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Salt Crusts on Bedrock Exposures in Dronning Maud Land, East Antarctica

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Abstract: Gypsum and calcite crusts were found on many outcrops of the metamorphic basement and on moraines in Dronning Maud Land. For the first time the copper mineral connellite was found in such crusts. Salt crust and efflorescences indicate an important role of chemical weathering even in a cold and arid climate such as the Antarctic interior. Findings of salt efflorescences few centimetres beneath the rock surface suggest the contribution of salt crystallization to the formation of the typical Antarctic cavernous or honeycomb weathering features.

Zusammenfassung: Gips- und Calcitkrusten wurden häufig auf Felsoberflächen und Moränen des metamorphen Basements im westlichen und zentralen Dronning Maud Land vorgefunden. Erstmalig konnte darin auch das Kupfermineral Connellit nachgewiesen werden. Die Salzkrusten belegen eine wichtige Rolle der chemischen Verwitterung auch in kaltariden Gebieten wie der Antarktis. Funde von Salzausblühungen wenige Zentimeter unter der Gesteinsoberfläche deuten auf einen Beitrag der Salzkristallisation zur Bildung typischer antarktischer Verwitterungsformen (kavernöse oder Wabenverwitterung) hin.

INTRODUCTION

In the cold and arid climate of Antarctica, physical weathering is often considered to be dominant over chemical weathering processes (e.g. WASHBURN 1980). A limiting factor for chemical weathering and the formation of secondary minerals is the availability of liquid water. The paucity of liquid water is not the only factor which restricts chemical weathering, the rates of chemical reactions such as hydrolysis, chelation and leaching are also reduced at low temperatures. Nevertheless, during the last years many advances in the understanding of chemical weathering and soil formation in Antarctica have been made (e.g. CLARIDGE 1965, UGOLINI 1986, CONCA & ASTOR 1987, BÖLTER et al. 1994, LYONS et al. 1997). Most of these studies focussed on the Dry Valley area of the Transantarctic Mountains, where soils cover large parts of the ice-free landscapes. The formation of secondary salts in soils or ponds of coastal regions of Antarctica has been interpreted as the result of infiltration and evaporation of salt-enriched meltwater. The salt content is assumed to originate from marine aerosols (e.g. MACNAMARA & USSELMAN 1972). This concept cannot cope salt efflorescences and crusts in areas about 200 km away from the open sea, such as for most of the ice-free areas of Dronning Maud Land (Fig. 1). WAND (1995) published a study on stable sulphur isotopes, proving a waning importance of marine spray aerosols, but an increase of in situ weathering process in the formation of salt efflorescences in the Antarctic interior.

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In this paper we present some observations of salt encrustations from the barren, steep rock walls of central and western Dronning Maud Land. VAN AUTENBOER (1964) first noticed gypsum encrustation on rock surfaces at Sør Rondane, eastern Dronning Maud Land. Rock samples bearing salt crusts were observed and collected during the German Antarctic expeditions to western and central Dronning Maud Land in the course of geological field studies and mapping campaigns.

OCCURRENCE OF SALT CRUSTS AND EFFLORESCENCES

The mountain ranges of Heimefrontfjella, Gjelsvikfjella, western Mühlig-Hofmann-Gebirge, Orvinfjella and Wohlthatmassiv (Fig. 1) were visited by the first author during four expeditions in 1993/94, 1995/96, 1999/2000 and 2000/01. These areas are characterized by steep escarpments or isolated nunataks, the altitude reaches 3000 m and occurrences of soil are restricted to a few smooth, ice-free slopes. All encrustations were found on rock walls 150-400 km away from the coast, on stable moraines and talus. On moraines and talus, very thin white efflorescences are either present directly on the surface or beneath boulders, coating small grains, in joints of boulders, or as a cement between fine-grained debris. Locally cementation affected the upper 2-3 decimetres of the talus.

