ROCK ART REPORTS FROM THE UNIVERSITY OF BERGEN 3

THE ROCK ART PROJECT
– SECURING AND PROTECTING ROCK ART –
UNIVERSITY OF BERGEN 1996–2005

Investigations at the Rock Art Sites
Vingen, Bremanger, Sogn og Fjordane
and
Hjemmeluft, Alta, Finnmark

Edited by Trond Klungseth Lødøen
2010

UNIVERSITY OF BERGEN
Bergen Museum

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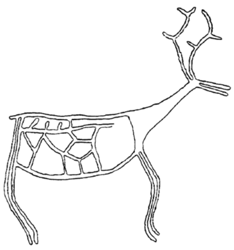
Front page: Aerial view of Vingen (photo: A. Kjersheim)
Backpage: Tracing of reed deer from Vehammaren, Vingen (E. Bakka).



PREFACE

This report is number three in the series of *Bergkunstrapporter fra Universitetet i Bergen* (Rock Art Reports from the University of Bergen, and the first of the reports in English. It builds partly on the results from the former Bergkunstrapporter fra Universitetet i Bergen 2, and summarizes most of the results from the National Rock Art Project. The objective of the project initiated by the Directorate for Cultural Heritage was the preservation of 300 sites throughout Norway by the year 2005. In addition, another 200 sites were to be fully documented within the same timeframe. As the project changed from a more time limited project based on funding to a more steady supply and permanency in financial support from 2006, some of the results from the years 2006-2009 are included in this report. To some extent the different authors have written their own contribution in English or translated their own work, or people have been hired for translation. Brian Robins, Professor of Geology at the University of Bergen has translated most of Linda Sæbø and Ingunn Thorseth's work on the geology of Vingen and Hjemmeluft. Most of the remaining report has been translated from Norwegian into English by translator Tim Challman, and later proof read by Jon Brokenbrow. The latter has also proofread the other components of the text. The topic of this report, as with the previous two, is the preservation of rock art, but it is also focused on the management, safeguarding and protection of valuable sources for a better understanding of the rock art and its former meaning. Since the early 1980s, a considerable amount of effort has been invested, under the auspices of the University of Bergen, on finding the causes for the degradation of rock art in the Counties of Hordaland and Sogn og Fjordane, and in the region of Sunnmøre. A number of measures have been taken, such as water drainage, protective covering and direct conservation efforts using both adhesives and cement. To remove lichens, both mechanical and chemical methods have been used. Due to uncertainty concerning the short-term and long-term effects of the methods, as well as the desire to gain more knowledge about the degradation processes, contacts were made in 1995 with various scientific displines, and a pilot investigative project was completed during 1995-1996. Based on the result of the pilot investigation, it was found necessary to implement a more comprehensive and systematic interdisciplinary project, the so-called Vingen project. The interdisciplinary panel comprised representatives from the professional fields of geology, botany, meteorology, microbiology and agricultural studies, who were asked to collaborate with the archaeological and conservation personnel of the University of Bergen. This collaboration began in summer 1997 with a primary focus on the issues associated with the degradation of rock art in Vingen, located in Bremanger municipality, Sogn og Fjordane County. The desire to procure data material of a more universally valid and supra-regional nature, as well as to draw in relevant bases of comparison for both rock art and the environment, led to the World Heritage rock art areas of Hjemmeluft in Alta, Finnmark, also being included as an object of study during the same year.

Based on the results of research from the investigations in Vingen and Hjemmeluft, the following report presents the degradational factors and processes that contribute towards the breakdown or deterioration of rock art. As a part of the process to identify remedial measures to prevent deterioration, selected preservation measures taken to prevent or delay degradation, and thereby preserve the rock art, are reviewed here.

Since issues overlap in the various authors' contributions, the editorial work has been relatively demanding. Another classic problem was that contributors delivered their contributions seriously delayed, and some did not deliver at all.

