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Depositional environments and stratigraphic correlation of the Karoo Sequence in northwestern Damaraland

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The continental sediments of the Karoo Sequence in the Huab Basin, northwestern Damaraland, Namibia, are interpreted as marginal equivalents of a more than 2000 m thick succession of Gondwana beds that have been accumulated in the Parana Basin of South America. The sediments, which attain a maximum thickness of 250 m, reflect a change from cold and nival to warm and arid climates. In the Huab Basin, the succession begins with tillites and periglacial diamictites and rhythmites (depositional units 1 and 2). These are covered by fluvial sandstones and coal deposited in a cold tundra-like environment (depositional unit 3). The succeeding fluvial sandstones and calcareous soils (depositional unit 4) cover a wide area and indicate a moderate, dry climate. The following, probably lacustrine, succession includes sediments with autochthonous carbonates (stromatolites, oolites), a widespread *Mesosaurus* bone bed and various marginal environments indicating warm climatic conditions (depositional units 5 and 6). The aqueous sequence is terminated by red beds of the Gai-as Formation (depositional unit 7). After a phase of erosion and non-deposition, continental sedimentation revived with fluvial deposits (depositional unit 8) and terminated with aeolian sandstones in a desert environment (Etjo Sandstone Formation, depositional unit 9). While the Huab sediments are broadly correlated with those of the Parana and Karoo basins, age determinations from fossils suggest that units 1 and 2 are Permo-Carboniferous and that units 3 to 7 are Permian. The exact age of the Mesozoic units 8 and 9 is uncertain

Introduction

Sedimentary deposits of the Karoo Sequence in northwestern Damaraland are exposed in the Goboboseb Mountains south of the Ugab River, as well as in an area approximately 100 by 50 km wide on both the northern and southern sides of the Huab River (Fig. 1). This latter area, referred to as the Huab Basin in the following discussion, has been investigated since 1987 with the aim of establishing the stratigraphic sequence and depositional conditions.

The basement to the Karoo Sequence is schist and granite of the Upper Proterozoic to Cambrian Damara Sequence. A hilly to mountainous topography was incised into the basement rocks during the Permo-Carboniferous glaciation (Martin, 1981) and it controlled, together with the subsidence of the Paraná Basin, the deposition of the Karoo Sequence up to the Gai-as Formation (unit 7). The top of the Karoo Sequence is made up of more than 500 m of Mesozoic mafic-to-acid lavas of the Etendeka Formation which partly interfinger with the uppermost sediments.

In this study the Karoo Sequence has been subdivided into nine depositional units which are described and interpreted in respect of their sedimentary facies. A schematic east-west cross-section through the Huab

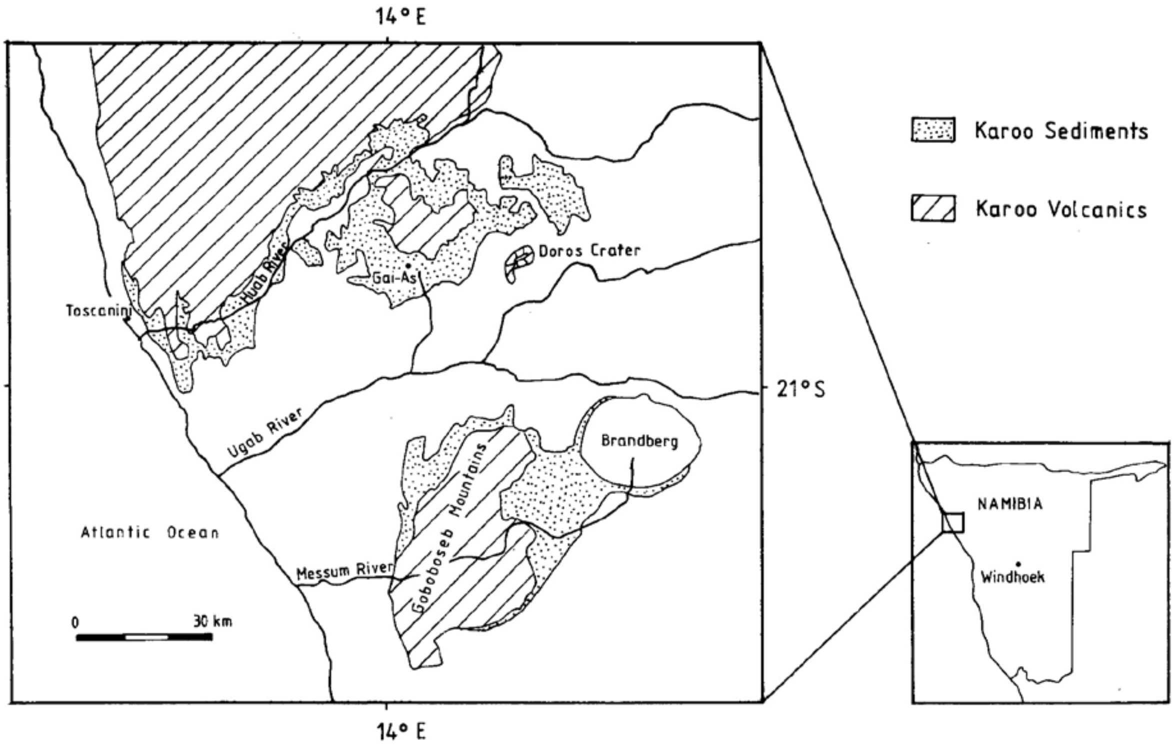
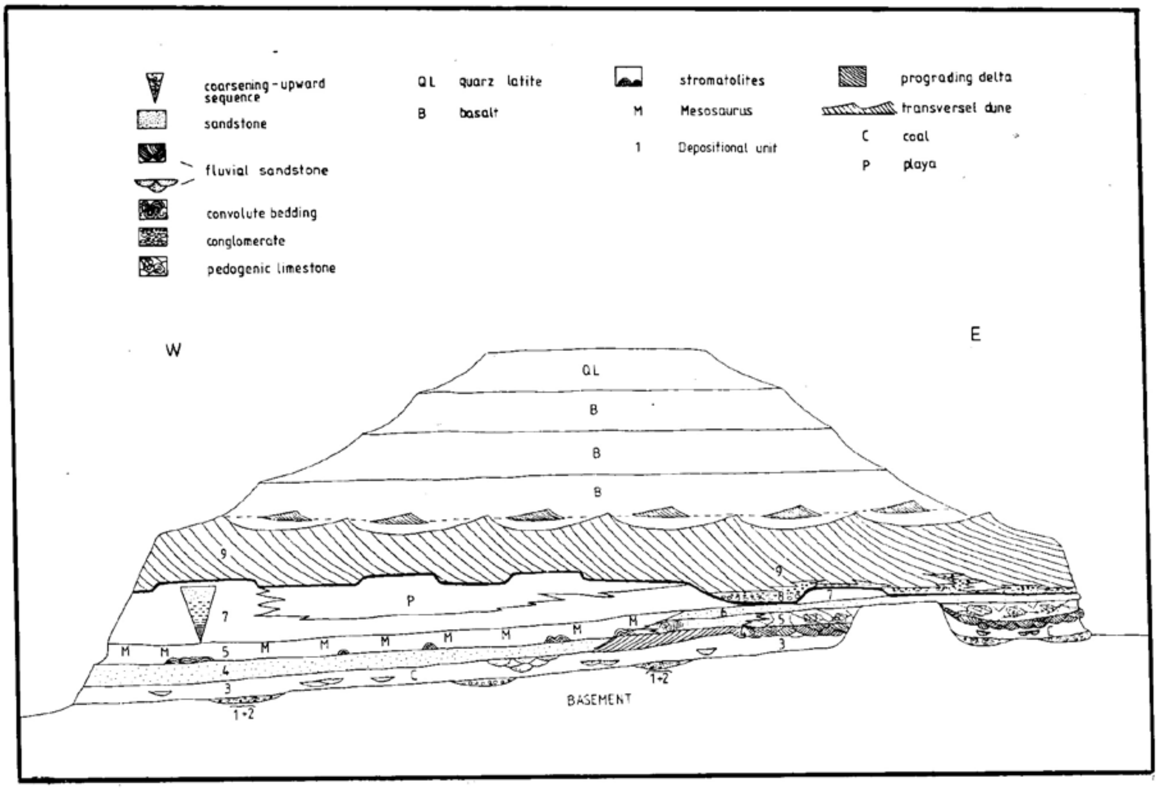