The most spectacular findings of salts however, are up to 3 cm thick crusts with nodular, irregular surfaces (Fig. 2), up to 10 cm in diameter and firmly attached to the rock. They occur in the lower parts of steep walls (Fig. 3) and on subvertical rock surfaces of the nunataks. They seem to be more abundant on the leeward rock surfaces, i.e. facing west to north-west, or, if they are present on the luff side, they are restricted to wind-protected niches. Salt crusts have been found on several bedrock types such as gneisses, migmatites, granitoids, amphibolites and basalts; no crusts were recorded on Permian sandstones, metapelites and quartzites. Their colour is in most cases white, on amphibolites however, also faint bluish-greenish crusts were observed.

COMPOSITION OF SALT CRUSTS

Specimens of the evaporite crusts were collected together with pieces of the adjacent host rocks. Both were separated manually and ground in a steel mill to <63 µm mesh and dried at 40 °C for 24 hours. The bulk mineralogical composition was determined using a Siemens D500 X-ray diffractometer at 35 kV and 30 mA. Each mount was scanned from 3° to 63° 2Θ at a scan rate of 1°min^{-1}. Detection limit for a mineral

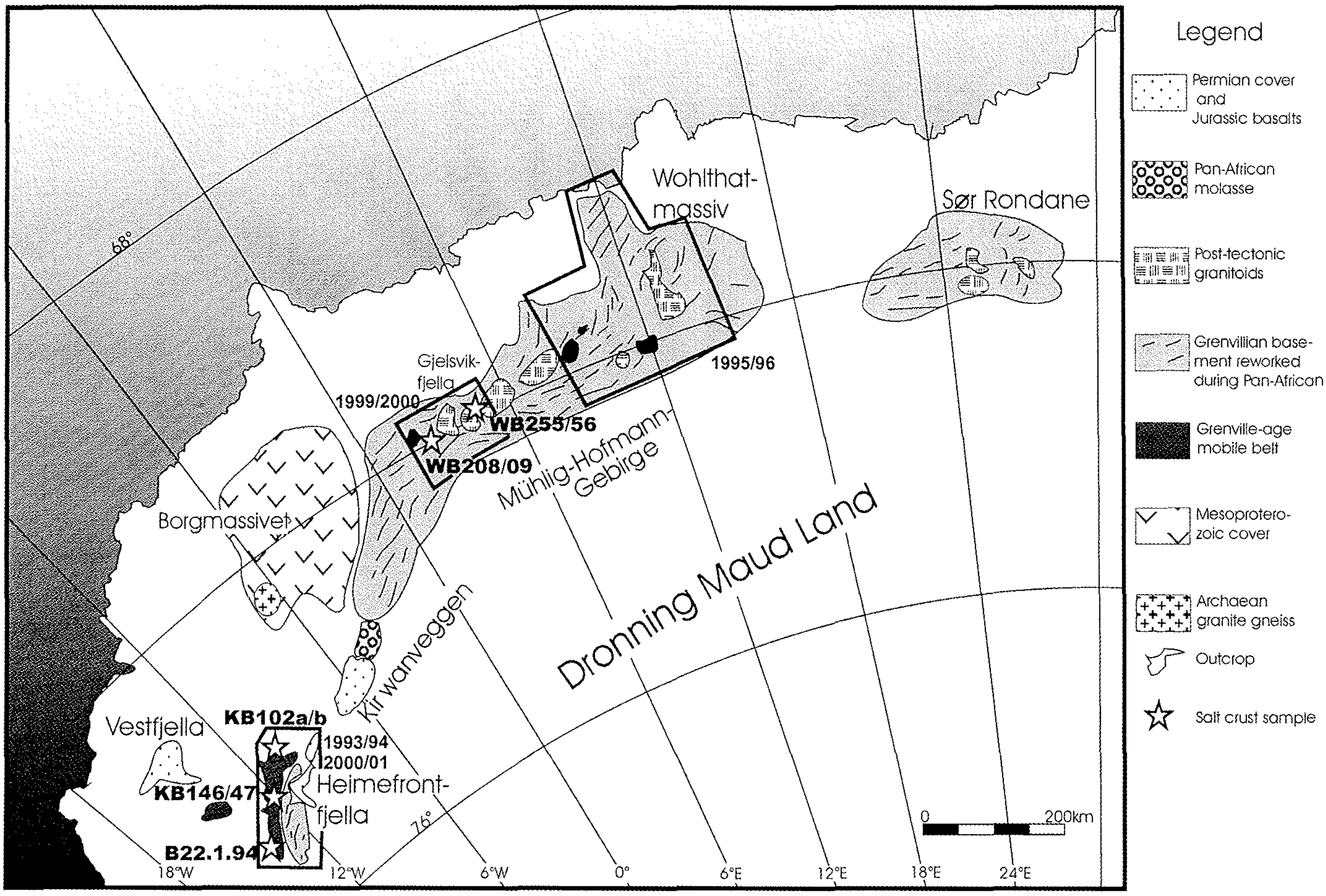


Fig. 1: Geological map of Dronning Maud Land with location of analysed salt samples.

Abb. 1: Geologische Karte des Königin Maud-Landes mit den Lokationen der beprobten Salzkrusten.

Fig. 2: Sample KB 102 from northern Heimefrontfjella, an augen gneiss with firmly attached salt crust.

Abb. 2: Probe KB 102 aus der nördlichen Heimefrontfjella, ein Augengneis mit fest anhaftender Salzkruste.

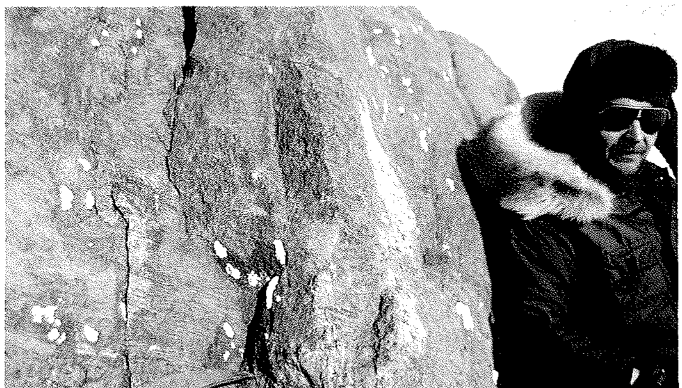


Fig. 3: Subvertical wall, facing NW, in the southern Heimefrontfjella, spotted with white salt crusts.

