

Late Cenozoic fluvial deposits of the Tsondab Valley, central Namib Desert

by

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CONTENTS

1 Introduction	257
2 The Tsondab catchment	258
3 Early Cenozoic history of the Tsondab	258
4 Character and distribution of late Cenozoic fluvial deposits in the Tsondab Valley	259
4.1 The capping conglomerate	259
4.2 The Hamilton Vlei conglomerate	261
4.3 The Narabeb formation	262
4.4 Interbedded gravels and silts of western areas	263
4.5 Silts and sands of the Tsondab Flats ...	264
4.6 Vlei silts	264
4.7 Valley side colluvial and alluvial deposits	266
5 Chronology of late Cenozoic fluvial events in the Tsondab Valley	266
6 Discussion	267
7 Conclusions	268
8 Acknowledgements	268
9 References	268

1 INTRODUCTION

The Namib Desert is crossed by a number of rivers draining from the highlands east of the Great Escarpment to the Atlantic (Fig. 1). Apart from the Kunene and Orange, which have their sources in the humid highlands of Angola and Lesotho, all flow seasonally or ephemerally. From the Kuiseb northwards, most of the larger streams are known to flow to the sea from time to time and have courses which can be traced to the coast. Between the Kuiseb and Orange Rivers, there are no rivers which reach the coast, partly as a result of the increasing aridity of the highland parts of their catchments, and partly as a result of the existence of the Namib sand sea, between 23 and 25°S. Larger streams such as the Koichab, Tsauchab and Tsondab penetrate up to 50 km into the sand sea, to end in terminal playas (called vleis in SWA/Namibia). Most, if not all, of these rivers possess deposits in their valleys or beyond their normal end points which indicate increased river flow at some time in the past. Such deposits may provide valuable information on paleoenvironments in the Namib and its hinterland, and indirectly may contribute to our knowledge of how the sand sea developed.

The importance of these fluvial deposits was recognised by early workers in the region (Gevers, 1936; Mabbutt, 1952; Korn and Martin, 1957), but to date only the deposits of the Kuiseb Valley have received detailed study (e.g. Marker, 1977; Rust and Weinecke, 1980). In contrast, the Tsondab has been investigated at a reconnaissance level only. Ollier (1977) noted the presence of river terraces in the vicinity of Tsondab Vlei and

ABSTRACT

Fluvial deposits, which include calcreted conglomerates, gravels, sands and silts are found up to 50 km west of the present end point of the Tsondab River. They provide evidence for periods of variably increased fluvial activity in the area during the late Cenozoic. Paleoclimatic interpretations of the deposits are difficult, but all were apparently laid down in arid or semi-arid environments. This suggests that, although there have been fluctuations in rainfall and run-off in the Tsondab Valley and its headwaters, they have mostly been of limited extent.

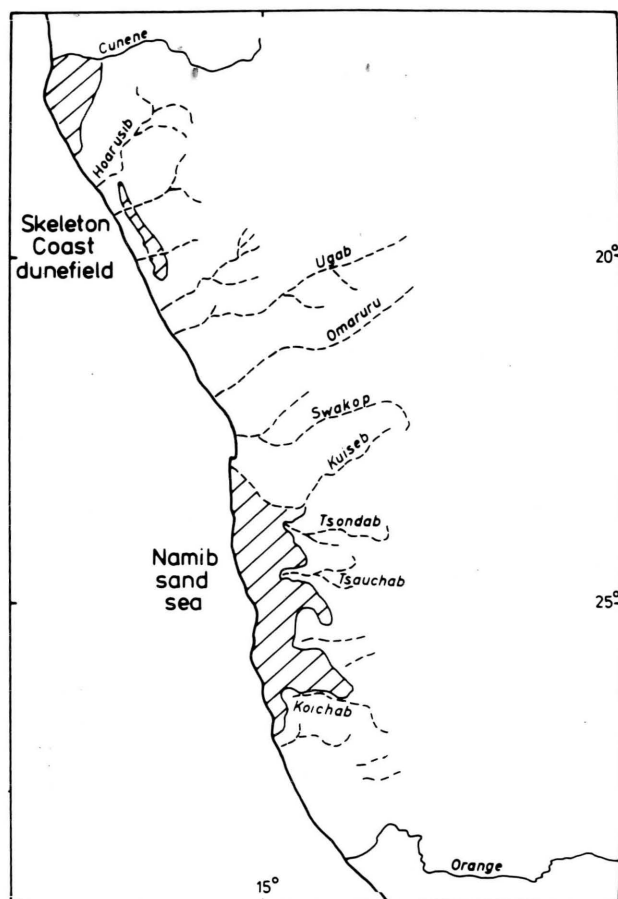


FIGURE 1: The Tsondab in relation to the rivers of the Namib Desert.

proposed a scheme for the geomorphic evolution of the Tsondab Valley. Some of the river terraces were mapped by Marker (1979), who failed to find any consistent altitudinal relationships between them, which she explained in terms of subsequent aeolian modification. Silt deposits at Narabeb, associated with Early and Middle Stone Age artifacts, were briefly studied by Seely and Sandelowsky (1974) and dated by Selby *et al.* (1979). Seely and Sandelowsky introduced the concept of progressive desiccation of the Tsondab Valley and retreat of its end point, based upon the apparent decrease in age of silt deposits upstream.

The close proximity of the Tsondab and Kuiseb Valleys, with as little as 20 km separating them at some places, offers the possibility of making comparisons between their fluvial histories, which may help to isolate regional and local elements in environmental change in the central Namib.

This paper reports the initial results of an investigation of the fluvial history and paleoenvironments in the Tsondab Valley and discusses some of the problems of the interpretation of the fluvial deposits.

2 THE TSONDAB CATCHMENT

The Tsondab River rises at an altitude of 1 450 m east of the Great Escarpment in a region of indeterminate drainage and flows for 110 km west and north-west to

its present end point at Tsondab Vlei, 90 km from the Atlantic, where a series of 100-150 m high dunes blocks its westward course. Beyond these dunes lie the Tsondab Flats, which extend for a further 30-40 km westwards. Further west "windows" of fluvial gravels in interdune areas and a disturbed pattern of the N-S trending linear dunes extend in a W-N-W direction to 20 km from the coast.