Bergen 4 October 2010
Trond Klungseth Lødøen

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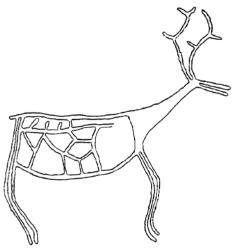


CHAPTER 1

Trond Klungseth Lødøen

SUMMARY

1.1 Introduction

Within the objectives of the Norwegian rock art project initiated by the Directorate for Cultural Heritage for the preservation and documentation of a number of sites, interdisciplinary research into processes that combine to break down rock art panels was carried out in Vingen, Bremanger municipality, and to a lesser extent also associated with the World Heritage rock art area at Hjemmeluft, Alta municipality. The project has been underway since 1997, and was scheduled to last until 2005. In addition to the research on weathering processes, various remedial measures to alleviate or prevent damage to rock art have been implemented and tested. In both Vingen and Hjemmeluft, the species used for rock carvings consists of metasandstone, but in several different states of composition. Both sites are situated near the sea, but in different climatic zones. A comparison of the results from Vingen and Hjemmeluft will make it possible to determine the significance of rock species and climate in the degradation of rock art and how this may affect the choice of preservation measures.

Postglacial chemical degradation has resulted in the rock surfaces in Vingen having developed a superficial porous weathering rind in which the least resistant minerals are entirely (calcite) or partially (chlorite and plagioclase) dissolved. The rock surfaces are as a result very vulnerable and are able to withstand very little further chemical dissolution or mechanical stress before the mineral grains loosen and the rock surfaces crumble (detritus degradation), or the surface cracks and flakes off.

Annual precipitation is considerable (2200–2600 mm), and the climate is relatively mild during winter, with snow cover occurring in only a few short periods. Many seasons with fluctuations between above zero and sub-zero temperatures results in frost erosion of exposed rock surfaces. Changes in the climate during the past 40 years, however, has led to a reduction in the frequency of the freeze-thaw cycle. Covering rock surfaces with 5 cm thick insulated mats serves to significantly moderate the effects of fluctuating temperature throughout the winter. Covering rock with mats, however, may inhibit natural evaporation of moisture, thus causing it to freeze during cold periods and thereby causing frost erosion. Mat coverings are nonetheless thought to be favourable, but preventive water drainage, as well as the choice of cover material, is also important.

Exposed rock surfaces have an average weathering depth of 9 mm, with the exception of rock surfaces in or near the shoreline, where the depth of degradation is only 2.5 mm. Direct exposure to seawater during high tide and incoming waves during gales therefore appears to reduce the chemical rate of degradation significantly, probably because of the high pH-value of seawater and because calcite is closer to equilibrium in seawater than in rainwater. The precipitation in Vingen is also strongly affected by seawater, with a relatively high pH-value and high concentration of sea salts. This very likely has a generally inhibitory effect on chemical degradation. However, salt crystals have not been found in the porous degradation zone, and fracturing due to salt erosion is probably not a significant degradation process in Vingen. This may be due to the large amounts of precipitation in the area. Deeper degradation zones (on the average 15.6 mm) in turf-covered rock surfaces than in exposed surfaces indicate that acids and ligands from the soil accelerate chemical degradation.

In Vingen, untreated, exposed rock surfaces are for the most part covered with lichen vegetation and lichenised fungi are found in great amounts throughout the porous weathering rind. The lichen species *Ophioparma ventosa* is more aggressive in terms of degradation than other species that were examined. Treatment with ethanol in combination with an opaque covering is an effective and gentle method of removing lichens from rock surfaces. The vegetation and cultural landscape in Vingen is maintained by careful management and grazing. On the hillsides, heather and deciduous trees are advancing in the direction of the main area because of decreased grazing. The aggregation of organic materials, changes in vegetation towards more heather and stagnation due to reduced grazing and the overgrowing of drainage ditches are all factors that have contributed to acidification of the soil. Lime treatments to the vegetation surfaces yield an increase in the pH factor and base saturation of the soil, and can reduce the chemical degradation. Sufficient grazing will also be able to prevent the development of thickets and woodland vegetation that otherwise result in the area becoming overgrown, as well as increased fracturing of rock surfaces due to tree root erosion and roots chafing against the stone. Agreements with property owners ensuring future grazing and care of the area are necessary.

In Hjemmeluft, post-glacial weathering has caused the rock surfaces to have a superficial, slightly porous weathering zone, with an average depth of about 4 mm. The weathering zone is generally thinner than in Vingen, since the rock species in Hjemmeluft consists of more resistant minerals. The amounts of precipitation are also less in Alta (400 mm) than in Vingen (2200–2600 mm). The porosity in the weathering zone is generally low and the rock surfaces are therefore less exposed to crumbling. However, as a result of crossing fractures and cracks, there are loose pieces of rock on many surfaces. Accumulated water in the fractures probably causes increased exfoliation of the weathering zone along the fractures, leading to frost weathering in colder periods.

