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Quaternary sediments and the depositional environment of the lower Uniab River area, Skeleton Coast, Namibia

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The first part of this paper is devoted to a general description of the unconsolidated Quaternary sand and gravels which have been incised by the nine distributaries of the lower Uniab River. The high sea cliff and incised distributary courses provide excellent exposures of the sedimentary structure along both lateral and longitudinal profiles. In the main section of the paper the nature of the sedimentary environment is investigated. The possibility of a progradational beach environment is rejected and evidence is provided for a terminal coastal fan environment. The fan shape can no longer be recognised due to recent stream rejuvenation and a general lowering of the landscape as a result of degradation. The perspective is that of the geomorphologist.

Die eerste deel van hierdie artikel word gewy aan 'n algemene beskrywing van die ongekonsolideerde Kwaternêre sand en gruis wat ingekerf is deur die nege vertakkings van die benede Uniabrivier. Die hoë strandkrans en ingekerfte rivierlope verskaf uitstekende blootstellings van die sedimentêre struktuur langs beide laterale en lengtedeursneë. In die hoofgedeelte van die artikel word die aard van die afsettingsomgewing ondersoek. Die moontlikheid van 'n progradasionale kusomgewing word uitgesluit en bewyse word verskaf vir 'n terminale kuswaaieromgewing. Die waaiervorm is nie meer herkenbaar nie as gevolg van onlangse rivierverjonging en 'n algemene verlaging van die landskap deur degradasie. Die perspektief is dié van die geomorfoloog.

Introduction

Very little has been written on the lower courses of the ephemeral streams north of the Kuiseb and Swakop Rivers in Namibia. Stengel (1966) dealt with the Omaruru and Ugab Rivers, Mabbutt (1951) with the middle Ugab valley, De Beer *et al.* (1981) with the water supply of the Omaruru, and Korn & Martin (1955) with the terraces of the Namibian rivers in general. Published works on the Kuiseb and Swakop include those by Ward (1987), Huntley (1985), and Stengel (1964). Nothing has been published on the depositional environment of the Skeleton Coast Rivers (north of Swakopmund).

The Uniab and Koigab are the shortest of the rivers which reach the Skeleton Coast of Namibia and episodically come down in flood. As the crow flies the source of the Uniab River is 96 km from the coast and that of the Koigab River is 97 km, in contrast with the 250 km of the Huab River, the 365 km of the Ugab River, the 175 km of the Hoanib River, and the 180 km of the Hoarusib River. The actual length of the Uniab is 117 km and the area of its drainage basin 4650 km^2. It compares unfavourably with the 486 km and the 25 300 km^2 respectively of the Ugab, the 315 km and 14 050 km^2 of the Omaruru and the 276 km and 16 300 km^2 of the Huab. In terms of size it is therefore a relatively insignificant river. Nevertheless the study area is remarkable for a number of reasons:

1. the river mouth system is extremely complex. The lower Uniab splits into nine major distributaries (Figure 1), each with its own river mouth. In addition there are a number of interconnected minor channels;
2. rapid rejuvenation resulted in the presence of extensive paired terraces, hanging valleys, canyons, and knick-points, including a scenic waterfall;

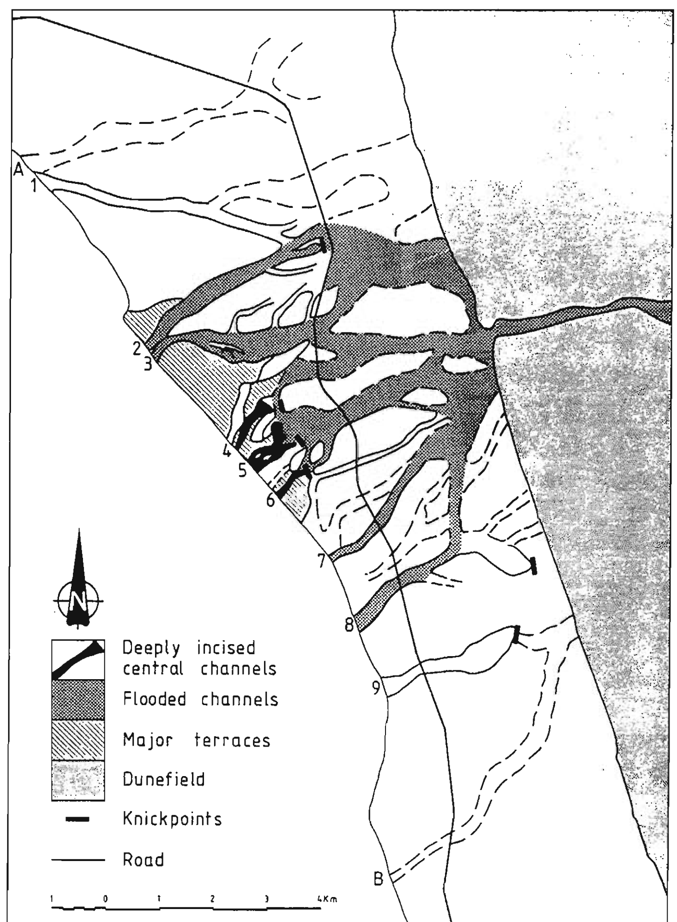

Figure 1 Landforms of the Uniab River mouths area. Flooded channels are those areas which are inundated during contemporary floods. The river mouths are numbered from 1 to 9.