The catchment area of the Tsondab is small, at only 3 640 km² (Stengel, 1970). Flows in the Tsondab River are ephemeral, or seasonal in some parts of the upper catchment. Water reaches the Tsondab Vlei only in years of exceptional rainfall. In its upper reaches, the Tsondab flows through the Bullspoort, a massive gash between the Naukluft and Remhoogte Mountains which rise to 1 800-1 900 m on each side. In this area it is joined by numerous tributaries from the mountains, which receive 100-200 mm of rainfall annually and probably contribute most of its discharge. West of the escarpment, the Tsondab flows across calcreted fan-glomerates and has a very shallow valley. At about 30 km from the escarpment it becomes incised into these and other relict fluvial deposits. Gradually the size of the valley and the depth of incision increase, reaching a maximum of 80-100 mm at Tsondab Vlei. The southern sides of the incised valley in its lower parts are invaded by sand-dunes, which almost cross to its northern side at several points, and may in the future repeat the blocking of the valley-way by dunes further to the west.

The Tsondab Flats consist of an extensive area of "terraced" topography, with prominent and widely developed surfaces at altitudes of 520-540 m and 550-570 m or around 10 and 40 m above the lowest areas which continue the present course of the Tsondab River. These surfaces, which are covered by spreads of gravels and desert pavement, are co-extensive with similar surfaces which are exposed in interdune areas for up to 20 km to the south. They are gradually being covered by the extension of the dunes from the south and south-west. Although Marker (1979) regarded many of these surfaces as a modified fluvial terrace topography, they probably represent lithological variations in the semi-consolidated Tsondab sandstone of probable Tertiary age which forms the bedrock in most of the lower parts of the valley. Bedrock geology of the upper parts of the Tsondab catchment is dominated by the limestones, shales and dolomites of the Naukluft nappe complex. These provide clasts with a distinctive oblate or bladed shape and pale blue or black colour which dominate the lithology of all fluvial deposits in the Tsondab Basin.

3 EARLY CENOZOIC HISTORY OF THE TSONDAB

According to Korn and Martin (1937), the Tsondab of early and mid Tertiary times drained towards the east. With later Tertiary uplift and formation of the escarpment drainage reversal took place as the early Tertiary

upper Tsondab was captured by streams cutting back into the escarpment. They consider that the large valley of the Bullspoort was formed at this time.

4 CHARACTER AND DISTRIBUTION OF LATE CENOZOIC FLUVIAL DEPOSITS IN THE TSONDAB VALLEY

The primary source for elucidating the fluvial history of the Tsondab is the identification and mapping of *in situ* alluvial and locally colluvial deposits. These deposits, often strongly cemented by calcium carbonate, are common in the lower Tsondab Valley and also extend up to 50 km west of the vlei. Mapping and correlation of the more recent deposits is complicated by their discontinuous distribution and unconsolidated nature.

4.1 The capping conglomerate

The oldest fluvial deposits to be recognised in the lower Tsondab Valley, apart from localised playa silts in the upper parts of the Tsondab sandstone formation, are termed the capping conglomerate. This forms an extensive flat to gently undulating surface which caps the Tsondab sandstone east of Tsondab Vlei, with outliers extending for 10–20 km west (Fig. 2). It was called by Ollier (1977) the Tsondab planation surface and the "Namib limestone", which manifestly it is not, by Marker (1982). The capping conglomerate surface rises gently eastwards from 700 m at Tsondab Vlei to the

900 m contour where it appears to grade imperceptibly eastwards into the calcreted fanglomerate at the base of the escarpment. It is cut by shallow meandering drainage lines, some of which end in closed, probably karstic, depressions, and Marker (1982) has described an extensive doline karst developed on this and related surfaces. The thickness of the capping conglomerate as determined by exposures and by drilling, Wilson (1979), is generally 1.5–2.0 m. Locally it may be up to 3–5 m thick along paleo-drainage lines. The conglomerate unconformably overlies weathered Tsondab sandstone with a calcareous or gypsiferous cement.

The composition of the capping conglomerate is variable, with rapid lateral facies changes. Clasts range from coarse, angular quartz sands to well-rounded tabular cobbles and boulders of pale blue or black Naukluft dolomites and limestones. Also present in quantity are angular to sub-angular clasts of red brown rhyolites and andesitic volcanics. Generally quartz and volcanics are more common towards the northern margins of the deposit and limestones and dolomites to the south. This appears to reflect the influence of variable sources, with outcrops of quartzites and volcanics on the northern margins of the basin and limestones and dolomites in the central and southern parts. Clast size varies considerably in any area, but overall declines from cobble grade in the east to pebble and gravel grade in western areas. All clasts are contained in a well-litified calcium carbonate matrix, which especially in the upper parts of the deposit effectively makes this a matrix supported conglomerate.

