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by

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## ABSTRACT

The Zandfontein Quartzite Formation in the Evander Goldfield consists of a basal oligomictic small-pebble conglomerate, the Zandfontein Reef, overlain by a 9m-thick siliceous, cross-bedded metaquartzite, the Zandfontein Quartzite. The Zandfontein Reef is impersistent, poorly mineralized and consists of a series of low-relief, elongate conglomerate bars which trend northeast-southwest. The overlying quartzite contains laterally persistent silt drapes. Palaeo-current trends from the Zandfontein Quartzite Formation are bipolar in places, but generally unimodal, with a dominant mode towards the southwest.

The Zandfontein Quartzite Formation was deposited conformably upon the planar, unconsolidated surface of the Booysens Shale Formation. The contact is remarkable due to the absence of erosional features. The Zandfontein Reef is interpreted here as a shallow marine shelf deposit. It was probably deposited by tidal processes with some modification by storm-induced currents. The conglomerate bars of the Zandfontein Reef are interpreted as tidal re-workings of storm-induced sediments on a marine shelf which had a generally low sediment supply. The conglomerate bars, which have been winnowed and eroded by tidal currents, are separated by longitudinal sand ribbons. Deposition took place during a marine regression over the Booysens shale.

The quartz arenite of the Zandfontein Quartzite Formation is interpreted as representing a marine sand-sheet facies with rare shallow scours. The maturity of this unit suggests that it was deposited during a period of relative basin stability and low sediment supply, with re-working by marine processes, yielding ideal conditions for deposition of a quartz arenite. The laterally persistent siltstone drapes within the quartzite are accounted for by periodic storm activity.

The presence of a conglomerate cannot be used in this case as an indicator of a tectonically active source nor of proximity to a source terrain. Certain sedimentological data that have previously been used as evidence for interpreting fluvial depositional processes are not definitive and are also compatible with deposition in a marine system.


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# THE ZANDFONTEIN QUARTZITE FORMATION, A MARINE DEPOSIT IN THE CENTRAL RAND GROUP, WITWATERSRAND SUPERGROUP

## I. INTRODUCTION

Rocks of the Witwatersrand Supergroup in the Evander Basin dip to the north at approximately 25° and are successively overlain by younger rocks of the Ventersdorp Supergroup and Transvaal and Karoo Sequences. The Evander Basin is bounded by a major peripheral fault system in the south, whereas the northern limit of the basin has yet to be defined (Tweedie, 1980). A thickness of only 750m of Central Rand Group rocks is preserved in the Evander Basin (Figure 1).

The Zandfontein Quartzite Formation and the upper portion of the Booysens Shale Formation of the Witwatersrand Supergroup were studied in underground exposures and borehole core from Bracken Mines Limited and from the northern portion of Kinross Mines Limited in the Evander Goldfield (Figure 2).

A total of 112 localities were investigated and pebble counts, samples of reef for assay, and the general characteristics of the Zandfontein Quartzite Formation and the upper portion of the Booysens Shale were studied. Underground exposures were generally limited to intersections in cross-cuts and drives, as no stoping of the Zandfontein Reef has been carried out to date. A total of 7 underground boreholes, covering the whole study area and which intersected the entire Zandfontein Quartzite Formation, were also examined.

Relatively few publications have described the geology of the Evander Basin. The sedimentology and stratigraphy of the Booysens Shale in the Evander Basin was documented by Tweedie (1968), and the alteration and mineralogy of the shale by Palmer *et al.* (1986, 1989). Phillips (1987) studied the mineral assemblages of the Booysens Shale, recording greenschist facies metamorphic conditions (350 ± 50°C and 1-2 kb). The general geology of the basin, and in particular the Kimberley Reef, has been documented by Tweedie (1978, 1980, 1986) and the detailed mineralogy of the Kimberley Reef has been described by Hirdes (1979) and Hirdes and Saager (1983).

The Zandfontein Quartzite Formation in the Evander Goldfield consists of a series of low-relief, elongated conglomerate bars which trend northeast-southwest and which are overlain by a siliceous, cross-bedded metaquartzite with laterally persistent silt drapes occurring on bedding surfaces. The formation has previously been interpreted as representing a significant change in depositional style from subaqueous to subaerial conditions (Tweedie, 1980).

This study re-examines the sedimentology of the upper part of the Booysens Shale Formation, the Zandfontein Reef, and the Zandfontein Quartzite. As a result a new interpretation has been postulated for the depositional palaeo-environments of this stratigraphic interval.

