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Fossil record and high-resolution tephrostratigraphy of Carboniferous glaciomarine mudstones, Dwyka Group, southern Namibia

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The Carboniferous Dwyka Group in southern Namibia can be subdivided into four upward-fining deglaciation sequences, each capped by relatively fine-grained glaciolacustrine or glaciomarine deposits. The uppermost part of the second deglaciation sequence comprises a thick fossiliferous mudstone unit, referred to as the "Ganigobis Shale Member". An abundance of marine macro- and ichnofossils as well as extrabasinally derived ashfall tuff horizons characterise the mudstones and provide the basis for an integrated high-resolution biostratigraphic and tephrostratigraphic framework.

The marine body and trace fossils record the extent of the first of a series of marine incursions into the disintegrating Gondwanan interior as early as the Carboniferous. Juvenile magmatic zircons separated from tuff horizons interbedded with the Ganigobis Shale Member yield SHRIMP-ages of 300-302 Ma. This dates the uppermost part of the second deglaciation sequence in southern Namibia to the late Carboniferous (Gzelian) and provides a minimum age for the onset of Karoo-equivalent marine deposition prior to the much more widespread Eurydesma transgression.

Introduction

Karoo equivalent strata are widespread in southern Africa (Smith *et al.*, 1993) and South America (Tankard *et al.*, 1995) and comprise mainly siliciclastic deposits which record a time interval lasting from the Late Carboniferous to the Early Jurassic. The glaciogenic Dwyka Group constitutes the lowest stratigraphic unit of the Karoo Supergroup and deposits are preserved at various localities in Namibia (cf. Haughton and Frommurze, 1927; 1936; Martin, 1981a; 1981b; Visser, 1983).

Whereas Dwyka Group sections in South Africa are dominated by thick diamictite units developing maximum thicknesses of 800 m (Visser, 1996), equivalent successions in southern Namibia preserve maximum thicknesses of 440 m and contain thick marine mudstone units interbedded with the diamictites. Two of the mudstone units are particularly widespread in southern Namibia and have been referred to as the Ganigobis Shale Member (Martin and Wilczewski, 1970) and the Hardap Shale Member (SACS, 1980), occurring higher in the succession. This contribution is focussed on the Dwyka Group in the Aranos and Karasburg basin areas of southern Namibia (Fig. 1), and more particularly, the Ganigobis Shale Member and its equivalents.

Table 1: Comparison between the lithological units of the Dwyka Group within the Aranos Basin suggested by Heath (1972) and the deglaciation sequences used in this study.

Heath (1972)	This study
Upper boulder mudstone	DS IV
Lower boulder mudstone	DS IV
Alternating sandstone and green mudstone	DS III: Hardap Shale Member
Tilloid and pebbly mudstone	DS III
Lower pebbly mudstone	DS II: Ganigobis Shale Member
Basal tillite	DS I/II

The principal framework of Dwyka deglaciation sequences in southern Namibia

Within the two southern Namibian outcrop areas the Dwyka Group is particularly well exposed along modern banks of (1) the Fish River between Mariental and Ganigobis and (2) the Orange River near Zwartbas, about 10 km west of Noordoewer (Fig. 1). Additional core material is provided by the Vreda well east of Mariental (Fig. 1). In both outcrop areas, Dwyka Group deposits rest unconfor-mably on sedimentary rocks of the Precambrian to lower Cambrian Nama Group (Gresse and Germs, 1993).

Applying the concept of deglaciation sequence analysis (Theron and Blignault, 1975; Visser, 1997), the Dwyka Group in southern Namibia can be subdivided into four upward-fining deglaciation sequences (DS). These compare well to the seven lithological units of the "Lower Stage" of the "Dwyka Series" described by Heath (1972); (Tab. 1).

Dwyka Group deposition begins with lodgement tillites of deglaciation sequence I (**DS I**) which reaches a maximum thickness of 10-25 m in the Mariental-

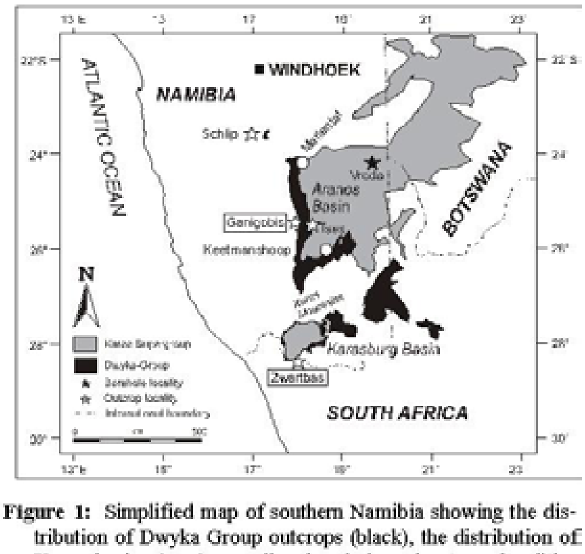

Figure 1: Simplified map of southern Namibia showing the distribution of Dwyka Group outcrops (black), the distribution of Karoo basins (grey) as well as borehole and outcrop localities mentioned in this study.

Ganigobis area (Fig. 3) where it has been described as "basal tillite" by Heath (1972). Both at the Ganigobis locality and in the Vreda borehole, DS I is capped by glaciolacustrine, varved siltstones and fine-grained sandstones. These are preserved preferentially as lenses associated with striated surfaces beneath the base of DS II. The continental subglacial facies association of DS I (Heath, 1972; Grill, 1997) is found in outcrops between Schlip and Tses (Fig. 1) and within the Vreda borehole but pinches out southwards. The absence of the continental facies association in the area west and south of Keetmanshoop is explained by a general southward deepening of the basin and an increasing distance from the ice margin which was presumably located farther north.

DS II, equating to the "lower pebbly mudstone" of Heath (1972), is well exposed in the eroded banks of the Fish River north of Ganigobis, east of the Anis Kubub farm and north of Gibeon (Fig. 2). It is also present in the Vreda borehole and at Zwartbas (Figs. 1 and 6). DS II is represented by a strongly heterolithic, upward-fining unit which records the transition from continental subglacial to continental proglacial and finally to marine proglacial environments (Heath, 1972). Northwest of Ganigobis the unit is 95 m thick and at Zwartbas about 100 m thick. A maximum thickness of about 240 m is present in the Vreda borehole. At Ganigobis, DS II starts with a distinctly glacially-scoured, coarse-grained tillite which is followed successively by channelised, trough-crossbedded conglomerates and weakly stratified diamictites representing tunnel-mouth deposits (Grill, 1997) and finally by dropstone-rich marine

