14 The Namib Plains: Gypsum Crusts and Stone Pavements

Abstract

In the central Namib gypsum crusts (gypcrete) are a widespread surface material, particularly in drier areas. Their origin is complex. One model to explain the presence of sulphate in the coastal tracts of the central Namib is that marine biogenic hydrogen sulphide (H_2S), developed on the highly productive Namibian shelf, erupts from time to time and is carried inland by south westerly winds. Another suggested source of sulphate is anhydrite and bedrock sulphide. Some of the Namib gypsum may be distributed across the desert surface by dust storms that have deflated evaporite material from the many small pans and sabkhas identified on satellite images. Another important surface type in the Namib Plains is the stone or desert pavement. These are armoured surfaces composed of a mosaic of fragments, usually only one or two stones thick, set on or in matrices of finer material. They are formed by a range of processes that cause coarse particle concentration at the surface: (a) deflation of fine material by wind; (b) removal of fines by surface runoff and/or creep; and (c) processes causing upward migration of coarse particles to the surface.

14.1 Gypsum Crusts

A number of different crusts have formed in the central Namib Desert. The most widespread crust type in the coastal sector is the gypsum crust or gypcrete ($CaSO_4 \cdot 2H_2O$) (Watson 1979). It is generally found in areas where the rainfall is less than 50 mm per year and in a belt within 50–70 km of the coast between Walvis Bay and the Ugab River (Eckardt 1996; Eckardt and Spiro 1999; Bao et al. 2000, 2001; Eckardt et al. 2001). Petrographic details are provided by Watson (1985, 1988) and profile details by Wilkinson (1990) and Heine and Walter (1996a).

Watson (1985) suggested that there were three main types of gypsum crust. The first of these he termed 'bedded crusts', which he believed originated as laminated, shallow-water evaporites which accumulate when shallow pools or lagoons evaporate to dryness. The second type he termed 'subsurface crusts'. These, he believed, occurred in two forms, one made up of large crystals (>1 mm in diameter), often called desert roses, and the other of mesocrystalline (finer than 1.0 mm in diameter) material. The former tended to develop in low-lying situations in association with evaporation from high groundwater levels (the *per ascensum* type), while the latter, which are widespread in the Namib and often have columnar structures, had an illuvial or *per descensum* origin (i.e. they formed by the sub-surface accumulation of gypsum materials brought in from the surface, leached downwards, and then precipitated when the infiltrating water dries up). The third category he termed 'surface crusts'. These are the result of the exhumation and degradation of subsurface crusts.

Gypsum-rich materials may cover around 207 million ha of Earth's surface and the majority occur where the mean annual rainfall is less than 200–250 mm. This is because gypsum is semi-soluble (~ 2.6 g/l at 25 °C) and is normally leached out under higher rainfall conditions. Gypsum crusts are recorded in many of the world's deserts, but it is probably in Tunisia and the Namib that they show their greatest development (Watson 1979, 1988). The relative aridity of the Namib favours gypsum accumulation (Heine and Walter 1996b), but considerable debate has surrounded the source of the sulphate that makes up the crusts. Gypsum crusts are relatively less well developed in the southern part of the Namib Desert (the Sperrgebiet), and this may in part be due to extreme wind scour preventing crusts from accumulating (Miller 2008, Sect. 25.6.8) and in part to

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the lack of sulphate as large sulphate inputs occur preferentially in the central Namib.

There are two main conceptual models to explain the source of sulphate for the Namib gypsum crusts (Figs. 14.1 and 14.2). The first model proposed by Henno Martin to explain the presence of sulphate in the coastal tracts of the central Namib is that marine biogenic hydrogen sulphide (H_2S), developed on the highly productive Namibian shelf, erupts from time to time (with malodorous consequences) and is carried into the desert by south westerly winds (Logan 1960; Martin 1963; Wilkinson et al. 1992) (Fig. 14.1). The location of the Central Namib favours such a scenario because it is both the foggiest part of the coast (Olivier 1995) and is adjacent to the thickest organic-rich sediment accumulations on the Namibian shelf, which are fed by the highly productive surface waters of the Benguela Current. Remote sensing studies suggest that such sulphide eruptions are large in extent, of frequent occurrence and of long duration (Brüchert et al. 2009). Some early analyses of fog water showed that it had high sulphate contents (Goudie 1972), although later analyses seemed to refute this. Another suggested source of the sulphate is anhydrite and bedrock sulphide (Cagle 1975). Some sulphate could be derived from deflation of inland saline pans (e.g. Etosha) and its transport to the western Namib by easterly 'berg' winds. However, sulphur isotope studies of potential sulphate sources and chemical analyses of fog water indicate that most fog water is extremely pure (Eckardt and Schemenauer 1998) and that neither biogenic H_2S nor bedrock are the source of the sulphate (Eckardt and Spiro 1999).

