ECONOMIC GEOLOGY RESEARCH UNIT

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STRATIGRAPHIC HISTORY OF THE MIDDLE PROTEROZOIC UMKONDO BASIN IN THE CHIPINGA AREA, SOUTHEASTERN RHODESIA

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INFORMATION CIRCULAR No. 108

UNIVERSITY OF THE WITWATERSRAND

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by

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March, 1977

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ABSTRACT

The 2 000 m thick middle Proterozoic Umkondo System in southeastern Rhodesia comprises gently deformed continental, marginal marine and marine sediments, deposited on an east-sloping continental margin. The basal sediments were laid down on an undulating granitic basement in a marginal-marine environment, in which the *sebkha* is thought to have been a prominent element. The inferred *sebkha* dolomites are algal laminated, show calcite-filled birdseye vugs, and carry scattered (probably aeolian) quartz sand grains. Continued subsidence and a low sediment input rate resulted in drowning of the *sebkha*, and carbonate-marl deposition on a marine shelf. These sediments were structured by algal-bound banks, similar to those described from the Upper Cretaceous of northern France. Bank margins underwent slumping, and gave rise to deformed slabs of sediment. With time, increasing volumes of muddy sediment were deposited on the shelf, and carbonate sedimentation was restricted to isolated algal bioherms. The mud represents the fine fraction associated with a system of braided fan deltas, which formed where east-flowing rivers entered the sea. The braided deltas prograded in an easterly direction, and built out a deltaic plain across the muddy shelf. Eventually, the rate of sediment input decreased, so that, with continued subsidence, the deltaic plain was taken below sea-level, and subjected to reworking on a shallow shelf. Renewed fluvial action resulted in deposition of a meandering fluvial assemblage. The fluvial assemblage is anomalous, comprising 95 per cent (by thickness) overbank fines (siltstones and mudstones). The meandering rivers, up to 15 m deep, flowed down an easterly-inclined palaeoslope.

Copper occurrences are located in a 50 km wide, north-northwest trending belt, parallel to depositional strike. Within this zone, many deposits are found just above the granitic basement, in a position consistent with Renfro's (1974) *sebkha model* for stratiform base metal concentrations. It can be predicted that such deposits should be elongated north-northwest, and be zoned copper-rich on the west to pyrite-rich in the east. Other deposits are found in secondary veins in the basement, in Umkondo sediments, volcanics and in dolerite. A major stratiform replacement body was formed in pyritic quartzite and shale at the Umkondo Mine. It is thought that the hydrothermal solutions responsible for these occurrences were generated from stratiform deposits of the *sebkha*. The fluids were probably driven by thermal gradients set up by the intrusive Umkondo dolerites.

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ISBN 0 85494 444 3

STRATIGRAPHIC HISTORY OF THE MIDDLE-PROTEROZOIC UMKONDO BASIN IN THE CHIPINGA AREA, SOUTHEASTERN RHODESIA

INTRODUCTION

The Umkondo System is a middle-Proterozoic sedimentary and volcanic succession which outcrops in southeastern Rhodesia and the neighbouring parts of Mocambique (Figure 1). The basin is the host to a large number of copper occurrences, and to one economic deposit, at the Umkondo Mine. Over the past 25 years, a number of geological mapping programmes, together with structural, petrological and

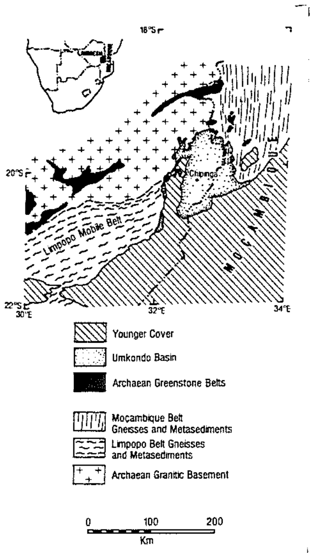


Figure 1 : Locality map, showing regional geological setting of the Umkondo Basin.

geochemical research investigations, have been carried out over parts of the basin. To gain a fuller appreciation of the depositional history of the succession it was decided to undertake a stratigraphic, palaeoenvironmental and palaeocurrent study of the Umkondo Basin. It was hoped that this study might assist in gaining further insights into the controls governing distribution of copper mineralization. An initial ten-week field investigation was undertaken in the Chipinga region, from October to December, 1975. Terrorist incursions, which began in early 1976 in this area, have made it impossible to continue the study. This report is a summary of work done to date. The original intention was to cover the whole basin, and to integrate this work with a study of copper occurrences. This has not been achieved, and must await cessation of hostilities.

PREVIOUS WORK

Prior to 1953, a number of short reports were written on various aspects of the geology of the Umkondo Basin. These have largely been superceded by the systematic work published by the Rhodesian Geological Survey, and will not be reviewed here.

The first systematic regional mapping in the area was in the lower reaches of the Sabi valley (Swift et al., 1953). In their report, the stratigraphy and petrology of the Umkondo System were briefly stated, and chemical analyses of carbonates were presented. The carbonates were judged to be unsuitable for cement manufacture on account of significant concentrations of MgO and SiO_2.

The geology of the middle parts of the Sabi valley was described by Swift (1962). The most complete stratigraphic column to date was published. A newly-discovered unit, the Mapari Series, was recognized, resting disconformably on the Umkondo System in the area west of the Sabi river. On lithological grounds, Swift favoured a correlation of the Umkondo strata with the Transvaal Supergroup, in South Africa.

The most extensive mapping in the area was undertaken by Watson, and published in 1969. He covered the northern half of the basin, in the Cashel, Melsetter and Chipinga regions. Watson demonstrated that the Frontier Series (exposed in the Chimanimani mountains, east of the Umkondo Basin) conformably underlies, and is the basal unit of, the Umkondo.

Viljoen (1962) investigated the origin of the copper mineralization at the Umkondo Mine, and concluded that the copper was epigenetically introduced. Investigations into the general and economic geology of the Sabi valley were undertaken by Newlands and Tyrwhitt (1964, 1965). A final report on their work is contained in Tyrwhitt's (1966) thesis. An investigation by Hodgson (1973) summarized previous work, and added new structural, mineralogical and petrological data. Hodgson was of the opinion that all the copper occurrences in the area were essentially epigenetic, except those in the volcanic formations, which were regarded as having volcanogenic affiliations.

REGIONAL GEOLOGY

General

The Umkondo Basin has a maximum north-south dimension of about 170 km, and averages about 80 km in width. In the north, the Umkondo System rests on the Archaean basement of the Rhodesian Craton. The southern half of the basin rests on the Limpopo Mobile Belt. The contact between these two basement domains trends east-northeast, and passes under the Umkondo Basin (Figure 2).

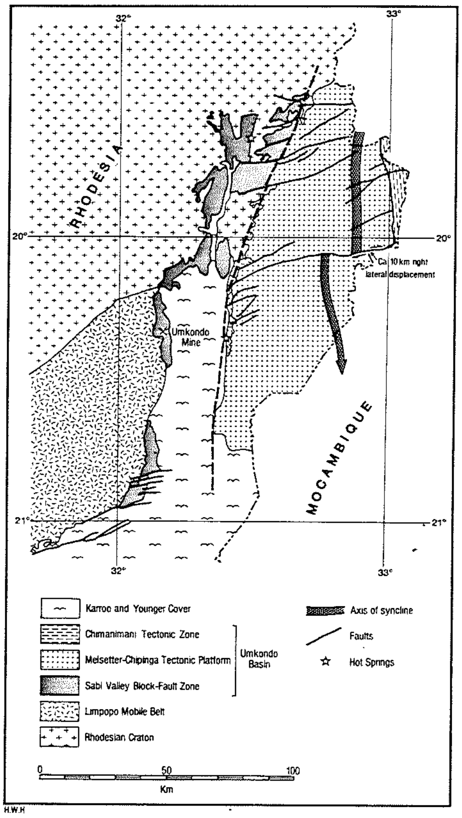


Figure 2 : Structural synthesis of the Umkondo Basin in southeastern Rhodesia

Structure

The structural geology of the Umkondo Basin is synthesized in the structural map of Figure 2, which has been modified from maps published by the Rhodesian Geological Survey. The basin is logically divided into three structural provinces. From west to east, these are the Sabi valley block-fault zone, the Melsetter-Chipinga tectonic platform, and the Chimanimani tectonic zone.

In the Sabi valley block-fault zone, a north-south structural fabric predominates. Faults diverge a little from this trend, which results in some wedge-shaped horsts and grabens. Within the block-fault zone, the Umkondo strata are frequently tilted to steep angles, but dips are usually to the east. The principal known copper occurrences (including the Umkondo Mine) and hot springs are confined to this zone.

The Melsetter-Chipinga tectonic platform is characterized by a north-south-trending, south-plunging syncline. The limbs dip towards the synclinal axis at less than 5 degrees. The structure is up to 60 km wide, and can be followed for a north-south distance of about 150 km.

The Chimanimani tectonic zone comprises basal Umkondo sediments strongly deformed about north-south axes. Numerous thrust faults have been mapped (Watson, 1969), and dip principally to the east. Movement on the thrusts has been one of upper plate towards the west. The tectonic zone is part of the Mocambique Belt, which extends in a north-south belt for many thousands of kilometres up the east side of Africa.

The three tectonic domains are cut by a system of east-northeast-trending high-angle faults (Figure 2). Most of the faults have been downthrown to the south. The major synclinal axis of the basin has apparently been offset by a 10 km right-lateral movement along one of these faults. The east-northeast faults are parallel to the junction of the Rhodesian Craton and the Limpopo Mobile Belt. They were probably formed by repeated adjustments along the tectonic boundary.

Stratigraphy

The Umkondo System is the oldest supracrustal sequence in the area studied. It has been subdivided into a number of units. Along the eastern margin of the basin, highly-deformed quartz arenites and schists comprise the basal unit, and are known as the *Frontier Series*. The latter is not represented along the western margin of the basin, having undergone a severe thinning and facies change (Watson, 1969).

The main body of the succession is made up of four major units, (Figure 3), in ascending order, the *Calcareous Series*, the *Lower Argillaceous Series*, the *Quartzite Series*, and the *Upper Argillaceous*

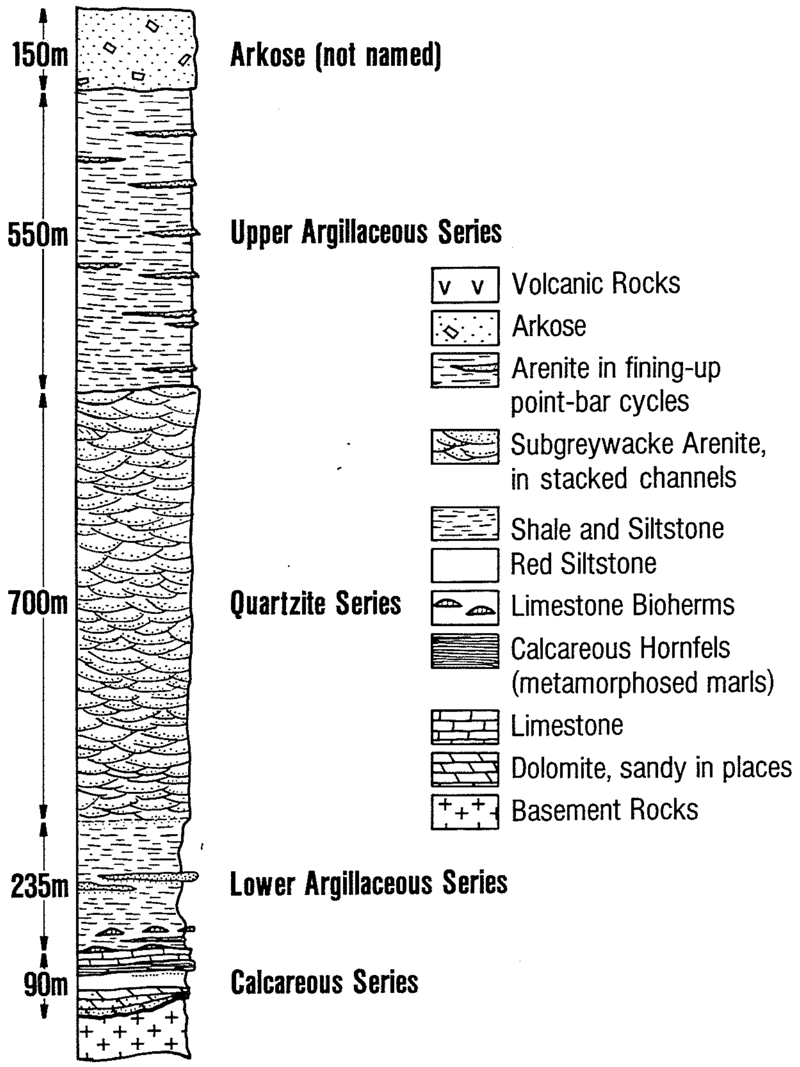


Figure 3 : Generalized stratigraphic column of the Umkondo System in the Chipinga area

Series. A volcanic unit is found at the top of the sedimentary pile, and is restricted principally to the Sabi valley block-fault zone. The *Mapari Series*, also restricted to the Sabi valley, is the youngest unit in the Umkondo, and rests unconformably on underlying formations. This study, being confined mainly to the Chipinga region, did not include the Frontier, Mapari or volcanic units.

Towards the south, successively greater proportions of the Umkondo System are covered by Karroo strata. The Umkondo is completely covered south of latitude 21°S (Figure 2).

The youngest sedimentary unit in the area is the alluvial fill of the Sabi valley. The fill, which covers a plain some 30 km wide, extends from Birchenough Bridge (in the north) to the Chisumbanje (in the south).

Geochronology

Before the advent of radiometric dating, the Umkondo Basin was loosely correlated with the 2 200 m.y. old Transvaal Basin (Swift, 1962). At present, the Umkondo is considered to be somewhat younger. The critical age determinations are the following :

(i) the Umkondo dolerites, which intrude the Umkondo System, have been dated at around 1 100 m.y. by the Rb/Sr whole rock method (Allsopp et al., 1973);

(ii) the Umkondo System has been deformed and metamorphosed in the Mozambique tectonic zone, at least 1 100 m.y. old in southern Malawi (Clifford, 1974); and

(iii) hornfelses in the Umkondo System have been dated at 1 120 ± 50 m.y. and 1 785 ± 80 m.y. by the K/Ar whole rock method (Vail and Dodson, 1969).

The Umkondo Basin is thus certainly older than 1 100 m.y., and is quite possibly some 1 800 m.y. old. Accurate dating of the Umkondo lavas is needed to settle the problem.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE UMKONDO SYSTEM

The account of Umkondo stratigraphy presented below is not entirely comprehensive. It is based on fieldwork done in the Chipinga area. The region covered extends from the Sabi River to the Mocambique border, and from about 20 to 21° south. With the exception of outcrops near Chisumbanje and Birchenough Bridge (blocks 1E and 2A, Figure 4), no work was carried out west of the Sabi River.

The stratigraphy of the Umkondo System was established by studying a number of profiles across the basin. The low dips and strong relief adjacent to the Sabi valley favoured the use of the Jacob staff for thickness control. The best exposures were studied in detail, a tape measure being used to record details of lithology and sedimentary structure.

The system of nomenclature used is that of the Rhodesian Geological Survey. This chronostratigraphic subdivision is basically outmoded in the Precambrian. It is retained here for the time being, since the Rhodesian Geological Survey is presently revising the system of nomenclature in that country.

Calcareous Series

The Calcareous Series comprises the basal formations of the Umkondo System along the western margin of the basin (Figure 4). It is intruded by as many as six basic sills. The percentage of sediment in the composite unit varies from 12 to 100, and averages 41. The sills caused pervasive thermal metamorphism of the sediments, and also caused structural complications through rotation of sedimentary slabs and changes in vertical position of units. Rounded boulders from the sills have blanketed large parts of the sedimentary succession. The result is that the precision of study of vertical and lateral changes in lithology is far less accurate than that usually required of a study of this kind. Consequently, the depositional environments and history of the Calcareous Series can only be framed in the most general terms.

Basal Arenaceous Unit

The basal arenaceous unit was encountered in 7 of the 20 traverses across the base of the Umkondo System. Where present, it usually forms a small ledge. It varies in thickness up to 5 metres, and averages 2,8 metres, where developed. Its sporadic development was probably controlled by palaeotopography (Figure 5).