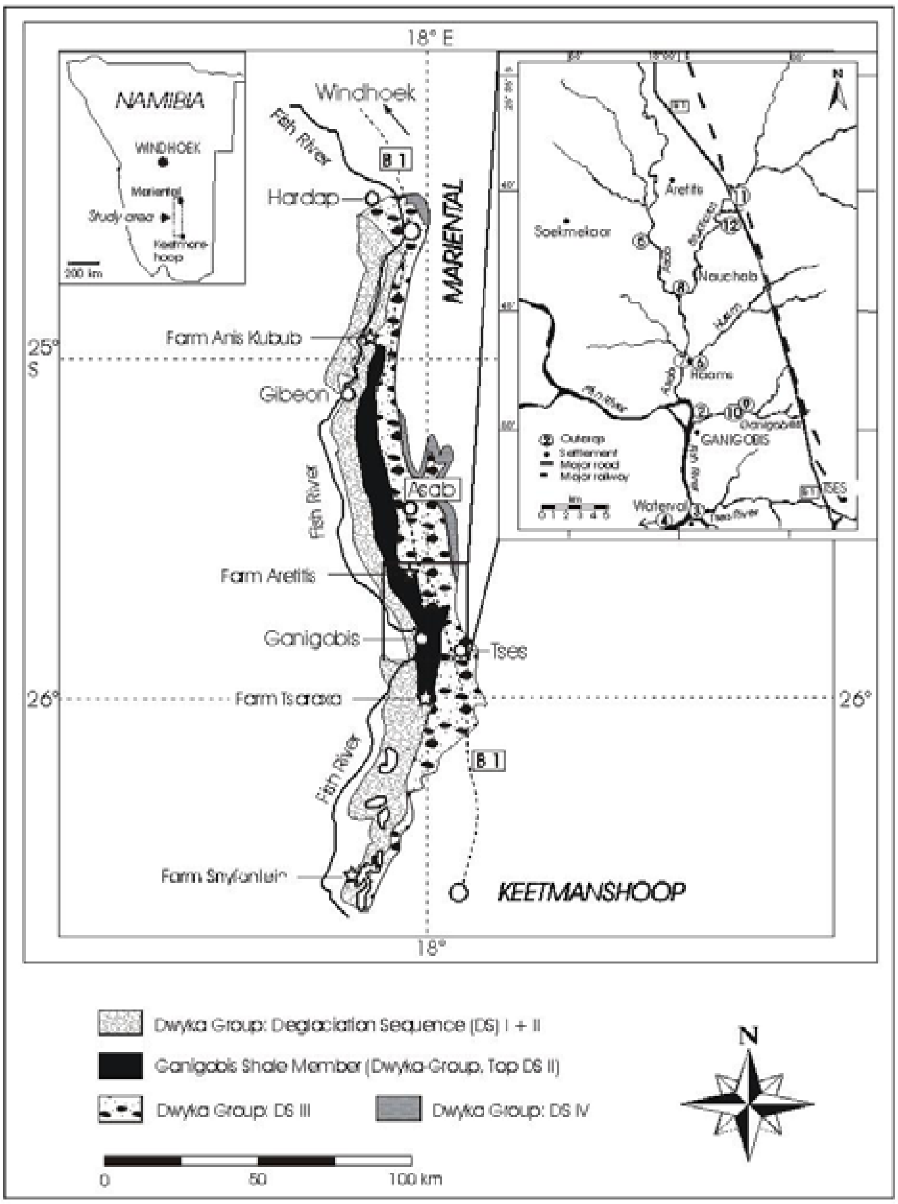

Figure 2: Simplified geological map of the area between Mariental and Keetmanshoop in southern Namibia showing the distribution of Dwyka Group deglaciation sequences (DS I-IV) and the Ganigobis Shale Member forming the uppermost part of DS II. Inset to the upper right provides a detailed location map of the type area of the Ganigobis Shale Member in the vicinity of Ganigobis, southern Namibia.

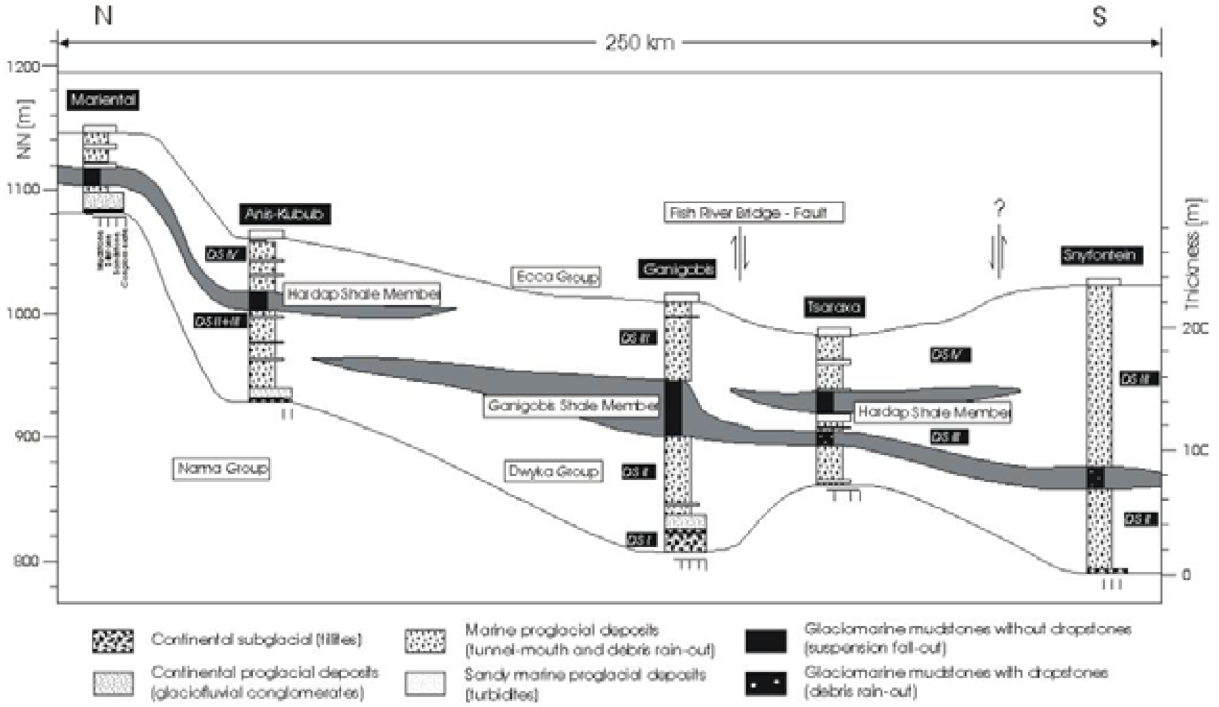

Figure 3: N-S cross-section between Mariental and Keetmanshoop illustrating the geometry of deglaciation sequences and the facies architecture of the Dwyka Group in southern Namibia showing important shale members. See Fig. 2 for location of individual sections.

mudstones, which were deposited in proximal to medial positions with respect to the ice margin (cf. von Brunn, 1996). In contrast, at Vreda, Snyfontein (Fig. 3) and Zwartbas the succession begins with marine, clast-poor diamictites formed by debris-rain out and dropstone-rich marine mudstones which may contain lenses of silty and sandy turbidite beds (cf. Visser, 1983; 1997). Particularly well developed at Ganigobis is a clast-poor diamictite unit, up to 30 m thick, with a fine-grained sandy to silty matrix that gradually changes up-section into massive or laminated mudstones with lonestones. Clasts embedded in these mudstones were released from debris-laden floating ice in a glaciomarine environment (Grill, 1997). A prominent, essentially dropstone-free, silty mudstone unit, termed Ganigobis Shale Member (Martin and Wilczewski, 1970), forms the uppermost part of DS II. Both sedimentary structures and fossil content suggest deposition mainly by offshore suspension load settling in a fully marine environment (Grill, 1997; Stollhofen *et al.*, in press). This mudstone unit is more than 40 m thick at Ganigobis and 65 m thick at Zwartbas and contains bentonitic ashfall tuff horizons, abundant concretionary nodules with remains of paleoniscoid fishes and bivalves besides various other fossil remnants and ichnofossils which are a major subject of our study.