Fig. 1: Simplified geological map of the Huab area and Goboboseb Mountains.



Fig, 2: Schematic east-west cross section through the Huab Basin; idealized sequence with exaggerated vertical scale.

area is illustrated in Fig. 2. Correlations with Karoo Sequence sediments in South Africa and South America (Uruguay, Brazil) are further discussed.

Previous work

A *Mesosaurus* bone bed discovered by Reuning and von Huene (1925) on the northern flank of the Doros Crater (Fig. 1) was the first evidence of a Karoo age for the sedimentary succession of the Huab Basin. However, a detailed description and subdivision of the sequence at Doros Crater was only presented 32 years later by Reuning and Martin (1957), who correlated the lower part with the Dwyka Formation and the upper part with the Stormberg Series of South Africa. During subsequent mapping of parts of the Huab Basin by Frets (1969) and Hodgson (1972), and after discovery of a vertebrate fauna north of Doros Crater by Keyser (1973), the present stratigraphic subdivision evolved: SACS (1980) attributes the sedimentary succession to the Dwyka Group, the Lower Ecca Group and the Drakensberg Group.

Description of the depositional units

Depositional unit 1

These sediments overlie the basement discordantly and in general attain a thickness of a few tens of centimetres. At one locality a thickness of 7 m was observed. Exposures of the sediments are rare and show that the lateral extension is restricted to several tens of square metres.

Lithofacies

The base of the Karoo Sequence comprises an unsorted, unbedded, matrix-supported conglomerate containing clasts ranging in diameter from a few centimetres to several tens of centimetres and set in a pelitic to psammitic matrix. Hodgson (1972) reported that the clasts consist mainly of quartz (80%) and additionally quartzite (10%) and schist (10%). Frets (1969) described an occurrence of striated pavement in the western Huab area which indicates that the ice movement was towards the west.

Interpretation

The sediment has been interpreted as a tillite by Reuning and Martin (1957) and Hodgson (1972). Martin (1981) also described parts of the Huab Valley as a deep glacially shaped valley. The restricted distribution of the tillite suggests a proximal position for the Huab area which was probably dominated by erosion during the glaciation and subsequent melting periods.

Depositional unit 2

The sediments of this unit, which attain a maximum thickness of 15 m, either directly overlie the tillite deposits or small restricted areas of Damaran basement.

Lithofacies

This unit is characterised by varying successions of conglomerate, sandstone, claystone and, in some places, marl or limestone. The sequence begins in many places with conglomerate, up to 50 cm thick, which contains pebbles up to 15 cm in diameter set in a matrix which is more psammitic than that of the tillite. Slump structures are frequent in places where the conglomerate interfingers with the sandstone. The sandstone exhibits different sedimentary structures: planar bedding, laminar, bedding and several types of cross-stratification are common.

The fine-grained parts of the unit, i.e. claystone, marl and siltstone, are mostly developed as rhythmites. Individual rhythmite layers are up to 5 cm thick and separated by remarkably subtle horizontal contacts caused by different grain size and various contents of calcite. All psammitic to pelitic layers of unit 2 frequently exhibit arthropod trace fossils of the Umfolosia type (Savage, 1971).

Interpretation

The association of matrix -supported conglomerate and thinly interbedded shale-siltstone successions is believed to represent a periglacial diamictite-rhythmite couple. Whereas frequently developed slump structures in the diamictite may be the result of solifluction-induced earthflow, interbedding of coarse-grained sandstone.or gravel and unsorted conglomerate probably indicate fluvial transport. The fine-grained rhythmites are thought to be deposited in small protected basins under low-energy conditions as indicated by the uniform lamination, straight and continuously crested ripples and undisturbed trace fossils.

Depositional unit 3

Sediments of unit 3 are widespread in the Huab Basin and form the first blanketing cover, up to 50 m thick, over the basement. They include shale and siltstone with thin coal seams, carbonaceous shale and intercalated sandstone.

Lithofacies

This unit usually starts with shale and siltstone. Carbonaceous shales with coalified relics of plants, locally preserved rootlet horizons and thin coal seams (1- 3 cm) are typical and occur repeatedly as intercalations. Fossil plants, especially *Glossopteris* and lepidophytes, are abundant in such layers. The succession continues with greyish to reddish shales in the upper portion which contains less organic material. The whole succession sporadically interfingers with coarse-grained feldspar-rich sandstone horizons which usually form lens-like bodies of about 5 m thickness and up to several tens of meters lateral extent. In upward-fining successions, the platy sandstone and siltstone contain abundant trace fossils of burrowing organisms. Sandstone intercalations interfinger laterally with the carbonaceous shales, while at the basal contact they often contain eroded particles of the underlying material. Unit 3 is capped by a calcareous-ferruginous palaeosol along the eastern margin of the study area, well exposed in the Twyfelfontein and Verbrande Berg region.

Interpretation

The association of mainly pelitic sediments, rootlet horizons and coal seams overlain by and partly interfingering with sandstones indicates a swampy, fluvially controlled depository. Two sedimentary environments can be distinguished in extended glacial valleys: a stable meandering system with clastic channel fills and wide areas characterised by permanent moisture and abundant vegetation (Cairncross and Cadle 1988).