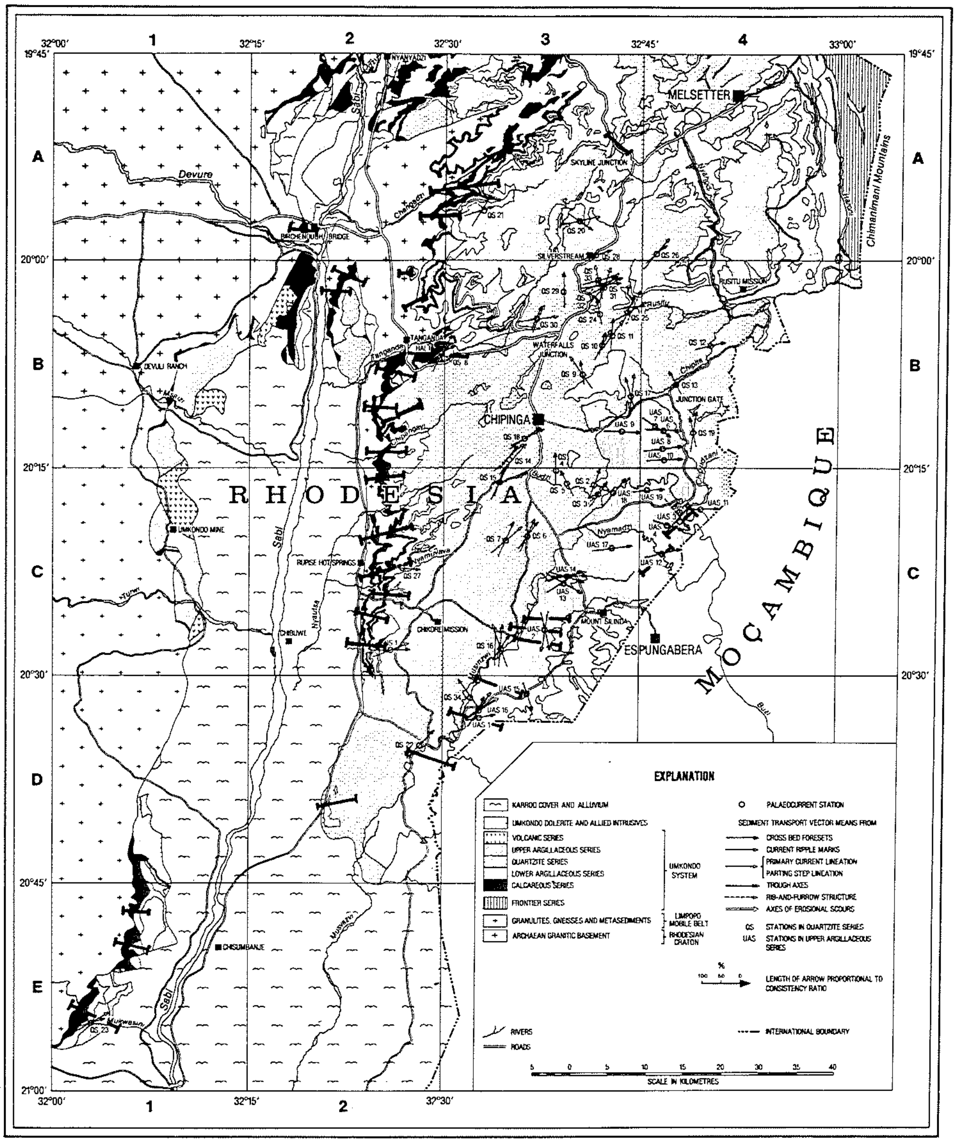


Figure 4 : *Simplified geological map of the Chipinga area (modified after Swift et al., 1953; Swift, 1962; Watson, 1969), showing palaeocurrent stations and measured profiles (heavy black lines)*

The basal contact of the unit is knife-sharp, and usually consists of arenite or conglomerate resting on the crystalline basement. Carbonate cement near the top of the arenite suggests gradation to the overlying dolomite unit.

The character of the basal arenite is variable, and is controlled largely by the nature of the underlying basement. In some profiles, it comprises mainly conglomerate, with clasts of vein quartz, pink felspar and some jasper and iron formation, in an argillaceous or arkosic matrix. Larger clasts are rounded, smaller clasts tend to be angular. Sorting is generally poor, and packing moderate. In other profiles, the basal conglomerate probably represents a palaeo-regolith, being made up of coarse-grained granitic detritus with scattered, pebble-sized fragments of angular quartz. The basal conglomerate has also been seen as a line of scattered pebbles along the unconformity. Scintillometer monitoring showed that the conglomerates are very mildly radioactive in places.

The arenaceous sediments following on the conglomerate are equally varied. A reddish arkose or felspathic quartzite is commonly developed, but a white, medium-grained siliceous quartzite is also represented. The arenite was frequently seen to fine upwards, from pebbly and gritty at the base, to fine-grained at the top.

Sedimentary structures seen include sporadic tabular and trough cross beds (in 10 cm sets), some ripple-marks and flat-bedding. Flat bedding is an expression of the vertical alternation of coarser- and finer-grained arenite. Vague sand-filled mud-cracks were discerned near the top of the arenite in one profile. Ripple marks are confined to the finer-grained arenites, are asymmetric, and have linear to lobate crest-lines.

In the most general terms, the basal arenite represents the re-worked detritus on the pre-Umkondo surface. The small amount of data collected does not allow a confident statement of the environment of deposition.

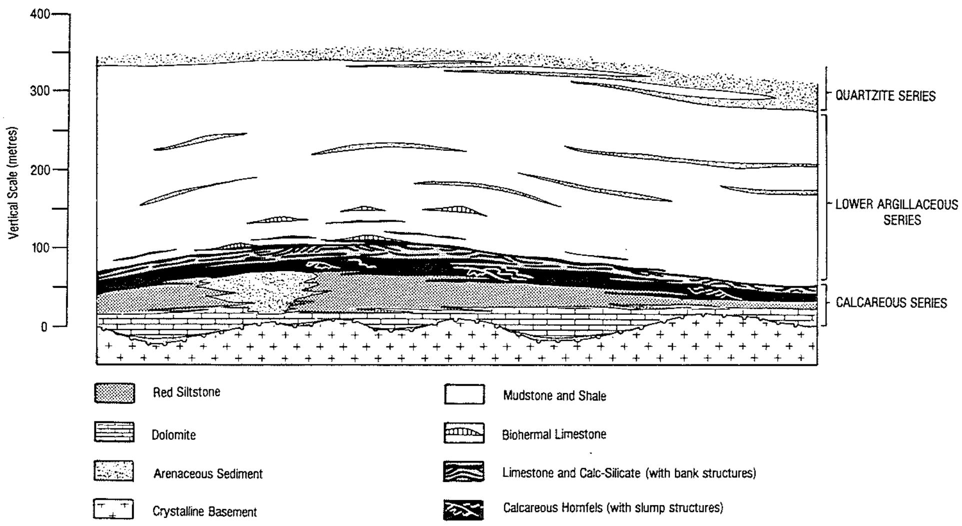


Figure 5 : Schematic diagram showing stratigraphic relationships in the Calcareous and Lower Argillaceous Series

Dolomite Unit

The basal dolomite usually forms a small ledge, which, in places, rests directly on the crystalline basement. In some profiles, the dolomite does not outcrop, being covered by rubble shed from overlying units. The thickness of the formation varies from 0 to 61 m (Figure 5), and averages 19 m. The lateral variation in apparent thickness is marked, and is probably due to basement topography, as well as to post-depositional structural complications.

On weathered surfaces, the dolomite is grey, dark grey or brownish in colour. De-dolomitized phases weather grey. On fresh surfaces, the dolomite is medium- or light-grey or, rarely buff-coloured, while the de-dolomitized phases are white and more coarsely crystalline. Serpentinization is locally important, and results in greenish rocks.

In many instances, the primary structures in the dolomite are partly or totally destroyed by jointing, structural deformation, recrystallization, de-dolomitization or serpentinization. The most common structure preserved is a very delicate crinkly (probably algal) lamination. Small (10 cm) domical structures (probably stromatolites) were very rarely seen, as were some tepee-like structures, outlined by chert. Mechanical structures were very infrequently seen, but included some intraclastic breccia, ripple-marks and poorly-defined cross-bedding.

The dolomite normally has a very fine-grained crystalline texture. The former presence of birdseye vugs is suggested by elongate blebs of white, crystalline carbonate. The blebs are disc-shaped, are up to a centimetre long by 2 to 3 mm thick, and are oriented with their major axes in the plane of the bedding. Spherical structures (1-2 cm diameter) are also present, and have a siliceous rim with a core of sparry calcite. Shinn (1968) has described two types of birdseye structure in carbonates. The disc-shaped vugs are formed by alternate wetting and drying of carbonate mud, usually in the supratidal setting. Spherical vugs (1-3 mm in diameter) are formed by gas bubbles in unconsolidated sediment, in supra- and intertidal carbonates. The spherical structures in the Umkondo are much larger, which could suggest that they are replaced evaporite nodules.

Chert is present in the dolomite, usually in very minor proportions. It is usually grey or white in colour, and occurs as thin films along bedding planes and along some joints, and as nodules, lenses, thin beds and irregular cross-cutting bodies. The chert is secondary in origin, and replaced pre-existing dolomite.

A siliclastic component is frequently admixed in the dolomite, and is most commonly seen as scattered, rounded grains of quartz, averaging about 1 mm in size. In rare instances, larger clasts, including some granules and small pebbles, are developed. The quartz grains are sometimes densely packed, and give rise to a dolomitic quartzite, and, in places, to a thin layer of orthoquartzite (up to 1 m thick). In addition, rare layers of pink-coloured siltstone have been seen in the dolomite, in beds up to 1 m thick.

A sulphide phase is usually associated with the dolomite. Most frequently, this takes the form of a few scattered pyrite specks, 0,5 mm in size. Other forms include iron oxide pseudomorphs, both as nodules and as fracture-fillings. In the latter, a few specks of malachite have been seen, suggesting, in addition, some copper-bearing sulphide.

The most common effect of metamorphism is to increase the dolomite grain-size, resulting in dolomitic marble in extreme cases. In other instances, de-dolomitization takes place, and results in limestone along bedding planes and joints. Serpentinization results from the reaction of chert and dolomite. No chrysotile fibre has been seen in association with the serpentine.

The association of sedimentary structures in the dolomite unit suggest that deposition occurred on a supratidal carbonate flat, or *sebkha*. The *sebkha* is usually dominated by algal lamination, domical stromatolites being comparatively rare. Peaked tepee structures suggest growth of evaporite crystals beneath the depositional interface. Elongate and spheroidal bodies of sparry calcite probably formed by filling of desiccation voids and replacement of evaporite nodules, respectively, and is consistent with the supratidal interpretation (Shinn, 1968). The odd occurrences of intraclastic breccia possibly formed by desiccation of algal-encrusted carbonate mud, subsequently re-worked during inundation. Pervasive dolomitization is characteristic of the sebkha, where evaporation results in high ground-water salinities (Renfro, 1974). Arenaceous sediments are frequently interbedded with contemporary sebkhas, and represent material transported onto the flat by aeolian processes (Shinn, 1973).

Red Siltstone Unit

The red siltstone unit is particularly poorly exposed in most stratigraphic profiles. Its apparent thickness varies from 0 to 70 m (Figure 5), and averages about 37 m. The extremes in thickness estimates could be due to structural complications or poor exposure. The red siltstone is best developed in the Tanganda area (B2, Figure 4).

The presence of the siltstone is most frequently indicated by red silty and shaly clasts in a light, cream-coloured soil. Small outcropping ledges were only occasionally encountered. The contacts with the over- and underlying units have never been seen in good exposures, but could be gradational.

The siltstone is usually pink or red in colour, with white reduction spots. Where indurated by sills, it takes on a mauve cast, and is hard and flinty. Metamorphic porphyroblasts are locally developed, and joints become epidote-smeared. In some outcrops, a colour-banding can be made out in the siltstone, the lighter coloured layers being richer in silt-sized material and in a carbonate cement. This compositional banding is reflected by a ribbed weathering pattern. Reduced, green-grey shales are very occasionally associated with the siltstone.

Sedimentary structures seen in the exposed parts of the unit include delicate lamination and some ripple cross-lamination. Minor erosional surfaces, with sinusoidal geometry in section, are seen to cut across some of the laminated siltstone. The sediment above these wavy erosive surfaces is bedded in the undulating pattern of the underlying surface. No signs of desiccation were seen in the available outcrops.

Minor intercalations of chert, serpentinized dolomite and calc-silicate meta-sediment were found in the siltstone. In one stream-bed exposure, 40 cm diameter linked domes were found in a cherty bed, and could be algal in origin. The chert between domes had a peculiar wrinkled appearance.

In one measured profile, some 50 m of green-grey, fine- to medium-grained, argillaceous and felspathic arenite is developed, largely in place of the siltstone (Figure 5). The arenite is interlayered with pink siltstone at the base. Minor beds of grey, chert-free carbonate were found to be interbedded in the arenite. The arenite outcrops very poorly. No distinct primary depositional structures were seen.

The upper limit of the siltstone unit is sometimes (4 traverses out of 15) marked by a thin body of white-weathering quartzite. Its thickness could not be established with certainty, but probably lies in the range of 2-7 m. It is a pure, medium-grained quartzite, sometimes carrying granules of milky vein quartz. It is strongly jointed, and frequently partly re-crystallized, so that depositional structures are obscured. In one instance, a vague flat bedding was made out, and is due to an alternation of purer and less pure layers.

Considering the fact that only a small proportion of the red siltstone unit is seen on outcrop, there could be significant thicknesses of a non-outcropping lithology interbedded in it.

The red siltstone was probably deposited in a lagoonal or lacustrine environment associated with the carbonate supratidal flat. The lens of impure arenite could represent a fluvial facies; it is very similar in character to the thick and extensive fluvio-deltaic arenites of the Quartzite Series. The clean quartzite lens at the top of the siltstone could have been introduced by aeolian agencies.

Calcareous Hornfels Unit

The calcareous hornfels unit is one of the most persistent formations in the Calcareous Series. It outcrops in one or more ledges, depending on the number of mafic sills intruded into it. The ledges are usually densely bushed, and can be mapped out on aerial photographs. It varies in thickness from 8,5 to 26 m. The average thickness of 11 traverses through it is 14,6 m.

On outcrop, the calcareous hornfels is usually weathered with a ribbed pattern, due to the variable resistance to erosion of its component layers. Cherty and calc-silicate layers weather positively, and are, respectively, white and rusty-brown coloured on outcrop. The minor carbonate layers weather recessively, and are grey on surface. Manganese dendrites, along joints and bedding planes, are almost ubiquitous.

On fresh surfaces, the calcareous hornfels is banded in shades of grey, green, brown, pink and white. It is an extremely tough, flinty-textured rock with a relatively high specific gravity. In the field, layers rich in chert, dolomite, epidote and calc-silicate minerals can be made out. Even pure-looking calc-silicate layers retain some carbonate. Under the microscope, Watson (1969) distinguished zoisite, chlorite, quartz, diopside, tremolite, albite and sericite, in addition to the phases mentioned above. On the basis of chemical analysis, Watson suggested that the calcareous hornfels was originally a siliceous marl.

The most conspicuous primary structure preserved in the calcareous hornfels is a regular, delicate bedding or lamination. Sedimentation units are commonly 1 mm to 1 cm in thickness. Carbonate layers show a crinkly lamination, which could be algal in origin.

Podded structures are common in the calcareous hornfels. In section, they are 1-2 cm thick, by 5-10 cm long, and are elongated parallel to stratification. In plan view, the pods are frequently circular. Irregular "amoeboid" pods (Trendall and Blockley, 1970), possibly the result of compounding of a number of circular structures, were also seen. In section, laminae can be followed through pods into the adjacent stratum. Spacing between laminae is somewhat greater within the pod than outside its limits (Figure 6). The pods are developed in the calc-silicate phase, and are best seen on weathered surfaces. The cores of pods tend to weather recessively, and probably contain slightly more calcareous material. They are probably diagenetic structures, and represent the loci of early lithification, which rendered them less compressible, explaining greater laminae spacing within them.