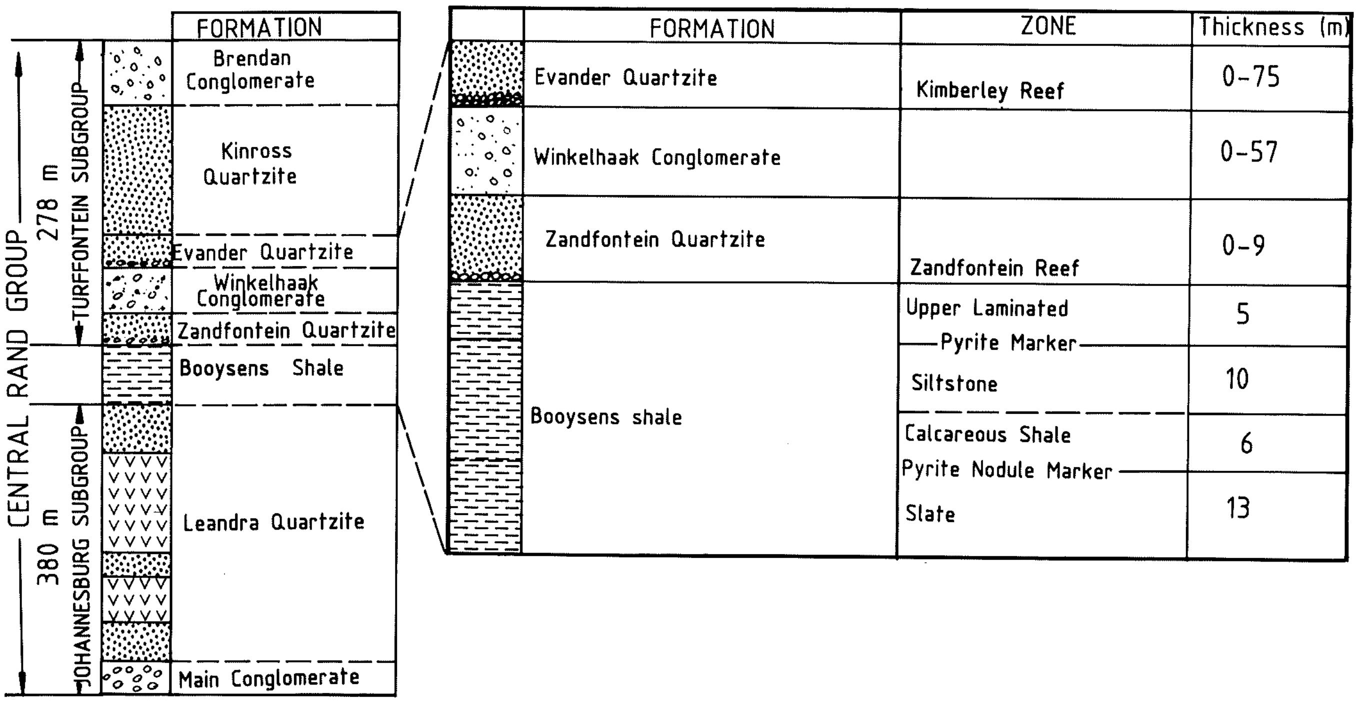


*Figure 1: Stratigraphy of the Central Rand Group in the Evander Goldfield (after Tweedie, 1986; fig. 3 p.707).*

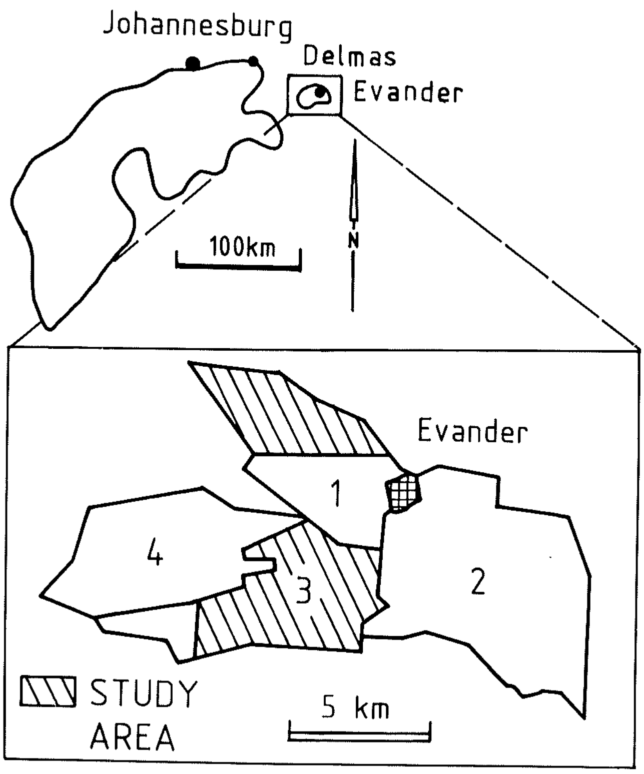


*Figure 2: Locality map of the Central Rand Group of the Witwatersrand Supergroup, with a detailed map of the Evander Goldfield. Mines of the Evander Goldfield are Kinross (1), Winkelhaak (2), Bracken (3) and Leslie (4).*

## II. STRATIGRAPHIC RELATIONSHIPS

The Zandfontein Quartzite Formation (locally known as the LK 1 quartzite) overlies the Booysens Shale Formation. Towards the edges of the Evander Basin the distance between the Zandfontein Quartzite and the pyrite marker, located near the top of the Booysens Shale, decreases (Tweedie, 1968) and the pyrite marker is absent to the northwest of the Evander Goldfield (Tweedie, 1986). On Bracken and Kinross mines the shale/quartzite contact is sharp, appears conformable, and parallels both small-scale laminations within the shale as well as the laterally continuous pyrite marker, which is itself parallel to bedding. In a structural remnant of Central Rand Group sediments in the Delmas area, to the northwest of Evander, the contact with the underlying Booysens Shale is gradational. Black shale bands up to 1.5m thick occur interbedded with 6-15m thick argillaceous sandstones (Button, 1968).

Where the contact between the Booysens Shale and the Zandfontein Quartzite Formation is sharp, the upper surface of the Booysens Shale displays current ripples, oscillation ripples, groove marks, striations (Tweedie, 1968), and soft sediment deformation features such as flame structures (Figure 3a) and load casts. The above data, together with the basin-wide extent of the Booysens Shale, indicate that the shale was deposited as a marine transgressive sequence.

Over distances of $>$25m along strike the parallelism of the base of the Zandfontein Quartzite Formation to sedimentary structures contained within the Booysens Shale confirms the lack of channelling or erosion along the Booysens shale/Zandfontein Quartzite contact. The Booysens Shale/Zandfontein Quartzite contact is, in places, defined by a pyrite layer of up to 6mm thick, consisting of fine-grained crystalline pyrite and rare compact detrital and porous pyrite grains. The contact is overlain, in places, by a laterally discontinuous small-pebble oligomict conglomerate (Zandfontein Reef, Figure 3b) consisting predominantly of subrounded to subangular chert and minor vein quartz clasts (Table 1). The conglomerate attains a maximum thickness of 60cm and in places contains granule-conglomerate and sandstone lenses. The conglomerate thickens, thins, and pinches out, revealing a lensiod geometry in cross-section.

A fine- to medium-grained cross-bedded quartzite containing granule-conglomerate lenses overlies the small-pebble conglomerate. These lenses are more abundant in the lower 2m of the quartzite. The quartzite varies from light- to medium-grey in colour, has a pervasive stippling of black, fine- to coarse-grained chert grains, and has an average thickness of 9m. Laterally persistent mudstone drapes ($<$2cm thick) are present along coset surfaces in places.

The upper contact of the Zandfontein Quartzite with the overlying Winkelhaak Conglomerate Formation (known locally as the MK 3 quartzite) is erosive. The Winkelhaak conglomerate is a pebbly, micaceous quartzite containing scattered clasts of chert and vein quartz and poorly to moderately packed, poorly sorted, scattered conglomerate bands.

