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A REVIEW OF THE STORMBERG GROUP AND DRAKENSBERG VOLCANICS IN SOUTHERN AFRICA

by

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ABSTRACT

The Molteno Sandstone, Red Beds and Cave Sandstone comprising the Stormberg Group (siliciclastics) in South Africa and their correlatives, based on lithology, depositional environments and tectonic cycles, in Zimbabwe, Botswana and Namibia are described. The Drakensberg Volcanics with radiometric ages of 114 My to 194 My cap the sedimentary sequence. A major unconformity separates the Stormberg sedimentary rocks from the lower Karoo strata.

Four Late Triassic depositional basins which were tectonically controlled are recognised. The Molteno Sandstone and Red Beds filling these basins represent braided and meandering stream deposits respectively. The Cave Sandstone covering the fluvial deposits formed as desert sand sheets reworked by westerly winds. Deposition was ended by the outpouring of the Drakensberg Volcanics.

CONTENTS

INTRODUCTION

The presence of coal in the northeastern Cape Province was the incentive for the first geological investigations of beds belonging to the Stormberg Group. Wyley (1859) was probably the first to use the name "Stormberg Beds", but the real pioneer was Dunn who in 1878 subdivided the Stormberg Beds into the Coal Measures, Red Beds, Cave Sandstone and Volcanic Beds. Green (1883) proposed the name "Molteno Beds" for the Coal Measures, while the name "Drakensberg Beds" later replaced "Volcanic Beds" (Rogers and Du Toit 1909, p. 167).

In South Africa very little detailed work on the Stormberg was carried out during the period preceding the sixties, except for sporadic descriptions in the course of mapping. The exception, however, was Sidney H. Haughton who in 1924 published a lengthy report on the fauna and stratigraphy of the Stormberg Group, dealing not only with the outcrops in South Africa, but also with those in Southern Rhodesia (Zimbabwe) and the Belgian Congo (Zaire). During 1959 the first detailed sedimentological/stratigraphic analysis of the Molteno Sandstone after Haughton's (1924) review was undertaken by Rust (1962) and this was subsequently followed in later years by a number of theses and papers on the coal, the general stratigraphy of each unit, as well as the sedimentation. In the text reference will be made to these publications. Rust (1975) reviewed the tectonic and sedimentary framework of the Gondwana basins in southern Africa and his realistic approach to sedimentation led to some of the ideas evolved in this review. In the northern part of the country beds correlated with the Stormberg Group were briefly described by Mellor (1905), Kynaston (1906) and others during regional mapping, but it was the search for fossil fuel in the isolated basins that yielded the greatest wealth of information. Some of these investigations are at present still in progress. Detailed studies of the Stormberg Group in Zimbabwe, Botswana and Namibia lag behind, although Molyneux (1903) gave a subdivision of the strata along the Zambesi River. In Namibia the upper units of the Karoo sequence have been up to now only superficially in-

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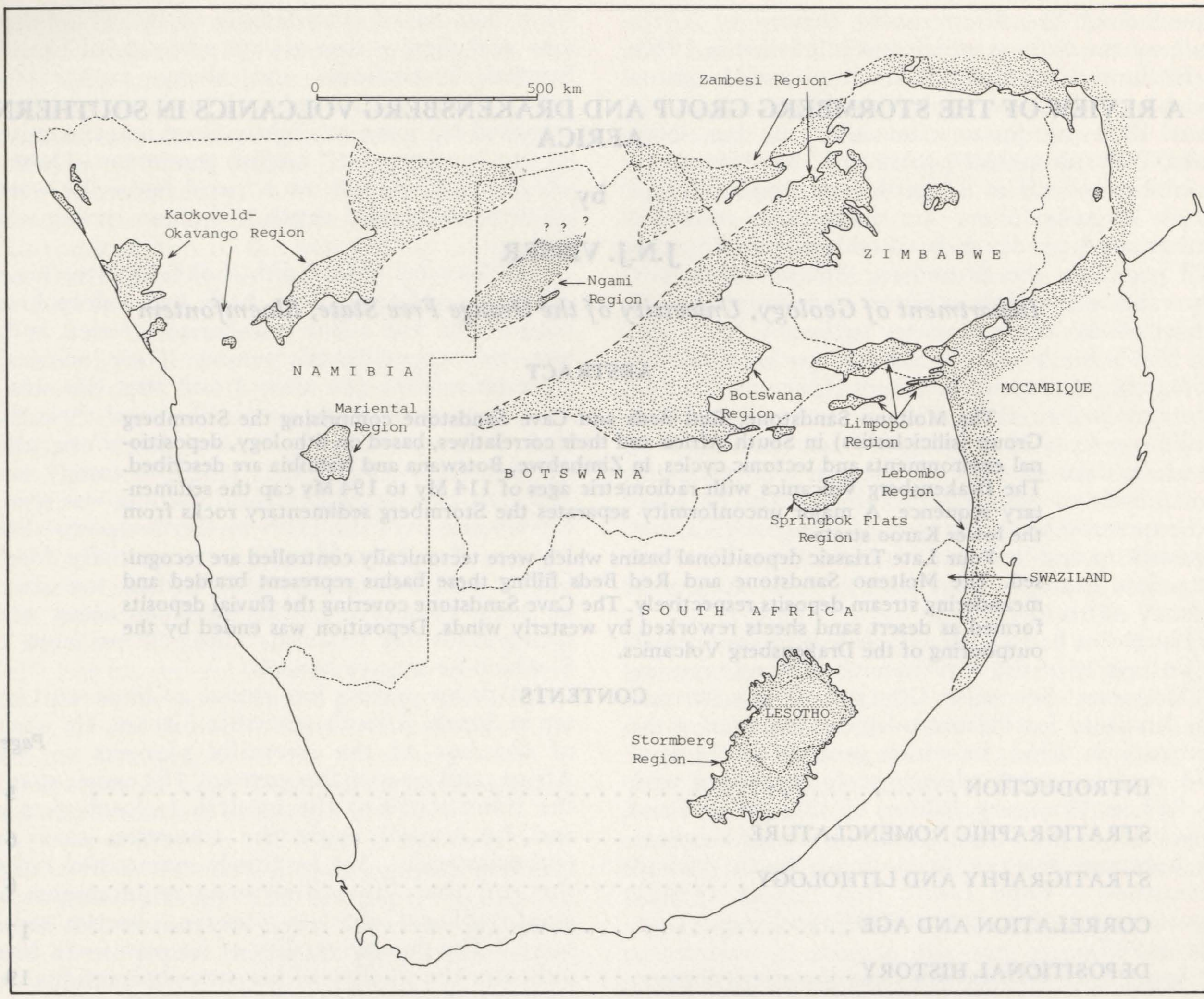

Fig. 1 Distribution of the Stormberg Group and overlying volcanics in southern Africa.

vestigated, while the thick cover of Kalahari Beds in Botswana prohibits detailed studies.

In the limited space available here, a rather superficial review of the Stormberg Group and overlying volcanics will be given. Generalised stratigraphic columns are frequently made use of to avoid lengthy description. Furthermore lack of age determinations and palaeontological data render some correlations doubtful and in such circumstances sedimentology has been applied to "correlate" events in the Late Triassic basins. To some such an approach, in view of the limitations, will be presumptuous, but to gain better understanding of Karoo sedimentation, progressive thinking is necessary in the future.

STRATIGRAPHIC NOMENCLATURE

The South African Committee for Stratigraphy (SACS) discarded the name "Stormberg", in spite of its usage since 1859. For the purpose of this review the name "Stormberg Group" is retained to include all the sedimentary rocks from the base of the Molteno to the top of the Cave Sandstone. This term is futhermore a collective one including all sedimentary strata resting unconformably on lower Karoo beds or older Basement and being overlain by a thick sequence of basic to acidic lavas. The name "Drakensberg Formation/Group" as first used by Rogers and Du Toit (1909, p. 219) has been retained for the volcanics at the top.

Almost 30 stratigraphic names have been proposed or are partly in use for the Stormberg and Drakensberg Groups in South Africa, Botswana, Namibia and Zimbabwe, which to any reader without a lexicon, could be utterly confusing. For this reason the well-established names like Molteno Sandstone, Red Beds and Cave Sandstone are informally used for all the regions and where possible the names as used by SACS or the local ones are given in brackets.

STRATIGRAPHY AND LITHOLOGY

The Stormberg siliciclastics and overlying Drakensberg volcanics are widely distributed over southern Africa and, for ease of description, nine regions are recognised (fig.1). These do not necessarily imply depositories, but were merely chosen on grounds of lithological similarity and being isolated by later crustal movements.

Fig. 2 Terraced foothills of the Drakensberg Escarpment near Elliot. The Molteno Sandstone builds the valley floor and the Cave Sandstone and Drakensberg basalt the krantzes.

Stormberg Region

The basin roughly covers an oval-shaped area in the eastern Cape Province extending northwards into the Orange Free State, Lesotho and Natal (fig. 1). The sedimentary strata build the terraced high ground of the Drakensberg foothills while the volcanics build the escarpment and the high Drakensberg Plateau (fig. 2). The beds have a horizontal to subhorizontal disposition with an inward dip towards Lesotho Dolerite dykes, volcanic necks and vents cut the strata.

Molteno Sandstone (Molteno Formation). The Molteno Sandstone overlies mudstone and sandstone of the Beaufort Group. The basal beds rest on an erosional surface of low relief (Rust 1975, p. 550; Turner 1975, p. 23), and occasionally concentrations of pebbles occur on the lower contact. The upper contact with the Red Beds is transitional and is arbitrarily taken at the top of the uppermost coarse sandstone and the first development of deep red shale and mudstone. This led Turner (1975, p. 27) to state that it is safest to base the contact on palaeontological data.

The Molteno Sandstone has a maximum thickness of 460 m near Maclear in the southeast but it thins to about 30 m in the north near Bethlehem, where it is mostly a single sandstone which forms a prominent cliff in the topography. Near Harrismith it is absent due to a local structural high in the floor. The entire Molteno succession can be seen as a clastic wedge which thins rapidly northwards. In the south it comprises six upward-fining megacycles (basal coarse-grained sandstone → fine-grained sandstone and silstone → shale and coal) each of them resting on an erosional surface (fig. 3). These megacycles decrease in both number and thickness northwards until, according to Turner (1975), only the second cycle comprising the Indwe Sandstone occurs in the north.

The general stratigraphy is shown by means of two composite sections in Figure 3. The lowermost megacycle, named the Bamboesberg Member by Turner (1975), pinches out rapidly northwards. The coarsest material in the Molteno is restricted to the second megacycle which comprises the Kolo Pebble Bed at the base, the prominent Indwe Sansdstone (maximum thickness 48 m), and in the west a shale unit at the top. The Indwe Sandstone together with the Kolo Pebble Bed overlaps the Bamboesberg Member and can be regarded as a blanket sandstone. Four coal zones, of which the Cala Pass and Guba (Gubenxa) coals are the most prominent, are present in the south. Some of the coal-bearing units are better developed towards the west, but all beds diminish in thickness northwards until only very thin streaks (up to few centimetres thick) remain. Individual coal zones have a maximum thickness of up to 0,7 m and consist of a mixture of coal, coaly shale and shale. In the west there is a porcellanite bed associated with micaceous siltstone near the top of the sequence and it forms part of the transition to the Red Beds.