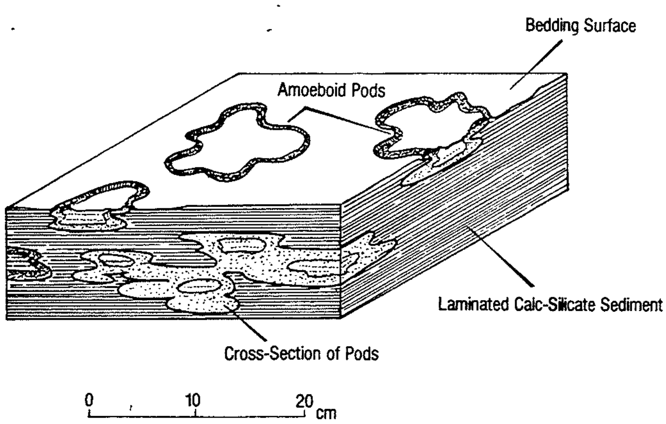


Figure 6 : Sketch of the geometry of podded structures in calc-silicate sediments of the calcareous hornfels unit

The regular, continuous bedding in the calcareous hornfels is frequently disturbed by minor faulting and folding, which do not affect the over- and underlying strata. These intraformational structures are most spectacularly developed on a small outlier of the Calcareous Series, about midway between the Chipangayi and Nyautsa rivers (top-centre of block C2, Figure 4). Here, a flat-topped hill is composed of a 17 m thick slab of highly-deformed calcareous hornfels. The folds have north-south-trending axes. Vertical and overturned dips were commonly observed. Folded bedding planes were seen to be erosionally truncated, and overlain by further folded sediment. The folded zones have no great lateral persistence, normal sediments being found within a few hundred metres.

The deformational structures described above are strikingly similar to those described from upper Cretaceous carbonates in northern France (Kennedy and Juignet, 1974). A discussion of their origin, and the depositional environment of the calcareous hornfels, will be postponed to the following section, which shows similar and related features.

Limestone and Calc-Silicate Unit

The uppermost unit of the Calcareous Series is the limestone and calc-silicate unit, which ranges in thickness from 7 to 31 m. The average thickness (16 determinations) is 18 m. The top of the unit is marked by the first appearance of substantial shale beds. The basal contact is gradational to the calcareous hornfels unit.

The carbonate and calc-silicate unit outcrops in a number of small ledges, the latter usually coinciding with the silicate-rich parts of the succession. A prominent ledge, up to 5 m high, usually marks the top of the unit, and is a good marker, both in the field and on aerial photographs.

The limestone and calc-silicate unit comprises the same end-members as the underlying calcareous hornfels unit, but their relative proportions are different. The formation under discussion is dominated by limestone, which forms between 50 and 90 per cent of the unit.

Outcrops usually show a ribbed weathering pattern, due to the varying resistance of layers (Figure 7 and Plate 1A). The carbonate weathers to a cement-grey colour, is very fine-grained and flinty-textured. On fresh surfaces, it varies from light green-grey to shades of light mauve, pink and green. The carbonate is essentially calcite, a fact confirmed by the analyses presented by Watson (1969). The cherty layers are grey or white, are frequently colour-banded, and weather white. The calc-silicate is shades of green-grey, green or pinkish, and is also colour-banded. In many cases, the resistant layers are composites of alternating cherty and calc-silicate layers.

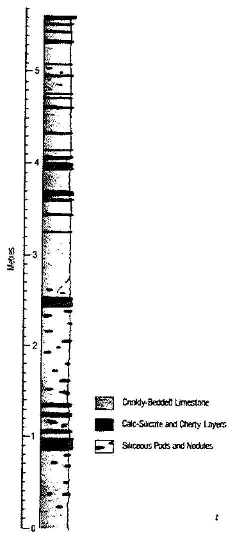


Figure 7 : Detailed profile of part of the limestone and calc-silicate unit, showing nature of bedding

The limestone is structured by delicate crinkly lamination (Plate 1B), which could be algal in origin. It sometimes contains spherical structures, comprising a siliceous or calc-silicate shell with a core of sparry calcite or milky vein-quartz. The spheres vary in diameter up to 2 cm (Plate 1B), and could owe their origin to filling of gas cavities. In places, the spheres are densely packed along certain bedding units. Some elongate discs of calc-silicate (up to 5 by 2 cm), and film-like sheets of the same material, are developed in the carbonate layers.

The cherty and calc-silicate layers are up to 10 cm thick (Figure 7, Plate 1A). They have sharply-defined bases and tops. Frequently, they outcrop as tables, that can be traced laterally for several tens of metres. Podded structures, identical to those in the calcareous hornfels unit, are developed in some of the thicker calc-silicate layers, especially those near the top of the unit. In rare instances, siliceous material can be seen in bodies which cross-cut stratification, and suggest secondary silicification.

Slump-structures, similar to those described in the calcareous hornfels, are developed in the unit under discussion. More common, however, are structures which bear a superficial resemblance to cross-bed sets (Plate 1C). In these structures, sets of inclined strata, varying from 0,1 to about 2 m in thickness, are erosively truncated by overlying, normally-bedded strata. Larger sets could possibly be present, but cannot be appreciated on account of the nature of outcrop. These structures closely resemble the eroded flanks and crests of the carbonate banks described from the upper Cretaceous of northern France (Kennedy and Juignet, 1974). In the case of the French structures, the banks were stabilized either by sea grasses or algal mats. In the Umkondo, the latter are indicated by the crinkly lamination in the limestone.

The depositional environment of the calcareous hornfels and the limestone and calc-silicate unit is considered to have been a relatively shallow marine shelf, within the photic zone. The bank-like structures and slump sheets in the Umkondo have close counterparts in the Cretaceous carbonates of northern France. A major difference would be that, in the Umkondo, a clay fraction was important, and imparted a marly nature to the sediments, subsequently to be metamorphosed to the calc-silicate units. With time, the volume of shaly material in the system increased, and resulted in the gradation to the overlying Lower Argillaceous Series.

Lower Argillaceous Series

The Lower Argillaceous Series follows on the Calcareous Series. It usually outcrops poorly, being swamped by scree from diabase sills and from the overlying Quartzite Series. It is most frequently represented by a cream-coloured soil with shaly fragments.

The Lower Argillaceous Series has an average thickness of 235 m in the area studied. The thickness is known to increase appreciably to the north and east (Watson, 1969). It is present, even in the extreme south of the basin, though its thickness is greatly reduced in that sector. The shaly assemblage is not shown as a separate formation on Swift's (1962) map of the Middle Sabi Valley, since it outcrops very poorly in that region.

The Lower Argillaceous Series includes a number of carbonate, calc-silicate and arenaceous layers. None of these has any great lateral persistence, so that the unit cannot be subdivided into smaller divisions of regional extent. In the paragraphs which follow, the shaly rocks are described, followed by an account of the other lithologies, and their stratigraphic and areal distribution.

Shales and Mudstones

The Lower Argillaceous Series comprises mainly orange- and red-weathering shales and mudstones. On fresh surfaces, these are green-grey or olive-coloured, or, infrequently, dull purple. Where baked by sills, a black metamorphic spotting is developed initially. At higher grades, the shales are converted to dense, dark-grey or black hornfelses. The hornfelses weather with a rusty-brown crust, and break with a conchoidal fracture. Small porphyroblasts of biotite and cordierite can sometimes be discerned in the field. Other metamorphic effects include the introduction of epidote, along joints and in small nests in the hornfels.

Bedding-planes of the shales show no sedimentary ornamentation. They consist of clay-sized material, and split naturally into layers and laminae down to a millimetre in thickness. A few millimetre-thick silty wisps are discerned, and are cross-laminated. Limonite concretions with micaceous rims are occasionally developed in elliptical bodies up to a centimetre in size. They are probably derived by oxidation of pyrite concretions. In one set of outcrops, contorted bedding in shaly rocks suggested soft-sediment deformation.

The shales become somewhat coarser grained upwards, and grade to the arenite lenses within the Lower Argillaceous Series, and, higher up, to the Quartzite Series (Figure 5). In these transition zones, a greater proportion of siltstone and of very fine-grained impure arenite, is developed. Micaceous bedding planes are a feature of these zones. A weak parting-step lineation has been seen in some bedding planes, as have odd mud-flakes and possible mud-cracks.

Calc-Silicate Sediments

One or two calc-silicate layers, up to a metre or two thick, sometimes crop out in the basal 30 m of the Upper Argillaceous Series (Figure 5). They outcrop in well-defined ledges. The calc-silicates display the same textures and structures as those in the underlying Calcareous Series. Podded structures are usually particularly well developed.

Stromatolitic Limestones

Stromatolitic limestones are frequently developed in the basal 40 m of the Lower Argillaceous Series (Figure 5), especially in the area up to 10 km north and south of Tanganda (B2, Figure 4). The stromatolites occur in bioherms, and are usually completely enclosed in shale. The bioherms are usually 2-3 m thick, and wedge out rapidly along strike, over distances of less than 100 m in some cases. In any one stratigraphic profile, no more than two bioherms were encountered.

The individual biohermal stromatolites are usually columnar in geometry, but lateral-linked domes are also developed. Stromatolites are composed of finely-laminated, cement-grey weathering limestone. The limestone is grey or pink on fresh surfaces. Individual laminae within stromatolites are accentuated by black carbonaceous, or calc-silicate, films. The inter-column fill is either calc-silicate material (originally marl) or limestone (both carbonaceous-pyritic and non-carbonaceous varieties). The calc-silicate and carbonaceous limestone are relatively resistant to weathering, and stand out positively.

In plan-view, both the domical and columnar forms are frequently elongated. There is a strong preferred orientation of the long axes, in a northeasterly sense (Plate 1D). Columns may also be circular, polygonal or irregularly-shaped in plan-view (Plate 1E).

Both columns and domes are usually less than 20 cm in diameter, the columns being up to 50 cm high. The internal structures of columns are frequently obliterated by recrystallization. In some, parallel branching, and bridging, between columns was noted (Plate 1F), while in others, a complex radiating form could be vaguely discerned. Columns are usually closely-spaced, but in some cases were up to a metre apart.

Arenite Lenses

Near the centre of the Lower Argillaceous Series (70 to 145 metres from the base of the unit), one or more (maximum of 4) lenses of arenite are usually developed. The lenses are a few metres thick, and outcrop in small, bush-covered ledges. They have abrupt tops, and probably have gradational bases, though this could not be ascertained with certainty because of scree-covered lower contacts.

The arenites are medium- to fine-grained, and weather in shades of red, brown and yellow. Where fresh, they are grey or green-grey. Near sills, felspar grains in the arenite are pinkened, and epidote is introduced. The green-grey colour frequently changes to a dark grey, mottled white. The arenites are texturally and mineralogically immature. They carry significant quantities of felspar, and have a high proportion of greenish phyllosilicate matrix.

The dominant sedimentary structure in the arenite is plane-bedding, formed by vertical alternation of slightly coarser and finer-grained layers. The plane-bedding is developed in sets, which truncate underlying sets at very low angles (less than 1 or 2 degrees). Plane-bedded surfaces are current lineated. Tabular and trough cross-bed sets, up to 30 cm thick, are also developed. Other structures seen include some symmetrical ripple marks, shale clasts and mud-cracks (Plate 2A).

Depositional Environment

The bulk of the Lower Argillaceous Series was deposited on a marine shelf, probably below wave-base, but within the photic zone. The shelf represents a continuation of conditions from the Calcareous Series, but one in which increasing volumes of fine-clastic sediment were being added to the system. Calc-silicate lenses were deposited in local areas of reduced clastic input, while a further reduction resulted in clear-water conditions and growth of algal bioherms on a muddy substrate. The bioherms were smothered by increased mud input, or died off after continued subsidence took them below the photic zone.

The upward-coarsening cycles, firstly to the arenite lenses, and finally to the Quartzite Series, are the result of regressive sedimentation, which brought prograding deltaic sand-lobes across delta-front, prodelta and shelf sediments. The character of the inferred deltas will be more fully documented in the section dealing with the Quartzite Series.

Quartzite Series

The Quartzite Series dominates the Umkondo Basin. It gives rise to the major escarpment which faces west onto the Sabi valley, and also underlies much of the Chipinga-Melsetter plateau area. Fresh outcrops are abundantly developed on the escarpment, but are difficult of access, being mainly cliff-faces. By contrast, the Quartzite Series is very deeply weathered and poorly exposed on the plateau, being represented by a pink or red sandy soil. In this environment, fresh exposures are restricted to river beds and to road-cuts.

It was not found possible to measure one continuous traverse across the Quartzite Series, so that no precise thickness values are available. It certainly exceeds 410 m, the thickest continuous section measured up the escarpment. An estimate of 700 to 800 metres has been made from geological cross-sections.

The Quartzite Series is a monotonous assemblage, with no internal marker units. This lack of lithological variation is probably responsible for the relative paucity of intrusive sills, which are preferentially emplaced along contacts of contrasting rock types.

The basal contact of the Quartzite Series is a coarsening-up transition from the Lower Argillaceous Series. The transition zone is almost invariably scree-covered, lying at the foot of the cliff-line of the escarpment overlooking the Sabi valley. One continuous exposure of the transition zone was located in cliffs and ledges on the south bank of the Nyunga river, north of Mount Rudd (north-centre of block B2, Figure 4). The section was measured in detail, and is shown in Figure 8. The transision is complete over a vertical extent of some 10 m. Mudstones pass upwards to an assemblage dominated by siltstone and fine-grained impure arenites. The arenites show some erosive-based units, commencing with layers of mud-chip breccia.

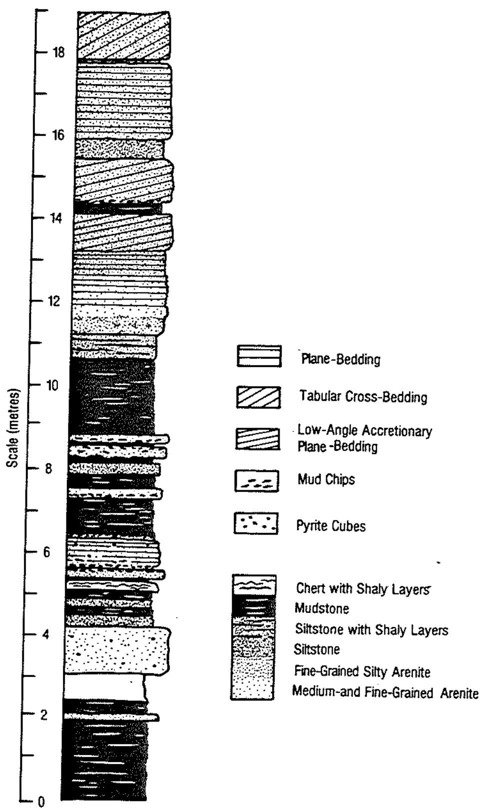


Figure 8 : Detailed measured profile, showing transition from Lower Argillaceous to Quartzite Series

The main body of the Quartzite Series comprises mainly greenish or green-grey arenite, occasionally banded due to minor compositional changes. A fine yellow dusting can sometimes be made out, and is probably due to leucoxene grains. On weathered surfaces, the arenite is buff, cream, brown or red in colour. It is a uniformly fine or medium- to fine-grained rock, but coarsens upwards to a medium-grained arenite. Coarse grains are very rare; small quartz pebbles have been seen in only one locality, in the extreme south, along the Mukwasini River (E1, Figure 4). Individual grains are angular to sub-angular in shape.

The arenite is a compositionally very impure sediment, comprising a large proportion of both felspar grains and of very fine-grained phyllosilicate (mainly chlorite) matrix. It can be termed an arkosic subgreywacke or wacke. Mica flakes are commonly smeared along bedding planes. A sulphide fraction, usually a fine pyritic dusting, is a common component of the arenites. Carbonate-cemented arenite phases are very rarely developed. In one instance, such an arenite was seen to carry a few specks of galena. Near intrusive sills, bedding-planes and joints become epidote-smeared. A speckled grey and white appearance to the arenite results.

