone-Shale Facies*

A thick sequence (70m) of siltstone with subordinate shales overlie the offshore shelf deposits in the Parktown Shale (Fig. 4) and also occur in the Orange Grove Quartzite (Fig. 5). On the Central Rand a thin basal (8m) quartz arenite occurs in some sections but not in others (Fig. 5). Horizontal lamination predominates but towards the top of the facies the siltstones are ripple-cross-laminated on a scale of less than 1cm. The association with the underlying offshore shelf sediments coupled with the evidence of low energy bedload processes suggests that this facies represents a nearshore shelf deposit. Weak traction currents resulted in intermittent ripple migration which alternated with suspension settling of silts and clays.

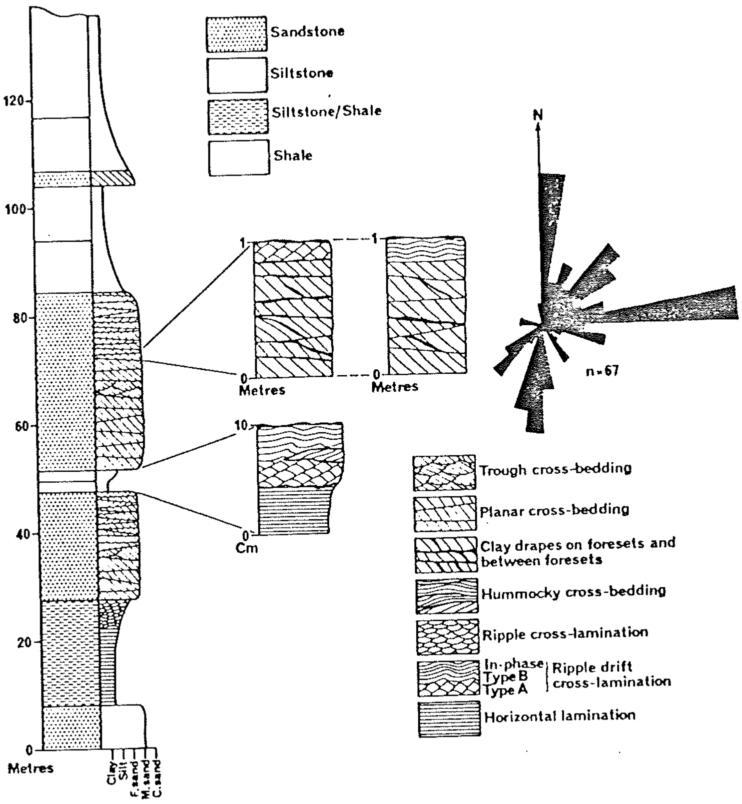

Figure 5 : Generalized stratigraphic column of the Orange Grove Quartzite on the Central Rand.

A subfacies occurs immediately beneath the upper Orange Grove Quartzite. It consits of repetitive 5-10cm thick cycles of horizontally laminated and ripple laminated siltstones capped by shale partings (Fig. 5 and Plate 1D). The erosively-based rippled units are characterised by ripple-drift cross-lamination, which often displays an internal cyclicity from types A and B to in-phase ripple-drift cross-lamination (Jopling and Walker, 1968). Hummocky cross-stratifaction (Harms et al., 1975) is also present within a number of cycles.

Grain size variations and the sequence of sedimentary structures in this subfacies can be related to single depositional events indicative of waning currents of probable storm origin (Vos, 1977). Individual sequences probably record a single event of storm turbulence causing resuspension of shelf floor silt. Since redeposition probably occurred as wave surge currents decreased in velocity, the sequence of structures records a waning current. Settling of clays during the final stages of suspension fall-out terminates the depositional sequence.

3. *Quartz Arenite Sandstone Facies*

Quartz arenite sandstones, which average 65m in thickness, gradationally overlie the upward coarsening shallow shelf deposits in both the Brixton Formation and Orange Grove Quartzite (Figs. 4 and 5). Medium-scale planar cross-beds are the dominant sedimentary structure although occasional trough sets occur.

The lowermost Brixton Quartzite also frequently contains large-scale planar cross-beds (Fig. 4). The upper 10m of both quartzite formations are characteristically structured by small-scale herringbone cross-bedding (Plate 2A). A trimodal distribution of cross-bed azimuths was obtained for the upper Orange Grove Quartzite (Fig. 5) and a bimodal-bipolar distribution for the lower Brixton Quartzite, in which the southerly (offshore) mode is generally dominant (Fig. 4).