Abb. 3: Steile, nach NW zeigende Felswand in der südlichen Heimefrontfjella, mit Flecken weißer Salzkrusten.

phase is 3 vol %. Additionally, mercury porosimetry and SEM images of sample B22.2.94 have been carried out for an investigation of internal structures of the crusts.

Newly discovered salt crust occurrences from Gjelsvikfjella, western Mühlig-Hofmann-Gebirge and Heimefrontfjella are composed of nearly pure gypsum and pure calcite, respectively (Tab. 1). Two salt crusts show a bluish-greenish colour (WB 255 and KB 147), but the responsible component was close or below the detection limit. In sample KB 147 the coloured mineral was identified as connellite, a hydrated copper sulphate chloride hydroxide ($Cu_{19}Cl_4SO_4(OH)_{32}\ 3H_2O$).

Sample#	Description	Location	Major components	Minor components*
KB102a	salt crust	74°18,81' S 09°51,96' W	calcite	quartz, microcline
KB102b	orthogneiss, host rock of KB102a	74°18,81' S 09°51,96' W	plagioclase, microcline, quartz, biotite	chlorite, calcite, muscovite, zircon
KB146	amphibolite, host rock of KB147	74°34,32' S 11°08,08' W	magnesio-hornblende, plagioclase	biotite, chlorite, quartz, epidote, chalcopyrite, pyrrhotite
KB147	salt crust	74°34,32' S 11°08,08' W	gypsum	connellite
WB208	salt crust	71°59,20' S 03°04,86' E	gypsum	quartz, biotite, microcline, plagioclase,
WB209	orthogneiss, host rock of WB208	71°59,20' S 03°04,86' E	quartz, biotite, plagioclase	microcline, chlorite, chalcopyrite, zircon
WB255	salt crust	72°02,92' S 03°54,03' E	gypsum	chlorite, plagioclase quartz
WB256	Bt-Pl-gneiss, host rock of WB255	72°02,92' S 03°54,03' E	quartz, biotite, plagioclase	microcline, zircon, chalcopyrite
B22.1.94	salt crust	75°00,96' S 12°48,75' W	calcite	none

Tab. 1: Composition of salt crusts and host rocks. * including impurities from attached host rocks.