Three new chemical analyses of arenites of the Quartzite Series are presented in Table I. The SiO_2 content varies from 73 to 88 per cent. Appreciable quantities of Na_2O, K_2O, MgO, CaO, Fe_2O_3, Al_2O_3 and TiO_2 are present. Typical analysis of other rock types are presented for comparison. There is a superficial similarity of the composition of the Quartzite Series arenites to the average arkose. However, the Umkondo rock contains more Fe and Mg, and less CaO, K_2O and CO_2 than the average arkose. The differences are explained by the greater proportion of chloritic matrix in the Umkondo arenite, which is developed at the expense of $CaCO_3$ cement, which is common in arkoses.

A characteristic rhythm, or cycle, is developed throughout the Quartzite Series. The cycles vary from about 0,3 to 2 m in thickness but are usually 0,5 to 1 m thick. The cyclical units are lenticular in shape, and resemble wide, shallow channels (Figure 9). These channel-like lenses usually rest on erosive surfaces, with a relief of up to a metre (Plate 2B). Lenses are usually convex-down, but some are convex-up, while others are bi-convex (Figure 9).

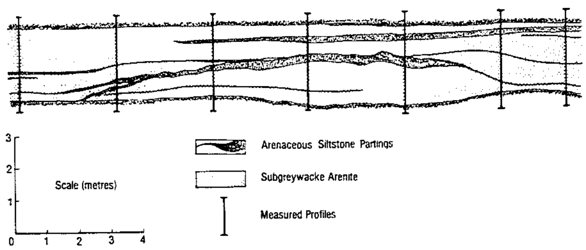


Figure 9 : Vertical face of arenites in the Quartzite Series, showing channeled sedimentation units

The individual cycles are characteristically structured by a repetitive sequence of sedimentary structures and lithologies, which are described in the following paragraphs.

Mud-Chip Breccia

A lag of mud-chip breccia is frequently found resting on an erosive surface (Figure 10). The shale clasts are green-grey to green-black in colour, platy-shaped, angular, and measure up to 5 cm along the major axis. Some have a flinty texture, and could include a tuffaceous component. The mud-chip breccia is up to about 10 cm thick. It tends to weather recessively, and is seen only in the cleanest outcrops.

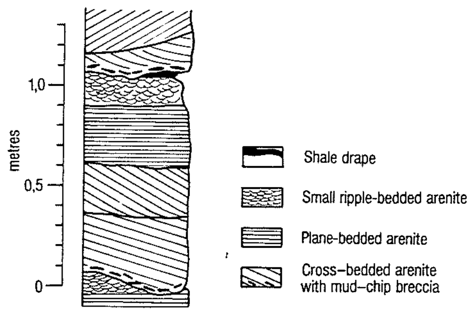


Figure 10 : Idealized sedimentary cycle in arenites of the Quartzite Series

Sample	U 66	U 76	U 107	G 22	G 440	Quartzite Series Average	Average Arkose (Pettijohn et. al., 1972)	Average Lithic Arenite (Pettijohn et. al., 1972)	Average Greywacke (Pettijohn et. al., 1972)
SiO_2	88,0	83,9	75,2	77,61	73,60	79,7	77,1	66,1	66,7
TiO_2	0,51	0,45	1,11	0,95	0,62	0,73	0,3	0,3	0,6
Al_2O_3	4,9	6,5	10,1	8,63	7,93	7,6	8,7	8,1	13,5
Fe_2O_3	3,20*	4,40*	4,60*	0,43	3,95	4,87*	1,5	3,8	1,6
FeO				3,84	3,15		0,7	1,4	3,5
MnO	0,04	0,04	0,06	0,06	0,03	0,05	0,2	0,1	0,1
MgO	0,3	0,5	1,5	1,39	1,27	0,99	0,5	2,4	2,1
CaO	0,50	0,60	1,5	1,21	0,82	0,93	2,7	6,2	2,5
Na_2O	1,2	1,5	2,6	2,70	3,52	2,3	1,5	0,9	2,9
K_2O	1,60	1,79	1,91	1,67	1,95	1,78	2,8	1,3	2,0
P_2O_5	0,05	0,07	0,15	0,60	0,39	0,25	0,1	0,1	0,2
H_2O^+	0,2	0,6	1,1	0,65	2,16	0,94	0,9	3,6	2,4
H_2O^-	0,07	0,09	0,10	0,15	0,71	0,22	-	0,7	0,6
CO_2	n.d.	n.d.	n.d.	0,10	0	-	3,0	5,0	1,2
S	n.d.	n.d.	n.d.	0,06	0	-	-	-	0,3 †
TOTAL	100,57	100,44	99,93	100,05	100,10	100,36	100,0	100,0	100,4

U 66 — Arenite, Quartzite Series, Mooifontein Farm, Chipinga District (Analysts - Bergström and Bakker)
U 76 — Arenite, Quartzite Series, boundary of Vermont/Wolfscrag farms (Analysts - Bergström and Bakker)
U 107 — Arenite, Quartzite Series, Joppa Farm, Melsetter District (Analysts - Bergström and Bakker)
G 22 — Quartzite, Quartzite Series, Waterfall Farm, Chipinga District (Phaup, 1973)
G 440 — Chloritic Quartzite, Quartzite Series, Kronstadt Farm, Melsetter District (Phaup, 1973)

n.d. = not determined
* = Total iron, quoted as Fe_2O_3
† = Expressed as SO_3

Table I : Chemical Analyses of Arenites from the Quartzite Series, with Comparative Analyses of Arkose, Lithic Arenite and Greywacke

Cross-Bedded Arenite

The mud-chip breccia is usually overlain by a cross-bedded interval. Cross-bed sets, both tabular and trough-shaped, are up to 1 m thick, but are more commonly 0,3 to 0,5 m thick. At any one locality, cross-bed azimuths tend to have a unimodal distribution pattern. In plan-view, foresets are usually concave down-current. Overturned foresets are not infrequently seen. Isolated shale clasts, probably reworked out of the basal mud-chip lag, are sometimes found along cross-bed foresets.

Plane-Bedded Arenite

The cross-bedded arenite is usually overlain by a plane-bedded facies, or by an alternation of plane- and cross-bedded material in 30-40 cm sets. In some cycles, the cross-bedded unit is not developed. In these, plane-bedded arenite rests directly on the mud-chip breccia.

The plane beds (Plate 2D) are due to very subtle changes in grain-size and in composition. The surfaces of plane beds are almost invariably ornamented by primary current and by parting-step lineation. In vertical sections, an underlying plane-bedded set was frequently seen to be truncated by an overlying one at very low angles (1 or 2 degrees).

The interpretation of the origin of the plane-bedding is debatable. The balance of evidence indicates that it was formed by a very thin film of water flowing on sand bars in braided channels. Plane-bedding can form in water depths which are too small to produce current ripple-marks. Under these conditions, migrating bedforms with very small amplitude and long wavelength produce near-horizontal lamination (Smith, 1971a; McBride et al., 1975).

Small Ripple-Bedded Arenite

A small ripple-bedded facies usually follows on the plane-bedded arenite (Figure 10). In some cases, a clearly-defined erosive surface was seen to be developed at the base of the ripple-bedded material, and truncates stratification planes in the underlying plane-bedded unit (Plate 2C). The general absence of climbing ripples suggests rather low suspension loads, and strong re-working (Reineck and Singh, 1973). In plan-view, the small ripple-bedding was seen as sheets of rib-and-furrow structure, which proved to be useful palaeocurrent indicators.

Shale Drape

In good exposures, many cycles were seen to be terminated by a green-grey shaly layer, usually less than 10 cm thick (Figure 10). The shale is differentiated into slightly coarser- and finer-grained fractions. Some ripple-marks and small ripple-bedded sets were made out. Occasional mud-cracks developed in this facies suggest desiccation at the end of each cycle.

The shaly member of the cycle is frequently missing, having been removed by the erosive event marking the start of the following cycle. The mud-chip breccia in the overlying unit was probably derived largely from this source.

Muddy drapes are not uncommonly preserved in braided stream environments (Smith, 1970). They form in abandoned channels, where near-stagnant conditions allow settling of fines. Eventual desiccation of the mud results in cracking, and provides mud clasts which are reworked into the lag deposits of subsequently-formed channels.

Where intrastratal movement has occurred in the Quartzite Series, it is usually concentrated in the shale drapes, and results in shearing and a crude cleavage.

Other Features

An exhumed scour pit, over 18 m long, by 5 m wide and 1 m deep was encountered cut into the arenite in a river bed exposure at station QS 17 (block B3, Figure 4). The pit had an elliptical outline, and was seen to be oriented parallel to palaeocurrent vectors in over- and underlying strata. It probably represents an erosional scour formed during deposition of the Quartzite Series, filled by relatively soft sediment which has been eroded away by the river in whose bed it outcrops.

Convoluted bedding, which results from a loss of strength of saturated sand through various possible mechanisms (Reineck and Singh, 1973), is also preserved in arenites of the Quartzite Series.

Depositional Environment

The depositional environment of the main body of the Quartzite Series is best discussed with reference to the sedimentary cycle described in the foregoing paragraphs. Metre-scale (or thicker), erosive-based, fining-up sedimentary cycles, in which little or no siltstone or shale is represented, are typically formed in the braided stream depositional system (Doeglas, 1962; Williams and Rust, 1969; Coleman, 1969; Smith, 1970; Boothroyd and Ashley, 1975). The cycles of the Quartzite Series are similar, in all important aspects, to those known to have formed by the action of braided streams. The impure arenites of the Quartzite Series are thought to have been deposited in this broad environment.

The detailed interpretation placed on each of the elements of the Quartzite Series cycles is summarized in Table 2.

Depositional Structures	Inferred Processes
Shale drape	Suspension settling in abandoned braid channel
Small ripple-bedding	Ripple migration on transverse bar, under shallow water
Plane-bedding	Lower flow-regime migration of long wavelength ripples in shallow water
Trough cross-bedding	Megaripple migration in deepest parts of braid channel
Tabular cross-bedding	Avalanching down slip - face of transverse or longitudinal sand bar (Smith, 1971b)
Mud-chip breccia	Lag deposit at base of braid channel

Table 2 : Depositional structures and inferred sedimentary processes in the sedimentary cycles of the Quartzite Series

In summary, the general characteristics of the Quartzite Series sedimentary cycles indicates deposition on a braided fluvial plain. Descriptions of contemporary braided systems are usually in regions where there is a substantial quantity of coarse sand and gravel (Doeglas, 1962; Williams and Rust, 1969; Smith, 1970; Eynon and Walker, 1974), and are thus not entirely analogous to the case in point. The Brahmaputra River carries sediment similar to that in the Quartzite Series (Coleman, 1969), and generates cycles similar to those in the Umkondo. However, channel-depths are much larger in the Brahmaputra, up to 15 m, which results in thicker cycles. Here, the finer-grained sediments near the tops of cycles were deposited (at low water stage) between the crests of giant ripples on the channel floor.

Braided fluvial systems can be developed at any location between the piedmont and the ocean. Taking into account the fact that the Quartzite Series progrades across what are thought to be marine shelf, prodeltaic and delta-front deposits, it seems likely that the Quartzite Series was deposited at the continent-marine margin, in a braided deltaic complex. An appropriate analogue (on a smaller scale) is the Gum Hollow fan delta, which is being built out into a bay along the Gulf coast in Texas (McGowen, 1970). The surface of the fan, which is nowhere more than a metre or two above sea level, is braided. The fan plain sediments show trough fill cross-bedding, small ripple bedding and parallel lamination, formed respectively in a channel, on a bar-margin, and on the bar. These are frequently arranged in vertical sequences not unlike those of the Quartzite Series.

The lower reaches of Alaskan braided outwash fans (Boothroyd and Ashley, 1975) show a cycle essentially identical to that discerned in the Quartzite Series. The cycle is formed by downstream migration of slip faces of longitudinal bars, which results in tabular cross-beds, overlain by plane beds, overlain by ripple-laminated sediment. Galloway (1976) described similar cycles in the braided deltaic plain of the Copper River fan delta, also in Alaska.

In summary, the Quartzite Series is thought to have been formed by sedimentation on a braided fan delta, building out into the body of water in which the Argillaceous Series was deposited. Channels were shallow (less than 2 m), and were filled by both lateral and vertical accretion processes. The sediments were deposited near sea level, and, with ongoing subsidence, were probably taken below water table soon after deposition, which explains the fact that the Quartzite Series arenites are reduced throughout.

Topmost Phase of the Quartzite Series

The uppermost part of the Quartzite Series differs markedly from the underlying mass, being consistently medium-grained, and siliceous or only slightly felspathic in composition. The exact thickness of this quartz arenite phase was hard to determine, since it is usually exposed on dip slopes. It certainly does not exceed 50 m in thickness, and thus makes up only a small part of the Quartzite Series.

The quartz arenite is white or grey in colour, and is sometimes colour-banded. It frequently carries scattered small pyritic cubes, or iron-oxide pseudomorphs after pyrite.

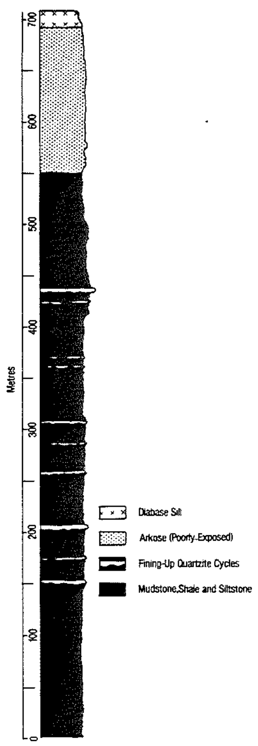
The quartzite is developed in 0,5 to 1 m beds with abrupt margins. These are sometimes separated by 0,1 to 1 m thick siltstone beds. Internally, the quartzite is cross-bedded (both trough and tabular types) in sets 0,05 to 0,6 m thick. In some of the tabular sets, individual foresets are parting-step lineated. Some overturned foresets are developed. Plane-bedded and small ripple bedded phases are less common. The former show current lineation. In one outcrop, the surface of a trough-like scour was seen to be ornamented by current ripple-marks.

The depositional environment of this quartz arenite phase of the Quartzite Series is problematical. It could result from a diminution in the subsidence rate, or in the rate of sediment supply to the fan delta, which afforded the braided streams the opportunity to re-work the fan surface. However, the mean palaeocurrent direction for the quartz arenite phase differs markedly from that of the Quartzite Series, a fact that will be discussed in the section describing the palaeocurrent work. It is thought that a diminution in the sediment supply rate to the fan delta, combined with continued subsidence, would have resulted in transgression of a marine shelf across the delta. The quartz arenite formed through re-working of the fan-delta arenites on a shallow marine shelf.

Galloway (1976) described a comparable situation in Alaska, where the Copper River fan-delta is prograding across the northern shelf of the Gulf of Alaska. However, in this case, the delta is marine-dominated, while the Umkondo delta was fluvial-dominated through most of its history.

Upper Argillaceous Series

The Upper Argillaceous Series comprises some 570 m of predominantly fine-grained sediment, principally siltstone, mudstone and shale. Within this pile, as many of 10 lenticular quartzite units are developed, which make up, on average, about 4 per cent of the total (Figure 11). Individual arenite bodies vary from less than 0,5 m to nearly 15 m in thickness, the average being 4,5 m. A histogram, based on 56 measurements, is shown in Figure 12, and indicates a slightly-skewed log-normal distribution.



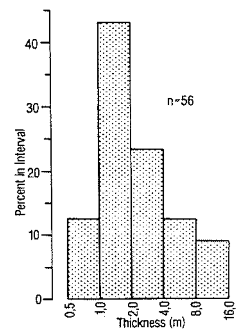


Figure 12 : *Histogram of thickness of quartzite lenses in the Upper Argillaceous Series*

Figure 11 : *A measured profile through the Upper Argillaceous Series*

The individual quartzites outcrop in ledges and small cliffs which are laterally impersistent. Their erosive-base, fining-up geometry, combined with unimodal palaeocurrent patterns, identifies them as the products of point-bar accretion in a meandering fluvial environment (Allen, 1965). The shales and siltstones are consequently the products of flood-basin sedimentation. The ratio of channel to overbank material (1:19, on average) is highly anomalous, a fact which will be discussed in a subsequent section.

Although over 90 per cent of the Upper Argillaceous Series is made up of siltstone, mudstone and shale, the amount of observation on these rocks is very limited. They seldom outcrop, are strongly weathered and often cleaved. The only good exposures are those found near waterfalls in riverbeds, where the shaley sediment has been swept clean of weathered material. In the best exposures, three associations have been noted, and are described below.

