13 Salt Weathering in the Namib: Soutrivier and the Coastal Salt Pans

Abstract
In the coastal zone of the Namib salt weathering is a potent agent of rock disintegration. It has also caused the corrosion and failure of various engineering structures. Spectacular examples of the impacts of salt weathering can be seen along the coastal road from Swakopmund to Henties Bay, and where the road from Vogelfederberg to Gobabeb crosses the Soutrivier. At Soutrivier there are salt crusts and efflorescences in and around the damp river bed, and the granites show a wide range of weathering phenomena, including splitting, flaking, alveoles and tafoni. Not only has salt weathering given rise to extensive weathering phenomena but it may help to explain the development of the central Namib plains by a process of 'haloplanation', generating the great topographic monotony of some of the Namib coastal plain areas. Furthermore, salt weathering may be an important source of dust which blows off the Namib coast in great plumes. Recently, various experiments based on field exposure of rock blocks over one or more years have demonstrated the rapidity of presumed salt weathering in the Namib. These studies using rock blocks have confirmed that highly aggressive ground conditions occur in the fog belt and within and around coastal salt pans, producing weathering 'hotspots'. Further inland conditions are less severe and salt weathering is limited to topographic hollows where suitable microclimatic conditions prevail and where groundwater seepage occurs.

13.1 Introduction

One consequence of the presence of substantial quantities of both calcium sulphate and sodium chloride in the coastal zone of the Namib is that salt weathering is a potent agent of rock disintegration (Viles and Goudie 2013). It has also caused the corrosion and failure of various engineering structures including the pipeline that supplies water from the Omaruru River aquifer to Swakopmund and Rössing (Bulley 1983) (Fig. 13.1). Signs of the potency of salt weathering can be seen in many places within the coastal Namib Desert, such as where the road from Vogelfederberg to Gobabeb crosses the aptly named, Soutrivier (Salt River) (Fig. 13.2). Here there are salt crusts and efflorescences in and around the damp river bed, and the granites show a wide range of weathering phenomena, including splitting, flaking, alveoles and tafoni (Fig. 13.3).

13.2 Salt Weathering Mechanisms and Implications

It has been known since antiquity that salt attacks rock and building materials (Goudie and Viles 1997), but major developments in the study of salt weathering only came from the end of the nineteenth century onwards. It has become clear that salt weathering comprises a range of mechanisms, some chemical and some mechanical. Experimental studies have demonstrated that, of the mechanical processes, crystal growth from solution in rock pores and cracks is the most effective. It results from a decrease in solubility as temperature falls, by evaporation of solutions, or by mixing of different salts in solution (the common ion effect).

However, disruptive stresses may also be exerted by anhydrous salts, dehydrated in high desert temperatures, which from time to time become hydrated. Sodium sulphate,

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Fig. 13.1 Water pipeline ruined by salt attack between Rössing and Swakopmund

Fig. 13.2 Soutrivier

sodium carbonate and magnesium sulphate are examples of these sorts of salts. As a change of phase takes place to the hydrated form, water is absorbed. This increases the volumes of the salt and thus develops pressure against pore walls. In addition, many common desert salts have high coefficients of volumetric expansion that are higher than those of common rocks such as granite (Cooke and Smalley 1968). Their expansion may set up disruptive stresses in the rock.

In addition to these three main categories of mechanical effects, salt can also cause chemical weathering in susceptible rocks (Schiavon et al. 1995), and experimental studies using a range of salts and scanning electron microscopy showed

Fig. 13.3 Soutrivier, showing weathering forms

that salts could cause chemical etching of quartz grains after only short periods of exposure (Magee et al. 1988).

Not only has salt weathering given rise to extensive relatively small scale landforms such as weathering phenomena but it may help to explain the development of the central Namib plains by a process of 'haloplanation', generating the great topographic monotony of some of the Namib coastal plain areas (as for example between Uis and Henties Bay). Evidence for this haloplanation action comes from observations of rocks suffering from what has been termed 'shark fin weathering', in that a narow fin is left protruding above the ground surface as a remnant of a much larger sub-surface clast (Fig. 13.4). Over time, the fins will disappear and the entire land surface becomes planed off. Salt weathering may also explain the high rates of denudation indicated by some cosmogenic isotope studies of inselbergs. Cockburn et al. (1999) used measurements of cosmogenic ^{10}Be and ^{26}Al from granite inselbergs at three central Namib locations at 40–80 km from the coast—Blutkopje, Mirabib and Vogelfederberg —to estimate long term erosion rates. A mean rate of summit lowering of 5.07 ± 1.1 m per million years over the last >10^5 years was recorded. In comparison with data from Australian inselbergs (where rates of around 0.7 m per million years have been calculated) this is quite rapid. They attributed this higher denudation rate in the central Namib to active salt weathering associated with ample fog precipitation at the sampled inselbergs.

