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Rock varnish coat on cobbles in Hornsund area, Spitsbergen

ABSTRACT: In Hornsund Fiord, West Spitsbergen, the cobbles with varnish coat on their surface were found. They occur on low Holocene terraces on older and lower moraine ridges of Hans Glacier. There are two types of chemical coats: 1. corresponding to the mineral and chemical substance of the rock they occur on, and 2. independent of the rock, sedimented under influence of external activities. First type of coats is created by oxidative processes. The second type, like manganese-iron coats of intensive dark colours, does not differ from the phenomenon defined as "desert varnish". They were developed in Holocene in present conditions of polar climate. The authors lean toward biological origin of the coats.

Key words: Arctic, Spitsbergen, chemical varnish.

Introduction

The phenomenon of chemical coats on rock is well known from arid climate regions. Hence its name: "desert varnish". These coats are from black through brown and reddish-violet to yellow in colour. Oxidized manganese and iron are their main compounds. The connection of their genesis with dry climate was repeatedly proved. Sharp variations of the temperature and moisture of the soil are favourable to their formation. The important problem whether these coats are dependent or independent on rock they occur on is far less known. If they are dependent, the mineral compounds of the coats are secondary to a rock coated by them, otherwise these coats may be chemical sediment and precipitates deposited by air and water (*e.g.* seasonal flood of valley bottom). Today, the concept of

biological (*e.g.* bacterial) origin of these coats have greater acceptance (Dorn and Oberländer 1981).

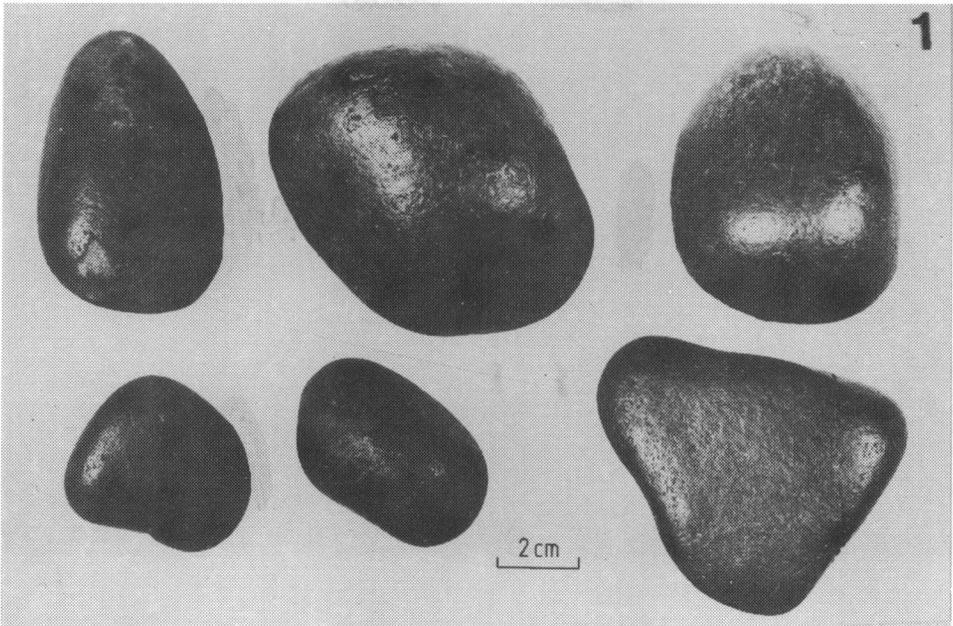
In polar zone, the chemical coats on rocks were unknown for a long time, in agreement with the opinion, that low temperatures do not favour chemical reactions. Nordenskiöld (1914) was one of the first who called into question these opinions. Everywhere on the shores of the drying tundra lakes in West Greenland he saw precipitates of red iron compounds. When in 1937 one of the authors of this article (Jahn) has carried out his studies in West Greenland in the same area as Nordenskiöld, he has also noticed these dried up lakes and rufescent reddish iron-bearing coats on the rocks. Tedrow (1977) in his handbook of polar soils accepted as proved fact, that desert varnish is frequent in this part of the globe and Stäblein (1982) simply wrote about ascertained aridity of the polar climate. The chemical coats on the rocks are frequently found in dry, extreme continental periglacial zone of Antarctica (Markow 1960). The real polar desert occur there and Kelly and Zumberge (1961) and Selby (1971) even wrote about appearance of typical coats of "desert varnish". It is worth mentioning, that this type of the coatings on rocks are known in mountains for a long time. Zahn (1930) has seen them in the Alps in the glacier front zone and Michalik (1955) is the author of an excellent monograph on such coats in Polish Tatra Mountains, called by him "enamels". He found them mostly on Liliowe Pass and Kondracka Kopa. Black and brown coats cover cobbles and rock debris but only on their upper parts above the soil surface.