Tab. 1: Zusammensetzung der Salzkrusten und der unterlagernden Gesteine.

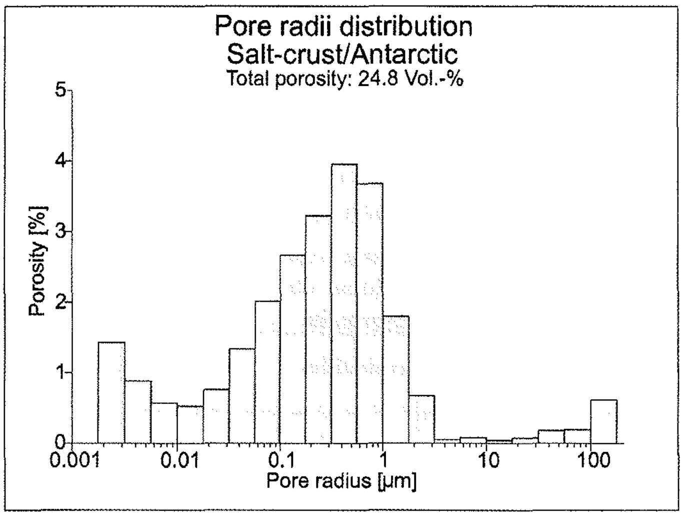
For a better understanding of the relevant chemical processes, X-ray diffractometry and light microscopical analyses were carried out on the attached host rocks. KB 102b is composed of quartz, plagioclase, biotite, chlorite and epidote (Tab. 1). The plagioclase grains ($An_{15}Ab_{85}$) are strongly saussuritized, thus leaching of soluble calcite from the plagioclase and evaporation at the rock surface is the probable source of salt crust formation. The plagioclases in the amphibolite KB 146, and the gneisses, WB 209 and WB 256, are relatively fresh. These three samples contain up to 1 vol % chalcopyrite ($CuFeS_2$) and pyrrothite ($Fe_{1-n}S$) which are potential sources for secondary sulphate minerals. Generally, amphibolites contain 5-10 vol % of opaque ore minerals and even in gneisses of felsic volcanic and granitic origin up to 5 vol % of ore minerals are common, but oxides such as ilmenite and magnetite predominate over sulphates (KÄMPF 1995, JACOBS et al. 2002).

Internal structures of calcite crust B22.2.94 have been studied in detail. This sample has a total porosity of 24.8 %. The pore radii distribution (Fig. 4a) is characterized by a median pore radius of 0.266 µm. Calcite has a density of 2.7 g cm^{-3}, but using the pore volume from 0.0019 up to 200 µm a density of only 2.515 g cm^{-3} can be calculated. This proves the existence of extremely fine pores which were not considered by the mercury porosimetry method. SEM images confirm the extremely porous fabric of the salt crust. In profile alternating layers of approximately 50 µm thickness are visible: coarse-grained layers with diameters of up to 10 µm and fine-grained layers with grain sizes ranging from 1 to 5 µm (individual precipitation events?). Coarse-grained layers are characterized by oblique, channel-like structures (Fig. 4b). Such a porous, sometimes sponge-like structure has no sealing effect on the rock surface but it allows an ongoing evaporation of liquid water and precipitation of secondary minerals.

DISCUSSION AND CONCLUSIONS

The presence of soluble carbonate and sulphate salts on bedrocks raises the question as to the possible source of free water. Long-time climatic data are only available for some near coastal stations. For the Schirmacher Oasis (70°46'S 11°45'E) in central Dronning Maud Land a 20 year annual mean temperature of -10.4°C was recorded (RICHTER & BORMANN 1995). This climate is characterized by a mean humidity of 51 % and a precipitation of 160 mm/a. In the mountain ranges of the hinterland, temperatures are lower and the aridity is more pronounced, but it has often been noted that the temperatures of rock surfaces under direct radiation exceed the air temperatures by up to 30 K. Small niches, joints, caverns etc., are often filled with snow after blizzards. Localized melting of this snow under direct sun exposition causes some temporary accumulations of free water which infiltrates the rock and becomes available for chemical processes.