3. the nine major distributaries and other minor channels have been carved into unconsolidated coarse- and medium-grained clastic sediments of Quaternary age. Exposures of such young sediments, with a thickness of over 40 m, are uncommon in Namibia and South Africa and therefore worthy of study;
4. five kilometres from the coast the Uniab maintains a 7 km-long poort through the Skeleton Coast Dunefield. The latter is younger than the river course; and
5. the coastal zone has three components: a wave-cut platform, a cobble beach, and a sea cliff. The wave-cut platform is partially developed on the same Early to Middle Pleistocene Oswater-equivalent conglomerate and sandstones which underlie the Quaternary sediments inland from the coast. Like elsewhere along the Skeleton Coast (Hallam, 1959) the beach is occupied by well-rounded cobbles and pebbles. An interesting feature of the beach is the long string of cusps in which sandy deposits of mainly garnets occur. This gravel-dominated beach is of the dissipative type (Bryant, 1984).

The sea cliff is located between Torra Bay, in the south, and the point where the road to Terrace Bay returns to the coast, about 24 km farther north (Figure 1). It reaches a height of more than 30 m in the vicinity of river mouths 2, 4, 5, and 6. From this central area there are regional slopes to both the north and south. The development of valleys 2, 3, 5, and 6 by downcutting and lateral planation caused the removal of substantial parts of the sea cliff. The base of the cliff is generally covered with sand dropping from the cliff itself, but in many places the sedimentary structures are clearly exposed both at higher levels and at the base.

The mouths of the northern (1) and southern (9) distributaries of the Uniab are 12.5 km apart. The study area is the section of the Skeleton coast between these two points and the dunefield, about 5 km from the coast.

The geological and geomorphological literature contains no detailed references to the sediments or landforms of the Uniab river mouth area west of the Skeleton Coast Dunefield. This paper deals with two related problems: 1) the general characteristics of the Quaternary sediments and 2) the nature of the sedimentary environment in which deposition took place. The perspective is that of the geomorphologist. The landforms and the processes responsible for their development are dealt with elsewhere (Van Zyl & Scheepers, in press).

Sediments

Figure 2 shows the simplified geology of the Namib Desert in the vicinity of part of northwestern Namibia, while the inset gives the general location of the study area within the country as a whole. Most of this information was derived from the 1 : 250 000 Cape Cross geological map (Geol. Surv. SWA: 2013 Cape Cross 1 : 250 000). In the northwest the area is underlain by detrital sedimentary rocks of Quaternary age deposited and dissected by the ephemeral distributary streams of the Uniab, west of the Skeleton Coast Dunefield.

In the immediate vicinity of the streams these unconsolidated Quaternary clastic sediments overlie apparent equivalents of the indurated Oswater Conglomerate Formation

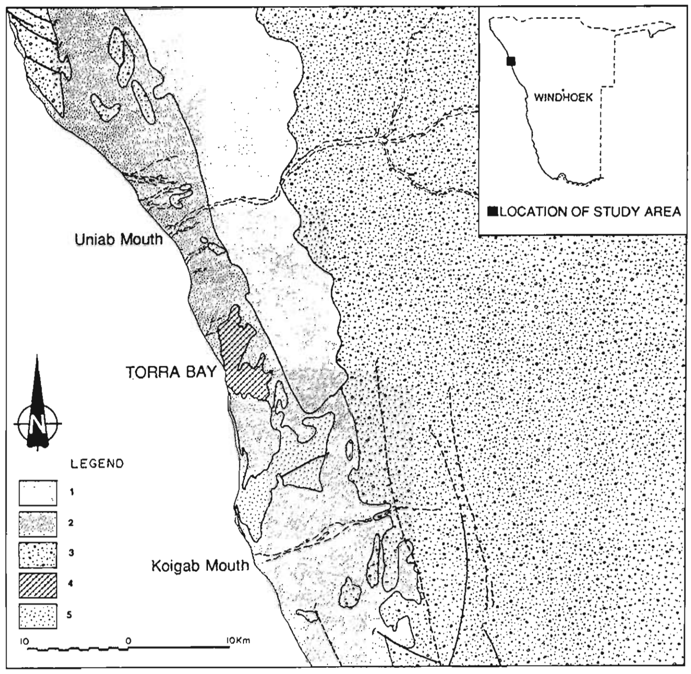

Figure 2 Generalized geological map of the Uniab River mouth area. 1. Quaternary aeolian sands; 2. Quaternary sand and rubble; 3. Lower Cretaceous Etendeka volcanics; 4. Cambrian Torrabaai Granite; 5. Late Proterozoic Kuiseb metasediments.

(Ward, 1987) and cross-bedded sandstones. Both have a maximum thickness of a few metres only in the study area. In the few places where the base is exposed the Oswater-type sediments usually overlie Pre-Karoo basement and migmatised greywacke of the upper Damara Sequence. The Oswater sediments are also exposed in the Uniab channel east of the dunefield, as well as in the Koigab River channel to the south. Similar but coarser conglomerates, occur in the lower Ugab River valley. In fact, Oswater equivalents are exposed in the channels of all the major Namib rivers north of the Kuiseb River (Ward, 1987).

