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# A PALAEOENVIRONMENTAL ANALYSIS OF THE MOLTENO FORMATION IN THE NATAL DRAKENSBERG

by

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**ABSTRACT**

The Upper Triassic Molteno Formation of the Natal Drakensberg forms part of the upper Karoo Sequence. It rests with an erosional base on the Beaufort Group and has a gradational upper contact with the Elliot Formation.

Four lithofacies are defined in the study area. Basal coarse-grained, trough cross-bedded sandstones, interpreted as in-channel dune and bedload deposits, are commonly overlain by fine- to medium-grained, planar cross-stratified sandstones. The latter probably reflect the migration of bar bedforms within braided fluvial systems. These sediments normally pass up into fine- to medium-grained sandstones with trough and planar cross-beds, laid down by sand flat processes which reworked emergent bars. The succeeding argillites of the fourth facies are postulated to be overbank or inter-channel floodplain sediments. The sequence is normally terminated by a second development of the bar facies.

The vertical lithofacies arrangement probably represents deposition by low sinuosity channel systems, which derived detritus from east-north-eastern and south-south-eastern source areas. Although this palaeoenvironment is very similar to the depositional models of I.C. Rust (1962) and Turner (1970 to 1983), bar migration and sand flat processes appear to have been more important in the north-east of the basin.

**CONTENTS**



## I. INTRODUCTION

The Molteno Formation crops out over a large region in the central high-lying areas of all four provinces of the Republic of South Africa, and in Lesotho. The study area is situated along the western border of Natal with Lesotho, and extends from Drakensberg Gardens in the south to Clarens and Harrismith in the north (Fig. 1). Previous workers who studied aspects of the Molteno Formation include Haughton (1924, 1969), Du Toit (1939), Stockley (1947), I.C. Rust (1962), Ellenberger *et al.* (1964), Botha and Theron (1967), Turner (1970, 1975a, b, 1977, 1978, 1980, 1983), Anderson (1974, 1976), and Kitching (1977).

This paper aims to interpret the depositional palaeoenvironment of the Molteno Formation in the study area. Detailed field work was concentrated in 21 specific areas (Fig. 1). For each locality a representative measured section was constructed which summarized data obtained in that area. Horizontal stratification recorded in the field was termed planar bedding if individual laminae exceeded 1 cm in thickness, and fine lamination if they did not; the same thickness division was used to discriminate between convolute bedding and lamination. Planar and trough cross-laminations were defined as having a maximum set thickness of 5 cm; thicker sets were termed cross-bedding.

## II. GENERAL GEOLOGY

The Molteno Formation belongs to the upper part of the Karoo Sequence and is of Upper Triassic age (Turner, 1983) (Table I). The rocks of this formation are generally flat-lying in the study area, but locally dip 1 to 9° towards the south and south-west. Faulting of the sediments is rare and was disregarded when making regional correlations. In some study regions, notably in the Golden Gate area, dolerite sills and dykes intrude the Molteno Formation.

The basal contact of the Molteno Formation with the underlying Beaufort Group is erosive, whereas the upper contact with the Elliot Formation is gradational. The dominantly arenaceous Molteno Formation, in many

