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GAS ESCAPE STRUCTURES IN PRECAMBRIAN PERITIDAL CARBONATE ROCKS

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ABSTRACT

Sub-vertical tubular structures from the lower Nama Group are described and compared with similar examples from the Damara Sequence of Namibia and from the Noonday Dolomite of California. At all localities the country rocks are light grey, peritidal cryptalgallaminated dolomite. The structures, 0,5 to 2,5 cm in diameter, are circular to oval in cross-section, their length varies between 0,1m and possibly several metres. The pipes were filled either immediately with carbonate mud or small framents of surrounding laminites, or at a later stage with chert and/or coarse sparite; some even remained open. The tubes are orientated vertically to the paleohorizon and flatlying lamination or at an angle to the lamination on the flanks of algal buildups. From their common environment it is inferred that the structures are facies-dependent. The shape of the pipes and composition of their fillings, as well as a comparison with modern, intermittently exposed shallow water sediment, suggest that they are gas- and water-escape structures. Gas is formed by the decay of the algal mats during low tide, while water could playa subsidiary role in generating high pressure.

1. INTRODUCTION

Mapping of the late Precambrian Kuibis Subgroup of the Nama Group in the eastern Windhoek and Gobabis Districts of Namibia (Fig. 1) proved an intertidal depositional environment for the Bildah Member of the Buschmannsklippe Formation (SACS 1980; Hegenberger, in prep.). This member consists of light coloured, cryptalgal laminated dolomite, up to 50 m thick, that displays desiccation cracks, algal buildups, stromatolites and indications of locally intensive reworking.

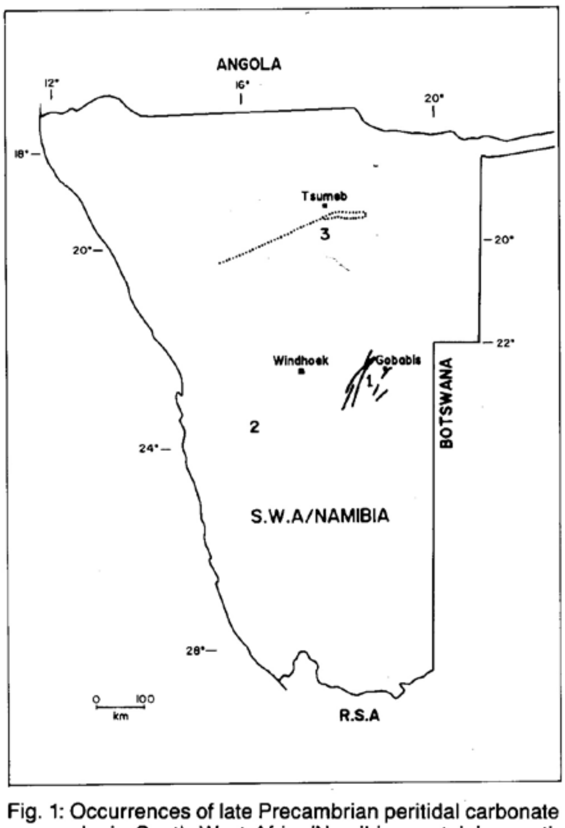

Fig. 1: Occurrences of late Precambrian peritidal carbonate rocks in South West Africa/Namibia, containing vertical tubes: 1 Bildah Member (Nama Group); 2 Noab Formation (Damara Sequence, Naukluft Nappe Complex); 3 Auros Formation (Otavi Group, Damara Sequence).

Within the Bildah dolomite, many bedding planes are studded with round to oval, 1 to 2,5 cm diameter, depressions and crater-like features, spaced 1 to 5 cm apart (Fig. 2). These features, which are commonly filled with large carbonate crystals (Fig. 3) and, more rarely, chert, are distributed irregularly through the Bildah dolomite but are most abundant in the central Witvlei Synclinorium (area 2218 CA). From natural exposures and large polished slabs ("Witvlei Marble" from Kehoro 183, area 2218 BA) it is obvious that the structures represent sections across tubular features that intersect the laminite (Figs. 4 and 5). Similar structures are known from the Noab Formation of the Naukluft Mountains (Hartnady, 1978) and from the Auros Formation of northern Namibia. These features from Namibia are comparable to structures described from the Noonday Dolomite of California (Cloud *et al.* 1974).

