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Report: Progress report on the sedimentology and stratigraphy of the Kuibis and Schwarzrand Subgroups, Witputs area, southwestern Namibia

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The Vendian-age Kuibis and Schwarzrand Subgroups of the Nama Group form a succession of shallow marine and minor fluvial sedimentary rocks exposed overmuch of central and southern Namibia. The sedimentology and sequence stratigraphy of the Kuibis and Schwarzrand Subgroups in the Witputs area are described. This study is part of a continuing work intended to place tighter environmental and geochronological constraints on the palaeontology and geochemistry of this important record of the Vendian earth and to investigate the relationship between the evolution of the Nama basin and the adjacent orogenic belts.

Introduction

During July to September of 1992, stratigraphic and geochronological studies of the Late Proterozoic Nama Group in Namibia were begun in order to reconstruct the depositional history of the Nama basin. Previous investigations of the Nama Group consisted of regional mapping and general description of facies (Germs, 1974; Germs, 1983) and K-Ar analysis of detrital micas (Horstmann *et al.*, 1990). This more detailed study will apply the concepts of sequence stratigraphy to identify unconformity bounded depositional sequences which can be used as time-lines for intrabasinal correlation (Vail *et al.*, 1977; Christie-Blick and Grotzinger, 1988; Van Wagoner *et al.*, 1990). In addition, U-Pb dating of zircons from ash beds and sandstone samples collected throughout the Nama Group (Fig. 1) will provide temporal calibration. The resulting time-stratigraphic framework will enable analysis of the sedimentation dynamics. Because the Nama Group is interpreted, at least in part, as foreland basin fill related to the Damara and Gariep orogenic belts (Fig. 2; Germs; 1974, Miller, 1983), this analysis will focus on determining the sedimentary response adjacent to orogenic evolution. In addition, because the Nama sediments were deposited during terminal Proterozoic and Early Cambrian time, this study will provide temporal and environmental constraints on the vast biological and geochemical changes that occurred during this important period in the earth's history (e.g. Knoll and Walter, 1992).

The Nama Group crops out extensively in central and southern Namibia. It consists of a mostly marine, carbonate and siliciclastic lower part (Kuibis and Schwarzrand Subgroups) and a fluvial upper part (Fish River Subgroup; Germs, 1983). This report summarises results of the first season's field work on exposures of the Kuibis and Schwarzrand Subgroups on the farm Witputs 31 between Rosh Pinah and Aus (Fig. 2).

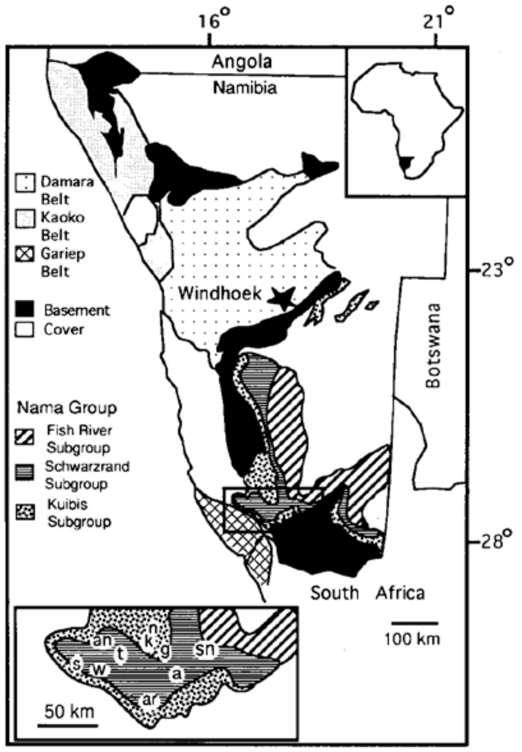

Figure 1: Map shows exposures of the Late Proterozoic Nama Group, and adjacent orogenic belts (after Miller, 1983; Horstmann, 1990). Inset shows location of measured sections on farms in the Witputs area of southern Namibia (a - Aub 81; ar - Arimas 93; g - Geelperdshoek 76; k - Kliphcok 72; n - Nooitgedacht 72; s - Swartkloofberg 95; sn - Sonntagsbrunn 108; t - Tierkloof 75; w - Witputs 31)

Kuibis Subgroup

The Nama Group non-conformably overlies crystalline basement throughout the study area. The contact is planar, extending for tens of kilometres with no discernible relief. The overlying Kanies, Mara, Kliphoek and Mooifontein Members of the Kuibis Subgroup comprise two sequences with coarse, siliciclastic bases and carbonate tops (Germs, 1983; Figs 1 and 3).

Description

Kanies Member

The Kanies member of the Kuibis Subgroup is characterised by very coarse to pebbly, poorly sorted, predominantly quartz sandstone. Beds range from 20-50 cm in thickness. They are laterally continuous and sheet-like in geometry.