Siltstone-Shale Association

This assemblage makes up the bulk of the Upper Argillaceous Series, possibly as much as 80 per cent of the formation. Both red and green sediments are present. The red colouration is not all due to contemporary oxidation, since red colours persist in perfectly fresh, river-scoured outcrops.

Massive, red, micaceous siltstones are a common element in this assemblage, and occur in beds up to 1 m thick (Figure 13). In other siltstones, a delicate red and green colour-banding can be discerned. The colour-bands are discontinuous when traced over several metres. There is a tendency for the green layers to be silty, the red to be shaly. Green siltstones are also developed, and are either massive or laminated. Small ripple-bedded silty or very fine-grained arenaceous lenses and wisps are encountered in the shaly assemblage (Figure 13). Bedding planes show some ripple-marks, primary current lineation (in fine arenites), mud-cracks and mud chips. These structures are not as abundantly developed as would be expected in a tidal flat assemblage. In one set of outcrops, halite casts and synaeresis cracks were developed (Button, 1976), and indicate saline waters and evaporative conditions.

The siltstone and shale association is thought to represent material deposited in the flood basin during periods when the meandering rivers overtopped their natural levees.

Siltstone-Arenite Association

In this assemblage, fine-grained argillaceous quartzite alternates with greenish siltstone on a centimetre to decimetre scale (Figure 13). The arenite is usually green-grey in colour, fine or very fine-grained, and argillaceous in composition. The arenites usually lens out when traced along strike. They have sharp, probably erosional bases, and sharp or gradational tops. When sharp, they tend to be ripple-marked. Internally, the arenite is either plane-bedded, small ripple-bedded or in-phase ripple-laminated (Figure 13). Plane-bedded surfaces are sometimes current-lineated. Graded arenite-siltstone couplets, from 1 to 5 cm thick, are fairly common. The siltstone fraction is usually green-grey in colour, and is differentiated into coarser and finer-grained layers. It sometimes carries scattered sand-sized quartz grains. Mud-cracks and curled-up mud clasts have been seen in this assemblage.

The siltstone-arenite association is interpreted as levee material. The alternation of coarser- and finer-grained material (especially in graded couplets) is typical of levee deposits (Reineck and Singh, 1973), and is the result of overtopping of the natural levee, deposition of thin sandy layers, followed by silty material during the falling stages of the flood.

Arenite Association

Arenite lenses, up to 60 or 70 cm thick, are associated with the shaley pile of the Upper Argillaceous Series. The arenites have sharp, weakly erosional bases, and sharp, frequently current-ripple marked tops. They are composed of green-grey, medium- to fine-grained argillaceous and felspathic quartzite. The lenses usually commence with a cross-bedded unit 30-40 cm thick, followed by small ripple-bedded arenite in 10 cm sets, separated by silty drapes.

These arenites probably represent crevasse-splay deposits, formed by breaching of the natural levee during flood stages, and tapping of bedload material into the flood-basin.

Point-Bar Association

Point-bar arenites, identified by their erosive-based, fining-up character, make up a minor proportion of the Upper Argillaceous Series, but are relatively well-studied because they form better outcrops. They are composed of quartzite, which weathers pink, buff or red, and bleaches white on surface. Where fresh, it is shades of green-grey in colour, sometimes speckled white due to felspar grains.

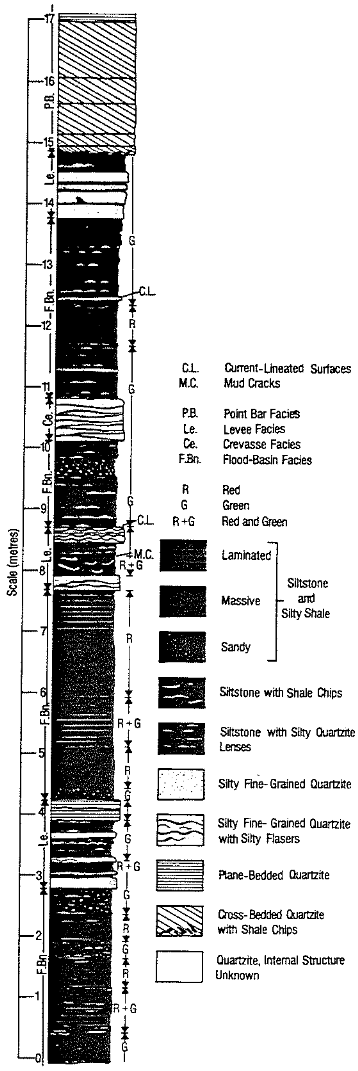


Figure 13 : *Detailed measured profile through fine-grained elements of the Upper Argillaceous Series*

Within the point-bar cycle, an upward decrease in average grain-size can usually be discerned. The coarsest grains measure 1-2 mm, and are infrequently found on foreset toes near the base of the cycle. More commonly, the grain-size varies from medium-grained to fine or very fine-grained at the top of the cycle.

The vertical change in grain-size was quantified in one 7 m cycle (Figure 14). Specimens were collected at convenient places up the sequence, and were subsequently sectioned. Under the microscope, the long axes of 100 randomly-selected grains were measured, using a graduated eyepiece. The results were grouped into logarithmic classes, and a cumulative frequency grain-size curve plotted for each sample. The median grain-size was determined and plotted against the height of the sample above the base of the cycle. The median grain-size decreases fairly regularly, from around 0,2 mm to 0,02 mm, that is from medium- to fine-grained sand to silt-size. There is an abrupt break in the grain-size curve at the transition from uppermost point-bar to overbank material (Figure 14).

The point-bar arenites usually carry some felspar and lithic grains in addition to quartz. Other constituents are some mica flakes, pyritic cubes and, in some instances, a carbonate cement. The proportion of fine-grained matrix increases with decreasing grain-size.

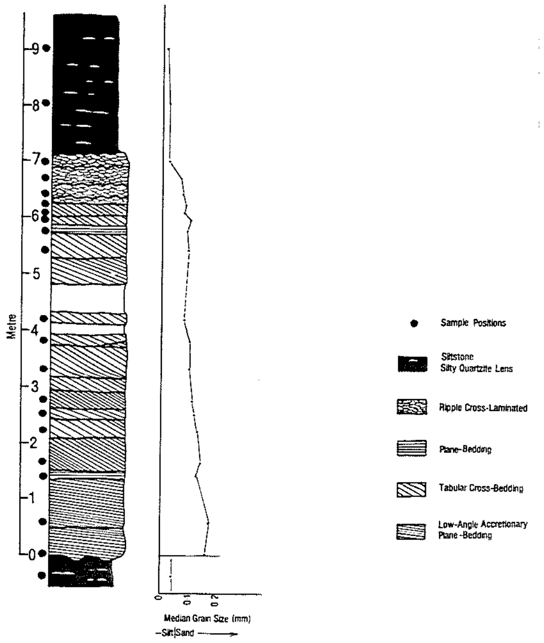


Figure 14 : *Measured profile through a point-bar cycle, showing upward decrease in grain-size*

There are a number of features which are common to most of the point-bar sequences. They all rest on erosive surfaces, some of which can be shown to have had a relief of at least 1 m. Linear scour-pits, in the shaley material below the arenites, are aligned more-or-less in the palaeotransport direction as determined from cross-beds and other directional features. The basal erosive surface clearly cross-cuts stratification in the underlying sediments. Further evidence of the erosive nature of the contact is the presence, in some cycles, of shale clasts in the lowermost arenite above the cut surface.

The basal erosive surface is inferred to represent the end-product of erosion at the foot of the cut-bank on the outside of a meander bend, and is characteristic of point-bar sequences (Allen, 1965).

Inclined plane-beds are encountered at the base of thicker cycles (generally those thicker than 7 or 8 m). The plane-beds are inclined at 2 to 4 degrees to the master stratification, and dip at right angles to the palaeotransport direction as determined from cross-beds. The individual plane surfaces are usually current-lineated. They are developed in sets up to about 1,5 m thick. Two such sets are developed in the cycle shown in Figure 14, and are overlain by a flat-bedded assemblage.

The inclined plane-beds are thought to be the lowermost parts of the gently-sloping point bar surface, deposited under upper flow-regime conditions. Their absence in thinner cycles suggests that upper regime conditions were only attained in relatively deep meandering channels.

In thinner cycles, cross-bedded quartzite usually rests directly on the basal erosive surface (Figures 13 and 15). Cross-bed sets vary in thickness from 1 to 0,1 m, and generally become thinner upward (Figure 14). Trough types are developed, but tabular types are more common. In plan-view, foresets are usually concave down-current, although one instance of the inverse relationship was found. Foresets are subtly colour banded due to minor changes in texture and composition. Grain orientation on foresets can be inferred by parting-step lineation sometimes found on foresets. Convoluted cross-bed sets were not infrequently seen.

The cross-bedded quartzite is inferred to have formed by sand-wave and megaripple migration at or near the thalweg of the meandering channel. The dominance of tabular cross-bedding suggests that sand-waves were the most common bedforms.

In some exposures, gently-inclined plane-bedding can be seen to terminate at an inflection point, and continues at a steeper angle as a cross-bed foreset (Plate 2E). This type of cross-bedding is referred to as microdelta cross-bedding by Reineck and Singh (1973). It can form where a very shallow sheet of water on a sandy bar encounters a front of deeper water, resulting in avalanching of sand grains down the front of the bar.

In a vertical sequence, flat-bedded quartzite usually succeeds the cross-bedded facies. The structure is the manifestation of alternating laminae of medium and finer-grained arenite. Bedding surfaces are almost invariably current lineated, which implies a preferred orientation of the long axes of quartz grains. The flat-bedded material is inferred to have formed in shallow water, on the emergent part of the point-bar. While a flat-bedded zone is commonly recorded on the upper and middle parts of a point bar (for example, Bernard et al., 1970), most authors avoid a discussion on its origin. In the Brazos river of Texas, the flat-bedded zone is situated between a megarippled zone (further down the point bar) and a small rippled zone (at the top of the point-bar). The flat-bedded material must have formed in water depths and velocities intermediate between the megarippled and rippled zones, both of which are lower flow regime bedforms. The flat-bedding, even though it shows current lineation, is inferred to be a lower regime bedform as well, and could have formed by migrating low amplitude, long wave length bedforms such as those described by Smith (1971a) and McBride et al. (1975).

The uppermost parts of many cycles are small ripple bedded (Figure 14). The rippled material is usually fine and very fine-grained arenite. In plan-view, linguoid current ripples have been seen on some surfaces; but sheets of rib-and-furrow structure are more common. Palaeocurrent determinations on these structures agree well with those measured for current lineations and cross-beds. The small ripple-bedded arenite is inferred to have been deposited on the emergent part of the point bar, where it merges with the natural levee.

Siltstone and silty shale are frequently found in the point-bar cycle as thin (1 to 10 cm) drapes (Plate 2F and Figure 15). The siltstone is greenish-grey, and often carries scattered sand-sized quartz grains. It weathers recessively, and is only seen in the best-exposed profiles. The simplest explanation for the siltstone drapes is that they formed at low water stage, between flood events. Some support for this simple interpretation is afforded by the fact that minor cycles within the overall point-bar sequence (Figure 15) are separated by silty drapes.

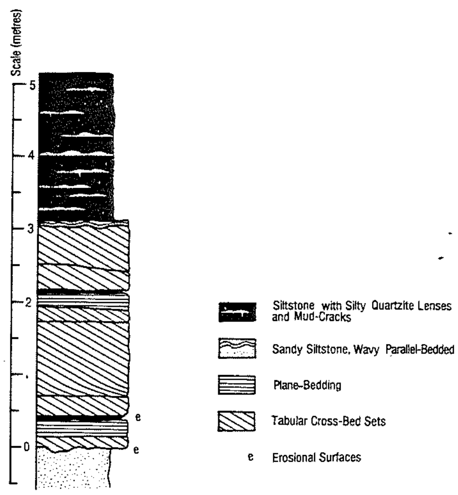


Figure 15 : *Measured profile through a point-bar cycle, showing siltstone-draped sub-cycles*

Depositional Model

The characteristics of the arenite lenses in the Upper Argillaceous Series identify them as point-bar deposits, formed by lateral accretion on the convex banks of meander bands. Channels varied in depth up to 15 m, but averaged only 4,5 m deep. In the best-developed point bars, the foot of the point-bar surface was plane-bedded, suggesting upper flow-regime conditions (Figure 16). Higher up the bar surface, migrating sandwaves with scalloped fronts were developed. Higher up still, plane beds and small current ripples were found. Multiple cycles, and mud drapes within the sequence, suggest repeated flood events, followed by low-stage intervals. The unimodal distribution of palaeotransport vectors, and general absence of other features suggesting current reversals (such as reactivation surfaces) indicate that the meandering streams were fluvial, rather than tidally influenced.

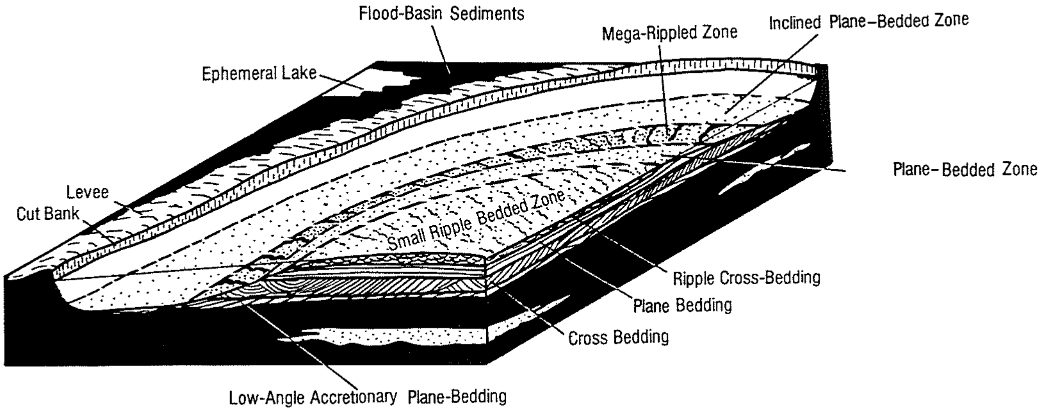


Figure 16 : Depositional model of point bars in the Upper Argillaceous Series, Umkondo System

The overbank sediments show some evidence of desiccation, including mud-cracks and curled-up mud-chips. Evaporative conditions were developed locally resulting in halite casts and synaeresis cracks. Most of the overbank material probably represents flood-basin sedimentation, but some probable levee and crevasse deposits were recognized. While alternating traction and suspension sedimentation was discerned, it was not as frequently or regularly developed as would be expected from tidal flat deposits. Signs of desiccation and of ripple-marking are, likewise, not ubiquitous.

The excessive proportion of overbank material (95 per cent) remains a problem. In the Devonian Catskill section of the northeastern United States, anomalously thick overbank deposits have been linked with periodic sea-level rises (McCave, 1969), which caused constriction of channels and long periods of overbank flooding. Such a condition cannot be implied in the Umkondo, since thick overbank is the rule through nearly 600 metres of the Upper Argillaceous Series. A more plausible explanation probably lies with the grain-size of the material fed to the basin. In the Quartzite Series, grains larger than medium-sized sand grains are statistically absent. The point-bar sequences, which concentrate the coarsest material available to the system, again carry nothing larger than medium sand grains, except in very rare instances. Thus, through some 1 400 metres of fluvial sedimentation, fine grain-sizes are the rule. It is suggested that, given the very low proportion of sand grains, a special modification of the meandering fluvial model, possibly unlike any known on the surface of the Earth today, operated. The absence of vegetation, both in source areas and in the depositional setting, may have played a crucial role. Overbank flooding must have been a frequent happening, possibly related to lack of levee stability due to the absence of stabilizing vegetation.

Upper Arkose Formation

The uppermost sedimentary formation in the Umkondo System around Chipinga is an arkose unit, estimated to be about 150 m thick (Figure 11). It is very poorly exposed, and gives rise to the sand-covered plateau which fringes the Umkondo dolerite sills around Mount Silinda (Figure 4, block C3). Even when it forms part of the escarpment overlooking the Musirizwi River to the west, it forms, at best, a few small ledges separated by sandy soil.