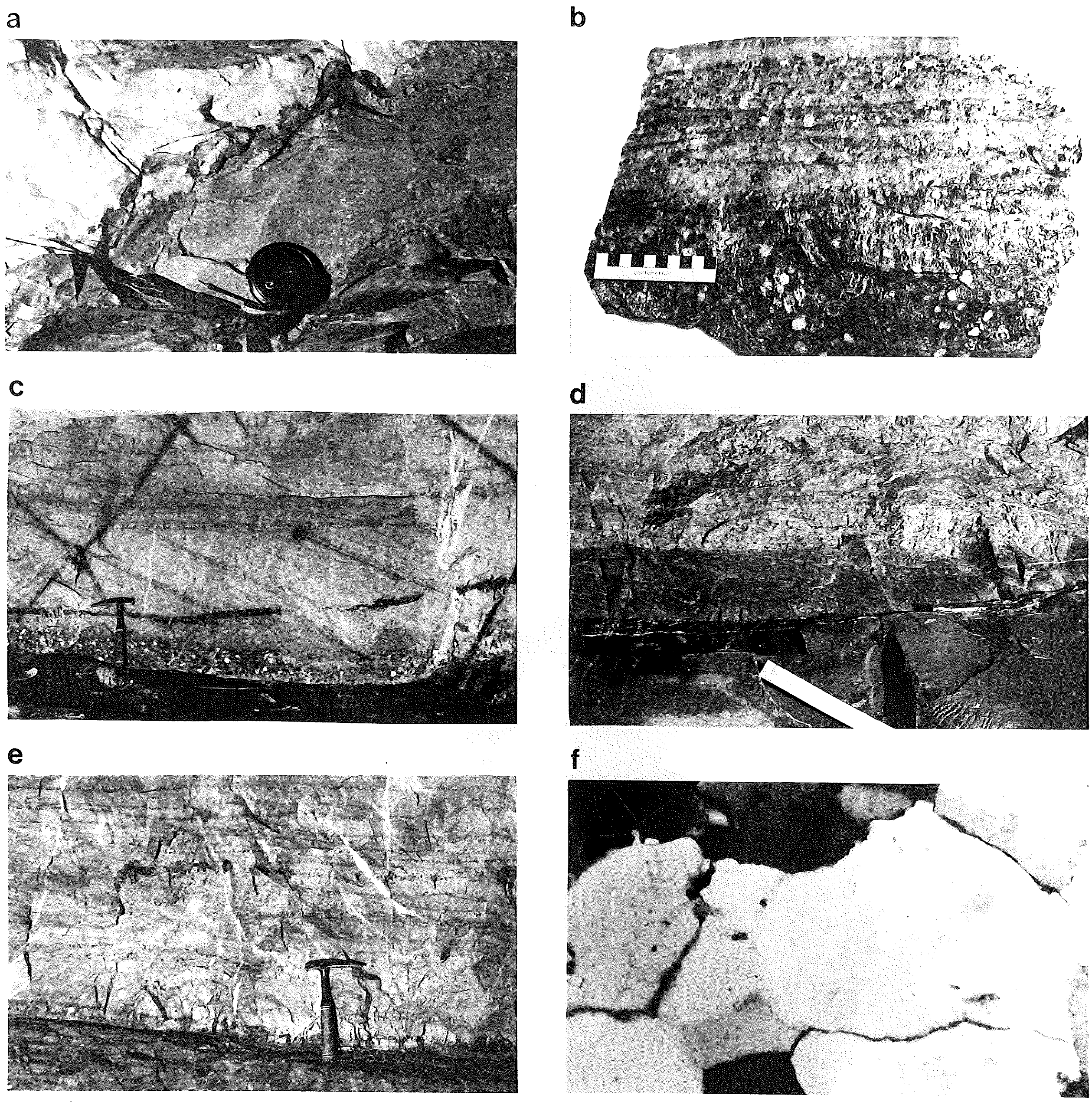


*Figure 3a:* *Soft sediment deformation at the base of the Zandfontein Quartzite.*

*b:* *Oligomict Zandfontein Reef, matrix supported and cross-bedded.*

*c:* *Booysens Shale overlain by the Zandfontein Reef, in turn overlain by large-scale planar cross-bedding. Overlying this are small-scale planar cross-beds.*

*d:* *Booysens Shale overlain by stacked planar cross-bed sets separated by a reactivation surface.*

*e:* *Booysens Shale overlain by plane-bedded sandstone.*

*f:* *Photomicrograph of the Zandfontein quartz arenite showing interlocking boundaries, with original well-rounded detrital outlines preserved in the secondary overgrowths. Field of view = 2mm.*

*Table 1: Modal proportions of pebble types for Bracken and Kinross mines*

| PEBBLE TYPE | PERCENTAGE |
|---|---|
| i) vein quartz | |
| a)clear............ | 26.0 |
| b)blue opalescent... | trace |
| ii) massive chert | |
| a)black/grey........ | 58.5 |
| iii) banded chert | |
| a)grey/black/white.. | 8.5 |
| b)green/grey........ | 2.8 |
| c)jasperlitic....... | 1.5 |
| iv) quartzite............. | trace |
| v) felsic volcanics...... | 1.0 |
| vi) silicified shale...... | trace |

## III. SEDIMENTOLOGY

### A. Facies Types

*(i) Interbedded mudstone and siltstone (Booysens Shale)*

The Booysens Shale Formation in the Evander area consists of four zones (Figure 1) all of which have been documented by Tweedie (1968). The Upper Laminated Zone and the contact of this zone with the Zandfontein Quartzite Formation are described below.

The Upper Laminated Zone comprises a dark-grey to black, pyritic, finely laminated, fissile mudstone interlaminated with grey siltstone and rare calcareous siltstone lenses. Mineralogically, it consists predominantly of angular quartz grains (0,004 - 0,06mm grain size) in a matrix of intergrown chlorite and muscovite (confirmed by XRD analysis). The most common sedimentary structures are parallel lamination, symmetrical ripples, load casts, slump and flame structures, and graded bedding. Symmetrical ripples are exposed on bedding planes and have wavelengths of 3-8cm and amplitudes of 1-3cm. Pyrite stringers and nodules, both consisting of fine-grained secondary crystalline pyrite, are also present in places along bedding planes.

The upper 2m of the Booysens Shale is characterized by a light-green discoloration in places, which decreases in intensity away from the contact (Law *et al.*, 1988). The contact zone is generally characterized by a foliation parallel to bedding, and which occurs irrespective of the colour changes.

*(ii) Conglomerate*

A wide spectrum of coarse-grained lithologies occur at the base of the Zandfontein Quartzite (Figure 4), ranging from pebbly sandstones through thin, impersistent pebble lags to well-packed, clast-supported conglomerates. The conglomerate rarely exceeds 50cm in thickness and is interbedded with sandstone and granule-conglomerate. A summary of the statistical data for a sample of the pebble population is presented in Table 2. Packing, sorting, and clast size vary laterally and vertically in