2. DESCRIPTION

2.1 Eastern Windhoek and Gobabis Districts

The structures are restricted to the dolomitic facies of

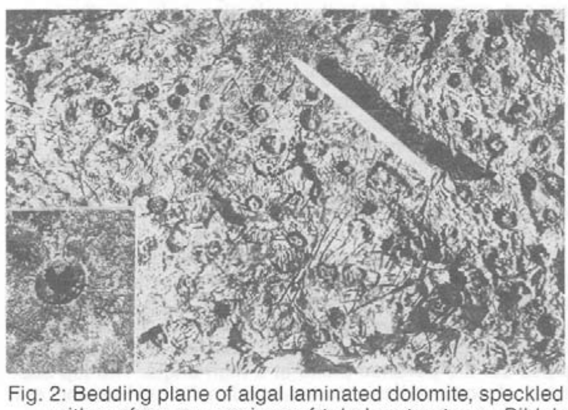

Fig. 2: Bedding plane of algal laminated dolomite, speckled with surface expressions of tubular structures. Bildah Member, Nama Group; Orochevley 216 (Windhoek District). Insert: Close-up of a single structure.

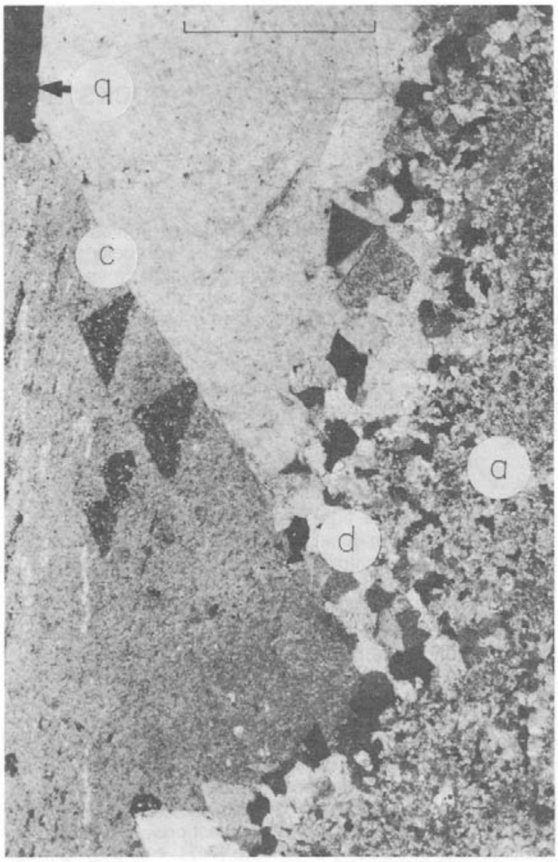

Fig. 3: Thin section through marginal area of pipe. Cryptalgal laminated country rock consists of microsparite to sparite (a); edge of pipe lined with irregular seam of dolomite rhombs (d); cavity of pipe filled with large calcite crystals (c) and megaquartz (q); x nicols, bar 0,5 mm long. Bildah Member, Nama Group; Orochevley 216 (Windhoek District).

the Bildah Member of the Buschmannsklippe Formation (Kuibis

Subgroup, lower Nama Group). Vertical sections show that the features on the bedding planes (Fig. 2) are the surface expression of tubular structures (longer than 30 cm) which are sub-perpendicular to the lamination. In longitudinal sections of polished slabs from Kehoro 183, the pipes are 1 to 2,5 cm in diameter, more than 5 cm apart, and deviate by up to 15° from a right angle to the lamination (Figs. 4, 5). Filling consists predominantly of coarse, crystalline carbonate or micrite with subordinate chert and megaquartz (Fig. 3) and tabular carbonate fragments, 0,5 to 1 cm long. The latter are apparently fractured and redeposited laminites that are orientated subhorizontally. Chlorite is a minor constituent of some pipe fillings (Fig. 6).