The arkose usually has a pinkish colour. It varies from fine- to medium-grained, and is composed of variable proportions of quartz and felspar. Scattered muscovite flakes, and small red mud-chips are common, but minor, constituents.

Sedimentary structures are rarely seen in natural exposures. However, in road-cuts around Mount Selinda, large-scale tabular cross-bed sets, up to 2 m thick, can be seen to characterize at least parts of the formation. The foresets are themselves current lineated. The cross-bedded sets are separated by metre-thick sets of plane-bedded arkose.

Only one cross-bed station was measured in the arkose, southwest of Mount Selinda (station UAS 15, Figure 18), and suggests transport to the south-southeast. This could be a random variation on an overall easterly pattern, which characterizes the underlying Upper Argillaceous Series.

No diagnostic structures were seen, but the characteristics of the Upper Arkose Formation are not inconsistent with deposition in a braided stream system.

The Umkondo Dolerite

While this study was aimed primarily at gaining a better understanding of the Umkondo sediments, the Umkondo dolerite was frequently encountered, traversed and measured during systematic stratigraphic profiling. It is considered worthwhile to place on record the results of these observations.

The name *Umkondo Dolerite* is applied to a suite of basic, usually sill-like intrusives into the Umkondo System. The intrusive province has a wide areal extent, from the Inyanga area, north of Umtali, to the southern limit of the Umkondo Basin. The suite has been dated at about 1 100 m.y. (Allsopp et al., 1973) by the Rb/Sr whole-rock method.

Outcrop

Typically, the Umkondo sills are marked by rounded boulders set in a red soil. The chill phases at the tops of sills frequently form cliffs and ledges. On aerial photographs, the sills are usually distinguished by a light tone, since they support a coarse grass, which bleaches white in winter, when the photography is flown.

Vertical Distribution

The Umkondo Dolerite is preferentially intruded near the base of the Umkondo sedimentary pile. On average, the dolerite makes up 59 per cent (by thickness) of the Calcareous Series, decreasing in the Lower Argillaceous and Quartzite Series, and virtually absent in the Upper Argillaceous Series. It re-appears in the Upper Arkose Formation around Mount Selinda, south of Chipinga.

The preferential intrusion of sills into the Calcareous Series is probably due to the rapid vertical alternation of laterally-persistent lithological units. The lithological contacts provided a large number of planes suitable for intrusion. By contrast, the Quartzite Series is vertically homogeneous, while the Upper Argillaceous Series is characterized by laterally-impersistent units.

Thickness

A total of 59 sills were measured in the course of stratigraphic profiling, mainly along the escarpment facing onto the Sabi valley. The majority of those measured are intrusive into the Calcareous and Lower Argillaceous Series. The sills range in thickness from 1,5 to 300 metres, and average 75 metres thick. The standard deviation from this mean is relatively large, and was calculated at 75 metres. A histogram of thicknesses was constructed (Figure 17) and shows a log-normal pattern.

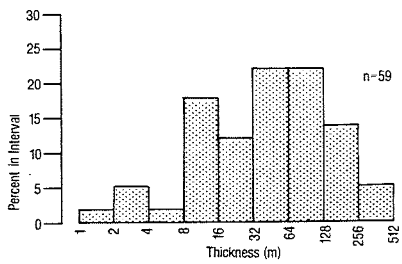


Figure 17 : Histogram of thickness of Umkondo basic sills

Vertical Changes in Lithology

The description presented below is based purely on a field examination of the sills. No thin-section or chemical work has been undertaken.

The thicker sills, generally those over 100 m thick, are significantly differentiated. Five intergradational zones can usually be made out; from base to top, a norite, gabbro, diabase, granophyric diabase and a chill zone.

The lowest zone usually comprises medium-grained norites, composed of fresh plagioclase and an orthopyroxene, with a few specks of biotite and pyrite. The pyroxene is characteristically translucent greenish-brown, and occurs in well-defined cumulus crystals. Orientation of pyroxene prisms has resulted in a discernable fabric in places. A poorly-defined compositional layering was seen in a few instances. No obvious olivine-bearing rocks were seen in this basal zone. These could possibly be present at the base of sills, which are invariably covered by rubble from higher units.

The norite passes up to a gabbro, which carries a dark grey intercumulus pyroxene, in addition to plagioclase and orthopyroxene. Mineral orientation and compositional layering are not obvious. Pyroxene-poor phases approach an anorthositic composition in places.

The third zone comprises diabases, which are medium-grained basic igneous rocks with hydrated ferromagnesian minerals. The diabases are speckled in shades of white, green-grey and green-black. Pyroxenes are mainly absent, their place being taken by green-black actinolitic amphibole. The felspars do not have the sparkling white lustre of those in the norite, but are a dull white, grey or green-grey. They are probably largely sericitized. Small brassy-coloured crystals were seen, and probably represent sphene, derived by the alteration of ilmenite.

The uppermost 20 to 30 m of many of the thicker sills comprises granophyric diabase. Here, grain-size is appreciably coarser, due to the increase in size of amphibole blades, some of which are up to 3 cm long. Pockets of pegmatitic-textured diabase are sometimes present. The felspars in the granophyric phase are usually pink or brick-red. Granophyric quartz intergrowths in the felspar can be made out with a hand lens. Some free quartz is developed. Epidote is a very common phase in the granophyric diabase, and is seen as millimetre-sized nests of small crystals and as a lining to joints in the diabase.

Chill-zones can be discerned at the top of most sills. They are composed of a very fine-grained, dense, green-black to green-grey groundmass, with some felspar phenocrysts. The chill phases are usually only a matter of 1 to 3 metres thick.

Xenoliths, on varying scales, were found in the mafic sills, most frequently near the top of the chill-zone. Blocks range in size up to 10 m long. The blocks are angular, and, in places, are packed densely enough to warrant the term *intrusion breccia*.

The Umkondo sediments are metamorphosed where they lie adjacent to sills. The nature of the metamorphism varies with the country rock lithology. The usual metamorphic effects have been described in preceding sections.

PALAEOCURRENT ANALYSIS

During the course of this preliminary investigation, a total of about 1 000 palaeocurrent measurements were made at 55 localities through the region. Of these, 375 measurements at 20 localities, were in the Upper Argillaceous Series. The balance were situated in arenites of the Quartzite Series (Appendix I).

The field procedure adopted was to measure up to about 20 vectoral properties at any one locality (station). The measurements were tabulated, and vectoral statistics calculated (vector mean, consistency ratio) for each different type of vector (cross-beds, ripple marks, current lineations). Since dips are less than 5 degrees, no correction was made for the structural tilting of the vectors. A palaeocurrent map was compiled (Figure 18), and shows the vector mean and consistency ratio for the directional parameters at the palaeocurrent stations. In that the sediments studied were deposited mainly in the fluvial system (braided and meandering), the mean palaeotransport direction is an approximation of the palaeoslope. Current rose diagrams (with 10 degree intervals) were constructed to give the gross palaeoslope in both the braided deltaic and meandering facies.

A variety of vectoral structures was measured. Most measurements made were on the azimuths of cross-bed foresets (both trough and tabular types). The orientation of trough axes was measured wherever this was possible. Current lineations on plane-beds were frequently encountered and measured. They could normally be found in intimate relation with cross-beds or current ripples, and were assigned the sense of movement determined from the latter structures. Current ripple-marks and rib-and-furrow structures provided further measures of sediment transport directions. In a few instances, the long axes of erosional scours were measured.

Quartzite Series

The palaeocurrent vector means for the Quartzite Series are shown plotted on Figure 18 at stations QS 1 to QS 33. In general, there is good agreement of the vector means for different sedimentary structures at the same locations.

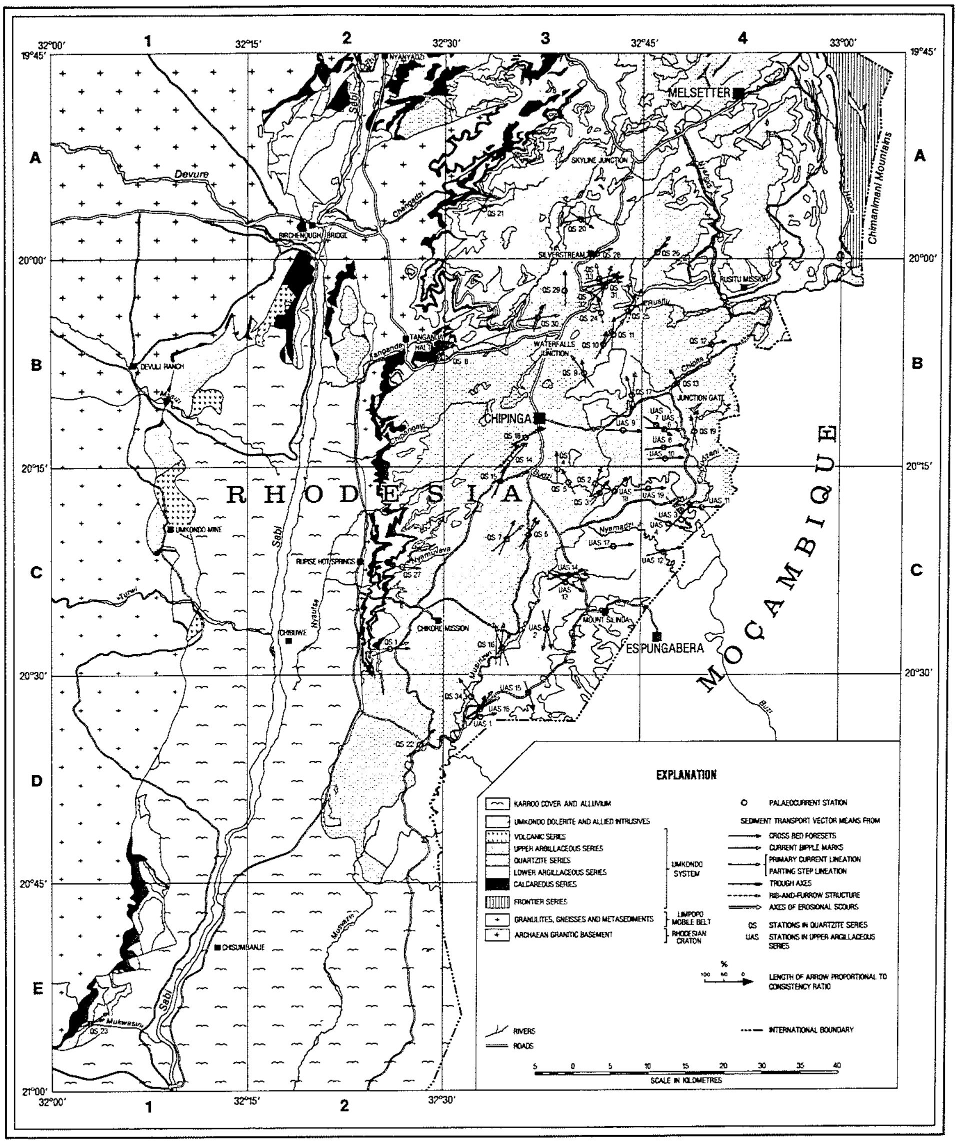


Figure 18 : Map showing the palaeocurrent vectors determined for sediments of the Umkondo System

In the Quartzite Series, sediment transport vectors are distributed in an arc, from easterly to northwesterly. There is a marked dependence of palaeocurrent vectors on stratigraphic position. The basal nine-tenths of the formation is characterized by vectors to the east and northeast, while the upper tenth, in a belt immediately beneath the Upper Argillaceous Series, usually shows northerly- and northwesterly-oriented vectors (Figure 18).

A current rose-diagram for the Quartzite Series as a whole is shown in Figure 19a. In the upper rose, the results of 478 cross-bed measurements are summarized. A spread of 180 degrees is apparent, with a concentration of vectors between 120 and 290 degrees. The current lineations and ripple-marks show a smaller spread, with mean transport towards the northeast.

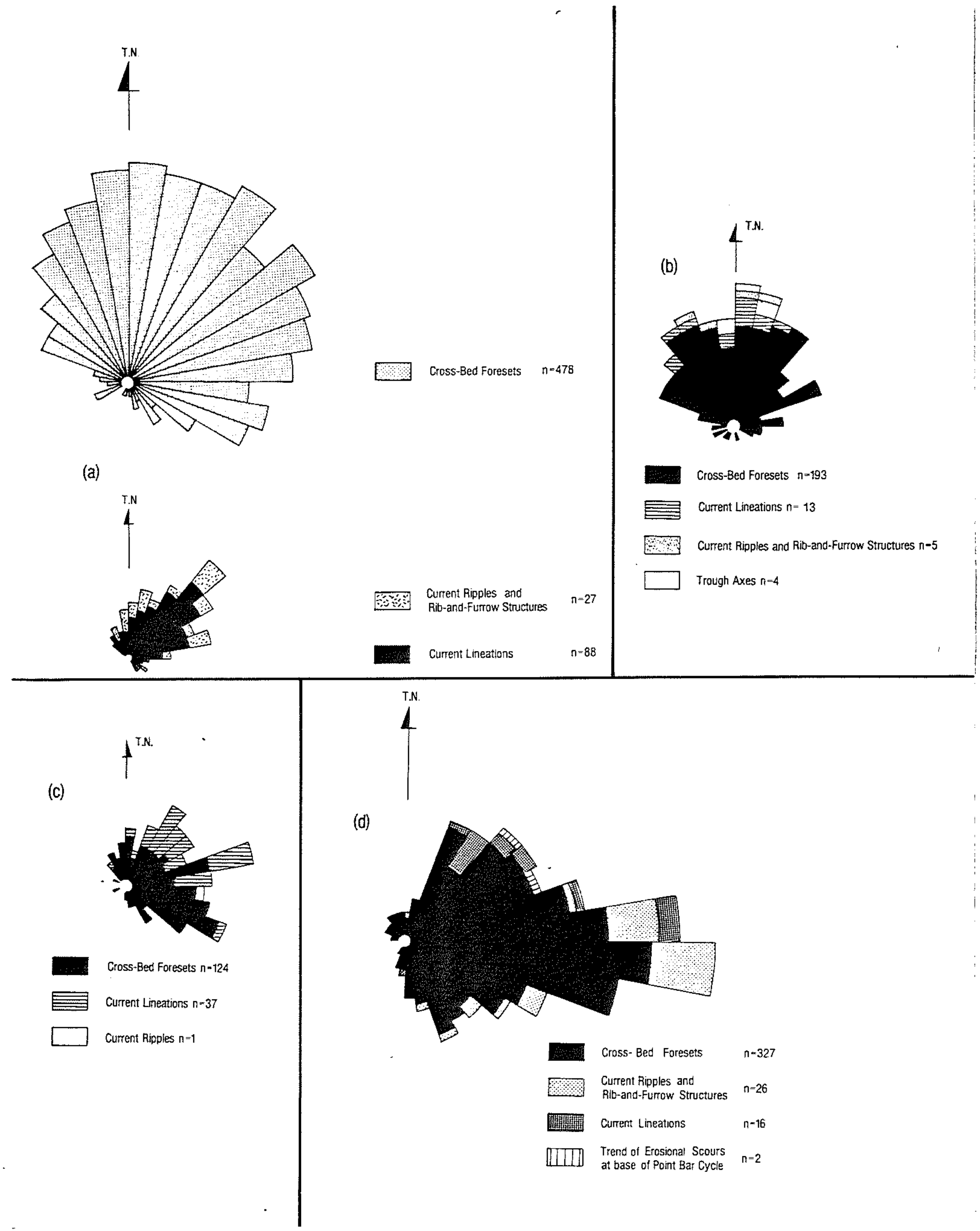


Figure 19 : *Rose diagrams of palaeocurrent vectors in the Umkondo System. (a) Quartzite Series as a whole; (b) uppermost phase of Quartzite Series; (c) basal half of Quartzite Series and (d) Upper Argillaceous Series*

The effects of stratigraphy were tested by compiling data for the upper tenth and basal half of the formation (Figures 19b and c, respectively). Figure 19b shows mean transport to the north, with a symmetrical 90 degree spread on either side of the mean; while Figure 19c shows an east-northeast mean. This confirms that there is a very clear change in mean sediment transport direction in the pure quartz arenites at the top of the Quartzite Series. The east-northeast mean for the bulk of the formation is interpreted as the palaeoslope, which controlled the orientation of braided streams on the fan-delta. The northerly transport in the reworked fan-delta sediments are thought to represent "contour-currents" on the submerged marine shelf.