DS III comprises (1) the "zone of alternating tilloid and pebbly mudstones", (2) the "zone of alternating sandstone and mudstone" and (3) the "zone of the yellow-green mudstone" of Heath (1972). DS III reaches a maximum thickness of about 120 m in the Vreda borehole (Fig. 4) but decreases to a thickness of 60 m in the vicinity of Ganigobis. At Zwartbas, DS III and overlying units are poorly exposed and will therefore not be considered. In the Vreda borehole, DS III mainly comprises weakly stratified proglacial tunnel mouth and debris rain-out diamictites and thick massive or cross-bedded sandstones, representing sediment gravity flow deposits (Heath, 1972; Grill, 1997). In contrast, outcrops in the vicinity of Ganigobis show only silty mudstones which contain isolated granitic or gneissic dropstones deposited by debris rain-out from floating icebergs. The top of DS III comprises a widespread, up to 75 m thick mudstone unit which starts with dropstone-rich sandy mudstones at its base. As sand and dropstone content decrease upwards, these dropstone-rich mudstones grade up-section into plane bedded dropstone-free mudstones. The latter are well exposed 4 km southeast of Hardap dam (Fig. 2) and have been referred to as Hardap Shale Member (SACS, 1980). This unit is characterised by occurrences of the marine bivalve *Eurydesma mytiloides* (Heath, 1972), Bryozoa and Asteroidea (Martin and Wilczewski, 1970) and thus relates to the Gondwana-wide Eurydesma-transgression (Dickins, 1984). In the area between Mariental and Anis Kubub farm (Fig. 2), massive or cross-bedded turbiditic sandstones showing Bouma B, C, and D subdivisions are intercalated and locally constitute up to 40% of the sequence (Heath, 1972; Grill, 1997).

DS IV is equivalent to the "lower" and "upper boulder-mudstone" zones of Heath (1972). The sequence is 60 m thick in the Vreda borehole but poorly exposed in

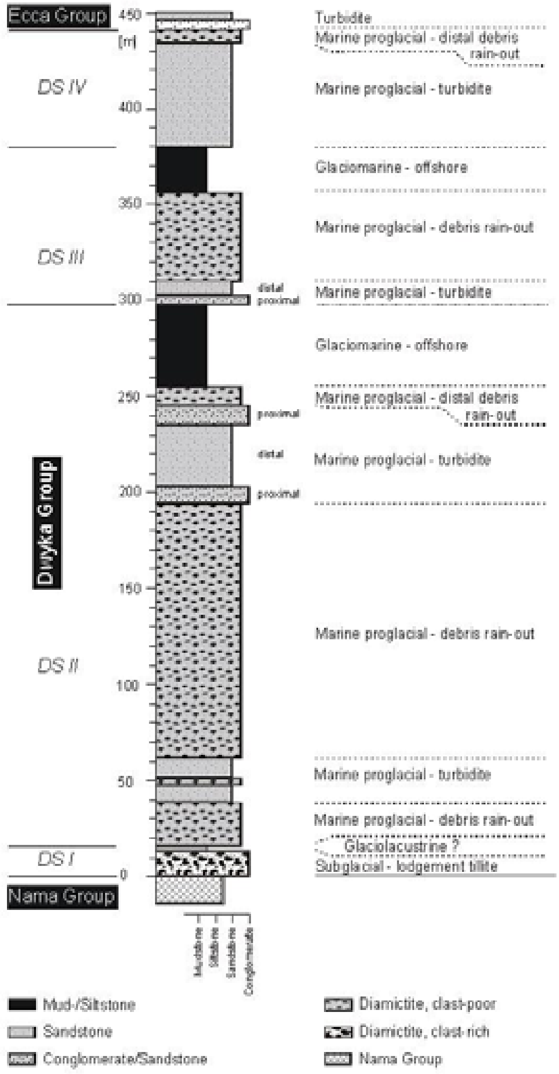

Figure 4: Logged borehole section of the Vreda borehole in southeastern Namibia (see Fig. 1 for location) showing the subdivision of the glaciogenic Dwyka Group based on deglaciation sequences (modified from Grill, 1997).

outcrops east of Asab. It consists of normally graded gravity flow sandstones followed by weakly bedded dropstone-bearing mudstones (Grill, 1997). This sequence is capped by greenish, dropstone-free mudstones containing thin (< 10 cm) graded sand horizons that are interpreted as distal prodeltaic turbidite beds (Kingsley, 1990) which define the base of the overlying, fluvially dominated delta complex of the Nossob Member (Prince Albert Formation).

The Ganigobis Shale Member and its equivalents in southern Namibia

This paper focuses on the Ganigobis Shale Member, forming the uppermost part of DS II, since no other shale unit with an equivalent thickness and a similar abundance of well preserved marine fossils and tuff horizons is known from the Dwyka Group of southern Africa (cf. Martin and Wilczewski, 1970). Both tuff beds and the fossil content provide the ideal background for the establishment of a high-resolution stratigraphic framework upon which radiometric dating of pyroclastic marker horizons could be superimposed.

Outcrops of the Ganigobis Shale Member can be traced from Snyfontein farm (west of Keetmanshoop) in the south to the Anis Kubub farm (southsouthwest of Mariental) in the north over a distance of about 180 km (Fig. 2). In this area the Dwyka Group dips at < 5° to the east. North of Aretitis farm (Fig. 2) the Ganigobis Shale Member grades into greenish silty shales which lack tuff horizons. By ana-logy, dropstone-bearing shales with only very thin bentonitic tuff horizons and only a few concretions containing fish remains occur south of Snyfontein farm. The dropstone-free facies of the Ganigobis Shale Member with the highest number of tuff beds and fossils is restricted to an outcrop area between Tsaraxa and Aretitis farms which is therefore chosen as type area for this study.

At Zwartbas, equivalent rocks of the Ganigobis Shale Member are well exposed for a distance of about 1 km on the north bank of the Orange River (28° 41’43” S / 17° 33’26”E to 28° 41’19” S / 17° 33’62” E). There, the dip of the shales changes over a distance of about 500 m from flat lying strata in the east to steep dipping in the west. This change of dips is attributed to the deformation caused by overriding glaciers.