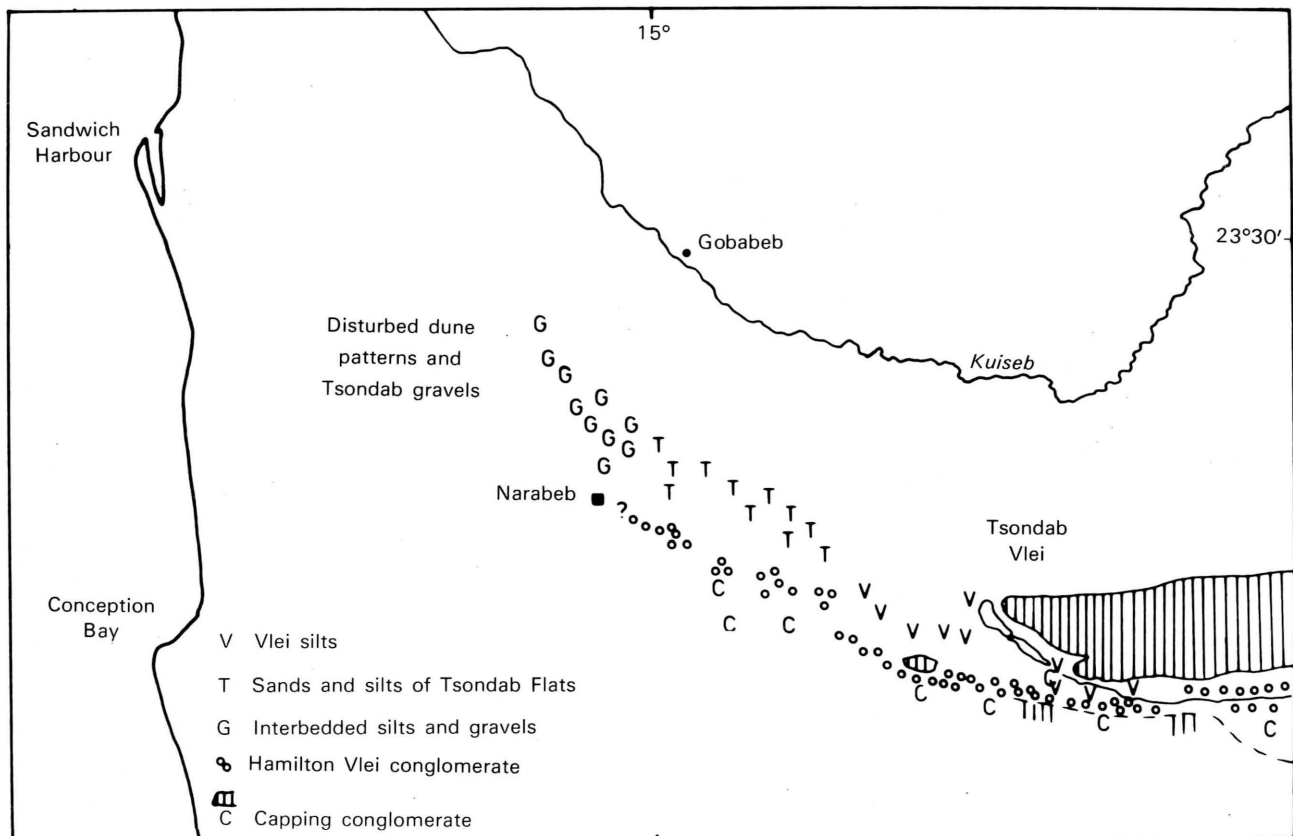


FIGURE 2: The lower Tsondab Valley, showing extent of principal fluvial deposits.



PLATE 1: Capping conglomerate outcrop at Tsondab Vlei, where it overlies 70 m of Tsondab sandstone.

Aerial photographs and LANDSAT images show indications of slightly sinuous prior channel-ways in the capping conglomerate. They appear to be correlated with changes in the size of surface clasts in a way which suggests that the conglomerate was laid down by anastomosing and braided streams in the distal parts of

a wide alluvial fan system extending westward from the Great Escarpment. In the area of the Tsondab Vlei, a 15 km wide shallow valley cut into the Tsondab sandstone. The capping conglomerate is equated with similar, but generally much thicker, units that sit in the Kuiseb catchment (Marker, 1990).

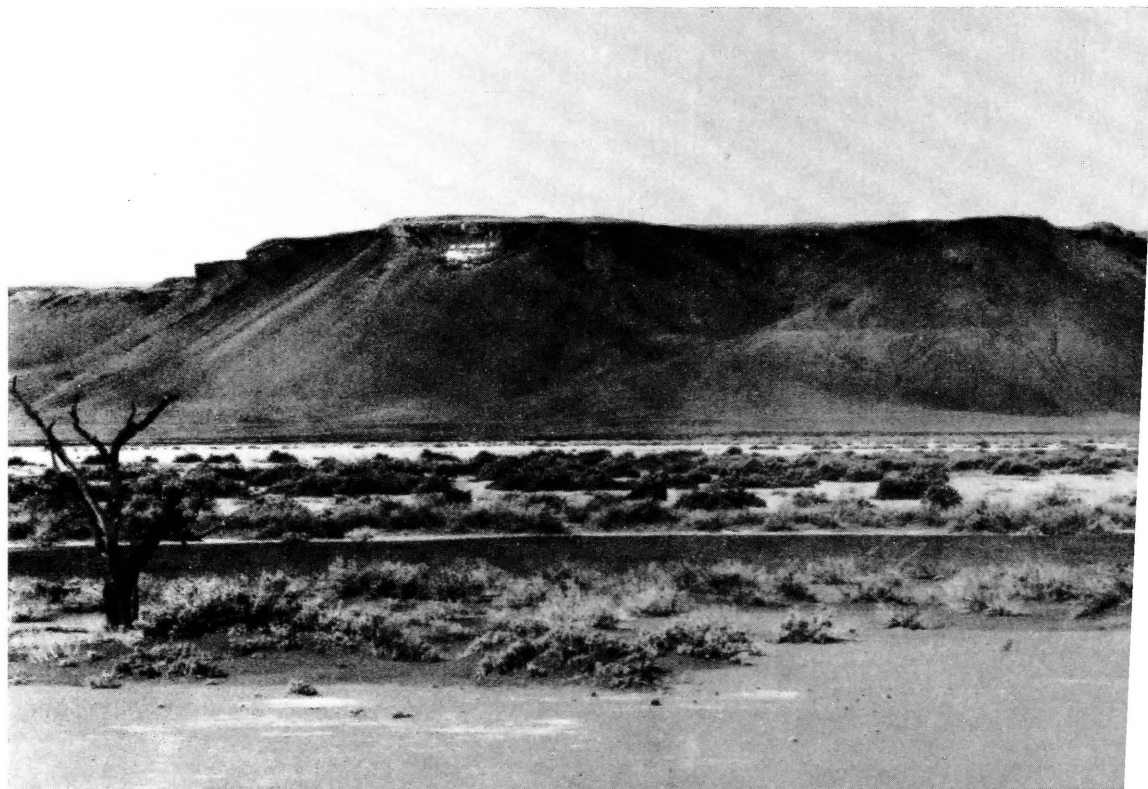


PLATE 2: Outcrops of Hamilton Vlei conglomerate 16–20 m above the middle Tsondab Valley.



PLATE 3: Close-up of Hamilton Vlei conglomerate outcrop; note strong calcrete cementing of upper parts of deposit and imbricated structures in lower parts.

thick pedogenic calcretes (Ya'alon & Ward, 1982) which formed during this period on the sandstone watershed areas.

4.2 The Hamilton Vlei conglomerate

Following at least partial cementation of the capping conglomerate, there occurred a period of moderate valley formation and dissection of the Tsondab sandstone. Maximum incision was in the order of 30 m. No deposits relating to this period have been recognised.

Tabular masses of calcreted conglomerates up to 8 m thickness (Plate 2) which unconformably overlie Tsondab sandstone occur from 30 km west of the escarpment and extend westwards to 100 km from the escarpment, or 30 km west of Tsondab Vlei (Fig. 2). Upstream of the vlei, they lie at an altitude of 15–20 m above present river level. Their lateral extent is limited to a maximum of 2 km in upstream outcrop areas and to 1 km in western areas. These conglomerates are termed the Hamilton Vlei conglomerates.