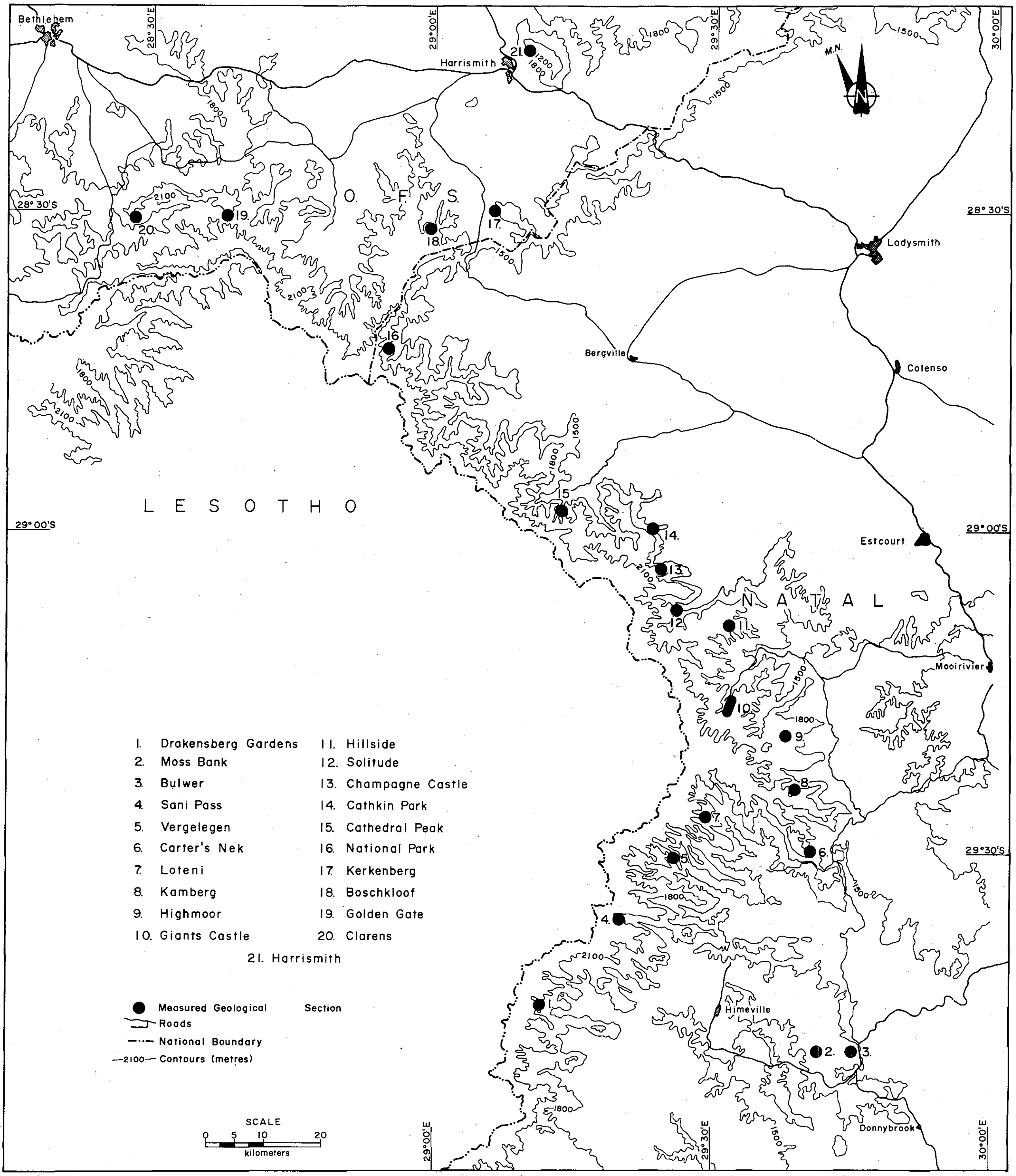


**Figure 1**
Location and topography of the study area.

**TABLE I**
**Stratigraphy and Ages of the Upper Part of the Karoo Sequence (Turner, 1983; Eriksson, 1983)**

| Sequence | Group | Formation | Age |
|---|---|---|---|
| Karoo Sequence | Drakensberg Group | | Upper Triassic–Lower Jurassic |
| | | Clarens Formation<br>Elliot Formation<br>Molteno Formation | Upper Triassic |
| | Beaufort Group | | Upper Permian–Lower Triassic |

places characterized by argillaceous beds and lenses, grades up into the Elliot deposits which normally display subordinate sandstone lenses set in massive argillites. The Molteno–Elliot contact is taken where the argillite: sandstone ratio exceeds one.

The Molteno Formation varies in thickness from less than 10 m to just over 100 m and is characterized by light-coloured fine- to very coarse-grained sandstones. These sandstones exhibit moderately poor sorting and subrounded to subangular grain shapes. The majority of the 38 samples investigated are quartz-rich feldspathic wackes with a relatively high content of interstitial material. The formation also displays subordinate argillaceous sediments and conglomeratic sandstones. The common occurrence of cross-bedding as well as some channels in the Molteno Formation outcrops points to an overall fluvial palaeoenvironment.

## III. SEDIMENTARY FACIES

Four lithofacies are distinguished in the Molteno Formation of the Natal Drakensberg study area.

### A. Facies One — Coarse-grained Trough Cross-bedded Sandstone

Facies 1 is dominated by very coarse-grained sandstone with trough cross-beds, lenses and beds of apparently massive conglomeratic sandstone, and an erosive basal contact. The conglomeratic sandstone lenses are 1 to 10 m wide and 10 to 30 cm thick; locally they may reach 20 m in width and 2 m in thickness. The conglomeratic sandstone beds are 10 cm to 1 m thick. These conglomeratic sandstones contain flattened mud clasts and rare carbonized plant fragments. They are mostly found at the base of the facies where they help to define its erosive lower contact; locally they exhibit flute moulds.

These basal features are normally succeeded by trough cross-beds, 1 to 5 m wide and 30 to 50 cm deep. They are found as both solitary and grouped sets, the latter type commonly being mutually erosive. Large trough cross-beds, up to 15 m wide and 2 m deep, occur locally and are erosive into smaller sets. The trough cross-bedded sandstones and conglomeratic beds and lenses are truncated in places by channels, 1 to 3 m deep and 15 to 25 m wide; in exceptional cases these channels may reach widths of 70 m. The channels are usually succeeded by further trough cross-beds, or, less often, they are cut by successive erosively based channels. One occurrence of planar bedding, 5 to 15 cm thick, was found at Kerkenberg.

### B. Facies Two — Fine- to Medium-grained Planar Cross-bedded Sandstone

The sediments of this facies are dominantly fine- to medium-grained sandstones. Planar cross-bedding of varying dimensions is ubiquitous. Set thicknesses vary from 6 cm to 3 m, and foreset angles mostly between 10 and 21°, but locally they attain 32°. The planar cross-stratification generally forms grouped tabular sets, with fewer wedge-shaped sets and rare solitary large sets. Grouped sets frequently display a sequence of varying cross-bed sizes, stacked above one another in no particular order. Isolated occurrences of mudcracks, horizontal *Planolites* burrows and small scour channels are found associated with the dominant planar cross-bedding.

### C. Facies Three — Fine- to Medium-grained Trough and Planar Cross-bedded Sandstone

Fine- to medium-grained sandstones exhibiting trough and planar cross-beds and channel fill trough cross-beds characterize this facies of the Molteno Formation. Structures of minor importance include small to medium channels, scour marks, ripples, mudcracks, planar stratification and mudstone lenses.