Most of the laminae pierced by a pipe are inclined toward this structure, thereby fürnishing a way-up criterion for identifying the top of unoriented slabs (Figs. 4 to 7). The maximum length measured on material from Kehoro, viz. 30 cm, is not the greatest actual length because the axes of the pipes cut the polished plane at a high angle. The top sections of some tubes, however, widen funnel-like and are overlain by flat-lying lamination (Fig. 7). This contrasts markedly with most other tubular structures: these "end" conically and the laminae "overlying" them form a depression in continuation of the tube's axis (Figs. 4 and 5). The funnel-shaped ends are interpreted as the orifices, but still the length of the specific structures remains unknown because the opposite end is not exposed.

Most of the tubes from Kehoro 183 are surrounded by a 1 to 5 mm wide zone of bleached country rock (Figs. 4 to 7); in some cases even the exterior portion of the micritic fill in the tubes has been discoloured. In one sample the bleached zone on both sides of the longitudinal section (3 - 4 mm wide) is fringed by an about 1 mm thick reddish seam which represents the leached and subsequently reprecipitated iron content of the discoloured core.

2.2 Naukluft Mountains

Hartnady (1978) described pipe-like features from a massive, finely layered dolomite of shallow tidal origin

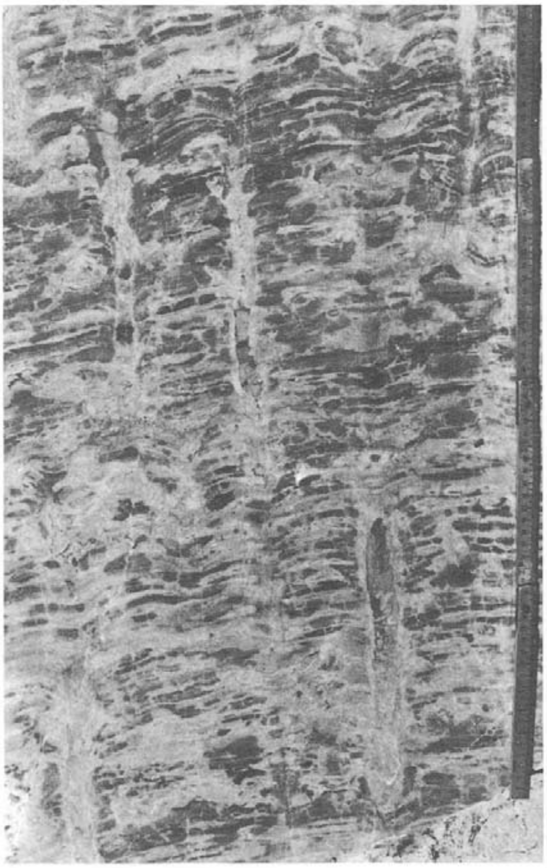

Fig. 4: Cryptalgal laminated dolomite with longitudinal sections of tubes. Because the polished surface is not entirely parallel to the axes of the tubes, these are not exposed over all their length. Upward and downward continuation of many of the pipes is indicated over considerable distances by discolouration and/or downward bent laminae. Bildah Member, Nama Group; Kehoro 183 (Gobabis District).

Fig. 5: Cryptalgal laminated dolomite with longitudinal sections of tubes. Strong lining of open space structures (laminae, sheet cracks and tubes) with light carbonate; light grey seams may be partly caused, however, by discolouring of the cryptalgal laminite. Bildah Member, Nama Group; Kehoro 183 (Gobabis District).

Fig. 6: Close-up of reddish brown laminated carbonate, cut by a tube nearly perpendicular to lamination. Horizontal seams are cryptalgal laminae and sheet cracks, their open spaces being filled with fibrous calcite and micrite. Tube filled with micrite and dark chlorite. Margins of the country rock along the tube and parts of its filling, together with sediment along sheet cracks, are discoloured. Bildah Member, Nama Group; Kehoro 183 (Gobabis District).

which belongs to the Noab Formation of the Naukluft Nappe Complex (Fig. 1). The structures are about 10 cm long, with circular cross-sections measuring 1,5 cm; these are filled by quartz, sparry calcite and dolomite. From Fig. 9 in Hartnady's thesis (1978) it is inferred that both their ends pass into bedding-parallel carbonate veins (sheet cracks?).