One link between weathering and erosion of specific interest which links the landscape of the central Namib to the global climate system concerns the interplay of salt weathering and dust production. Great plumes of dust can often be seen blowing off the Namibian desert in MODIS and other satellite imagery (e.g. Viles and Goudie 2007, Fig. 9). Weathering in salt pans is one key source of such fine-grained debris, which plays an important role in soil development and biogeochemical cycles within the desert environment and can also be entrained in upper winds and carried across the Atlantic. The fact that there are several semi-permanent

Fig. 13.4 Two examples of 'shark fin weathering' from the moist salty zone at Tomato Pan, north of Swakopmund

groundwater seeps across the central Namib, which are likely to experience similarly high rates of salt weathering, means that such weathering hotspots are highly likely to be important contributors to the dust budget here.

13.3 Weathering Experiments: The Role of Moisture

Recently, various experiments based on field exposure over one or more years of rock blocks have demonstrated the efficacy of salt weathering in the Namib. Goudie et al. (1997) emplaced blocks of a Jurassic oolitic limestone in a near-coastal salt pan (Tomato Pan) within the fog belt 22 km north of Swakopmund and at a distance of c 4 km from the coast. The land surface there is often moist and is impregnated with halite (NaCl) and gypsum. Rock outcrops display flakes, splits, alveoli, shark fin weathering etc. The rock blocks were left in this environment for 2 years. Many displayed considerable disintegration, particularly those that had been emplaced on salty, stone pavement surfaces. Geochemical analyses of the weathered blocks suggested that the active salt was halite and the climatology of the area implies that numerous salt crystallization cycles occurred in response to frequent wetting of rocks by fogs and subsequent drying by the sun and the wind. Subsequent laboratory simulations under Namib conditions confirmed the effectiveness of sodium chloride crystallization in such a coastal, foggy, pavement environment (Goudie and Parker 1998).

Viles and Goudie (2007) emplaced a wider range of rock types, including two Namibian rocks, Karibib marble and Damara granite, at the same Tomato Pan site. After 2 years of exposure the pre-weighed cut blocks were reweighed, tested for strength (Dynamic Young's Modulus) using the Grindosonic apparatus, examined under the SEM, and had their soluble salt contents determined. The Karibib marble blocks showed observable deterioration, whilst the Damara granite ones were characterized by strength increases and pore-filling by soluble salts.

These studies using rock blocks have confirmed that highly aggressive ground conditions occur within and around coastal salt pans producing weathering 'hotspots', whereas inland conditions are less severe and salt weathering is limited to topographic hollows where suitable microclimatic conditions might prevail (Viles 2005). A potentially very important source of moisture for weathering processes in near-coastal areas is fog. Directly fog provides a source of moisture for a range of chemical and physical weathering processes, especially salt weathering, whilst indirectly fog can support diverse lichen communities which themselves have been shown to play a key role in weathering here (Viles and Goudie 2000).

As well as fog, dew may be an important source of moisture for weathering processes in the Namib Desert. Henschel and Seely (2008, p. 364) stated that dew in the Namib "occurs very frequently during most of the year". They report that in 2001 dew occurred on 53 nights at Gobabeb. As Eckardt et al. (2012) note it is hard to distinguish fog from dew and it can be highly patchy. As with fog, dew is a key additional source of moisture which can contribute to the weathering of rock surfaces and both directly through facilitation of chemical reactions and indirectly through its enhancement of lichen growth. Information on the amount and importance of dew and fog precipitation at Gobabeb and Kleinberg is provided by Kaseke et al. (2012).

The Namib also shows large diurnal swings in relative humidity, which are important in terms of salt crystallization and hydration cycles. Analyses by Viles (2005, Table 5) indicate that at Vogelfederberg there may be over 20 days a month when relative humidity values cross crucial thresholds for the hydration and crystallization of sodium sulphate (one of the common desert salts proven to be highly effective as a weathering agent). Given that, in reality, a number of salts in mixtures are often found on rocks in the Namib, (e.g. sodium chloride and calcium sulphate mixtures as reported by Viles and Goudie 2007), it is likely that key thresholds (which vary from salt to salt) will be crossed very frequently. If one considers the combined occurrence of rain, fog precipitation and dew fall it is apparent that at Gobabeb moisture is potentially deposited on rock surfaces on about 40 % of the days of the year (Henschel and Seely 2008, p. 364). Some rock surfaces will experience longer periods of wetness as a result of microenvironmental conditions (shading, topographic hollows etc.) which favour slow evaporation rates.

In addition to fog, rain and dew, another important source of moisture in some parts of the central Namib is groundwater discharge via springs, seeps and pans (Viles and Goudie 2013). This is particularly true of the coastal zone to the north of Swakopmund, where there are large areas of moist ground that are readily identifiable on satellite imagery. However, ground water discharge is also evident at some localities further inland, as, for example, on the pediment slopes on the southern side of Rössing Mountain, along the Swakop canyon, in the bed of the Soutrivier (Day and Seely 1988) and also at Ubib in the central Namib plains (Brain and Koste 1993). It is clear that groundwater is of great importance for weathering in the central Namib as it provides an often perennial source of moisture, and one which usually has high dissolved salt concentrations. Furthermore, groundwater discharge provides a deep seated and consistent source of moisture for weathering, rather than the more superficial and intermittent delivery of moisture from fogs, dews and rainfall.

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