ASPECTS OF NAMIB GEOMORPHOLOGY: A DOLINE KARST

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ABSTRACT

Doline Karst occurs in the upper catchments of the Tsondab, Gaub and Kuiseb rivers in the central Namib. The karst extends from the Escarpment foot westwards decreasing in density and altitude for 40 to 50 km. The existence of this well-developed karst is anomalous. The aridity and episodic torrential showers are not conducive to infiltration with attendant karst development. The impurity of the Namib Limestone, the chief karst host is similarly inhibitive. The existence of the karst arouses questions.

The analysis yielded results that question assumptions that the limestone surface has undergone deformation and is multicyclic. It confirms the view that in the Namib there exist two limestones capable of hosting karst that are age and altitude distinct.

INTRODUCTION

A relict sporadically dense shallow doline karst can be recognised from air photos and on the ground immediately west of the embayed mountain of the Namib escarpment. Various workers have recorded the existence of dolines without consideration of their morphology or of their karst implications (Hüser 1976, Marker 1978, 1980). The dolines occurring in the Ubib valley have been acknowledged as being out of phase with the present aridity (Marker 1980). This paper demonstrates the distribution of karst in the catchment of the Tsondab, Gaub and Kuiseb rivers of the central Namib and considers problems of karst evolution and implications for the elucidation of the landscape history.

THE KARST: DISTRIBUTION AND MORPHOLOGY

The actual area surveyed extends from 23°10′ to 24°00′ south and from 15°15′ to 16°00′ east (Figure 1). This area was selected after another geomor-