The second conceptual model to explain the source of sulphur for the Namib Desert gypsum crusts proposes that the primary source is the oxidation of marine dimethyl sulphide (DMS), with secondary reworking. This aerosol-derived material (Fig. 14.2) may have been accumulating in the old and hyper-arid Namib since the late Miocene and is redistributed by wind action (including deflation from numerous pans) and sporadic surface runoff (Eckardt et al. 2001). Evidence from $\Delta^{17}O$ studies by Bao et al. (2000, 2001) seems to point in the same direction.

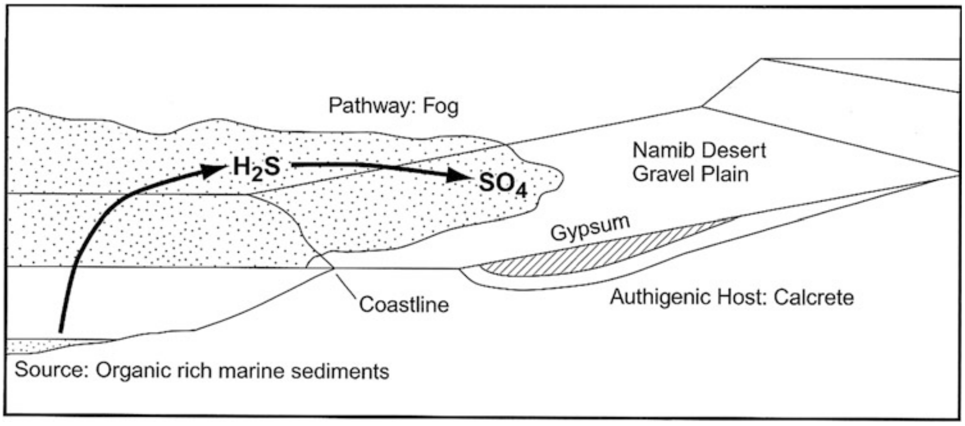

Fig. 14.1 Martin's model of gypsum crust development (courtesy of Dr. Frank Eckardt)

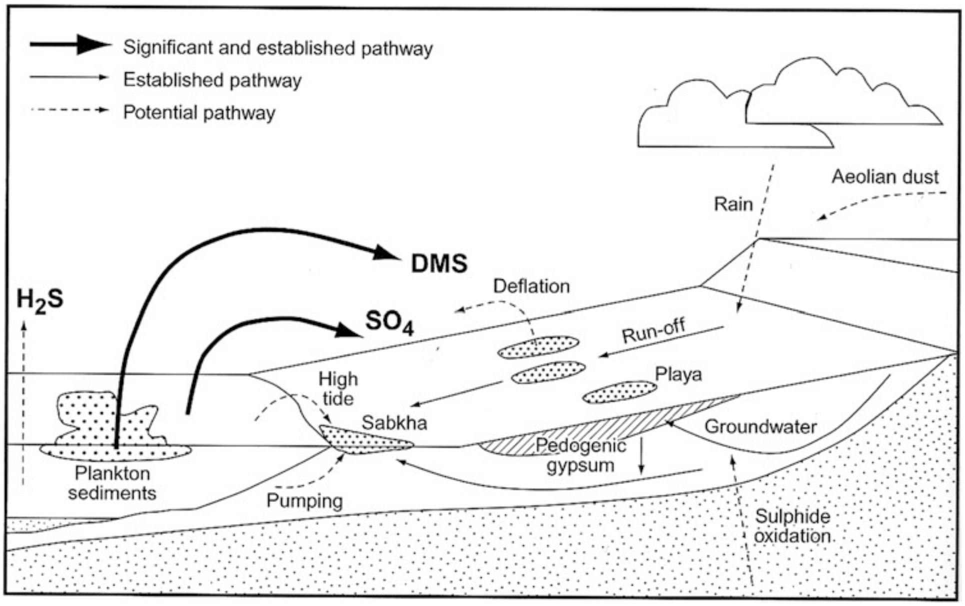

Fig. 14.2 Eckardt's model of gypsum crust development (courtesy of Dr. Frank Eckardt)

Whatever its primary source, some of the Namib gypsum may be distributed across the desert surface by dust storms that have deflated evaporite material from the many small pans and sabkhas that have been identified on satellite images (Eckardt et al. 2001). This gypsum contributes to further weathering through its contribution to salt weathering processes. Furthermore, the presence of gypcrete up to 1.5 m thick within soil profiles affects the balance between weathering and erosion across large swathes of the coastal gravel plains, probably contributing to the relatively low rates of long term denudation recorded there by cosmogenic isotope studies.