The Quaternary sediments consist of unconsolidated but slightly compacted sand and gravel. The gravels are predominantly derived from the basic and acid lavas of the early Cretaceous Etendeka Formation, east of the dunes (Figure 2). These are either silica-rich basalts or latites (Milner, 1986; Milner & Duncan, 1987). The age of the lavas varies between 114 and 136 Ma. They are therefore somewhat younger than the Drakensberg Basalt Formation of South Africa. Exposures of the Etendeka volcanics terminate about 5 km east of the Skeleton Coast Dunefield.

Unconsolidated sand is the dominant sediment type in the study area. As Barnard (1989) points out, the sands antedate the Skeleton Coast Dunefield. The bulk appears to have been brought down by the bedload stream of the Uniab River. Fine-grained sediments such as shales are largely absent from the Uniab catchment as well as from the river channel east of the dunefield and from the Quaternary deposits. Only very small quantities of silt were found in the sand samples collected from the sea cliff and the distributaries. Another feature of the sand is that the grains are not as well-rounded as those usually found in the dunes of the Namib (Lancaster, 1982; Barnard, 1989). Significant

Figure 3 Northern Sea cliff with thin and practically horizontal gravel strata. Note the cobble beach.

quantities of wind-blown sands were therefore not deposited as part of the lower Uniab sediments.

There are major spatial differences in the external sedimentary structures of the Quaternary deposits. The gravels in the northern and southern parts of the sea cliff (north of river mouth 2 and south of river mouth 6, in Figure 1) form sheets extending more or less horizontally for hundreds of metres parallel to the shore and pinch out farther north and south (Figure 3). These gravels appear at different levels between the base and the summit of the sea cliff. The base of the cliff (just above sea-level) and the base of the Quaternary sediments practically coincide.

In the central sea cliff section (river mouths 2 – 6) but more particularly the vicinity of river mouths 2 and 3, the gravels are usually of a massive nature (Figure 4). They are laterally discontinuous, pinching out over short distances or forming wedges. They too may be found at varying elevations in the sea cliff, anywhere between the base and the summit. In this area the lateral bases (parallel to the coast) of the gravels are sometimes flat and relatively horizontal, but are often uneven and may have a pronounced lateral dip. The lenses, wedges, and trough fillings generally do not have simple geometries. A local unconformity often exists between the gravels and the underlying sand. The sand layers are generally thicker than the gravel bodies.

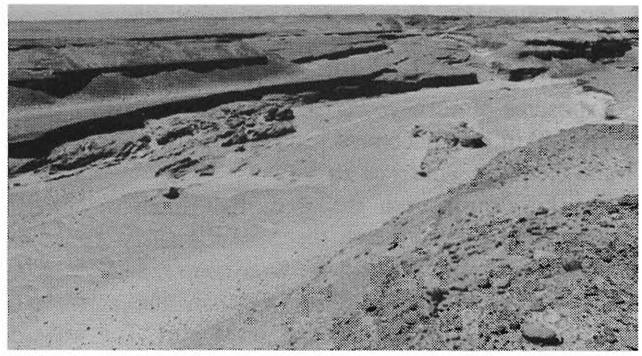

Figure 5 Longitudinal profile of Quaternary sediments near river mouth 5.

The external sedimentary structures of the northern and southern parts of the study area ultimately differ from those of the central area in three important respects:

(i) the gravels are much scarcer and their layers are thinner than in the central area;

(ii) the strata have a strong horizontal trend; and

(iii) the clasts are smaller and can be described as pebble-sized.

The gravels are very well exposed in the valley flanks where they form continuous strata extending upstream for hundreds of metres. In valley 5 (Figure 5) at least four of these strata run parallel to each other, all with a gentle dip towards the coast. They have a strong structural influence on the formation of terraces in this incised distributary valley. It is difficult to determine their lateral extent (parallel to the coast), but they seem to represent gravel sheets rather than channel bars.

The sands display a great variety of lateral internal structures in the sea cliff including: (i) 2 – 3 m-thick layers of sand showing practically no structure at all; (ii) irregular deposits with cross-bedding; and (iii) sands with horizontal and dipping strata or laminae, sometimes with isolated cobbles and pebbles. Very little grading occurs within individual stratigraphic units.

In the northern sea cliff delicate individual sandy laminae may curve upwards from horizontal to vertical positions, providing evidence of deposition under quiet conditions

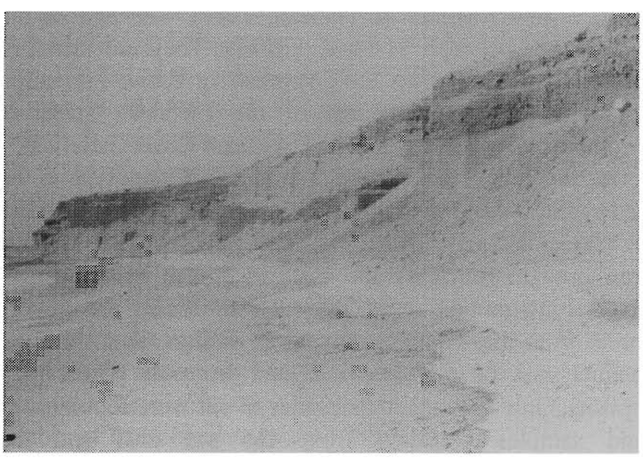

Figure 4 Central sea cliff near river mouth 3, showing thick accumulations of gravel and sand.