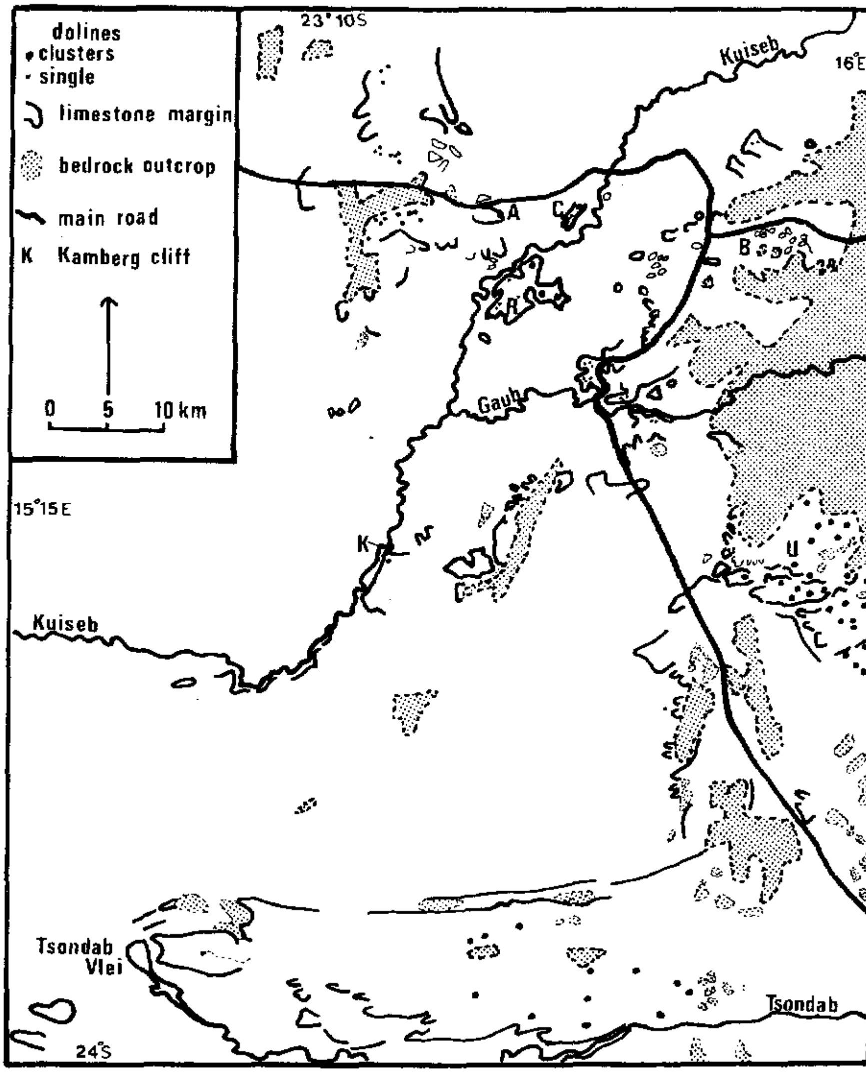

Figure 1. Doline distribution in relation to Namib Limestone in the central Namib (A: Aruvlei, B: Berghof, C: Carp Cliff, R: Kuiseb residual, U: Ubib embayment.

phological analysis had shown the unexpected existence of doline karst. Detailed ground analysis has been confined to two regions of higher karst density, in the Ubib catchment (Figure 2) and on a residual close to the Kuiseb canyon (Figure 3). The former area occupies an embayment surrounded by bedrock outliers of the mountain front. The latter area occupies a residual mesa overlooking the Kuiseb river whose catchment is so small that karst development is unexpected.

The karst map was compiled from stereoscopic air photo coverage on a scale of approximately 1:60 000 (Figure 1). Ground checking was made of accessible areas. Every distinct doline large enough to identify on the photos has been mapped. For the Ubib embayment air photos on a scale of 1:44 680 were used and the survey extended 12 km east of 16°00′ east to include the entire karst zone (Figure 2). Any unequivocal karst drainage patterns and marked breaks of slope, the apparent limits to karst development, were also plotted.

The doline distribution shows particularly high densities in areas of the Ubib catchment. High densities are also recorded from the middle Tsondab valley and locally from sites such as Aruvlei, Carp Cliff and the Kuiseb residual. In general doline density diminishes westwards with isolated doline occurrence rather than clusters 30 to 50 km from the Escarpment. On the ground it is apparent that most dolines are located on the highest local surface and have developed in what has frequently been classed as calcrete but which is geologically better considered to be a limestone (Besler & Marker 1979). Dolines are absent wherever dissection interrupts the level surface. Dolines are also absent from some plains otherwise apparently suitable for doline development such as south of Donkerhoek, in the upper Tsondab catchment and east of the Kamberge.

When the dolines, individually and as clusters, are plotted, a straight line relationship between doline altitude and distance west from the mountain front can be recognised (Figure 4). Only seven dolines lie outside the 99 % confidence limits. The Tsondab dolines do not show such a distinct relationship as they are less spread, but the correlation is again high (Table 1). This suggests that doline development is associated with a single surface and not with several such surfaces as postulated by Hüser (1976). The addition of plains without doline development to the plot shows that many lie outside or close to the confidence limits, that is, either above or below the main karst development level.

Most dolines are let down a maximum of 2 to 3 m below the general broken surface level. The limestone surface is rubble strewn or covered by a stony lag of water worn cobbles where the limestone is more properly a fanglomerate, or of angular quartz fragments where the limestone has a colluvial component. These lags indicate that the doline surface is now degrading. The dolines are by no means preferentially located where the limestone has fewer inclusions.

The gradient of the doline sides is low, rarely exceeding 2° and maximum floor diameters are 25 m. Such large diameter dolines have level silted floors, the product of wind deposition. Smaller dolines tend to be partially infilled with either rubble, insoluble cobbles or quartz, weathered out from the limestone. The present morphology of these dolines has clearly been modified by infilling, since any hollow in that environment acts as a local trap.