According to Retallack (1980), the Lower Permian *Gangamopteris-Glossopteris* floral assemblage may be readily compared with present-day boreal plant communities. Also, the boreal wetlands, bogs and shallow pools of Canada have been taken as an example to explain the Lower Permian coal deposits of Australia (Martini and Glooschenko, 1985). Cairncross and Cadle (1988), in describing the sedimentary facies of the Witbank Coalfields (Vryheid Formation, South Africa), have distinguished phases of prevailing coal formation and of predominantly clastic sedimentation. Climatic changes have been claimed to be the main reason for this variation. Thus, in cold periods and under waterlogged conditions, a widespread autochthonous vegetation could develop, whereas in warmer more moderate climatic intervals, sheet -like fluvial deposits were spread over the area. Similarly, it is thought that deposition of unit 3 began under cold climatic conditions which gave rise to the formation of coal in the lower part of the succession. With climatic melioration, a sandy fluvial facies (unit 4, described below) established itself and, towards the east, was accompanied by the formation of early calcareous-ferruginous soils.

Depositional unit 4

Unit 4 overlies unit 3 concordantly but, at some places, with a sharp, locally erosive contact. It consists, in contrast to the underlying sediments, of pure clastic material. Where unit 3 terminates with a palaeosol, reworking has occurred and fragments of the palaeosol are abundant in the basal beds of unit 4. Three depositional domains with differing lithologies can be distinguished from east to west (see Fig. 3).

Lithofacies

In the eastern domain (fs in Fig. 3) unit 4 is characterised by a regionally distributed sheet-like succession of sandstone attaining a thickness of up to 10m. The coars-

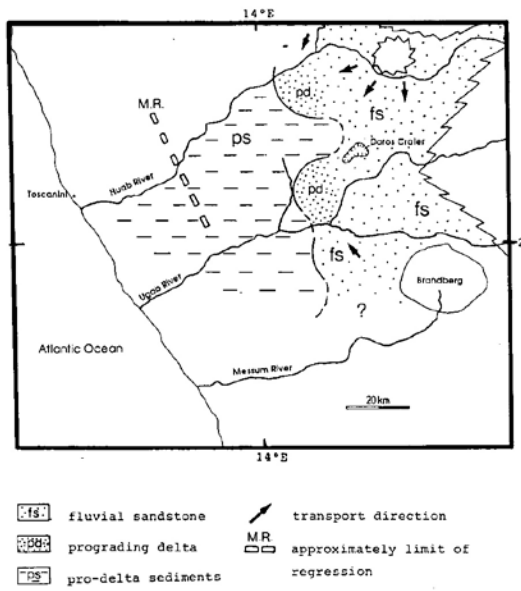


Fig. 3: Facies distribution - unit 4.

egrained, feldspar-rich sandstone is poorly sorted and locally slightly calcareous. Individual layers exhibit a distinct planar cross-bedding and subordinate trough cross-bedding, both of which are generally large scale. Upward-fining sequences are frequent, but locally sections show reverse grading with gravels on top. Erosive contacts between successive individual layers are common. Traced laterally and vertically, dips of the cross-bed sets show very variable transport directions. The transport directions in Fig. 3 are generalised.

The sheet-like sandstone changes westward to an upward-coarsening sequence of siltstone and fine- to coarse-grained and gritty sandstone, up to 60 m thick (pd in Fig. 3). The lower 30 m is dominated by silty shales and platy sandstones, while in the upper half of the succession a 20 m thick zone with horizontal layers of coarse-grained sandstone and low-angle cross-stratification (hummocky crossbedding) is overlain successively by a 10m thick coarse grit and sandstone similar to the fluvial sandstone found in the eastern domain (fs. in Fig. 3). The coarse-grained horizontal and low-angle cross-stratified sandstone layers contain large numbers of well-preserved silicified trunks. Other characteristic features occurring in this part of unit 4 are tube-like burrows of mono- and diplocraterion type.

In the western part of the study area (ps in Fig. 3), unit 4 is made up of a 30 m succession of shale and siltstone into which an upward-coarsening and subsequently upward-fining cycle is intercalated. In this domain, the succession of unit 4 starts with 12 m of thinly laminated shale and siltstone which is overlain by fine-grained sandstone (3 m). These are successively overlain by coarse grit, in some cases conglomerate (up to 30 cm), and again fine-grained sandstone (3 m). The conglomerate contains abundant scales and teeth of Actinopterygians and Selachians as well as coprolites and bone fragments of Labyrinthodonts. The unit terminates with 12 m of shale and siltstone.

Interpretation

Three closely related facies domains (labelled ps, pd and Is in Fig. 3) have been deduced from regional lithological variations exhibited in unit 4. According to diagnostic features established by Galloway and Hobday (1984) and Miall (1977), we suggest a fluvial depository dominated by bed-load braided streams for the fs domain (Fig. 3). The most important features used here are the regional sheet-like distribution of coarse-grained sandstone, the almost complete lack of clay deposits, the abundance of shallow channels, the frequency of planar cross-bedding, and the upward-fining nature of beds. Also typical for bed-load streams is the large palaeocurrent divergence indicated by the cross-bedding (Walker and Douglas, 1984).

A late Pleistocene association of sediments, similar to that of the ps domain (Fig. 3), has been described by Sneh (1971) and interpreted as fan-delta deposits. Prograding delta deposits, transitional from fluvial to the westerly opening basin, tonn an overall upward-coarsening sequence and are developed in small restricted areas (pd in Fig. 3). More specifically, the unit 4 succession of this region may be described as a fan-delta deposit in which the coarse-grained to gritty sandstone represents the fan-delta plain, while the fine-grained sandstone and siltstone are equated with the fan-delta front. In this scenario, the basal siltstone sequence is interpreted as the prodelta. Development of a fan delta is favoured by a relatively steep gradient between a source area and the depository and bed-load braided streams in the hinterland (Wescott and Etheridge, 1980; fs in Fig. 3).

To the west of the prodelta subfacies, a lacustrine domain (ps in Fig. 3) becomes recognisable as indicated by 30 m of laminated shale and siltstone. The fossiliferous conglomerate situated at the turning-point of the coarsening and subsequently upward-fining sequence represents the climax of a phase of regression. This layer disappears westward indicating the maximum extent of the emerged area (M.R. in Fig. 3).

Depositional unit 5

Unit 5 deposits are present over most of the study area, but show variation in lithology, succession and facies. This unit attains a thickness of up to 18 m in the ,central and western parts of the area, but varies in thickness from 10 to 50 m along the eastern margins. Deposits comprise various carbonates and siliciclastic sediments.

