ECONOMIC GEOLOGY

RESEARCH UNIT

University of the Witwatersrand

Johannesburg

ALLUVIAL AND DESTRUCTIVE BEACH FACIES IN THE ARCHAEAN MOODIES GROUP OF THE BARBERTON MOUNTAIN LAND

K. A. ERIKSSON

INFORMATION CIRCULAR No. 115

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

ALLUVIAL AND DESTRUCTIVE BEACH FACIES IN THE ARCHAEAN MOODIES GROUP OF THE BARBERTON MOUNTAIN LAND

by

K. A. ERIKSSON
(Senior Lecturer, Department of Geology, University of the Witwatersrand)

ECONOMIC GEOLOGY RESEARCH UNIT
INFORMATION CIRCULAR No. 115
March, 1978

<u>ALLUVIAL AND DESTRUCTIVE BEACH FACIES IN THE ARCHAEAN MOODIES GROUP OF THE BARBERTON MOUNTAIN LAND</u>

ABSTRACT

The Moodies Group, approximately 3 300 m.y. in age, is the oldest relatively unmetamorphosed quartzitic assemblage of sediments presently known. This succession consists of a wide variety of sedimentary facies which accumulated *inter alia* in diverse alluvial and marginal marine depositional environments. A remarkable similarity is shown to exist between Holocene physical sedimentary processes and those operative during the Archaean.

A depositional model is proposed to relate the different alluvial sedimentary environments in space. Proximal alluvial plain deposits consist of matrix- and clast-supported conglomerates which were deposited, respectively, by mass flow and tractional processes. Mid-alluvial plain sandstones developed through vertical aggradation and mid-channel bar formation during falling stages of epdisodic floods. The most distal alluvial plain sediments comprise upward-fining channel-fill sequences enclosed within interlayered siltstones and shales of probable overbank origin. Vertical sequences of alluvial facies were determined by source area tectonics. During most active progradation alluvial plain sediments built directly onto shelf accumulations in the form of fan deltas. Marginal destructive swash bars developed on the fan deltas at the cessation of fluvial influx.

This investigation has shown that exposed granitic terrains existed greater than 3 000 m.y. ago, the erosion of which resulted in extensive subaerial alluvial sedimentation. The mineralogy of the fluvial sediments is indicative of an anoxygenic atmosphere at the time of their deposition. Braided fluvial processes predominated in the absence of levee stabilization by plant growth but a stable crust, on which prolonged reworking of sediments occurred, is indicated by the orthoquartzitic swash bar sandstones.

* *

ALLUVIAL AND DESTRUCTIVE BEACH FACIES IN THE ARCHAEAN MOODIES GROUP OF THE BARBERTON MOUNTAIN LAND

CONTENTS

* *

ISBN 0 85494 499 0

ALLUVIAL AND DESTRUCTIVE BEACH FACIES IN THE ARCHAEAN MOODIES GROUP OF THE BARBERTON MOUNTAIN LAND

INTRODUCTION

Detailed palaeoenvironmental analyses on Archaean sediments are rare and have, to date, been confined almost exclusively to North America. Resedimented deep-water sequences predominate (see for example Donaldson and Jackson, 1965; Ojakangas, 1972; Turner and Walker, 1973; Hyde, 1975) but shallow-water alluvial deposits have also been identified (Turner and Walker, 1973; Hyde, 1975). In this account, an extensive assemblage of immature alluvial and intercalated mature beach sediments from the Moodies Group in the Barberton Mountain Land (Figure 1) are discussed and related spatially in a single depositional model.

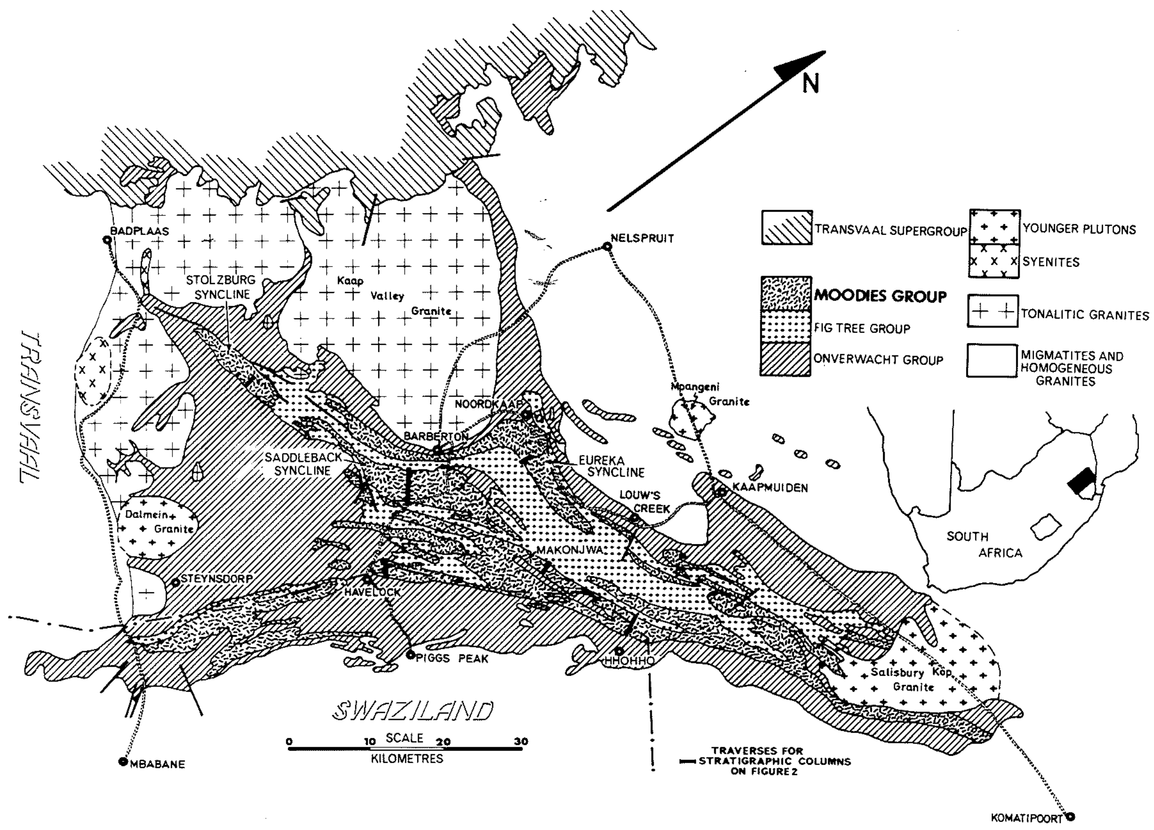

Figure 1 : *Geological map of the Barberton Mountain Land with inset map of South Africa (modified after Truswell, 1970; after Anhaeusser et al., 1968).*

The recognition and palaeoenvironmental interpretation of Archaean alluvial and marginal marine sequences can provide important information pertaining to physical processes operative on the surface of the primitive earth. Extensive and diverse fluvial facies, furthermore, would indicate a moderately stable crust on which lateral channel migration could have occurred on broad alluvial plains. In addition, the presence or absence of iron oxide grain coatings in fluvial sediments holds one key to determining the composition of the Archaean atmosphere.

STRATIGRAPHIC FRAMEWORK AND AGE OF THE MOODIES GROUP

The Moodies Group is the upper of three subdivisions of the Swaziland Supergroup (Figure 1). The basal Onverwacht Group consists predominantly of volcanics with only minor sediments (see Viljoen and Viljoen, 1969; Anhaeusser, 1973; amongst others) and is conformably overlain by immature clastic and chemical sediments of the Fig Tree Group (Reimer, 1975). In the southern parts of the Barberton Mountain Land, most notably in Swaziland, the Moodies Group rests directly on Onverwacht volcanics (Jones, 1969) and in the central parts unconformably on Fig Tree sediments. From the Makonjwa Range northwards (Figure 1), as was established by Tomlinson (1967) and Anhaeusser (1969), a gradational contact exists between the Fig Tree and Moodies Groups.

No direct age determinations have been carried out on the Moodies Group, but these sediments can be dated relative to upper Onverwacht felsic volcanics, with an age of 3 360 ± 100 m.y. (Van Niekerk and Burger, 1969) at less than 3 400 m.y. A minimum age for the Moodies sediments is more difficult to determine. The 'intrusive' nature of the Kaap Valley Granite, which is dated at 3 310 ± 40 m.y. (Oosthuyzen, 1970), is now disputed and other more reliable evidence must be sought. As the Swaziland Supergroup is strongly deformed, the age of non-foliated or post-tectonic granites will provide a minimum age for the Moodies Group. Granites of this type include the intrusive Lochiel or Homogeneous Hood Granite, dated at 3 070 ± 60 m.y. (Allsopp et al., 1962) and the intrusive Salisburykop Pluton which has an age of 3 060 ± 30 m.y. (Oosthuyzen, 1970). The oldest non-foliated granite is the Dalmein Pluton which is dated at 3 290 ± 80 m.y. (Oosthuyzen, 1970). This suggests that the Moodies Group is at least 3 300 m.y. in age which, in view of the conformable nature of the three groups within the Swaziland Supergroup, is not incompatible with the age of the upper Onverwacht. The Moodies Group is thus older than any of the sedimentary basins on the Kaap Vaal craton. The oldest of these is the Pongola Supergrpup which rests on granites of the Lochiel-type dated at 3 000 ± 200 m.y. (H.L. Allsopp, personal communication, 1975).

The Moodies Group attains its greatest thickness in the Eureka Syncline (Figure 1) and is subdivisible into five stratigraphic units (MD1 - MD5; Figure 2). A prominent amygdaloidal lava horizon at the base of unit MD4 allows for correlation between the Eureka, Saddleback and Stolzburg Synclines (Figure 1). In the latter two synclines the Moodies Group is represented by stratigraphic units MD1 through MD4. South of the Saddleback Syncline no correlatable stratigraphy, apart from a basal conglomerate, can be recognized (Figure 2).