The sandstone zones consist of stacked lenticular bodies, each forming a typical upward-fining fluviatile cycle. The base of the cycle is characterised by scouring with scour channels filled with shale chips, plant debris, very coarse sandstone and pebbles. The basal part is frequently ferruginised. The major part of the cycle consists of whitish medium-grained lithic to feldspathic arenite with mica more abundant in the finer-grained types. The sandstones frequently have a glittering appearance due to the secondary deposition of silica on certain of the quartz grains leading to the formation of crystal faces which reflect the light (Haughton 1969, p. 366). The top of the fluviatile cycle, if not removed by erosion, consists of black carbonaceous to pale to bluish-grey silty shale and mudstone. Sedimentary structures include medium- to large-scale trough as well as planar cross-bedding, ripple marks, current lineation, sole structures,

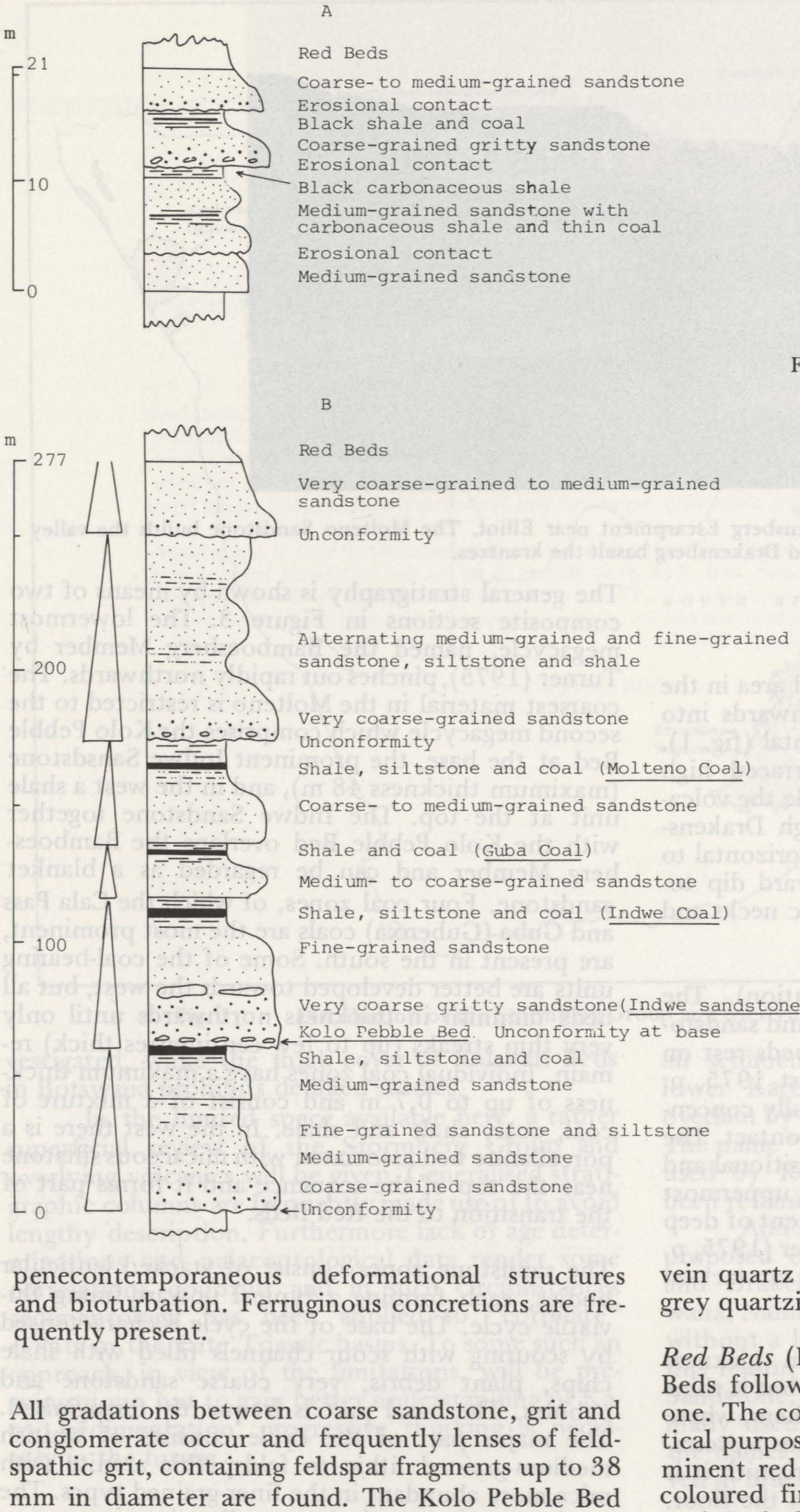

Fig. 3 Stratigraphic sequence of the Molteno Sandstone near Ficksburg (A) and near Indwe (B). (Sections after Turner 1975 and Rust 1962).

penecontemporaneous deformational structures and bioturbation. Ferruginous concretions are frequently present.

All gradations between coarse sandstone, grit and conglomerate occur and frequently lenses of feldspathic grit, containing feldspar fragments up to 38 mm in diameter are found. The Kolo Pebble Bed which is up to 3,6 m thick consists of oval to ellipsoidal well-rounded pebbles, cobbles and boulders set in a coarse-grained gritty matrix. A maximum clast size of 75 cm was recorded by Turner (1975) in the south, and up to 15 cm by Stockley (1947) in the north. In the south and southwest more than 90 percent of the pebbles are of white to pale grey quartzite (Rust 1962, p. 196) with the rest consisting of hornfels, slate, vein quartz, jasper, granite-gneiss and pegmatite. To the east and northwest vein quartz is more abundant followed by pink and grey quartzite and jasper.

Red Beds (Elliot Formation). Everywhere the Red Beds follow conformably on the Molteno Sandstone. The contact is normally transitional. For practical purposes the contact is taken at the first prominent red mudstone which is followed by buff-coloured fine- to medium-grained sandstone. The Red Beds have a maximum thickness of 480 m in the south but like the Molteno Sandstone, they thin rapidly to about 20 m in the north.

As the Red Beds consist of an alternation of sandstone, siltstone and mudstone, a lithological subdivision of the sequence is not practical but, on the basis of sand body geometry, Visser and Botha (1980) subdivide the sequence in the south into three units. The lower one is characterised by thick, stacked, lenticular sandstones; the middle one by thin laterally continuous sandstone beds; while the upper unit consists of thick laterally continuous sandstones (fig. 4). In the north, where the total thickness of the Red Beds is greatly reduced, the three zones can still be recognised. The maximum amount of sandstone occurs in the southeast and east, while in the northwest mudstone is dominant. The coarsest grain sizes were also recorded in the east (Le Roux 1974).

The typical Red Beds sequence is shown in Figure 4. The prominent sandstones in the lower part of the sequence attain thicknesses of up to 15 m and consist of multi-storeyed sandstone bodies which laterally pinch out. Each sandstone body represents an upward-fining fluviatile cycle with a scoured base. Mud-pellet conglomerate is frequently developed in the scour channels, while occasionally grit and small, well-rounded pebbles of quartzite and vein-quartz, up to 7,5 cm in diameter, are found. The massive cream to buff-coloured sandstones can be classified as fine- to medium-grained feldspathic wackes which frequently contain mica. The greenish yellow to reddish thin-bedded sandstone beds seldom exceed 1 m in thickness, are usually silty with frequent vertical and lateral transitions to siltstone, and both upward-fining and upward-coarsening cycles are present. The upper sandstones are up to 5 m thick, medium-grained and show well-developed trough cross-bedding at the top. Sedimentary structures in the sandstone include small to medium-scale trough cross-bedding, ripple cross-lamination, current lineation, sole structures, desiccation cracks, dewatering structures and bioturbation.

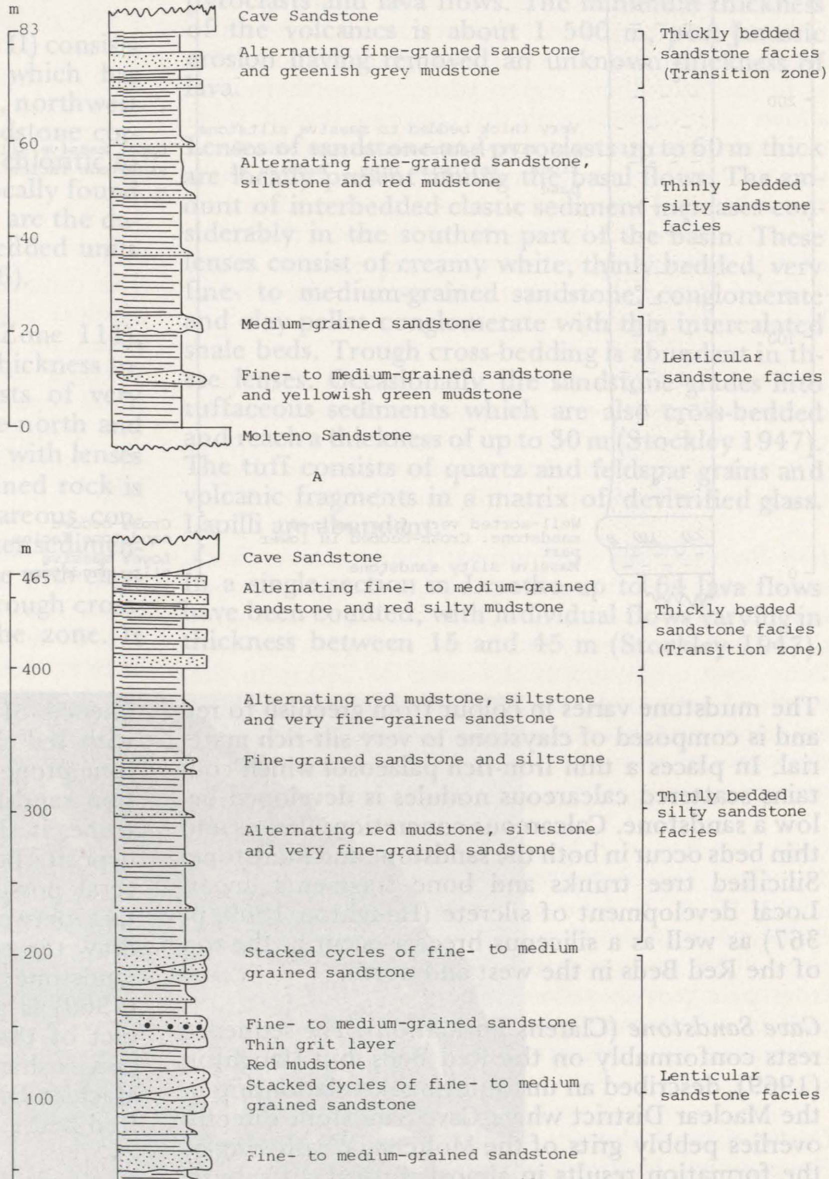

Fig. 4 Stratigraphic sequence of the Red Beds near Senekal (A) and near Elliot (B).

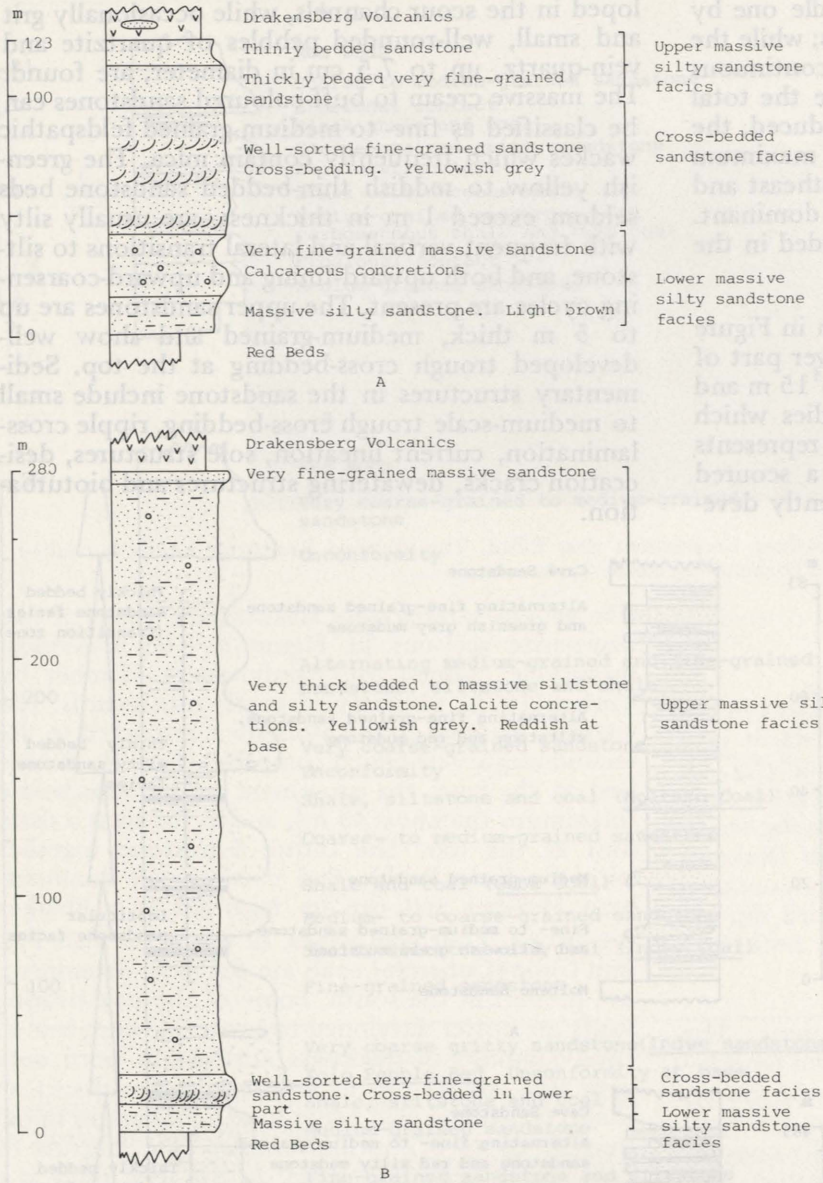

Fig. 5 Stratigraphic sequence of the Cave Sandstone near Senekal (A) and near Elliot (B). (After Beukes 1969).

The mudstone varies in colour from greenish to red and is composed of claystone to very silt-rich material. In places a thin iron-rich palaeosol which contains scattered calcareous nodules is developed below a sandstone. Calcareous concretions, lenses and thin beds occur in both the sandstone and mudstone. Silicified tree trunks and bone fragments occur. Local development of silcrete (Haughton 1969, p. 367) as well as a siliceous breccia occur at the top of the Red Beds in the west and north.