Lithofacies

Four typical lithostratigraphic sections of unit 5 (sections 2-5) are presented in Fig. 4. The positions of the sections are shown in Fig. 5. A section from the Paraná

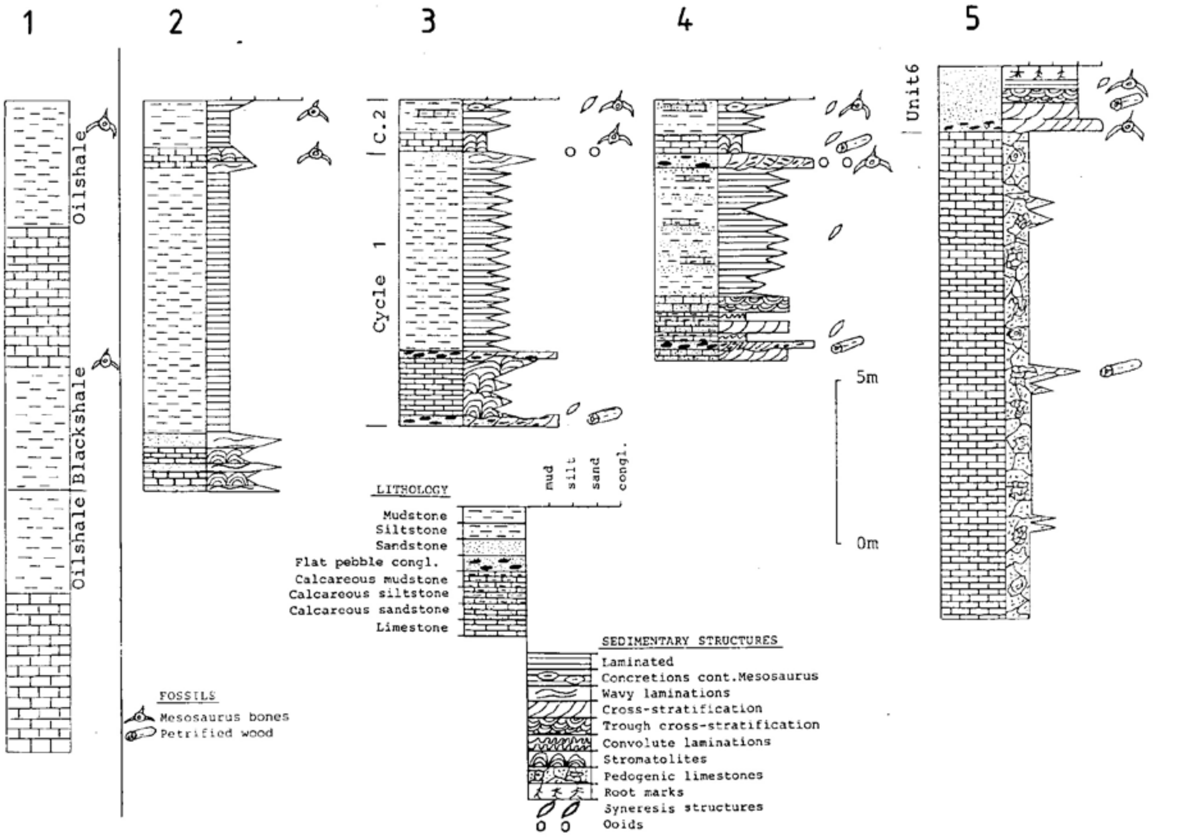


Fig. 4: Unit 5, sections 2-5 from western to eastern Huab Basin, section 1 is from Sao Mateus, Brazil.

Basin (section 1 in Fig. 4) has been added for comparison and correlation.

Unit 5 generally exhibits two sedimentary cycles (sections 2-4 in Fig. 4). Cycle 1 begins with algal laminites or stromatolites, up to 5 m thick, locally associated with calcareous flat pebbles and followed by slightly calcareous silty to sandy shales. Thinly laminated and weakly undulating algal laminites occur in the wide central areas of the Huab Basin (section 2 in Fig. 4). Close to the Atlantic coast cycle 1 is represented by silty, slightly kerogenous limestone (Fig. 5). In the area represented by section 3 (Fig. 4), stromatolites increase gradually in size up to 30 m long and 10m wide. The long axes of these algal biohenns are oriented in an east-west direction. Individual laminae may be more than 1 cm thick and may contain coarse, sand-size clastic material. The stromatolite bodies have occasionally been eroded on their flanks by coarse clastic channel deposits which usually contain calcareous flat pebbles and fragments of petrified wood. Locally, stromatolites have also been hollowed and partly collapsed. Elsewhere individual bioherms have coalesced to form major continuous bodies with reduced surfaces.

Further east (section 4 in Fig. 4) cycle 1 is represented by a condensed succession of interbedded micritic limestones, coarse-grained sandstones, cross-bedded calcareous sandstones and intercalated flat-pebble conglomerates followed by a few metres of medium-grained platy sandstone or silty shale.

Along the eastern margin of the study area (section 5 in Fig. 4) unit 5 is 10 to 50 m thick and contains abundant ferruginous carbonate concretions, variously shaped calcsilicate aggregates, ferruginous nodules, irregular chert aggregates and chert layers. Sedimentary structures are not recognisable in the succession. On acetate peels, the concretions frequently exhibit concentric growth structures with several generations of shrinkage cracks and corroded detrital grains set in a micritic matrix.

Cycle 2 again starts with carbonates which are of domal stromatolitic nature in the west (section 2 in Fig. 4), but oolitic further east (sections 3 and 4 in Fig. 4). The stromatolite bioherms still have elongated domal structures and exhibit east-west orientation. In contrast to the stromatolites of cycle 1, these algal laminites have a larger extent towards the west, the domes are smaller (the long axis does not exceed 1 m) and individual laminae are very thin (less than 1 mm), undisturbed and contain kerogen, but no coarse clastic material.

The ooids are restricted to a conglomerate horizon up to 50 cm thick in which they typically form the matrix, but oolites may occur as pebbles. In both domains, the carbonates are overlain by silty, partly calcareous shales which locally contain abundant syneresis cracks (e.g. section 4 in Fig. 4). Cycle 2 is of special regional importance in that it ubiquitously and, in virtually all lithological units, contains bones of the amphibious reptile *Mesosaurus tenuidens*.

Interpretation

Depositional unit 5 reflects the development of a probably lacustrine basin opening towards the west and fringed by mud flats and areas with intense pedogenesis along the eastern margin. The occurrence of the first autochthonous aqueous carbonates (stromatolites and oolites) of the Karoo Sequence in this unit indicates progressive melioration of the climate.

Three facies domains may be distinguished based on the regional distribution of different types of carbonates in cycle 1 (Fig. 5). In the distal western part, a sublittoral domain (sl in Fig. 5), approximately 50 km wide, is characterised by thinly laminated algal mats. Domal stromatolites increase in size towards the proximal and shallowing eastern part. By analogy with recent stromatolites, e.g. Shark Bay, Australia (Playford and Cockbain, 1976), the parallel orientation of the long axes of the stromatolite domes, as well as their lateral erosion and high content of clastic material, indicate an environment with high-energy unidirectional currents. A tidal influence seems to be unlikely to cause these currents because of the palaeogeographic situation (Fig. 7). The eventual marine connection in the south of the Paraná-Karoo Basin proposed by Oelofson (1987) would have been too far away to let a strong tidal influence pass through the shallow and narrow Paraná Basin. The elongation of the stromatolites and the related high-energy environment are believed to be wave-induced features which indicate the existence of a major basin with sufficient fetch. It appears that a large lacustrine depository, including at least the Paraná and Huab basins (Oelofsen and Araujo, 1987), had already formed at this stage. The unidirectional east-west elongation of the stromatolites in the Huab area changes to northwest-southeast in the northern Goboboseb mountains. Expecting an orientation of the long axes at right angles to the coastline, the latter should have had a northeast-southwest orientation in the northern Goboboseb area (Fig. 5).