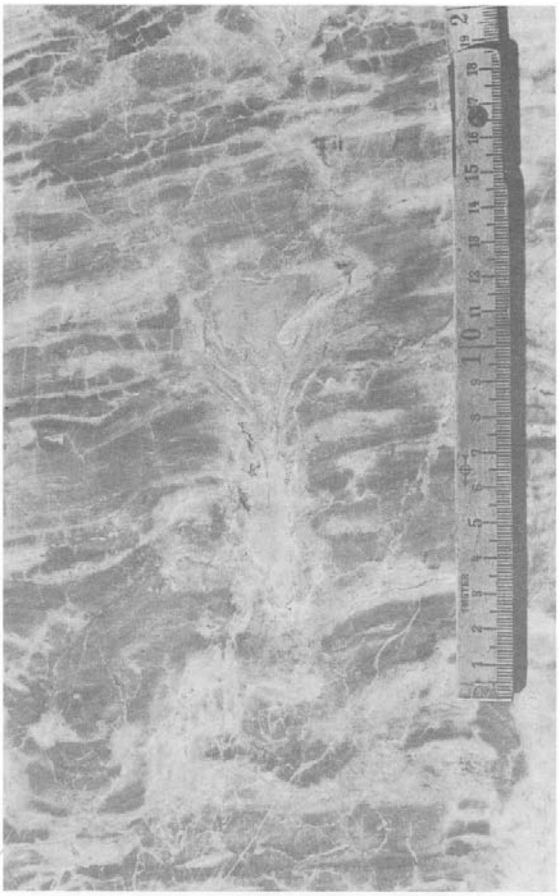

Fig. 7: Funnel-shaped upper end of tube is supposed to be its orifice and is covered by flat-lying laminae. Top of succession was identified by downward bent laminae along margin of pipe, caused by sagging. Tube was filled (most probably from above) with homogeneous lime mud. Bildah Member, Nama Group; Kehoro 183 (Gobabis District).

2.3 Grootfontein and Outjo Districts

In the uppermost portion of the Auros Formation (Abenab Subgroup, Otavi Group, Damara Sequence) a marker, known to the geologists of the Tsumeb Corporation as "quartz cluster" structures, is found at scattered localities over a distance of 300 km along strike (Fig. 1). The descriptive term "quartz clusters" applies to plug-like siliceous bodies of irregular circular to oval cross-section which rise for 1 to 2 cm above the bedding-parallel surface. They represent portions of vertically disposed quartz fillings of pipes which form resistant studs after the surrounding dolomite has been eroded (Fig. 8). The country rocks are light grey, finely laminated, forming thick layers. On Gauss 40 and Auros 595 in the Otavi Mountains it is clearly visible that many of the subvertical structures developed out of sheet cracks, i.e. cracks formed parallel to algal lamination and caused by decay of the algal matter (Figs. 9 and 10). On Bothashof 476, 85 km west of Outjo, the tubes have a minimum length of 70 cm (Fig. 11) and are filled with chert, quartz and sparry carbonate. In many of them silica forms a thin outer seam while the centre of the tube is occupied by carbonate crystals or left hollow (Fig. 12). Round structures measure 1 to 2 cm across, but some are compressed to an elliptical cross-section. Distances between them vary from 1 to 5 cm (Figs. 8, 11-13). Where the sparite filling predominates, the structures look identical to those in the Bildah Member, while those with a higher silica content are "quartz clusters" (Fig. 8). The country rock is again light grey, laminated dolomite. Thin chert seams, probably filling of sheet cracks, accentuate lamination and generally form at right or steep angle to the pipes (Figs. 11 and 12). A dome-shaped organic buildup, about 8-10 m across, is riddled by tubes irrespective of the dip of the laminae which, at the flanks, is as steep as 60°. There the tubes stand vertical as everywhere else but form an angle of 30° with the lamination (Fig. 13). Throughout the domal structure they are parallel to each other and to those in the flat-lying strata.