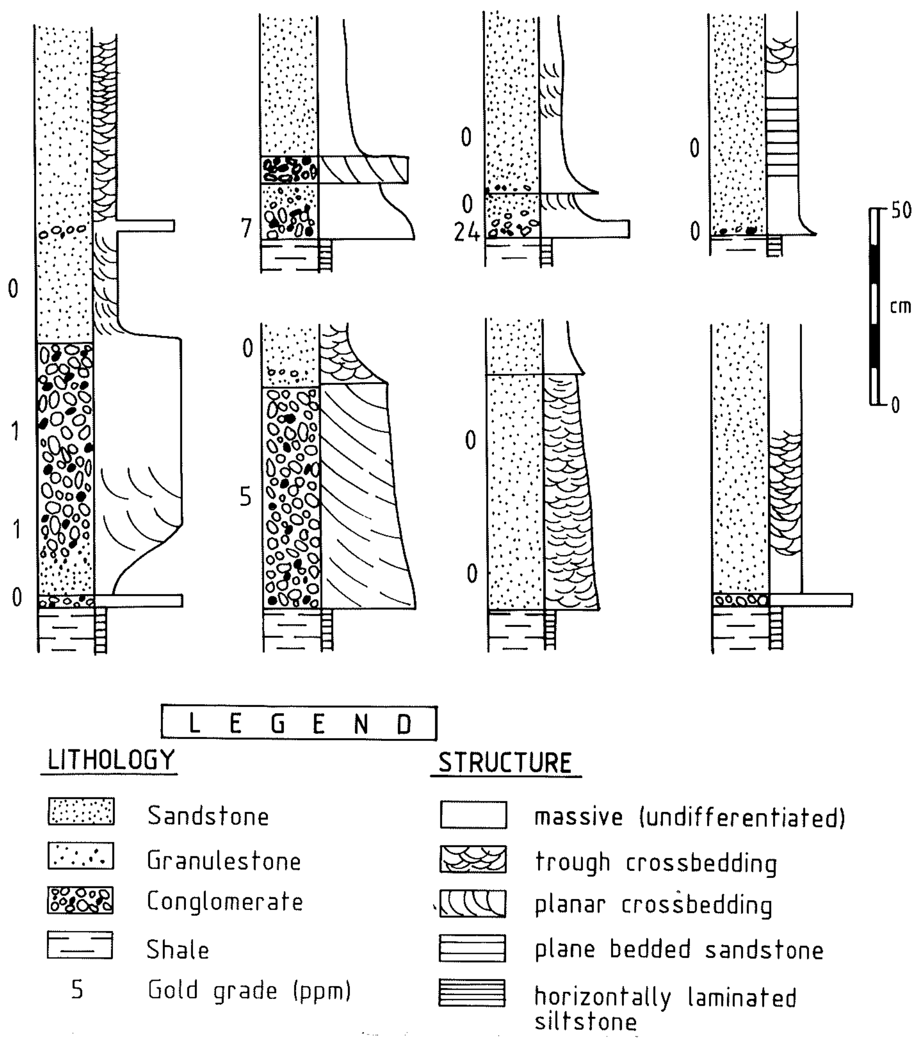


*Figure 4: Representative profiles of the Zandfontein Reef Zone showing varying facies developments from the base of the Zandfontein Quartzite Formation which overlies the Booysens Shale. Profile widths are schematic and the profiles are not shown in any particular sequence.*

*Table 2: Statistical data for 64 localities of the Zandfontein Reef. Arithmetic means of the pebble data have been calculated for each locality. Gold grades are calculated as a geometric mean. $C=S/\bar{x}$, where S is the standard deviation and $\bar{x}$ the mean pebble diameter. Sp=DL/DS, where DL is the estimated long axis and DS the estimated short axis of each pebble. $ND=(DLxDS)^{\frac{1}{2}}$, DL and DS as above.*

| PARAMETER | AVERAGE VALUE |
|---|---|
| MEAN PEBBLE DIAMETER x (mm) | 9.20 |
| SORTING (C) | .52 |
| SPHERICITY (Sp) | 1.60 |
| NOMINAL DIAMETER (ND)(mm) | 8.70 |
| GOLD GRADE (ppm) | .54 |
| THICKNESS (cm) | 14.00 |
| CHERT / VEIN QUARTZ | 3.30 |
| PACKING (%) | 38.00 |
| LARGEST PEBBLE (mm) | 60.00 |