At individual palaeocurrent stations in the uppermost part of the Quartzite Series, a suggestion of bimodal sediment dispersal patterns was detected. In most cases, the secondary mode was very subordinate to the primary, and could possibly represent a deficiency in sampling. The modes were usually separated by 90 degrees, and were oriented north-northwest and east-northeast. In only one case was there a suggestion of a bipolar distribution. The bimodal patterns suggest two sets of sandwaves (or megaripples) on the marine shelf, which were active during different phases of the daily or monthly tidal cycles.

Upper Argillaceous Series

In the Upper Argillaceous Series, measurement of vectoral properties was restricted to coarser-grained rocks in the point-bar sequences. Vectoral means are plotted on Figure 18, and indicates a mean easterly sediment transport direction. The rose-diagram (Figure 19d) confirms a fairly tightly grouped easterly mean. An easterly inclined palaeoslope can be confidently inferred.

The preponderance of fine-grained sediment in the Upper Argillaceous Series (95 per cent) is anomalously high for a meandering stream system. It could be speculated that the shaly sediments are mud-flat deposits, and that the point-bar sequences were formed by meandering tidal creeks. However, all other evidence excluded, the very marked unimodal sediment transport pattern, reflected in Figure 19d, argues against that conclusion. While tidal creeks can, under some circumstances, be either flood or ebb-dominated, some suggestion of bipolar sediment transport would almost certainly be preserved. No such pattern is seen in Figure 19d. Other special conditions have been invoked to explain the mud and silt-dominated meandering alluvial system of the Umkondo Basin.

DEPOSITIONAL MODEL

The depositional history inferred for the Umkondo System is summarized in Figure 20. In the first stage (Figure 20.1), a more-or-less north-south trending supratidal carbonate flat is shown. The *sebkha* carbonates are characterized by algal lamination, by carbonate-filled birdseye vugs and by scattered quartz grains. The latter may well have been introduced onto the *sebkha* by aeolian agencies. Shinn (1973) has stressed the role of aeolian processes on carbonate supratidal flats.

The carbonates and associated siltstones are cut by a channel-like body of subgreywacke arenite. This is taken to be the product of sedimentation in an ephemeral stream course. The depositional environment of the red siltstone is hard to determine, but could have been in lakes or lagoons associated with the *sebkha*.

Continued subsidence resulted in drowning of the *sebkha* under a marine shelf. On the outer shelf, carbonates and marls were deposited. The limestones and marls are structured by banks, which were probably algal-bound. Slumping of unconsolidated material down bank slopes under the influence of gravity resulted in sheets of deformed sediment.

A muddy shelf gradually prograded across the carbonate shelf (Figure 20.2). On the outer parts of the shelf, within the photic zone, algal bioherms were developed. They probably formed in regions of reduced mud input. Further progradation brought prodeltaic muds, silts and sands across the shelf , which were, in turn, covered by arenites deposited in prograding braided fan-deltas. Palaeocurrent work on the fan delta arenites suggests sediment transport to the east-northeast (Figure 20.2).

The deltaic episode persisted for a relatively long period of time, and gave rise to the 700-800 m thick Quartzite Series. Eventually, the rate of sediment input must have diminished, so that continued subsidence took the deltaic plain below sea-level. The topmost phase of the deltaic plain was reworked by currents on a marine shelf. Sediment transport on the shelf was mainly to the north, though some bimodal transport patterns suggest two sets of bed forms, which were active during different stages of daily or monthly tidal cycles (Figure 20.3).

Finally, renewed clastic input resulted in a meandering fluvial plain being built out across the shelf (Figure 20.4). Meandering flow was down an easterly palaeoslope. On account of the very large proportion of silt and mud fed to the system, point-bar sediments make up only 5 per cent of the assemblage. Channels were, on average, some 4,5 m deep. The flood basins were frequently dried out, resulting in desiccation features. Saline groundwater was present in places, and produced halite crystals and synaeresis cracks. The dominance of flood basin sedimentation is probably due to the fine-grained sediment being supplied to the rivers, and, possibly, to lack of levee stability due to absence of vegetative cover.

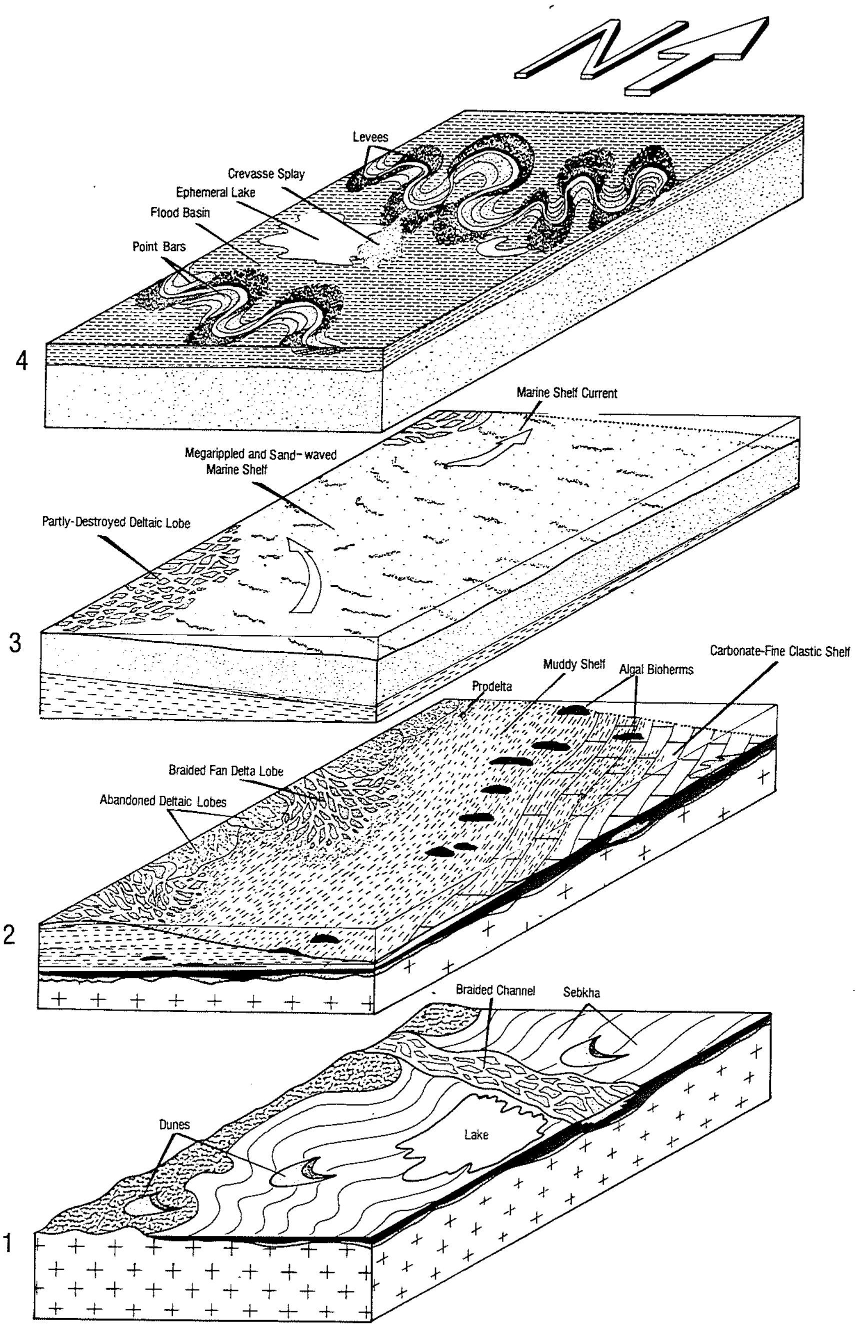


Figure 20 : *Depositional models inferred for units within the Umkondo System in the Chipinga area*

ECONOMIC IMPLICATIONS

Renfro (1974) has reviewed the origin of stratiform, evaporite-associated metalliferous deposits, and has concluded that *sebkha* processes are largely responsible for their formation. In summary, he argued that evaporation on the *sebkha* sets up hydraulic gradients, so that subsurface water flows towards the *sebkha* both from the sea and the land. The terrestrial waters are acid and relatively oxygenated, and can dissolve and transport base metals. As the *sebkha* progrades seawards, it covers previously deposited intertidal (algal mat bearing) sediments, in which H_2S is being generated. Terrestrial waters moving up towards the *sebkha* surface must pass through the H_2S laden algal mat, which results in precipitation of their metal content. The metals are deposited in a zoned sequence, frequently commencing (landward) with chalcocite (least soluble in the presence of H_2S) to pyrite (seaward).

The present study has indicated that the basal arkose of the Umkondo is overlain by dolomite, inferred to have been formed on a *sebkha*. The stratigraphic arrangement is very similar to that described in Renfro's model. In terms of this concept, sulphides should be found more-or-less at the top contact of the arkose, contained in reduced argillite, dolomite or arkose. The model requires metal zoning, from chalcocite (landward) to pyrite (seaward).

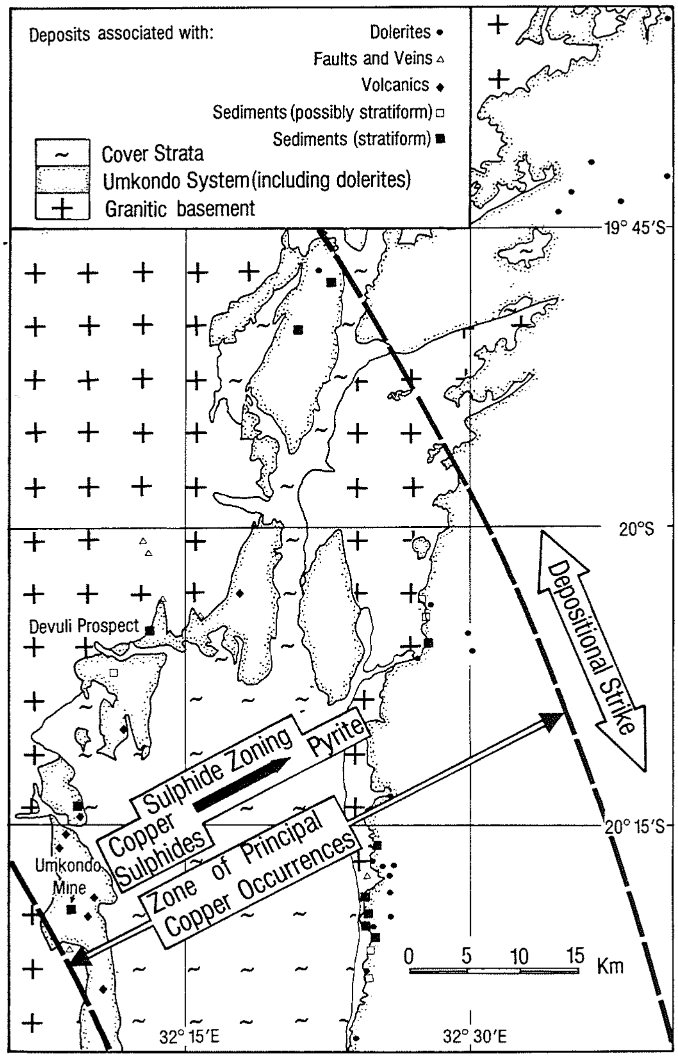


Figure 21 : *Distribution of copper occurrences in the Umkondo Basin (after Tyrwhitt, 1966), and an interpretation of controls of distribution and metal zoning*

Over 50 copper occurrences are known from the middle Sabi valley (Tyrwhitt, 1966), and are shown plotted on Figure 21. Many of the occurrences are mere shows, from which no ore has been extracted. This is particularly the case for the shows associated with the Umkondo dolerite, many of which are no more than a smear of sulphide along joints and fractures in the dolerite. If this class of deposit is ignored, the remaining occurrences are confined within a 50 km wide, north-northwest-trending belt of country (Figure 21). This belt is more-or-less parallel with the depositional strike of the lower Umkondo Basin. It is suggested that this belt represents the mineralized zone of the *sebkha*, and that any truly stratiform deposits within the lowermost Umkondo sediments should be elongated in this direction. The belt represents a long period of time, when the mineralized facet of the *sebkha* moved seaward and landward in response to variations in the rate of subsidence and sediment supply. Secondly, individual orebodies should be zoned, from copper sulphides in the west, to pyrite along their eastern margin. Thus, for example, the stratiform pyrite-chalcopyrite body of the Devuli prospect (Figure 21) could represent the seaward edge of a deposit of copper-sulphide lying further west, and now erosively removed.

In addition to stratiform deposits in the *sebkha* setting, copper deposits showing "hydrothermal" properties are very common, and include vein, fracture and fault lode deposits in dolerite and in basement granite, and replacement lodes in sediment (such as at the Umkondo Mine) and in volcanics. These deposits are thought to have been formed by mobilization of the *sebkha*-sulphides. The intrusion of dolerite sills into the Calcareous Series, which make up (on average) 60 per cent of the formation, could have provided the fluids and the thermal gradients necessary for the migration of copper. Although Hodgson (1973) was of the opinion that the copper associated with the Umkondo lavas was syngenetic, it is possible that these also owe their origin to mobilization of copper out of the primary deposits.

In summary, the mineralized belt shown in Figure 21 is thought to represent the zone across which a migrating *sebkha* was responsible for copper deposition. The individual orebodies should be elongated north-northwest, and should be zoned from copper-rich in the west, to pyrite-rich in the east The subsequent flooding of the Calcareous Series by basic sills is thought to have mobilized some of the copper into vein deposits in granite, in Umkondo sediments, and in the dolerite itself. The hydrothermal solutions which resulted in the Umkondo Mine replacement body could have had the same source. Some of the stratiform sulphide remained in place, and is seen as deposits such as the Devuli prospect. Other deposits of this type probably remain to be discovered, especially in the covered area under Sabi valley alluvium.

* *

ACKNOWLEDGEMENTS

The assistance of the following individuals and organizations is gratefully acknowledged :

(i) the director and staff of the Rhodesian Geological Survey, for guidance and for assistance in obtaining permits;

(ii) the director and staff of the Institute for Mining Research in Salisbury, for discussions and publications;

(iii) the staff of the District Commissioners office, and the Rhodesian police in Chipinga, for local guidance;

(iv) the people of the Chipinga area, for permission to undertake fieldwork on private property;

(v) the Abrahams family of Chipinga, for accommodation during part of the field period;

(vi) the manager of the Chisumbanje irrigation scheme, for accommodation while doing field work in the southern part of the basin;

(vii) Mr. Sayeneti Mhlanga, for assistance in the field;

(viii) Miss D. Myhill, for assistance in processing palaeocurrent data;

(ix) Mr. R. Osborne, for grain-size determinations;

(x) Mr. K.A. Eriksson, for helpful discussions;

(xi) Dr. J. Martini, for examining some thin sections of Umkondo arenites, and,

(xii) Mrs. B.M. Button, for the initial tabulation of field data.

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* *

PLATE 1

A : Outcrop, showing typical style of layering in the limestone and calc-silicate unit, Calcareous Series.

B : Crinkly lamination and calcite-filled spherical structures in limestone and calc-silicate unit, Calcareous Series (spheres 2 cm diameter).

C : Inclined stratification on edge of bank structure, overlain by horizontal layering, limestone and calc-silicate unit, Calcareous Series (rod is 2 m high).

D : Plan-view of columnar stromatolites, showing preferred orientation, Lower Argillaceous Series (photograph 63 cm long).