Although dolines are widespread and conspicuous, they are not the only karst form. Associated drainage disruption occurs and may be far more exten-

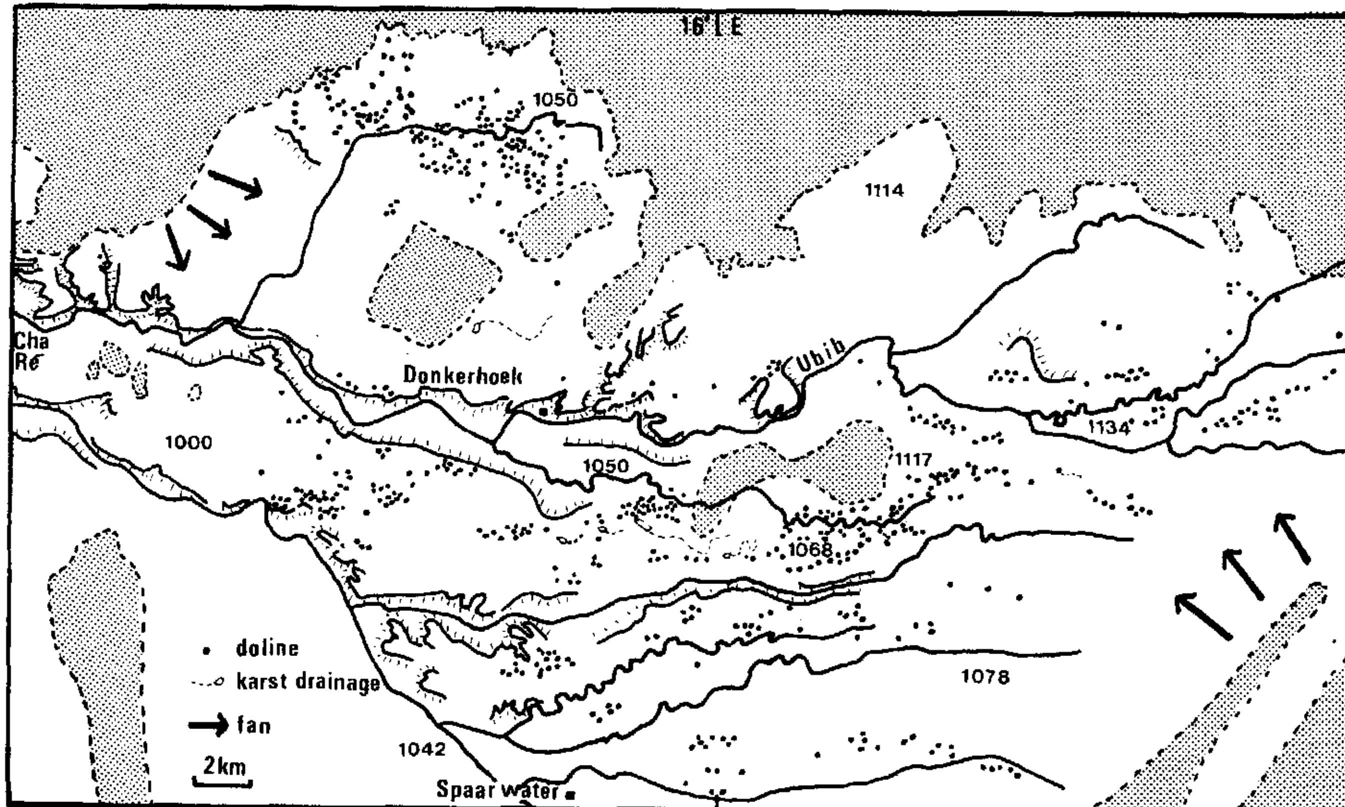

Figure 2. The Ubib embayment (bedrock residuals stippled, breaks of slope on the Namib Limestone, altitudes in metres).