n = 1800

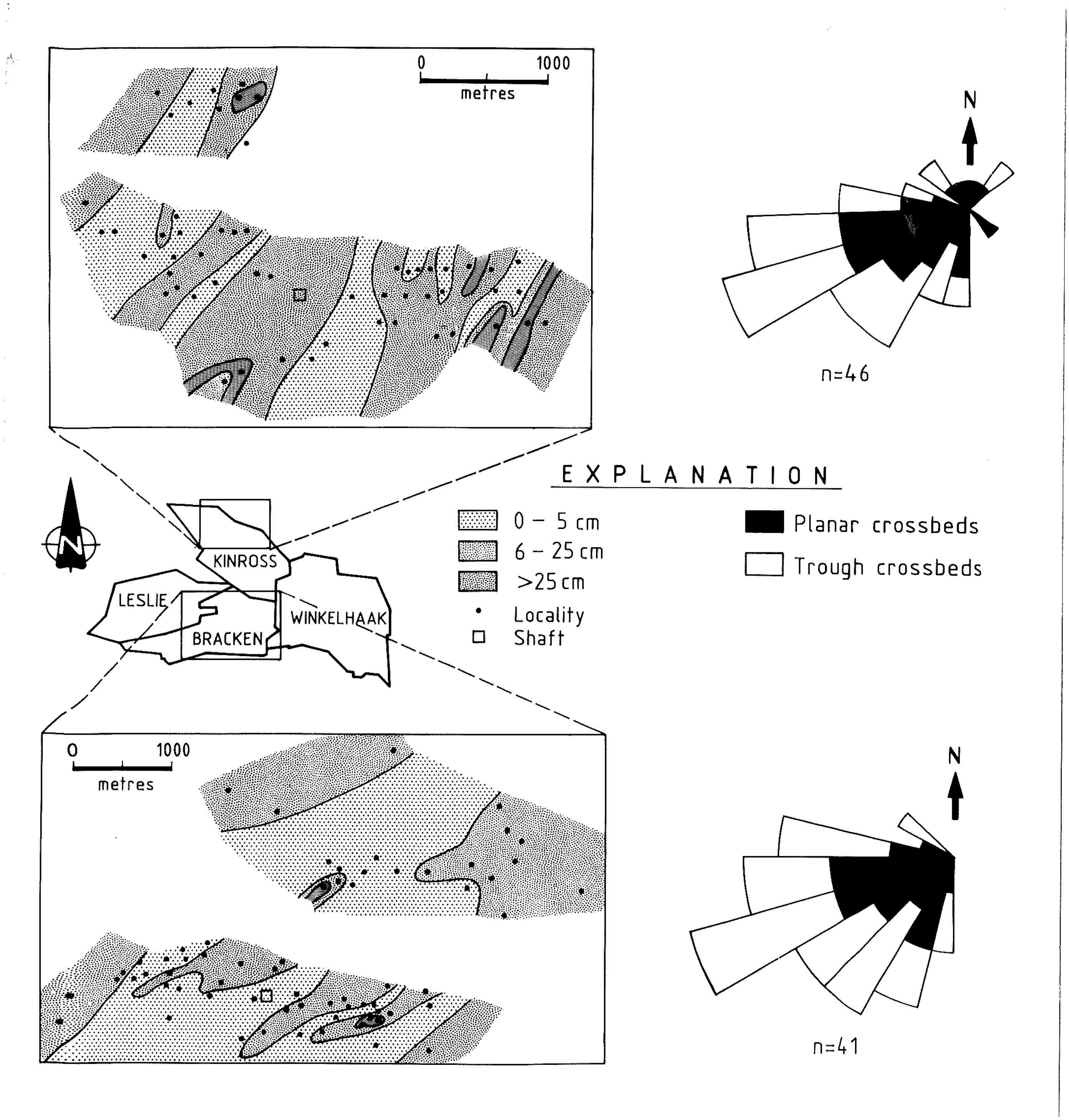


*Figure 5: Isopach plan of the Zandfontein Reef Zone defining northeast/southwest-trending conglomerate bars. Palaeocurrent rose diagrams for the Zandfontein Quartzite Formation in the Kinross and Bracken areas, respectively, are also shown (class interval =15°).*

the reef zone. In general the reef is ungraded, but normal and reverse grading both occur, with normal grading dominant. The lateral distribution and thickness of the reef package (conglomerate and inter-bedded sandstone) indicate a number of northeast to southwest-trending conglomerate bars with widths of up to 100m and lengths of several hundred metres (Figure 5). Where the conglomerate is absent, the Booysens Shale is overlain by either trough or planar cross-bedded, medium- to coarse-grained sandstone.

Conglomerates of the Zandfontein Reef display a mound-shaped cross-sectional geometry upon the planar upper surface of the Booysens Shale Formation (Figure 6). Thickness variations from 0 - 50cm in the Zandfontein Reef occur over distances of 5 - $>$25m.

The mineralogy of the conglomerate is dominated by quartz, white mica, and chlorite, which occur in the argillaceous matrix of the Zandfontein Reef. The Zandfontein Reef and quartzites contain neither pristine nor partly altered feldspar grains.

*(iii)* *Sandstone*

The sandstones range from fine- to very coarse-grained and are well sorted. Sandstone beds are separated by mudstone drapes in places. These mudstone drapes are present in both borehole core and underground exposures where they have a maximum thickness of 4cm and extend laterally for distances in excess of 30m.

The mineralogy of the Zandfontein Quartzite is relatively simple. The quartzite consists of a light yellow-grey, fine- to medium-grained quartz arenite with $<$4% matrix (Figure 3f). Some quartz grains exhibit undulose extinction and have interlocking boundaries, with original well-rounded to very well-rounded detrital outlines preserved in the secondary over-growths.

Stylolitic partings parallel to bedding are abundant. These have a green chloritic staining up to 2cm wide on either side of the parting and contain anomalous concentrations of pyrite. These surfaces are the result of the removal of quartz by pressure solution, a process particularly common in clean quartzitic sediments (Whisonant, 1970).

The modal mineralogy of the Zandfontein Quartzite as revealed by point count analyses of 14 thin sections is as follows;

| | |
|---|---|
| quartz | 91,1 % |
| chert | 5,1 % |
| interstitial chlorite and white mica | 3,8 % |

Four sandstone subdivisions of the Zandfontein Quartzite have been defined on the basis of sedimentary structures:

(1) trough and planar cross-bedded sandstone (Figure 3c). Trough cross-bedding in this facies consists of solitary sets or cosets of mutually cross-cutting troughs. Set thickness varies from 5 - 50cm with corresponding widths of 20 - 200cm. Trough cross-bedded cosets of $>$1,5m thick occur in places. A pebble lag may be present lining the erosional bases of troughs. Foresets are defined by concentrations of heavy minerals (pyrite, zircon, leucoxene, chromite) and chlorite.

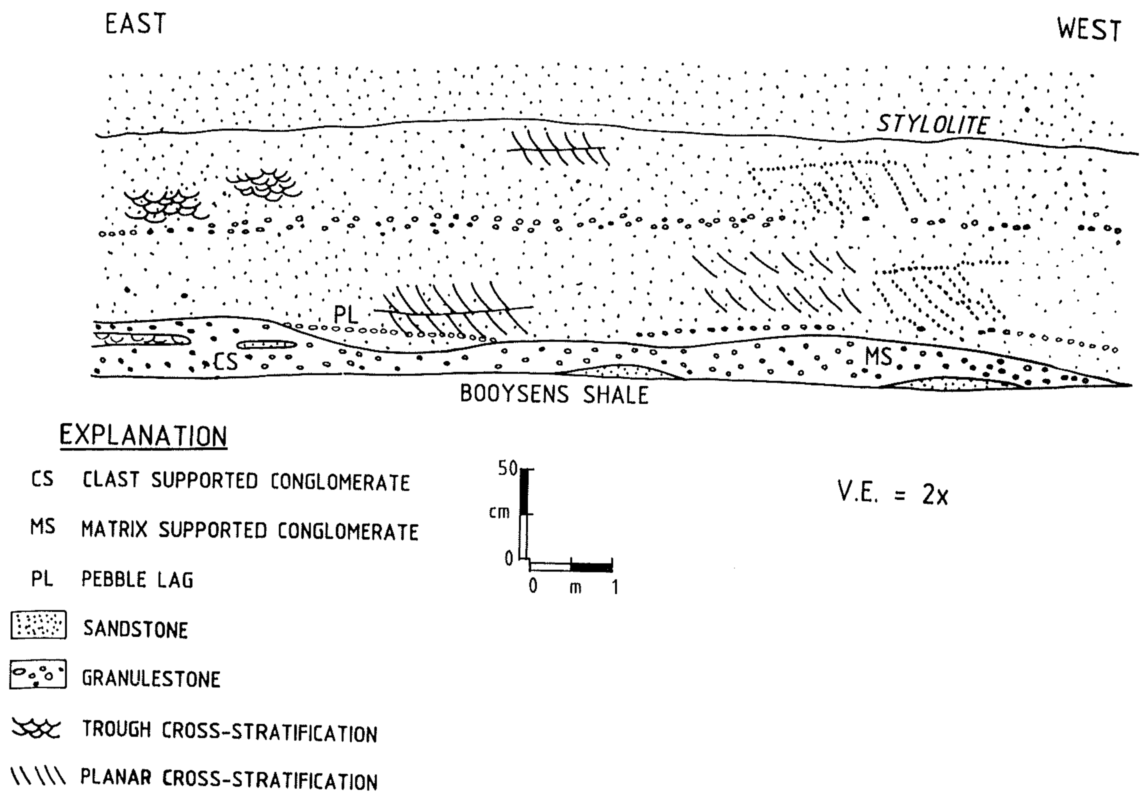


*Figure 6: Cross-section of the upper portion of the Booysens Shale and the lower portion of the Zandfontein Quartzite Formation, from the northern part of Bracken Mine.*