Sedimentary sequences with an average thickness of 1m are particularly apparent where offshore-directed cross-beds predominate in the upper Orange Grove Quartzite (Fig. 5). These sequences consist of 3-6 stacked cross-bed sets often capped by a thin Type A and/or in-phase ripple-drift cross-laminated unit. These are analogous to the 'B-C' sequence of Klein (1970a). Shale partings occur between and within sedimentary sequences. Shale partings within sequences are less common and occur between the foresets of individual cross-bedded sets or along foresets where they define reactivation surfaces.

The Ripple Marked Quartzite, which is enclosed within shallow shelf siltstones and shales (Fig. 1), displays many similarities with the middle and upper Orange Grove and lowermost Brixton Quartzites. Herringbone cross-bedding is ubiquitous and gives bimodal-bipolar palaeocurrent patterns. Shale drapes occur within and between sedimentary sequences; these are capped with ripple-cross-laminae which, in plan-view, display linear, sinuous and superimposed ripple patterns (Plate 2B).

The quartz arenite sandstone facies displays abundant evidence of sedimentation in a tide-dominated environment. Palaeocurrent patterns for each of the quartzites indicate bedload transport with reversals in flow direction. Flood currents advanced in a general northeasterly direction and ebb currents retreated to the south and southwest. Ebb currents were stronger, especially during deposition of the lowermost Brixton Quartzite (Fig. 4) and, coupled with the frequent reactivation surfaces, indicate time-velocity asymmetry (Klein, 1970b). The 'B-C' sequences in this facies (Figs. 4 and 5) developed in response to waning ebb currents and, at least in the case of the superimposed ripples (Plate 2B), imply late-stage emergence of the depositional surface. More commonly, however, subaqueous migration of current ripples produced ripple cross-lamination while the accumulation of fine-grained sands and silts generated in-phase ripple-drift cross-lamination during the final waning stages of ebb retreat. Suspension sedimentation of clays during slack water periods resulted in the formation of shale partings and their association with sandstone indicates alternating bedload transport and suspension settling (Reineck and Wunderlich, 1968), characteristic of tidal deposits.

4. *Quartz Arenite Sandstone-Shale Facies*

Stacked upward-fining sequences from 20-30m thick overlie the lower Brixton and upper Orange Grove Quartzites (Figs. 4 and 5). Basal orthoquartzitic sandstones are herringbone cross-bedded throughout with abundant shale flasers and flakes present on foresets and between cross-bed sets (Plate 2C). The overlying shale intervals contain lenticular bedding (Plate 2D) in which quartz arenite sandstone and siltstone lenses are wave- and current-ripple cross-laminated. Wave ripples are distinguished on the basis of irregular lower bounding surfaces and the complex internal arrangement of cross-laminae (Boersma, 1970). Tidal bedding composed of mm-scale siltstone-shale alternations is also present in the upper part of the sequence (Wunderlich, 1970).

Upward-fining sequences of this type result from seaward progradation of tidal flat subenvironments (Klein, 1971; 1972). Bedload reworking of sand dominates on lower tidal flats and, in response to current reversals, herringbone cross-bedding is developed. Suspension settling of clays at high slackwater generated the associated shale flasers which were desiccated at low-tide to produce shale flakes. Clays are transported predominantly onto upper tidal flats and accumulate due to settling and scour lag effects (Postma, 1967). Sands and silts were probably introduced onto upper tidal flats during storms (Reineck, 1967; McCave, 1970) where tidal and wave reworking of starved ripples occurred. Subsequent high-water suspension sedimentation produced lenticular bedding.

The lowermost Brixton Quartzite and middle and upper Orange Grove Quartzites on the Central Rand and West Rand cap upward-coarsening sequences which resemble progradational beach-offshore shelf deposits (Figs. 4 and 5). Detailed sedimentological analysis, however, indicates an absence of wave effects with sedimentation occurring along a non-barred macrotidal coastline. Upward-fining sequences above the quartzites (Figs. 4 and 5) are interpreted as having accumulated on flanking tidal flats.