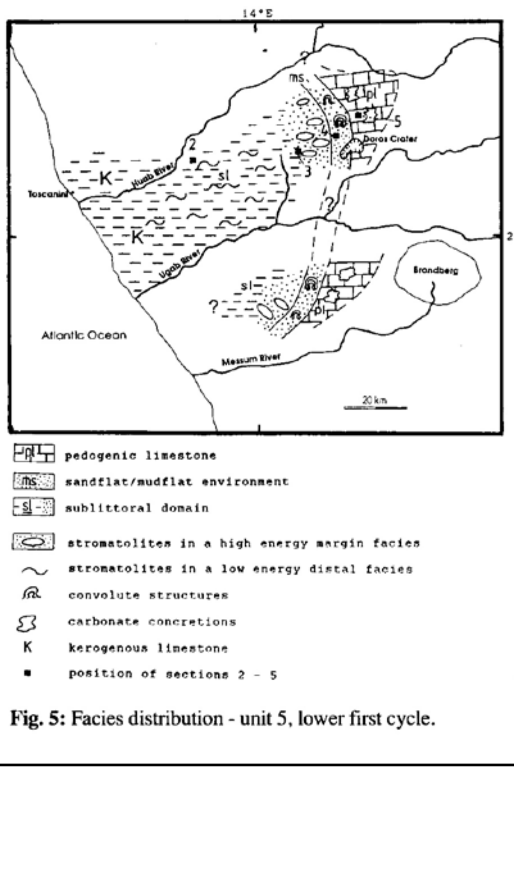


Fig. 5: Facies distribution - unit 5, lower first cycle.

To the east a marginal mud-flat to sand-flat facies (ms in Fig. 5), approximately 5 km wide, is represented by alternating thinly bedded mud-flat micritic limestones, cross-bedded calcareous sandstones and layers of flat pebble-bearing, coarse-grained, quartzose sandstone. Much of the micrite is preserved in the form of these flat-pebbles which indicates temporary desiccation and erosion of the slightly indurated deposits. Other remnants of mud flat deposits show convolute structures when they are overlain by rapidly transported coarse-grained sandstone.

An enormous fluvial influence is indicated in this area during cycle 1 accumulation by abundant calcified and silicified wood fragments.

A pedogenic limestone facies (pI in Fig. 5) which established itself along the outer margin of the lake consists of up to 50 m of concretionary carbonates, ferruginous nodules and cherty aggregates. These diagenetic bodies contain several kinds of pedogenic features: root marks, desiccation and transport breccias (Freyted and Plaziat, 1982), skew and curved planes, and several generations of shrinkage and desiccation cracks. In some parts of the laterally varying successions, these typical features of hydromorphic calcimorph soils can be compared with the palustrine limestones described by Freytet and Plaziat (op. cit.). In other parts of the sections, however, the amount of siliciclastic components increases, indicating a more fluvially controlled environment with waterlogged hydromorphic soils, flood-plain soils (Freytet and Plaziat, op. cit.) and dry crusts.

Within the lake, the basal carbonates are overlain by siliciclastic deposits, viz. silty shales in the distal sublittoral domain and platy sandstones in the adjoining eastern domain. For the upper first cycle, these sediments may indicate a pluvial interval with comparatively high rates of sedimentation which did not allow the stromatolites to survive.

After a regression and cessation of increased sediment influx, algal growth revived at the onset of cycle 2, probably in a shallower lake with increased salinity. This is indicated by a further westward extension of the stromatolitic sublittoral facies and the occurrence of ooids and abundant syneresis structures. Vadose meniscus cements between the ooids indicate temporary drying out of the shallow, saline environment with deposition of ooids and erosion of early diagenetic oolites.
The uppermost calcareous shales and platy sandstones still represent a shallow and saline environment, but the growth of algal laminites was again stopped by increas-

ing clastic influx.

Depositional unit 6

The unit is represented by a 3 to 15 m thick sheet-like sandstone which covers the eastern margin of unit 5.

Lithofacies

The remarkable quartz-dominated dark sandstone is characterised by root marks within the uppermost layers and frequent layers of flat-pebble conglomerate at the base. Sedimentary structures, e.g. planar and trough cross-bedding, are abundant in some areas in the east, but absent in most areas north of Doros where upward-fining sequences are terminated by silty shales.

Interpretation

Unit 6 is a clastic, fluvially controlled time-equivalent of cycle 2 within unit 5 as evidenced by the occurrence of *Mesosaurus tenuidens* throughout the entire succession. Interfingering with the calcareous shallow-water sediments of cycle 2, this sandstone reflects the eastern border of the lacustrine environment during the upper Whitehill/Iratitime. Rootlet horizons at the top of the succession and locally restricted silty shales (probably accumulated in small ponds) suggest a vegetated, estuarine-like environment.

Depositional unit 7

Unit 7, known as the Gai-as Formation in the Huab region, is the most widespread depositional unit within the study area. The approximately 70 m thick succession is easily distinguished from all the other units by its characteristic reddish to violet colour. The Gai-as Formation gradationally overlies the lacustrine deposits of unit 5 in the western part of the area, but in the east succeeds the fluvial deposits of unit 6 with a sharp contact (Fig. 2). The basal beds of the formation are ubiquitously represented by fine-grained distal deposits and imply a much larger extent of the formation due to the absence of sediments from marginal environments.

Lithofacies

The lower part of the succession is formed by approximately 50 m of thick reddish-violet, slightly calcareous shales. In the lower half of this mainly pelitic succession, intercalations of dark brown, very often concretionary calcareous layers up to 1m thick, occur. These layers contain siltstone beds which locally exhibit flaser bedding, oscillation ripples and hummocky cross-bedding. The calcareous layers also contain small fossiliferous lenses with fishbones. The upper half of the basal shaly section contains a few layers, 10-20 cm thick, which are whitish and analcime-rich and occasionally thin layers of green chert.

The basal beds grade into a 20 m thick succession of silty to fine-grained, and eventually medium- to coarse-grained, sandstone. Sections of the uppermost part of unit 7 show various types of intercalations: silt- and sandstone layers grade laterally into sequences of interbedded shale and sandstone with occasional intercalations of stromatolitic layers, carbonate horizons with molluscs, bone beds of fish scales and white layers rich in authigenic feldspar. The shale frequently exhibits desiccation cracks, whereas root marks are abundant in sandstone. Halite crystal moulds have been found locally.