14.2 Stone Pavements

Another important surface type in the Namib Plains is the stone or desert pavement. These are armoured surfaces composed of a mosaic of fragments, usually only one or two stones thick, set on or in matrices of finer material comprising varying mixtures of sand, silt or clay.

They are formed by a range of processes that cause coarse particle concentration at the surface: (a) the classic mechanism of deflation of fine material by wind (Fig. 14.3); (b) removal of fines by surface runoff and/or creep; and (c) processes causing upward migration of coarse particles to the surface. In addition, it has become increasingly clear that pavements may evolve in close association not only with aeolian erosion but also with dust deposition and soil-profile differentiation caused by weathering.

Pavements have usually been explained as being produced by the classical mechanism of deflation of fine material from the surface, which leaves a residue, lag or armour of coarse particles. The concentration of coarse particles has been seen as a function of their distribution in the original sediment and the extent of deflation. However, lateral movement of fine materials could also be achieved by the second mechanism, i.e. removal by runoff or creep. Experimental observations show that some pavements are often composed, at least in part, of coarse particles that remain after finer materials have been dislodged and removed by raindrop erosion and running water (Wainwright et al. 1995). Plainly the role of sheetfloods should not be ignored as a horizontal transport mechanism (Williams and Zimbelman 1994; Dietze et al. 2013).

The third group of hypotheses involves vertical rather than horizontal movement of particles. The concentration of coarse particles at the surface and at depth, and the relative scarcity of coarse particles in the upper soil profile suggest that stones may have moved upwards through the soil to the surface by cycles of freezing and thawing, wetting and drying, or salt heave. Of these the most effective and widespread migration mechanism in deserts is thought to be associated with wetting and drying of the surface soil (McFadden et al. 1987). When a soil containing expanding clay minerals is wetted, it expands and a coarse particle is lifted slightly. As the soil shrinks on drying, cracks are produced around the particle and within the soil. Because of its large size the coarse particle cannot move down into the cracks, whereas finer particles can. The net effect is an upward displacement of the coarse particle. Subsidiary mechanisms of upward migration applicable to the Namib Desert may be salt heave (Searl and Rankin 1993), and the activity of soil fauna, including ants, termites, and burrowing mammals. Whether or not bioturbation causes stone pavement formation or disruption is, however, still a matter of debate. On the one hand, churning and burrowing may bring fine material to the surface, where it can be deflated, while on the other the process may cause coarse particles to sink and for homogenisation to occur. Under higher rainfall conditions, e.g. during pluvials, it is probable that pavement disruption predominates. Lichens may also contribute to the stabilisation of pavement surfaces once established, and there is good evidence that the lichen-dominated biological soil crusts along the coastal area of the central Namib Desert are agents of bioprotection (Lalley and Viles 2008; Viles 2008). Once damaged or destroyed by, for example, off-road driving, this bioprotection is lost and fine material is easily blown away. Finally, in recent years it has become appreciated that significant amounts of dust are delivered to desert

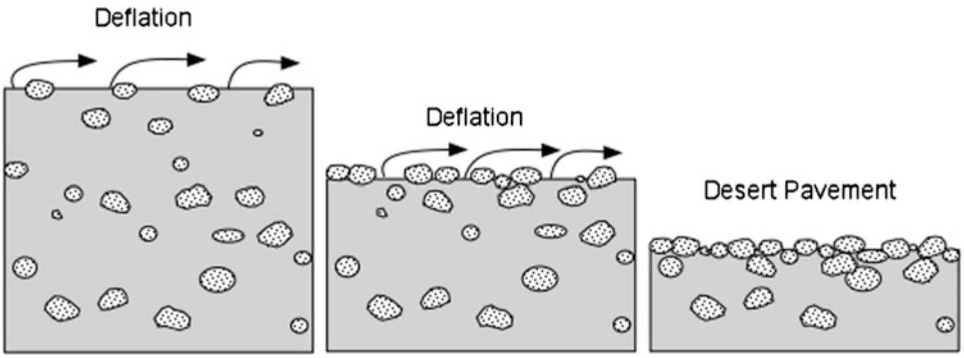

Fig. 14.3 The deflational model of stone pavement formation

surfaces by dust storms, and it is therefore inevitable that such dust contributes to the development of stone pavements.

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