Typically these conglomerates are clast supported and composed of well-sorted, rounded tabular and bladed cobbles and boulders of pale blue and black limestone and dolomites of the Nama formation (Plate 3). There are also occasional clasts of rolled capping conglomerates. Frequently imbricated structures are well-developed, indicating deposition by streams flowing towards the west or west-south-west. Average clast size decreases from 150–150 mm (long axis) in eastern areas, where there are also occasional tabular boulders of

quartzites up to 500 mm or exceptionally 1 m across; to 100–150 mm in central areas and 50–100 mm in the west. Within outcrops, short distance lateral and vertical changes in clast size are common, and frequently there are indications of gravel size lenses in cobble and boulder size conglomerates and coarse sand lenses in gravel size outcrops. Thickness of the Hamilton Vlei conglomerate declines from a maximum of 8 m, with a mean of 4–5 m in proximal, eastern areas to 1–2 m in western distal areas. Particularly in the east, the base of the deposits clearly indicates deposition in shallow channels cut in underlying sandstone. Upstream of Tsondab Vlei, the upper parts of the conglomerate are strongly cemented with calcium carbonate, whilst the lower parts are frequently loosely cemented. Towards the west, the whole of the deposit is strongly to moderately indurated.

The age of these conglomerates is uncertain. If they are related to the Narabeb lacustrine deposits, then following Selby *et al.* (1979), they are in the order of 200 000 years old. The Hamilton Vlei conglomerates can, on stratigraphic terms, be tentatively correlated with the Oswater conglomerates of the Kuiseb Valley (Ward, 1982).

The distribution of outcrops of Hamilton Vlei conglomerate shows that they were laid down by a river which had a course parallel to that of the modern Tsondab in eastern areas, which then diverged from the modern course to flow west and west-north-west at a point some 10 km east of Tsondab Vlei (Fig. 2). The altitudes of these conglomerates decline westward at a somewhat lower rate (1:220) than the gradient of the

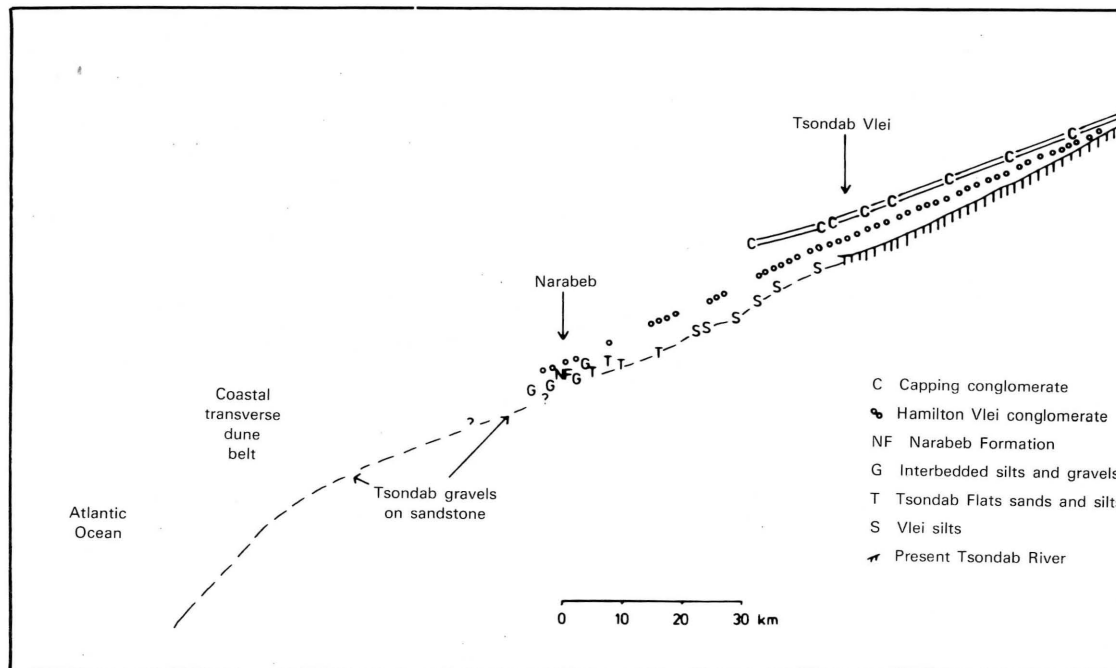


FIGURE 3: Long profiles of the Tsondab Valley to show altitudinal relationships between major fluvial deposits.

lower reaches of the modern Tsondab (1:195) (Fig. 3). The westward limits of the Hamilton Vlei conglomerates are uncertain. No *in situ* deposits could be traced beyond a point some 5 km east of Narabeb. Scattered gravels of a similar nature continue west to Narabeb itself, and it may be that the Hamilton Vlei conglomerate stream had its end point in a playa in this area. Related interfluvial deposits appear to be the well-developed pedogenic calcretes found in some southern areas of the Tsondab Flats. The character and distribution of the Hamilton Vlei conglomerates suggest that they were deposited by a shallow probably braided stream flowing in an open valley flanked by sandstone slopes capped by eroding capping conglomerates. The generally good sorting of the gravels and cobbles suggests deposition in quite a high energy environment.

4.3 The Narabeb formation

At Narabeb, 40 km west of Tsondab Vlei and midway between there and the Atlantic, there is an extensive outcrop of clays, silts and fluvial sands, up to 12 m thick, which lie in a 25–30 m deep depression, closed to the north and east. They were first described by Seely and Sandelowsky (1974) who suggested that they represented deposits laid down at the end point of a predecessor of the modern Tsondab River. Subsequently, Selby *et al.* (1979) obtained $^{234}\text{U}/^{230}\text{Th}$ dates of 210–24 000 years BP for a lower member of the deposits.

The deposits at Narabeb, herewith termed the Narabeb formation, consist of up to 12 m of horizontally bedded clays, silts, silty sands and sands (Plate 4). Some of the clayey members of the formation are strongly indurated by calcium carbonate. The main outcrop extends for 4 km along the western side of one of the north-south linear dunes. Related deposits, mainly powdery car-

bonates and indurated silty clays, cover 20 km² in the adjacent dune corridors north-west. To the south occasional sands and gravels cover the silts. The formation overlies consolidated red sands.

The main sequence of deposits at Narabeb consists of five main indurated clayey members, well-indurated silts, silty sands and sands, which is capped by up to 5 m of coarse sands. The lower unit is separated from the upper by 2 m of sands and silty sands and consists of clays and silty clays directly overlying sands, often with abundant pedotubules. The beds dipping steeply west and the sands are interpreted as aeolian and not as Tsondab sandstone formation.