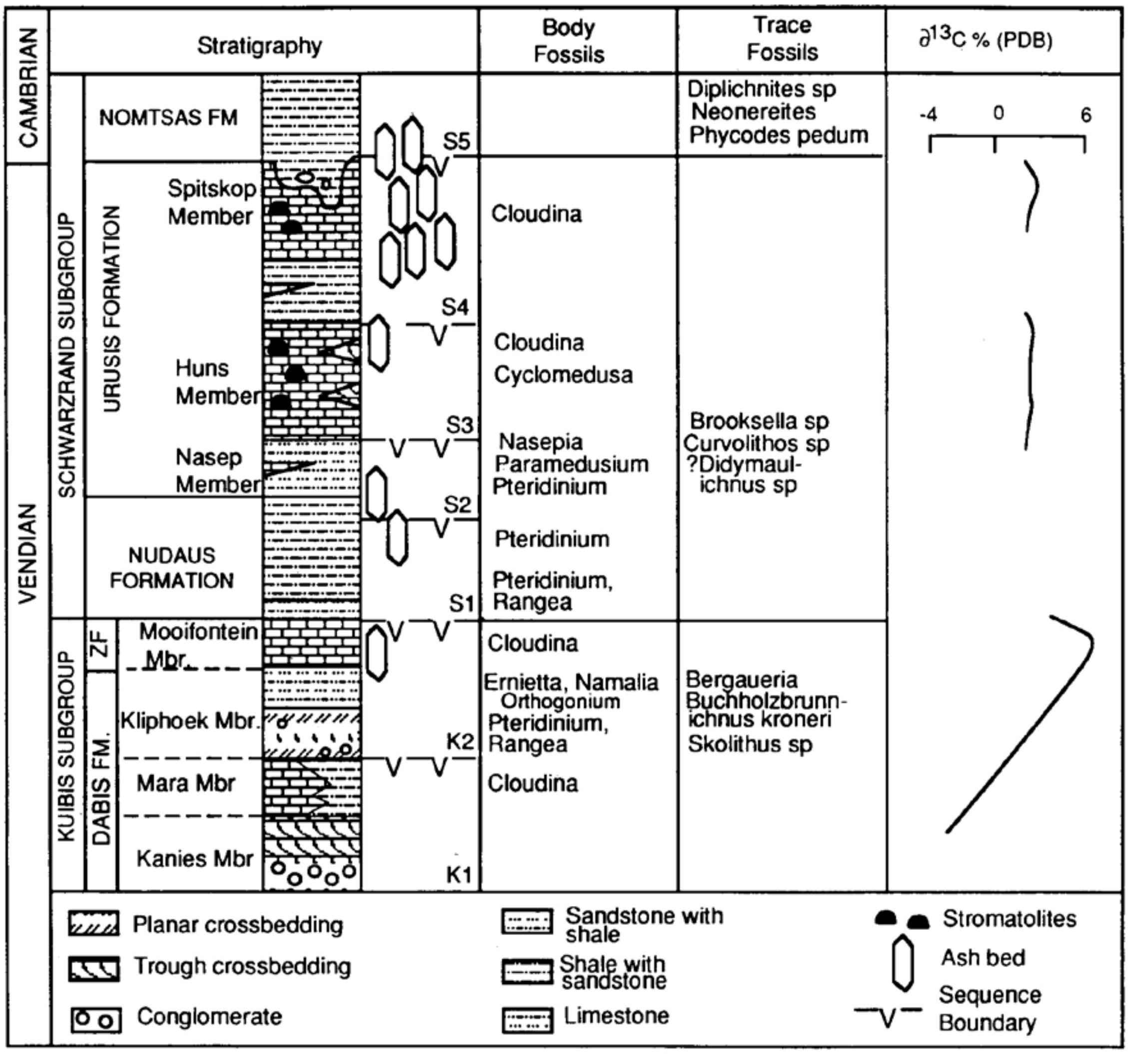

Figure 2: Generalised stratigraphic column for the Kuibis and Schwarzrand Subgroups (after Germs, 1983) showing fossil horizons, the values of Nama carbonates measured by Kaufman *et al.* (1991), sequence boundaries and the distribution of ash beds collected for U-Pb dating

Facies in the Kanies Member change from east to west (Fig. 3). In the field area's eastern exposures, abundant 5-20 cm scale trough cross-stratification predominates, but intervals of low-angle and hummocky cross-stratification also are present. Palaeocurrent measurements on trough azimuths are unimodal to the east, consistent with Germs' (1983) grouped measurements. In western exposures, planar-stratified sandstone with flase- to wavy bedding and minor ripples dominates the sedimentary style. Fine material, which is absent from eastern exposures, is present as shale partings and siltstone intervals in western sections. Mud chips are common throughout.

Mara Member

A one- to two-metre transitional interval of thinly interbedded siltstone, sandstone and sandy carbonate leads into the Mara carbonate member (Fig. 3). The Mara Member is characterised by thin- to medium-bedded calcisiltite and calcarenite. Beds are planar to irregular in geometry and range from 5-25 cm thick. Commonly the beds have sharp, scoured bases. Shale forms partings between carbonate beds and rarely is present as beds up to 20 cm thick. Planar stratification, as well as current- and wave-ripple laminations are abundant. Dolomitised carbonate mud commonly drapes the rippled calcarenite. There are dolomitised breccias, polygonal cracks, and flat-pebble intraclasts. Cross-stratified ooid and intraclast grainstone is a minor constituent.

Kliphoek Member

Coarse sand deposition recommenced with the Kliphoek Member which sharply overlies the Mara Member (Fig. 3). Eastern exposures of the Kliphoek Member consist of a lower, resistant sandstone unit and an upper more recessive sandstone and siltstone unit. The sandstone of the Kliphoek Member, like that of the Kanies Member, is coarse to pebbly, poorly sorted, composi-