Cave Sandstone (Clarens Formation). The sequence rests conformably on the Red Beds but Haughton (1969), described an unconformable relationship in the Maclear District where Cave Sandstone directly overlies pebbly grits of the Molteno. Weathering of the formation results in almost vertical cliffs, buttresses and spikes up to 100 m in height, with shallow caves at the base in places. The lower contact of the formation is transitional. Van Eeden (1937, p. 27-30) used the term "transition beds" for a sequence of medium-grained sandstone alternating with red silty mudstone between the Cave Sandstone proper and the Red Beds. Although the transition sandstone is coarser than normal Cave Sandstone, it shows many characteristics of an aeolian deposit. Beukes (1969) discussed the merits of several possible stratigraphic positions for the contact between the two formations. He decided to draw the contact at the base of the massive aeolian sandstone; this boundary as suggested by Beukes (1969) is also used in this review. The upper contact of the Cave Sandstone with the Drakensberg lava is sharp, although very uneven, so that in the Maclear District the volcanics directly overlie the Red Beds.

The Cave Sandstone has a maximum thickness of about 277 m in the south, but towards the west and north the thickness decreases to less than 30 m near Jamestown and less than 120 m near Ladybrand. It also decreases in thickness eastwards so that along the Drakensberg Escarpment in Natal it is frequently less than 90 m thick. This rapid thickness variation could be related firstly to the mode of deposition of the Cave Sandstone and secondly to the sporadic start of the Drakensberg volcanism.

Beukes (1969) recognised on a regional scale three lithostratigraphic zones in the Cave Sandstone (fig. 5), although Eriksson (1981) in a detailed study of an area in Natal found a more complex distribution of lithologies. The lower sandstone facies (Zone I of Beukes), which has its maximum development in the north, consists of thickly bedded to massive, light reddish-brown to yellowish-grey, silty sandstone and very fine-grained sandstone. Sedimentary structures include symmetrical ripple marks, desiccation cracks, clay-pellet conglomerate and ripple cross-lamination. Calcareous concretions are abundant.

The cross-bedded sandstone facies (Zone II) consists of well-sorted fine-grained sandstone which has its maximum development in the north, northwest and southwest. In composition the sandstone corresponds with a quartz wacke having a chloritic to calcitic matrix. Erosional channels are locally found while cross-bedding and graded bedding are the dominant sedimentary structures. Cross-bedded units up to 10 m thick occur in Zone II (fig. 6).

The upper massive sandstone facies (Zone 111), which shows a considerable increase in thickness towards the south and southeast, consists of very fine-grained immature sandstone in the north and a silty sandstone in the south and east, with lenses of fine-grained sandstone. The fine-grained rock is mottled, contains abundant small calcareous concretions and exhibits typical shallow water sedimentary structures. Thinly bedded sandstone with clay-pellet conglomerate, ripple marks and trough cross-bedding occurs towards the top of the zone. It grades locally into coarse-grained cross-bedded sandstone and conglomerate on the contact with the lava.

An interesting feature of the Cave Sandstone is the presence of dune structures. Beukes (1969, p. 42-43) describes palaeo-dunes near Rosendal with a height of about 17 m, and at Barkly East a dune structure with an amplitude of 110 m occurs. Remains of silicified tree trunks are also reported.

Drakensberg Volcanics (Drakensberg Group). The volcanic beds build the deeply dissected mass of Lesotho and the adjoining high ground of which the Drakensberg Escarpment on the southeastern side reaches heights in excess of 3 000 m above sea level. Although the lavas in general rest upon a fairly even surface of Cave Sandstone, there are channels and valleys in the sandstone filled with pyroclasts and lava flows. The minimum thickness of the volcanics is about 1 500 m, post-Jurassic erosion having removed an unknown thickness of lava.

Lenses of sandstone and pyroclasts up to 60 m thick are locally present among the basal flows. The amount of interbedded clastic sediment increases considerably in the southern part of the basin. These lenses consist of creamy white, thinly bedded, very fine- to medium-grained sandstone, conglomerate and clay-pellet conglomerate with thin intercalated shale beds. Trough cross-bedding is abundant in these lenses. Occasionally the sandstone grades into tuffaceous sediments which are also cross-bedded and reach a thickness of up to 30 m (Stockley 1947). The tuff consists of quartz and feldspar grains and volcanic fragments in a matrix of devitrified glass. Lapilli are abundant.

In a single section in Lesotho up to 64 lava flows have been counted, with individual flows varying in thickness between 15 and 45 m (Stockley 1947).

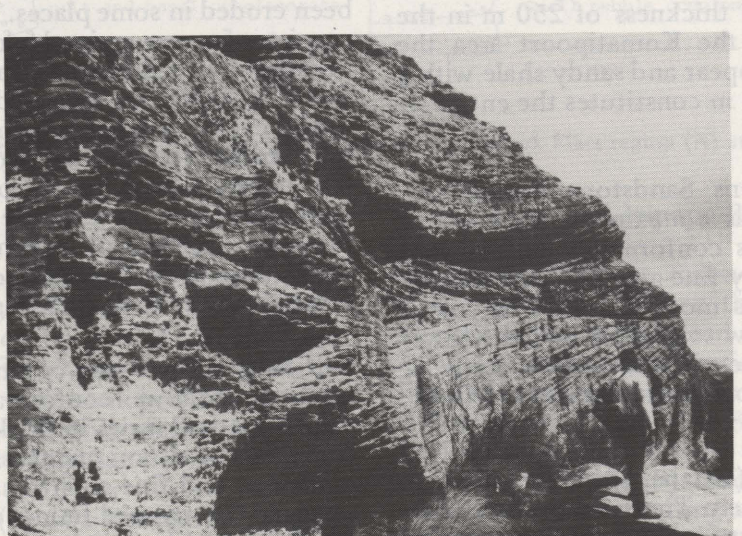

Fig. 6 Large-scale cross-bedding in the Cave Sandstone of the Stormberg region. (Photo: N.J. Beukes).

The lava varies from massive to amygdaloidal. Amygdales consist primarily of agate, chalcedony, quartz, calcite and zeolites and are concentrated mostly at the base of flows. It is largely basalt with minor flows of olivine basalt, andesite and trachyte. The lower flows in the southwest tend to be andesite. The lava has a granulitic to subophitic texture and ranges from dark greyish to blackish in colour. Pillow structures occur in the basal lava flows. Many volcanic necks, vents and diatremes are associated with the volcanics.

Lebombo Region

This outcrop belt extends from northeastern Natal, through Swaziland, northwards along the eastern boundary of the Republic of South Africa where the sequence builds the Lebombo Mountains (fig. 1). The Karoo beds lie on the eastern limb of a monoclinal fold and dip eastwards at 10° to 20°, although some apparent dips are much higher. The southern part has the same stratigraphic succession as in the Stormberg region while the northern part shows relationships with the Limpopo region. Considerable uncertainty surrounds the correlation of the sedimentary strata and the subdivision given in the following paragraphs should be considered as tentative. In northeastern Natal the total thickness of the Stormberg sedimentary sequence is about 4 000 m, but it decreases northwards to about 60 m before it completely wedges out.

Molteno Sandstone (Ntabene Formation). This predominantly coarse-grained unit rests unconformably on Beaufort sediments and consists of sandstone, grit and subordinate shale. Cross-bedding is ubiquitously present. Maximum thickness is about 100 m.

Red Beds (Nyoka Formation). The sequence which rests conformably on the Molteno Sandstone consists of thinly bedded, dark red to greenish silty shale, red mudstone, sandstone and grit The Red Beds have a maximum thickness of 250 m in the south. Northwards in the Komatipoort area the sandstone and grit disappear and sandy shale with a thickness of about 100 m constitutes the entire sequence.

Cave Sandstone (Clarens Sandstone Formation). The Cave Sandstone has a maximum thickness of about 45 m. It follows conformably on the Red Beds and consists of very fine-grained massive sandstone. The sandstone is mottled, varies in colour from pale greyish-yellow to pinkish and the lower part is calcareous Spheroidal as well as irregular calcareous concretions occur throughout the succession.

Drakensberg Volcanics (Letaba, Jozini and Movene Formations). In the eastern Transvaal the lava overlaps firstly the Stormberg sediments, then beds of the Ecca Group, and further north rests directly on the Archaean rocks. The pioneering work of Du Toit (1929) has shown that the volcanics can be subdivided into a lower basaltic lava group having a thickness of about 1 600 m and an upper acidic group approximately 4 800 m thick. The lower basalts vary from amygdaloidal to non-amygdaloidal; interbedded tuff and sandstone occur amongst the bottom flows. The basalts are olivine-poor in the south, but become olivine-rich northwards. The acidic group in the southern Lebombo region was investigated in detail by Stratten (1970), Bristow (1978) and Cleverly (1978). Rhyolite, dacite, ignimbrite, tuffs and sandy material are the dominant rock types. The rhyolites probably originated by the remobilisation of ash-flow tuffs (Cleverly 1978, p. 12-14).

Wachendorf (1971) proposes a threefold subdivision consisting of lower basic lavas with a thickness of up to 3 000 m, overlain by acidic lavas about 7 600 m thick and again basic lavas (2 000 + m) at the top. In the upper basic lavas occurs a lenticular unit of rhyolitic lava up to 500 m thick. Geophysical work by Darracott and Kleywegt (1974, p. 301-308) tends to support Du Toit's (1929) thickness values rather than those of Wachendorf.

Springbok Flats Region

The outcrops to the north of Pretoria build a featureless plain so that most of the information is based on drilling results. Post-Karoo faulting and warping have affected the beds resulting in two small separate basins bounded by east-west faults. The Stormberg succession rests unconformably on the Ecca Group, the Beaufort Group being absent (fig. 7A).

Molteno Sandstone (Lower part of Irrigasie Formation). The unit rests with a strong unconformity on lower Karoo strata. Deep valleys had been cut into the floor so that underlying Ecca coal beds had been eroded in some places. The Molteno Sandstone consists of coarse-grained feldspathic sandstone with occasional conglomerate, mudstone and siltstone. The lithologies are arranged in upward-fining fluviatile cycles: a basal conglomerate grades upwards into sandstone, siltstone and mudstone. Pebbles in the poorly sorted basal conglomerate consist of quartzite, felsite and granite. The upper part of the formation consists of brownish mudstone and siltstone. The total thickness of the unit varies over short distances from 0 m (high-lying areas) to 60 m.

Red Beds (Upper part of Irrigasie Formation). The sequence follows conformably on the Molteno Sandstone and varies in thickness from 5 to 150 m. It consists of alternating massive purplish and green mudstone and fine-grained sandstone and siltstone arranged in upward-fining cycles. Thick beds of poorly sorted breccia and conglomerate consisting solely of limestone clasts up to 2 cm in diameter interfinger with the mudstone.

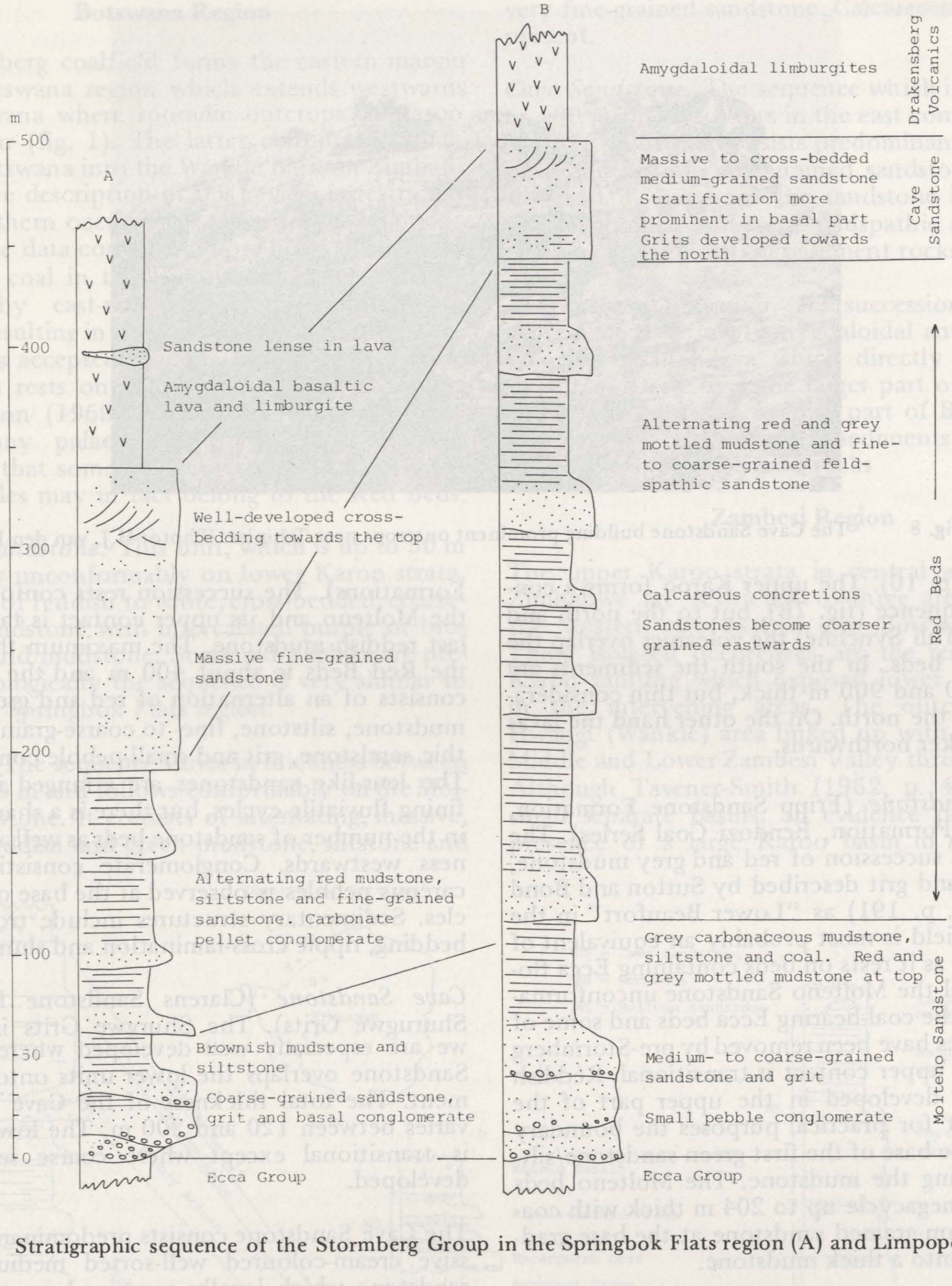

Fig. 7 Stratigraphic sequence of the Stormberg Group in the Springbok Flats region (A) and Limpopo region (B).