The trough cross-beds are normally 1 to 4 m wide and 20 to 80 cm deep; both grouped and solitary sets occur. Channel fill trough cross-beds are 6 to 20 m wide and 90 cm to 3 m deep; they are often found as grouped sets displaying mutually erosive relationships. The tabular planar cross-stratification exhibits set thicknesses between 5 and 80 cm and inclination angles ranging from 5 to 20°. The sedimentary structures in this facies do not display any preferred vertical or lateral interrelationships on a regional scale.

### D. Facies Four — Argillite

Although outcrops of this facies range in thickness from less than 1 m to nearly 25 m, their poor quality makes them difficult to describe in full detail. Facies 4 is dominated by argillites, ranging from very fine-grained sandstone–siltstone–mudstones to siltstones and mudstones. Planar bedding, 5 to 10 cm thick, and small channels with massive argillaceous fills are the most common sedimentary features.

Rare carbonaceous mudstones, which display fine laminations and plant fragments, also occur. The plant fragments cannot be identified with any certainty (J.W. Kitching and E.D. van Dijk, 1980, pers. comm.), but most likely belong to the widespread *Dicroidium* flora of the Molteno Formation.

### E. Palaeocurrent Directions

The palaeocurrent data (Fig. 2) are not sufficient to attempt detailed analysis of variances within cross-bed sets or between different sets within outcrops as, for example, discussed by Miall (1976) or Potter and Pettijohn (1977). Thus the data cannot be utilized to help construct a depositional facies model, but must rather be considered on

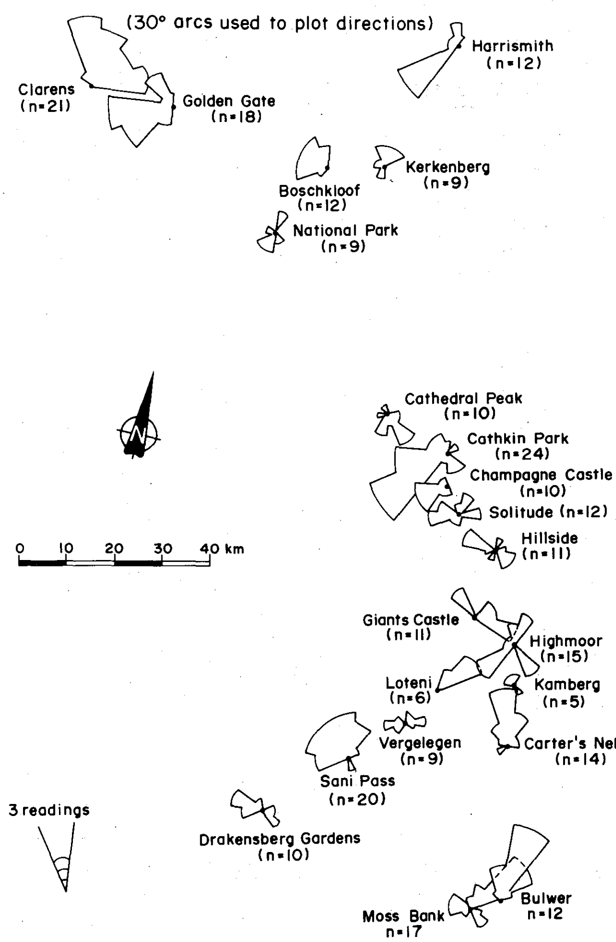


**Figure 2**
Palaeocurrent directions measured in the Molteno Formation (n = 267).

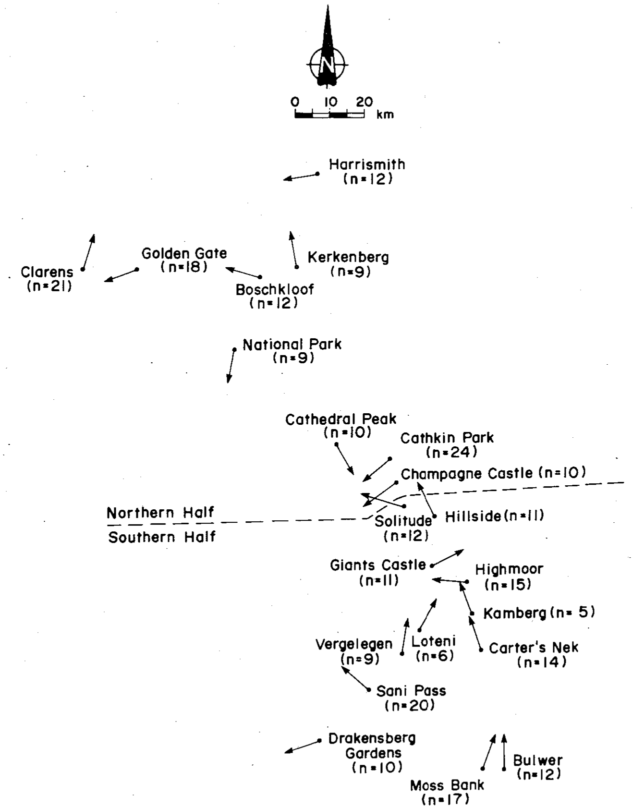


**Figure 3**
Vector means of Molteno Formation palaeocurrents (n = 267).

a regional basis, as reflecting source terrane locations and broad scale trends.

With the exception of the Sani Pass, Vergelegen, Highmoor, and Clarens regions, most areas display reasonably unidirectional palaeocurrent trends (Fig. 2). Vector means (Fig. 3), calculated according to the method outlined by Royse (1970), are predominantly orientated from approximately east to west in the northern half of the study area and from south to north in the southern half. Within each of the two halves, the vectors spread out in a fan-like pattern; the northern fan-like pattern is aligned from east-north-east to west-south-west, and that in the south from south-south-east to north-north-west.