Planar cross-beds (Figure 3d) have sharp, flat, set bases with set thickness ranging from 5 - 150cm. Some foresets are normally graded and show a grain size range from granule-conglomerate to fine-grained sandstone. Foresets are defined by concentrations of pyrite and heavy minerals. Planar cosets are vertically stacked (up to 150cm) and laterally persistent for up to 20m. These cosets may be separated by reactivation surfaces;

*(2)* *scour and fill structures* are also present in the Zandfontein Quartzite. Shallow scours, which rarely exceed 30cm in depth and 5m in width, have eroded the trough and planar cross-bedded sandstone facies. They contain numerous small fining-up planar and trough cross-bedded sets (10cm thick);

*(3)* *plane bedded sandstone.* This facies is defined by fine-grained, plane bedded argillaceous sandstone with slightly undulating bedding surfaces. These sets, less than 1cm thick, have gradational upper contacts and are separated by quartz arenite interbeds, in places of up to 10cm thick (Figure 3e); and

*(4)* *massive sandstone.* These sandstones appear as either massive or crudely bedded and range in thickness from a few centimetres to several metres. The sandstone is fine- to medium-grained and texturally and mineralogically mature. The good sorting and lack of argillaceous material and heavy mineral concentrations on foresets and bedding planes may account for the massive nature of these sandstones. Massive sandstones overlie the conglomerate and planar and trough cross-bedded sandstone facies.

Rare lenticular beds of quartz wacke, up to 20cm thick and which persist laterally for up to 20m, occur interbedded within massive sandstone. The quartz wacke is medium- to coarse-grained and is green due to the presence of mica and chlorite.

## B. Facies Interpretation

### *(i) Interbedded mudstone and siltstone (Booysens Shale)*

The thick, regionally persistent nature of this unit indicates subaqueous deposition in a low-energy environment. The interbedded mudstone-siltstone laminations of the Upper Laminated Zone are indicative of cyclic sedimentation. These laminations resemble fine-grained turbidity current laminae (c.f. Stow and Shanmugam, 1980), being similar to the `D' and `E' sequence of turbidites (c.f. Bouma, 1962). These inter-laminated units were evidently subjected to periodic wave action, which produced the symmetrical ripples.

### *(ii) Conglomerate*

Pebbly sandstones at the base of the Zandfontein Quartzite Formation resulted from a low pebble-to-sand ratio with intermittent pebble movement on a sand bed. The concentration, in places, of conglomerates at the base of the formation in places, resulted from a lowering of the sand-to-pebble ratio, either reflecting changing characteristics of the source, with a related decrease in the sand supply, or an increase in depositional energy of the system, leading to increased winnowing of the sand fraction. Increased packing towards the top of thicker conglomerate beds suggests that winnowing of the upper-bed surface was an important depositional control. Well-packed conglomerates resulted from the deflation, winnowing, and reworking of earlier deposits as a result of low sediment supply and attendant low rates of aggradation. The conglomerate facies is, therefore, interpreted as being deposited by traction currents and thereafter reworked and winnowed in an environment with a low sediment supply.

### *(iii) Sandstone*

The maturity of the Zandfontein Quartzite indicates that a significant amount of reworking occurred prior to or during the deposition of this material. Argillaceous laminations within horizontally bedded sandstones are interpreted as suspended load material deposited during low energy conditions via suspension settling.

Massive beds may be formed either by very rapid deposition from suspension or by deposition from highly concentrated sediment dispersions (Blatt *et al.*, 1980). Lens-shaped beds of massive quartz wackes are interpreted here as rapidly deposited subaqueous sediments, possibly as a result of storm action. No evidence of hummocky cross-stratification has been found, however, which could serve to confirm such storm action. Laminations formed during deposition may also have been destroyed by liquefaction soon after deposition (Blatt *et al.*, 1980), but no evidence of widespread de-watering and deformation is present. The massive sandstones also reflect the sorting and maturity of the Zandfontein Quartzite ($<$4% argillaceous material).

Trough cross-bedded sandstones of the Zandfontein succession were deposited by migrating sand ripples and dunes. The sand ripples (small sand waves) are independent of water depth provided water depth exceeds several ripple heights (Stride, 1982). As flow rate increased the sand ripples were smoothed out and larger wavelength bedforms (sand waves) appeared.

The scour and fill structures present in the Zandfontein Quartzite represent separate erosional and depositional events as shallow scours are filled by a number of upward fining depositional units.

## IV. PALAEOCURRENT DATA

Directional measurements from trough and planar cross-stratification for the Zandfontein Quartzite indicate that sediment transport was weakly bipolar, but predominantly towards the southwest (Figure 5). Diametrically opposed current directions occur in stacked, small-scale, trough cross-beds. The transport direction parallels the northeast/southwest palaeocurrent trends and southwesterly directional indices which occur in the underlying Booysens Shale Formation. These data were measured by Tweedie (1968) using the crest strikes of current ripples, wave ripples, groove casts, and flute casts.

The palaeocurrent directions for the Zandfontein and Kimberley Reefs are diametrically opposed in the Evander Goldfield (west-southwest for the Zandfontein Reef and east-northeast to north for the Kimberley Reef; Tweedie, 1980). In each of these reefs the palaeocurrent directions are, however, consistent between the conglomerate and overlying quartzite.

## V. MINERALIZATION

Sulphides account for $<5\%$ (by volume) of the total conglomerate, of which pyrite accounts for $>95\%$ of these sulphides. Gold grades vary from 0 to 25ppm with a geometric mean of 0,54 ppm from 68 samples. Pyrite-rich samples generally contain higher gold grades. Uranium content of the Zandfontein Reef is low (± 30ppm). A pyrite layer of 0,5 - 6mm thick and consisting of fine-grained crystalline pyrite up to 4mm in diameter and compact round pyrite of 0,5 - 2mm in diameter is developed in places along the upper contact of the Booysens Shale. Also present are rare porous pyrite grains up to 1cm in diameter. The pyrite layer branches and transgresses in places into the reef zone and disseminated as well as crystalline pyrite also occurs as replacements of massive and banded chert clasts, particularly along their bedding planes.

Other minerals present in the Zandfontein Reef include pentlandite, chalcopyrite, galena, zircon, and chromite.

## VI. DISCUSSION

### A. The Zandfontein Quartzite Formation: a Marine Deposit

The Zandfontein Reef displays a number of features which are consistent with those of offshore marine gravels. These features as well as those of offshore marine gravels and fluvial gravels, and their associated sediments, are compared in Table 3.