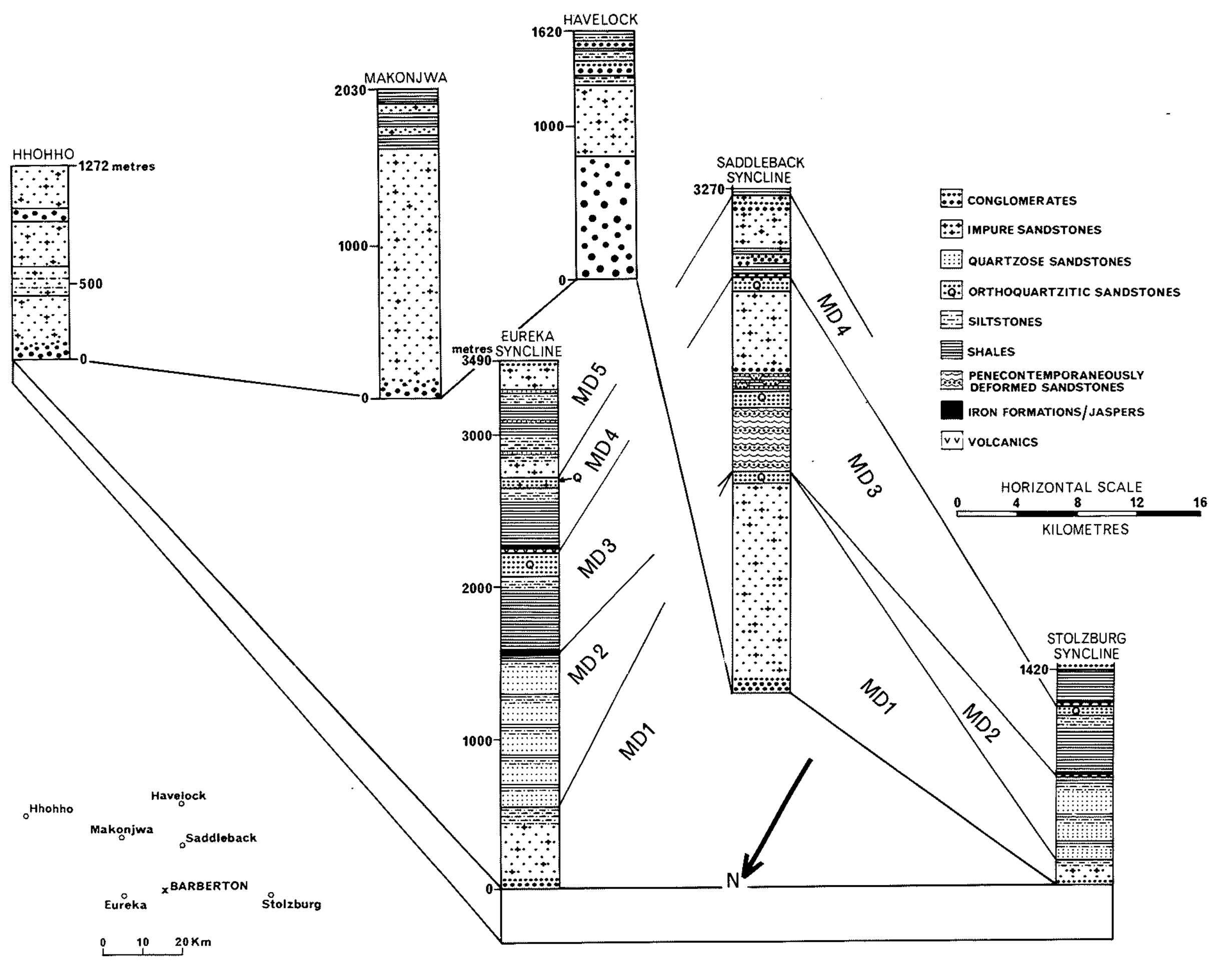

Figure 2 : *Representative stratigraphic columns of the Moodies Group. Inset shows ground positions of column localities relative to Barberton. Orthoquartzitic sandstones contain greater than 95 per cent quartz and quartzose sandstones between 90 and 95 per cent quartz.*

Stratigraphic units discussed in this account are made up of an assemblage of sedimentary facies composed of conglomerates within thick impure sandstone sequences, subordinate shales and thin intercalated orthoquartzitic sandstones. In the southern parts of the Barberton Mountain Land, notably along the Swaziland border and northwards to the Makonjwa Range (Figure 1), these are the only sedimentary facies present (see Figure 2). In the Saddleback Syncline stratigraphic units MD1, the upper parts of MD3, and MD4 consist of this facies assemblage while further north representatives of this assemblage are less common and comprise only MD1, the upper part of MD4, and MD5 in the Eureka Syncline, and MD1 and the upper part of MD4 in the Stolzburg Syncline. Four sedimentary facies are distinguished in this assemblage and are characterized below in terms of their lithologies (Dott, 1964), sedimentary structures and vertical sequences which are then used to interpret specific shallow-water depositional environments with reference to Holocene depositional models from poorly-vegetated areas.

SEDIMENTARY FACIES

Conglomerate Facies

Occurrences of this facies are indicated on Figure 2, from which it is apparent that the thickest development of conglomerates occurs in the south, and specifically around Havelock. The conglomerates are very coarse, with an average mean pebble diameter of -5,1Ø (3,3 cm) (Table 1) but often contain boulders greater than 25 cm in diameter. Pebbles and boulders are generally spherical and rounded to well-rounded except in the Hhohho area (Figure 1) where a thin conglomerate with angular to subangular clasts occurs at the base of the succession. Sorting (dispersion) is commonly poor (>1,0Ø) and rarely moderate (,70-1,0Ø) (Folk, 1968, see Table 1). White, black and banded cherts, and jasper are the predominant clast types in the conglomerates (Table 2). Acid volcanic clasts, often silicified, are fairly abundant, but mafic varieties are rare. Granitic clasts, often greater than 25 cm in diameter, are confined to the basal conglomerate and occur most commonly in the Eureka Syncline.

TABLE 1

STATISTICAL PARAMETERS FOR MOODIES CONGLOMERATES

	E1	E2	E3	E4	S1	S2	S3	S4
Mean (Ø)	-4,88	-5,25	-5,07	-4,56	-5,41	-5,62	-5,40	-4,65
Variance (Ø)	1,03	1,41	1,82	1,17	1,37	2,40	1,58	,55
Std. Dev. (Ø) (Dispersion)	1,01	1,19	1,35	1,08	1,17	1,55	1,26	,74
Max. Clast Size (cm)	12	30	50	24	33	45	38	16
Number of Clasts Measured	119	129	108	108	111	127	110	120

E1 - E4 : Basal Conglomerate, Havelock Area

S1 and S2 : Middle MD3 Conglomerate, Saddleback Syncline

S3 : Lower MD4 Conglomerate, Saddleback Syncline

S4 : Upper MD4 Conglomerate, Saddleback Syncline (see Figure 2 for stratigraphic positions).

Statistical parameters are calculated for grouped data with frequency count by class. Maximum diameters of all clasts >1 cm in diameter were measured at each locality.

Equations :

$$\mu \text{ (mean)} = \frac{\sum_{i=1}^{k} f_i x_i}{N}$$

$$\sigma^2 \text{ variance} = \frac{\sum_{i=1}^{k} f_i x_i^2 - \frac{\left(\sum_{i=1}^{k} f_i x_i\right)^2}{N}}{N - 1}$$

where : x_i = Midpoint of Class Interval

f_i = Frequency in Each Class

k = Number of Classes

N = Number of Observations

(after Edwards, 1964, p. 41 and 59).

TABLE 2

CLAST TYPES IN MOODIES CONGLOMERATES

Sample Number	E1	E4	S1	S3	S4
White Chert	10,5	1,9	25,2	45,5	8,1
Black Chert	26,8	48,2	30,0	1,8	58,5
Banded Chert	39,0	25,0	13,5	18,8	8,9
Vein Quartz	4,9	1,9	,9	1,8	4,1
Acid Volcanic	9,8	6,5	9,0	16,1	8,2
Mafic Volcanic	-	,9	3,6	8,1	1,6
Ironstone	3,2	2,8	17,1	6,5	-
Jasper	4,1	13,0	-	-	2,4
Brecciated Chert	1,6	-	,9	1,0	-

Figures in Percentages
Samples as in Table 1

Two conglomerate types occur in this facies; one is matrix-supported and the other clast-supported. Matrix-supported types are most common lower down in the sedimentary succession, especially in the southern parts of the outcrop-belt. The basal conglomerate in the Havelock area, for instance, is predominantly matrix-supported with only occasional thin intercalated clast-supported units. Clast-supported conglomerates are more abundant higher up in the stratigraphic succession, notably in unit MD4 in the Saddleback and Stolzburg synclines (Figure 2). Contacts between sedimentary units, as defined by thin intercalated sandstones, are regular and non-erosional in the matrix-supported variety, while the clast-supported type frequently displays irregular basal contacts which may have a relief of up to 10 m. Imbrication is not apparent in the matrix-supported conglomerates but is sometimes seen in the clast-supported types. The matrix-supported conglomerates display no size-grading of clasts, but an upward-fining is often noticeable in the clast-supported varieties. The relationship between bed thickness and maximum clast size for four different conglomerates is illustrated in Figure 3. Correlation is best for conglomerates which are clearly matrix-supported (Havelock and MD2 Saddleback) and very poor for the lower MD4 clast-supported variety (Figure 3). A fair correlation exists for the upper MD4 occurrence which contains both matrix- and clast-supported conglomerates.

The matrix of the conglomerates consists of medium- to coarse-grained, poorly- to very poorly-sorted lithic arenites and sublitharenites. The intercalated pebble-free sandstones are similar in composition to the matrix. These are most commonly plane-bedded and rarely greater than 1 m in thickness. They persist laterally for tens of metres where associated with the matrix-supported conglomerates, but tend to pinch out along strike where intercalated within the clast-supported variety (Figure 4). Trough cross-bedded sandstones vertically separate some individual conglomerate units of the clast-supported type, and often grade laterally into these conglomerates.

The two end-member conglomerate types are best typified by the Havelock and lower MD4 conglomerates, respectively. Frequently, however, the matrix and clast-supported conglomerates display a rapid alternation in pairs varying between 4 and 10 m in thickness. This is particularly noticeable in the upper MD4 conglomerate of the Saddleback area (Figure 2).