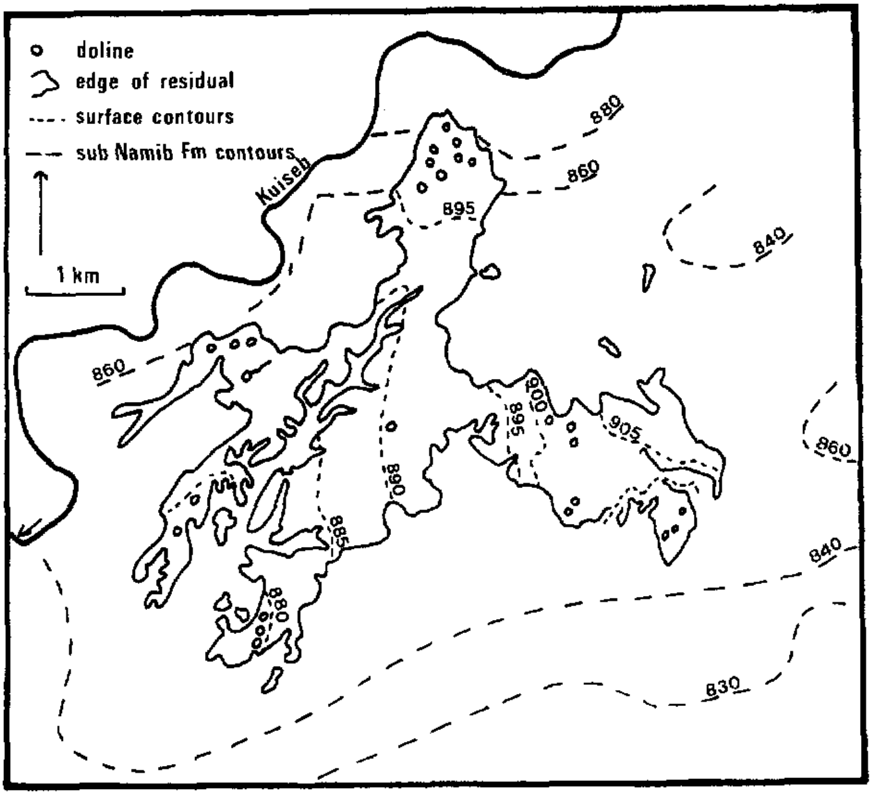

Figure 3. The Kuiseb residual (all altitudes in metres).

sive than identified, since, in such an arid environment subject to only sporadic high intensity runoff, the surface evidence is difficult to attribute directly to karst development. Solution-widened joints and associated microkarren are found on the surface of limestone residual margins (Figure 6). The polygonal patterns of the Kuiseb terraces and Tsondab Flats may possibly be other karst forms. Calcium carbonate mobilisation and reprecipitation has been an important factor in landscape evolution for every level surface is encrusted and patches of cemented colluvium fringe are also known. The original calcium carbonate source is undoubtedly the Palaeozoic Schwarzkalk and dolomite bands in the Damara System of the mountain hinterland.

THE UBIB EMBAYMENT

The Ubib embayment on the farm Donkerhoek has locally high densities of dolines ranging from a maximum of 24/km². Average cluster densities are 17/km² in the north, in the east, 11/km² and in the south, 12/km². Doline