The phenomenon of chemical weathering is known for a long time in Spitsbergen, Högbom (1912) simply wrote about desert phenomenon (Wüstenerscheinungen). Cegła and Kozarski (1977) and Drozdowski (1982) connect the chemistry of Spitsbergen waters with ice cover. Pulina (1984) found that these are predominantly cryochemical processes. The results of pedologists studies are also important. Especially those discovering the biological influences (Szerszeń 1974), the contribution of clay minerals (Szerszeń and Chodak 1983) and easily mobile iron compounds (Chodak 1988) in chemical environment of Hornsund area.

Results

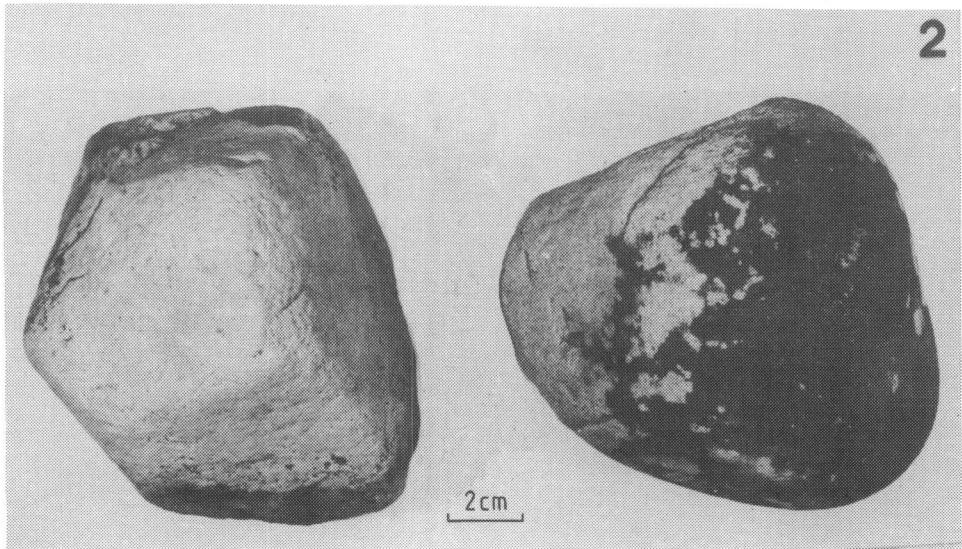
Rock varnish in the front of the moraines of Hans Glacier

Many stones, cobbles and even small blocks but mostly pebbles with chemical coats on their surfaces were found at the distance of 1 km to the East from Polish Polar Station, in the direction of Hans Glacier, at the foot of Fugleberget mountain. It was possible to distinguish three sites of their occurrence, which are shown on the enclosed map (Fig. 1) and profile (Fig. 2). The most typical specimens were found on the surface and slopes of the hills of