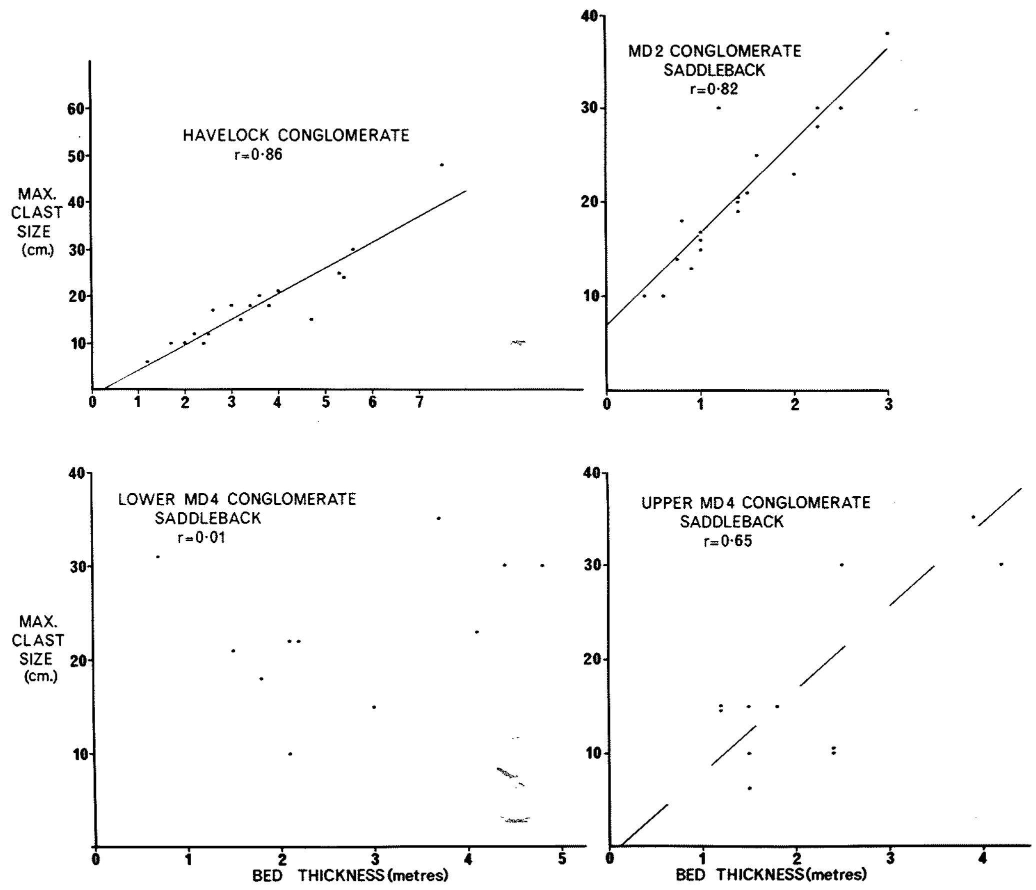

Figure 3 : *Graphic plot of bed thickness against maximum clast-size for four different conglomerates (r = correlation coefficient). Graphs A and B are for matrix-supported, graph C for clast-supported, and graph D for interlayered clast and matrix-supported conglomerates.*

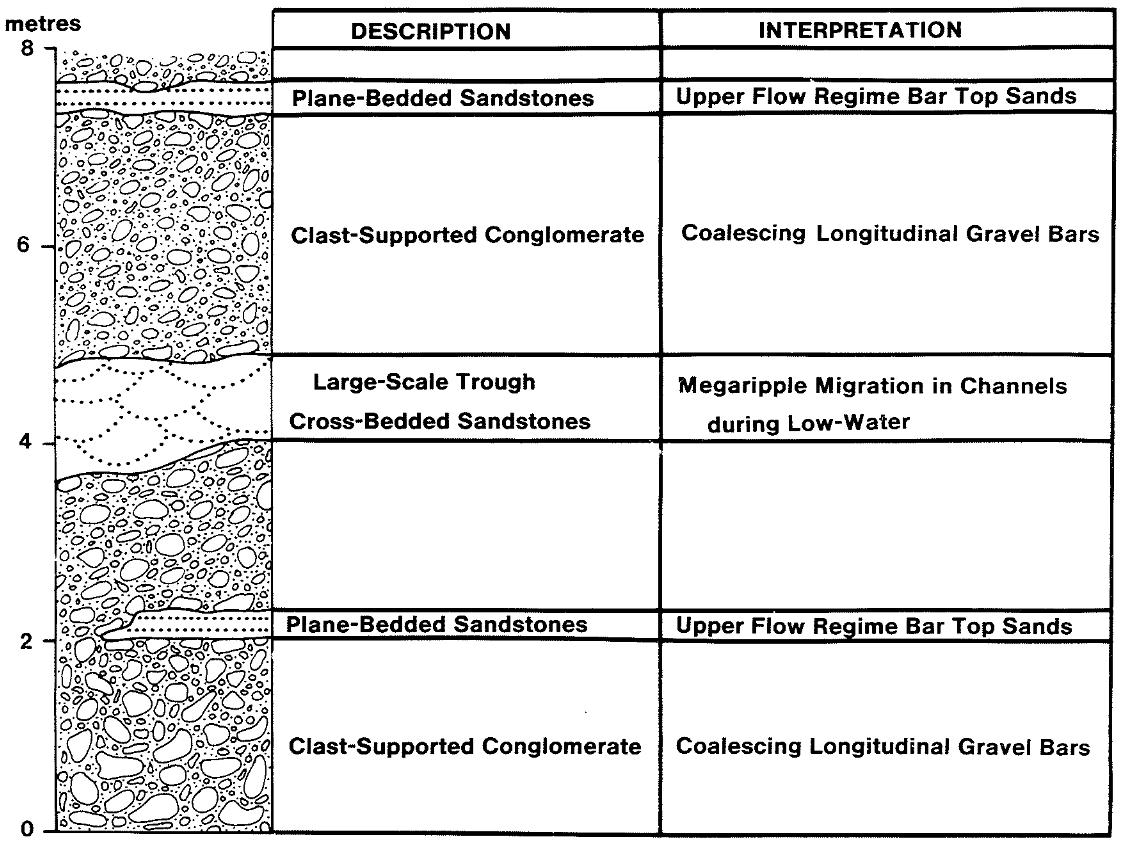

Figure 4 : *Measured stratigraphic section through clast-supported conglomerates and associated sandstones : upper conglomerate; Unit MD4; Saddleback Syncline.*

Trough Cross-Bedded Sandstone Facies

Sediments belonging to this facies are grouped together on Figure 2 as 'impure sandstones'. The sandstones vary in composition from sublitharenites and litharenites to lithic greywackes, are fine- to coarse-grained, poorly- to very-poorly sorted and are devoid of iron oxide pigmentation. Cumulative frequency curves (Figure 5) and statistical parameters (Table 3) for a number of samples from this facies indicate their highly immature character. Framework - matrix relationships show that the clay minerals are primary and not diagenetic. Scattered pebbles, predominantly chert, are common but siltstone and shale layers constitute a very small proportion of this facies.

TABLE 3

STATISTICAL PARAMETERS FOR MOODIES IMPURE SANDSTONES

	M8	M6	M013	23	M26	M9	M10
Mean (Ø)	3,35	2,03	2,43	3,03	3,18	2,36	3,18
Variance (Ø)	3,24	2,86	4,33	3,76	3,72	1,54	3,76
Std. Dev. (Ø)	1,80	1,69	2,08	1,93	2,21	1,24	1,93
Number of Measurements	200	200	200	200	200	200	200

M8 : Unit MD1, Saddleback Syncline

M6 : Unit MD3, Saddleback Syncline

M013 : Unit MD4, Saddleback Syncline

23 : Matrix to Lower Conglomerate in Unit MD4, Saddleback Syncline

M26 : Makonjwa Area

M9 : Makonjwa Area

M10 : Makonjwa Area

(See Figure 2 for stratigraphic positions)

Longest diameters of 200 grains were measured in thin section for each sample. Statistical parameters were calculated using the equations of Inman (1952) after converting cumulative frequency thin section percentiles to sieve equivalents (conversion equations after Harrell and Eriksson, in preparation).

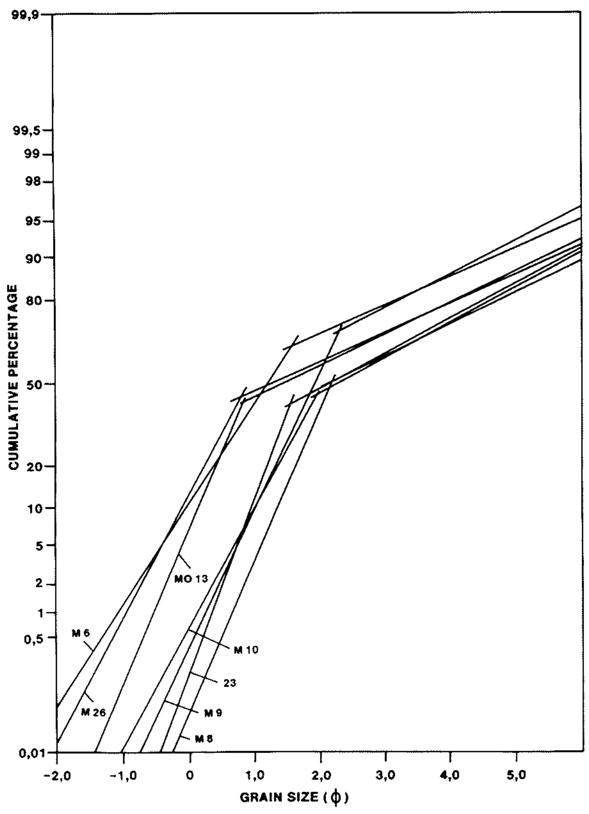

Figure 5 : Grain-size cumulative frequency curves for impure sandstones. See Table 3 for sample localities. Curves drawn for converted sieve equivalent percentiles.