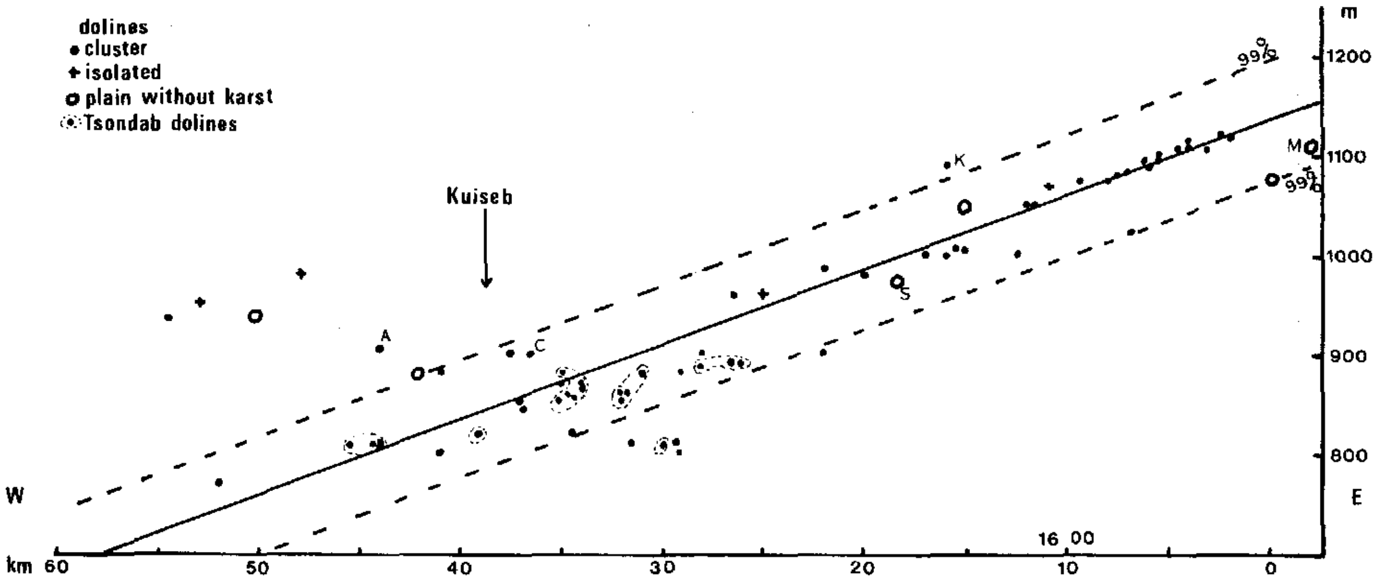

Figure 4. The relationship between doline altitude and distance west with the calculated regression line. (A: Aruvlei, C: Carp Cliff, K: Kuiseb residual, M: Middelplaas, S: Solitaire).

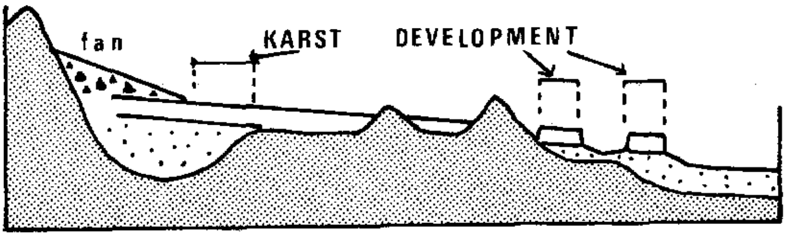

Figure 5. Hypothetical cross section to indicate favourable localities for karst development.

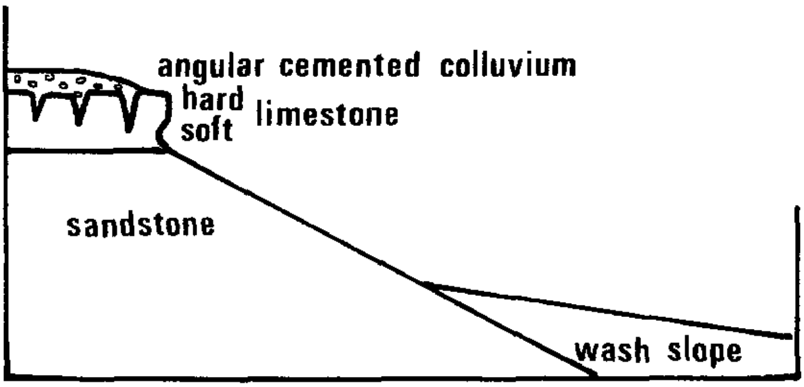

Figure 6. Cross section of a limestone residual at Berghof showing karst pipes with infilling by colluvium.