The character of the Narabeb formation indicates deposition in a fluctuating lake environment with a strong fluvial input. The formation consists of calcareous clays and muds with silts and sands, reflecting a changing inflow and water level conditions. The overall increase in fluvial input towards the formation. Fine-grained members consist of playa and channel fill deposits, which are deposited seasonally. Coarser members consist of channel deposits.

A preliminary interpretation is that the Narabeb formation represents a sequence of deposits deposited in a marginal or marginal flood basin of the Tsondab. Although absolute dates of 210–24 000 years BP are available (Selby *et al.*, 1979) the stratigraphic relationships of the Narabeb formation to the Tsondab are uncertain. The proximity of the western limits of the Hamilton Vlei conglomerates and the apparent mixing of fine-grained deposits in marginal areas, suggest that

mation may have been laid down by a westward extension of the river which deposited the Hamilton Vlei conglomerates.

Abundant stone artifacts occur in the area and rest upon the surface of the deposits (Seely and Sandelowsky, 1974). They appear to be of "Early Stone Age" affinities at Narabeb itself, but of "Middle Stone Age" type at a site in the dune corridor immediately west of Narabeb (Shackley, personal communication). The artifacts give a minimum age for the deposits of 60–100 000 years. Calcified pedotubules from the consolidated red sands were dated by Vogel (Pta 1197) to $28\,500 \pm 500$ BP. The available information seems to indicate that following initial deposition of the Narabeb formation prior to 100 000 BP, there was sufficient moisture available to permit human occupation, at least seasonally, in Middle Stone Age times, and the growth of vegetation around 28–30 000 BP. This is explainable by the particular topographic situation of Narabeb, in a depression in the pre-dune surface, which would favour ephemeral or seasonal water accumulation in periods of increased rainfall.

4.4 Interbedded gravels and silts of western areas

Following a degree of induration of the Hamilton Vlei conglomerates the Tsondab Valley experienced a major period of erosion, during which a wide valley at least 60 m deep was carved in the sandstones west of Tsondab Vlei and the extensive sandstone relief of the Tsondab Flats was largely eroded. Calcreted conglomerates

of earlier periods acted as cap rocks and protected some of the sandstones from erosion leading to relief inversion and to the northerly course of the major valley-way. There are no deposits which can be unequivocally related to this period. It is probable that much of the eroded material of sand size was carried to the Atlantic or has subsequently been incorporated in dunes to the north of the Tsondab. In many areas to the west and north-west of Narabeb rounded cobbles of the matrix and smaller clasts of both capping and Hamilton Vlei conglomerates are frequently encountered in desert pavement surfaces, and it is possible that they were reworked at this period.

Middle Stone Age artifacts are widespread in the Tsondab Valley. Most of them are found in an unrolled state and are confined to higher surfaces. Scattered rolled examples are encountered in lower areas and suggest a minimum age for this erosion period.

All subsequent deposits are confined to the major valley-way west of Tsondab Vlei and its ill-defined extension north-westwards into the dunes. These deposits, of presumed Upper Pleistocene age, are dominated by fine-grained materials, notably sands and silts.

The earliest of these deposits is a series of interbedded silts and gravels which are found discontinuously in areas west and north-west of the Tsondab Flats (Fig. 2). Typically these consist of loose poorly sorted gravels containing rounded conglomerate clasts, together with sub-rounded to rounded clasts of rhyolites, limestones and dolomitic limestones, and occasional rolled Middle Stone Age cores and flakes. Interbedded amongst these are 15–20 cm thick layers of silts and (Plate 5) sandy



PLATE 4: Main outcrop of the Narabeb formation at Narabeb. Note banded nature of indurated clay members.

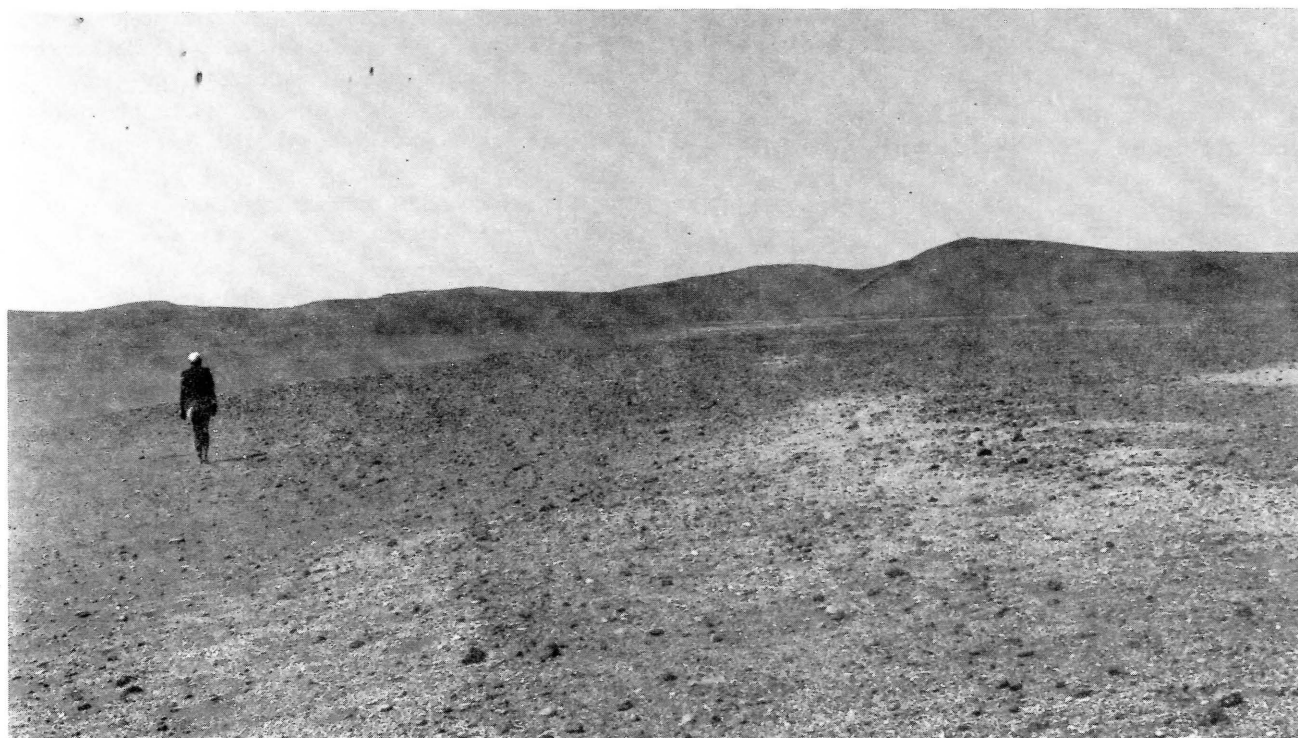


PLATE 5: Interbedded silts and gravels in the dunes west of the Tsondab Flats.

silts. Trace fossils in these are indicative of reeds and aquatic vegetation. Total exposed thickness of these deposits is 2–3 m. In an area some 60 km north-west of Tsondab Vlei these deposits appear to intercalate with quartz gravels of the Kuiseb system and may be associated with extensive areas of silts up to 5 m thick, with occasional reed beds and organic rich muds.