Examples of vertical sequences of sedimentary structures developed in this facies are illustrated in Figure 6. Depositional cycles vary from 5 to 30 m in thickness, and often commence with a scattered pebble layer. Medium- and large-scale trough and occasional planar cross-beds are the predominant sedimentary structures in overlying sandstones. Troughs are up to 6 m in width and vary from 20 cm to 2,5 m in thickness. Markedly erosional contacts, which may be occupied by shale-partings, separate the trough cross-bed sets. Shale-partings and flakes occur along some cross-bed foresets. Depositional cycles are capped by a variety of sedimentary structures including small-scale cross-bedding or ripple-cross-lamination, plane-bedding with or without primary current lineations, ripple-drift cross-lamination and desiccated shale-partings, shale drape-laminae and convolute lamination in siltstone. The thick sequences of 'impure sandstones' (Figure 2) consist of stacked, overlapping and often scour-based partial or complete cycles of the types illustrated in Figure 6. Where not fully developed, the upper parts of cycles are missing, and thick uninterrupted intervals of trough cross-bedded sandstones are developed.

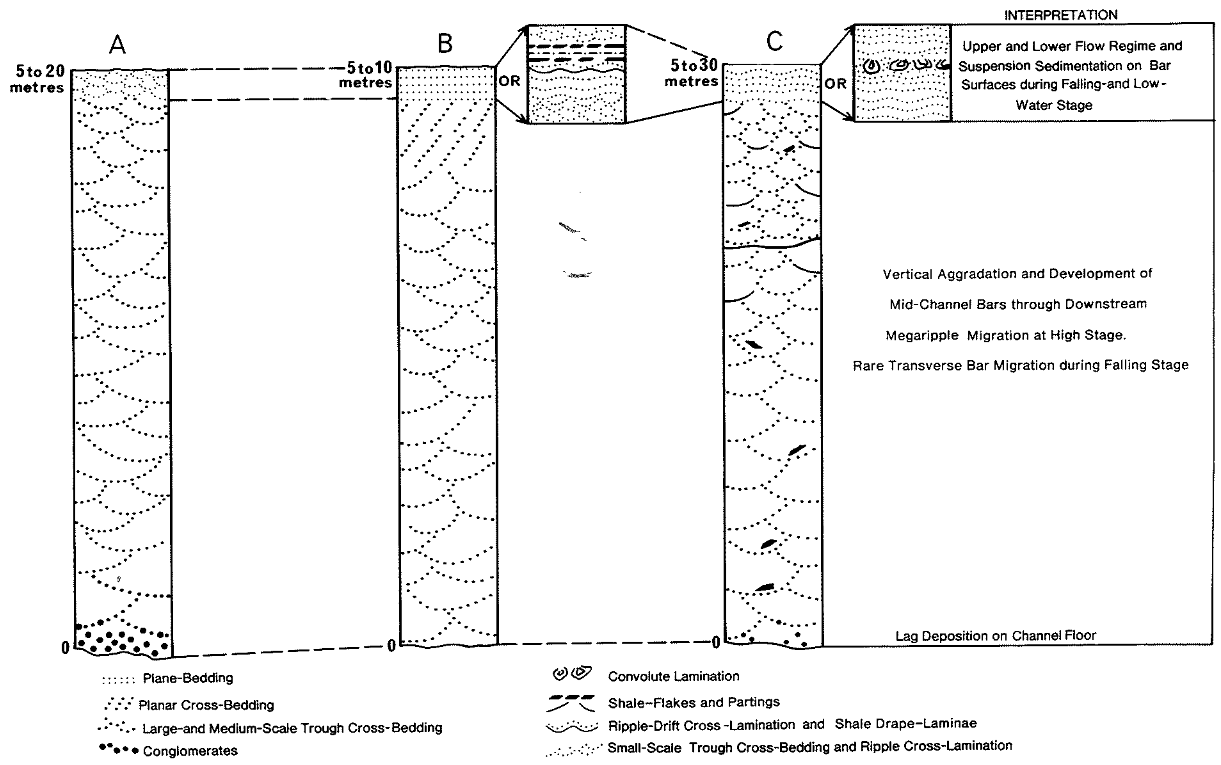

Figure 6 : *Measured vertical sequences of lithologies and sedimentary structures in the trough cross-bedded sandstone facies.*

Palaeocurrent measurements on medium-scale trough cross-beds were made at a number of stations on different stratigraphic units. The cumulative results of these measurements for each stratigraphic unit are shown in Figure 7 (see Figures 1 and 2 for localities). A consistent northerly transport direction is indicated throughout the deposition of this facies.

Impure Sandstone - Siltstone - Shale Facies

Sediments of this facies, although somewhat restricted in their vertical extent, occur as laterally persistent stratigraphic units under- and overlain by either of the two previously described facies. This facies is illustrated in Figure 2 as siltstones and shales in the Makonjwa and Havelock areas, part of unit MD1 and much of MD5 in the Eureka Syncline, limited portions of unit MD4 in the Saddleback Syncline and part of unit MD1 in the Stolzburg Syncline. Thin conglomerate-sandstone sequences, which always constitute less than 10 per cent of measured stratigraphic intervals, occur as lenses, up to 100 m in strike length within the predominant alternating siltstones and shales.

The coarse-grained sediments of this facies are arranged in 2 to 6 m thick upward-fining sequences (Figure 8). Thin scattered pebble- and shale-flake conglomerates pass upwards into lithic greywackes structured by northerly-directed small- and medium-scale trough cross-beds. These sandstones decrease in grain-size upwards from coarse at the base to medium- and fine-grained at the top of the cycles. An upward decrease in cross-bed set thickness, from 30 to less than 10 cm, also occurs. The upper fine-grained sandstones occasionally display plane-bedding with primary current

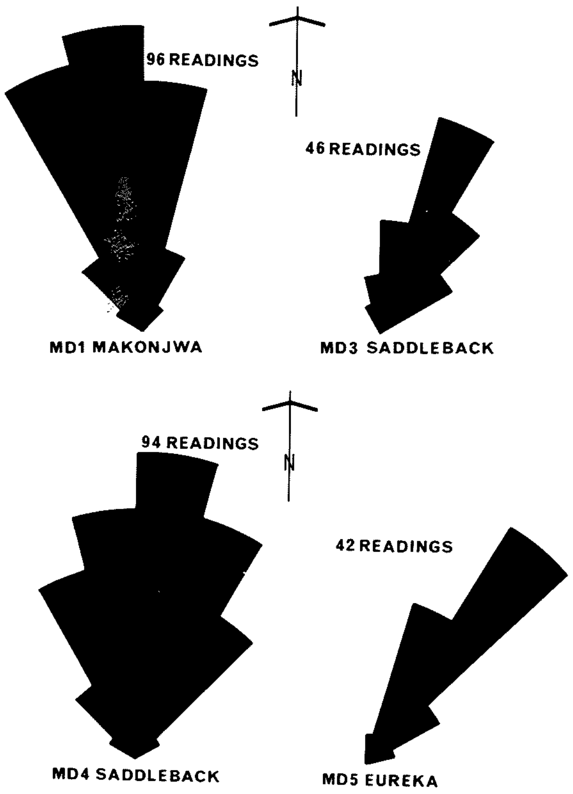

Figure 7 : *Cross-bed vector rose diagrams for the trough cross-bedded sandstone facies.*

lineations, and are in turn overlain by siltstones with thin desiccated shale-partings. Single upward-fining cycles are enclosed within 20 to 50 m thick sequences of horizontally-laminated and less commonly ripple cross-laminated siltstones and horizontally-laminated shales. The latter are commonly arranged in graded upward-fining units between 1 and 5 cm in thickness.

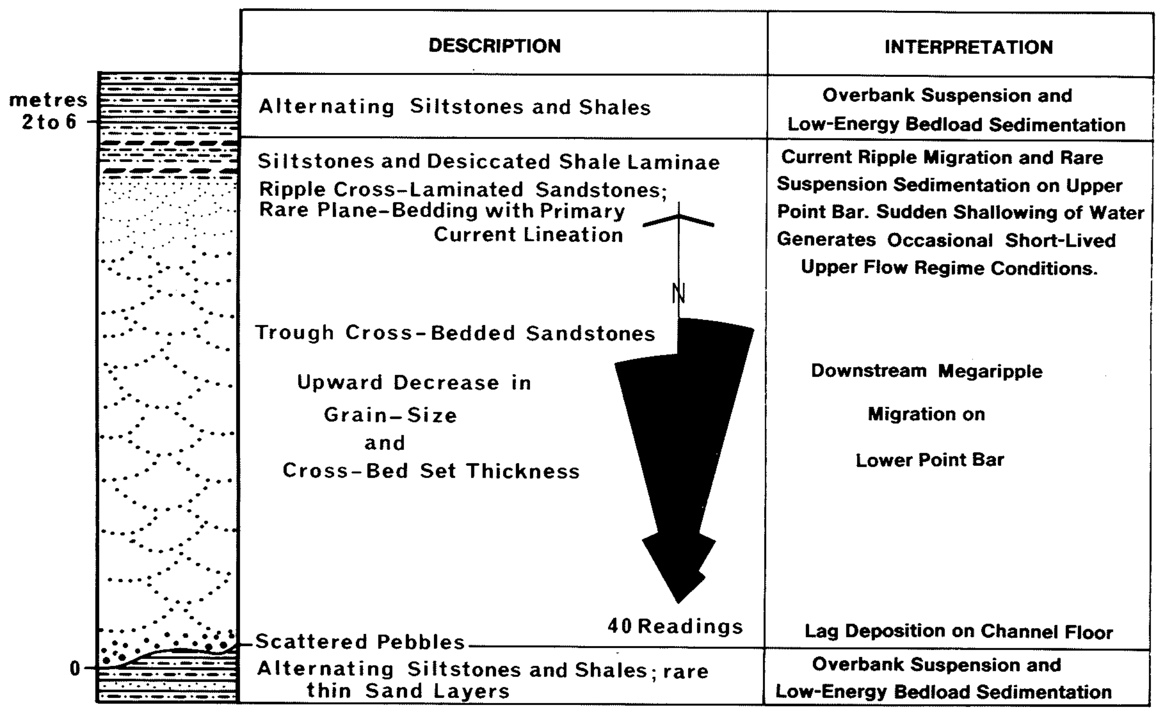

Figure 8 : *Measured stratigraphic section through impure sandstone-siltstone-shale facies : Makonjwa area.*

PALAEOENVIRONMENTAL INTERPRETATION

General Alluvial Depositional Environment

A number of features exhibited by the three facies of this assemblage can be used in a general palaeoenvironmental interpretation. The most important of these are the immature character of the sediments, the strongly unimodal palaeocurrent patterns, and the widespread evidence of desiccation. These criteria indicate an environment of limited reworking which was influenced by unidirectional dispersal currents and subjected periodically to subaerial exposure, and are most compatible with an alluvial depositional setting. The shape of the cumulative frequency curves, specifically the high suspended population (Figure 5; Visher, 1969) as well as the vertical sequences of lithologies and sedimentary structures developed in this facies assemblage (Figures 4, 6 and 8) (see for example Klein, 1972; Boothroyd and Ashley, 1975), further support an alluvial depositional environment.