Cave Sandstone (Clarens Sandstone Formation). The Cave Sandstone has a thickness of 70 to 170 m. It follows conformably on the Red Beds and consists mainly of massive fine-grained yellow pinkish sandstone which shows well-developed cross-bedding towards the top. Tuffaceous material is also present in the upper part of the sandstone.

Drakensberg Volcanics (Letaba Formation). Amygdaloidal basalt and limburgite, showing definite flows, attain a total thickness of over 600 m. Lenses of fine-grained sandstone occur between the lower flows.

Limpopo Region

This region includes east-northeast-trending belts of Karoo rocks between the Limpopo River and the Soutpansberg, scattered outcrops in the Limpopo Valley, and fairly continuous outcrops in the Tuli and Nuanetsi synclines north of the Limpopo in Zimbabwe (fig. 1). The Stormberg Group forms the low-lying areas but the Cave Sandstone makes prominent hills (fig. 8). The strata are much affected by post-Karoo faulting and folding and most of the outcrops occur in grabens or half-grabens. There is abundant evidence that, at least for the outcrops in the south, Karoo beds occupied a larger basin before the faulting took place (Van den

Fig. 8 The Cave Sandstone building prominent outcrops near Tshipise. (Photo: H.J. van den Berg).

Berg 1980, p. 10). The upper Karoo forms a conformable sequence (fig. 7B), but to the north and northwest (Tuli Syncline) the volcanics overlap the sedimentary beds. In the south the sediments are between 550 and 900 m thick, but thin considerably towards the north. On the other hand the lavas become thicker northwards.

Molteno Sandstone (Fripp Sandstone Formation, Malilongwe Formation, Bendozi Coal Series). The 200 m thick succession of red and grey mudstone, coaly shale and grit described by Sutton and Bond (Bond 1967, p. 191) as "Lower Beaufort" in the Bubye Coalfield is most probably an equivalent of the Molteno as it rests on beds containing Ecca flora. In general the Molteno Sandstone unconformably overlies the coal-bearing Ecca beds and some of the coal facies have been removed by pre-Stormberg erosion. The upper contact is transitional. Reddish mudstone is developed in the upper part of the Molteno, but for practical purposes the boundary is taken at the base of the first green sandstone/siltstone overlying the mudstone. The Molteno beds represent a megacycle up to 204 m thick with coarse- to medium-grained sandstone at the base grading upwards into a thick mudstone.

The basal sandstone consists of a number of upward-fining, first-order fluviatile cycles with grit and small-pebble conglomerate at the base grading upwards into medium- to coarse-grained feldspathic sandstone. Both trough and planar cross-bedding is the dominant sedimentary structure. The lower part of the mudstone unit is grey in colour, micaceous and carbonaceous in composition, and contains thin coal seams associated with siltstone and minor sandstone. The upper part consists of reddish and grey mottled mudstone containing *Dicroidium* (Van den Berg 1980, p.55).

Red Beds (Solitude, Klopperfontein and Nakab Formations). The succession rests conformably on the Molteno and its upper contact is taken as the last reddish mudstone. The maximum thickness of the Red Beds is about 400 m and the succession consists of an alternation of red and grey mottled mudstone, siltstone, fine- to coarse-grained feldspathic sandstone, grit and small-pebble conglomerate. The lens-like sandstones are arranged in upward-fining fluviatile cycles, but there is a sharp decrease in the number of sandstone beds as well as in coarseness westwards. Conglomerate consisting of calcareous pebbles is observed at the base of some cycles. Sedimentary structures include trough cross-bedding, ripple cross-lamination and slumping.

Cave Sandstone (Clarens Sandstone Formation, Shurugwe Grits). The Shurgwe Grits in Zimbabwe are especially well developed where the Cave Sandstone overlaps the lower units onto the basement. The total thickness of the Cave Sandstone varies between 120 and 200 m. The lower contact is transitional except where coarse sediment is developed.

The Cave Sandstone consists predominantly of massive cream-coloured well-sorted medium-grained sandstone which locally contains large trough and planar cross-bedded sets up to 12 m high. The basal part is in general coarser grained, stratified and shows small-scale trough cross-bedding and ripple cross-lamination. Silicified nodules are present in the beds.

Drakensberg Volcanics (Letaba Formation). In the south the lava has a maximum thickness of about 1300 m, but this value increases northeastwards to about 8000 m in the Nuanetsi Syncline. The basal part is olivine-rich and consists of nephelinite, limburgite and picrite. The middle portion consists of amygdaloidal tholeiitic basalt while the upper part is built by rhyolitic lava and ignimbrite with thin basaltic flows (Haughton 1969).

Botswana Region

The Waterberg coalfield forms the eastern margin of the Botswana region which extends westwards into Botswana where sporadic outcrops of Karoo rocks occur (fig. 1). The latter continue through eastern Botswana into the Wankie Basin in Zimbabwe, but the description in this review is restricted to the southern occurrences. As outcrops are poor most of the data come from bore-holes sunk in the search for coal in the Ecca Group. The strata are affected by east-northeast-trending post-Karoo faulting, resulting in grabens and half-grabens. In the past it was accepted that the Stormberg Group in this region rests on the Beaufort beds. According to Haughton (1969, p. 350) this is a correlation without any palaeontological support, and he concludes that some of the sediments encountered in bore-holes may in fact belong to the Red Beds.

Molteno Sandstone. This unit, which is up to 50 m thick, rests unconformably on lower Karoo strata. It consists of reddish to white, cross-bedded, coarse-grained sandstone with intercalated purple or brown shale and mudstone. Scattered pebbles are present. Lithologically the sequence is very similar to that in the Springbok Flats region.

Red Beds. The sequence varies in thickness between 60 and 110 m and follows conformably on the Molteno Sandstone. It consists of alternating, massive, mottled reddish and green mudstone, siltstone and very fine-grained sandstone. Calcareous nodules are present.

Cave Sandstone. The sequence which is slightly over 100 m thick, follows in the east conformably on the Red Beds and consists predominantly of white, pink and reddish fine-grained sandstone. Towards the west in Botswana the sandstone is somewhat coarser grained and more feldspathic and overlaps the Red Beds to rest on basement rocks.

Drakensberg Volcanics. The succession consists of more than 100 m of amygdaloidal and non-amygdaloidal basaltic lava which directly overlies the Cave Sandstone over the larger part of the region. In the northern and western part of Botswana the lava overlaps the Stormberg sediments and rests on lower Karoo or pre-Karoo rocks

Zambesi Region

The upper Karoo strata in central and northern Zimbabwe are restricted to three areas of which the western two extend into Botswana (fig. 1). These isolated occurences are the result of post-Karoo faulting which exposed lower Karoo rocks in the intervening areas. The outcrops in the Hwangi (Wankie) area linked up with those in the Middle and Lower Zambesi Valley through Zambia. Although Tavener-Smith (1962, p. 44) refers to small separate basins, all evidence points to the presence of a large Karoo basin in north-central

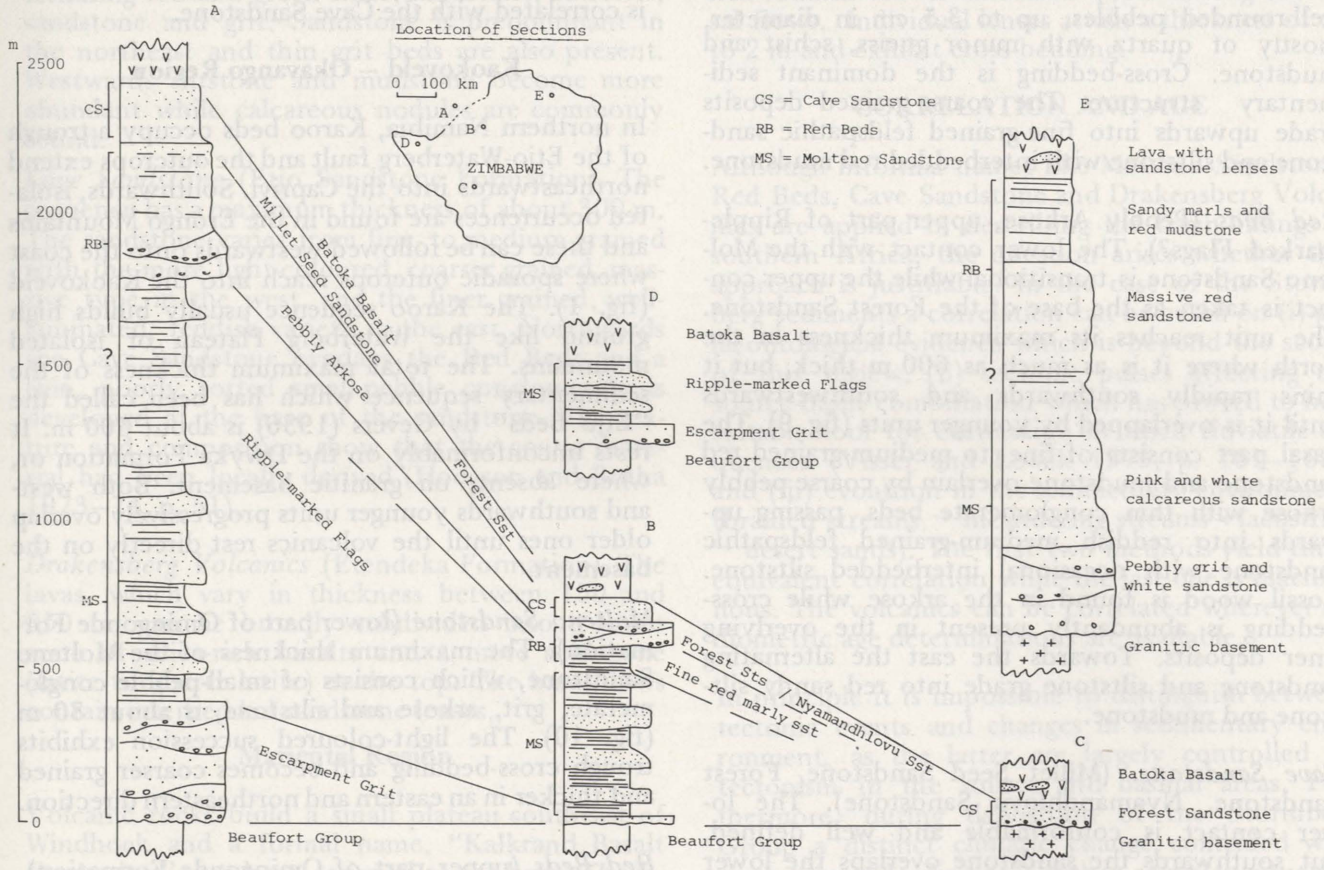

Fig. 9 Stratigraphic sequence of the Stormberg Group in the Zambesi region.

Zimbabwe, extending westwards into Botswana.

The Stormberg rocks are largely covered by superficial deposits and the only reasonably continuous exposures are along the courses of the larger rivers. The succession is affected in the north by northeast-trending faulting and warping which resulted in isolated outcrops, but in the south (north of Bulawayo) the succession is relatively undisturbed. In the northwest the Stormberg Group unconformably overlies the lower Karoo strata, but southwards and eastwards it rests on basement with younger units overlapping older ones. The sequence represents a typical clastic wedge, thinning considerably over a short distance from north to south (fig. 9) and having its maximum thickness of more than 3 000 m just north of the Zambesi River.

Molteno Sandstone (Escarpment Grit, Ripple-marked Flags). The correlation of the Ripple-marked Flags with the Molteno Sandstone is based on the occurrence of *Dicroidium* flora, but the possibility exists that the upper part of this unit could well be correlated with the Red Beds. The maximum thickness of the Molteno Sandstone, which has an uneven lower contact, is about 400, but it pinches out southwards. The sequence consists of multistoreyed, red, feldspathic, medium- to coarse-grained sandstone and grit bodies with locally developed pebble beds. Intercalations occur of green and reddish siltstone and in places mudstone. Pebble beds are up to 2 m thick and consist of well-rounded pebbles, up to 3,5 cm in diameter, mostly of quartz with minor gneiss, schist and mudstone. Cross-bedding is the dominant sedimentary structure. The coarse-grained deposits grade upwards into fine-grained feldspathic sandstone and siltstone with interbedded red mudstone.