Interpretation of these deposits is uncertain. Their discontinuous distribution in western areas and mixed composition suggest deposition by low energy streams which were reworking gravels upstream. Deposition of fine-grained silts dominated in this low energy environment, with occasional floods promoting gravel deposition. The parallels with the modern Tsondab River are clear, where interfingering of gravels and silts occurs in areas upstream from the vlei.

4.5 Silts and sands of the Tsondab Flats

The lower areas of the Tsondab Flats form a wide valley-way bounded by dunes to the north, which is flooded by pale sands with patches of gravels and small cobbles in eastern areas and extensive areas of thin silts, muds and sandy silts in western areas. The silts are thinly laminated with sand-filled and mud-filled desiccation cracks in their upper members. Exposures are rare, but test pits show the silts to be generally thin (Plate 6), with an average thickness of between 10 and 50 cm. They overlie cross- or planar-bedded angular to sub-rounded sands with frequent coarse sand and gravel lenses and occasional silt layers. Pedogenic calcrete formation is rare to absent, in contrast to higher and older surfaces in the flats. Many of the clasts of the gravel and pebble lenses contain rolled pieces of older conglomerates.

In western areas, the sands members of this formation appear to overlie the upper members of the earlier interbedded gravels and silts. Altitudinal relationships of this suite of deposits indicate that they were deposited by a stream with a gradient which continues that of the present Tsondab (Fig. 3).

Inferred depositional environments for this suite of sandy and silty deposits are a low energy flood-plain with a locus of deposition fluctuating as seasonal flood discharges varied and braided channels shifted position, perhaps in response to dune invasion. Upstream equivalents of this group of deposits are absent, but probably comparable gravels, lightly cemented by calcium carbonate occur locally on the north side of the Tsondab Flats.

4.6 Vlei silts

Silts and muds, mostly calcareous, form the surface of the present ephemerally flooded terminal playa of Tsondab Vlei. There are also four smaller areas of silts in an area some 10–15 km upstream. These probably represent the modern and historical terminal playas of the Tsondab River. It is possible that the upstream vleis, which are marginal to the major stream bed of the Tsondab, represent former end points of the river, perhaps when dune patterns in the area were different. Holes drilled at the western end of Tsondab Vlei in the course of a prospecting programme penetrated up to 12 m of fine-grained grey calcareous silts and muds, overlying a thick sequence of aeolian sands with occasional gravel lenses (Wilson, 1979). They indicate long continued sedimentation at Tsondab Vlei. Upstream silts are thinner with an average thickness of 4–5 m. Vogel and Vis-

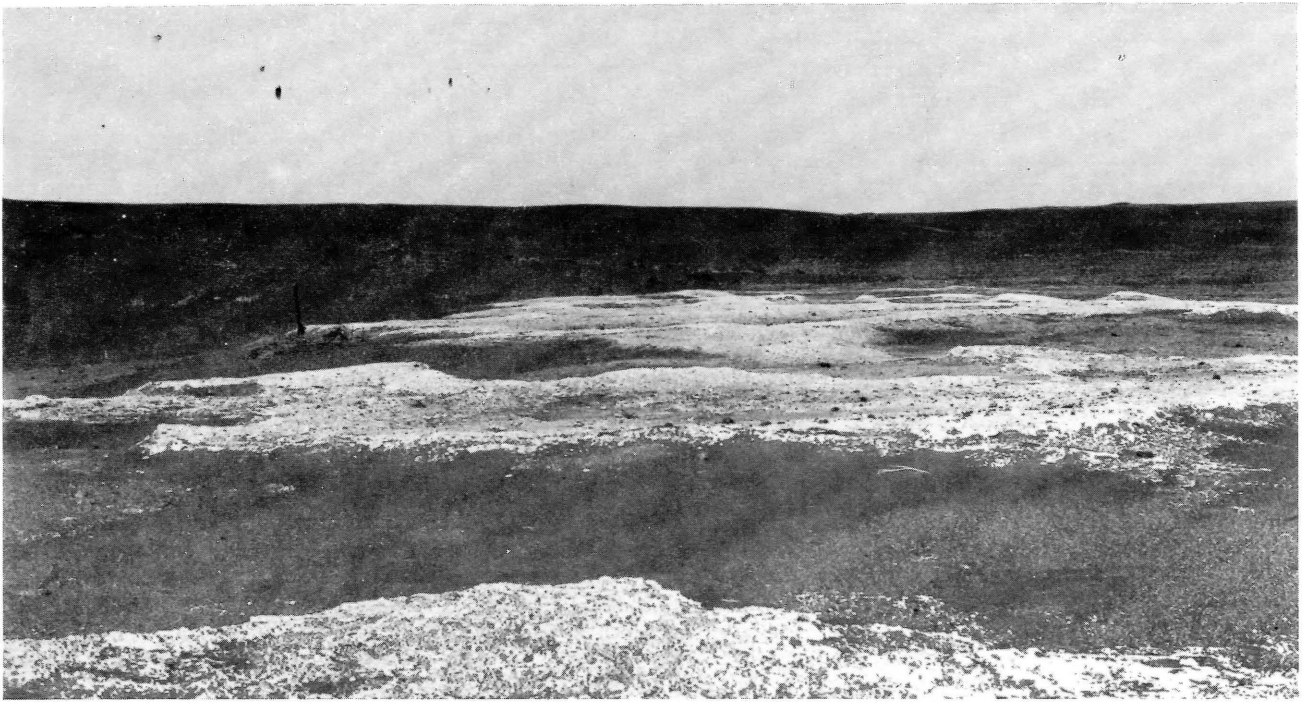


PLATE 6: Silt outcrops in the western Tsondab Flats.

ser (1981) report a ^{14}C date of $8\,640 \pm 70$ BP (Pta 1501) from the surface members of these silts.