The three facies of this assemblage are now analyzed in the context of the broadly defined alluvial plain depositional environment.

Conglomerate Facies

The two readily distinguishable conglomerate types developed in this facies must have originated in different sedimentary subenvironments and as a result of contrasting depositional processes within the general alluvial setting.

The coarseness of the matrix-supported conglomerates, their poor sorting, lack of grading and stratification, and the general absence of associated cross-bedding as well as the consistent lateral thickness of individual beds, are all suggestive of a debris-flow mode of origin (Blissenbach, 1954; Bull, 1972; Walker, 1975). The arenaceous matrix in these conglomerates, however, argues against a true debris flow origin. Similar sand-supported conglomerates have been ascribed by Miall (1970) to 'debris flood' processes which are essentially sand debris flow phenomena. The less specific term 'mass flow' is preferred for these matrix-supported conglomerates which contain no direct evidence for a viscous, matrix-strength support mechanism during their transport (Middleton and Hampton, 1973). Individual matrix-supported conglomerate beds are thought to be related to separate mass flows, which were probably generated during successive floods. The bed thickness to maximum clast-size graphic plots (Figure 3) provide further information as to the process involved in the deposition of the matrix-supported conglomerates. Bluck (1967) showed that conglomerates deposited by torrential floods exhibit a good correlation between those two variables. This is due to the fact that more intense floods can transport greater quantities of sediment and larger clasts which are deposited almost instantaneously as single bedding units. The excellent correlation between bed thickness and maximum clast-size in the matrix-supported conglomerates from this facies indicates that individual bedding units can be related to separate mass flows. The minor interbedded sandstones were probably formed during waning stages of individual floods.

Although coarse-grained and poorly-sorted, the clast-supported conglomerates of this facies are frequently well stratified and often display internal grading and weak imbrication. In addition, abundant channelling occurs, and the intercalated sandstones are frequently cross-bedded (Figure 4). These features suggest that traction was the important process involved in the deposition of these alluvial conglomerates and associated sandstones. The poor correlation between clast-size and bed thickness in the lower MD4 conglomerate (Figure 3) further supports this hypothesis.

The upper reaches of modern braided alluvial plains are frequently structured by longitudinal bars composed of pebbles, cobbles and boulders (see, for example, Doeglas, 1962; Boothroyd, 1972; Gustavson, 1974; Boothroyd and Ashley, 1975). These bars are believed by some workers to be initiated by deposition of the coarse bedload fraction of a stream as lags in the middle of the channel (Leopold and Wolman, 1957; Rust, 1972). The height of the bars may be determined by fluid and sediment discharge (Hein and Walker, 1977). If both remain high after deposition of the lag, the bar will grow downstream faster than it aggrades vertically. A rapid decrease in both fluid and sediment discharge conversely results in vertical aggradation of the bar. Exposed Holocene gravel bars are generally capped by sands which, depending on the flow regime, may be ripple-cross-laminated, small-scale cross-bedded or plane-bedded (Rust, 1972). Channels adjacent to the gravel bars frequently contain lower flow regime megaripples which continue to migrate at low flow stages after gravel movement has ceased (Williams and Rust, 1969; Boothroyd and Ashley, 1975). The clast-supported conglomerates and associated sandstones of this facies (Figure 4) can be explained in terms of these Holocene processes. Open gravel frameworks developed during relatively high discharge with the matrix deposited during waning flow. The predominance of plane-bedding in the intercalated sandstones implies short-lived upper flow regime conditions across the surfaces of longitudinal gravel bars, and which was associated with rapid lowering of water level (Boothroyd and Ashley, 1975). Intercalated trough cross-bedded sandstones are thought to represent low-water channel deposits over which gravel bars migrated as they shifted laterally (Doeglas, 1962).

The alternating matrix- and clast-supported conglomerates can be interpreted as due to tranctional, possible sheetflood (Bull, 1972) reworking of earlier mass flow deposits. The moderate correlation between bed thickness and maximum clast-size in the upper MD4 conglomerates of the Saddleback Syncline may be a reflection of these two depositional processes, and contrasts with the excellent and poor correlations of the end member Havelock and lower MD4 occurrences, respectively.

Trough Cross-Bedded Sandstone Facies

Upward-fining fluvial cycles form by channel-filling either through vertical aggradation (Moody-Stuart, 1966; Coleman, 1969; Cant and Walker, 1976; Cant, 1977) or lateral point bar accretion (Allen, 1970). The lack of evidence for point bar and overbank sedimentation in this facies favours vertical aggradation and consequent mid-channel bar formation as the dominant depositional process. Braided channels of the Brahmaputra River, for instance, are characterized by innumerable sandbars and mid-channel islands which are diamond-shaped in plan view, have their long axes parallel to the flow, and are covered on their longer downstream faces by ripples and larger bedforms. Vertical accumulations of cross-bedded sandstones, up to 18 m in thickness, are deposited in relatively short periods of time and are attributed to deposition by migrating sandbars during single flood cycles. As a result of rapid lateral migration of the thalweg, a large percentage of these sand units are preserved throughout the length of the river.

Similar depositional processes, including vertical aggradation and braid bar formation, can be invoked for the cross-bedded sandstone sequences in this facies (Figure 6). The considerable vertical thicknesses of the cycles in this facies (Figure 6) are, however, probably a result of stacking of partial depositional sequences. Migration of megaripples within channels, resulting in the formation of trough cross-beds, was the dominant depositional process. Downstream accretion of transverse bars during falling stage could account for the occasional planar cross-beds present in this facies (Figure 6B). The abundance of trough cross-bedding suggests that the braided streams had a low-sinuosity (Moody-Stuart, 1966), a hypothesis which is supported by the strongly unimodal palaeocurrent patterns (Figure 7). Low sinuosity streams also characteristically develop channel-fills by vertical aggradation, rather than lateral migration (Moody-Stuart, 1966). Basal conglomerates are interpreted as channel lags which formed during highest discharge and over which megaripples migrated as the stream velocity decreased.

Migration of large-scale bedforms occurs primarily during high stage. With decreasing discharge and resulting drop in waterlevel, a variety of hydraulic regimes are generated on bar surfaces. These are reflected in the diverse assemblage of sedimentary structures which cap-depositional cycles. Plane-bedded sandstones (Figure 6B) formed under upper flow regime conditions as a response to rapid lowering of the water-level (Boothroyd and Ashley, 1975). With gradually decreasing flow velocities, high-amplitude gave way to low-amplitude beforms, leading to the development of small-scale cross-beds or ripple-cross-lamination at the top of depositional cycles (Figure 6A). Capping ripple-drift cross-lamination (Figure 6B and C) formed when abundant sand and silt were deposited rapidly from suspension. The gradation from type B to in-phase ripple-drift cross-lamination (Figure 6C) reflects an increasing suspended load to bedload ratio (Jopling and Walker, 1968) under waning flow velocities (Gustavson *et al.*, 1975). Associated convolute lamination (Figure 6C) is also indicative of rapid suspension sedimentation and developed during dewatering of the inherently saturated ripple-drift cross-laminated sands and silts. In-phase ripple-drift cross-lamination and associated shale drape-laminae are similar to overbank levee accumulations in modern braided alluvial plains (Boothroyd and Ashley, 1975) and represent the only such deposits in this facies. Overbank sedimentation was confined to abandoned reaches of braided alluvial plains.

Although vertical aggradation is considered to have been the most important process involved in the development of this facies, the persistence of the trough cross-bedded sandstones both along strike and down the palaeoslope indicates that downstream and later migration were likewise significant. Sandbars in the Brahmaputra River migrate downstream for up to 1 700 m during a single flood, at rates of between 90 and 120 m per day. The same river has been found to migrate laterally for distances of over 700 m in short periods of time (Coleman, 1969). Even greater lateral migration rates occur for the Kosi River for which figures of up to 30 km per year have been measured (Fahnestock, 1963). Braided flood-plains are thus highly active depositional regimes consisting of active and abandoned channels. Through constant shifting of stream courses, thick vertical accumulations of sediments are developed. Erosion during the lateral shifting of channels is responsible for the frequent removal of the bar surface surface deposits (Figure 6) resulting in the formation of thick sequences of overlapping, scour-based trough cross-bedded sandstone lenses of the type present in this facies.

Impure Sandstone - Siltstone - Shale Facies

The character of the sediments in this facies indicates deposition in two contrasting fluvial subenvironments (see review by Allen, 1965). In terms of their textures, sedimentary structures and vertical sequences (Figure 8), the conglomerates and sandstones are analogous to channel sediments of modern streams (Harms and Fahnestock, 1965; Sarkar and Basumallick, 1968). The enclosing finer-grained sediments closely resemble contemporary overbank floodplain deposits (McKee *et al.*, 1967).