Figure 6 Closer view of sedimentary structure exposed in central sea cliff below a hanging valley.

(Twenhofel, 1950; Pettijohn, 1957). Such laminar flows take the form of relatively slow streamline motions which curve smoothly around irregularities in their paths (Krumbein & Sloss, 1963).

The gravel clasts are not as well-rounded as those found on the present beach. Boulders are rare in both the Uniab deposits and the beach. The gravels are matrix- rather than clast-supported. The sandy matrix therefore does not only fill the voids but separates the cobbles and pebbles. There are great differences in the spacing of the clasts. Well-graded structures do not occur but imbrication perpendicular to the coast is common in the longitudinal profile (Figure 6). Crude sorting was observed within most of the gravel units.

It is difficult to provide firm data on the gravel–sand ratio as exposed in the sea cliff. Particularly in those sections where sand predominates, it builds up from the base of the cliff to cover large parts of the sedimentary structure. A second reason is that in the central cliff section the ratio varies greatly over short distances because of the limited lateral extent of channel fillings or the presence of wedges.

It can nevertheless be stated with certainty that the ratio exceeds 1 : 10 in the far northern and southern parts of the sea cliff where the beds are more or less horizontal. As one approaches river mouths 2 and 3 the ratio decreases as the gravel beds get thicker, but even in the central cliff section the ratio is generally not less than 1 : 2. In exceptional cases it may, however, be as low as 1 : 1 or even close to 2 : 1 (Figure 4).

Since large parts of the sea cliff are obscured by sand creeping down the slope, observations about the thickness of the beds are restricted to those which can be inspected. Even in the central section of the cliff where gravels are well represented sand beds are thicker than 3 m. In some cases such sedimentary units are separated by a single lamination or thin sandy layer with different characteristics.

As far as age relationships are concerned we are dependent on observations made by Ward (1987). He correlates the Uniab Quaternary deposits with the Awa-gamteb muds of the Kuiseb River: '... it is suggested here that Awa-gamteb muds are the coastal, distal equivalents of the Homeb Silt Formation. This correlation, and the presence of rolled Middle Stone Age (MSA) artifacts in the overlying Gobabeb Gravels, implies a minimum, Late Pleistocene age for the Awa-gamteb muds' (Ward, 1987).

Sedimentary depositional environment

The major concern of this article is the circumstances under which deposition of the Quaternary sediments took place. Of the three principal types, the marine environment need not be considered because of the coarseness of the sediments. As far as continental sedimentary types are concerned, only the fluvial environment must receive attention. As for the transitional environments, lagoonal conditions can also be eliminated because of the presence of coarse-grained conglomerates, at both the base and the higher horizons of the succession (Elliot, 1986). A possible littoral sedimentary environment, however, deserves serious consideration.

The absence of fine-grained sediments provides evidence that tidal flat conditions did not exist in a littoral environment (Elliot, 1986). If the Uniab sediments represent littoral conditions at all, the (presumed) cobble and sandy beach materials must be indicative of high-energy waves and strongly agitated waters. The possibility that the Uniab deposits can be of the progradational beach type, will be briefly discussed.

Progradational beach environment?

The term progradation is defined as a seaward advance of the shoreline resulting from the nearshore deposition of sediments brought to the sea by rivers (American Geological Institute, 1962). An excellent recent work by Massari & Parea (1989) is perhaps the best frame of reference for studies of progradational beach deposits. There are, however, other useful recent studies of fan-deltas (Hayward, 1983) and beaches (Short & Wright, 1981; Bryant, 1984) which shed light on this topic.

Although sand predominates, gravels are well represented in the Quaternary sediments of the Uniab River mouth area. As Massari & Parea (1989) point out, progradational gravel sequences deposited in wave-dominated littoral environments are not very common in the stratigraphic record, since they require special conditions for deposition and preservation. Important among these is a high rate of supply of coarse-grained sediment from nearby source areas. Despite the aridity of the region, the major rivers of the Skeleton Coast (including the Uniab) may be said to, at least partially, fulfil the above requirement. The present river channels are all characterized by large accumulations of cobbles and pebbles which are carried down to the sea when they episodically come down in flood. It can be assumed with safety that more or less the same fluvial conditions prevailed when the Quaternary deposits were laid down (Tyson, 1986). At the present time there are extensive cobble beaches at intervals along the Skeleton Coast (Hallam, 1959).

Progradational gravel beaches are usually part of wave-dominated coarse-grained delta or fan-delta systems. In such systems the clasts may be distributed laterally by longshore drift, eventually to become wave-worked gravels. These clasts are well-rounded. Emphasis is generally placed on the fact that storms leave the basic imprint on these nearshore deposits. Without changes in sea-level such beach deposits will be of rather limited width. The inland extent of such conglomeratic sediments will therefore be relatively limited.