distribution is clearly related to the present distribution of remnants of the limestone surface (Figure 2). Dolines are absent along major channels where incision has occurred and where the surface is affected by slope dissection. They are also absent north of the Ubib river where the presence of bedrock outliers may indicate that the limestone is thin. They are absent where colluvial fans with steeper gradient converge to bury the limestone surface (Figure 5). The broader interfluves show a degree of blind valley development with imposition of a karst drainage pattern. Along the margins of the residuals massive jointed limestone is exposed, the overlying cobbles or rubble having been stripped. The limestone blocks carry rain pit karren of recent formation but no indubitable evidence of solution widening along joints is present. In the Ubib embayment dolines are the major karst forms and are clearly relict. The present geomorphological process is fluvial incision initiated by episodic storms. This, with attendant slope degradation is destroying the doline karst and associated blind valleys. Furthermore, the annual rainfall 150-250 mm is probably too low to account for such a dense doline karst.

THE KUISEB RESIDUAL

The dolines on the Kuiseb residual occur at an altitude of just under 900 m on a surface almost 200 m above the floor of the Kuiseb canyon (Figure 3). The residual is a western plateau extension of a lower sandstone ridge preserved along the Kuiseb-Gaub watershed. The 7,2 km^2 plateau surface slopes from northeast to southwest with a gradient of 1:190 which is similar to that of other areas of Namib Limestone. The surface is degrading. In the north and east the lag is of cobbles and limestone blocks, elsewhere of limestone with a low percentage of angular quartz fragments. The cliffed plateau margins are highly indented. Limestone 1-3 m thick, overlain by lithified cobble conglomerate on the north and northeast, forms cliffs and overhangs and rests on sandstone which gives rise to 15 to 25° rectilinear slopes. Damara System bedrock is exposed at the base of the residual. Bedrock contours indicate that the preservation of the residual so close to the Kuiseb canyon is the effect of a bedrock high to the north that has served to retain the Kuiseb river (Figure 3).

Dolines are preferentially located along the margins of the plateau. From 5 to 15 m in diameter most have level silt filled floors. The overall doline density, 3,5/km^2, is lower than in the Ubib embayment according with the general decrease in density away from the mountain front. Annual precipitation probably averages under 150 mm per annum which on such a small catchment is considered to be insufficient to initiate and maintain doline development. These dolines therefore also accord with the hypothesis that doline development is relict having originated on a continuous Namib limestone surface probably under former wetter conditions.

THE KARST ROCK

The doline karst and associated landforms is developed in Namib Limestone which overlies Namib Sandstone together comprising the Namib Formation, a probable Kalahari Formation equivalent (Beaudet & Michel 1978, Besler & Marker 1979). The Namib Formation rests unconformably on an uneven bedrock surface here cut across the Damara System complex. In the area surveyed, the Namib Limestone has been dissected by fluvial incision and subsequent pedimentation to produce a stepped planar topography. Blumel (1976) demonstrates that the upper few metres of the limestone is considerably more indurated than the underlying lower limestone. The case-hardened limestone, sometimes covered by colluvial wash material recemented onto it, provides a resistant caprock that preserves residuals of the original surface.

A secondary lower surface may be cut across the softer limestone and lower multiple surfaces are cut across the sandstone. The amount of vertical incision that initiated each subsequent pediplanation phase appears to be related to the regime of the specific catchment. Thus altitudinally distinct surfaces are less pronounced in the Tsondab valley than further north. Local multiplication of surfaces occurs where converging drainage creates a number of different base levels, as in the vicinity of Cha Ré on the northwest edge of the Ubib embayment, the area studied by Hüser (1976). These surfaces have been attributed to distinct erosion cycles (Hüser 1976) whereas it is more probable that only two surfaces are cyclic and the others are structurally induced under specific local conditions. Remobilisation of calcium carbonate has ensured that every surface except the lowest is calcretised.