Red Beds (Pebbly Arkose, upper part of Ripple-marked Flags?). The lower contact with the Molteno Sandstone is transitional while the upper contact is taken as the base of the Forest Sandstone. The unit reaches its maximum thickness in the north where it is as much as 600 m thick, but it thins rapidly southwards and southwestwards until it is overlapped by younger units (fig. 9). The basal part consists of fine- to medium-grained red sandstone and mudstone overlain by coarse pebbly arkose with thin conglomerate beds, passing upwards into reddish medium-grained feldspathic sandstone with occasional interbedded siltstone. Fossil wood is found in the arkose while cross-bedding is abundantly present in the overlying finer deposits. Towards the east the alternating sandstone and siltstone grade into red sandy siltstone and mudstone.

Cave Sandstone. (Millet Seed Sandstone, Forest Sandstone, Nyamandhlovu Sandstone). The lower contact is conformable and well defined, but southwards the sandstone overlaps the lower units onto granitic basement. Towards the east and west the Cave Sandstone is apparently absent and lava rests directly on either the Molteno Sandstone or Red Beds. The Cave Sandstone reaches a maximum thickness of about 200 m in the north, but this decreases to between 50 and 60 m in the south. Poorly stratified, bright red, well-sorted medium-grained sandstone consisting predominantly of quartz grains with minor feldspar is the major rock type. Cross-bedding is present. Where the sequence directly overlies basement the basal beds are conglomeratic in places and are better stratified.

Drakensberg Volcanics (Batoka Basalts). The lavas reach a thickness of more than 1500 m in the east and consist predominantly of basalt. Various flows can be recognised. Sandstone lenses occur amongst the basal flows, especially in the east.

Ngami Region

Very little is known about the upper Karoo outcrops in the northwest of Botswana. The outcrop belt probably extends south-westwards to the border of Namibia (fig. 1). The main outcrops are located south of Lake Ngami and the lithology is described by Wright (quoted in Boocock and Van Straten 1962, p. 148). A sequence of brick-red and white sandstone, probably of aeolian origin, occurs in a down-faulted trough. The sandstone rests unconformably on basement and is overlain by basaltic lava. Known locally as "Bodibeng Sandstone" it is correlated with the Cave Sandstone.

Kaokoveld – Okavango Region

In northern Namibia, Karoo beds occupy a trough of the Etjo-Waterberg fault and the outcrops extend northeastwards into the Caprivi. Southwards, isolated occurrences are found in the Erongo Mountains and these can be followed westwards onto the coast where sporadic outcrops reach into the Kaokoveld (fig. 1). The Karoo sequence usually builds high ground like the Waterberg Plateau or isolated mountains. The total maximum thickness of the sedimentary sequence which has been called the "Etjo Beds" by Gevers (1936) is about 600 m. It rests unconformably on the Dwyka Formation or, where absent, on granitic basement. Both west- and southwards younger units progressively overlap older ones until the volcanics rest directly on the basement.

Molteno Sandstone (lower part of Omingonde Formation). The maximum thickness of the Molteno Sandstone, which consists of small-pebble conglomerate, grit, arkose and siltstone, is about 80 m (fig. 10). The light-coloured succession exhibits trough cross-bedding and becomes coarser grained and thicker in an eastern and northeastern direction.

Red Beds (upper part of Omingonde Formation). Both the upper and lower contacts of the Red Bed

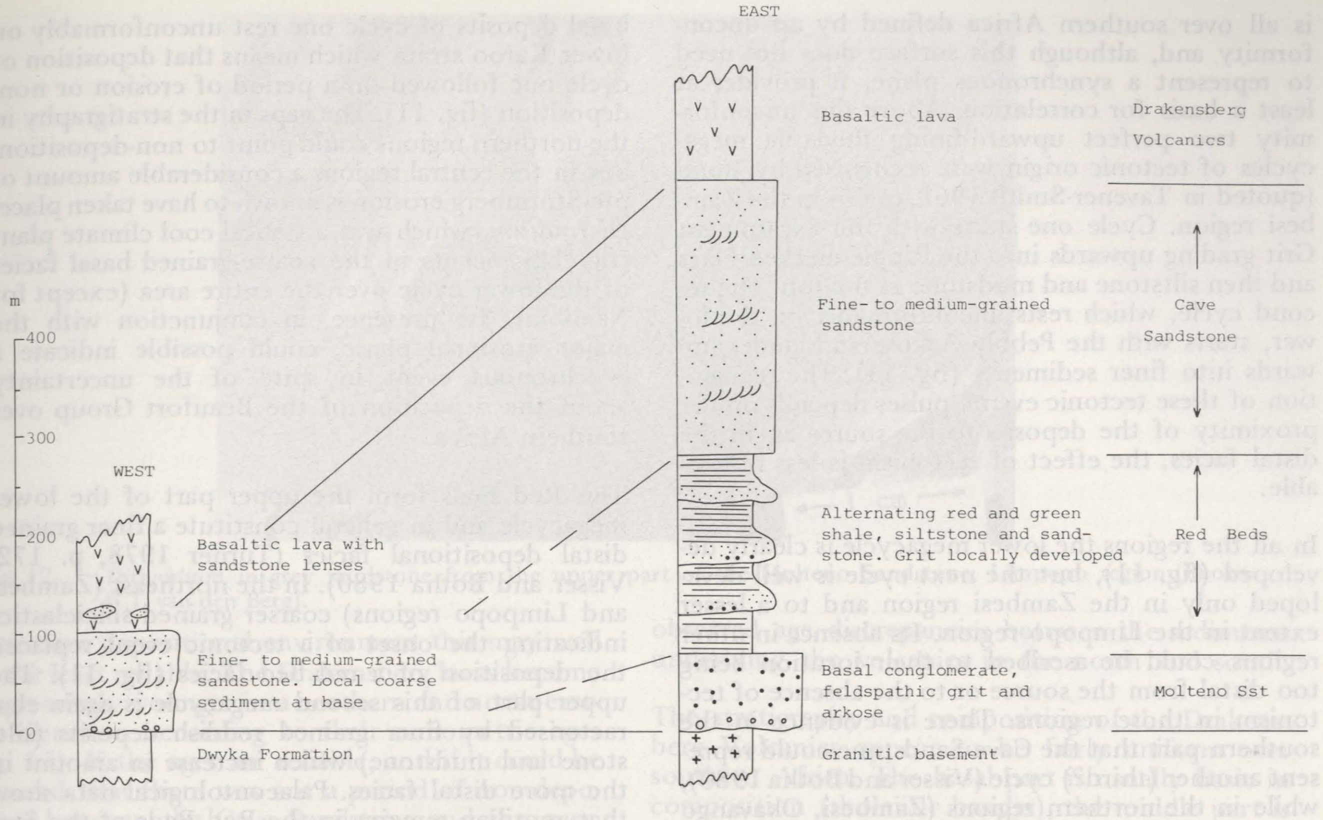

Fig. 10 Stratigraphic sequence of the Stormberg Group in the Kaokoveld-Okavango region.

sequence are transitional. The sequence has a maximum thickness of about 200 m and consists of alternating red and green shale, mudstone, siltstone, sandstone and grit. Sandstone is predominant in the northeast and thin grit beds are also present. Westwards siltstone and mudstone become more abundant while calcareous nodules are commonly found.

Cave Sandstone (Etjo Sandstone Formation). The sequence has a maximum thickness of about 300 m. The sandstone varies from fine- to medium-grained with the more light-coloured, coarser grained, massive type in the west, and the finer grained, well-laminated, reddish variety in the east. Northwards the Cave Sandstone overlaps the Red Beds and a thin, poorly sorted small-pebble conglomerate is developed at the base of the sandstone. The texture and composition show that the coarse material had been locally derived (Hodgson and Botha 1973–74, p. 51).

Drakensberg Volcanics (Etendeka Formation). The lavas, which vary in thickness between 150 and 850 m, can be broadly subdivided into a lower zone of silica-rich basalts and a more acid zone (latite to quartz latite) at the top. The basal flows contain interbedded sandstone lenses.

Mariental Region

Volcanic rocks build a small plateau southeast of Windhoek and a formal name, "Kalkrand Basalt Formation", has been assigned to the beds. The lavas follow unconformably on a thick succession of Dwyka sediments and consist of more than 360 m of amygdaloidal basalt in which lenses of fine-grained reddish brown sandstone occur among the basal flows. Individual lenses attain a thickness of up to 2 m and exhibit cross-bedding.

CORRELATION AND AGE

Although informal names like Molteno Sandstone, Red Beds, Cave Sandstone and Drakensberg Volcanics are applied in describing the basin fillings in southern Africa, the question arises whether this approach is justifiable. In the case of the Stormberg sediments a correlation can be based on (i) palaeontological evidence which is beyond the scope of this review, (ii) tectonic pulses affecting the source-basin combination which has proved to be a suitable tool for correlation in thick fluviatile sequences (Visser and Loock 1979, p. 161–162), and (iii) evolution in the sedimentary environment (braided streams → meandering streams +lacustrine → desert sands). The first two methods yield time-equivalent correlation while the last one is diachronous. The volcanics can be correlated wherever radiometric age determinations are available.

In principle it is impossible to distinguish between tectonic events and changes in sedimentary environment, as the latter are largely controlled by tectonism in the source and basinal areas. Furthermore, during deposition of the Stormberg Group a distinct climatic change coincided with these events leading to a rather complex situation for correlation. However, the base of the sequence is all over southern Africa defined by an unconformity and, although this surface does not need to represent a synchronous plane, it provides at least a basis for correlation. Above this unconformity two perfect upward-fining fluviatile megacycles of tectonic origin were recognised by Bond (quoted in Tavener-Smith 1962, p. 65) in the Zambesi region. Cycle one starts with the Escarpment Grit grading upwards into the Ripple-marked Flags and then siltstone and mudstone at the top. The second cycle, which rests unconformably on the lower, starts with the Pebbly Arkose and grades upwards into finer sediments (fig. 11). The recognition of these tectonic events/pulses depends on the proximity of the deposits to the source as, in the distal facies, the effect of tectonism is less noticeable.

In all the regions the lower megacycle is clearly developed (fig. 11), but the next cycle is well developed only in the Zambesi region and to a lesser extent in the Limpopo region. Its absence in other regions could be ascribed to their location being too distal from the source or to the absence of tectonism in those regions. There is evidence in the southern part that the Cave Sandstone could represent another (third?) cycle (Visser and Botha 1980), while in the northern regions (Zambesi, Okavango and Botswana) the Cave Sandstone undoubtedly represents the start of such a cycle. Thus as regards the Stormberg Group three cyclic events can be recognised in the north and at least two in the west and south. This can be used as a basis for a tentative correlation (fig. 11). The question arises whether the megacycles were synchronous, but to answer this palaeontological and sedimentological evidence have to be considered. The coarse-grained basal deposits of cycle one rest unconformably on lower Karoo strata which means that deposition of cycle one followed on a period of erosion or non-deposition (fig. 11). The gaps in the stratigraphy in the northern regions could point to non-deposition, but in the central regions a considerable amount of pre-Stormberg erosion is known to have taken place. *Dicroidium*, which was a typical cool climate plant (fig. 12), occurs in the coarse-grained basal facies of the lower cycle over the entire area (except for Namibia). Its presence, in conjunction with the major erosional phase, could possible indicate a synchronous event in spite of the uncertainty about the deposition of the Beaufort Group over southern Africa.

The Red Beds form the upper part of the lower megacycle and in general constitute a finer grained distal depositional facies (Turner 1978, p. 172; Visser and Botha 1980). In the northeast (Zambesi and Limpopo regions) coarser grained siliciclastics indicating the onset of a tectonic event replaced the deposition of a red bed facies (fig. 11). The upper part of this second megacycle is again characterised by finer grained reddish deposits (siltstone and mudstone) which increase in amount in the more distal facies. Palaeontological data show that reptilian remains in the Red Beds of the Stormberg region correlate with species in the Forest Sandstone of the Zambesi region. This implies that the second tectonic event in the north was probably of local extent and that north-south lithological correlation of the upper sedimentary units could be diachronous.