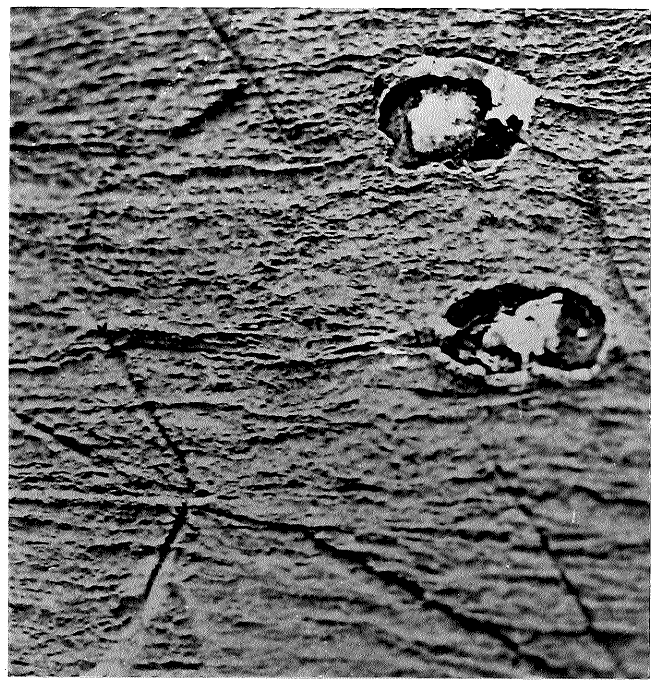
E : Plan-view of columnar stromatolites, inter-column fill is carbon-rich, and weathers white, Lower Argillaceous Series.

F : Sectional view of columnar stromatolites, showing occasional bridging between columns, Lower Argillaceous Series (photograph 27 cm high).

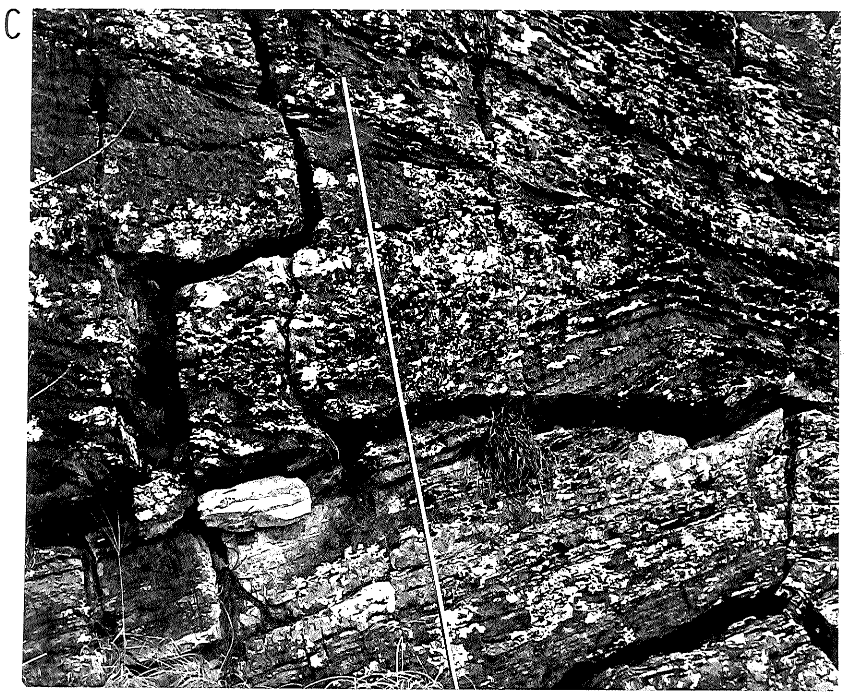
PLATE 1

A

B

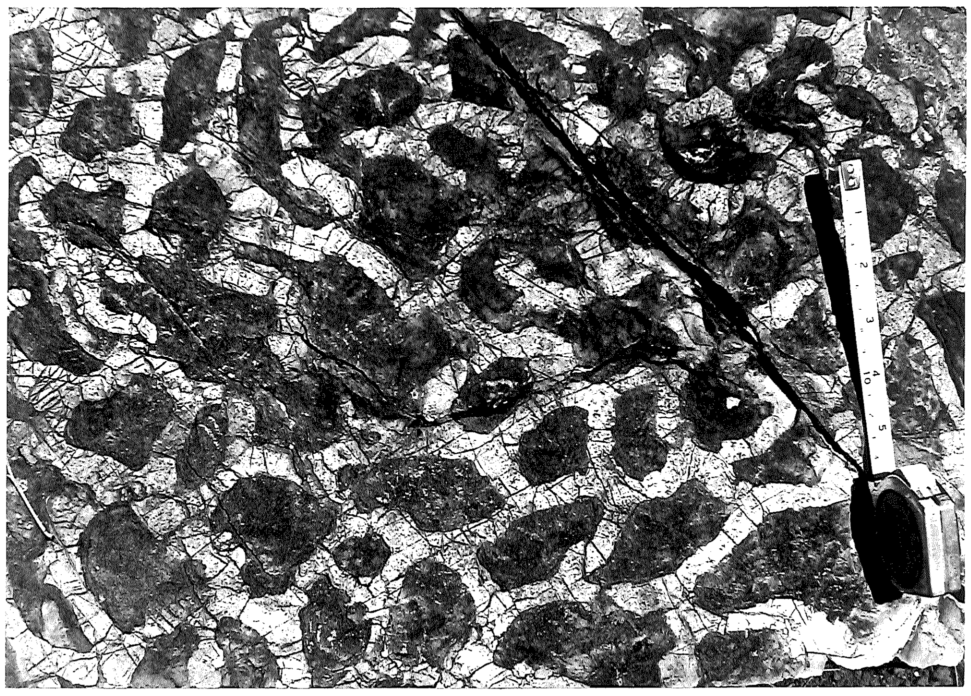


C



D

E



F

PLATE 2

A : Mud-cracks in arenite lens in the Lower Argillaceous Series (photograph 30 cm long).

B : Erosive base of a braided stream cycle in the arenites of the Quartzite Series (photograph 75 cm high).

C : Small ripple-bedded arenite resting on erosive surface cut into plane-bedded arenite, Quartzite Series (photograph 20 cm high).

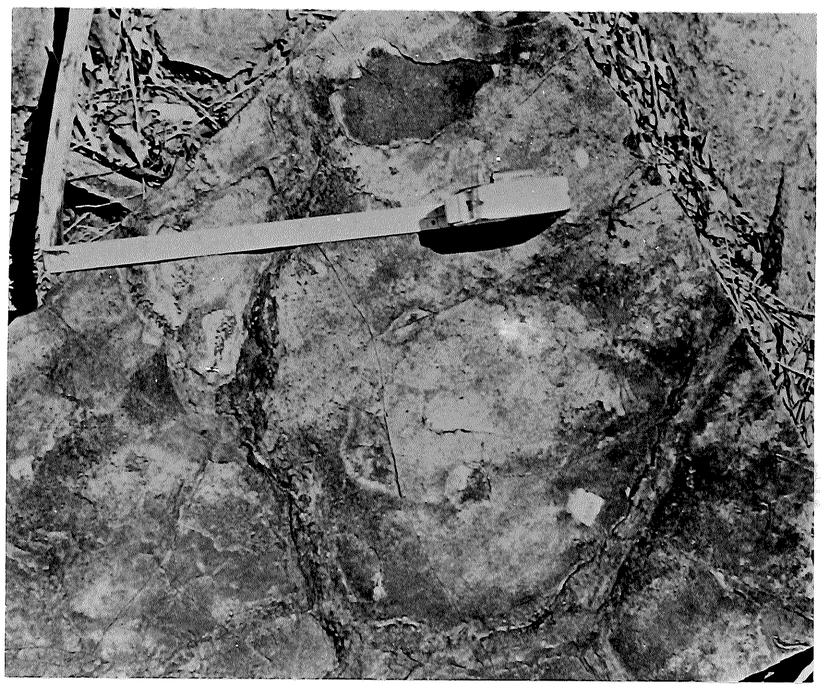
D : Plane-bedding in arenite of the Quartzite Series [note very gentle angular discordance at base of upper set] (photograph 35 cm high).

E : Sets of gently-inclined plane-bedding, some of which can be traced through inflection points, into foresets; point-bar facies of the Upper Argillaceous Series (photograph is 90 cm high).

F : Sets of plane-bedded arenite separated by a siltstone drape; point-bar facies of the Upper Argillaceous Series.

PLATE 2

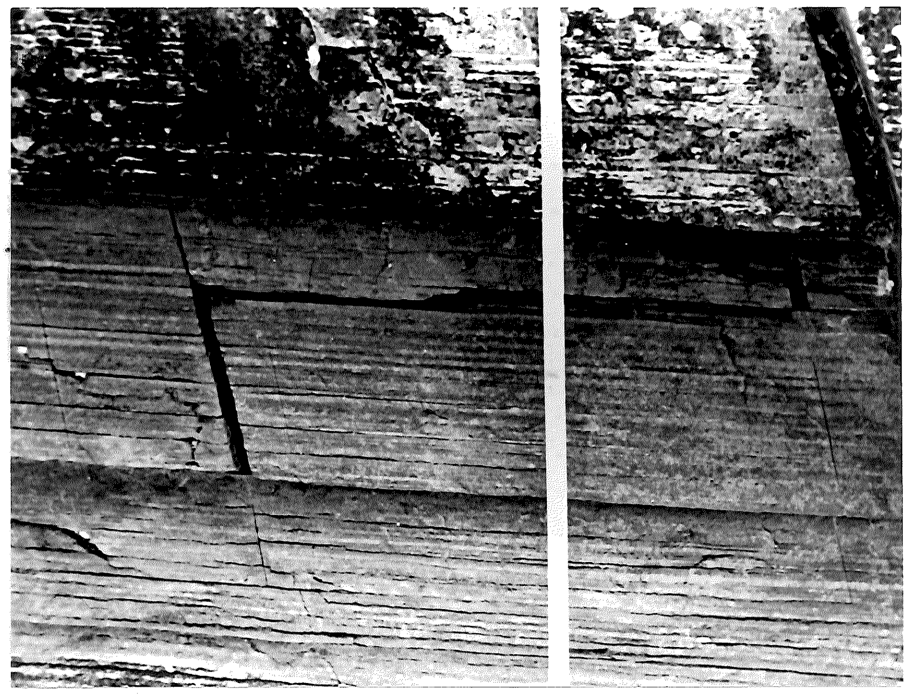
A



B

C

D



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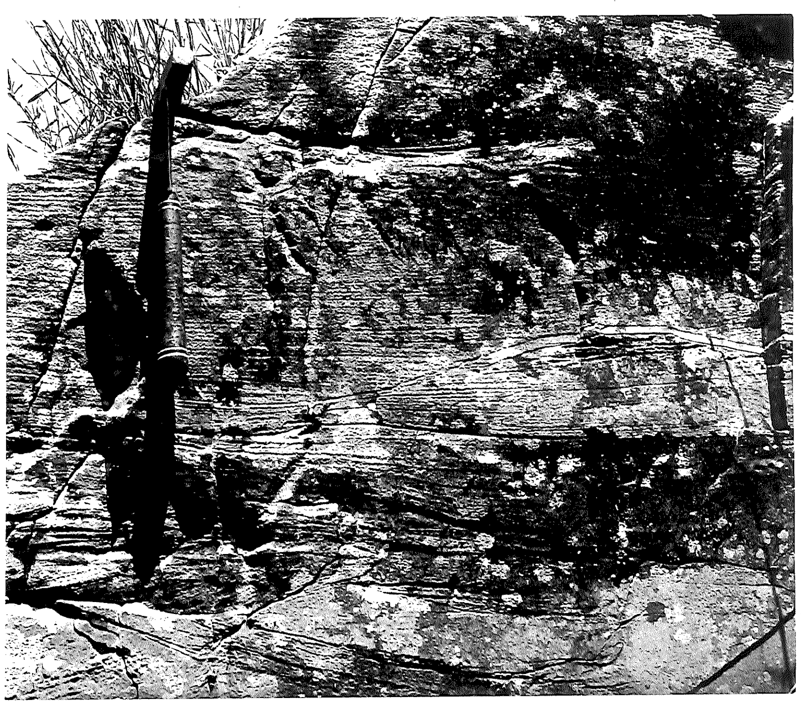
F



APPENDIX I

PALAEOCURRENT STATISTICS - UMKONDO SYSTEM

Station	Sedimentary Structure	Number of Observations	Vector Mean (°T)	Consistency Ratio (%)	Grid Reference
QS 1	Cross Beds	4	088	96	E2
	Lineations	8	069	94	E2
QS 2	Cross Beds	16	019	76	E3
QS 3	Cross Beds	20	035	77	E3
QS 4	Cross Beds	20	359	75	E3
QS 5	Cross Beds	21	334	65	E3
QS 6	Cross Beds	20	037	81	E3
	Lineations	4	024	93	E3
QS 7	Cross Beds	4	023	95	E3
	Lineations	3	050	95	E3
QS 8	Cross Beds	20	059	71	D2
	Lineations	5	028	99	D2
QS 9	Cross Beds	22	352	54	D3
	Lineations	3	325	97	D3
QS 10	Cross Beds	19	015	48	D3
	Lineations	10	027	82	D3
QS 11	Cross Beds	10	004	71	D3
	Lineations	4	035	96	D3
QS 12	Cross Beds	8	076	71	D4
QS 13	Cross Beds	13	335	61	D4
QS 14	Cross Beds	4	038	76	D3
	Rib-and-Furrow	2	047	98	D3
	Lineations	5	041	99	D3
QS 15	Cross Beds	22	019	78	E3
	Lineations	1	026	-	E3
QS 16	Cross Beds	13	032	70	E3
	Lineations	5	001	90	E3
	Trough Axes	3	003	98	E3
	Linguoid Ripple Marks	3	341	98	E3
QS 17	Cross Beds	20	345	81	D3
	Rib-and-Furrow	5	006	99	D3
QS 18	Cross Beds	4	062	90	D3
	Lineations	4	055	89	D3
QS 19	Cross Beds	17	349	71	D4
	Lineations	5	006	99	D4
QS 19a	Cross Beds	3	065	99	B4
QS 19b	Cross Beds	2	036	28	B4
QS 20	Cross Beds	18	123	65	C3
	Lineations	1	076	-	C3
QS 21	Cross Beds	22	072	71	C3
	Lineations	1	033	-	C3
QS 22	Cross Beds	20	044	94	F2
QS 23	Cross Beds	12	071	61	G1
	Lineations	17	060	92	G1
QS 24	Cross Beds	9	348	65	D3
QS 25	Cross Beds	20	024	83	D3
	Lineations	4	060	99	D3
	Rib-and-Furrow	1	024	-	D3
QS 26	Cross Beds	15	047	65	C4
	Lineations	2	040	98	C4
QS 27	Cross Beds	19	095	81	E2
QS 28	Cross Beds	12	071	78	C3
QS 29	Cross Beds	20	357	82	D3
QS 30	Cross Beds	6	022	60	D3
	Lineations	3	024	67	D3
	Current Ripples	1	080	-	D3
QS 31	Cross Beds	3	062	97	D3
	Lineations	1	045	-	D3
	Current Ripples	3	019	95	D3
QS 32	Cross Beds	5	070	87	D3
	Lineations	2	348	93	D3
	Rib-and-Furrow	12	081	81	D3
QS 33	Cross Beds	12	075	76	D3
		Total = 593			

APPENDIX I (Continued)

UAS 1	Cross Beds	7	080	72	F2
UAS 2	Cross Beds	21	167	95	E3
	Lineations	1	188	-	E3
UAS 3	Cross Beds	21	042	92	E4
UAS 3a	Rib-and-Furrow	3	141	95	E4
UAS 4	Cross Beds	18	107	76	E4
UAS 5	Cross Beds	11	324	87	F3
UAS 6	Cross Beds	25	093	83	D4
UAS 7	Cross Beds	20	123	84	D4
UAS 8	Cross Beds	25	083	91	D4
UAS 9	Cross Beds	30	091	89	D3
	Lineations on Foresets	1	054	-	D3
UAS 10	Cross Beds	18	086	86	D4
UAS 11	Cross Beds	6	090	75	E4
UAS 12	Cross Beds	14	077	92	E4
UAS 13	Cross Beds	3	057	98	E3
	Current Ripples	5	119	99	E3
UAS 14	Cross Beds	35	105	90	E3
	Rib-and-Furrow	16	087	100	E3
	Lineations	6	076	98	E3
UAS 15	Cross Beds	19	160	69	F3
UAS 16	Cross Beds	20	024	65	F2
	Lineations	8	033	99	F2
UAS 16a	Cross Beds	3	063	92	F2
	Low-Angle Accretionary Plane Beds	6	099	93	F2
	Axial Trend of Basal Scour	2	057	98	F2
UAS 17	Cross Beds	8	83	96	E3
UAS 18	Cross Beds	14	040	90	E3
UAS 19	Cross Beds	9	084	76	E4
		Total = 375			