Tephrostratigraphy of the Ganigobis Shale Member

In its type area, the Ganigobis Shale Member embodies 21 fine-grained ash-fall derived tuff horizons, 0.1-2.5 cm thick, which are bundled into 8 groups (Fig. 5). The shales at Zwartbas contain 65 tuff horizons, 0.1-3.5 cm thick, which occur in 38 groups. At Ganigobis the tuffs and the enclosed shale intervals can be traced laterally over tens of kilometres. Cm-thick but widespread, graded layers with sharp planar lower contacts together with fine-grained, well sorted grain sizes suggest a distal pyroclastic fallout origin for the majority of the tuff horizons (Grill, 1997; Stollhofen, 1999). The tuffs are yellowish-brown due to intense alteration of the primary volcanic ash to mixed layered smectite-illite clays. The volcanic origin is proven by juvenile quartz and plagioclase crystal fragments, along with platy volcanic glass shard pseudomorphs and a heavy mineral suite consisting of juvenile zircon, apatite, monazite and occasionally sphene (Bangert *et al.*, 1999).

Juvenile, magmatic zircon grains separated from the tuff horizon IIb at localities #3 and #4 in the Ganigobis area gave $^{206*}Pb/^{238}U$ ages of 302.0±3.0 Ma and 299.5±3.1 Ma, respectively (Bangert *et al.*, 1999). SHRIMP-analyses carried out on zircons separated from tuff horizons IIIb and XXXIV at Zwartbas (Fig. 6), gave weighted mean $^{206*}Pb/^{238}U$ ages of 302.3 ± 2.1 Ma and 300.3 ± 6.3 Ma, respectively (Bangert, 2000).

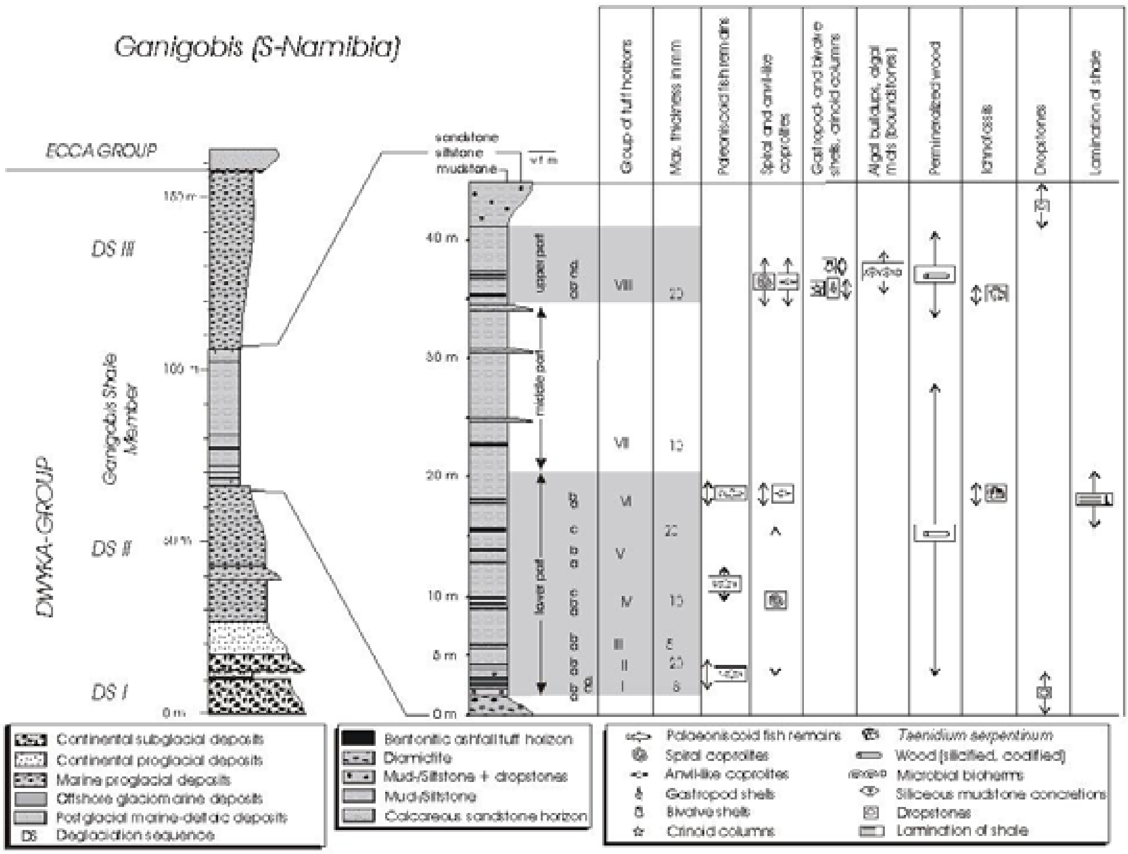

Figure 5: Logged section of the Dwyka Group in the vicinity of Ganigobis (southern Namibia) with proposed deglaciation sequences (cf. Visser, 1997). Detailed tephrostratigraphy and fossil record of the glaciomarine Ganigobis Shale Member at Ganigobis is shown in the right column. See Fig. 2 for location.

This confirms the correlation between the two outcrop areas which is based on the framework of deglaciation sequences. According to the new radiometric age determinations, the Ganigobis Shale Member falls within the late Carboniferous Kasimovian stage (cf. Menning *et al.*, 1997).

Petrography of the Ganigobis Shale Member

In its type area (the vicinity of Ganigobis), the shales of the Ganigobis Shale Member vary in colour from medium grey to bluish-black and exhibit a threefold subdivision. The lower part of the succession (up to 1.5 m above tuff horizon VIb, Fig. 5) consists of bluish-black massive, silty mudstones from the base up to tuff horizon Vc. Medium grey silty mudstones, which display a distinct lamination with an average laminae thickness of < 1mm, occur from close above tuff horizon Vc up to 1.5 m above tuff horizon VIb (Fig. 5). The middle part of the Ganigobis Shale Member (from 1.5 m above tuff horizon VIb to tuff horizon VIIIa) mainly consists of black mudstones and commonly contains normally graded, calcareous, less than 1 m thick sandstone interbeds which are interpreted as distal turbidite deposits. The upper part (from tuff horizon VIIIa to the top of the Ganigobis Shale Member) is again comprised of black mudstones with sporadic sandstone interbeds.

The silty mudstones of the Ganigobis Shale Member mainly consist of quartz, illitic-chloritic clay minerals and feldspars. Total organic carbon contents vary between 0.7-2.4 weight % (Bangert, 2000), with low values for inorganic carbon (0-0.1 weight %, Grill, 1997) and sulphur contents of up to 1.16 weight % (Bangert, 2000).

At Ganigobis, dropstones occur in decreasing numbers towards a level 0.7 m below tuff horizon Ia (Fig. 5). Between tuff horizon groups II and V isolated dropstones were found, whereas dropstones are absent higher up in the succession. The section at Zwartbas contains dropstone-bearing horizons scattered throughout the whole succession. The majority of the dropstones are well rounded to subrounded, a few are also faceted and striated. A maximum clast size of 1.5 m diameter has been measured at Zwartbas and 0.6 m at Ganigobis, with an average of 3 cm and 1 cm, respectively. At Ganigobis clasts mainly comprise reddish and greyish quartzites, less frequently also granitic and undeformed gabbroid, trachytic, andesitic and basaltic dropstones occur, the latter two being frequently amygdaloidal. Dropstones at Zwartbas, however, mainly comprise subangular plates of grey to green schist and quartzite, with less common pebbles of granite, pegmatite, gneiss, and amygdaloidal basalts.