Their persistence along strike and limited thickness suggest that lateral rather than vertical accretion was the most important process responsible for the deposition of the conglomerates and sandstones of this facies. Meandering rivers most commonly undergo this type of lateral migration as a result of erosion of the outer and deposition on the inner bank. Vertical changes in depositional structures and grain-size within the coarse member can be attributed to decreasing bed shear stress (Allen, 1970). Basal scattered-pebble conglomerates represent channel lag deposits across which lower point bar coarse- and medium-grained trough cross-bedded sandstones accreted (see Figure 8). A continuing decrease in flow velocity at shallower water depths resulted in the development of finer-grained sandstones, structured by small-scale trough cross-beds and ripple-cross-lamination, on the upper point bar. Occasional primary current lineations on plane-bedded fine-grained sandstones indicate short-lived upper flow regime conditions on the upper point bars as a result of a decrease in water depth.

The fine-grained member of this facies developed under waning bedload and suspension sedimentation processes on overbank floodplains and, as indicated by the absence of desiccation cracks, were probably maintained in a continually saturated state. The predominance of ripple-cross-lamination and plane-bedding in the siltstones and fine-grained sandstones, to the exclusion of large-scale sedimentary structures, is in accord with experimental findings. Willis *et al.* (1972) have shown that, for grain-sizes of less than 0,10 mm, increasing flow velocities result in ripples giving way directly to upper phase flat beds. Wolman and Leopold (1957) in turn found that high velocities are common during overbank flows.

In many respects the depositional model proposed for this facies corresponds to the high-sinuosity model of Moody-Stuart (1966). Although extensive large-scale planar cross-beds (epsilon cross-bedding of Allen, 1963) are not developed, lateral point bar migration was still an important process involved in the formation of the thin upward-fining cycles. Furthermore, the thickness of the coarse-grained units indicate that channel-depths varied between 2 and 6 m (Schumm, 1972; Leeder, 1973).

INTERRELATIONSHIPS OF THE DEPOSITIONAL ENVIRONMENTS

The Alluvial Facies

Having interpreted each alluvial facies in terms of local processes it is now necessary to develop a single depositional model for the assemblage of fluvial sediments. In general terms, braided alluvial plains are characterised by a downstream decrease in grain-size, especially for sediments which constitute bars (Smith, 1974; Boothroyd and Ashley, 1975), and a downstream variation in bar morphology. Channels in the upper reaches of braided alluvial plains generally contain longitudinal bars, while those in lower alluvial plains are more commonly structured by transverse or linguoid bars (Smith, 1970; Boothroyd and Ashley, 1975). Braided channels develop on steeper proximal slopes and meandering channels on low gradient, more distal parts of alluvial plains (Leopold and Wolman, 1957).

Following erosion of an emergent mixed granitic - volcanic source terrain to the south of the outcrop belt, sedimentation occurred under various hydrodynamic conditions on an extensive alluvial plain. Based on the preceding discussions, it can be inferred that the conglomeratic facies of this assemblage was deposited on the proximal, more southerly reaches, the thick sequences of trough cross-bedded sandstones on intermediate reaches, and the impure sandstone - siltstone - shale facies on the more northerly, distal reaches of the alluvial plain. The ubiquitously drab colour exhibited by the sediments of this fluvial assemblage indicates that the depositional and diagenetic environments were anoxygenic.

The exact nature of the upper alluvial plain, on which conglomerates were deposited by both mass flow and tractional processes, requires further clarification. Debris flows most characteristically occur on dry region alluvial fans and result in the formation of muddy, matrix-supported conglomerates (Bull, 1972). Sandy, matrix-supported conglomerates of the type present in this facies are atypical of alluvial fans, and may have developed instead on the upper parts of humid region alluvial plains during floods. Interrelationships between the clast-supported conglomerates and associated sandstones are similar to those for gravel bar and channel sediments on the upper reaches of the Scott and Yana fans in Alaska (Boothroyd and Ashley, 1975). Both conglomerate-types thus probably accumulated on upper alluvial plains but with the matrix-supported conglomerates deposited proximal to the clast-supported types (Hooke, 1967). The frequent interlayering of the two conglomerate types indicates that mass flow and tractional processes alternated through time on the upper alluvial plains.

Point bar and overbank deposits, of the type represented by the impure sandstone - siltstone - shale facies are rare in Precambrian sedimentary successions due to a lack of levee stabilization by vegetation at that time (Schumm, 1968). Their occurrence in the Moodies Group may imply a broad, low-gradient distal alluvial plain on which high-sinuosity streams could have developed.

Vertical Stratigraphic Relationships

Vertical stacking of the depositional environments described here was determined by the intensity of terrigenous input (as controlled by source area tectonics) and the rate of basin subsidence which together regulated the landward or basinward migration of the facies belts.

Thus it can be suggested that stratigraphic unit MD1 (Figure 2) throughout the Barberton Mountain Land developed as a result of the slow sourceward retreat of the alluvial plain facies belts due to a diminution of the source area relief. This was in response to normal weathering processes and denudation in the source area, although pebble types in the basal conglomerate, such as the granitic clasts in the Eureka Syncline, often reflect derivation from local floor irregularities.

Active progradation, as controlled exclusively by source area tectonics, resulted in the development of the upper part of unit MD3 in the Saddleback Syncline (Figure 2), while unit MD4 in the same syncline displays evidence of two periods of progradational sedimentation. The lower of the two upward-coarsening sequences consists of distal alluvial plain siltstones and shales, scoured into by proximal gravel bar deposits. Under conditions of maximum sediment input, mid-alluvial plain sandstones and conglomerates prograded directly onto interlayered sandstones, siltstones and shales, which are considered to be shallow shelf deposits (Figure 9; Eriksson, 1977). This situation is analogous to the fan deltas along the coast of Alaska (Galloway, 1976) and is well illustrated at the top of unit MD4 in the Eureka and Stolzburg synclines (Figure 2).

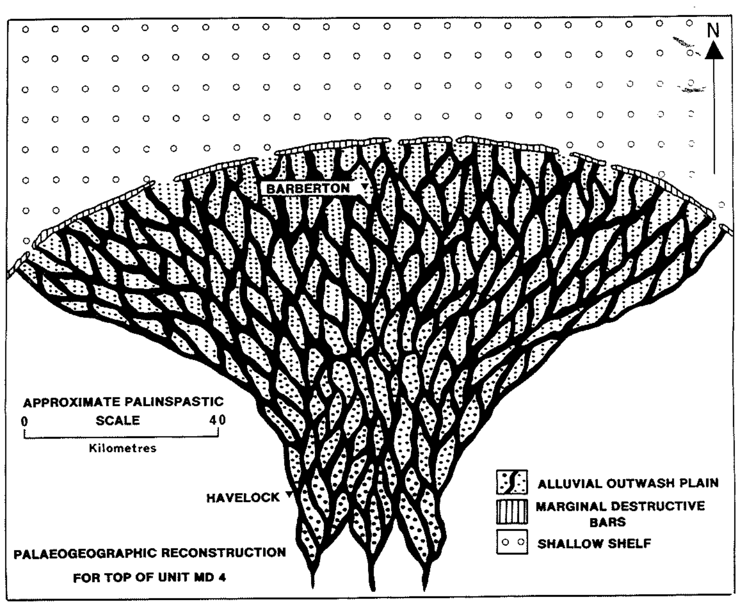

Figure 9 : Palaeogeographic fan delta model for actively prograding alluvial system : upper unit MD4, Moodies Group, Barberton Mountain Land.

Marginal Destruction of the Alluvial Plain

Orthoquartzitic sandstone lenses up to 6 m in thickness and which may extend along strike for greater than 1 km occur at the top of unit MD4 in the Eureka and Stolzburg Synclines and cap units MD1 and MD4 in the Stolzburg Syncline (Figure 2). Thin, well- to poorly-packed conglomerate lenses, composed of well-rounded resistant pebble types, and separated by orthoquartzitic sandstones, are present within the upper MD3 and MD4 sandstones of the Saddleback and Stolzburg Synclines, respectively.

Cumulative frequency curves (Figure 10) and statistical parameters (Table 4) for samples from one of these sandstones indicate them to be medium-grained and moderately- to well-sorted with suspension populations entirely absent from two of the samples. Plane-bedding is the dominant sedimentary structure in the sandstones while low-angle discordances and planar cross-bed intrasets, which have an easterly mode and vary from 15 to 80 cm in thickness, are also common.

The abundance of plane-bedding indicates a depositional environment that was subjected predominantly to upper flow regime conditions. Evidence of extensive reworking is provided by the well-sorted nature of the sandstones (Table 4). These criteria, coupled with the shape of the cumulative frequency curves (Figure 10; Visher, 1969), are suggestive of a beach environment, and more specifically of a swash zone. The lateral impersistence of these sandstones favours their development on swash bars rather than along a foreshore. Associated planar cross-bedding is oriented at right angles to the fluvial palaeocurrent directions and probably reflects a longshore current influence. The intercalated conglomerates are similar to wave-worked deposits described from the west coast of the U.S.A. by Clifton (1973). Their lensoid nature and occurrence within clean sandstones serves to distinguish them from the fluvial gravels.

The plane-bedded orthoquartzitic sandstones are considered to have developed as a result of marginal reworking of alluvial plain sediments upon cessation of sediment supply (Figure 9) and are

TABLE 4

STATISTICAL PARAMETERS FOR MOODIES ORTHOQUARTZITES INTERCALATED WITHIN IMPURE SANDSTONES

Sample No.		M21	MO15	MO21	M79
Mean	(Ø)	0,77	0,67	1,18	0,54
Variance	(Ø)	0,28	0,52	0,56	0,21
Std. Dev.	(Ø)	0,53	0,72	0,75	0,46
Number of Measurements		200	200	200	200

All samples from top of Unit MD3, Saddleback Syncline. (see Figure 2 for Stratigraphic Position).

Procedures for calculating the statistical parameters were the same as discussed in Table 3.

indicative of a relatively stable crust. The poorly-sorted fluvial and mature beach (swash zone) sandstones are clearly separated on a plot of mean grain diameter against grain-size standard deviation for samples from the two inferred depositional environments (Figure 11). The samples lie within or close to their respective fields as delineated by Moiola and Weiser (1968) using samples from known Holocene environments of deposition.