Almost all karst development is restricted to the case hardened upper Namib Limestone although isolated dolines are located in the softer lower limestone as mapped by Hüser (1976). A few dolines and sand filled pits also occur close to the Kuiseb river on a limestone co-extensive with the pedimented sandstone surface. Sections at Kamberg Cliff and at Carp Cliff suggest that a later phase of limestone deposition occurred following a period of incision by major rivers into Damara System bedrock and Namib Sandstone (Besler & Marker 1979). A similar depositional history is recorded on the north eastern side of the Kuiseb residual. There sandstone in situ is overlain by reworked sandstone and then by limestone. Both the Namib Limestone and this later limestone can support doline development but Namib Limestone is the dominant karst host rock. Polygon development is however related to solutional widening of joints in the sandstone. It has therefore a very different distribution from other karst forms.

The lithology of the Namib Limestone is variable. In the Ubib embayment a hard fairly pure limestone contains angular quartz and pebbles. Under microscopic examination it is apparent that the limestone is actually a conglomerate of waterworn limestone pebbles in a sparitic matrix. Considerable recrystallisation has occurred with calcite rims forming round individual inclusions. The matrix tends to exhibit reticulate veining within pressure cracks. In other samples the limestone pebbles contain allochems other than calcite. The degree of foreign inclusions appears to be related to proximity to bedrock outliers. At Berghof the limestone is also crystalline and hard but contains fewer quartz inclusions. It is however overlain by angular partially cemented quartz rubble that fills pipes and solution hollows in the limestone surface (Figure 6). The rubble is younger than the karst phase. Further east the limestone contains far more sand derived from reworking of the sandstone. Near the Kuiseb river the purer limestone is overlain by a lithified conglomerate in a limestone matrix but with little evidence of intervening karst development.

The Namib Limestone is always well lithified particularly where exposed. It is relatively thin rarely exceeding 5 m although up to 10 m have been recorded. This minimal thickness could be anticipated to inhibit karst development. However wherever dolines have developed the limestone rests on Namib Sandstone. It is postulated that the lack of thickness is compensated by the permeable character of the underlying sandstone. If this is the case it may further be postulated that dolines are preferentially developed in hard Namib Limestone overlying Namib Sandstone which ensures a capacity for vertical

Table 1. Gradients on the Namib Limestone

	Gradient	Slope	Correlation coefficient
Regression slopes			
All dolines	1:164	0°20′	70,4 %
Doline clusters	1:170	0°19′	78,8 %
Tsondab dolines	1:200	0°18′	86,6 %
Ground surface slopes			
at Schliessen	1:500	0°06′	
at Berghof	1:250	0°12′	
at Ubib-Kuiseb	1:220	0°16′	
Solitaire-Tsondab	1:262	0°12′	

infiltration. As the Namib Limestone member is known to have a wider distribution than the sandstone and to transgress from sandstone onto Palaeozoic bedrock, the absence of dolines from certain plains, such as north of the Ubib river, may be due to an inadequate thickness of permeable strata (Figure 5).

The direct association between doline altitude and distance from the mountains accords with the view that the Namib Limestone was a fan deposit. It strengthens the belief that the dolines are preferentially developed on the original Namib Limestone surface rather than on a series of progressively lower and younger surfaces. The relationship is most perfect in the east close to the mountain front. It breaks down in the Upper Kuiseb where dolines on the north bank lie anomalously high, perhaps because the gradient there sloped eastwards towards the river.

Gradients for regressions of all dolines, high density doline clusters and Tsondab dolines as well as the actual ground gradients are very low, under 1° slope (Table 1). This seems at variance with the view that considerable deformation of the Namib Limestone surface has occurred following uplift along the line of the Escarpment (Rust & Wienecke 1973). If deformation and uplift created the escarpment embayments by recession, then this event preceded emplacement of the Namib Formation.

IMPLICATIONS

The presence of a high degree of karst development on the eastern margin of the central Namib has a number of implications for the interpretation of both the geomorphological and climatic history of the region. The development of a doline karst presupposes a limestone which is subject to solution and in which water penetration is preferentially concentrated at specific points. Furthermore a sufficiency of percolation water charged with biotic carbon dioxide is required. The Namib Limestone contains remarkably high percentages of non-soluble inclusions, quartz fragments, cobbles and sand grains, to favour karst development. Its high degree of lithification and attendant joint development apparently compensates for lack of purity. Infiltration has taken place along joints and has been preferential where Namib Sandstone underlies the limestone providing a thick permeable substrata. Where the sandstone is absent or where later deposits bury the limestone karst development is absent (Figure 5).