Although the correlation of the Cave Sandstone seems obvious on the grounds of a common and

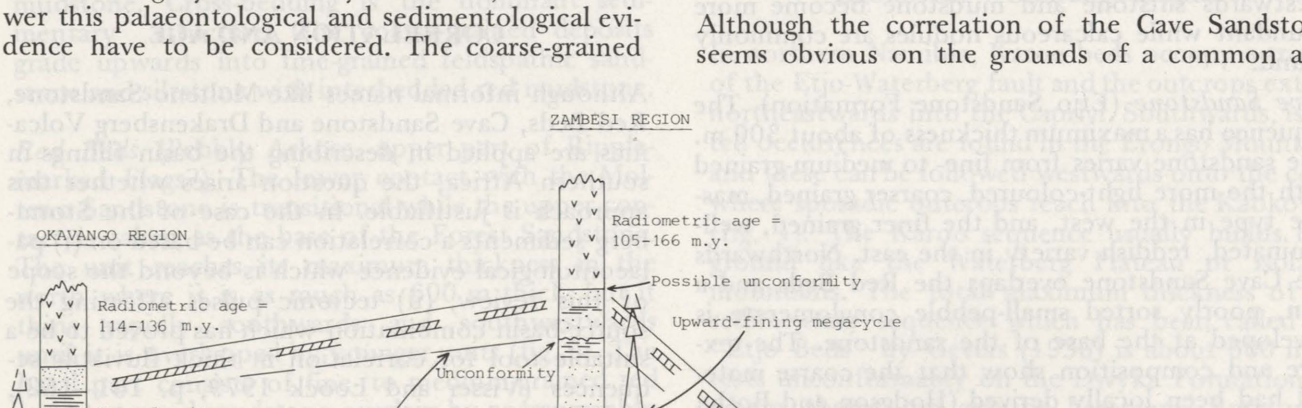

Fig. 11 Correlation of the Stormberg Group and Drakensberg Volcanics in southern Africa.

Fig. 12 *Dicroidium* in grey mudstone from the upper part of the Molteno Sandstone, Limpopo region (Photo: H.J. van den Berg).

distinctive depositional environment this may well be the least reliable. The Drakensberg lavas become progressively younger in a northern and north-eastern direction according to their radiometric ages (fig. 11). If the ages are reliable, and if it could be assumed that there was not a period of non-deposition between the Cave Sandstone and the overlying lava, this implies that the Cave Sandstone in Namibia must be Cretaceous to Jurassic in age and that the aeolian sandstones become older in a southerly direction. This is contradictory to the palaeontological as well as the sedimentological evidence. Beukes (1969, p. 124) postulated on purely sedimentological grounds that the Cave Sandstone should be older in the north, and if the pole wandering path (Frakes and Crowell 1970, p. 103) is assumed correct, the climatic zones would have shifted from northwest to southeast over this part of Gondwana. One way to explain this contradictory evidence is to postulate a time lapse between the closing stages of Cave Sandstone deposition and the volcanism in certain regions despite the apparently conformable stratigraphic relationships. Reference to an unconformity at the base of the lavas was made by Beukes (1969) for the Stormberg region and by Bond (1967) for the Zambesi region. It is known that near Maclear in the Stormberg region the Cave Sandstone is missing and that lava directly overlies the Red Beds Palaeontological evidence from the sandstone lenses among the basal lava flows in the Zambesi region suggests a Jurassic age for the deposits (pers. comm. Dr. J.W. A. van Heerden, formerly of the National Museum, Bloemfontein). The presumed equivalents of the Cave Sandstone in the north show characteristics (basal conglomerate, petrified wood) unlike those of the sequence in the type locality in the south. This could imply dissimilar desert conditions over southern Africa at the end of the Triassic. If this conclusion proves to be valid a time correlation of so-called "aeolian" deposits will be untenable. A diachronous relationship would also explain the observed age discrepancies between the sediments underlying the volcanics in the north and south.

The stratigraphy and composition of the Drakensberg Volcanics appear to be fairly uniform over southern Africa. The basal part is usually basic in composition (tholeiitic basalts), the middle part is acidic (rhyolitic) and the upper part is again basic (flood basalts) with lenses of rhyolitic lava. Fitch and Miller (1971, p. 64–84) use age determinations to correlate the lavas of the Lebombo and Stormberg regions. Considering the known wide areal distribution and the observed differences in ages, it is reasonable to accept that various eruption centres were active at different times.

There appears to be sufficient evidence for a major sedimentary cycle starting during the Late Triassic (Carnian) related to a climatic change and considerable uplift in the source areas. This resulted in the deposition of the Molteno Sandstone which is correlateable over southern Africa. However, deposition which followed this major event was probably diachronous over the entire area. Correlation of the upper sedimentary units of the Stormberg Group is thus necessarily speculative. The termination of sedimentation by volcanism probably started earlier in the south and east than in the north and west.

DEPOSITIONAL HISTORY

Fluvial Sedimentation

Sedimentation of the Stormberg Group is related to different basins in which sediments accumulated during the Late Triassic. Considering lithological assemblages, facies changes and transport directions, four possible basins are defined (fig. 13) and it will be shown in the last section how these link up with one another. In discussing basin fill the fluviatile sediments are separated from the "aeolian" deposits as the distribution of the former is strictly controlled by palaeoslope, the latter less so.

Fig. 13 Main sedimentary basins for the Molteno Sandstone and Red Beds during the Upper Triassic in southern Africa.

Stormberg Basin. An isopach map of the Stormberg Basin (fig. 14) shows a northeast-southwest trending basin with a well-defined hinge line which coincides with the rapid thickening of the sequence in the south. In the northeast the Harrismith High had an effect on basin development so that the lower units pinch out again the high. The lithic fill, which ranges in texture from conglomerate to mudstone including organic material, represents an upward fining, sourceward-coarsening clastic wedge.

In the Molteno six depositional cycles, tectonic in origin, were recognised by Rust (1962) and Turner (1975). Rust (1962, p. 218) described them as cyclothems starting with coarse material and ending with coal deposits at the top. The coarse material was deposited by braided streams (proximal facies during deposition of the Indwe Sandstone), while the finer grained sediments were laid down by meandering streams. The coals were deposited in swamps on flood plains where the plants grew *in situ* (Rust 1962, p. 178). The climate was temperate to cool with high rainfall and seasonal variation. The change from braided to meandering streams could be related to a decrease in palaeoslope. Towards the top of the Molteno streams tend to be ephemeral, which is indicative of a drier climate.

The overlying Red Beds consist of floodplain deposits in the lower part and predominantly flood-basin deposits in the middle and upper parts (fig. 15). The change in river morphology from the Molteno to the Red Beds could be ascribed to a drier climate as well as denudation of the source areas. Under the more arid climatic conditions preservation of organic material becomes unfavourable and largely reddish silts and muds were deposited during oxidising conditions. The transition zone at the top of the Red Beds is interpreted by Visser and Botha (1980) as a mixed flood fan and dune facies. In the semi-desert sediment was brought in by wadi's and was deposited by floods as sheet sands or sometimes in playas. Reworking of this sediment by wind resulted in the association of fluvial and aeolian deposits.

Palaeocurrent and facies data indicate source areas in the south, southeast and east (fig. 16). This led to north-south facies changes which imply that the Red Beds in the north are the time equivalent of the Molteno Sandstone in the south (fig. 15). According to Turner (1975) the depocentre also migrated steadily eastwards, indicating that the southern source areas were more effective in the beginning, but were later replaced by source areas in the east. Rust (1962 , p. 214; 1975, p. 551) speculates that the source areas were at a distance of 300 to 400 km from the basin, while calculations based on pebble sizes in the Molteno led Turner (1975) to locate the source areas approximately 200 km off the present southern coast of South Africa. Visser (1978, p. 89) has shown that the composition of the source rocks for both the Molteno and the Red Beds largely remained the same during deposition and that the mountain chains underwent uplift for a considerable period. Pebble lithology varies with location and it is apparently the southern highlands only that yielded low-grade metamorphic rocks (mainly quartzite) to the basin (Rust 1962; Turner 1975). The southeastern source yielded mostly granitic and high-grade metamorphic material and judging from the overall mineralogical composition of the Molteno Sandstone and the Red Beds the source area was composed primarily of granitic to gneissic rocks.

Limpopo-Botswana Basin. The Springbok Flats region is considered part of this basin while the northward extension of the basin and its possible connection with the Zambesi Basin is uncertain (fig. 13). The precise basin geometry is also unknown, but both the Molteno and the Red Beds thicken towards the east and northeast, which implies that the basin extended in that direction. Furthermore, east-west syndepositional faulting also

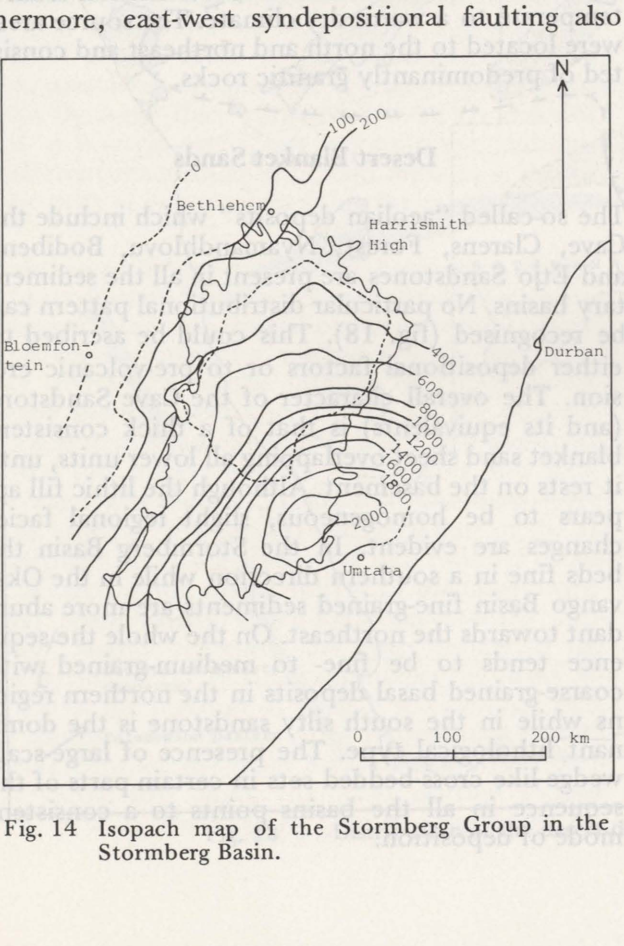

Fig. 14 Isopach map of the Stormberg Group in the Stormberg Basin.

controlled sedimentation and basin development to a large extent.

The Molteno-Red Beds sequence represents a megacycle with the coarsest material at the base and finer sediments towards the top (fig. 17). The Molteno Sandstone rests on an eroded surface with the thickest and coarsest deposits restricted to the valleys. The coarse sediments were laid down by braided streams but these changed in time to meandering ones with extensive flood plains on which the argillaceous upper part of the Molteno was deposited together with organic material (Van den Berg 1980). This change in river morphology could be related to a decrease in palaeoslope and denudation of the source area. The climate was cool temperate, but it warmed considerably during deposition of the upper sediments. The Red Beds represent point-bar, levee, crevasse-splay and mud plain deposits originating in a meandering stream environment. Floodplain sedimentation was interrupted by an influx of coarse-grained sediment deposited in possibly straight channels during temporary uplift of the source area (fig. 17). Deposition of the red bed facies occurred during a dry seasonal climate as indicated by scarcity of organic remains and presence of calcareous nodules.

A granitic source in the east and southeast supplied most of the sediments of the Molteno and Red Beds. However, syndepositional faulting in the basin resulted in the uplift of the underlying Soutpansberg Supergroup which also supplied clastic material to the depository during the closing stages of sedimentation (Van den Berg 1980, p. 110–112).

Zambesi Basin. Rust (1975, p. 553) is of opinion that sedimentation occurred in an elongated yoked basin and the presence of a source-ward thickening clastic wedge (fig. 9) supports this view. Very little is known about tectonics in the basin except for post-Karoo faulting. A feature of the lithic fill is the presence of two megacycles in which each represents a tectonic event with several first- and second-order fluviatile cycles superimposed on them.