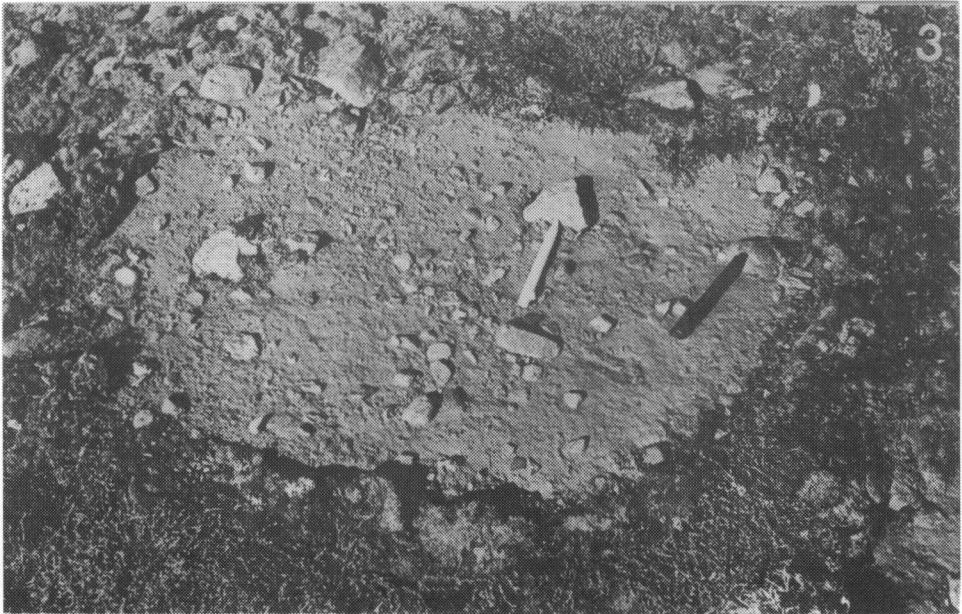
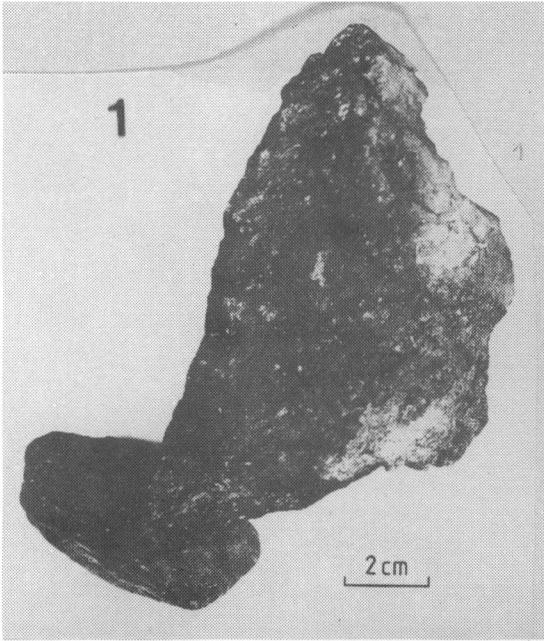
1 — The pebbles covered with glossy almost black chemical coat

2 — The cobbles with chemical coat, site No. 1. The material with variable petrography and size



1 — Asymmetry of the coat on the largest cobble with rock varnish

2 — Two specimens of sandstone, the right one is asymmetrically covered with chemical coats, the left one is polished by wind, with the remnants of chemical coat preserved



- 1 — One of the fragments of the moraine debris (site 2). Only the left side (upper in natural position) of the cobble is covered with chemical coat
- 2 — Siderite rock from site 2 with chemical coat. This specimen was the subject of the petrographic analysis
- 3 — Active cell of polygonal net, in the middle the inverted cobble, on the borders (pointed by the dark pencil) the cobble in normal position

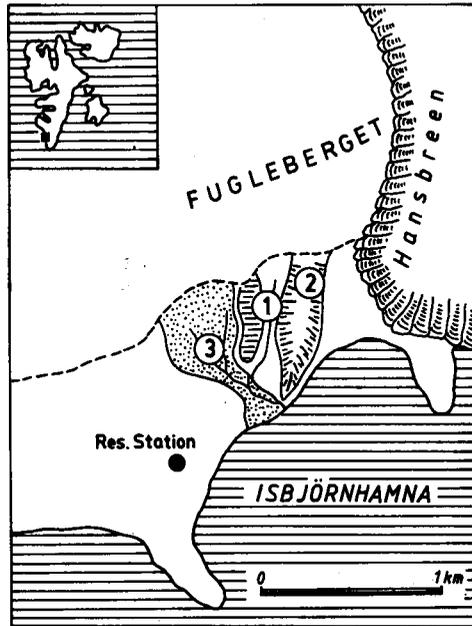


Fig. 1. The map of the vicinity of Polish Research Station in Hornsund showing the sites where the specimens of cobbles with rock varnish were collected

the old moraine and on the forms defined by Karczewski *et al.* (1981) in their morphological map as the “older outwash levels”. They occurred also in the neighbouring basins partly filled with water. The site No. 2 is located within the range of high ice core moraines and the site No. 3 on an alluvial fan in the front of the moraines and at the foot of Fugleberget mountain.