One to two kilometres west and south-west of Tsondab Vlei 4–8 m of silts and sandy silts outcrop in interdune corridors. These silts are thinly laminated and horizontally bedded, with abundant desiccation cracks (Plate 7). Particularly in their lower members, the silts are domed up around small (1–2 m diameter) inclusions of red brown sands. These appear to have a modern parallel in the deposition of silts around sand mounds which form

around shrubs and bushes of *Salsola* spp growing on the surface of the modern vlei. The silts overlie red brown cross-bedded sands of probable aeolian origin. Basal silts also appear to have overridden the lower slopes of small dunes. Scattered outcrops of essentially similar deposits up to 2 m thick occur between the Tsondab Vlei and Flats.

On the northern side of the Tsondab Flats, 10–15 km west of the vlei, similar but rather thinner silts and muds outcrop. Maximum thickness of these deposits is 50 cm



PLATE 7: Outcrop of vlei silts 5 km south-west of Tsondab Vlei.

to 1 m, and they overlie red brown cross-bedded sands, which are muddy and have slightly distorted bedding in their upper parts. These deposits, first described by Seely and Sandelowsky (1974), contain shells of the fresh water molluscs *Lymnea natalensis* and *Biomphalaria pfeifferi* which appear to require at least seasonally continuous moisture. Vogel and Visser (1981) report ^{14}C dates of $13\,300 \pm 90$ BP (Pta 1043) from these shells and $14\,300 \pm 130$ BP (Pta 1502) from a calcified layer in the upper parts of these deposits. Sandelowsky *et al.* (1976) located the unidentified tracks of a large mammal in the surface of these silts. Similar deposits outcrop discontinuously for some 12 km along the foot of the dunes that form the northern margin of the Tsondab Flats.

The general character of the silts which outcrop to the west of the Tsondab Vlei is essentially the same as of those which occur in the vlei itself. They represent the former position of the terminal playa of the Tsondab River, which appears to have retreated progressively from a position on the Tsondab Flats prior to 14 000 BP.

4.7 Valley side colluvial and alluvial deposits

The relatively wide valley of the Tsondab River upstream from the vlei, and the absence of strong fluvial activity in the main channel favour the preservation of widespread valley side deposits. These are of two main varieties.

Unit 1 consists of up to 1 m of poorly sorted gravels, cobbles and boulders, lightly cemented by calcium carbonate, which mantle the slopes of the Tsondab Valley and its tributaries in the area from 5 km to 20 km upstream from Tsondab Vlei. In major north bank tributaries' valleys similar deposits up to 3 m thick occur (Plate 8). These deposits, which are dissected by the Tsondab River and cut through by its tributary gullies, appear to consist largely of clasts derived by weathering of the capping and particularly the Hamilton Vlei conglomerates. They would appear to mark a period of considerable weathering and soil formation under stable conditions to allow the cementation of the colluvial mantles to take place. Stream channels were apparently much narrower than at present, suggesting much smaller formative discharge.

Unit 2 consists of coalescing valley side alluvial fans in the area immediately upstream from Tsondab Vlei, at the base of the sandstone escarpment, together with similar but smaller fans in the eastern areas of the Tsondab Flats. Deposits consist of small arcuate fans, often only 200–500 m wide, which are composed of poorly sorted angular blocks of the capping conglomerate and its matrix, together with irregular sandstone clasts. The fans have been lightly recemented by calcium carbonate and gypsum and then dissected by small gullies. This unit would appear to have been deposited in conditions similar to those of today, but with more frequently occurring locally derived run-off.



PLATE 8: Exposure of colluvial gravels in middle Tsondab Valley. Note uncemented, poorly sorted nature of this deposit.

5 CHRONOLOGY OF LATE CENOZOIC FLUVIAL EVENTS IN THE TSONDAB VALLEY

Stratigraphic and geomorphic relationships between deposits in the Tsondab Valley enable an overall picture of late Cenozoic fluvial events to be established for the area. A tentative chronology of events with suggested dating is summarised below, from oldest to youngest.

- 1 Proto Tsondab erodes wide, shallow valley in sandstone. Deposition of gravels by distal reaches of Tsondab River extending westwards from the escarpment. Middle to late Miocene.
- 2 Calcrete cementation of gravels to form capping conglomerate. Widespread pedogenic calcretes on sandstone interfluvies. End Miocene.
- 3 Erosion of capping conglomerates and sandstone to depth of 30–40 m in western areas. Early Pliocene.
- 4 Deposition of Hamilton Vlei conglomerates, possibly Narabeb formation. $\pm 250\text{--}200\,000$ years BP.
- 5 Calcreting of Hamilton Vlei conglomerates, limited to pedogenic calcretes on adjacent slopes.
- 6 Extensive erosion of conglomerates and sands to depth of 70–80 m or more. Formation of Tsondab Flats erosion surfaces. Possibly correlates with late Pliocene/early Pleistocene.

"Middle Stone Age Pluvial" of Korn and Martin (1957). Later mid to early Upper Pleistocene.

- 7 Localised reworking of conglomerates and gravels to form interbedded silts and gravels in western areas. Pedogenic calcretes on Tsondab Flats surface. Probably a transition phase between period 6 and 8.
- 8 Deposition of Tsondab Flats sands and silts. Water and vegetation at Narabeb. 25–35 000 BP.
- 9 Deposition of vlei silts in eastern Tsondab Flats. Retreat of end point from flats following dune invasion after 12 000 BP. Formation of valley side colluvial mantles in areas east of vlei.
- 10 Localised fan development and trenching. Incision of middle and lower Tsondab River to depth of 2–3 m. Holocene.

6 DISCUSSION

The deposits and landforms of the Tsondab Valley preserve a record of irregularly fluctuating activity throughout the late Cenozoic.

Limited aggradation of gravel and cobble size material is represented by the capping and Hamilton Vlei conglomerates, whilst the complex of sands, silts and occasional gravels in the Tsondab Flats and areas further west represents aggradation of finer grade material. These are separated by periods of erosion and incision, of which only one is of major proportions.

The nature of the deposits preserved in the Tsondab seems to indicate a general fining trend through the Cenozoic. This would imply an overall decrease in discharge and stream energy, a trend which is consistent with the suggestions of a progressive late Cenozoic increase in aridity by Tankard and Rogers (1978). The generally thin nature of the deposits is a reflection of the relatively small size and hence sediment production of the Tsondab catchment (3 640 km²) and the wide, shallow nature of the Tsondab Valley. It may also be partly explained by the existence of outcrops of limestones and dolomites in the Naukluft Mountains. Karst features, especially tufas, are widely developed here, suggesting that much of the sediment removal from this area has taken place in the form of dissolved, rather than solid, load.