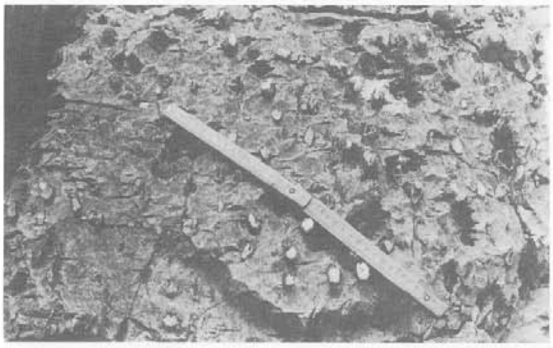

Fig. 8: "Quartz cluster" structures. Erosion surface is about parallel with cryptalgal lamination. Chert fillings of tubes are more resistant to weathering than the dolomite of the host rocks, and thus protrude about 2 cm above the surface. Auros Formation, Otavi Group; Bothashof 476 (Outjo District).

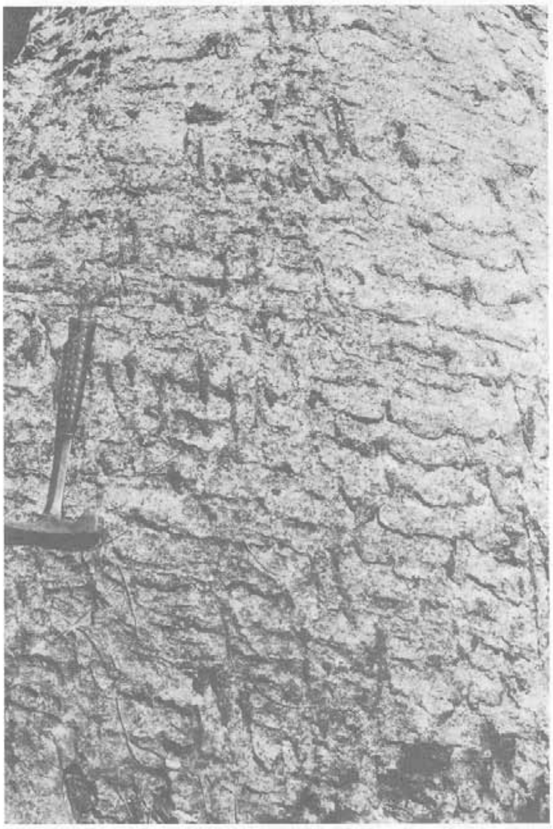

Fig. 9: Cryptalgal lamination is accentuated by sheet cracks, filled with dark chert. Surface of exposure runs nearly parallel to tubular structures, characterised by a filling of dark chert. Relation between sheet cracks and tubes becomes evident. Auros Formation, Otavi Group; Auros 595 (Grootfontein District).

2.4 Noonday Dolomite, California

Tubular structures in cryptalgal carbonate have been described in great detail by Cloud *et al.*, (1974) from the Noonday Dolomite of eastern California (Wright *et al.*, 1978). They were observed in large algal mounds where they display the same relation to lamination as those in the Auros Formation on Bothashof; however, they are absent in those portions of the mounds where the inclination of the strata at the flanks exceeds 20°. The maximum length of apparently several metres (Cloud *et al.*, 1974, p. 1880) is much more than is known from the Bildah Member, the Noab Formation and the Auros Formation, but this might partly be a result of better exposure of the Noonday Dolomite.

Fig. 10: Chert fillings (dark) indicate that sheet cracks of different levels are connected by tubes. Tubular structures are parallel to each other but not strictly perpendicular to lamination. Auros Formation, Otavi Group; Auros 595 (Grootfontein District).