Deposits which extend continuously for hundreds of metres both along the coast and away from the coast and which have a gentle seaward dip, like the conglomerate in the north and south of the Uniab river mouth area, may be the result of marine regressive overlap (offlapping) . By this process the beach deposits migrate seawards. Coarser clastics indicative of shallow-water strata, will progressively overlie finer clastics that were deposited in deeper water. The opposite process (onlapping) may take place during marine transgression, but neither overall fining upward nor coarsening upward sediments occur in the study area. Furthermore, the bedding planes between sands and gravel deposits are usually very sharp in the Uniab area. Such sharp transitions are not typical of progradational beach deposits (Elliott, 1986). In addition, offlapping or onlapping cannot explain the totally different sedimentary structures of the central part of the river mouth system, as exposed in the sea cliff.

In summary, the following features of progradational wave-dominated shorelines do not accord with the structure of the sediments found in the Uniab river mouth area.

1. The clasts forming the Uniab gravels (e.g. in the sea cliff) are not as well-rounded as those found on cobble beaches, including those of the study area.
2. Most progradational wave-dominated sequences commence in fine-grained offshore or shelf facies and coarsen upwards through the offshore-transition facies until foreshore facies of a conglomeratic nature may be reached (Elliott, 1986). No systematic upward coarsening is evident in the Uniab sediments. The full sequence from the base upwards is exposed in many places. Gravels alternate with sand throughout the sequence. Coarse-grained sediments, and in particular gravels, can only be associated with foreshore facies (Elliott, 1986).
3. According to Elliott (1986) foreshore facies usually consist of well-sorted parallel laminated sandstones with primary current lineation reflecting plane bed conditions produced by breaker, surf, and swash zone processes. Subordinate structures include cross-bedding, which usually occur as single sets and wave ripple surfaces. Large-scale parallel lamination is not a general characteristic of the central Uniab sands.
4. Rapid lateral pinching out of stratigraphic units, particularly of the gravels or conglomerates, is not typical of progradational beach deposits, but is a feature of the central Uniab sea cliff deposits. These gravel deposits with a thickness of several metres may have a lateral extent of no more than 20 m. Though well-shaped lenses are rather scarce, most of the conglomerate deposits in the central area can be interpreted as trough or channel fills.
5. While clasts of progradational beach deposits are usually in contact with each other, this is not true of the Uniab River mouth gravels. They are matrix-supported.
6. Present-day beach gravels are characterized by their good sorting — generally much better than fluvial gravels — and are almost all unimodal while fluvial gravels are mostly bimodal (Elliott, 1986). The Uniab gravels are poorly sorted and multimodal.
7. The Uniab clasts show an upcurrent dip or imbrication and the long (a-) axes of the cobbles and pebbles are oriented in the direction of stream current flow as can be expected of fluvial deposits.
8. Remnants of marine life forms are, for practical purposes, absent from the Uniab Quaternary sediments. A few shell fragments were found near sea-level at river mouth 6, but further inspection of the sea cliff yielded nothing.

Terminal coastal fan environment

When a low-gradient bedload stream such as the Uniab has been confined to a single braided channel for practically its full length and then debouches onto a plain, the resulting depositional feature can be referred to as a terminal fan, if it does not reach the ocean (Collinson, 1986). If the base of the fan has prograded into the sea, such a fan should rather be called a fan-delta or a coastal alluvial fan. The latter term is preferred by Hayward (1983: p.333) '... as in many cases terrestrial relief is the major control on sedimentation and the fans frequently show no clear relationship to a marine base level'. The concept 'fan-delta' or 'coastal alluvial fan' is, however, usually associated with piedmont environments, which do not exist in the case of the Uniab.

The Uniab fan shares characteristics of the above two types and may best be described as a terminal coastal fan. While terminal fans and fan-deltas have been described often enough, the available literature does not pay attention to analogues or models of terminal coastal fans such as the one found in the Uniab coastal area. Its sedimentary structures therefore also differ from those described elsewhere.

To illustrate the differences between the three types of alluvial fan the results of two case studies are summarized very briefly and contrasted with the sedimentological characteristics of the Uniab mouth area. The study area has the advantage that rejuvenation provided us with both lateral and longitudinal profiles of its sediments.

In his study of coastal alluvial fans in a piedmont environment of south-western Turkey, Hayward (1983) found that conglomerates made up more than half the sedimentary body. Clast sizes reached 1.30 m and sand and gravel were poorly segregated. Debris flow deposits were relatively scarce but did occur. Individual conglomerate beds were several metres thick and formed laterally continuous sheets over distances of more than 400 m. Fining upward units were common.

The conditions conducive to the development of such fan-deltas or semi-arid and coastal alluvial fans were described by Hayward (1983, p.334): 'development of coastal alluvial fans requires high relief adjacent to the coastal zone and short-headed, high-gradient bedload streams that remain braided to the coast'. It will be noticed that most of the above characteristics contrast sharply with those of the Uniab terminal coastal fan as described earlier. The lower Uniab area, does not have high relief nor a steep gradient close to the coast.

While both streams are of an ephemeral nature and have rather straight courses, there are major differences between the inland terminal fan of the Markanda (Parkash *et al.*, 1983) and the coastal fan of the Uniab. The former river flows across an alluvial piedmont zone and a flood plain before it ends in the terminal fan. The sediments consist of sand, silt, and mud facies, while the channel sediments are characterized by fining-up sequences. The sedimentary environment of these two fan types are so different that no further comparisons are necessary.