Interpretation

The Gai-as Formation as a whole displays an upward-coarsening sequence which starts with distal shallow lacustrine shales. The occurrence of flaser bedding, oscillation ripples and hummocky cross-stratification in silty intercalations indicates that the sediment, surface must have been above the storm wave base.

The remarkably high content of analcime (30 vol.%) in some layers may be indicative of contemporaneous volcanic activity. Early diagenetic formation of analcime from volcanic glass in an alkaline environment has been described by Van Houten (1962) and Surdam and Sheppard (1978). High alkalinity of the lake water may also have been the reason for the almost complete lack of fossils in this part of the section.

The overlying succession of sandstones, siltstones, stromatolites and emerged horizons reflects the upward shallowing of unit 7. Besides extensive sand flats, large playas, several square kilometres in size, must have existed during the final stages of deposition. The playa deposits are represented by shaly sediments with intercalated feldspar-rich layers (2-4 cm), stromatolite horizons (5-15 cm) and fish scale bone beds (3-5 cm). Fossiliferous stratiform carbonates (10-15 cm thick) with molluscs of the Terraia altissima type are transitional to the sand-flat facies which is characterised by sandy, flat and lenticular deposits and occasionally contain abundant root marks.

Depositional units 8 and 9

The sedimentary units 8 and 9, collectively named Etjo Sandstone Formation (SACS, 1980), overlie the older sediments discordantly and are not restricted to the sedimentary basin described above (Fig. 2). The Etjo sandstone interfingers with the overlying basic lavas of the Etendeka Formation.

Lithofacies

Depositional unit 8 is restricted to the northeastern part of the area and consists of up to 10m of conglomerate, grit and coarse-grained pebbly sandstone. The conglomerate and sandstone layers are locally interbedded with fine-grained, well-sorted sandstone. Pebbles are generally well-rounded and consist of Damaran vein quartz, Karoo pebbles being extremely rare. Prominent planar and trough crossbedding developed in the coarse-grained sandstone indicates transport to the north-northwest. In the Huab Valley, the erosive base of unit 8 reaches down to unit 4 sandstones.

Depositional unit 9 is represented by up to 100 m of medium-grained, well-sorted, yellowish-white sandstone which exhibits predominantly planar cross-bedding with foresets up to several metres high in the direction of transport. Perpendicular to the transport direction, a tabular-type bedding is developed with subhorizontal layering on the lee side.

In the western Huab Basin, the aeolian sandstone immediately overlies the Gai-as Formation. Small deflation planes are only exhibited in some transition zones between units 8 and 9. Near Gai-as, where unit 8 dies out, a lag gravel consisting almost entirely of Damaran vein quartz forms the base of unit 9. These pebbles are distinctly wind-grooved and partly wind-faceted. A palaeocurrent analysis undertaken by Hodgson (1972) showed an average foreset dip of 22° towards the northeast, the probable mean direction of transport in the Huab area.

Interpretation

The Etjo Sandstone Formation clearly exhibits two different sedimentary facies, viz. an alluvial facies represented by the coarse clastic deposits of unit 8 and an aeolian facies manifested in the fine-grained, large-scale cross-bedded sandstone of unit 9. Both facies were closely related during the early stages of deposition, since aeolian deposits have been eroded by fluvial action and redeposited in the alluvial succession, e.g. outcrop on the farm Krone 721. Later encroachment by the aeolian facies upon the alluvial deposits has resulted in the latter not being encountered higher up in the succession.

Planar-tabular cross-bedding and long, high-angled foresets in the aeolian sandstone are regarded as typical features of transverse dunes (McKee, 1966). The palaeocurrent data are in accordance with those measured for the Botucatu sandstone of Brazil (Bigarella, 1970), thus indicating a continuous land surface between South America and Africa at that time.

Age and correlation

Seven of the nine depositional units that can be distinguished in the Huab area are readily correlated with stratigraphic units of the Paraná Basin of South America, while the remaining two represent local fluvial deposits (units 6 and 8). Correlations of the Huab sediments with schematic sections of the Paraná and the Great Karoo Basin are discussed below and presented in Table 1.

Both glacial and periglacial deposits in the Huab Basin are restricted to local occurrences of very limited thickness that have escaped intra-Karoo erosion. Central parts of the Paraná Basin in South America preserve

TABLE 1: Regional stratigraphic correlations.

			PARANA BASIN (Rio Grande do Sul)	HUAB BASIN	KAROO BASIN (Eastern Cape Province)		
Cret. / Jur.		Sao Bente Group	Serra Geral Fm.	Etendeka Fm.	Drakensberg Fm.		Jur.
Triassic			Botucatu Sandst. Fm.	Unit 9 Etjo Sandst. Fm.	Clarens Sandstone Fm.		
			Piramboia Fm.	Unit 8	Elliot Fm. Molteno Fm.		Triassic
Permian	Serie Serra do Espigao	Passa Dois Group	Rio do Rasto Fm.		Burgersdorp Fm. Katberg Fm. Balfour Fm. Middleton Fm. Koonap Fm.	Beaufort Group	
			Terezinha Fm.	Unit 7 Gai-as Fm.	Waterford Fm. Fort Brown Fm. Ripon Fm. Collingham Fm.	Ecca Group	Permian
			Serra Alta Fm.				
	Serie Rio Tiete		Irati Shale Fm.	Unit 5 / Unit 6	Whitehill Fm.		
		Tubarao Group	Palermo Fm.	Unit 4	Prince Albert Fm.		
			Rio Bonito Fm.	Unit 3			
Carb.			Itarare Fm.	Unit 2 Unit 1	Dwyka Fm.		Carb.

a more complete succession of comparable rocks; these attain a thickness of several hundred metres in the Itarare Group and have been described as a series of interbedded tillites, diamictites, rhythmites, sandstones and coal deposits which include marine intercalations and interglacial deposits (Rocha-Campos, 1967). A correlation of depositional units 1 and 2 of the Huab Basin with the Itarare Group of the Paraná Basin appears justified since, in both areas, the deposits appear to be related to the same glaciation and ice-movement directions (Bigarella, 1970; Martin, 1975). Thus depositional units 1 and 2 are regarded as representing proximal equivalents of the more distally deposited Itarare Group. França and Potter (1988) gave the name "Kaokoveld Lobe" to one of the major glacial lobes that reached into the Paraná Basin and interpreted the Kaokoveld as the source area. Units 1 and 2 were deposited along the eastern elevated margins of a major "Paraná Basin" and, in this position, have undergone partial erosion before the onset of deposition of the following unit 3 (Fig. 6).

A distal correlative of unit 3 is the coal-bearing Rio Bonito Formation in South America. This succession is several hundred metres thick and contains intercalations of marine ingressions which probably did not reach the marginal parts of the basin such as the Huab area.

Unit 4 is correlated with the Palermo Formation of South America, described as a clastic succession overlying the coal-bearing Rio Bonito Formation and covered by calcareous sediments (Northfteet *et al.*, 1969). There is no comparable formation situated between the Prince Albert Formation and the Whitehill Shale Formation in South Africa.