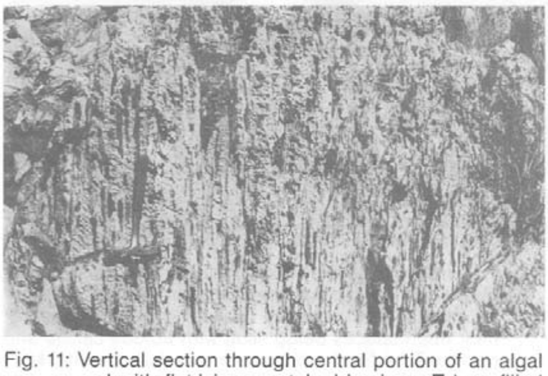

Fig. 11: Vertical section through central portion of an algal mound with flat-lying cryptalgal laminae. Tubes, filled with chert and up to 1 m long, are about perpendicular to lamination. Auros Formation, Otavi Group; Bothashof 476 (Outjo District).

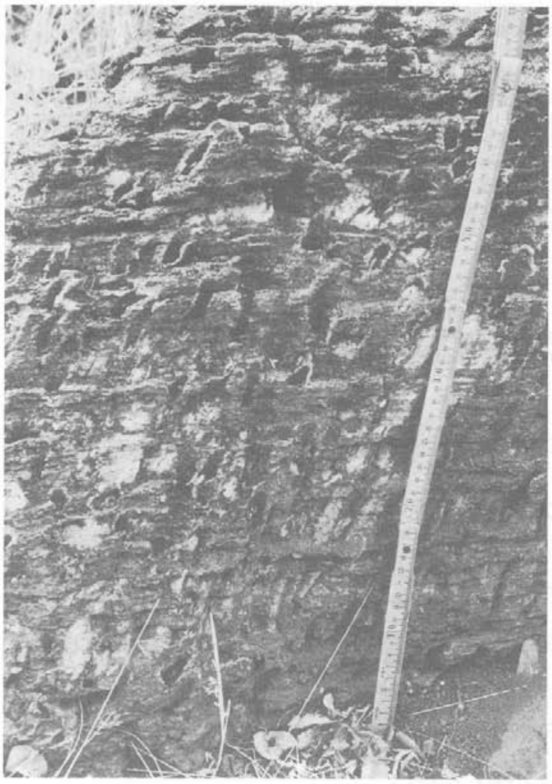

Fig. 12: Section through cryptalgal laminite, its lamination being accentuated by chert seams (sheet cracks). Tubes stand at an angle to lamination and to the plane of exposure. Most tubes are lined with chert while their centres remained open. Auros Formation, Otavi Group; Bothashof 476 (Outjo District).-

Fig. 13: Same situation as Fig. 11, but located on flank of algal mound: Cryptalgal lamination dips steeply to the left and forms angles between 30° and 45° with the pipes which stand vertically on the paleohorizon. Auros Formation, Otavi Group; Bothashof 476 (Outjo District).

3. ORIGIN OF THE STRUCTURES

From their appearance in the Bildah Member one can assume that the structures originated as hollow tubes; they were filled either from above by lime mud or from below by fragments of the laminae which were reworked and expelled by the same forces that produced the pipes, and in places settled out of the transporting medium in a layered manner. Many of the tubes, however, remained open for a while and were diagenetically filled by sparite and/or chert. The stability of the cavities, even if they penetrated a still soft sediment, was ensured by the internal cohesion of the surrounding algal mats. Fragmentation of the laminae indicates that portions of the wall rocks were slightly hardened, probably by previous desiccation, while downward dip of the laminae around the pipe points to a certain plasticity of the sediment, causing sagging into the cavity. This downward dip of many of the laminae around the channels observed in polished sections of the Bildah Member, is not common in the Noonday Dolomite (Cloud *et al.*, 1974, p. 1877) and is also not apparent in the Auros Formation. This may be attributed to greater stability of the sediment as compared with the Bildah Member. The walls of the pipes are irregularly indented, possibly due to differential reaction by the laminated matter of the wall rocks to pressure.