D. Facies Stacking

Following deposition of the thin, laterally impersistent lower Orange Grove Quartzite (Fig. 1) along a transgressive shoreline, southward progradation of a macrotidal coastline produced the vertical stacking of the four facies described previously (Figs. 4 and 5). The Parktown Shale, as well as the fine-grained clastics intercalated within the Orange Grove Quartzite, accumulated under low-energy conditions on an offshore and nearshore shelf. Traction currents related to storm surges periodically influenced sedimentation on the nearshore shelf. Shallow subtidal reworking of sands by tidal currents produced the middle and upper Orange Grove Quartzites, the Ripple Marked Quartzite and the lowermost Brixton Quartzite (Figs. 1, 4 and 5). Certain of these sheet sands may have been exposed at low tide, as implied, for example by the superimposed ripples in the Ripple Marked Quartzite. Time velocity asymmetry of tidal currents is reflected in the palaeocurrent patterns derived from these quartzites, in which flood and ebb currents dominated in different parts of the depository. Tidal processes effectively separated sands and clays onto the lower and upper tidal flats respectively. The 20-30m thicknesses of tidal flat sequences are not considered to reflect tidal range as suggested by Klein (1972) but are probably a result of facies stacking.

Macrotidal conditions, such as envisaged during deposition of the Hospital Hill Subgroup on the Central Rand and West Rand, are associated with coastline embayments (Mofjeld, 1976) or wide continental shelves (Redfield, 1958; Davies, 1964). The lateral persistence of the macrotidal sequence in the Hospital Hill Subgroup favour a shelf width control. A contemporary analogue exists along the northwest coast of Australia where amplification of tidal wave across the broad contintental shelf produces widespread macrotidal conditions (Coleman and Wright, 1975).

III. DISCUSSION

Evidence of mesotidal to macrotidal conditions during deposition of the Hospital Hill Subgroup exists in the form of tide-dominated inlet and upward-coarsening non-barred coastline sequences. These exaggerated tidal ranges are considered to have developed as a direct consequence of amplification of the tidal wave across the stable Kaapvaal cratonic shelf (Fig. 6).

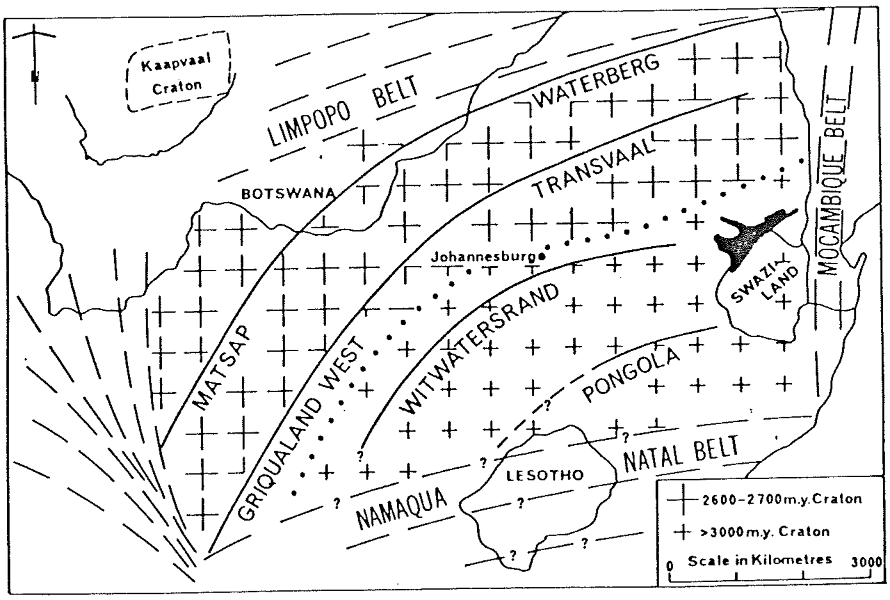

Figure 6 : The Kaapvaal craton showing the Witwatersrand Supergroup and other major depositional sequences on the craton in relation to the Natal-Namaqua and other metamorphic belts.

The southeastern half of this craton, on which the Witwatersrand Supergroup was deposited, had stabilized by 3 000m.y. (Hunter, 1974). The presence of strong tidal currents implies that the Witwatersrand Basin was connected with an ocean basin. Tidal waves originate in deep oceans and are then propagated into adjacent shelf seas where they may influence coastal development and the preserved sedimentary record. Even large enclosed seas such as the Mediterranean, which may be deep and have a small connection with the open ocean have negligible tidal activity. The high tidal ranges under which the Hospital Hill Subgroup accumulated imply an epicratonic depository and, as revealed by isopach data (Pretorius, 1974), it is likely that the basin opened to the southwest, at least during the early stages of its evolution. This area is now occupied by the 1 000m.y. old high-grade Natal-Namaqua metamorphic belt (Fig. 6). It has been suggested that this mobile belt may in part be a collision orogen (Nicolaysen and Burger, 1965; Matthews, 1972) in which case any deep-water facies equivalent to the shallow marine Hospital Hill sediments would have been metamorphosed or eliminated. Tidal reworking of sediments explains the contrast between the supermature orthoquartzites in the Hospital Hill Subgroup and the overlying placer gold-bearing immature subgreywackes, feldspathic quartzites and conglomerates of fluvial origin.