The majority of the fossils described below are con-

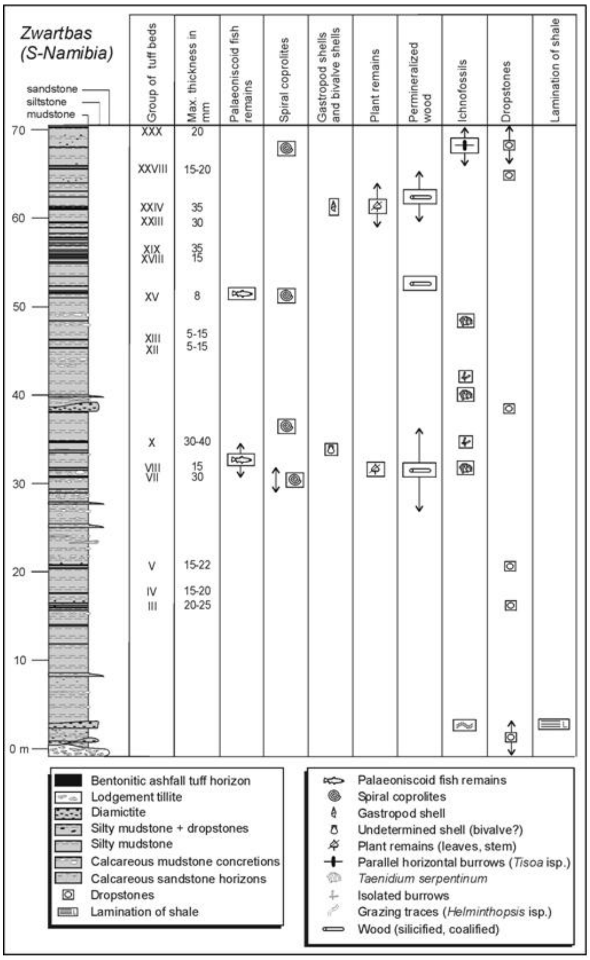

Figure 6: Logged section of the basal part of the Dwyka Group in the vicinity of Zwartbas combined with the detailed tephrostratigraphy and fossil record of Ganigobis Shale Member equivalent deposits (Dwyka Group, southern Namibia). See Fig. 1 for location.

tained within phosphatic-siliceous concretions. The concretions are mostly spherical to disc-shaped and flattened parallel to bedding with a typical diameter of 3-8 cm and a thickness of 1-6 cm. In places they amalgamate to form laterally intermittent layers up to 0.3 m thick and several tens of meters wide. Particularly in the middle part of the Ganigobis Shale Member in its type area, yellowish weat-hering (sodiumjarosite?), pyrite-bearing mudstone concretions occur around cm-sized, funnel-shaped coprolites.

Fossil record of the Ganigobis Shale Member

Palaeoniscoid fishes

Scales, fins, skull fragments and jaws with rows of 1 mm-sized teeth of disarticulated paleoniscoid fishes are preserved in numerous, oval-shaped, phosphatic-siliceous concretions, some with disseminated fine-grained pyrite. The fish remains are mostly oriented perpendicular to the c-axis of the concretions, in places they are preserved in oblique or dorso-ventral position (Evans, 1998). Except for one example occurring in locality #4 (Fig. 2), the fishes were never found articulated. Entire skulls are commonly preserved solely within mudstone concretions; other concretions only show the caudal areas of the fish in an articulated and splayed state, without anterior trunk. It is significant that fossil finds are strictly confined to certain stratigraphic intervals only, associated with tephrostratigraphic marker horizons Id-IIb, IVc-Va and VIa-VIb at Ganigobis (Fig. 5) and VIb-IXa and XIV to XVIa at Zwartbas (Fig. 6).

All of the fish remains found in the Ganigobis Shale Member at localities #2, 3, 4 and 7 near Ganigobis belong to palaeoniscoid fishes (order: Palaeoniscoidea; family: Acrolepidae). Two thirds of the sampled concretions contained remains of *Namaichthys schroederi* Gürich whereas the contents of one third most probably belong to *Watsonichthys lotzi* Gürich (cf. Gürich, 1923; Gardiner, 1962). As the fossilised bones of the fishes are mostly disrupted, generic names were mainly assigned on the basis of analyses of the mostly coherently

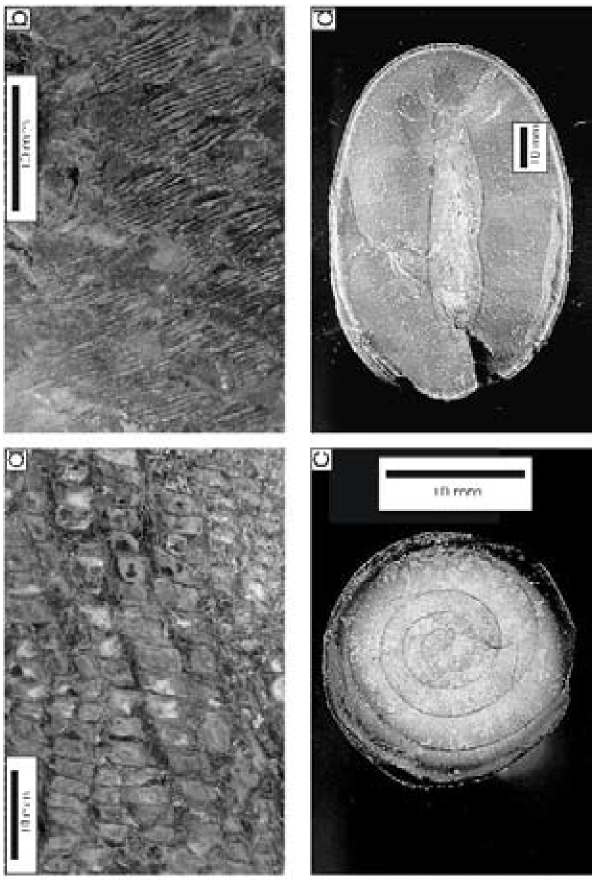

Figure 7: Fossil record of the Ganigobis Shale Member illustrated by:
- a, Scales of palaeoniscoid fish *Namaichthys schroederi* Gürich. Note the missing ornamentation and the missing imbrication of the scales (cf. Fig. 7b).
- b, Scales of palaeoniscoid fish *Watsonichthys lotzi* Gürich. Note the strong ornamentation and the imbrication of the scales (cf. Fig. 7a).
- c, Cross section of a spiral coprolite showing an enrolment with 5 whorls.
- d, Longitudinal section of a spiral coprolite showing a flattened conical shape.

preserved scales which are recorded in about half of the sampled concretions. Two major types of fish scales were recognised (Schultze, 1999 pers. comm.):

(a) Rhombic to rectangular scales: not imbricated, slight or no ornamentation, partly bluish enamel, size: 2-4x1-4 mm: *Namaichthys schroederi* Gürich (Fig. 7a).
(b) Rhombic scales: mostly imbricated, partly rounded, strongly ornamented, about 8 ridges parallel to the long axis of the rhombohedran, no bluish enamel, size: 5-7x3-5 mm: *Watsonichthys lotzi* Gürich (Fig. 7b).