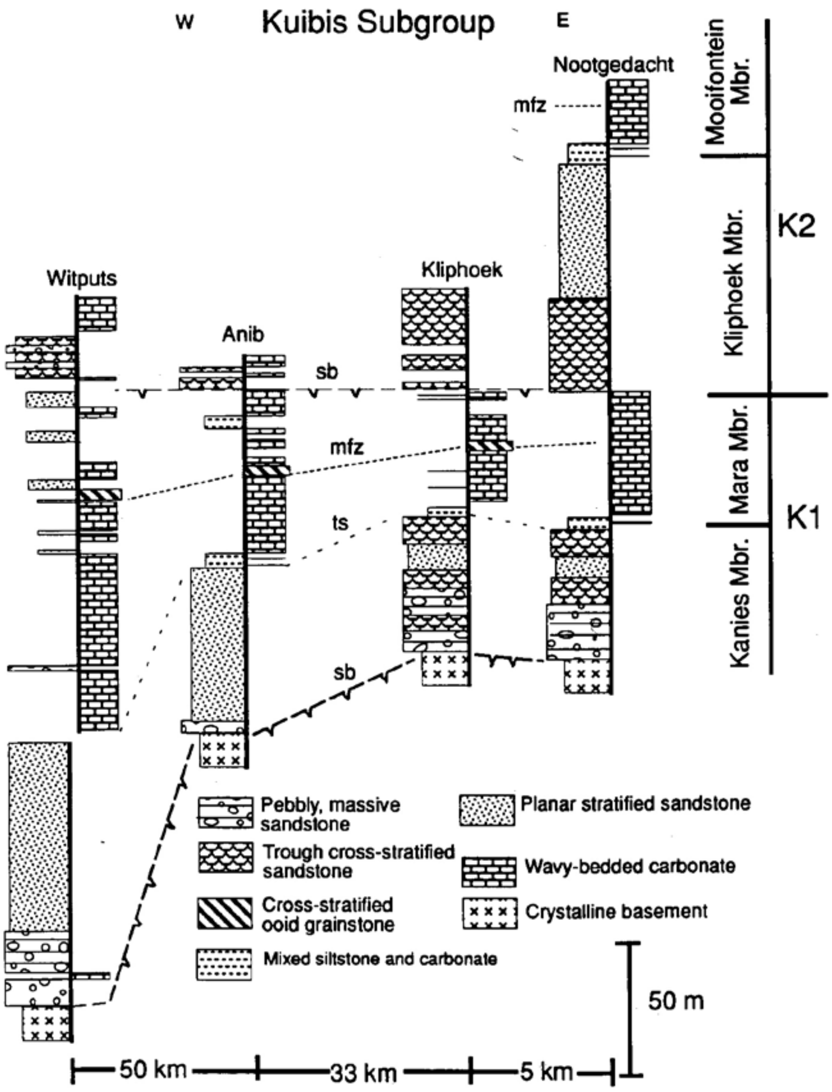

Figure 3: Representative measured stratigraphic sections through the Kuibis Subgroup showing the sequence stratigraphic framework

tionally mature and contains abundant mud chips. Beds range from 50-200 cm in thickness and are trough and planar cross-stratified. The troughs display unimodal southwest-directed palaeocurrents, which are consistent with Germs' (1983) previous measurements. In contrast to the Kanies Member, beds of the Kliphoek Member are irregular and lensoidal in geometry, with channels and scoured surfaces.

The upper unit of the Kliphoek Member usually crops out poorly. It is finer grained than the underlying unit and consists predominantly of medium-grained quartz sand and minor beds of red and green siltstone. Beds are 30-50 cm thick with generally poorly developed planar-stratification. Possible Ediacaran medusoids were found in this part of the Kliphoek Member. The presence of medusoids is consistent with Germs' (1972c) description of a variety of Ediacaran fauna from the upper Kuibis Subgroup.

In the western sections that were measured, the upper part of the Kliphoek Member is not exposed. There, the Kliphoek Member consists of metre-scale beds of coarse and pebbly sandstone within limestone (Fig. 3). The sandstone beds are 50 to 200 cm thick and are trough cross-stratified. They have sharp, scoured lower contacts and incorporate carbonate intraclasts near their bases. The limestone is generally thin and irregularly bedded, but there are also thicker beds of trough cross-stratified ooid and intraclast grainstone. In outcrop, the limestone appears to be quite pure, having only minor quartz pebbles at the bases of beds overlying sandstone.

Mooifontein Member

The Mooifontein Member consists of thin, irregular-bedded limestone composed of mixtures of carbonate silt and sand-sized particles, ooids, Cloudina, and carbonate intraclasts. There are rare beds of flat-pebble conglomerates. Chert nodules are common along bedding planes. Thin interbeds of red and green siltstone and calcisiltite characterise the upper and lower contacts of the Mooifontein Member.

Interpretation

The coarse grain size, abundant trough cross-stratification and unimodal palaeocurrents in the Kanies and Kliphoek Members, and the channelisation in the Kliphoek Member are consistent with either shallow marine or fluvial depositional environments. The presence of hummocky cross-stratification, flaser and wavy bedding, Ediacaran body fossils, and the lack of evidence for desiccation, however, suggest a predominantly shallow marine environment (Johnson, 1975; De Raaf *et al.*, 1977; Johnson, 1977a). In the Witputs area, the Kanies and Kliphoek Members are interpreted as mainly upper shoreface sandstone. An adjacent fluvial system introduced the coarse sand and produced strong currents and channels.

The carbonate members of the Kuibis Subgroup also record shallow marine conditions. Wavy bedding, ripples and desiccation cracks are all indicative of a shallow subtidal to tidal environment for some the Mara Member (Shinn, 1983). The thin interbeds of coarse and fine carbonate material that characterise the Mooifontein Member are similar to "ribbon rocks" described from many Neoproterozoic and lower Palaeozoic sections (Demicco, 1983). "Ribbon rocks" form in shallow-subtidal to intertidal environments. Because no signs of exposure were identified, the Mooifontein Member probably formed in a wave-influenced, predominantly shallow subtidal environment.

The above interpretations are consistent with Germs' (1983) interpretation of a fluvial to shallow marine environment for Kuibis Subgroup deposition. Palaeocurrent indicators and lateral facies changes, including the westward increase in carbonate and siltstone content, and the westward increase in wave- over current-generated features supports Germs' (1983) interpretation that deposition occurred on a westward-dipping shelf.

Discussion

The Kanies and Mara Members of the Kuibis Subgroup compose the K1 sequence, the lowest depositional sequence in the Nama Group. The base of the Mara Member is a flooding surface (Fig. 3). Because both the Kanies and the Mara Members consist of shallow-water facies, the rapid lithology change from coarse-grained sand to pure carbonate reflects, not so much a change in water depth, but instead, a shut-off of the siliciclastic sediment influx. Probably, the coarse siliciclastic sediments were trapped in the near-shore environment while the carbonate sediments developed best in the clear, more distal environments (Holmes and Evans, 1963; Mount, 1984). Marine transgression pushed the siliciclastic shoreline far landward shutting off the siliciclastic input to the basin and allowing the carbonate sediments to onlap. Carbonate production rates were sufficiently high to maintain shallow-water conditions. This interpretation is consistent with sedimentary facies relations and palaeocurrent measurements that indicate a cratonic siliciclastic source located eastward of a carbonate source.