Interpretation of the deposits of the Tsondab in paleoclimatic terms is difficult. Firstly, there are many conceptual problems in deducing paleoclimates from fluvial deposits, as has been pointed out by numerous workers (e.g. Butzer *et al.*, 1973; Allchin *et al.*, 1978). Secondly, the Tsondab derives its discharge from an area which is adjacent to the Namib and at considerably higher altitude. Thus it is difficult to transfer the climatic implications of increased discharge in the escarpment zone to the Namib Desert itself.

It is tempting to view the sequence of fluvial deposits and landforms as the product of arid aggradation and humid incision. Such a simple model is inappropriate for

arid and semi-arid sub-tropical areas as Helgren (1979) has shown. Further, as the contemporary floods in the Tsondab occasionally reach the present end point and flows are ephemeral in its middle reaches significant sediment transport is very limited. The presence of well-sorted, cobble and gravel grade deposits up to 100 km west of the escarpment, and silt deposits 40 km west of the present end point is therefore clear evidence for streams which had considerably greater discharge and/or competency than the modern Tsondab. Therefore all fluvial deposits in the Tsondab imply conditions in its headwaters which were more humid than today.

The character of all the deposits in the Tsondab indicates deposition in arid or semi-arid conditions. In this context, aggradation is frequently the result of increasing sediment concentrations down stream as water sinks into permeable stream beds and evaporation increases. It may be accompanied by upstream erosion and incision. The locus of deposition will thus reflect the magnitude of the flood discharges in relation to sediment supply, much of which will be derived in reworking of older fluvial deposits. Overall incision and valley development in the arid context implies that run-off and stream discharges are high enough to remove sediment from the middle and lower parts of the basin. In the case of the Tsondab, the major mid to Upper Pleistocene period of erosion and valley development in the arid context implies that run-off and stream discharge are high enough to remove sediments from the middle and lower parts of the basin. In the case of the Tsondab, the major mid to Upper Pleistocene period of erosion and valley development was concentrated in an area 60 to 100 km from the escarpment, in the lower reaches of the modern valley and on the Tsondab Flats. The existence of extensive tributary valley areas implies that run-off was high in the Namib itself, and the western locus of the major erosion suggests that valley sides upstream were stable, perhaps with a well-developed vegetation cover.

The courses of successively younger streams in the area west of Hamilton Vlei have each taken a more northerly position and trend to the north-west, as indicated by Fig. 2. The deviations become progressively greater towards the west. It is possible that this reflects invasion of the river valleys from the south by dunes, but such a process may more reasonably reflect the diversion of river flow away from the indurated conglomerates to the south. Dune invasion may only have played a part in determining the trends of the more recent streams.

Correlation of events between the Tsondab and Kuiseb is made possible by the overall similarity between their fluvial histories. It would appear that the capping conglomerate is equivalent to the deposits termed the calcrete cap rock by Marker (1977) which predate the incision of the Kuiseb Valley. In both the Kuiseb and Tsondab there then followed a period of valley incision, in turn followed, in the mid Pleistocene, by aggradation and the deposition of Oswater type conglomerates (Ward, 1982). Subsequently, as in the Tsondab, these

deposits were cemented by calcium carbonate prior to a major period of incision and erosion, which is apparently equivalent in age to the major erosion period in the Tson-dab. There is no obvious equivalent in the Tson-dab to the Homeb silts of the Kuiseb, deposited in the period 23–19 000 BP (Vogel 1982), but a tentative correlation with the sands and silts of the Tson-dab-Flats may be made. Major differences in the scale and nature of the deposits between the two valleys may be largely related to catchment and lithological differences. The larger catchment of the Kuiseb (16 200 km²) provides it with a much larger effective discharge, which has enabled the Kuiseb to maintain a course to the Atlantic. With the probable exception of the major late Middle to early Upper Pleistocene erosion period in the Tson-dab, there is no evidence to indicate that the Tson-dab reached the Atlantic at any period during the Pleistocene. Apart from the greater sediment supply consequent upon its larger catchment area, deposits in the Kuiseb Valley tend to be thicker because they are confined in a narrow valley, which is cut in schists and granites which are clearly much more resistant than the Tson-dab sandstone, which erodes relatively easily to form the open Tson-dab Valley, in which fluvial deposits are thinly spread.

7 CONCLUSIONS

Evidence derived from a study of fluvial deposits and landforms in the Tson-dab Valley suggests that in the context of a present day arid to hyper-arid climate in the Namib, all periods of fluvial activity imply greater stream discharge and thus probably higher rainfall and more frequent run-off in the highland part of the catchment. Essentially the Tson-dab River has behaved as the distal end of a large alluvial fan extending west from the escarpment. During periods of low rainfall fluvial activity is confined to the proximal and middle reaches of the valley. These deposits are subsequently eroded and redeposited further west in periods of increased rainfall and stream flow, which produce a pattern of upstream incision and down stream deposition. According to the magnitude of these increases in discharge the locus and the extent of depositional and erosional areas change. The scattered and discontinuous nature of deposition produced by such processes renders the production of a secure chronology difficult and paleoclimatic deductions hazardous.

Lacustrine and associated deposits are inherently more meaningful in paleoclimatic terms, and in the Tson-dab Valley have provided the most important information. Deposits at Narabeb indicate that substantial water flows reached a point 50 km west of the escarpment and 40 km beyond the present end point 200–240 000 years ago. Around 28–30 000 BP there was evidently sufficient moisture possibly from local rainfall and run-off in the Narabeb area to permit the growth of vegetation. ¹⁴C dates from vleis in the eastern parts of the Tson-dab Flats indicate that flows reached this locality prior

to 12 000 BP, which implies that the dune blocking of the valley post-dates this period. However, there is no evidence to support the idea of a progressive retreat of the end point of the Tson-dab River, as first suggested by Seely and Sandelowsky (1974).

Deposits and landforms of fluvial origin have provided much information on the late Cenozoic geomorphic evolution of the Tson-dab Valley, but have proved difficult to interpret in paleoclimatic terms. They do however indicate that climatic fluctuations in the central Namib in this period have been limited in degree and no climates more humid than sub-arid or semi-arid have affected the region.

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