The coarse-grained Escarpment Grit (= Molteno Sandstone) was deposited by braided streams which probably changed to meandering streams southwards as the palaeoslope decreased basinwards. As deposition proceeded the entire character of the fluvial system changed to meandering with extensive flood plains on which the upper part of the Molteno (Ripple-marked Flags) was deposited. The climate was probably temperate. The Pebbly Arkose (= Red Beds) represents a period of tectonic uplift in the source areas, an increase in palaeoslope, and a reversion to braided stream deposition. This event was, however, short-lived and the effects were largely restricted to the entry points into the basin. The braided streams were soon replaced by meandering ones and the deposition of flood-plain sedime-

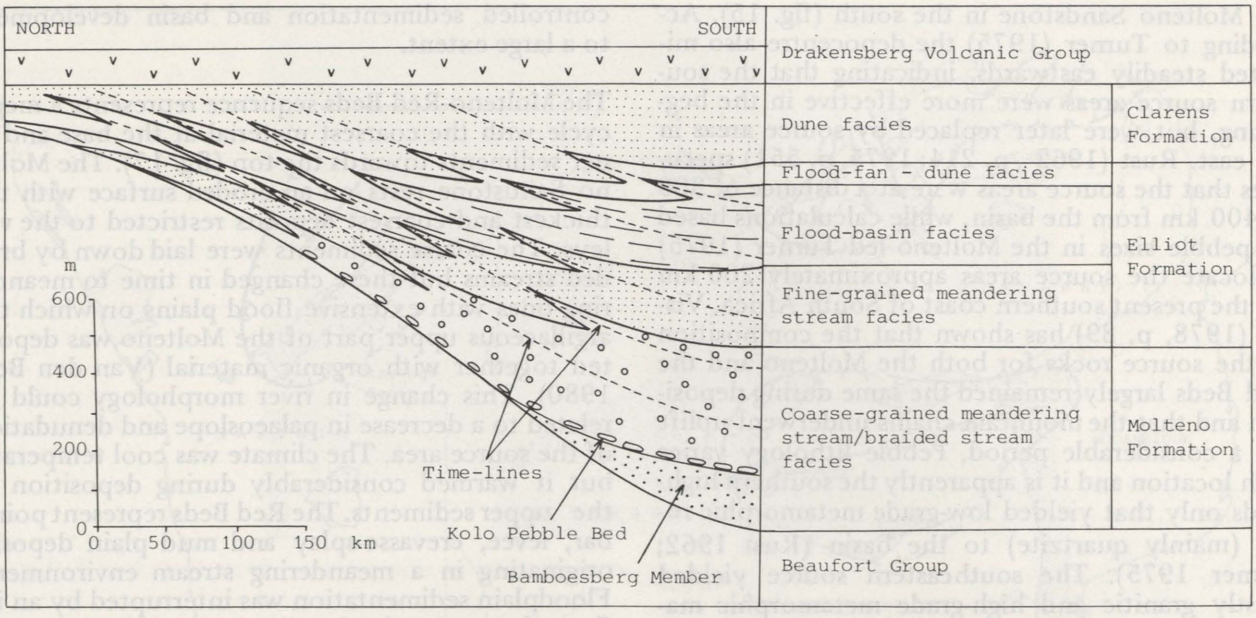

Fig. 15 Generalised north-south section across the Stormberg Basin (after Visser and Botha 1980).

nts continued. As the climate became progressively drier, less material reached the distal environments and a stage of almost non-deposition developed. Towards the close of sedimentation extremely dry seasonal conditions occurred as indicated by the calcareous character of some of the sandstones.

The source area of the sediments was located to the north and northwest (fig. 13) and consisted of metamorphic and granitic rocks. Tavener-Smith (1962, p. 44) described it as the Lusaka-Kalomo Upland, while heavy-mineral studies show that the Lomagundi Highlands could also have yielded material (Bond, 1967, p. 188).

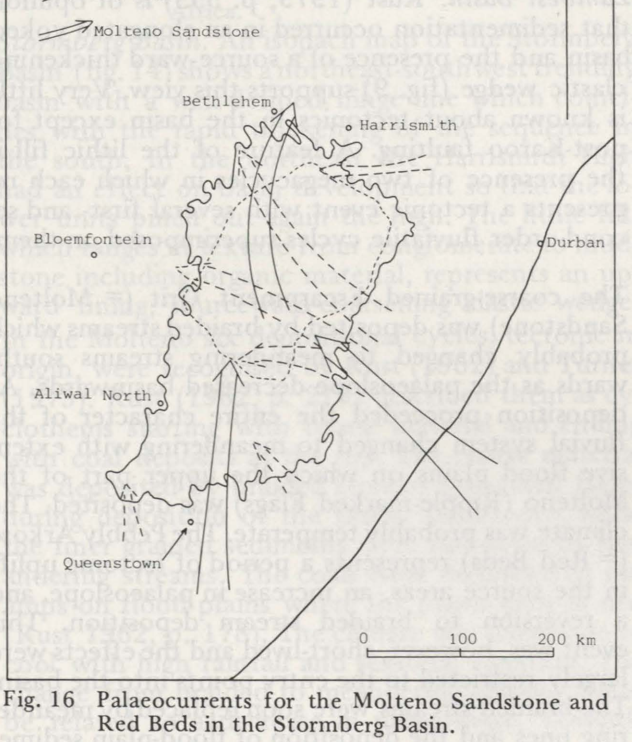

Fig. 16 Palaeocurrents for the Molteno Sandstone and Red Beds in the Stormberg Basin.

Okavango Basin. As this basin is largely covered by superficial deposits, most deductions are speculative. Generally, the sediments form an upward-fining southwestward-thinning clastic wedge, indicating that the major part of the basin was probably located in the northeast (fig. 13). The basal Molteno Sandstone was possibly deposited by braided streams. As sedimentation proceeded a decrease in palaeoslope led to a change in river morphology to largely meandering streams depositing point-bar and floodplain sediments. A colour change in the sediments could be indicative of transition from a temperate to a warm dry climate. The source areas were located to the north and northeast and consisted of predominantly granitic rocks.

Desert Blanket Sands

The so-called "aeolian deposits" which include the Cave, Clarens, Forest, Nyamandhlovu, Bodibeng and Etjo Sandstones are present in all the sedimentary basins. No particular distributional pattern can be recognised (fig. 18). This could be ascribed to either depositional factors or to pre-volcanic erosion. The overall character of the Cave Sandstone (and its equivalents) is that of a thick consistent blanket sand sheet overlapping all lower units, until it rests on the basement. Although the lithic fill appears to be homogeneous, slight regional facies changes are evident. In the Stormberg Basin the beds fine in a southern direction while in the Okavango Basin fine-grained sediments are more abundant towards the northeast. On the whole the sequence tends to be fine- to medium-grained with coarse-grained basal deposits in the northern regions while in the south silty sandstone is the dominant lithological type. The presence of large-scale wedge-like cross-bedded sets in certain parts of the sequence in all the basins points to a consistent mode of deposition.

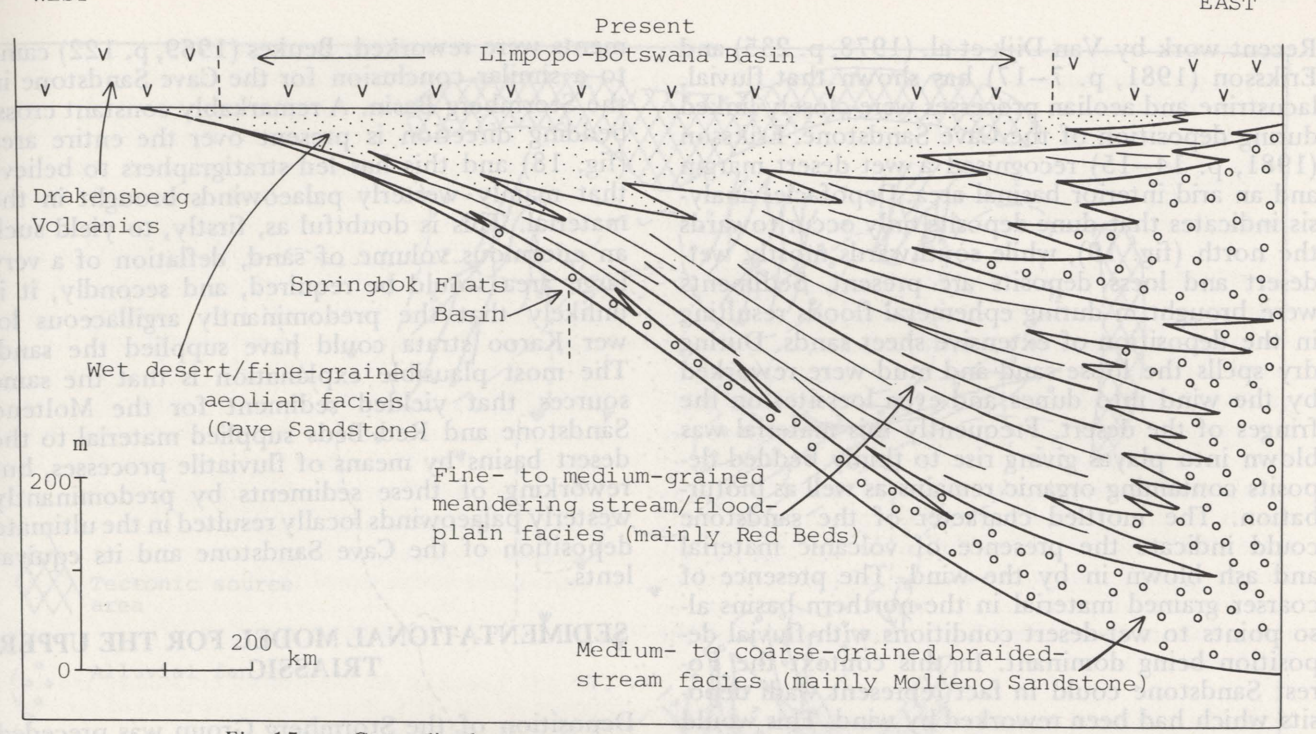

Fig. 17 Generalised east-west section across the Limpopo-Botswana Basin.

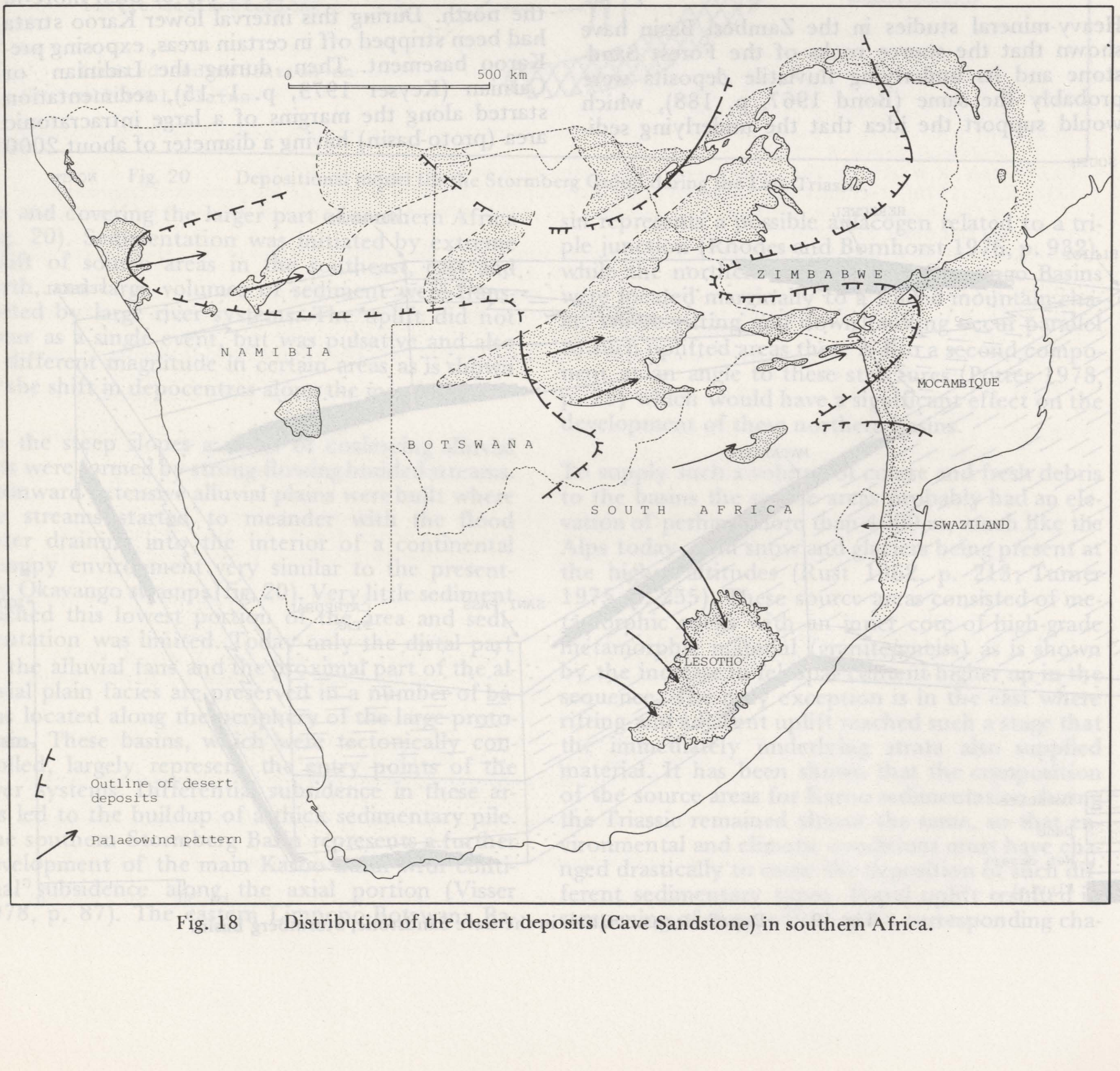

Fig. 18 Distribution of the desert deposits (Cave Sandstone) in southern Africa.

Recent work by Van Dijk et al. (1978, p. 235) and Eriksson (1981, p. 7–17) has shown that fluvial, lacustrine and aeolian processes were closely linked during deposition of the Cave Sandstone. Eriksson (1981, p. 14–15) recognised a wet desert margin and an arid interior basinal area. Depofacies analysis indicates that dune deposits only occur towards the north (fig. 19), while southwards mostly wet-desert and loess deposits are present. Sediments were brought in during ephemeral floods resulting in the deposition of extensive sheet sands. During dry spells the loose sand and mud were reworked by the wind into dunes and even loessites on the fringes of the desert. Frequently this material was blown into playas giving rise to thinly bedded deposits containing organic remains as well as bioturbation. The mottled character of the sandstone could indicate the presence of volcanic material and ash blown in by the wind. The presence of coarser grained material in the northern basins also points to wet-desert conditions with fluvial deposition being dominant. In this context the Forest Sandstone could in fact represent wadi deposits which had been reworked by wind. This would explain the more mature character of the sandstone.