Following the Mara transgression, relative sea-level fall caused shoreline progradation which injected coarse sand into the basin. The abrupt superposition of the coarse sandstone of the Kliphoek Member over the carbonate of the Mara Member resulted from this injection and is interpreted as a sequence boundary (Fig. 3). There may be a corresponding craton ward erosional unconformity.

The K2 sequence consists of the Kliphoek and Mooifontein Members; it is similar to the K1 sequence. The base consists of coarse, shallow-marine siliciclastic rocks. The metre-scale mixing of coarse siliciclastic sand and pure carbonate that characterises the western exposures of the Kliphoek Member may record sediment interaction resulting from short-term variations in relative sea level superimposed on the longer-term sea-level low-stand. The base of the Mooifontein Member, like the base of the Mara Member, is a flooding surface above which carbonate sediments accumulated.

Lower Schwarzrand Subgroup

The Schwarzrand Subgroup consists of a siliciclastic lower part and a carbonate upper part (Fig. 1). In contrast to the siliciclastic Kanies and Kliphoek Members of the Kuibis Subgroup, the siliciclastic strata of the Lower Schwarzrand Subgroup are fine grained. Siltstone, with interspersed sandstone beds, is the predominant facies. It sharply overlies the Mara Member of the Kuibis Subgroup. There are also some thicker sandstone units and subordinate limestone beds (Fig. 3).

Description

Siltstone and tabular sandstone beds

Thin, tabular sandstone beds are interspersed in green siltstone. The sandstone beds are distributed in 5 to 15 m intervals characterised by upward-increasing bed thickness and decreasing bed spacing. Individual beds within these intervals range from 5 to 30 cm thick and are composed of well-sorted, fine-grained sandstone. The sandstone beds are generally parallel-laminated, but also display some low-angle and hummocky cross-stratification. Current ripples, flute marks, and ball-and-pillow structures are abundant. Wave and interference ripples also are present.

Hummocky cross-stratified sandstone

Two thick sandstone units were identified throughout exposures of the lower Schwarzrand Subgroup (Fig. 4); they form marker horizons. At the bases of both sandstone units, isolated sandstone beds grade upward to amalgamated sandstone beds. The sandstone beds are fine grained and hummocky cross-stratified. There is also some trough cross-stratification.

Massive sandstone

There is an abrupt, in places erosional, contact in the middle of the lower sandstone unit. It separates massive, fine sandstone from the underlying hummocky cross-stratified sandstone (Fig. 4). Locally and in western-most sections there is an intervening few metres of calcarenite. The erosional surface cuts down below the limestone and scours into the underlying hummocky cross-stratified sandstone. Carbonate clast conglomerate locally marks the contact.

The massive-looking sandstone is 10 to IS m thick, well sorted and fine grained. There is metre-scale soft-sediment deformation. The massive sandstone is sharply overlain by current-rippled sandstone followed by green siltstone.

Limestone beds

Limestone intervals within the fine siliciclastic rocks of the lower Schwarzrand Subgroup thicken westward across the field area (Fig. 4). Commonly the limestone beds are planar in geometry and laterally continuous for hundreds of metres of outcrop. However, there are also lenticular carbonate beds which pinch out within tens of metres. The limestone consists of thin-bedded, nodular-weathering calcisiltite and calcarenite. There is some planar and low -angle stratification. Flat-pebble intraclasts are abundant.

Interpretation of environments

The siltstone and thin, tabular sandstone beds are interpreted as offshore deposits (Swift *et al.*, 1987). The sandstone beds' planar geometries, and associated gutter casts and load structures, indicate event bed deposition. Usually, only the fine silt was carried out to the shelf. During storm events however, high-velocity flows bypassed the nearshore area, decelerated in the deeper water of the outer shelf and deposited their sediment load there (Hamblin and Walker, 1979; Walker, 1985; Myrow, 1992a). Interference and wave ripples, and hummocky cross-stratification record some wave