Lithification, in particular recrystallisation and induration, takes time. The evidence from the Ubib and Berghof samples where Namib Limestone has been partially protected by colluvium from degradation indicates that the limestone is probably older than previously postulated (Besler & Marker 1979). The protective colluvium caps isolated residuals in the Berghof area and fills karst hollows and pipes in the limestone surface implying that karst formation preceded the emplacement of colluvial gravels onto a continuous undissected Namib Limestone surface. The karst is therefore also old. Blumel's (1976) evidence that where complete limestone sections are preserved, the Namib Limestone has a case hardened upper portion, suggests that after emplacement as a fan deposit the limestone was exposed to subaerial lithification prior to or coincident with karst formation.

The diminishing concentration of dolines away from the mountain front and downslope accords with the view that runoff from the impermeable Damara System basement relief promoted high density doline development in the mountain embayments. Such a pattern is characteristic of most doline development. Nevertheless it can also be deduced that the climatic regime differed at that time. At present total precipitation is of the order of 150 to 250 mm per annum, almost too low given the high evaporation rates, for any karst solution to occur. Furthermore most rain falls as high intensity storms promoting run off at the expense of infiltration. Little vegetation cover is present resulting in low carbon dioxide potential. It is postulated that both a higher total precipitation and a more evenly distributed rainfall regime with lower intensity individual storms obtained at the time of maximum karst development. This would have favoured a high density of vegetation cover particularly on the mountain slopes with concomitant greater carbon dioxide availability to promote solution.

The consistently low gradients, under 1°, both for the doline surface slope and for selected sections across the original Namib Limestone surface would appear to refute the view that deformation along the mountain front postdates the development of the Namib surface and explains pedimentation into it (Rust & Wienecke 1973). There is no evidence within the area studied for such flexing. Nevertheless renewed incision has undoubtedly occurred to initiate and cut the multiple sandstone surfaces and the valley in valley Kuiseb incision. This incision was not as marked to the south in the Tsondab catchment. The evidence from this analysis is insufficient to establish whether the differences in degree of dissection are a function of warping or of differences in discharge.

The karst evidence confirms the view that there are at least two limestones as distinct from calcretised surfaces in the Namib. The main karst host rock is the Namib Limestone of the Namib Formation. This is highly jointed and lithified. At lower elevation along major drainage lines and infilling valleys incised into the Namib Formation is a bedded limestone, also hosting karst development, co-extensive with the sandstone surface. This is the limestone well exposed at Kamberg Cliff above the Kuiseb Canyon (Besler & Marker 1979).

Neither the age of the limestone nor the age of its karst can as yet be precisely determined. The lithological evidence for the Namib Formation being older than previously postulated indicates an early Tertiary age. The need for a much moister climatic regime to permit karst development implies that the main-phase karst itself must pre-date aridification of the Namib. The onset of Namib aridification has now been attributed, on the basis of both land and off shore evidence, to the mid-Tertiary period. The difference between early Pliocene (Tankard & Rogers 1978) and late Miocene (Siesser 1978) is slight. If the karst is Miocene, which incidentally accords with evidence from other southern African karst areas, then the Namib Limestone is earlier still and the entire Namib Formation (Marker 1972, 1974), like its Kalahari Formation equivalent is pushed back to the very early Tertiary period. Since it apparently postdates major deformation along the Escarpment, this suggests that the tectonics previous to its emplacement were associated with continental break up rather than with subsequent adjustment.

SUMMARY

The doline karst of the central Namib is a relict formation now undergoing incision and surface degradation. The evidence provided by this karst in its present context calls for a re-evaluation of the age of the Namib Formation as well as of the tectonic and climatic history of the Namib.

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