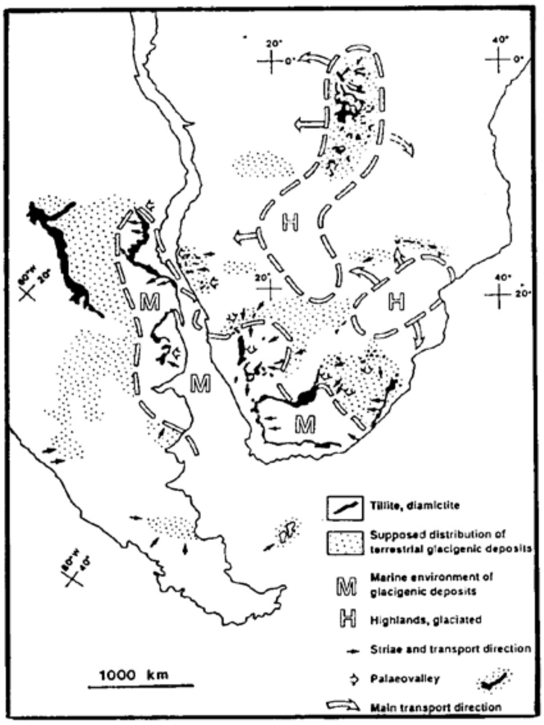


Fig. 6: Dwyka group and correlative units.

The widespread occurrence of a bone bed with abundant relics of *Mesosaurus tenuidens* in virtually all facies domains and sediment types of cycle 2 (unit 5) is a strong tool for correlations within and beyond the study area. A detailed description of the animal and its regional dispersal in the Whitehill Formation of South Africa and the Irati Shale Formation of South America has been presented by Oelofsen and Araujo (1987). These authors conclude that *Mesosaurus* was an endemic reptile whose specific environment extended from the Karoo Basin of South Africa to the Paraná Basin of South America (Fig. 7).

Mesosaurus-bearing beds in South America and South Africa are succeeded by shales comparable to the basal beds of the Gai-as Formation, e.g. the Collingham and Tierberg Shales of the Ecca Group in South Africa and the Serra Alta Formation in Brazil. The regional distribution of these sediments delineates the minimum

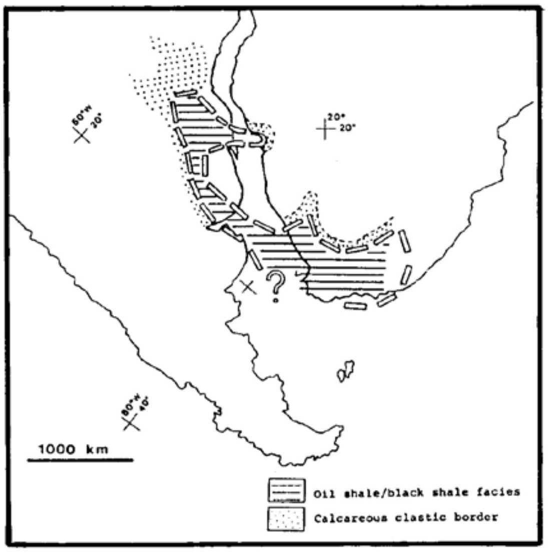


Fig. 7: Irati and Whitehill Formations (modified after Oelofsen, 1987).

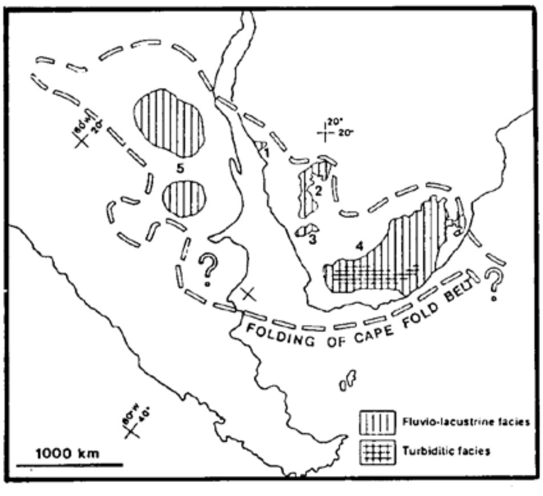


Fig. 8: Middle to upper Ecca Group and correlative units (after Cooper and Kensley, 1984).

extent of the interconnected Karoo and Paraná basins (Fig. 8). The Gai-as Formation is readily correlated with the Estrada Nova Formation of Brazil which contains the same mollusc fauna (Newell and Runnegar, 1971). Gama *et al*. (1982) divided the Estrada Nova Formation into the lower Serra Alta Formation, which consists of shales, and the upper, sandstone-bearing, calcareous Terrezinha Formation (Table 1). Due to increased subsidence in the central Paraná Basin, thicknesses are considerably greater and attain a maximum of 1200 m (Mendes, 1967).

The uppermost two sedimentary units developed in the study area are collectively called "Etjo Sandstone Formation". The stratigraphic position of this formation is uncertain and available information leads to the conclusion that a position between uppermost Triassic and lowermost Cretaceous could be possible. The formation has been described as "a prominent sandstone unit of presumed aeolian origin which overlies any other Karoo sediments that may be present and underlies the volcanic Etendeka Formation" (SACS, 1980, p. 543). It has to be added that, at several locations in the northern part of the study area, the Etjo sandstone interfingers with basic lavas of the Etendeka Formation which are believed to be of Lower Cretaceous age (Erlank *et al*., 1984). The Etjo Sandstone Formation at Mount Etjo, central Namibia, exhibits similar sedimentary structures and is believed to be of uppermost Triassic age (Keyser, 1973); this coincides with the age of the Clarens Formation in South Africa (SACS, 1980). The aeolian sandstone in the Huab Valley was accumulated by almost unidirectional wind currents. These directions are best compared with those of the Botucatu Sandstone in Santa Catarina, southern Brazil, which has been dated at Lower Cretaceous by Bigarella (1970), but Upper Triassic to Lower Jurassic by Northfleet *et al*. (1969) and Gama *et al*. (1982).

The hiatus between unit 7 and units 8 and 9 comprises at least the whole of the Beaufort Group. Since no indication of soil or crust development occurs at the top of unit 7 and no erosional relics of the latter have been found in the Huab area, it is not clear what happened between unit 7 and the Etjo Sandstone Formation.

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References

Bigarella, J.J. 1970. Continental Drift and paleocurrent analysis (A comparision between Africa and South America). *Proc. Pap. IUGS 2nd Gondwana Symp. (South Africa*), 73-97.

Cairncross, B. and Cadle, A.B. 1988. Depositional palaeoenvironments of the coal-bearing Permian Vryheid Formation in the Witbank Coalfield, South Africa. *S. Afr. J. Geol*., **91**, 1-17.