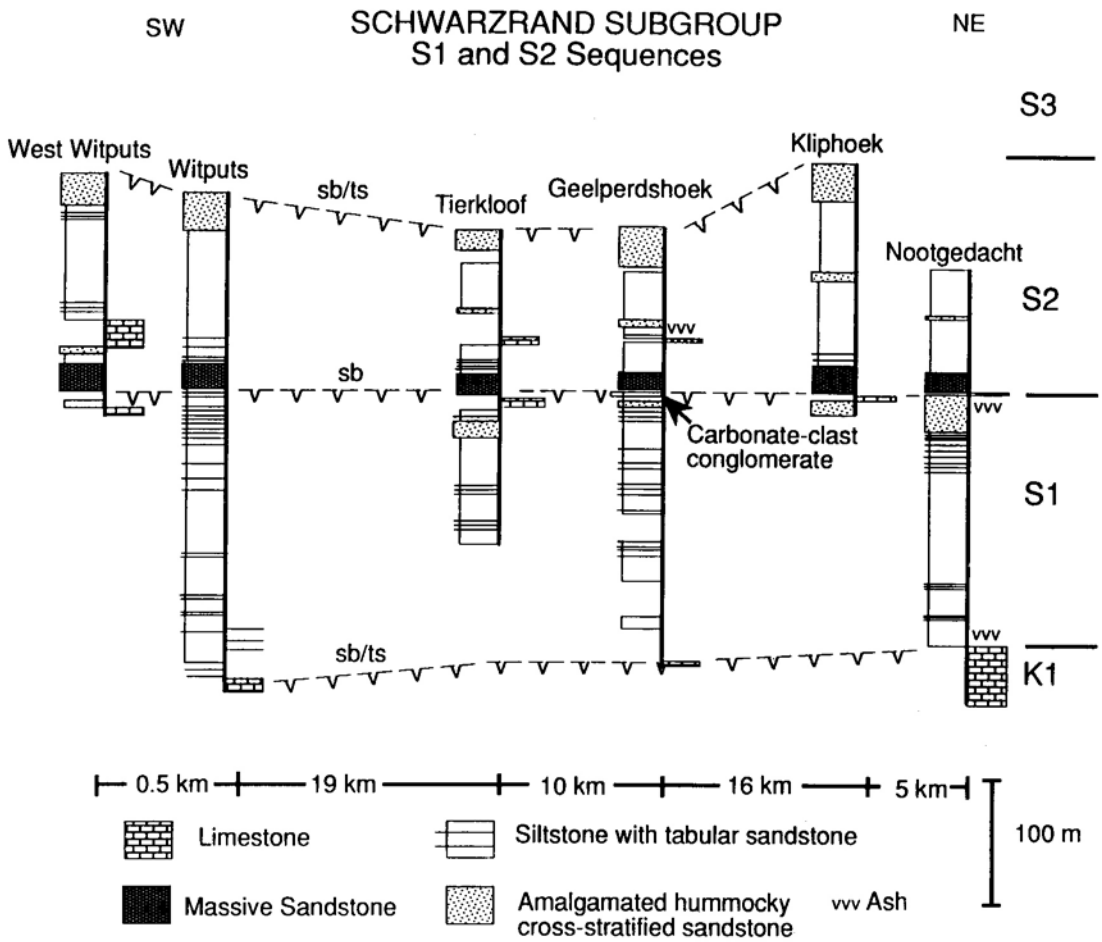

Figure 4: Measured stratigraphic sections through the Lower Schwarzrand Subgroup, S1 and S2 sequences

influence, indicating that water depths remained near to storm-wave base.

The amalgamated beds of hummocky and subordinate trough cross-stratified sandstone that compose the two thick, marker sandstone units record more proximal lower to upper shoreface conditions (Johnson, 1977a; Johnson, 1977b). A paucity of sedimentary structures in the massive sandstone makes interpretation difficult, but soft-sediment deformation may indicate some type of loading deformation during a mass emplacement event or events.

Sedimentary structures in the limestone beds of the lower Schwarzrand Subgroup are similar to those in the sandstone event beds. They may have formed in a similar environment; probably the sediment source was different.

Discussion

Much of the lower Schwarzrand Subgroup is offshore marine, more distal than any of the Kuibis Subgroup. The sharp transition from the limestone of the Mooifontein Member to the offshore siltstone of the lower Schwarzrand Subgroup is a flooding surface (Fig. 4). The flooding surface may also be coincident with a sequence boundary. Further craton ward, Germs (1983) described a sandstone interval that lies between the carbonate and the siltstone and has an erosional surface at its top. In these more distal sections, the highstand sandstone is absent; the erosional surface is probably correlative with a sequence boundary at the base of the Schwarzrand Subgroup's siltstone and top of the limestone.

Transitions that shoal upward from the offshore siltstone are recorded by the thick marker sandstone units. These units record shoreline progradation during a sea-level highstand and mark the tops of two depositional sequences that compose the lower Schwarzrand Subgroup, the s_1 and s_2 depositional sequences (Fig. 4). The boundary between the s_1 and s_2 sequences is the erosional surface at the base of the massive sandstone. It is important to note that the sequence boundary does not always correspond to the change in lithology. Instead, similar to shelf sandstone in Cretaceous foreland basin deposits of the southwestern United States, the sequence boundary commonly lies in the middle of fine sandstone (Swift *et al.*, 1987; Van Wagoner *et al.*, 1990).

Huns Member

The upper boundary of the s_2 sequence boundary is placed at the top of the upper sandstone unit (Figs 4 and 5). There is a sharp surface above which lies an interval of mixed siliciclastic and carbonate sediments. The mixed siliciclastic and carbonate sediments form a succession of backstepping parasequences, progressively deeper-water cycles that are transitional to development of the Huns Member carbonate platform. A broad diversity of facies, including stromatolites, thin-bedded calcisiltites, breccias, and trough cross-stratified limestone provide great lateral and vertical variability throughout the platform (Fig. 5).

Description

Siltstone with fine tabular sandstone

The siltstone intervals are similar to the fine siliciclastic rocks of the lower Schwarzrand Subgroup. There are 1-5 m-thick units of green siltstone with some fine sandstone beds. The sandstone beds are planar- to low-angle cross-stratified. The basal contact of the siliciclastic intervals is generally sharp. In places, the surface is marked by erosion or karst development in the underlying limestones. More commonly, chert is developed along the contact. In general, the siliciclastic intervals are thicker and more abundant in the eastern and rare in western exposures of the platform.

Cross-stratified mixed facies

This facies consists of a mixture of cross-stratified calcisiltites, wackestone/packstones and conglomerates. It is composed predominantly of carbonate silt. Coarser material consists of rounded intraclasts of carbonate mud, flat pebble intraclasts, ooids, Cloudina and carbonate flakes. The carbonate flakes most commonly are present in association with stromatolites suggesting that the flakes are ripped-up stromatolitic remnants. Beds range in thickness from 10 to 50 cm and are trough-, tabular-planar and hummocky cross-stratified. The beds are usually amalgamated and have sharp or scoured bases. This facies is voluminous in eastern exposures of the platform, but absent from western exposures.

Stromatolites

Stromatolites are present in all measured sections, but are more prominent westward. Branching, elongate stromatolites are the most common and laterally extensive form. These linked stromatolites reach heights up to 150 cm, widths of 5 to 15 cm and have relief of 5 to 10 cm. They are elongate along a northeast-southwest trend. Locally, smaller elongate stromatolites grow piggyback on larger (0.5-1 m diameter), similarly elongate bioherms.

The elongate stromatolites characteristically develop on sharp surfaces, usually with underlying dolomitised breccias and microkarst. This trend is best developed in western exposures of the platform. For example, at Swartkloofberg (95), karst surfaces with potholes up to 2 m deep truncate metre-scale cycles with stromatolite bases and calcisiltite tops.

Large columnar stromatolites and columnar thrombolites are limited to western exposures. Columnar stromatolites reach heights of 1-2m and diameters of 50 cm and have relief of 30 cm. They commonly develop in clusters. Broad domal stromatolites, up to 2 m in diameter, with less than 30 cm of relief, also are present. The columnar stromatolites are overlain by green siltstone.