On Bracken and Kinross mines the Booysens Shale/Zandfontein Quartzite contact may represent a period of non-deposition or planar erosion. The contact is extremely flat, as indicated by its parallelism with both the horizontal laminations and the bedding-parallel pyrite marker in the Booysens Shale (Tweedie, 1968). Also, soft-sediment deformation and sole marks are present on the contact. These factors indicate that the contact

*Table 3: A comparson of offshore marine and fluvial gravels (modified from Leckie and Walker, 1982, table 1)*

| PARAMETER | FLUVIAL GRAVELS | OFFSHORE GRAVEL BARS AND GRADED STORM LAYERS | ZANDFONTEIN CONGLOMERATE |
|---|---|---|---|
| THICKNESS | 0-38m | 0-5m, generally <70cm | 0-60cm |
| BASAL CONTACT | sharp with grooves | sharp, planar? | sharp, planar |
| CLAST SIZE | < 20cm | average 2-3cm<br>maximum 6cm | average 1.3cm<br>maximum 6cm |
| TEXTURE | clast-supported<br>sandy matrix | clast- to matrix-supported<br>sand matrix | clast- to matrix-supported<br>sand matrix |
| PALAEOCURRENTS | unimodal, commonly 180° spread | unimodal or bipolar | unimodal and weakly bipolar |
| TOP CONTACT | planar | symmetrical gravel bedforms | low amplitude gravel bars |

is conformable and that the conglomerate was deposited on the unconsolidated and planar surface of the Booysens Shale.

No subaerial exposure features were found during this study nor have they been described previously. The Booysens Shale does, however, display grooves, striations, spatulate impressions and current and wave ripple marks. These data led Tweedie (1968) to interpret a distal marine environment for the deposition of this formation.

The elongate conglomerate bars which overlie the Booysens Shale show a vertical increase in conglomerate packing density and a concentration of pebble lags on the edges of these bars. This suggests that winnowing processes, by sea-bottom currents, were responsible for the concentration of heavy minerals as the sand fraction was removed. These features are interpreted as evidence for the tidal current or storm-induced current reworking of the conglomerates.

The Zandfontein Quartzite is both texturally and mineralogically mature and many authors consider marine (and particularly tidal) currents to be one of the most effective agents in producing such deposits, (e.g. Johnson and Baldwin, 1986; Balazs and Klein, 1972; Banks, 1973).

Laterally extensive mud drapes of the Zandfontein Quartzite are indicative of a tidal regime or of a storm-dominated shelf, but they are less common and pronounced where time-velocity asymmetry is less and reactivation surfaces are more common (Reineck and Singh, 1973). Silt and mud drapes probably represent periods of post-storm stillstand, as intertidal stillstands are of insufficient duration for the deposition of suspended material, and they may be entirely absent or partially eroded in turbulent tidal regimes (Johnson and Baldwin, 1986).

Other features indicative of a marine environment, and possibly suggesting a tidal regime, are erosion scours of low relief (less than 1m; Boersma and Terwindt, 1981). Erosion channels within the Zandfontein Quartzite are <30cm in depth.

Palaeocurrent trends within the Zandfontein Quartzite are weakly bimodal, but are generally unimodal to the southwest. Most inferred ancient tidal shelf sandstone deposits do not show predominant current reversals (Johnson and Baldwin, 1986), and the most commonly documented palaeocurrent patterns are unidirectional (e.g. Narayan, 1971; McCave, 1973; Anderton, 1976; Johnson, 1977a, b; Levell, 1980; Johnson and Baldwin, 1986).

The quartz arenites which separate the conglomerates of the Zandfontein Reef are considered to represent sand patches. These may be transverse or longitudinal (relative to the current flow direction) and are accumulations of sand swept from surrounding conglomerate bars by winnowing processes. Gravel, flushed onto the shelf during high energy storm events, is reworked to form low-amplitude gravel bars. Sand ribbons parallel gravel bars and reach 200m in width, but are less than 1m thick. The areas of sandstone which occur between individual conglomerate bars of the Zandfontein Reef, and which show a variety of bedforms including trough and planar cross-bedding, are interpreted here as being sand ribbons.

Planar cross-beds (amplitude $>$1m) and trough cross-beds (sets 10 - 200cm thick) which occur in the Zandfontein Quartzite Formation are generally vertically stacked and have laterally extensive cosets. Such deposits result from the migration of sandwaves and dunes in tide-dominated continental shelf deposits (Johnson and Baldwin, 1986).

The general progression of facies types, bedforms, and hydrodynamic zones present on a marine shelf with a low sediment supply relative to the palaeoshoreline, is illustrated (Figure 7). The concept of seaward fining of clastic sediments is commonly incorrect as applied to present-day continental shelves. In many cases outer continental shelf sediments are coarser than those found on inner shelves because outer shelf sediments represent re-workings of beach and fluvial deposits (McCave, 1985). Bedforms may be transverse and/or longitudinal relative to the palaeoshoreline, with current velocities increasing towards the palaeoshoreline. The Zandfontein Reef and Quartzite could represent the vertical stacking of shoreward facies zones on conglomerate bars of the more distal facies zone, during a continued regression.

The unusual lateral facies association of gravel and the low-energy argillites of the Booysens Shale is a result of rapid deposition from storm-induced currents, marine winnowing, and reworking of the sand-depleted outer shelf. The stratigraphically equivalent sediments of the Booysens Shale and Zandfontein Quartzite in the Delmas area have been documented by Button (1968) and the gradational contact in this area may represent the zone of interfingering between the deep water Booysens Shale facies and the laterally equivalent tidal marine shelf deposits of the Evander area.

The lithological, textural, and sedimentary structures suggest evidence for both storm (laterally persistent silt drapes) and tidal (trough and planar cross-bedded quartz arenite) processes. Tide/storm interactive systems are not uncommon to Precambrian and Cambrian rocks and have been documented in Norway and Scotland by Banks (1973), Anderton (1976), Johnson (1977a, b) and Levell (1980). Moreover, tidal processes have been documented for the West Rand Group of the Witwatersrand Supergroup by Eriksson *et al.* (1981).