On the site 1 chemical coats occur on almost all cobbles (Pl. 1, Fig 1) including pebbles of diameter from 2 cm to 30 cm. They are intensive black, black with violet reflection and yellow-brown in colour. A material represents typical moraine settled in the past on the edge of Hans Glacier and contain crystalline schists, grey and white sandstones, quartzites, quartzes and arcose sandstones. Similar cobbles with chemical coat were found by Andrzej Traczyk in the front of Arie Glacier on old and young moraines (*pers. comm.*).

This material was brought by the glacier from the interior of the island. It is characteristic that there are no chemical coats on limestone cobbles. The chemical coats on this site remind what we call “desert varnish”. They are real chemical crust consisting mainly of manganese and iron oxides of the thickness reaching even 0.5 mm. On crystalline rocks and on quartzites they form a dense layers of peeling tendency, but on the porous sandstones the coating substance penetrate in pores of the rock. The chemically impregnated layer is 2–3 mm thick. Although these cobbles were on the hills of the high of 20 metres they occurred

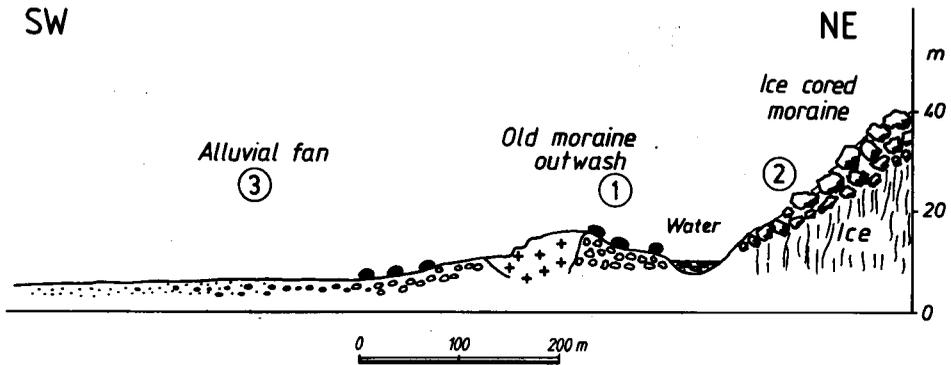


Fig. 2. The profile between glacier and alluvial cone. The position of the sites is marked

mainly within the old outwash fans 8–12 m high (Pl. 1, Fig 2). It is possible to observe their accumulation in the hollows between hills and ridge of great ice cored moraines, on the shore of shallow lakes drying up in summer. During spring, with high levels of water in the lakes these cobbles are in the flood zone. However it does not seem that the water play a significant role in the formation of the chemical crust, because the most typical specimens are beyond of its reach. The origin of chemical coats on cobbles should be investigated additionally.

This crusts occur only on the parts of cobbles jutting above the soil. The parts buried in the soil, particularly in case of light sandstones, look different. They show a clean, partly bleached colour of the rock (Pl. 1, Fig 2). The largest cobble (30 cm in diameter) with chemical coat has dark dyed on its upper part of surface. A sharp line separate this part from a clean surface buried in the soil. Some smaller pebbles are entirely covered with the varnish, what can be probably attributed to their mobility. They are not buried in the soil but they lie on its surface (Pl. 2, Fig. 1). They could be turned either by water flowing down the hills or by wind.

Certain asymmetry of cores with chemical crust was observed on cobbles. The south-eastern side exposed to sunlight activity was favoured. This side is also exposed to the eastern winds of glacier fehn's character which are frequent there.

The chemical coats on cobbles are resistant to water activity but undergo destruction under mechanical influence. The sand or perhaps snow-ice crystals carried with the winds are able to "tear out" the chemical coats from the cobbles. The cobbles presented on (Pl. 2, Fig. 2) are the examples of this eolian erosion. It seems, that eolian activity in this area is younger than the period of intensive formation of this chemical coats.