Thin-bedded calcisiltites

Thin-bedded calcisiltite is best developed in western portions of the platform. This facies is composed of planar to sometimes wavy, 2- to 5-cm-thick calcisiltite beds. Some coarser-grained beds, graded beds, platy clast conglomerate beds and thin siltstone beds are interspersed. Calcisiltite is interbedded with stromatolites in western exposures (Swartkloofberg 95).

Interpretation of environments

The facies relations of the Huns Limestone are similar to those of many carbonate platforms described in the literature (James and Mountjoy, 1983; Grotzinger, 1986). The fine-grained siliciclastic material was sourced from the craton to the east and is more abundant in that direction, while the highest carbonate production occurred in the basinward, stromatolite-rich, western part of the platform.

The trough and hummocky cross-stratified facies, with its abundant intraclasts is a high-energy, wave- and current-influenced platform deposit. Units of thin-bedded calcisiltite are interpreted as lower-energy, deeper-water deposits. These interpretations are consistent with facies relations which show a westward decrease in the high-energy deposits and suggest that during carbonate platform development, as during earlier periods, the Nama basin deepened westward

Microkarst-based, calcisiltite-topped stromatolite cycles of western Huns exposures demonstrate cyclic reef growth. Because the associated calcisiltites contain little allodapic material and no reef-derived material, the platform is interpreted as a ramp and the abundant stromatolites as down-slope reefs (James and Mountjoy, 1983). These down-slope reefs would have provided the platform with little protection against waves and storms which is consistent with the abundance of high-energy deposits on the platform interior. During future work, the facies boundaries will be traced out laterally to determine if the stromatolites in the interior of the platform are patch reefs, or if they are laterally continuous, and record periods of cratonward reef progradation.

Discussion

The lateral and vertical patterns of facies relationships present many intriguing problems for future research. The abundant karst surfaces between stromatolite cycles are clear evidence for rapid, relative sea level fluctuation. Future work will focus on characterising carbonate cycles within the Huns. For example, the progradation of the siltstone intervals basinward across the platform may record periods of marine transgression, when reef flooding shut off carbonate production (Walker, 1985; Grotzinger, 1986; Myrow, 1992b). Conversely, the stromatolite reefs may have prograded cratonward across the platform during sea level falls. There is great potential for correlating these cycles and, with the superb exposure, of walking out facies transitions.

Swartkloofberg

Description

Germs (1983) identified two carbonate horizons, the Huns and Spitzkopf Members, which are separated by shale. However, he had difficulty distinguishing and correlating the two carbonate packages (pers. comm.). Similar difficulties were encountered during the course of this study. Two separate carbonate intervals were identified only at Swartkloofberg (95; Fig. 5)

A remarkable transect of the uppermost part of the Schwarzrand Subgroup is exposed. There are numerous sharp facies transitions including pinnacle reefs and an incised valley. The area is particularly critical because the unconformity represented by the incised valley probably spans the Precambrian-Cambrian boundary.

Green siltstone sharply overlies the downslope stromatolite cycles of the Huns Member. Within the green siltstone interval are pinnacle reefs that reach 60 m in height. This interval, in turn, is overlain by dark, thin-bedded calcisiltite (Spitzkopf Member?) that contains abundant metre-thick, platy-clast breccia beds and intervals of incipient breccia formation. Stromatolitic dolostone overlies the calcisiltite. This uppermost stromatolite-rich layer is dolomitised, brecciated and diagenetically altered.

An erosional surface, with at least 60 m of relief, scours through the calcisiltite breccia. The erosion surface has steep margins such that valley-fill conglomerates, diamictites and green siltstones abut the calcisiltite of the Spitzkopf Member. Germs suggested that, in addition to the conglomerates and siltstones, the pinnacle reefs are fill within the erosional valley that incised the platy-clast calcisiltites. However, this study shows that many, perhaps all of the pinnacle reefs underlie the platy-clast breccia unit and are thus older than the incised valley (Fig. 5).

An interval of interbedded stratified and unstratified conglomerates, sandstones and minor siltstone forms the lower part of the valley fill. The conglomerate clasts are angular, and range up to 30 cm in size. Clasts consist of thin-bedded calcisiltite and stromatolitic lithologies and minor sandstone and siltstone. Thus, unlike the platy-clast conglomerates, these conglomerates are heterolithic and polymictic. Many of the unstratified conglomerates have flat bases, are matrix-supported and show inverse grading, with large (50 cm) boulders suspended at their tops. The stratified conglomerates have clasts that are similar in size and composition to the unstratified conglomerates, but the stratified conglomerates are clast-supported.

The upper part of the valley fill consists predominantly of green siltstone with interspersed 1 to 10-cm-scale clasts of carbonate and sandstone. There are occasional beds of platy-clast conglomerate and outsized boulders, up to 5 m in diameter, of sandstone, carbonate and volcanic ash. Planar and low-angle cross-stratified fine sandstone is present near the top of the section.

Interpretation

The pinnacle reefs overlie the stromatolite cycles and probably developed during platform flooding. That flooding surface may be coincident with a sequence boundary (Fig. 5). Rise in relative sea level was so rapid that, except for local reefs, the carbonate production could not keep up.

The reefs are exposed only where exhumed from the enclosing shales. Consequently, it is difficult to determine if siltstone deposition was synchronous with or postdated reef development. Still, the siltstone is interpreted as deep-water deposits that may have bypassed the platform, and accumulated on the slope during the highstand (Goldhammer and Harris, 1989).

The overlying thin-bedded calcisiltite is interpreted as slope deposits, with the platy-clast breccias and incipient breccias recording slope failures (McIlreath and James, 1984). Carbonate production on the platform had resumed during a sea-level highstand. Eventually, sea level may have fallen sufficiently to allow reef progradation across the slope deposits and the development of the upper stromatolite unit.