### F. Facies Relationships

The large variation in the thickness of the Molteno Formation over relatively short distances, and the small vertical dimensions of facies in some of the measured sections, precluded the construction of a regional stratigraphic cross-section to illustrate lateral facies relationships. Interrelationships between the four Molteno facies can best be examined by vertical facies transitions, determined from the measured sections. As these sections display relatively few vertical facies changes they do not lend themselves to Markov analysis. Instead an idealized vertical profile model of the Molteno Formation in the Natal Drakensberg was constructed (Fig. 4), based on a detailed examination and comparison of the 21 measured sections. This profile model is never found in complete form in the field.

Examination of the model indicates the predominance of Facies 2 and 3 sediments and also reveals a distinct upward-fining trend of rock types in the lower four facies. Apart from the uppermost sandstones this model bears a close resemblance to the upward-fining Molteno sequence defined by I.C. Rust (1962) and Turner (1970, 1975a, 1983). The latter sequence comprises basal conglomerates, overlain by sandstones and shales, with coal deposits at the top (I.C. Rust, 1962). Carbonaceous material appears to be rare in the Natal Drakensberg in comparison with the southern portion of the basin (Turner, 1975a). There is a cyclical repetition of the upward-fining sequence in the south of the main Karoo basin (I.C. Rust, 1962; Turner, 1975a, 1977); a basal Bamboesberg Member is overlain by the Indwe Sandstone, which is succeeded by four further cycles (Turner, 1975a, pp. 15–24, 26–27, 73, folder 1). Only the second cycle occurs throughout most of the depository (Turner, 1975a, pp. 26–27, 74) and the profile model defined in the present study thus belongs to the Indwe Sandstone Member.

## IV. PALAEOENVIRONMENTAL INTERPRETATION

### A. General Depositional Setting

Several features of the Molteno Formation in the Natal Drakensberg can be utilized to attempt a broad palaeoenvironmental interpretation. A continental palaeoenvironment is indicated by the *Planolites* burrows in Facies 2 (Frey, 1975), the mudcracks in Facies 2 and 3, and by the plant remains in Facies 1 and 4. The basal erosive contact with the Beaufort Group, the channels and channel fill trough cross-bedding found in certain outcrops, the relatively immature sediments, and the predominance of cross-stratified sandstones in this unit point to an alluvial depositional setting within this palaeoenvironment.

The vertical profile model constructed for the study area is similar to Miall's (1978) South Saskatchewan and Platte braided river models and to B.R. Rust's (1978) $S_{II}$ braided river–alluvial plain facies assemblage. There is also a degree of correlation with the upward-fining meandering river vertical sequence of Collinson (1978). A vertical repetition of trough and planar cross-bedded sandstones, commonly seen in measured sections from the study area, can also be found in coarse meandering river deposits (Nijman and Puigdefabregas, 1978).

The sediments of the Molteno Formation were probably laid down within a fluvial palaeoenvironmental setting. The four lithofacies can thus be interpreted in the context of this general depositional framework.

### B. Facies One

The coarse-grained trough cross-bedded sandstones of Facies 1, with their conglomeratic lenses, underlying coarse lag deposits, and other basal erosion features suggest a fluvial channel origin, characterized by high energy basal erosive scouring action, bedload deposition, and dune migration. These sediments display similar characteristics to the basal coarse-grained sandstone and overlying trough cross-bedded sandstone facies (facies SS, A and B) defined by Cant and Walker (1976) in the braided river Battery Point Formation of Quebec. Similar facies occur in the present-day South Saskatchewan River (Cant and Walker, 1978). When comparing the South Saskatchewan River and Battery Point Formation depositional environments, Cant (1978) assigned the origin of these facies to basal channel scour and in-channel dune migration. Facies 1 of the Molteno Formation also bears a close resemblance to Miall's (1977, 1978) St braided river facies.

Coarse-grained trough cross-bedded sandstones are reported from point bar sediments of the Castisent Sandstone Formation in the Eocene of the southern Pyrenees, Spain. These sandstones occur in association with pebble lenses and underlying conglomeratic lag deposits, overlying a basal scoured surface (Nijman and Puigdefabregas, 1978). In a generalized discussion of meandering river systems, Walker and Cant (1979) described trough cross-bedded sandstones which overlie coarse-grained lag deposits on preserved channel floors.

### C. Facies Two

Tabular planar cross-stratified sandstones, such as predominate in Facies 2 of the Molteno Formation, are