Alta has a climate with both relatively cold winters and warm summer temperatures, and rock surfaces are exposed to greater and more rapid fluctuations in temperature than the rock surfaces in Vingen. The most exposed periods are autumn and spring when there is no snow, so that covering the rock surface with insulation mats has a greater effect during these periods. Diffusion of water beneath the mats results in a large amount of moisture, which will freeze during cold periods. During the last 40 years, there has been a general change towards more unstable weather conditions in the transition between autumn and winter (December), which has led to an increasing number of freeze/thaw episodes.

Due to the climatic conditions in Northern Norway and Alta, the lichen flora at Hjemmeluft is similar to the lichen flora in the mountains further south, which is different from the species found in Vingen. However, the aggressive lichen species *Ophioparma ventosa* is also present in Hjemmeluft.

1.1.1 Participants, disciplines and areas of Responsibility

The project is based on archaeological and conservational issues associated with the preservation of rock art, as well as a pressing need to define the degradation processes that are active and the remedial measures that can be implemented to prevent or limit these processes.

Surveys of the preservation status for Norwegian rock art had already begun by the mid-1970s and continued with varying intensity into the 1980s and early 1990s. In 1995, through the Directorate of Cultural Heritage's *"Plan for Measures to Preserve Rock Art"*, alarming finding was disclosed showing that 92.4% of Norway's rock art sites were in varying degrees of deterioration. The consequence of this was that the Directorate, in 1996, launched a nationwide project to preserve rock art, an initiative that was planned to last until 2005. Later this was prolonged into a more permanent approach

In order to identify the key factors contributing to the degradation of rock art, an interdisciplinary panel was established at the University of Bergen in 1996/1997 comprising researchers from the fields of agricultural studies, botany, geology, meteorology and microbiology in addition to archaeologists. The problem areas are very complex in terms of the scientific fields in question and demanded close collaboration between the researchers in the respective professional fields. Completion of the project, moreover, required a closely integrated cooperation between archaeologists, conservation experts and scientific researchers.

Research in the field of geomicrobiology began at the University of Bergen in the early 1990s and since that time a strong interdisciplinary environment has gradually been built up comprising geologists and microbiologists. In response to an enquiry from Bergen Museum and the former Department of Archaeology, University of Bergen, concerning the degradation of rock art, it was natural that this group of researchers, along with professionals at the Department of Botany researching lichens, became involved in the issues raised. Cooperation with the Department of Botany has also led to a strengthening and expansion of the professional field of geomicrobiology at UiB. With the inclusion of soil specialists and meteorologists, the project has resulted in an integrated collaboration between various disciplines, which in turn has made it possible to investigate complex issues related to the degradation of rock art in a manner that would otherwise have been challenging.

Professor Gro Mandt, of the former Department of Archaeology, UiB, has been responsible for ensuring that archaeological aspects of the project have been given proper attention. Beginning in June 2001, she served as coordinator for the project. From 2003 this grew into cooperation with researcher Trond Klungseth Lødøen from Bergen Museum, taking responsibility for the archaeological aspects, including scientific testing.

Senior engineer Kirsti Hauge Riisøen of the Conservation Department of Bergen Museum was responsible for the professional conservational aspects of the project. Curator Kjartan Gran from Tromsø took part in the development of conservation methods and tests of products from 2003.

Associate Professor Ingunn H. Thorseth from the Department of Geology, UiB, has had primary responsibility for the geological surveys. In addition she served as coordinator for the scientific portion of the project from January 1999 until June 2001. Since June 1999, Linda Sæbø, MSc from the Department of Geology, UiB, has been employed on the project and, since June 2001, been responsible for the geological surveys.

Doctoral fellowship holder Torbjørg Bjelland of the Department of Botany, UiB, has been responsible for the survey and documentation of lichen flora and research associated with lichens, resulting in a D.Sc. thesis.

Researcher Terje Torsvik from the Department of Microbiology, UiB, has been responsible for the microbiological surveys.