Additional species were described by Gürich (1923) from the Ganigobis type area as *Elonichthys?* sp. along with *Rhadinichthys?* sp. and a fifth genus by Range (1928) as *Helichthys loangwae*. The descriptions of the two genera by Gürich (1923), however, were based on fragmentary remains and are thus doubtful (Gardiner, 1962).

Coprolites

Basically two types of coprolites occur within the Ganigobis Shale Member: (1) spiral coprolites and (2) anvil-shaped coprolites. Coprolites of the first type are frequently found at two stratigraphic levels within the lower part (tuff horizons Id-Va) and the upper part (tuff horizons VIIIa-VIIId) of the Ganigobis Shale Member in its type area. At Zwartbas, they have been determined at four stratigraphic levels, coinciding with tuff horizons VIa-VIIIb, 2 m below XIb, and immediately below XV and XXIX. The coprolites are up to 5 cm long and 2 cm in diameter and form the nuclei of siliceous mudstone concretions of type one, in places containing finely dispersed pyrite. Typically they display a spiral-like structure with up to 5 spirals in cross-section (Fig. 7c) whereas longitudinal sections (Fig. 7d) reveal a flattened conical shape displaying small hooks at the turning points. These structures have been regarded as being ”enterospirae” i.e. the fossilised content of an intestinal spiral valve, probably of a shark (McLachlan and Anderson, 1973).

Anvil-shaped coprolites were found in the Ganigobis area to occur only at a stratigraphic level defined by marker horizons VIa-VIb and VIIIa. They are particularly abundant at localities #8 and 12 (Fig. 2). The structures are elongate with conical terminations, measure up to 15 cm in length and 2 cm in diameter and reveal quadratic to rhomboidal cross-sections. They are made up of a brownish ferruginous, coarse-grained sparitic material. Such coprolites are mostly oriented vertically to sub-vertically to the bedding of the enclosing mudstones and only a few were found embedded in siliceous mudstone concretions.

Microbial bioherms

In the Ganigobis type area only, columnar, microbial limestone bioherms (Fig. 8) reaching a height of up to 2.5 m and a maximum width of 1.5 m were found. They are embedded in black massive mudstones and grey calcareous nodular siltstones at the stratigraphic level of marker horizons VIIIa-VIIId. In plan view, these structures form mounds with diameters of up to 4-5 m and heights of up to 1.5 m. Localities #9, 11 and 12 (Fig. 2) provide excellent exposures with the latter two showing the bioherms in plan view.

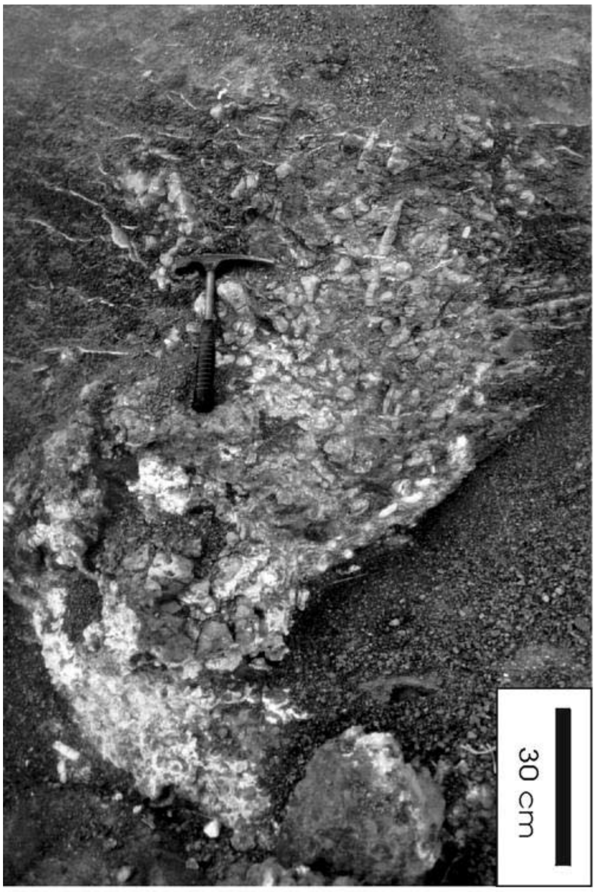

Figure 8: Outcrop photograph of columnar, microbial limestone bioherm with micritic limestone tubes, up to 40 cm long and up to 1 cm in diameter (scale equals 1 m), probably representing burrows (locality #9).

At locality # 9 (Fig. 2), Grill (1997) distinguished four facies types: (1) the algal mat facies, (2) the algal-serpulid build-up facies (3) the nodular micrite build-up facies and (4) the nodular siltstone (inter-build-up) facies. The “algal mat facies” is characterised by relatively thin boundstone horizons which reach thicknesses of about 5-20 cm and tend to rest on the top of tuff horizon VIIIa. This facies is essentially made up of up to 10 mm-thick limestone layers produced by blue-green algae (Cyanophycean algae) interbedded with thin (1-4 mm) mudstone layers (Grill, 1997). The “algal-serpulid build-up facies” forms the major vertical structures and are mainly comprised of boundstones made up of Dasycladacean algae (*Mizzia* sp.), Cyanophycean algae as well as less frequent serpulids, ostracod shells and sponge spicules (Grill, 1997). Associated with these build-ups are micritic limestone tubes up to 40 cm long and about 1 cm in diameter (Fig. 8) which probably represent burrowing structures. The “nodular micrite build-up facies” consists of nodules of brownish-grey, massive, micritic limestone up to 5x3 cm in size with a few Dasycladacean algae as the only apparent fossils.

Between the bioherms, grey calcareous, nodular siltstones predominate containing large calcareous concretions up to 30x6 cm in size. This “nodular siltstone facies” is relatively devoid of body fossils but in some of the concretions debris of the biogenic build-up material is preserved (Grill, 1997).

Gastropods

Numerous gastropod shells of a single species were discovered in the Ganigobis area (locality #12), in the vicinity of the microbial bioherms. The shells are restricted to a relatively narrow stratigraphic interval marked by tuff horizon VIIIa. They are found concentrated in irregular, partly branching mudstone concretions which appear to represent fossilised burrows with widths of up to 10 cm. The height of the gastropods averages 5 mm with a maximum of 10 mm and a width of about 6 mm. Most of the shells are poorly preserved and show three, but in some cases also four or five whorls. The upper whorl surface is almost straight with the slit-band at the outer edge (Fig. 9a). Below the slit-band the outline of the shell is concave and the apical angle ranges from 38° to 46°. The shells are related to *Peruvispira vipersdorfensis* Dickins. The type examples of this gastropod species came from the Vipersdorf 63 farm near Gibeon (Fig. 2) and have been described by Dickins (1961) along with additional material from the Tses Reserve near the main road B1, 13 km north of Tses. The latter sample site most probably corresponds to locality #12.