While the Koigab River to the south has a contemporary coastal fan which shows up clearly on aerial photographs, no alluvial fan as such can be observed above the Uniab river mouths. The dunefield presumably covers the apex or fanhead, the midfan is dissected by the rejuvenated distributaries, and the base has been eroded and covered by the sea. The surface topography thus displays no features typical of coastal alluvial fans. We are dependent on the sedimentology and geological structure of this elevated section of the coastal plain for evidence that the sediments are alluvial in nature and deposited as part of a fan.

The terminal coastal fan of the Uniab shares some general characteristics with other alluvial fans. Most alluvial fans display pronounced tensing due to the frequent lateral shifting of the stream channel(s) as aggradation takes place. Both random and progressive shifting of the main channel(s) across the surface of a fan may take place. There are marked changes in the size of deposits both vertically and laterally as a result of the cut and fill processes. The exact composition and nature of the sediments are controlled by the source of the rock debris and its location within the fan.

Two major types of fans have been distinguished: stream-dominated and semi-arid (Collinson, 1986). Stream-dominated fans are usually deposited by low-sinuosity streams. Such fans are characterized by gentler slopes than those of the semi-arid fans. The latter is often associated with tectonically active basin margins where mass-flow processes play a part in deposition (Collinson, 1986). They are typical of the American basin-and-range region. However, the Uniab fan should be interpreted as a stream-dominated fan even though it is located in an arid region.

The general spatial characteristics of stream-dominated fans are described by Collinson (1986). Sheet bars of coarse material may be found in the upper fan segment while longitudinal boulder or cobble channel bars are more typical in the middle fan segment and sandy transverse bars occur in the lower fan segment or base of the fan. A terminal coastal fan like that of the Uniab need not necessarily display these features, but there are similarities.

The Uniab coastal deposits, exposed in the central valley side slopes and the coastal sea cliff seem to have the characteristics of central fan deposits. The base of the Uniab fan must have been deposited west of the present coastline as far as the central river mouth area is concerned. Middle fan deposits display pronounced tensing due to the lateral shifting of stream channels and channel fillings are common (Collinson, 1986). Those parts of the sea cliff south of river mouth 6 and north of river mouth 2 are distant from the apex and may be part of the base of the fan where sandy transverse bars with relatively horizontal strata predominate.

The same gravels are well exposed in the valley flanks where they continue upstream for hundreds of metres. In valley 5 at least four of these parallel each other, all with a gentle dip towards the coast. They have a strong structural influence on the formation of terraces in this incised valley. These beds may be longitudinally-extensive gravel channel bars overlapping each other at different elevations, but it is more likely that they represent relatively thin gravel sheets with appreciable lateral extent. Since the terraces are covered with a thin sheet of sand, their lateral extent cannot always be determined, but it is at least tens of metres in places. Gravel sheets, therefore, occur extensively in the fan as a whole.

It should not simply be accepted that terminal coastal fans display the three segments (upper, middle, and lower) usually distinguished in piedmont alluvial fans. Since the fan slope is very gentle, clearly identifiable changes in slope are difficult to observe in the Koigab fan just to the south of the Uniab. The Uniab, in contrast, does not have an undisturbed contemporary fan surface. The deposits therefore need not necessarily be associated with positions in specific fan segments.

The continuous gravel strata of large parts of the Uniab Fan can be attributed to the flash flood nature of the deposition. The pebbles could have spread out in lateral sheets covering large parts of the fan surface during periods of heavy flooding (Reinick & Singh, 1974).

Channel fillings are, however, common in the vicinity of the Uniab's central tributaries (2 – 6) and more particularly courses 2 and 3. Such deposits were probably restricted to the stream channels as they existed at the time of deposition. Water flow would have been concentrated in these channels during and after sheet flooding of the rest of the fan. Such deposits may have developed as elongate lenses oriented downstream. They are characterized by cut-and-fill structures and abrupt changes in particle size. The lower part of the deposit often is trough-shaped. Both the top and bottom can, however, also display a clear transverse slant.

Sediment and process: a summarily interpretation and conclusions

Since the coastal terminal alluvial fan as a landform type has not been described and discussed elsewhere for Namibia, it is dangerous to generalize on the basis of a single example. It may nevertheless be useful to draw attention to what seems to be the result of depositional processes associated with this type of fan.

Semi-arid fans are more common than stream-dominated (terminal and glacial outwash) fans (Collinson, 1986). The former are generally associated with tectonic instability, steep gradients, and debris flows. Stream-dominated fans are seldom associated with faulting and tectonic uplift and their stream gradients are low. This is true of the Uniab coastal terminal fan and the river upstream from the fan.

The present stream gradient east of the Skeleton Coast Dune field is 1 : 150 over a distance of 15 km, while the middle course has a gradient of 1 : 125 over a distance of 25 km. Because of the short time span involved, the stream gradient could not have been much different from the present at the time of deposition.