Researcher Endre Skaar from the Norwegian Institute for Plant Research/Department of Geophysics, UiB, has been responsible for the meteorological survey program as well as for the analyses of gathered data. In addition, he has served as mentor for Tor de Lange, who has had Vingen as his field of research since 1999, specifically for the collecting of micrometeorological data for his dissertation on meteorology at the Department of Geophysics.

Researcher Samson Øpstad from the Norwegian Institute for Plant Research (now Bioforsk), was responsible for the agriculture-related aspects of the project. Since June 1999, researcher Knut Anders Hovstad, from the same institution, has taken part in the project. During the period of 1996–97, researcher Karl Jan Erstad, at the time associated with the Norwegian Institute for Plant Research, also took part. From 2003 much of this work has been in the hands of Pål Torvaldsen, Bioforsk.

Researcher/Associate Professor Kari Loe Hjelle from Bergen Museum, UiB, has been responsible for pollen analytical investigations in the project.

The farmer with grazing rights at Vingen, Helga Vingelven, has contributed significantly to the conservation of the area through proper grazing, and has also achieved a favourable agro-environmental result. In addition, she has contributed by providing practical assistance, transportation, and has regularly supervised the test field and weather station, as well as collecting water samples for the project. After Helga's death, her brother, Rolf Vingelven, took over the farm and assumed the tasks connected with the Vingen project.

Since 1996, the preservation, documentation and scientific investigations in Vingen have been financed by the Directorate for Cultural Heritage's national rock art budget. Portions of the preventive measures have been financed through the Agricultural Department of the County Governor in Sogn og Fjordane, from the Fureneset professional (Bioforsk) centre and from the Meltzer Fund. The Research Council of Norway (NFR) financed a three-year doctoral fellowship for Torbjørg Bjelland during the period 1999–2001.

1.1.2 Structure of the Report

In the continuation of *Chapter 1,* the objectives and preliminary results for the project are summarized. The primary issue for research is associated with the degradation of rock art in Vingen. In *Chapter 2* the background for the project is reviewed. This includes on the one hand a description of the natural character of the area and a discussion of local property ownership. On the other hand, the discussion encompasses the extent and location of the rock art and other cultural monuments, their datings and explanatory models that have been proposed for the rock art in the area. Additionally, a discussion is included concerning management of the area and the challenges faced.

Rock art in Vingen came to public attention in 1910, and has been the object of scientific documentation since 1913. This work has proceeded intensively up until the present time. Because increasing numbers of carvings have been found, and because many panels and figures have been difficult to see, efforts have been made to improve the systematizing and documentation of the material, including the implementation of a more detailed system of surveying the individual fields and figures. In *Chapter 3* this process is reviewed. In addition, a brief background for the research effort in rock art preservation is given, as well as a description of the state of the rock carvings and preservation measures that have been implemented in Vingen. In *Chapter 4* the rock species in Vingen, the area's climate and the macro- and microvegetation are described. A description is also included here of the cultural landscape and how it has acquired the character that it has today.

Chapter 5 is dedicated to a review of the physical, chemical and biological processes that combine to deteriorate rock art, as well as a description of the methods and measures taken for research into these factors. Through an evaluation of the research methods and specific measures, substantiated and preliminary conclusions are drawn, many of which in turn call for further research. In *Chapter 6* various types of materials and products that have been tested or applied during the course of the project are presented.

Chapter 7 presents some of the archaeological and palaeobotanical results showing the environment and contemporary context of the rock art, as well as the vegetation development from the Mesolithic until today.

Chapter 8 focuses on future management and care of the Vingen site as well as conditions that must be met if there is to be hope of preserving the rock art for future generations. The most important single measure to be taken is sheep and goat grazing, a measure that is not entirely compatible with unrestricted human traffic in the area. The chapter also discusses the problems and challenges faced in terms of documentation and precautions designed to avoid further damage. It is also a fact that the effort in Vingen over the years has substantiated that it is not only rock carvings that constitute the sole cultural material of historical value. Subsoil strata conceal large deposits of archaeological material that comprise important sources for the rock art, and which also require closer attention and protection. Finally, problems associated with protection and public access to cultural monuments are discussed, particularly with regard to Vingen.

Chapter 9 deals with the topic of the World Heritage rock art in Hjemmeluft, Alta, Finnmark. A description is provided of rock species, microvegetation and climate, as well as a specific comparison of these parameters and effects from measures taken with the results of investigations in Vingen.