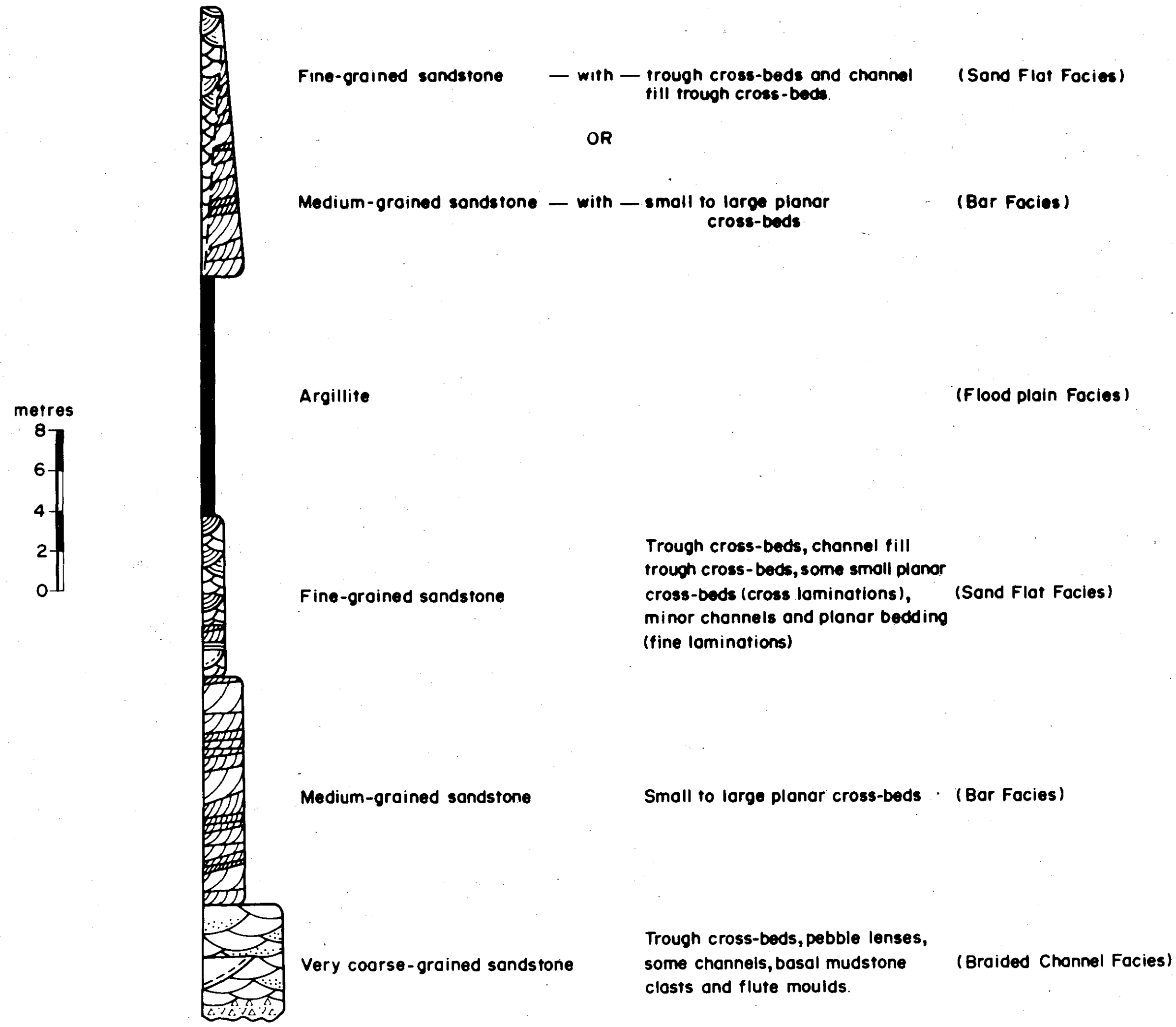


**Figure 4**
Idealized vertical profile model of the Molteno Formation. (Facies thicknesses based on average of field outcrops.)

abundant in fluvial settings, particularly those characterized by braided rivers, where they owe their formation to the migration of bar bedforms. Similar cross-bedded sandstones result from foreset deposition at the margins of transverse bars in the present-day braided Platte River (N.D. Smith, 1970, 1971, 1972), a feature also described by Harms and Fahnestock (1965) for the Rio Grande River and by Collinson (1970) for the braided Tana River in Norway.

An analogous environmental setting is envisaged by Miall (1977) for his Sp, planar cross-bedded sandstone facies. Two tabular planar cross-stratified facies (facies C and D) are discussed by Cant and Walker (1976) for the Battery Point Sandstone, and these were later related, by Cant (1978), to similar features formed by transverse bar migration in the braided South Saskatchewan River. Although planar cross-bedded sandstones are very common in braided fluvial deposits, they are also reported in coarse-grained meandering river sediments (Nijman and Puigdefabregas, 1978).

### D. Facies Three

These fine- to medium-grained sandstones display trough, tabular planar and channel fill trough cross-bedding. These features indicate dune and bar migration and the filling of cut channels in a fluvial depositional setting, possibly one characterized by sand flat development in braided rivers.

Cant and Walker (1978) reported sand flat sediments, characterized by small planar and trough cross-beds, planar stratification and ripple cross-lamination, which result from reworking of emergent bar surfaces in the braided South Saskatchewan River during lower flow stages. Minor ripples and planar stratification are found in Facies 3 of the Molteno Formation. Blodgett and Stanley (1980) stressed the role of low flow channels, floored by dunes, bars or plane beds, in the development of sand flat sandstones in the Platte River.

Although neither Miall (1977) nor Cant and Walker (1976) reported a single braided stream facies closely resembling those of the Molteno sediments, they did describe a number of facies which display some of the structures seen in the third lithofacies. Miall (1977) defined an Ss facies, typified by large scours and scour fillings, which has much in common with the Molteno channel fill trough cross-beds. Cant and Walker (1976) discussed a similar facies (facies E) in the Battery Point Formation, as well as two other facies (facies F and G) characterized, respectively, by ripple cross-lamination and low angle planar cross-stratification.

Channel fill trough cross-beds are documented in meandering river sediments of the Gomti River, India (Singh, 1972). Finer trough cross-stratified sandstones, similar to those of Facies 3, frequently overlie basal coarse-grained trough cross-bedded material in the classic meandering river vertical sequence (Walker and Cant, 1979), but do not display an association with planar and channel-fill trough cross-stratification.