The disorganised, inversely graded conglomerates that fill the erosional valley are typical of debris flows, while the planar-stratified conglomerates are more consistent with some sort of current emplacement or reworking (Hiscott and James, 1984). The upper part of the section, which consists mostly of siltstone and diamictite, is also interpreted as predominantly sediment gravity flow deposits. These upper sediments however, blanket the erosional relief in the vicinity; there is no evident source for the clasts nor topographic relief to initiate the flows. Nevertheless, the clast composition in the diamictite is similar to that of the underlying conglomerates. The diamictites may be related to diachronous flooding of the same surface further cratonward.

Discussion

Germs (1983) interpreted the incised valley at Swartkloofberg and similar valleys further eastward in the platform as glacial in origin. Although glaciation cannot be ruled out, there is no need to call on it to produce the diamictites, the conglomerates or the erosion. An alternative explanation is erosion of the platform' edge during sea level fall. Submarine incision of carbonate platforms is common (Schlager and Chermak, 1986; Grammer and Ginsburg, 1992; Franseen *et al.*, 1989; Christie-Blick *et al.*, 1990). However, the brecciation, dolomitisation and other karst indicators in the sediments underlying the erosion surface suggest that the

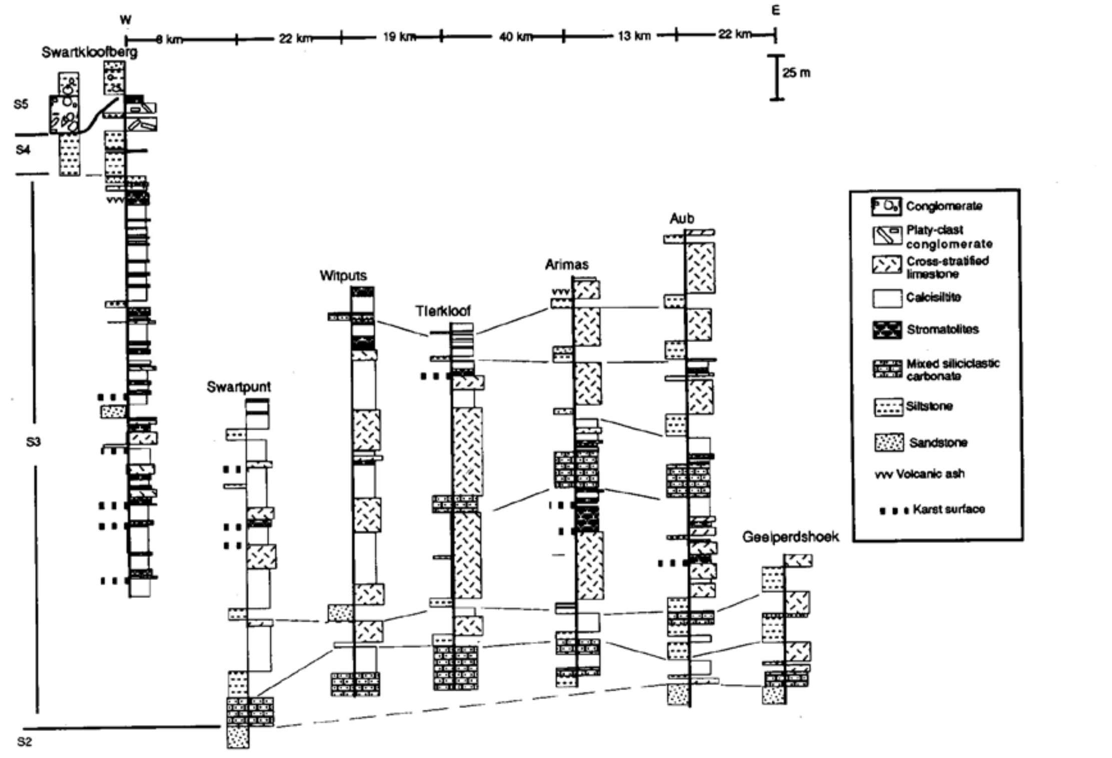

Figure 5: Measured stratigraphic section through the Huns Member. There is great lateral variation from east to west across the platform. At Swartkloofberg, the Spitskopf Member and the Nomtsas Formation are also exposed. The erosional unconformity at the base of the Nomtsas Formation scours through the Spitskopf Member. This disconformity most likely contains the Vendian—Cambrian boundary

platform edge may have been subaerially exposed. Additional incised valleys further eastward, at Sonntagsbrunn (Fig. 2), are probably craton-ward equivalents of this impressive sequence boundary.

Thus, the sediments at Swartkloofberg seem to record relatively rapid sea-level fluctuation with amplitudes of 10s to 100 m. Relative sea-level rises and falls of that magnitude demand either glacial eustasy or active tectonic movement. Future work will focus on characterising the sea-level fluctuation which flooded then exposed the carbonate platform, and attempting to relate it to orogenesis. A pointed search for glacial indicators will also continue, but accumulated evidence seems to point towards tectonic control. The relative sea-level change could reflect increased orogenesis in the Damara Belt to the north, or the onset of orogenesis in the Gariep Belt to the west.

Field relationships from this study definitively show that some of the pinnacle reefs are older than the incised slope breccias, while none of the relationships requires that any of the pinnacle reefs postdate valley incision. These relationships indicate that reef development preceded valley incision. These relationships are important because the pinnacle reefs contain Cloudina, a Vendian fossil, and the Nomstas Formation, which infills the valley, contains Phycodes pedum, a Cambrian trace fossil (Crimes and Germs, 1982). If the pinnacle reefs are in the valley fill, it is the only known Cambrian occurrence of Cloudina in the world. This study's conclusions would make that exception unnecessary.

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References

Christie-Blick, N., Grotzinger, J.P. and Von der Borch, C.C. 1988. Sequence stratigraphy in Proterozoic successions. *Geology*, **16**, 100-104.

Christie-Blick, N., Von der Borch, C.C. and DiBona, P.A. 1990. Working hypotheses for the origin of the W onoka canyons (Neoproterozoic), South Australia. *Am. J. Science*, **290-A**, 295-332.

De Raaf, J.F.M., Boersma, J.R. and Van Gelder, A 1977. Wave-generated structures and sequences from a shallow marine succession, Lower Carboniferous, County Cork, Ireland. *Sedimentology*, **24**, 451-483.