The Uniab must therefore have been a braided, low-gradient bedload stream of low sinuosity, carrying a very small percentage of fine-grained material in suspension. While the scarcity of fine-grained sediments is typical of bedload streams (Collinson, 1986), argillaceous rocks are furthermore practically absent from the whole catchment area. Not surprisingly therefore, the Quaternary sediments of the Uniab fan are characterized by sand and gravel. Mud balls and silty deposits, however, do occur on a small scale.

Terminal stream-dominated fans are associated with ephemeral rivers. They usually occur in arid basins of inland drainage in which the water discharge is progressively reduced, both downstream and on the fan surface. No water leaves the fan by surface flow as a result of infiltration and evaporation (Collinson, 1986).

The difference between the inland terminal fan and the Uniab coastal terminal fan is that, in the case of the Uniab (and other Skeleton Coast rivers), the stream is in turbulent flood when it debouches onto the coastal plain. In constrast with the inland fan it carries both sand and a heavy gravel load. Channel deposits and sheet flood deposits occur in both but they differ in sedimentary structure. Inland channel deposits are dominated by cross-bedding while sheet flood deposits are characterized by parallel lamination and ripple cross-lamination (Collinson, 1986). Since the Uniab currents are stronger and much more turbulent, the sedimentary structures must display different features.

The fact was stressed that bedding thickness and lateral continuity vary greatly in the central sea cliff and particularly in the vicinity of river mouths 2 and 3. Gravel beds are also much thicker than farther north and south in the sea cliff, while clasts are cobble-sized. Bed thickness is related to current competence — strong currents produce thicker and commonly coarser beds (Pettijohn *et al.*, 1972). At the time of deposition the strongest flowing channel with greatest depositional capacity must, therefore, have been in the vicinity of river mouths 2 and 3 where gravel beds are several metres thick.

Stream channel deposits are more common on the upper (proximal) part of a fan and, to a lesser extent, on the mid-fan. It is deduced from the available evidence that the central sea cliff with its thick gravel deposits represents the mid-fan. The major active distributary channel or channels on the mid-fan must have been up to several metres deep. The channel currents were turbulent and strong enough to transport cobble-sized clasts kilometres from the fan apex despite the low stream gradient typical of stream-dominated fans.

According to Collinson (1986) present-day bedload streams debouching onto glacial outwash stream-dominated fans are concentrated in well-defined zones while abandoned channels and bars in the rest of the fan are unaffected. In such circumstances continuous horizontal beds spreading over several square kilometres would hardly be the result. In the case of the Uniab terminal fan it seems more likely that the continuous sub-horizontal pebble beds displayed in the northern and southern sea cliff were spread out by sheet floods covering major parts of the fan simultaneously. There are thus clear differences between the two types of stream-dominated fans.

Very few gravel beds in the central sea cliff area are characterized by grading throughout the unit, although local grading may occur in part of the bed. Those with local grading may be cyclic in nature, the result of more than one flooding episode. The majority of gravel beds can, however, be described as massive in overall terms. It can, therefore, be concluded that such units were not formed by deposition from continuously decaying currents.

Some of the sand deposits in the central sea cliff area with a thickness of up to several metres are seemingly without internal structure. Even if, after further field work, these beds prove not to be truly massive, they still lack recognisable layers or lamination. The conditions of sedimentation must, therefore, have been very uniform for each unit as a whole. The stream must have been able to carry a uniform sandy load over a long enough period for the sand to accumulate to a thickness of several metres without developing an obvious internal structure (Lindholm, 1987).

Since the sand grains are not as well-rounded as those usually found in the dunes of the Namib, it is concluded that significant quantities of wind-blown sands were not deposited as part of the lower Uniab sediments. This aspect, however, awaits more detailed study.

Cross-bedded units are relatively scarce and small in the sea cliff area. They usually do not occur in sets (lithologic units composed of two or more consecutive beds of the same lithology) (Pettijohn *et al.*, 1972, p. 106). Cross-bedding of this type seems to be the product of down-current migration of a sand wave of some kind rather than deposition by wind.

The evidence for a fluviatile origin of the sediments is particularly strong in the central part of the fan which appears to be the area in which the master streams were particularly active. The following can, in fact, be listed:

1. the gravel deposits are elongate parallel to the courses of the stream;
2. the materials accumulated in discontinuous layers;
3. beds vary greatly in thickness;
4. sorting of the gravel is poor;
5. the gravels are matrix-supported;
6. the cobbles and pebbles are not as well-rounded as those found in littoral environments;
7. where gravels overlie sand an erosional contact generally separates the two;
8. while gravels in littoral conditions are typically basal, those in the study area alternate vertically with sand in the study area; and
9. practically no remnants of marine life forms are found in the deposits.

In the light of the above there can be little doubt that the Quaternary sediments of the Uniab mouth area are of an alluvial nature and that the resulting landform can be described as a terminal coastal fan, even though the fan shape can no longer be recognized due to denudation.

The fact that the beach was probably raised (Van Zyl & Scheepers, 1991), means that at least the lower strata of the present sea cliff must have been below present sea-level. Since the sediments prove to be alluvial in origin, only the base of the fan might have developed in littoral conditions.