### E. Facies Four

These planar-bedded argillaceous sediments, cut by small channels with massive, fine-grained fills and containing uncommon organic material, point to low velocity suspension settling and subordinate low energy scouring action in locally swampy overbank or inter-channel fluvial floodplain areas. Similar sediments are frequently found in braided (Cant and Walker, 1978; Williams and B.R. Rust, 1969; Collinson, 1978), meandering (Walker and Cant, 1979; Jackson, 1978), and anastomosing (Smith and Smith, 1980) river settings. Although argillaceous sediments are more common in anastomosing rivers than in braided or meandering systems, the absence of any associated crevasse splay deposits in the Molteno Formation favours a braided fluvial palaeoenvironment rather than meandering or anastomosing river settings.

### F. Depositional Model

Interpretation of the four Molteno lithofacies suggests fluvial deposition involving a number of processes. These include high energy basal erosive scouring, bedload deposition and dune migration within channels, the migration of transverse or linguoid bars, the reworking of emergent bars to form sand flats under lower flow conditions, and low energy floodplain sedimentation. The sand flat sediments of Facies 3 may be considered as the reworked equivalents of the Facies 2 bar deposits, a supposition supported by their similar lithology. Braided, meandering, and anastomosing river depositional settings were considered for the four lithofacies.

However, the Molteno Formation is dominated by sandstones, with an irregular distribution of subordinate argillaceous material, thus ruling out an anastomosing fluvial interpretation. Anastomosing river successions are characterized by discrete sand or gravel channel deposits set in the predominant floodplain argillites which typify these environments, in both arid and more temperate climatic settings (Smith and Smith, 1980; B.R. Rust, 1981).

The Molteno Formation in the study area is characterized by predominant Facies 2 and 3 bar and sand flat sediments, with a relatively poor development of Facies 1 channel base and dune migration deposits (Fig. 4). Accumulation of fine-grained Facies 4 sediments in floodplain areas was significant, but subservient to the formation and modification of transverse or linguoid bars. The combination of these four lithofacies suggests the possibility of braided river deposition, dominated by bar migration, with reworking taking place as these bedforms became emergent under lower flow conditions.

Unfortunately, the palaeocurrent data are not extensive enough to help discriminate between braided and more sinuous channel systems. However, the regional fan-like patterns observed in the study area could be related to proximal alluvial fan development. Any association with fan sedimentation would be more consistent with a braided rather than a meandering fluvial setting.

The Molteno vertical facies arrangement shows some resemblance to Miall's (1978) South Saskatchewan and Platte braided river profile models, and can be assigned to B.R. Rust's (1978) $S_{II}$ facies assemblage, which embraces both the Platte and South Saskatchewan models. Deposition of this $S_{II}$ assemblage is ascribed to distal braided rivers and alluvial plains, which may be transitional to meandering rivers (B.R. Rust, 1978).

The Molteno profile model also shows some similarity to Walker and Cant's (1979) generalized meandering river succession, and more with that of Collinson (1978). But neither of these meandering models displays a prominent bar-reworked bar component as found in the Molteno sediments. The absence of epsilon cross-stratification in this formation also mitigates against a meandering origin; however, Jackson (1978) found that this structure cannot be regarded as a reliable index of fluvial setting. He suggested that the only reliable indicators of a meandering channel pattern are substantial mud in the coarse member, a thick development of the fine member, asymmetric mud-rich channel fills, and exhumed meander belts. None of these features are characteristic of the Molteno sediments.

In their entirety the Molteno deposits in the study area are most compatible with braided river sedimentation, although the correlation with B.R. Rust's (1978) $S_{II}$ facies assemblage implies a possible transition to meandering channels in the palaeoenvironment. Nijman and Puigdefabregas (1978) proposed that the vertical succession from coarse-grained point bar sediments can be very similar to certain braided river profiles. The point bar deposits of the Castisent Formation in Spain display well-developed transverse bar planar cross-bedded sandstones, trough cross-stratified sandstones, and basal conglomerates (Nijman and Puigdefabregas, 1978); all these features are present in the Molteno profile model. However, the dominance of the bar facies in the Molteno Formation, as well as the evidence for fairly extensive sand flat reworking of bars, strongly favours a typically braided river setting rather than coarse sinuous channel systems.

The low sinuosity, braided fluvial depositional model proposed here for the Natal Drakensberg shows no significant departures from the shallow water fluvial palaeoenvironment of I.C. Rust (1962) or the braided river model proposed for the Molteno basin by Turner (1970 to 1983). However, the writer's model stresses the role of fluvial bar migration within the palaeoenvironment of the study area, in contrast to the dominance of in-channel dune bedforms described by Turner (1983); in addition, sand flat reworking of emergent bars appears to have been important within the north-eastern part of the basin.

The Molteno Formation was deposited under cool and humid palaeoclimatic conditions (I.C. Rust, 1962; Turner, 1983); the plant fossil assemblage of these sediments supports this contention (Anderson, 1976). The *Dicroidium* flora of the Molteno formation is relatively abundant and diverse (Anderson, 1974, 1976) and large *Dadoxylon* trees also grew within the palaeoenvironment (I.C. Rust, 1962; Turner, 1983). The rare insects and crustacea (Anderson, 1976), suspected bivalve or gastropod trace fossils (Turner, 1978), and fish remains (Jubb, 1973) found in these deposits further support humid conditions. Reptilian fossils reported by Ellenberger *et al.* (1964) have since been assigned to stratigraphically higher or lower units (Kitching, 1977). The very limited fossil assemblage and relative paucity of carbonaceous argillite in the present study area, as well as the minor occurrences of mudcracks in Facies 2 and 3, may indicate a more temperate humid palaeoclimate in the north-east of the basin.