The nature of the filling, which lacks any regular lamination, excludes an interpretation of the tubes as columnar stromatolites, such as they are known from the Bildah Member (Fig. 14). From the regular, straight shape and the parallel orientation, an explanation of the tubular features as animal burrows can be excluded, particularly as no Ediacarian burrowing animals are known which could have produced borings of that size (Glaessner, 1984).

The approximately 700 m.y. old Auros Formation of

Fig. 14: Pseudocolumnar stromatolite in intertidal crypt laminite; desiccation cracks and distorted fragmer algal mats are indicated by arrows. Bildah Mer Nama Group; Kehoro 183 (Gobabis District).

the Otavi area and the Noab Formation of the Naukluft Nappe Complex are about coeval, while the base of the Nama is slightly younger, about 650 m.y. old (R. Miller, 1983). The age of the Noonday Dolomite is most probably pre-Nama and could be somewhere between 800 and 1 200 m.y. (P Cloud, pers. comm., 1986); more recently, however, a latest Proterozoic age (600 to 700 m.y.) was suggested (J. Miller, 1987). Therefore it is not quite clear whether the tubes were formed repeatedly during different ages or whether the process leading to their generation was, to some extent, time dependent. However, all structures occur in strata laid down in a shallow marine to intertidal, carbonate precipitating environment, and it seems most likely that their origin is thus related to processes inherent in this environment.

One can conclude, therefore, that the structures were the pathways for either a gas or a liquid and could have originated by the following processes:

a) Decaying organic matter - here algal mats - formed gas, mainly carbon dioxide, methane, ammonia, hydrogen sulphide and hydrogen (Cloud, 1960). In the intertidal environment this happened mainly during desiccation, i.e. at low tide. The gas collected along sheet cracks (resulting from decomposition of algal matter in laminae) and forced its way through the overlying sediment pile when pressure grew strong enough, e.g. when the hydrostatic pressure decreased during lowering of the water level (Cloud, 1960).

   Klippel (1939) described a mud-bank in an abandoned river channel which some time after emergence above water level was studded with thousands of small craters (pit and mound structures) caused by repeated gas eruptions. The main conditions to be met were: Slowly moving to stagnant water, deposition of mud enriched in organic material, subsiding water and emergence for days during hot weather leading to decomposition of the organic material. Similar gas craters in muddy sediments in the tidal zone of the Wadden Sea were men-tioned by Häntzschel (1941). Experiments performed by Schäfer (1954), with air pressed into mud from underneath, showed that the sediment cracked when covered with shallow water but formed discrete craters if not under water.

b) Escape of water could have been caused by artesian egression (Cloud *et al*., 1974) or by expulsion of pore water by compression of the lime mud during continuing sedimentation. But this alone would not explain the reduction seams and precipitation of iron compounds at the walls of the tubes. It could, however, better account for their length than decay of organic material alone can, which is believed to affect mainly the uppermost part of the sediment. A combination of both agents, viz. gas kinetics and hydraulics, is offered by Goemann (1939) who explains gas escaping from sediments in the tidal zone of an estuary as generated by decomposition of organic material during low tide, forced out of the sediment during tidal rise, going together with a rise of the groundwater table within the sediment. The maximum length of the escape channels observed by Goemann (1939) was 1,5 cm; they were surrounded by reduction zones, caused by hydrogen sulphide.

Cloud *et al.* (1974) discussed the origin of the tubes in the Noonday Dolomite and rejected 1) factors controlled by jointing, 2) metazoan burrows, 3) interpretation as interspaces between columnar stromatolites, 4) columnar stromatolites, 5) solution pipes, 6) root casts. They rather agreed that the structures were formed by syndepositional upward escape of gas and/or water; this is confirmed by the structures studied at SWA/Namibian occurrences.

To sum up, there is strong evidence that gas produced by decaying algal mats played a major role in forming the pipes. But it is uncertain whether this alone was sufficient to generate a pressure strong enough to pierce through nearly one metre or more of sediment, or whether it was promoted by compaction of the lime mud (possibly accelerated by dewatering during low tide), groundwater rising with the tide or other agents.

4. ACKNOWLEDGEMENTS

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