These young deposits of the Uniab river mouth area are rather unique in Southern Africa, but not along the Namib coast. They are similar to other sedimentary packages, e.g. Awa-gamteb muds; described by Ward (1987) in the Kuiseb Valley, the Omaruru 'delta', on the Namib coast, but are unusual in the southern African context. The entrenchment of the distributaries and the existence of the sea cliff provide longitudinal and cross profiles affording excellent opportunities for sedimentological studies. More detailed field work should be done in this area.

References

American Geological Institute (1960). *Glossary of Geology and Related Sciences*. Amer. Geol. Inst., Washington, 325 pp.

Barnard, W.S. (1989). Die sandseë van die Namib en hulle verbreiding. *S. Afr. Geogr.*, **16**, 14–38.

Bryant, E. (1984). Sediment characteristics of some eastern Australian foreshores. *Austral. Geogr.*, **16**, 5–15.

Collinson, J.D. (1986). Alluvial sediments. *In*: Reading, H.G. (Ed.), *Sedimentary Environments and Facies*. Blackwell, Oxford, 615 pp.

De Beer, J.H., Joubert, S.J. & Van Zyl, J.S.V. (1981). Resistivity studies of an alluvial aquifer in the Omaruru delta, South West Africa/ Namibia. *Trans. geol. Soc. S. Afr.*, **84**, 115–122.

Elliott, T. (1986). Shallow siliciclastic seas. *In*: Reading, H.G. (Ed.), *Sedimentary Environments and Facies*. Blackwell, Oxford, 615 pp.

Hallam, C.D. (1964). The geology of coastal diamond deposits of southern Africa. *In*: Haughton, S.H., *The Geology of Some Ore*

Deposits of Southern Africa, Vol II. Geol. Soc. S. Afr., 677–728.

Hayward, A.B. (1983). Coastal alluvial fans and associated marine facies in the Miocene of SW Turkey. *Spec. Publ. Int. Assoc. Sediment.*, **6**, 323–336.

Huntley, B.J. (Ed.) (1985). The Kuiseb environment: the development of a monitoring baseline. *S. Afr. Nat. Sci. Prog. Rept.*, **106**, 138 pp.

Korn, H. & Martin, H. (1955). The Pleistocene in South West Africa. *Proc. 3rd Pan-Afr. Congr. Prehist.*, Livingstone, 14–22.

Krumbein, W.C. & Sloss, L.L. (1963). *Stratigraphy and Sedimentation.* Freeman, San Francisco, 660 pp.

Lancaster, N. (1982). Dunes on the Skeleton Coast, Namibia (SWA): geomorphology and grain size relationships. *Earth Surface Processes and Landforms*, **7**, 575–587.

Lindholm, R. (1987). *A Practical Approach to Sedimentology*. Allen & Unwin, London, 276 pp.

Mabbutt, J.A. (1951). The evolution of the middle Ugab valley, Damaraland, South West Africa. *Trans. Roy. Soc. S. Afr.*, **33**, 333–365.

Massari, F. & Parea, G.C. (1988). Progradational gravel beach sequences in a moderate- to high-energy, microtidal marine environment. *Sedimentology,* **35**, 881–913.

Milner, S.C. (1986). The geological zand volcanological features of the quartz latites of the Etendeka Formation. *Communs. geol. Surv. S.W. Africa/Namibia*, **2**, 109–116.

---- & Duncan, A.R. (1987). Geochemical characterisation of quartz latite units in the Etendeka Formation. *Communs. geol. Surv. S.W. Africa/ Namibia*, **3**, 83–90.

Parkash, B., Awasthi, A.K. & Gohain, K. (1983). Lithofacies of the Markanda terminal fan, Kurukshetra district, Haryana, India. *Spec. Publ. Int. Assoc. Sediment.*, **6**, 337–344.

Pettijohn, F.J. (1957). *Sedimentary Rocks*. Harper & Brothers, New York, 718 pp.

----, Potter, P.E. & Siever, R. (1972). *Sand and Sandstone*. Springer-Verlag, Berlin, 618 pp.

Reineck, H.E. & Singh, I.B. (1974). *Depositional Sedimentary Environments*. Springer-Verlag, Berlin, 549 pp.

Short, A.D. & Wright, L.D. (1981). Beach systems of the Sydney region. *Austral. Geogr.*, **15**, 8–16.

Stengel, H.W. (1964). Die riviere der Namib und ihr zulauf zum Atlantik, I Teil: Kuiseb und Swakop. *Scient. Papers Namib Desert Research Station,* **22**, 49 pp.

---- (1966). The rivers of the Namib and their discharge into the Atlantic. Part II: Omaruru and Ugab. *Scient. Papers Namib Desert Research Station,* **30**, 34 pp.

Twenhofel, W.H. (1950). *Principles of Sedimentation.* McGraw-Hill, New York, 673 pp.

Tyson, P.D. (1986). *Climatic Change and Variability in Southern Africa.* Oxford University Press, Cape Town, 220 pp.

Van Zyl, J.A. & Scheepers, A.C.T. (1992). Landforms and geomorphic processes of the Uniab mouth area. *S. Afr. Geogr.* (in press).

Ward, J.D. (1987). The Cenozoic succession in the Kuiseb valley, central Namib Desert. *Mem. geol. Surv. S. W. Afr., Namibia,* **9**, 124 pp.