### G. Source Areas

A southern source area, comprising predominantly Cape Supergroup sedimentary rocks, and a south-eastern, probably granitic provenance region supplied detritus to the Molteno basin (I.C. Rust, 1962; Botha and Theron, 1967; Turner, 1975a, 1980). The Molteno sediments of the study area belong to the Indwe Sandstone Member, which is believed to have derived most of its material from the south-eastern source area (I.C. Rust, 1973; Turner, 1975a, 1980, 1983). The two major palaeocurrent trends obtained in the Natal Drakensberg (Fig. 3) indicate that this south-eastern provenance region may have extended further to the north than previously thought.

### H. Tectonics and Basin Fill

Turner (1983) related the lower Molteno sediments, restricted to the south of the basin, to an initial uplift of the southern provenance region. Following this, tectonism affected the south-eastern source terrane, where marked elevation led to the deposition of the basin-wide Indwe Sandstone (Turner, 1983). Turner (1983) ascribed the upper Molteno cycles, found only in the south of the basin, to subdued uplift of the southern provenance area, combined with a sourceward retreat of the depositional system. Tectonism in the source terranes was accompanied by the development of alluvial fans adjacent to these areas (Turner, 1977, 1983); these proximal fans were probably responsible for the fan-like palaeocurrent spreads observed within the present study area.

## V. CONCLUSIONS

The Molteno Formation in the Natal Drakensberg and north-eastern Orange Free State was laid down by low sinuosity channel systems. These rivers were characterized by the migration of transverse or linguoid bars, often reworked into sand flats upon emergence during lower river stages. During these lower river stages significant quantities of fine argillaceous material were deposited in abandoned floodplain areas and, in places, swamps developed where vegetation flourished. Although this proposed palaeoenvironment is very similar to the depositional models of I.C. Rust (1962) and Turner (1970 to 1983), the present study stresses the importance of fluvial bar migration and sand flat processes in the north-east of the Molteno basin. Palaeocurrent measurements in the study area indicate that the south-eastern source area proposed by Turner (1983) probably extended further to the north.

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## REFERENCES


Anderson, H.M. (1974). A brief review of the flora of the Molteno "Formation" (Triassic), South Africa. *Palaeont. afr.*, **17**, 1–10.

---- (1976). *A revision of the genus Dicroidium from the Molteno Formation.* Ph.D. thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 146 pp.

Blodgett, R.H., and Stanley, K.G. (1980). Stratification, bed forms, and discharge relations of the Platte braided river system, Nebraska. *J. sedim. Petrol.*, **50**, 139–148.

Botha, B.J.V., and Theron, J.C. (1967). Sedimentologiese aspekte van die Étage Molteno, Sisteem Karroo. *Tydskr. Natuurwet.*, **8**, 158–162.

Cant, D.J. (1978). Development of a facies model for sandy braided river sedimentation: comparison of the South Saskatchewan River and the Battery Point Formation, 627–639. *In:* Miall, A.D., Ed., *Fluvial Sedimentology.* Can. Soc. Petrol. Geol., Calgary, Alberta, 859 pp.

----, and Walker, R.G. (1976). Development of a braided-fluvial facies model for the Devonian Battery Point Sandstone, Quebec. *Can. J. Earth Sci.*, **13**, 102–119.

----, and ---- (1978). Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada. *Sedimentology,* **25**, 625–648.

Collinson, J.D. (1970). Bedforms of the Tana River, Norway. *Geogr. Ann., Ser. A.*, **52**, 31–56.

---- (1978). Alluvial sediments, 15–60. *In:* Reading, H.G., Ed., *Sedimentary Environments.* Blackwell Scientific Publications, Oxford, 557 pp.

Du Toit, A.L. (1939). *The Geology of South Africa.* Oliver and Boyd, Edinburgh, 539 pp.

Ellenberger, F., Ellenberger, P., Fabre, J., Ginsburg, L., and Mendrez, C. (1964). The Stormberg Series of Basutoland (South Africa). *Rep. 22nd Session Int. Geol. Congr.*, Calcutta, India, 320–330.

Eriksson, P.G. (1983). *A palaeoenvironmental study of the Molteno, Elliot and Clarens Formations in the Natal Drakensberg and northeastern Orange Free State.* Ph.D. thesis (unpubl.), Univ. Natal, Pietermaritzburg, 209 pp.

Frey, R.W. (1975). The realm of ichnology, its strengths and limitations, 13–38. *In:* Frey, R.W., Ed., *The Study of Trace Fossils.* Springer Verlag, Berlin, 562 pp.

Harms, J.C., and Fahnestock, R.K. (1965). Stratification, bed forms, and flow phenomena (with an example from the Rio Grande), 84–115. *In:* Middleton, G.V., Ed., *Primary Sedimentary Structures and their Hydrodynamic Interpretation.* Spec. Publ. Soc. Econ. Paleont. Mineral., **12**, 265 pp.

Haughton, S.H. (1924). The fauna and stratigraphy of the Stormberg Series. *Ann. S. Afr. Mus.*, **12**, 323–395.

---- (1969). *Geological History of Southern Africa.* Geol. Soc. S. Afr., 535 pp.

Jackson, R.G. (1978). Preliminary evaluation of lithofacies models for meandering alluvial streams, 543–576. *In:* Miall, A.D., Ed., *Fluvial Sedimentology.* Can. Soc. Petrol. Geol., Calgary, Alberta, 859 pp.