High ridge of the end and side moraine of Hans Glacier were another sites of occurrence of the cobbles with chemical coats (the site 2). These are ice-cored moraines built predominantly from thick blocks. The chemical coats covering rough surface of sharp-edged rock chips (Pl. 3, Fig. 1) were more frequently of

brown-red colour although darker cobbles were also found. However intensively black, incrustated specimens were absent. Their single examples were limited only to some types of the rocks (Pl. 3, Fig. 2).

On the site 3 on the alluvial fan we found the chemically coated cobbles in the streams and on the debris ridges of gelifluction. The majority of pebbles and cobbles with chemical coats occurring in the streams were coated chemically not in water but on a dry surface of the soil. It is evidenced by the fact that they are covered only in half, thus similarly to the cobbles from the site 1, they stuck some time ago half-buried in the soil.

There is an interesting relation of these cobbles to polygonal nets of debris, covering lower part of the fan. Within the stone ridges of the nets the cobbles retained their normal position, that means with their chemical coat on their upper side whereas the colourless lower part stuck in the soil. On the other hand, the cobbles in the middle of polygonal cells had often the inverted position, their light parts were exposed to the outside (P. 3, Fig. 3). This fact proves young cryoturbation activity of polygonal fields. Frost heaved clay inside flows to the sides and during this movement some cobbles underwent the inversion. It was young, perhaps contemporary process, at least younger than the period of chemical coats formation. Keeping track of these inverted cobbles allows to find the youngest, structurally active soils.

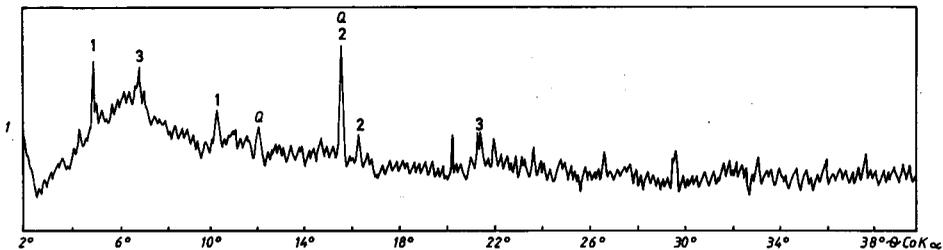


Fig. 3. The X-ray powder pattern of the black chemical coat from a cobble of the site 1, Q — quartz. Weakly crystallized compounds probably of the following types: 1 — $(\text{Na}, \text{Mn})_4\text{Mn}_{12}\text{O}_{18}\cdot 8\text{H}_2\text{O}$; 2 — $(\text{FeMn})\text{Fe}_2(\text{PO}_4)_2(\text{OH})_2$; 3 — MnO

The chemical and mineral composition of the rock varnish

The studies were carried out in the laboratory of the Department of Mineralogy and Geochemistry of the Mining-Metallurgic Academy in Cracow. Thin sections were done from coats and rocks and microscope studies in polarized light were conducted. The X-ray powder patterns were recorded at the

angle 2–40° with HZG–4 (TUR–62M) diffractometer using CoK_α and CuK_α radiation and counter technique.

The pebble from the site 1 covered with black substance is a weakly changed arcose sandstone. Its black varnish is not genetically related in any way to the mineral substance of the rock. It is a weakly crystallized substance consisted mainly of iron and magnesium hydroxides. The compounds of phosphate type are also possible (Fig. 3). The sample coming from the surface of young moraine (site 2) is siderite rock with small admixture of quartz and even smaller of feldspars (Fig. 4). The outside integument of the sample, hard and of red colour, consists predominantly of hematite with some siderite, clay minerals from the kaolinite-illite group, quartz and traces of feldspars. Conformity of the both X-ray powder patterns indicates that mineral compounds of the rock are the source of the varnish: the oxidated siderite passes into hematite.