Demicco, R.V. 1983. Wavy and lenticular-bedded carbonate ribbon rocks of the Upper Cambrian Conococheague Limestone, central Appalachians. *J. Sed. Petrology*, **53**, 1121-1132.

Franseen, E.K., Fekete, T.E. and Pray, L.C. 1989. Evolution and destruction of a carbonate bank at the shelf margin: Grayburg Formation (Permian) western escarpment, Guadalupe Mountains, TX. *In*: P.D. Crevello, J.F. Sarg and J.F. Read, Eds. *Controls on carbonate platform and basin development*. pp. 289-304.

Germs, G.J.B. 1972c. The stratigraphy and paleontology of the lower Nama Group, South West Africa. *Bull. Precam. Res. Unit., Univ. Cape Town*, **12**, 250.

Germs, G.J.B. 1974. The Nama Group of South West Africa and its relationship to the Pan-African geosyncline. *J. Geol*., **82**, 82-90.

Germs, G.J.B. 1983. Implications of a seQimentary facies and depositional analysis of the Nama Group in South West Africa/Namibia. *Spec. Publ. geol. Soc. S.Afr*., **11**, 89-114.

Goldhammer, R.K. and Harris, M.T. 1989. Eustatic controls on the stratigraphy and geometry of the latemer buildup (Middle Triassic), the dolomites of northern Italy. *In*: P.D. Crevello, J.L. Wilson, J.F. Sarg and J.F. Read. *Controls on Carbonate Platform and Basin Development*. pp. 323-338.

Grammer, G.M. and Ginsburg, R.N. 1992. Highstand versus lowstand deposition on carbonate platform margins: insight from Quaternary foreslopes in the Bahamas. *Marine Geol.*, **103**, 125-136.

Grotzinger, J.P. 1986. Cyclicity and paleoenvironmental dynamics, Rocknest platform, northwest Canada. *Geol. Soc. Am. Bull*., **97**, 1208-1231.

Hamblin, A.P. and Walker, RG. 1979. Storm dominated shallow marine deposits: the Fernie-Kootenay transition, southern Rocky Mountains. *Can. J. Earth. Sci*., **16**, 1673-1690.

Hiscott, R.N. and James, N.P. 1984. Carbonate debris flows, Cow Head Group, western Newfoundland. *Jour. Sed. Petrology*, **55**, 735-745.

Holmes, C.W. and Evans, R.C. 1963. Sedimentology of Gullivan bay and vicinity, Florida. *Sedimentology*, **2**, 189-206.

Horstmann, U.E., Ahrendt, H., Clauer, N. and Porada, H. 1990. The metamorphic history of the Damara Orogen based on K/Ar data of detrital white micas from the Nama Group, Namibia. *Prec. Res*., **48**, 51-61.

James, N.P. 1984. Shallowing upward sequences in carbonates. *In*: R.G. Walker. *Facies Models*. Geoscience Canada, Reprint Series **1**, pp. 213-227.

Johnson, H.D. 1975. Tide- and wave-dominated inshore and shoreline sequences from the late Precambrian Finnmark, North Norway. *Sedimentology*, **22**, 45-74.

Johnson, H.D. 1977a. Shallow marine sand bar sequences: an example from the late Precambrian of North Norway. *Sedimentology*, **24**, 245-270.

Johnson, H.D. 1977b. Sedimentation and water escape structures in some late Precambrian shallow marine sandstones from Finmark, North Norway. *Sedimentology*, **24**, 389-411.

Knoll, A.H. and Walter, M.R. 1992. Latest Proterozoic stratigraphy and Earth history. *Nature*, **356**, 673-678.

McIlreath, I.A. and James, N.P. 1984. Carbonate Slopes. *In*: R.G. Walker. *Facies Models*. pp. 245-257.

Miller, RMcG. 1983. The Pan-African Damara Orogen of South West Africa/Namibia. *In*: Miller R.McG., *Evolution of the Damara Orogen of South West Africa/Namibia*. Spec. Pub. geol. Soc. S. Afr., **11**. pp. 431-515.

Mount, J.F. 1984. Mixing of siliciclastic and carbonate sediments in shallow-shelf environments. *Geology*, **12**, 432-435.

Myrow, P.M. 1992a. Bypass-zone tempestite facies model and proximality trends for an ancient muddy shoreline and shelf. *J. Sed. Pet*., **62**, 99-115.

Myrow, P.M. 1992b. Mixed siliciclastic-carbonate deposition in an Early Cambrian oxygen-stratified basin, Chapel Island Formation, Southeastern Newfoundland. *J. Sed. Petr*., **62**, 455-473.

Schlager, W. and Chermak, A. 1986. Submarine slope angles, drowning unconformities, and self erosion of limestone escarpments. *Geology,* **14**, 762-765.

Shinn, E.A. 1983. Tidal flat *In*: P.A. Scholle, D.G. Bebout and C.H. Moore. *Carbonate depositional environments*. AAPG Memoir, **33**, pp. 171-211.

Swift, D.P., Hudelson, P.M., Brenner, RL. and Thompson, P. 1987. Shelf construction of s foreland basin: storm beds, shelf sandbodies, and shelf-slope depositional sequences in the Upper Cretaceous Mesaverde Group, Book Cliffs, Utah. *Sedimentology,* **34**, 423-457.

Vail, P.R., Mitchum, R.M. and Thompson, S. 1977. Seismic stratigraphy and global changes in sea-level, Part 3: Relative changes in sea-level from coastal onlap. *In*: C. Payton. *Seismic stratigraphy-Applications to hydrocarbon exploration*. pp. 11-71.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M. and Rahmanian, V.D. 1990. *Siliciclastic Sequence Stratigraphy in Well Logs, Cores, and Outcrops*. pp. 88.

Walker, RG. 1985. Geological evidence of storm transportation and deposition on ancient shelves. *In*: RW. Tillman, D.J.P. Swift and R.G. Walker. *Shelf Sands and Sandstone Reservoirs*. pp.243-302.