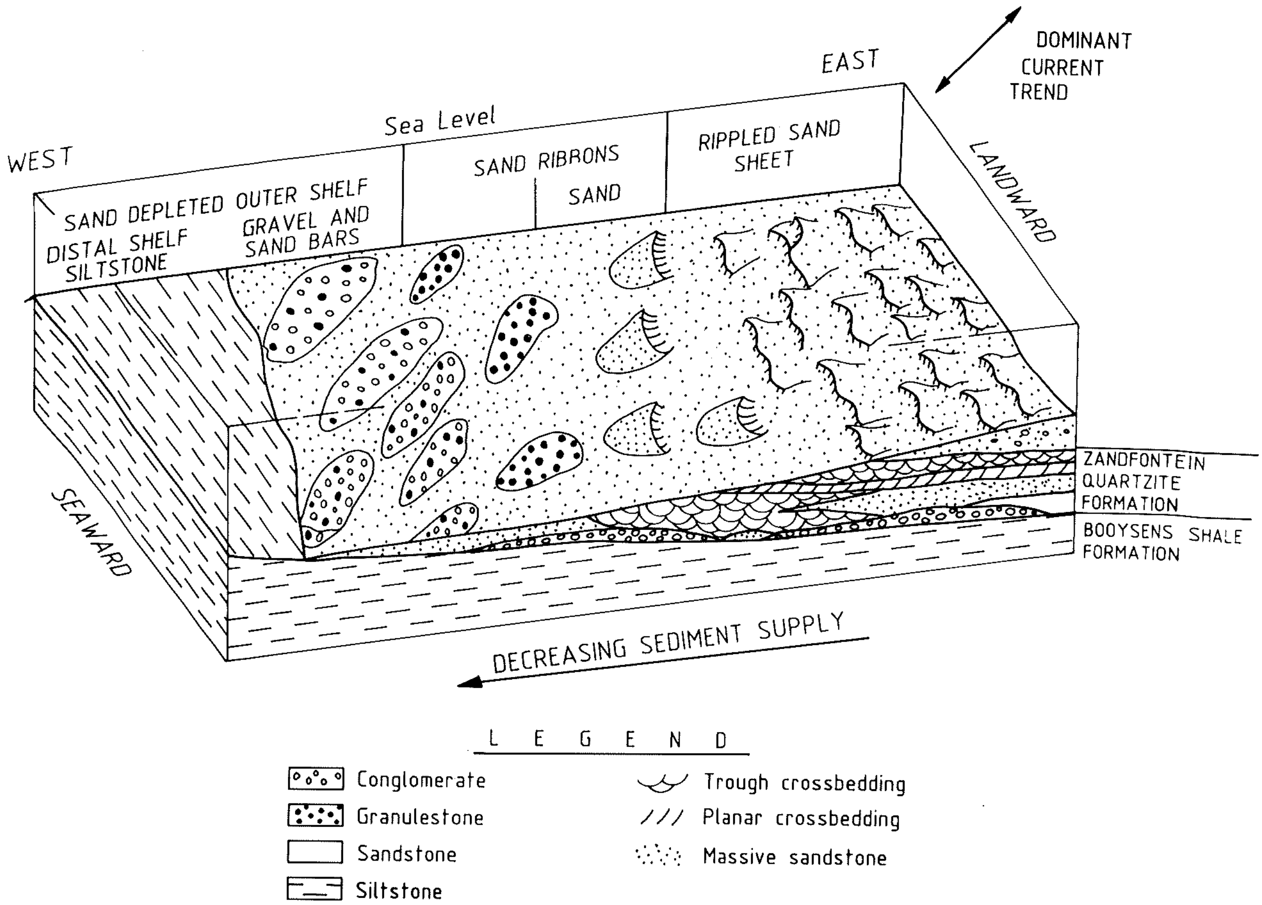


*Figure 7. Distribution of facies zones on a shallow marine shelf (modified after Stride, 1982, fig. 2).*

The facies relationships between the Zandfontein Quartzite Formation and the overlying Winkelhaak Conglomerate Formation are unclear due to the erosive nature of the contact which may represent a significant break in sedimentation.

The facies sequences preserved on the southeast African coast (Flemming, 1980) show a seaward progression from sand, to a sand-depleted, outer-shelf-conglomerate pavement similar to that described by Stride (1982). A regression would thus result in an upward-fining sequence, with a basal conglomerate such as that preserved within the Zandfontein Quartzite Formation.

The occurrence of a marine arenite overlying a marine shale has been documented in the Cretaceous Gallup Sandstone (marginal marine) which conformably overlies the horizontally bedded Marcos Shale (marine) in the southwestern San Juan basin, New Mexico (McCubbin, 1972). The Cretaceous Shannon and Sussex Sandstones of Wyoming also formed as sandy off-hore accumulations about 100km from the nearest shoreline deposits. These sandstones conformably overlie and are contained within marine shales (Harms *et al.*, 1975). The Campanian Hygiene Sandstone of Colorado comprises a similar stratigraphic sequence (Porter, 1976).

The above examples occur within aggradational sequences in broad epicontinental seas, with the sandstone bodies being isolated from shoreline trends and showing no consistent relation to disconformities (Harms *et al.*, 1982). The bedforms described above have also been documented in modern tidal deposits around the British Isles, the Celtic Sea and the Georges Bank, U.S.A. (Stride, 1982).

### B. Problems with a Fluvial Model for the Zandfontein Quartzite Formation

The following points mitigate against a braided stream depositional environment being inferred for the Zandfontein Quartzite Formation:

(1) the supermature rounding and sorting of grains, which are characteristic of inter- and sub-tidal sandstone bodies (Klein, 1977),
(2) the laterally extensive silt drapes;
(3) the lateral extent of the Zandfontein Quartzite and the lack of mineralogical and textural variation within the study area;
(4) the lack of a systematic change in statistical parameters of the reef such as decreasing pebble size or roundness in the direction of transport;
(5) the absence of laterally and vertically stacked longitudinal conglomerate bars (the Zandfontein Reef consists of a series of stratigraphically equivalent elongate conglomerate bars directly overlying the Booysens Shale);
(6) the deposition of the Zandfontein Reef on the planar and apparently unconsolidated surface of the Booysens shale without significant erosion;
(7) the lack of channelling; and
(8) the lack of complex bedforms which have been modified by numerous erosional and depositional events after their initial formation (Smith, 1974).

## VII. CONCLUSIONS

The Zandfontein Reef in Evander represents a series of low-relief elongate conglomerate bars deposited on a shallow marine shelf. Deposition occurred during a marine regression on the unconsolidated palaeosurface of the Booysens shale. Sedimentation was probably influenced by both storm- and tidal-currents. The conglomerate bars were winnowed and eroded locally by tidal currents, and are separated by longitudinal sand ribbons similar to those described by Stride (1982). The overlying Zandfontein Quartzite represents a sand-sheet facies with unipolar and rare bipolar cross-bedding and shallow channels.

The low sediment supply and maturity of the Zandfontein Quartzite, which is reflected in sorting, packing, and the lack of argillaceous material, suggests that the sediments were deposited during a period of relative basin stability.

The recognition of marine sediments in the Central Rand Group suggests that marine processes and the marine/terrestrial interface may be important in the deposition of other Witwatersrand conglomerates.

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