Cooper, M.R. and Kensley, B. 1984. Endemic South American Permian bivalve molluscs from the Ecca of South Africa. *J. Paleont*., **58**, 1360-1363.

Erlank, A.J., Marsh, J.S., Duncan, A.R., Miller, R.McG., Hawkesworth, C.J., Betton, P.J. and Rex, D.C. 1984. Geochemistry and petrogenesis of the Etendeka volcanic rocks from SWA/Namibia. *Spec. Publn geol. Soc. S. Afr*., **13**, 201-210.

França, A.B. and Potter, P.E. 1988. Estratigrafia e ambiente depositional do Grupo Itararé (Permocarbonífero), Bacia do Paraná (Parte 1). *Boletim Geociências da Petro bras, Rio de Janeiro*, **2**, 147-192

Frets, D.C. 1969. Geology and structure of the Huab-Welwitschia area, South West Africa. *Bull. Precambr. Res. Unit. Univ. Cape Town*, **5**, 235 pp.

Freytet, P. and Plaziat, J.C. 1982. Continental Carbonate Sedimentation and Pedogenesis - Late Cretaceous and Early Tertiary of Southern France. *In*: Füchtbauer, H., Lisitzyn, A.P., Milliman, J.D. and Seibold, E. (Eds). *Contrib. Sediment*., **12**, 213 pp.

Galloway, W.E. and Hobday, D.K. 1983. *Terrigenous Clastic Depositional Systems: Applications to Petroleum, Coal, and Uranium Exploration*. Springer-Verlag, New York, 423 pp.

Gama, E. Jr., Bandeira, A.N. Jr. and França, A.B. 1982. Distribuiçao espacial e temporal das unidades lito-estratigráficas Paleozóicas na parte central da Bacia do Paraná. *Revista Brasileira de Geociências*, **12**, 578-589.

Hodgson, F.D.I. 1972. *The geology of the Brandberg - Aba Huab area. South West Africa*. D.Sc. thesis (unpubl.), Univ. Orange Free State, 174 pp.

Keyser, A.W. 1973. A new Triassic vertebrate fauna from South West Africa. *Palaeont. afr*., **16**, 1-15.

Martin, H. 1975. Structural and palaeogeographical evidence for an Upper Palaeozoic sea between Southern Africa and South America. *Proc. Pap. IUGS 3rd Gondwana Symp. (Canberra*), 37-51.

Martin, H. 1981. The Late Palaeozoic Dwyka Group of the South Kalahari Basin in Namibia and Botswana and the subglacial valleys of the Kaokoveld in Namibia, 61-66. *In*: Hambrey, M.J. and Harland, W.B. (Eds) *Earth's Pre-Pleistocene Glacial Record*.

Martini, I.P. and Glooschenko, W.A. 1985. Cold climate peat formation, and its relevance to Lower Permian coal measures of Australia. *Earth Sci. Rev*., **22**, 107-140.

McKee, E.D. 1966. Structures of dunes at White Sands National Monument, New Mexico (and a comparision with structures of dunes from other selected areas). *Sedimentology*, **7**, 1-69.

Mendes, J.C. 1967. The Passa Dois Group. *Proc. Pap.*

IUGS 1st Gondwana Symp. (Brazil), 119-166.

Newell, N.D. and Runnegar, B. 1971. Caspian like relict molluscan fauna in the South American Permian. *Bull. Am. Mus. nat. Hist.*, **146**, 66 pp.

Northfleet, A.A., Medeiros,R.A. and Muhlmann, H. 1969. Reavaliaçao dos Dados Geológicos da Bacia do Paraná. *Boletim Técnico da Petrobrás, Rio de Janeiro*, **12**, 291-346.

Oelofsen, B.W. 1987. The Biostratigraphy and Fossils of the Whitehill and Irati Shale Formations of the Karoo and Paraná Basins. *Proc. Pap. IUGS 6th Gondwana Symp. (USA*), 131-138.

Oelofsen, B.W. and Araujo, D.L. 1987. *Mesosaurus tenuidens* and Stereosternum tumidum from the Permian Gondwana of both Southern Africa and South America. *S. Afr. J. Sci*., **83**, 370-372.

Playford, P.E. and Cockbain, A.B. 1976. Modern Algal Stromatolites at Hamelin Pool, a hypersaline barred basin in Shark Bay, Western Australia, 389-413. *In*: Walter, M.R. (Ed.) *Stromatolites, developments in sedimentology*. New York.

Retallack, G. 1980. Late Carboniferous to Middle Triassic megafossil floras from the Sydney Basin, 384-430. *In*: Herbert, C. and Helby, R. (Eds). *A Guide to Sydney Basin*. Bull. geol. Surv. N.S.W., **26**.

Reuning, E. und Martin, H. 1957. Die Prä-Karroo-Landschaft, die Karroo-Sedimente und Karroo-Eruptivgesteine des südlichen Kaokofeldes. *Neues Jb. Miner. Geol. Paläont*., **91**, 193-212.

Reuning, E. und Von Huene, F. 1925. Fossilführende Karrooschichten im nördlichen Südwestafrika. *Neues Jb. Miner. Geol. Paläont*., **52**, B, 94-122.

Rocha-Campos, A.C. 1967. The Tubarao Group in the Brazilian Portion of the Paraná Basin. *Proc. Pap. IUGS 1st Gondwana Symp. (Brazil*), 25-102.

South African Committee for Stratigraphy (SACS). 1980. Kent, L.E., (Comp.) *Stratigraphy of South Africa. Part 1. Lithostratigraphy of South Africa, South West Africa/Namibia, and the Republics of Bophuthatswana, Transkei and Venda*. Handb. geol. Surv. S. Afr., **8**, 690 pp.

Savage, N.M. 1971. A varvite ichnicoenosis from the Dwyka Series of Natal. *Lethaia*, **4**, 217-233.

Sneh, A. 1979. Late Pleistocene Fan-Deltas along the Dead Sea Rift. *J. sedim. Petrol*., **49**, 541-552.

Surdam, R.e. and Sheppard, R.A. 1978. Zeolites in Saline, Alkaline-lake Deposits, 145-174. *In*: Sand, L.B. and Mumpton, F.A. (Eds) *Natural Zeolites*. Pergamon Press, Oxford.

Van Houten, F.E. 1962. Cyclic sedimentation and the origin of analcime-rich Upper Triassic Lockatong Formation, West-Central New Jersey and adjacent Pennsylvania. *Am. J. Sci*., **260**, 561-576.

Walker, R.G. and Douglas, J.C. 1984. Sandy Fluvial Systems, 71-89. *In*: Walker, R.G. (Ed.) *Facies Models*. Geosci. Canada. Repr. Ser., **1**, 317 pp.

Wescott, W.A. and Ethridge, F.G. 1980. Fan-Delta Sedimentology and Tectonic Setting - Yallahs Fan-Delta, Southeast Jamaica. *Am. Ass. Petrol. Geol*., **46**, 374-399.