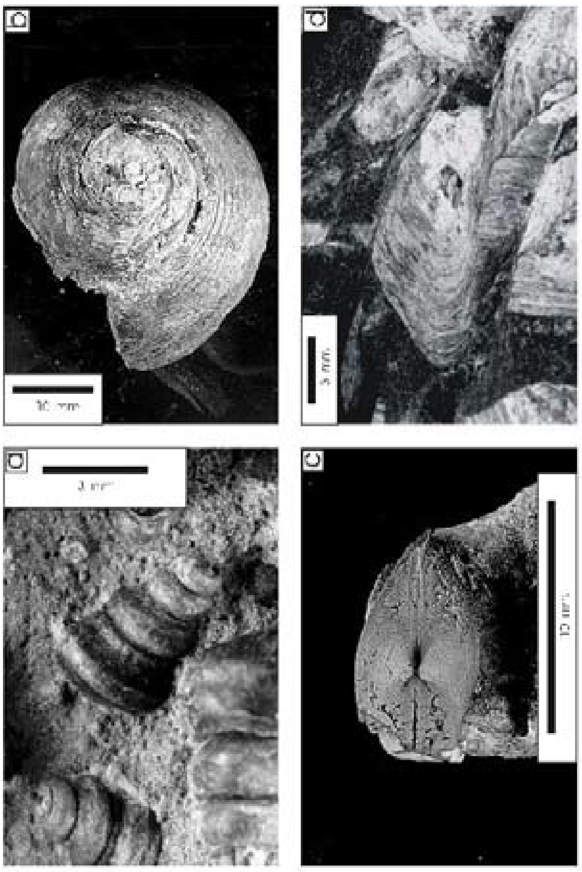

Figure 9: Fossil record of the Ganigobis Shale Member
a, Gastropod shell of the genus *Peruvispira vipersdorfensis* (Dickins, 1961). Shells mainly display three whorls, only a few show four or five whorls.
b, Gastropod shell of the genus *Omphalonema* (apical view) showing a turbiniform shape, a spiral-like ornamentation, no shoulder and a narrow umbilicus.
c, Dorsal view of a nuculanid bivalve (genus *Paleyoldia*, family Nuculanidae) showing a subtrigonal shell with concentric ornamentation and a palaeotaxodont hinge (collected by H. Grill).
d, Bivalve shells probably of the genus *Myonia* with thin, elongate shells; note the prominent growth lines.

A single, weakly trochospiral, gastropod shell with a maximum diameter of 4.3x3.2 cm and a height of 2.5 cm was found 2 m below tuff horizon VIIIa at locality #11. The turbiniform shape and the spiral-like ornament suggest a relation to the genus *Omphalonema* (superfamily Platyceratacea; family: Holopeidae). *Omphalonema* has no shoulders and the umbilicus is narrow (not seen in the illustrated sample, Fig. 9b). This genus has not previously been recorded in the Dwyka Group of southern Africa but has been described from the lower Permian of northeast Asia (Grabau, 1936).

At Zwartbas, only one evolute, trochospiral gastropod shell, measuring 0.6 cm in height was found between tuff horizons XXIV and XXV but is indeterminable due to its poor preservation.

Bivalves

Two types of bivalve shells have been found in association with tuff horizons VIIIa-VIIIc in the vicinity of Ganigobis (localities #9 and 11). At locality #11 two small bivalves were collected. The shell has a subtrigonal shape and is equivalved, the anterior side is elongated and the posterior side is truncated without any ornamentation. The anterior-posterior diameter ranges between 5 and 6 mm and the dorso-ventral diameter totals 3 mm. It is further characterised by a taxodont hinge; the teeth cannot be seen. These shells relate to the family Nuculidae. Nuculanid bivalves of the genus *Paleyoldia* sp. (Nuculanidae) were also identified by Grill (1997) at locality #9 (Fig. 9c). The nuculanids *Phestia* sp. along with *Nuculopsis* sp. are described from the Prince Albert Formation (Ecca Group) at Blaauw Krantz farm in the northwestern part of the main Karoo Basin (McLachlan and Anderson, 1973).

The second type of bivalve is thin-shelled and elongate, with an anterior-posterior diameter up to 1 cm and the dorso-ventral diameter up to 4 mm (Fig. 9d). Furthermore, the shells are characterised by prominent growth lines. Hinge and teeth cannot be seen. The bivalves most probably belong to the genus *Myonia* (subclass: Anomalodesmata; order: Pholadomyoida). *Myonia* is well known from Carboniferous to Permian strata in Australia, India, Brazil and Argentina (Rocha-Campos, 1970). The bivalves were discovered in a large mudstone concretion 55 cm above tuff marker VIIIa at locality #11.

At Zwartbas, two external shell moulds were observed between tuff horizons IX and X. The mould is crescent-shaped with a curved ridge extending from the shorter wing to the middle of the convex side. Dendritic structures cover the shell. The shape of the moulds suggests either a bivalve or crustacean.

Conulariida

The presence of *Conularia* sp. (class: Scyphozoa, subclass: Conulata) in the Ganigobis type area has been originally reported by Schroeder (1908) and illustrated by Range (1912). A sample of *Conularia* sp. collected at locality #12 was found at the stratigraphic level of tuff marker horizon VIIIa. It is characterised by a conical shape and a maximum length of 3 cm with a diameter of 1.5 cm. The upper end is rectangular in cross-section and the outer surface is covered by a grid of fine lines.

Porifera

Sponge spicules have been reported from the vicinity of Tses occurring in Dwyka Group strata above the Ganigobis Shale Member (Martin and Wilczewski, 1970). Sponge spicules which partly branch were found at the level of tuff group VIII. The sponge spicules display irregular shapes and possess a 1 mm thick, calcareous peel. Localities #9 and #10 in particular show abundant spicules associated with the algal-serpulid build-up facies described above. The sponges most probably found support on the slightly elevated microbial bioherms.

Crinoid stalks

Boundstones of the nodular micrite build-up facies contain stalks of crinoids and small sponge spicules. They were collected next to bioherm mounds at locality #12 in the Ganigobis area. The stalk segments have 0.2-1.0 cm length with 0.1-0.5 cm diameter; single ossicles are <0.1-0.2 cm long. The host rock displays angular to subrounded clasts of grey micrite embedded in a brownish, sparitic matrix with the crinoid stalks oriented in various directions. This shows that the crinoids were not preserved in their living position, indicating reworking of the crinoid stalks.