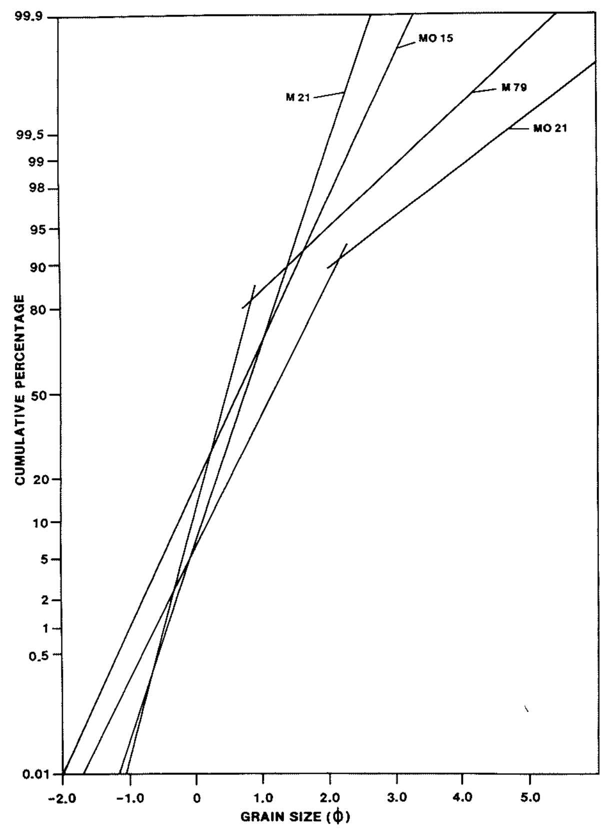

Figure 10 : *Grain-size cumulative frequency curves for plane-bedded orthoquartzitic sandstones at the top of unit MD3, Saddleback Syncline. Curves drawn for converted sieve equivalent percentiles.*

Similar destructive onlap relationships to those envisaged for this depositional system have been documented from the Mississippi Delta. Following abandonment of individual lobes and compaction of the sediment pile, clean sandstones are developed during transgressive wave reworking of the deltaic plain (Scruton, 1960; Kolb and Van Lopik, 1966; Morgan, 1970). The Gum Hollow fan delta (McGowen, 1970) and Santee River Delta (Stephens *et al.*, 1976) display identical destructive relationships. Wave reworking of the Santee River Delta followed reduction and eventual termination of sediment supply through artificial damming-up of the river and its tributaries.

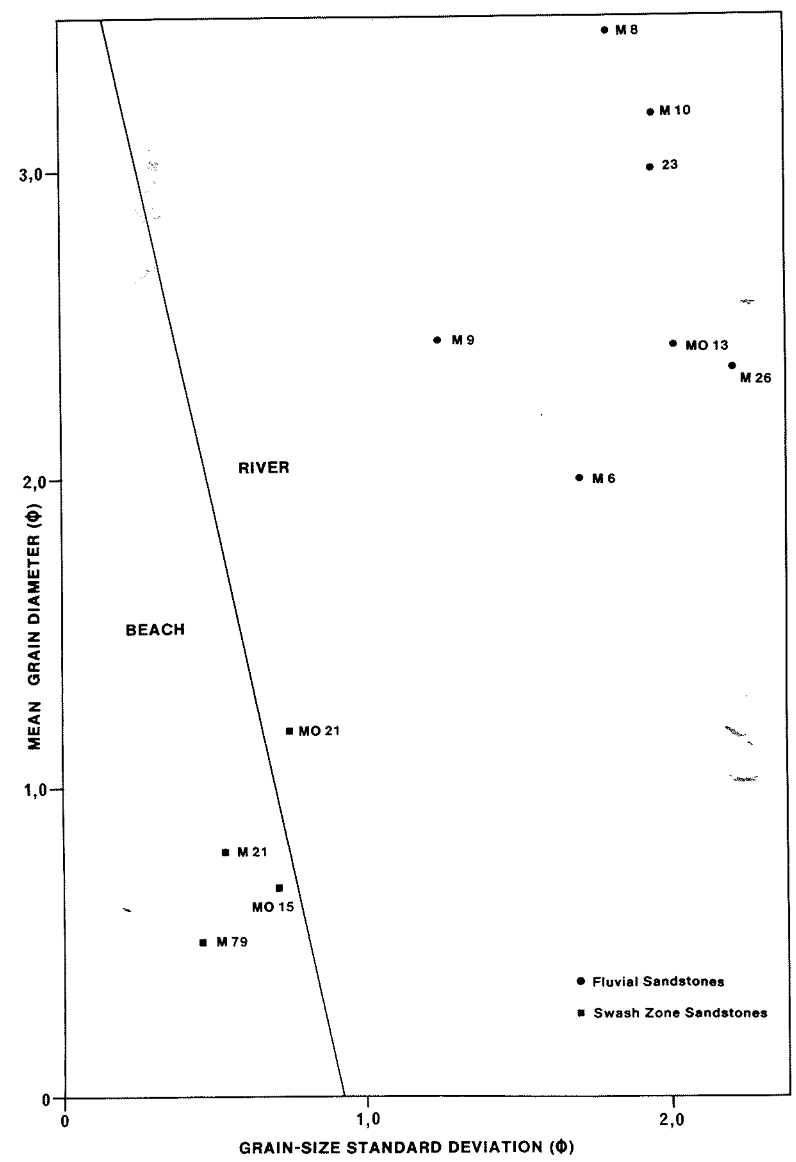

Figure 11 : Plot of mean grain diameter against grain-size standard deviation for immature fluvial and beach (swash zone) sandstones. Boundary between fluvial and beach fields after Moiola and Weiser (1968). Sample localities are described in Tables 3 and 4.

CONCLUSIONS

(a) The Moodies Group contains the oldest extensive and recognizable alluvial plain deposits.

(b) Braided fluvial sedimentary processes dominated and have analogues in a number of Holocene alluvial plains.

(c) The paucity of meander belt deposits is typical of the Precambrian and related to a lack of stabilization of levees by vegetation at that time. Poorly developed meander belt sequences in the Moodies Group probably formed on low-gradient distal alluvial plains.

(d) The quartzo-felspathic nature of arenaceous sediments in the Moodies Group indicates the widespread occurrence of granitic rocks at the time of deposition of these Archaean sediments. Unequivocal evidence in favour of emergent landmasses to the south of the outcrop belt exists, and contradicts the suggestion of Hargraves (1976) that a primordial sea covered the earth until 2 000 m.y. ago.

(e) The orthoquartzitic swash bar sandstones imply a relatively stable crust with slow subsidence at the time of deposition of the Moodies Group, on which prolonged reworking of sediments occurred.

(f) Vertical stratigraphic sequences illustrate the intimate relationship between source area tectonics and sedimentation.

(g) In contrast to the red colouration commonly exhibited by arenaceous fluvial sediments less than 2 000 m.y. in age (see for example Cloud, 1976), those in the Moodies Group are drab coloured, indicating an anoxygenic atmosphere at their time of deposition.

* * * * * * * * * * *

ACKNOWLEDGEMENTS

The Council of the University of the Witwatersrand, and the Council for Scientific and Industrial Research financially supported the field work. Helpful discussions were had with A. Button, D.K. Hobday, and G. de V. Klein during preparation of the manuscript. N.D. Smith and B.R. Turner provided constructive comments leading to the final revision of the paper. Mrs. M.S. McCarthy is thanked for typing the manuscript and M.H. Hudson and M. Taylor provided photographic and cartographic assistance.

REFERENCES

Allen, J.R.L., 1963. The classification of cross-stratified units, with notes on their origin. Sedimentology, 2, 93-114.

Allen, J.R.L., 1965. A review of the origin and characteristics of recent alluvial sediments. Sedimentology, 5, 91-191.

Allen, R.J.L., 1970. Studies in fluviatile sedimentation : a comparison of fining-upward cyclothems with special reference to coarse-member composition and interpretation. J. Sediment. Petrol., 40, 298-323.

Allsopp, H.L., Roberts, H.R., Schreiner, G.D.L. and Hunter, D.R., 1962. Rb-Sr age measurements on various Swaziland granites. J. Geophys. Res., 67, 5307-5313.

Anhaeusser, C.R., 1969. The stratigraphy, structure, and gold mineralization of the Jamestown and Sheba Hills areas of the Barberton Mountain Land. Unpubl. Ph.D. thesis, Univ. of the Witwatersrand, Johannesburg.

Anhaeusser, C.R., 1973. The evolution of the early Precambrian crust of South Africa. Phil. Trans. R. Soc. Lond., A.273, 359-388.

Anhaeusser, C.R., Roering, C., Viljoen, M.J. and Viljoen, R.P., 1968. The Barberton Mountain Land : a model of the elements and evolution of an Archaean fold belt. Trans. geol. Soc. S. Afr., 71 (annex.), 225-253.

Blissenbach, E., 1954. Geology of alluvial fans in semi-arid regions. Bull. Geol. Soc. Amer., 39, 465-484.

Bluck, B.J., 1967. Deposition of some Upper Old Red Sandstone conglomerates in the Clyde area : a study in the significance of bedding. Scot. J. Geol., 3, 139-167.

Boothroyd, J.C., 1972. Coarse-grained sedimentation on a braided outwash fan, northeast Gulf of Alaska. Coastal Research Division, Univ. of South Carolina, Tech. Rept. No. 6 - CRD.

Boothroyd, J.C. and Ashley, G.M., 1975. Processes, bar morphology and sedimentary structures on braided outwash fans, northeastern Gulf of Alaska, 193-222, in:Jopling, A.V. and McDonald, B.C. (eds.), Glaciofluvial and Galciolacustrine Sedimentation. Soc. Econ. Paleontologists and Mineralogists. Spec. Publ. 23.

Bull, W.B., 1972. Recognition of alluvial fan deposits in the stratigraphic record 63-83, in: Rigby, J.K. and Hamblin, W.K. (eds.), Recognition of Ancient Sedimentary Environments. Soc. Econ. Paleontologists and Mineralogists, Spec. Publ. 16.

Cant, D.J., 1977. Development of a facies model for sandy braided river sedimentation. Intl. Sympos. Fluv. Sedimentology, Calgary, Abst. with Prog., 5.

Cant, D.J. and Walker, R.G., 1976. Development of a braided-fluvial facies model for the Devonian Battery Point Sandstone, Quebec. Canad. J. Earth Sci., 13, 102-119.