Jubb, R.A. (1973). Brief synthesis of present information on the geographical and stratigraphical distribution of fossil fish within the Stormberg Series, South Africa. *Palaeont. afr.*, **16**, 17–23.

Kitching, J.W. (1977). *The Distribution of the Karoo Vertebrate Fauna.* Mem. Bernard Price Inst. for Palaeontological Res., Univ. Witwatersrand, Johannesburg, **1**, 131 pp.

Miall, A.D. (1976). Palaeocurrent and palaeohydrologic analysis of some vertical profiles through a Cretaceous braided stream deposit, Banks Island, Arctic Canada. *Sedimentology,* **23**, 459–483.

---- (1977). A review of the braided-river depositional environment. *Earth-Sci. Rev.*, **13**, 1–62.

---- (1978). Lithofacies types and vertical profile models in braided river deposits: a summary, 597–604. *In:* Miall, A.D., Ed., *Fluvial Sedimentology.* Can. Soc. Petrol. Geol., Calgary, Alberta, 859 pp.

Nijman, W., and Puigdefabregas, C. (1978). Coarse-grained point bar structure in a molasse-type fluvial system, Eocene Castisent Sandstone Formation, South Pyrenean Basin, 487–510. *In:* Miall, A.D., Ed., *Fluvial Sedimentology.* Can. Soc. Petrol. Geol., Calgary, Alberta, 859 pp.

Potter, P.E., and Pettijohn, F.J. (1977). *Paleocurrents and Basin Analysis.* Springer Verlag, Berlin, 425 pp.

Royse, C.F. (1970). *An Introduction to Sediment Analysis.* Arizona State Univ., Tempe, 180 pp.

Rust, B.R. (1978). Depositional models for braided alluvium, 605–625. *In:* Miall, A.D., Ed., *Fluvial Sedimentology.* Can. Soc. Petrol. Geol., Calgary, Alberta, 859 pp.

---- (1981). Sedimentation in an arid-zone anastomosing fluvial system: Cooper's Creek, Central Australia. *J. sedim. Petrol.*, **51**, 745–755.

Rust, I.C. (1962). On the sedimentation of the Molteno sandstones in the vicinity of Molteno, C.P. *Ann. Univ. Stellenbosch,* **37**, 165–236.

---- (1973). Tectonic and sedimentary framework of Gondwana basins in Southern Africa, 537–564. *In:* Campbell, K.S.W., Ed., *Gondwana Geology.* Aust. Nat. Univ. Press, Canberra, 823 pp.

Singh, I.B. (1972). On the bedding in the natural-levee and the point-bar deposits of the Gomti River, Uttar Pradesh, India. *Sediment. Geol.*, **7**, 309–317.

Smith, D.G., and Smith, N.D. (1980). Sedimentation in anastomosed river systems: examples from alluvial valleys near Banff, Alberta. *J. sedim. Petrol.*, **50**, 157–164.

Smith, N.D. (1970). The braided stream depositional environment: comparison of the Platte River with some

Silurian clastic rocks, North-Central Appalachians. *Bull. geol. Soc. Amer.*, **81**, 2993–3014.

---- (1971). Transverse bars and braiding in the Lower Platte River, Nebraska. *Bull. geol. Soc. Amer.*, **82**, 3407–3420.

---- (1972). Some sedimentological aspects of planar cross-stratification in a sandy braided river. *J. sedim. Petrol.*, **42**, 624–634.

Stockley, G.M. (1947). *Report on the Geology of Basutoland.* Morija Printing Works, Morija, Lesotho, 114 pp.

Turner, B.R. (1970). Facies analysis of the Molteno sedimentary cycle, 313–319. *In:* Haughton, S.H., Ed., *Proc. 2nd IUGS Symposium on Gondwana Stratigraphy and Palaeontology.* CSIR, Pretoria, 684 pp.

---- (1975a). *The stratigraphy and sedimentary history of the Molteno Formation in the main Karoo Basin of South Africa and Lesotho.* Ph.D. thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 314 pp.

---- (1975b). Statistical appraisal of Molteno (Triassic) sedimentary cycles from the upper part of the Karoo (Gondwana) system in South Africa. *J. sedim. Petrol.*, **45**, 95–104.

---- (1977). Fluviatile cross-bedding patterns in the upper Triassic Molteno Formation of the Karoo (Gondwana) Supergroup in South Africa and Lesotho. *Trans. geol. Soc. S. Afr.*, **80**, 241–252.

---- (1978). Trace fossils from the Upper Triassic fluviatile Molteno Formation of the Karoo (Gondwana) Supergroup, Lesotho. *J. Paleontol.*, **52**, 959–963.

---- (1980). Palaeohydraulics of an Upper Triassic braided river system in the Main Karoo Basin, South Africa. *Trans. geol. Soc. S. Afr.*, **83**, 425–431.

---- (1983). Braidplain deposition of the Upper Triassic Molteno Formation in the main Karoo (Gondwana) Basin, South Africa. *Sedimentology*, **30**, 77–89.

Walker, R.G., and Cant, D.J. (1979). Sandy fluvial systems, 23–31. *In:* Walker, R.G., Ed., *Facies Models.* Geol. Assoc. Can., Univ. Waterloo, Ontario, 211 pp.

Williams, P.F., and Rust, B.R. (1969). The sedimentology of a braided river. *J. sedim. Petrol.*, **39**, 649–678.

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