Permineralised wood

Pieces of silicified wood and plant remains (Phyllotheca) are common both at Ganigobis and Zwartbas (Figs. 5 and 6). In the Ganigobis area, logs and fragments of permineralised wood were found in two stratigraphic intervals (1) from 0.75 m above tuff horizon Ic up-section to 1.1 m below tuff horizon Vc (locality #2) and (2) from 2m below tuff horizon VIIIa up to tuff VIIIe at localities #11 and 12. Samples from the lower stratigraphic level were identified as *Araucarioxylon* sp. Kräusel (Bamford, pers. comm. 1999). The logs are usually flattened to oval-shaped in cross-section with some surfaces draped by a thin coaly layer. The upper stratigraphic level provided logs of *Megaporoxylon scherzi* Kräusel (Bangert and Bamford, in press.) showing particularly well preserved annual growth rings, 1-7 mm thick.

At Zwartbas, fragments of permineralised wood are concentrated at three stratigraphic levels (Fig. 6), with some of the wood fragments enclosed in concretions. Logs are preferentially associated with tuff group VI and the stratigraphic intervals between tuff groups IX and X and between XVI and XXVIII.

Trace fossils

Planar bedding planes of fine-grained, turbiditic sandstones at locality #12 reveal four types of trace fossils occurring at the stratigraphic level of tuff group VIII: (1) unbranched, straight to gently curved sub-horizontal burrows (< 3 mm wide and 1-2 cm long), interpreted as *Planolites* isp., (2) U- and S-shaped, meandering trails 1 mm wide and up to 5 mm long, interpreted as *Planolites montanus*, (3) U-shaped meandering traces, cyclindrical with menisci-like fillings about 8 mm wide, and (4) up to 15 cm long, mudstone-filled tubes with of up to 2 cm diameter. Types three and four were probably produced by deposit-feeding burrowing organisms. Particularly well preserved trace fossils of the ichnogenus *Taenidium*, up to 10 cm long and 0.5 cm wide, with single menisci, were found at locality # 8 associated with a fine-grained, turbiditic sandstone horizon. Even if all of these traces are not indicative of a particular facies, is a marine rather than a non-marine palaeo-environment indicated by the high degreee of bioturbation.

At Zwartbas, traces of *Helminthopsis* isp. only occur 1.1-1.6 m above the base of deglaciation sequence II within a varved horizon. The highest degree of bioturbation, however, is developed in the central part of the section. Conspicuous worm-shaped traces identified as *Taenidium serpentinum* were observed between tuff horizons VII and XV. These traces cover black, fossiliferous concretions occurring within the mudstones. Fracture planes in the rocks give transverse sections of the bioturbated sediment, and show sediment-filled burrows winding their way through the mud without apparent orientation. The traces were probably produced by an infaunal deposit feeder. Higher in the section, at the level of tuff horizons X to XI, isolated horizontal or vertical burrows, 2-3 cm long, are present. The 0.5

cm thick hollow tubes with 0.1 cm thick walls are often filled with calcite. Two or even three, subparallel, cylindrical tubes within conical or cylindrical siliceous mudstone concretions (< 5 cm in diameter) represent the trace fossil *Tisoa* isp., found between tuff horizons XXVIII and XXXI. This type of trace fossil is a burrow generated either by an arthropod (Frey and Cowles, 1969) or suspension-feeding bivalves (Wang, 1997).

Conclusions

Widespread fallout tuff horizons have permitted the establishment of a detailed tephrostratigraphy in both outcrop areas of the Ganigobis Shale Member (Figs. 5 and 6). Considering the stratigraphic abundance of tuff horizons and of fossil fauna the sections of the Ganigobis Shale can be subdivided into three sub-units. Both fossils and tuffs are concentrated within a lower (Ganigobis tuff beds I-VI, Zwartbas tuff beds I-X) and an upper unit (Ganigobis tuff beds VIIIa-VIIIe, Zwartbas tuff beds XV-XXX). The intervening unit contains only a few fossils and tuff horizons (Figs. 5 and 6) but many sandy, calcareous turbidite beds. Fossils thus appear to be most abundant within those parts of the section which show the highest frequency of tuff horizons (e.g. tuffs VII-X at Zwartbas). This might not only be due to the preservation potential of the depositional environment, the influence of ash on climate and life should also be considered (cf. Axelrod, 1981).

The significance of the fossil biota in the Ganigobis Shale Member is that the majority are indicative of a marine depositional environment. This is particularly well constrained by occurrences of marine bivalves (*Paleyoldia* and *Myonia*), scyphozoans (*Conularia*), sponge spicules and crinoid stalks. The marine setting is further confirmed by published data on a nautiloid cephalopod (*Orthoceras* sp.; Du Toit, 1916), a goniatite (Eosianites [*Glaphyrites*]; Martin *et al.*, 1970), radiolaria (Martin and Wilczewski, 1970), foraminifers (*Hyperammina, Ammodiscus, Glomospira, Ammobacculites* and *Spiroplectammina*; Martin and Wilczewski, 1970) and a single arm of a starfish (Lane and Frakes, 1970) from equivalent stratigraphic levels. The occurrence of a goniatite and of a thriving population of radiolaria led Martin and Wilczewski (1970) to estimate water depths of about 600 m. The preservation of lamination at the top of the lower part of the shales outcropping at Ganigobis also suggests deposition below storm-wave base and the virtual absence of bioturbation. In addition, the abundance of finely disseminated pyrite indicates an dysaerobic to anaerobic basin floor during deposition of the laminites. The latter does not contradict the reported abundance and diversity of fossil fauna because much of the faunal remnants, such as the palaeoniscoid fishes are nektonic. The observation that abundant fossils of only one particular species (e.g. the gastropod *Peruvispira vipersdorfensis* or the fish *Namaichthys schroederi*) are concentrated at certain stratigraphic levels within strictly confined horizons most probably indicates a temporarily stressed environment. This might originate from short-term changes in sea water salinity, presumably during peaks of freshwater discharge.

Sections of the Ganigobis Shale Member exposed in the Ganigobis type area and in the vicinity of Zwartbas correlate over a distance of >330 km in terms of their position within the framework of Dwyka Group deglaciation sequences, their fossil record and their ages deduced from SHRIMP-dating of zircons separated from intercalated tuff beds. The new radiometric ages cluster around 300-302 Ma and indicate a late Carboniferous age for both occurrences of the Ganigobis Shale Member in southern Namibia. On the basis of additional radiometric ages, Bangert *et al.* (1999) calculated that the time involved in each of the Dwyka Group deglaciation sequences was about 5-7 Ma. These time spans are important as they provide reliable constraints on the duration of global tectono-eustatic events controlling relative sea-level changes during the deposition of the glaciogenic Dwyka Group (cf. Visser, 1997; Stollhofen *et al.*, 2000). In addition, the late Carboniferous dates provide a minimum age for the onset of Karoo-equivalent marine deposition prior to the much more widespread Eurydesma transgression (cf. Dickins, 1984). The extent and age of Dwyka-equivalent marine deposits in Africa (McLachlan and Anderson, 1973; Martin, 1975; Visser, 1997) and South America (Santos *et al.*, 1996) is also important from the geodynamic perspective as they trace the future line of disintegration between Africa and South America as early as during the Carboniferous (Stollhofen *et al.*, 2000).

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