Clifton, H.E., 1973. Pebble segregation and bed lenticularity in wave-worked versus alluvial gravels. Sedimentology, 20, 173-187.

Cloud, P.E., 1976. Major features in crustal evolution. Alex du Toit Mem. Lecture No. 14, Geol. Soc. S. Afr., 33 pp.

Coleman, J.M., 1969. Brahmaputra river channel processes and sedimentation. Sediment. Geol. 3, 129, 239.

Doeglas, D.J., 1962. The structure of sedimentary deposits of braided rivers. Sedimentology, 1, 167-190.

Donaldson, J.A. and Jackson, G.P., 1965. Archaean sedimentary rocks of North Spirit Lake area, N.W. Ontario, Canada. Canad. J. Earth Sci., 2, 622-647.

Dott, R.H., 1964. Wacke, graywacke, and matrix - what approach to immature sandstone classification? J. Sediment. Petrol., 34, 625-632.

Edwards, A.L., 1964. Statistical Analysis. Holt, Rinehart and Winston, New York, 234 pp.

Eriksson, K.A., 1977. A palaeoenvironmental analysis of the Archaean Moodies Group, Barberton Mountain Land, South Africa. Unpubl. Ph.D. thesis, Univ. of the Witwatersrand, Johannesburg.

Fahnestock, R.K., 1963. Morphology and hydrology of a glacial stream. U.S. Geol. Surv., Prof. Paper 422-A, 1-70.

Folk, R.L., 1968. Petrology of sedimentary rocks. Hemphills, Austin, Texas, 170 pp.

Galloway, W.E., 1976. Sediments and stratigraphic framework of the Copper River fan-delta, Alaska. J. Sediment. Petrol., 46, 726-737.

Gustavson, T.C., 1974. Sedimentation of gravel outwash fans, Malaspina Glacier Foreland, Alaska. J. Sediment. Petrol., 44, 378-389.

Gustavson, T.C., Boothroyd, J.C. and Ashley, G.M., 1975. Depositional sequences in glaciolacustrine deltas, 264-280, in:Jopling, A.V. and McDonald, B.C. (eds.), Glaciofluvial and Glaciolacustrine Sedimentation. Soc. Econ. Paleontologists and Mineralogists, Spec. Publ. 23.

Hargraves, R.B., 1976. Precambrian geologic history. Nature, 193, 363-371.

Harms, J.C. and Fahnestock, R.I.C., 1965. Stratification, bedforms and flow phenomena (with an example from the Rio Grande), 84-115, in:Middleton, G.V. (ed.), Primary Sedimentary Structures and their Hydrodynamic Interpretation. Soc. Econ. Paleontologists and Mineralogists. Spec. Publ. 12.

Harrell, J. and Eriksson, K.A., in preparation. Empirical conversion equations for thin-section and sieve derived size distribution statistics.

Hein, F.J. and Walker, R.G., 1977. Bar evolution and development of stratification in the gravelly, braided Kicking Horse River, British Columbia. Canad. J. Earth Sci., 14, 562-570.

Hooke, R.L., 1967. Processes on arid-region alluvial fans. J. Geol., 75, 438-460.

Hyde, R.S., 1975. Depositional environment of Archaean exhalites, Kirkland Lake - Larder Lake area, Ontario. Geol. Soc. Amer., North-Central Sectn. Abst. with Prog., 789.

Inman, D.L., 1952. Measures for describing the size distribution of sediments. J. Sediment. Petrol., 22, 125-145.

Jones, D.H., 1969. Geology and gold mineralization of the Hhohho area, north-western Swaziland. Unpubl. M.Sc. Thesis, Univ. of the Witwatersrand, Johannesburg.

Jopling, A.V. and Walker, R.G., 1968. Morphology and origin of ripple-drift cross-lamination with examples from the Pleistocene of Massachusetts. J. Sediment. Petrol., 38, 971-984.

Klein, G. de V., 1972. Sedimentary model for determining paleotidal range : reply.Bull. Geol. Soc. Amer., 83, 539-546.

Kolb, C.R. and Van Lopik, J.R., 1966. Depositional environments of the Mississippi River deltaic plain-southeastern Louisiana 17-62, in:Shirley, M.L. and Ragsdale, J.A. (eds.), Deltas in their Geologic Framework. Houston Geol. Soc., Houston, Tex.

Leeder, M.R., 1973. Fluvial fining-upward cycles and the magnitude of palaeochannels. Geol. Mag., 110, 265-276.

Leopold, L.B. and Wolman, M.G., 1957. River channel patterns : braided, meandering and straight. U.S. Geol. Surv. Prof. Paper 282-B.

McGowen, J.H., 1970. Gum Hollow fan delta : Hueces Bay, Texas. Report of Investigations No. 69, Bureau of Econ. Geol., Austin, Texas, 91 pp.

McKee, E.D., Crosby, E.J. and Berryhill, H.L., 1967. Flood deposits, Bijou Creek, Colorado. J. Sediment. Petrol., 37, 829-851.

Miall, A.D., 1970. Devonian alluvial fans, Prince of Wales Island, Arctic, Canada. J. Sediment. Petrol., 40, 556-571.

Middleton, G.V. and Hampton, M.A., 1973. Sediment gravity flows : mechanics of flow and deposition, 1-38, in:Middleton, G.V. and Bouma, A.H. (eds.), Turbidites and Deep-water Sedimentation. Soc. Econ. Paleontologists and Mineralogists. Short Course Syllabus of Pacific Section.

Moiola, R.D. and Weiser, D.D., 1968. Textural parameters and their evaluation. J. Sediment. Petrol., 38, 45-63.

Moody-Stuart, M., 1966. High and low sinuosity stream deposits with examples from the Devonian of Spitzbergen. J. Sediment. Petrol., 36, 1102-1117.

Morgan, J.P., 1970. Depositional processes and products in the deltaic environment, 31-47, in: Morgan, J.P. (ed.), Deltaic Sedimentation, Modern and Ancient. Soc. Econ. Paleontologists and Mineralogists, Spec. Publ. 15.

Ojakangas, R.W., 1972. Archaean volcanogenic greywackes of the Vermilion District, northeastern Minnesota. Bull. Geol. Soc. Amer., 83, 429-442.

Oosthuyzen, E.J., 1970. The geochronology of a suite of rocks from the granitic terrain surrounding the Barberton Mountain Land. Unpubl. Ph.D. Thesis, Univ. of the Witwatersrand, Johannesburg.

Reimer, T.O., 1975. Untersuchungen über abtragung, sedimentation und diagenese im frühen Präkambrium am beispiel der Sheba - Formation (Südafrika). Geologisches Jahrb., Reihe B., Heft, 17, 108 pp.

Rust, B.R., 1972. Structures and processes in a braided river. Sedimentology, 18, 221-245.

Sarkar, S.K. and Basumallick, S., 1968. Morphology, structure and evolution of a channel island in the Barakar River, Barakar, West Bengal. J. Sediment. Petrol., 38, 746-754.

Schumm, S.A., 1968. Speculations concerning paleohydrologic controls of terrestrial sedimentation. Bull. Geol. Soc. Amer., 79, 1573-1588.

Schumm, S.A., 1972. Fluvial paleochannels, 98-107, in:Rigby, J.K. and Hamblin, W.K. (eds.), Recognition of Ancient Sedimentary Environments. Soc. Econ. Paleontologists and Mineralogists, Spec. Publ. 16.

Scruton, P.C., 1960. Delta building and the deltaic sequence, 82-102, in:Shepard, F.P., Phleger, F.B. and Van Andel, T.H. (eds.), Recent sediments, northwest Gulf of Mexico.

Smith, N.D., 1970. The braided stream depositional environment : a comparison of the Platte River with some Silurian clastic rocks, North-central Appalachians. Bull. Geol. Soc. Amer., 81, 2993-3014.

Smith, N.D., 1974. Sedimentology and bar formation in the Upper Kicking Horse River, a braided outwash stream. J. Geol., 81, 205-223.

Stephens, D.G., van Niewenhuise, D.S., Mullin, P., Lee, C. and Kanes, W.H., 1976. Destructive phases of deltaic development : North Santee River Delta. J. Sediment. Petrol., 46, 132-144.

Tomlinson, R.S., 1967. The geology of the area between the Staircase Ridge and the Emlembe Range, Barberton Mountain Land. Unpubl. M.Sc. Thesis, Natal University, Durban.

Truswell, J.F., 1970. An Introduction to the Historical Geology of South Africa. Purnell, Cape Town, 167 pp.

Turner, C.C. and Walker, R.G., 1973. Sedimentology, stratigraphy and the crustal evolution of the Archaean greenstone belt near Sioux Lookout, Ontario. Canad. J. Earth Sci., 10, 817-845.

Van Niekerk, C.B. and Burger, A.J., 1969. A note on the minimum age of the acid lava of the Onverwacht Series of the Swaziland System. Trans. geol. Soc. S. Afr., 72, 9-21.

Viljoen, M.J. and Viljoen, R.P., 1969. An introduction to the geology of the Barberton granite-greenstone terrain. Geol. Soc. S. Afr., Spec. Publ. 2, 9-28.

Visher, G.S., 1969. Grain-size distribution and depositional processes. J. Sediment. Petrol., 39, 1074-1106.

Walker, R.G., 1975. Conglomerate : Sedimentary structures and facies models, 133-161, in:Harms, J.C., Southard, J.B., Spearing, D.R. and Walker, R.G. (eds.), Depositional Environments as Interpreted from Primary Sedimentary Structures and Stratification Sequences. Soc. Econ. Paleontologists and Mineralogists, Short Course Syllabus.

Williams, P.F. and Rust, B.R., 1969. The sedimentology of a braided river. J. Sediment. Petrol., 39, 649-679.

Willis, J.C., Coleman, N.L. and Ellis, W.M., 1972. Laboratory study of transport of fine sand. Proc. Amer. Soc. Civil Eng., J. Hydraul. Div. 98, 489-501.

Wolman, M.G. and Leopold, L.B., 1957. River flood plains : some observations on their formation. U.S. Geol. Surv. Prof. Paper 282-C.

* *