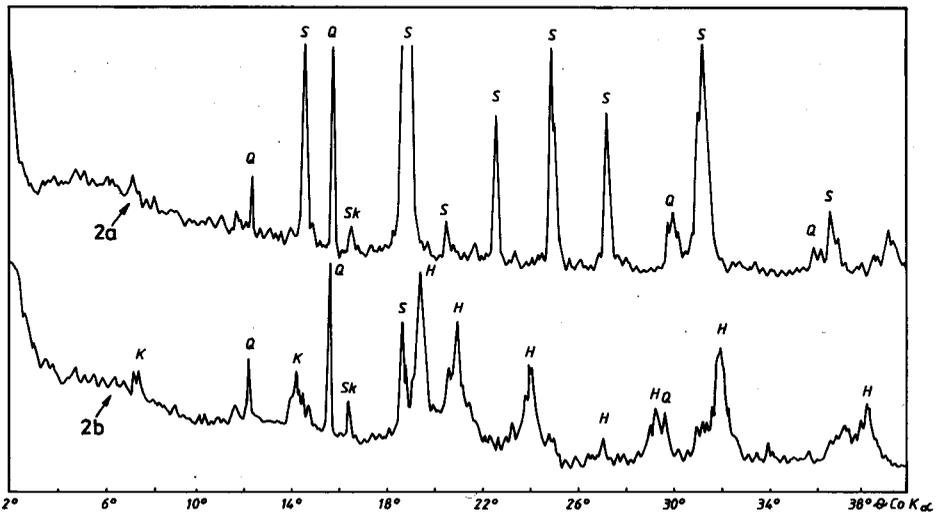


Fig. 4. The X-ray powder pattern of the rock from moraine of Hans Glacier (site 2). 2a — inner cobble rock zone; 2b — chemical coat. S — siderite, Q — quartz, Sk — feldspar, H — hematite, K — kaolinite-illite

Discussion

The fact, that chemical varnish on the cobbles was discovered in almost classical form in Hornusund area proves that this is nearly ubiquitous phenomenon. Formerly this was ascribed only to the climate of warm deserts. This way the idea most strongly presented by Krumbein (1969) is confirmed. Although the material in our disposal was relatively poor we may attempt to answer the question whether the source of chemical varnish covering the cobbles is of internal (rock) or external (air and water) nature. In the abundant literature

both sources were discussed. Engel and Sharp (1958) represented the first opinion and Allen (1958) the second one. Their conclusions refer to almost the same dry regions of California and Mexico.

In our opinion both sources are possible. Rocks rich in easily soluble or easily oxidizing minerals as in presented above example of siderite (the site 2) give chemical varnish identical with rock composition. Siderite (FeCO_3) oxidized to hematite (Fe_2O_3). The only problem is whether such coats can be defined as "rock varnish" or "desert varnish". Certainly this term refers to black-brown-violet coats on the rocks of different type of site 1. The allochthonic origin is beyond any doubt there, and the main argument is that the same type of varnish occurs on different rocks. It should be mentioned that the limestones are an exception here. We have not found varnish on the limestones, what may be explained that even if they were coated, they underwent a secondary washing. The limestones generally had a strongly corroded surface indicating that it underwent the destructive activity of the rain and melting waters.

Ascertaining the external origin of iron-manganese rock varnish formation one may look for its source in the soil in which the cobbles stuck elsewhere. The fact, that the cobbles sticking in soil have chemical varnish only on the exposed surface part, negates the first possibility. Chodak (1988) found in the soil of Hornsund area a large amount of iron of these compounds, but the same time he reported the downward displacement of these compounds resulting in accumulation of iron on the lower line of active level of the permafrost. It is an argument against the origin of the rock varnish from local soil.

The following facts support an external origin of the coats under the influence of air and water:

- 1) The cobbles covered with the varnish are abundant in the depressions of the terrain or on gentle slopes of the old moraines.
- 2) There is an asymmetry of the coats with their exposing (in this case they are exposed to the South and East).

The first observation may indicate water as a source of the mineral accumulation. According to Pulina (1984) the waters of permafrost are strongly mineralised. However Krzyszowska (1985) made clear that water at the foot of Fugleberget, where the studied varnish-covered cobbles came from, do not contain substantial amounts of chemical compounds. The cobbles found in the streams are frequently — what we had mentioned above — covered with varnish from one side only. Thus the process of the mineral coating took place on the land. Therefore, we should rather consider the air as a more likely cause of chemical varnish deposition.

The region of Polish Polar Station in Hornsund has certain features of the arid climate (Baranowski 1968, Pereyma 1983). Kamiński (1985) had measured relatively large (above 20°) amplitudes of the daily temperature in July on the southern side of the fjord. The Spitsbergen Summer creates conditions of drying surface of the soil. There is a certain analogy to a desert conditions, although such conditions do not occur every year. Polar climate of Spitsbergen was

hitherto regarded as oceanic form of polar climate. Today we notice certain features of its continentalization. The climate of Hornsund is one of the cause of chemical varnish deposition.