Heavy-mineral studies in the Zambesi Basin have shown that the source rocks of the Forest Sandstone and its underlying fluviatile deposits were probably the same (Bond 1967, p. 188), which would support the idea that the underlying sediments were reworked. Beukes (1969, p. 122) came to a similar conclusion for the Cave Sandstone in the Stormberg Basin. A remarkably constant cross-bedding direction is present over the entire area (fig. 18) and this has led stratigraphers to believe that mainly westerly palaeowinds brought in the material. This is doubtful as, firstly, to yield such an enormous volume of sand, deflation of a very large area would be required, and secondly, it is unlikely that the predominantly argillaceous lower Karoo strata could have supplied the sand. The most plausible explanation is that the same sources that yielded sediment for the Molteno Sandstone and Red Beds supplied material to the desert basins by means of fluviatile processes, but reworking of these sediments by predominantly westerly palaeowinds locally resulted in the ultimate deposition of the Cave Sandstone and its equivalents.

SEDIMENTATIONAL MODEL FOR THE UPPER TRIASSIC

Deposition of the Stormberg Group was preceded by an erosional period of limited extent in the south but in the order of about 50 My or even more in the north. During this interval lower Karoo strata had been stripped off in certain areas, exposing pre-Karoo basement. Then, during the Ladinian or Carnian (Keyser 1973, p. 1–15), sedimentation started along the margins of a large intracratonic area (proto-basin) having a diameter of about 2000

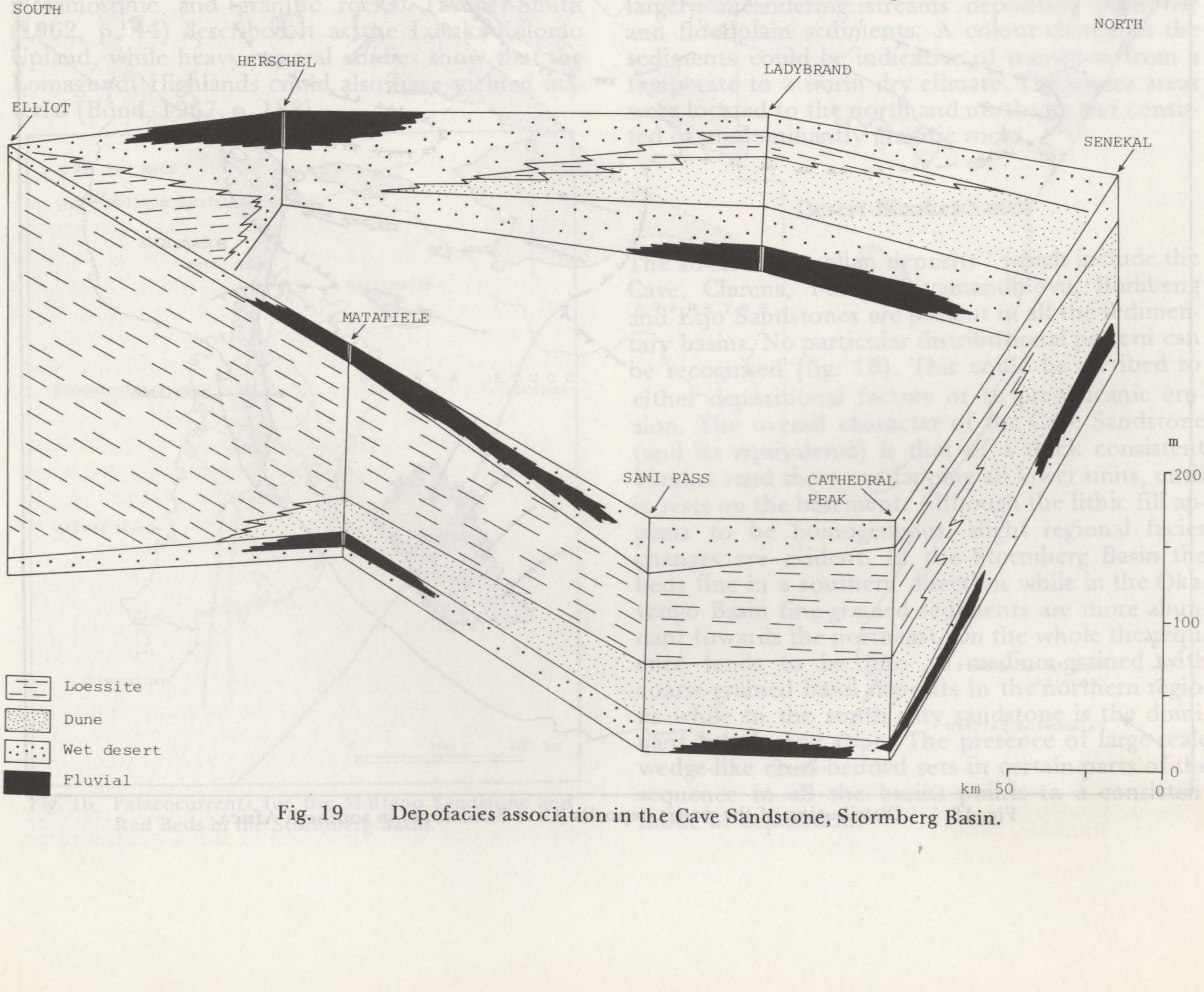

Fig. 19 Depofacies association in the Cave Sandstone, Stormberg Basin.

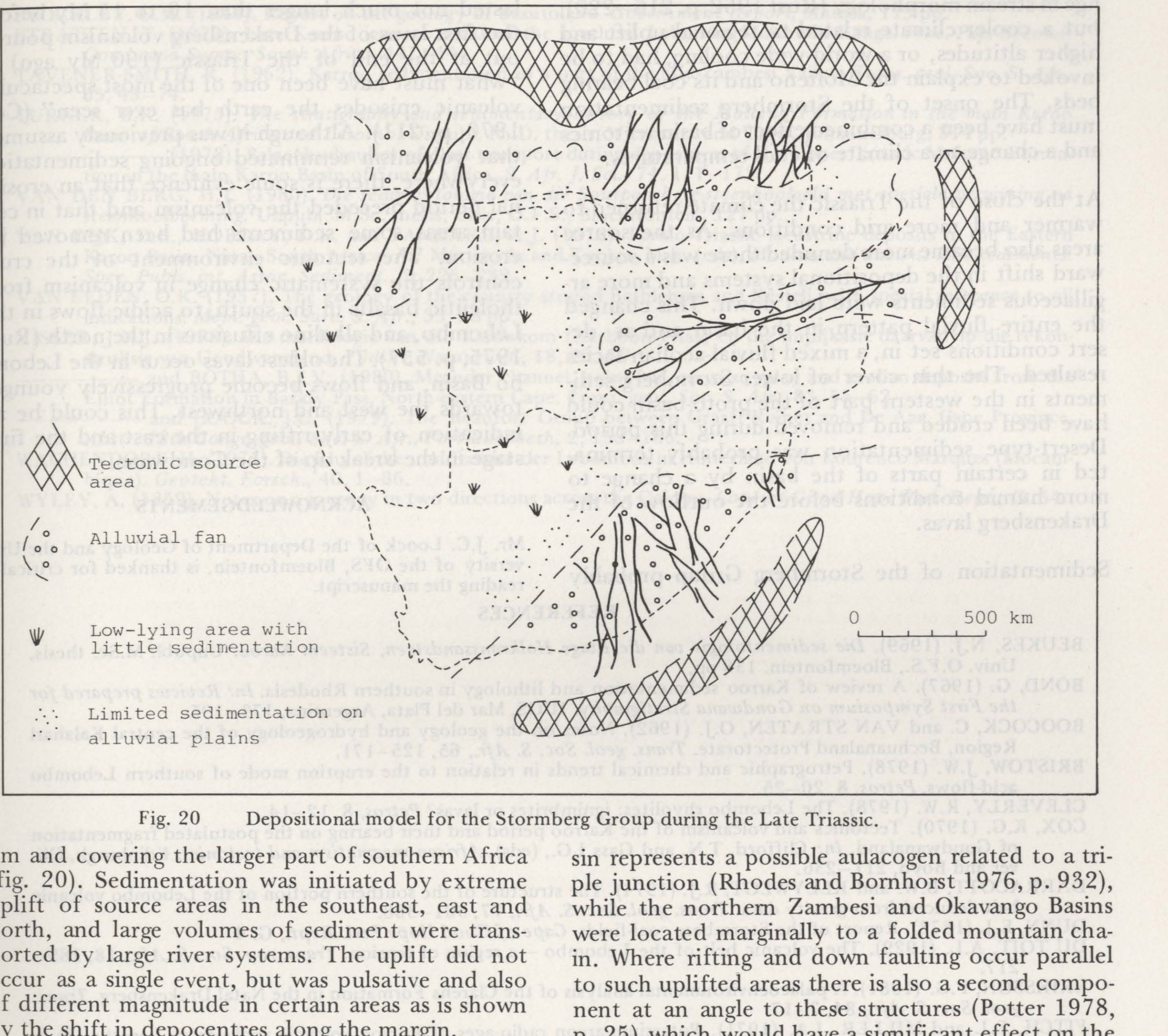

Fig. 20 Depositional model for the Stormberg Group during the Late Triassic.

km and covering the larger part of southern Africa (fig. 20). Sedimentation was initiated by extreme uplift of source areas in the southeast, east and north, and large volumes of sediment were transported by large river systems. The uplift did not occur as a single event, but was pulsative and also of different magnitude in certain areas as is shown by the shift in depocentres along the margin.

On the steep slopes a series of coalescing alluvial fans were formed by strong-flowing braided streams. Basinward extensive alluvial plains were built where the streams started to meander with the flood water draining into the interior of a continental swampy environment very similar to the present-day Okavango swamps (fig. 20). Very little sediment reached this lowest portion of the area and sedimentation was limited. Today only the distal part of the alluvial fans and the proximal part of the alluvial plain facies are preserved in a number of basins located along the periphery of the large proto-basin. These basins, which were tectonically controlled, largely represent the entry points of the river systems. Differential subsidence in these areas led to the buildup of a thick sedimentary pile. The southern Stormberg Basin represents a further development of the main Karoo Basin with continual subsidence along the axial portion (Visser 1978, p. 87). The eastern Limpopo-Botswana Basin represents a possible aulacogen related to a triple junction (Rhodes and Bornhorst 1976, p. 932), while the northern Zambesi and Okavango Basins were located marginally to a folded mountain chain. Where rifting and down faulting occur parallel to such uplifted areas there is also a second component at an angle to these structures (Potter 1978, p. 25) which would have a significant effect on the development of these northern basins.

To supply such a volume of coarse and fresh debris to the basins the source areas probably had an elevation of perhaps more than 4000 m, much like the Alps today, with snow and glaciers being present at the higher altitudes (Rust 1962, p. 213; Turner 1975, p. 255). These source areas consisted of metamorphic rocks with an inner core of high-grade metamorphic material (granite/gneiss) as is shown by the increase in feldspar content higher up in the sequence. The only exception is in the east where rifting and adjacent uplift reached such a stage that the immediately underlying strata also supplied material. It has been shown that the composition of the source areas for Karoo sedimentation during the Triassic remained almost the same, so that environmental and climatic conditions must have changed drastically to cause the deposition of such different sedimentary types. Rapid uplift resulted in steepening of the gradient and a corresponding change in stream morphology (Rust 1962, p. 216–220), but a cooler climate related to regional uplift and higher altitudes, or a world-wide cooling, had to be invoked to explain the Molteno and its coal-bearing beds. The onset of the Stormberg sedimentation must have been a combined effect of basin tectonics and a change to a climate of cool temperatures.

At the close of the Triassic the climate returned to warmer and more arid conditions. As the source areas also became more denuded there was a sourceward shift in the depositional systems and more argillaceous sediments were laid down. This changed the entire fluvial pattern in the basin and as desert conditions set in, a mixed fluvial-aeolian facies resulted. The thin cover of lower Stormberg sediments in the western part of the proto-basin could have been eroded and removed during this period. Desert-type sedimentation was probably terminated in certain parts of the basin by a change to more humid conditions before the outflow of the Drakensberg lavas.

Sedimentation of the Stormberg Group probably lasted not much longer than 10 to 15 My before the first lavas of the Drakensberg volcanism poured out at the end of the Triassic (190 My ago) in "what must have been one of the most spectacular volcanic episodes the earth has ever seen" (Cox 1970, p. 211). Although it was previously assumed that volcanism terminated ongoing sedimentation everywhere, there is some evidence that an erosional period preceded the volcanism and that in certain areas some sediments had been removed by erosion. The tectonic environment of the crust controls the systematic change in volcanism from tholeiitic basalts in the south, to acidic flows in the Lebombo, and alkaline effusions in the north (Rust 1975, p. 557). The oldest lavas occur in the Lebombo Basin, and flows become progressively younger towards the west and northwest. This could be an indication of early rifting in the east and the first stage in the break up of the Gondwana.

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