Salt efflorescences may also play an important role in the formation of cavernous, honeycomb or taffoni weathering forms. According to AVSYUK et al. (1958) and BARDIN (1963) these typical Antarctic weathering forms may be a wind-influenced feature, since the caverns are concentrated on the luff faces of rocks. An important contribution of moisture flux,



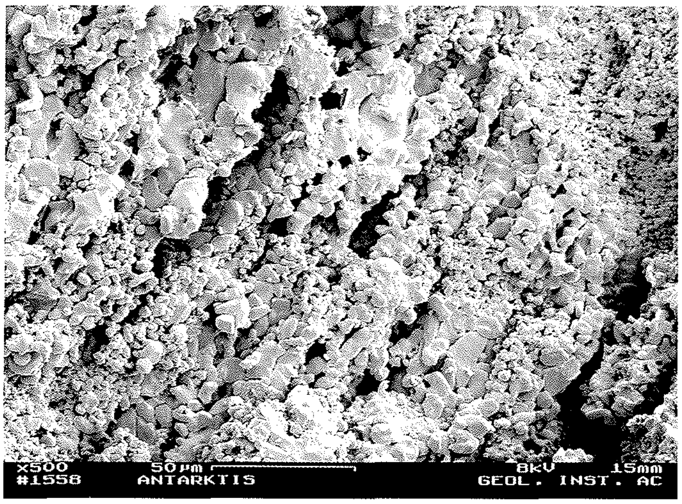


Fig. 4: a) Pore radii distribution of calcite crust B22.2.94 from southern Heimefrontfjella. b) SEM image of B22.2.94 in profile (lower margin parallel to rock surface), showing a coarse-grained layer with oblique channel-like pores.

Abb. 4: a) Histogramm der Porenradien-Verteilung in der Calcitkruste B22.2.94. b) Rastereletronenmikroskop-Aufnahme von B22.2.94 im Profil (untere Bildkante parallel zur Gesteinsoberfläche), mit deutlich erkennbaren schlauchförmigen Poren in einer grobkörnigen Calcitlage.

freeze-thaw and chemical weathering rather than a mainly aeolian effect has been proved (e. g. UGOLINI 1986, CONCA & ASTOR 1987, BALKE & RICHTER 1995). A large number of different salt types have been found in Antarctica so far, and many workers have noted the break-down of rocks where efflorescences are present (GOUDIE & VILES 1997). During the expeditions to Dronning Maud Land it was noted that a 2-3 cm thick layer from the steep, wind-exposed rock surfaces can be easily removed with a hammer. This outer layer is already loosened from the solid rock by a zone of enhanced salt crystallization. Individual rock-forming minerals are surrounded by thin calcite or gypsum efflorescences. Their crystallization pressure has decreased the coherence of the metamorphic or magmatic fabrics.

In the cold and arid climate of the Antarctic interior, physical weathering is often considered to be the most effective form of weathering (e.g. UGOLINI 1986). Processes of chemical weathering have been studied in detail in the areas of the Dry Valleys of the Transantarctic Mountains (e.g. LYONS et al. 1997), whereas the mountainous regions in other parts of Antarctica attracted less attention. Our study covers the ice-free exposures of large areas in Dronning Maud Land, where salt efflorescences and crusts are common features of chemical weathering of magmatic and metamorphic rock types (Fig. 1). Encrustations are formed by gypsum and calcite, these minerals were reported by VAN AUTENBOER (1964) and TASCH & ANGINO (1968) as the most common secondary minerals of the Antarctic interior. The extent of chemical weathering and salt precipitation may still be underestimated since resulting efflorescences and crusts are only partially visible on rock surfaces, another part developed a few centimeters beneath the rock surfaces. Here, salt crystallization, together with freeze-thaw weathering, is probably responsible for the early stages of rock disintegration and the formation of the cavernous weathering.

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