It is possible to connect chemical rock varnish of Spitsbergen with the most recent view about its biological origin. Tedorow (1977) had already written about a possibility of connecting these coats with the presence of algae in the polar zone. Algae are common on Spitsbergen. Red coloured patches of snow are visible everywhere during Spring. We have no solid data about biogenetic origin of rock varnish of Hornsund. Nevertheless, the hypothesis about possibility of mineralization by organic substances is supported by the following observations:

- 1) Weakly crystallized, almost amorphous character of these coats.
- 2) Their thickness reaching even 0.5 mm.
- 3) Asymmetry of the coats, favouring these sides of cobbles on which algae could settle and develop.
- 4) Rock varnish forms in places climatically privileged, in sheltered basins on quiet warm slopes, rather wet than dry. The presence of Spring snow patches faster its formation.

The age of coats is variable. Red coloured surface varnish coats generated by oxidization are very young. They are younger than moraines on which surface they were formed, thus younger than the ice transgression of Little Ice Age. Hence they could be formed during the last 100 years. They may be regarded as equivalent of a red sand-marly pebbles, which are often met on the youngest low beaches of the Hornsund shore. Accepting oxidative genesis of the coats we must agree, that they were always formed for as long as a rock was exposed to the atmospheric activity. The examples described refer to the youngest phenomena. Incrusted black iron-manganese coats are of exactly defined age. They are older than oxidative coats on moraines of Hans Glacier. They cannot be older than terraces, on which they occur. Being located 8 m above the present sea level they belong to the Holocene terrace of the estimated age of 5–10 thousand years B.C. (Jahn 1959, Birkenmajer and Olsson 1970, Karczewski *et al.* 1981). Thus, the rock varnish was formed during the last few thousand years. This statement refers to the youngest chemical coats only, whereas on the higher terraces there are also cobbles with older coats. The cooling of the Little Ice Age did not favour the formation of these coats. Nevertheless, there was a warmer period just before the last transgression of the glaciers about thousand years ago. The soils from this period contain relatively high percentage of colloidal clay, and show the features of advanced chemical weathering (Baranowski and Szerszeń 1968). It is possible to assume, that just that time, a majority of chemical coats on cobbles at the foot of Fugleberget in the Hornsund area was formed. The cooling following this period degradation of the tundra, mobile sand caused some destruction of the rock varnish. Eolic faced pebbles on whose walls the remnants of coats remained are from this period. Nowadays climate locally favours the development of the coats.

Conclusions

1) The chemical coats found on cobbles belong to two types: a) oxidative, weathering coats, formed from the rock covered by them; b) coats generated mainly by substances delivered from outside. Considering their chemical composition (iron-manganese) and colour they do not differ from the coats called "desert varnish". Their biological origin cannot be excluded.

2) The coats of the rock varnish type were formed in younger Holocene before Little Ice Age and may be formed nowadays but only in favourable conditions of the local climate. Thus the coats are not a fossil phenomenon. Their presence in Spitsbergen, allows to assume that they may develop in polar climate not only in its variety of distinctive aridal features (Antarctica) but also in oceanic variety.

3) The processes of chemical incrustation of cobbles and eolization are mutually exclusive phenomena. Part of coats is destroyed by eolic corrosion developing recently.

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Streszczenie

We fiordzie Hornsund, Spitsbergen Zachodni, znaleziono głazy z powłoką chemiczną na ich powierzchni. Występują one na niskich, holocenijskich terasach, na starszych i młodszych wałach moreny lodowca Hansa. Są dwa typy powłok chemicznych: 1 — odpowiadające mineralogicznej i chemicznej substancji skały, na której występują i 2 — niezależne od skały, osadzone przez działanie zewnętrzne. Pierwszy typ powłok powstał przez działania oksydacyjne. Drugi typ, a więc skorupy manganowo-żelaziste o intensywnych ciemnych barwach, nie różni się niczym od powłok określanych mianem „desert varnish”. Powstały one w holocenie, rozwijają się we współczesnych warunkach klimatu polarnego. Autorzy skłaniają się do poglądu o biologicznej genezie zjawiska.