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PLATE I

A. Conglomerate in the Orange Grove Quartzite at Zwartkops.

B. Plane bedding in the Orange Grove Quartzite at Zwartkops.

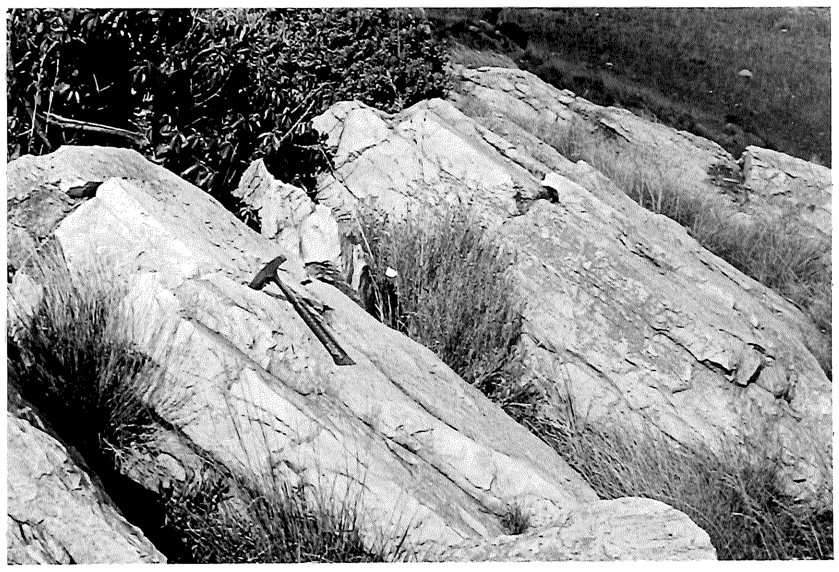
C. Tectonically deformed Banded Iron-Formation (contorted bed) in the Parktown Shale.

D. Horizontally laminated and rippled cycles in the Orange Grove Quartzite.

PLATE I

A

B



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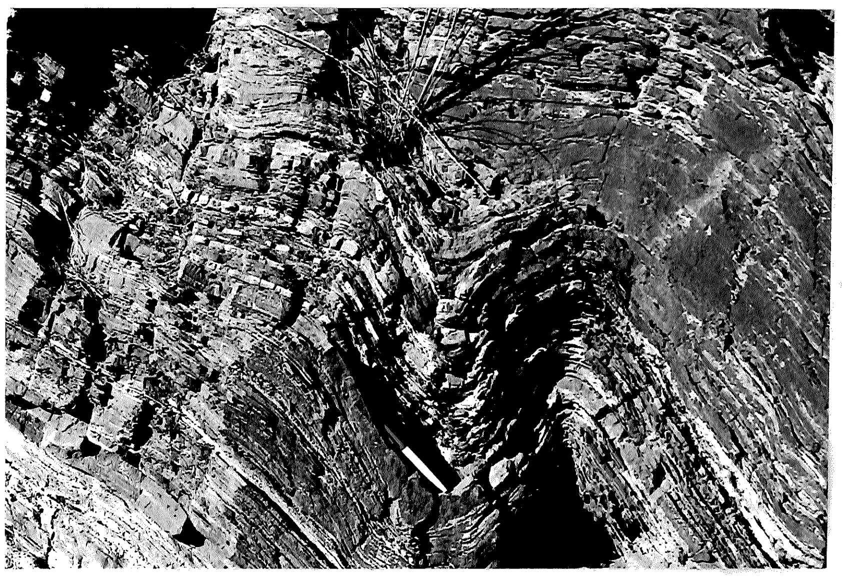

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PLATE II

A. Herringbone cross-bedding in the Hospital Hill Quartzite.

B. Superimposed small on large wave-length ripples in the Ripple Marked Quartzite.

C. Herringbone cross-bedding with clay drapes in the Hospital Hill Quartzite.

D. Lenses of quartz arenite in shale (lenticular bedding) in the Hospital Hill Quartzite.

PLATE II