In *Chapter 10* a summary is given of the objectives set for the project period and a discussion of how future work is proposed to be carried out. A discussion is also included on how future cooperation should be structured, as well as the required competence that must be built up in order to properly maintain and preserve the rock art.

1.2 Aims and approaches for the national rock art project – Objectives of the Directorate for Cultural Heritage

The overall objective of the rock art project initiated by the Directorate for Cultural Heritage was the preservation of 300 sites throughout Norway by the year 2005. In addition, another 200 sites were to be fully documented. The preservation process followed a 4-stage progression documented in accordance with the Directorate's documentation standard (1), the development of a care and maintenance plan (2), and the implementation of necessary measures (3). Upon completion of phase 3, preservation is considered to have been achieved, but maintenance of cultural monuments is regarded as a continual conservation effort, entailing the need for follow-up (4) [Table 1.2.1-1].

Within the framework of the rock art project, competences were also built up at the regional archaeological museums and at the county level in order to ensure high professional quality in the continuing effort. As a component in preservation strategy, one important objective was to acquire knowledge capable of promoting favourable preservation measures, from an archaeological and scientific standpoint, a goal that entails intensive research into the degradation processes and into the effectiveness of measures taken to counter these processes.

Table 1.2.1-1 The Four-phase Process of the Directorate for Cultural Heritage

Preservation Phase	Definition
Phase 1: Documentation	Documentation including assessment of status (archaeological and technical/ scientific documentation, photographic documentation)
Phase 2: Care and Maintenance Plan	The care and maintenance plan is developed. A standardized template is used which provides guidance for long- and short-term measures to be taken, structure for collaboration and formal fiscal responsibility
Phase 3: Measures	Physical measures, when prescribed, are implemented. When phase 3 has been completed, the preservation is considered to be accomplished.
Phase 4: Follow-up	Follow-up, circulation and review of the care and maintenance plan

The overall objective for the project was to identify the significance and interplay of physical, chemical and biological factors that control the degradation of rock art and to devise methods and measures that will serve to preserve it and prevent damage in the future.

Subsidiary Objectives

Factors in and Rates of Degradation

- To document the state of the rock carvings today and compare it with older documentation in order to determine changes over time.
- To examine the status of degradation of the rock species and to determine the significance of various environmental factors in the degradation process.
- To investigate the significance of climate in the degradation process on rock faces.
- To examine the ecology and mechanical/chemical degradation effects associated with selected predominant lichen species.
- To examine changes in vegetation and acidification of the soil.

Measures

- To evaluate the effects of covering rock surfaces.
- To evaluate various methods for the removal of lichen growths and to develop methods to prevent re-growth.
- To evaluate the effects of lime treatments and grazing on the soil, on plant growth and the cultural landscape.
- To evaluate various methods of conservation, materials and products.

1.3 Sites

The on-site studies were mainly carried out in Vingen, Bremanger municipality, in Sogn og Fjordane county. A number of investigations were also conducted in Hjemmeluft, Alta municipality, Finnmark county. In both Vingen and Hjemmeluft, the species used for rock carvings consists of metasandstone, but in several different states of composition. Both sites are located near the coast, but the climates are nonetheless quite different. A comparison of the results from Vingen and Hjemmeluft made it possible to determine the significance of rock species and climate in the degradation of rock art and how this may affect the choice of preservation measures.

1.4 Summary and Conclusions

1.4.1 Vingen, Bremanger municipality

The Rock Carvings

More than 2000 figures carved in stone are spread throughout approximately 300 panels around a small fjord arm, Vingepollen, on the southern side of Nordfjorden's mouth in Sogn og Fjordane county. The carvings are found on large rock surfaces, on boulders and on both embedded and loose stones. They are carved on surfaces that face in all directions, between talus stones, beneath glacial boulders and on the underside of large stones. The extent of damage is dramatic, characterized by the degradation of rock species, incrustation and stagnation as critical characteristics. Some documentation of rock art goes back to the early 1900s and makes it possible to determine the rate of degradation. The diversity of location for the rock art, and thus the high variation in exposure to different degradation factors, makes the area well suited to studies of the deterioration processes.

Rock Species, Climate and Vegetation: Current State

The rock species in Vingen is a Devonian (385 million year-old), medium to fine grained arcosic metasandstone. The sandstone mainly consists of quartz and feldspar minerals. Of the two feldspar types – plagioclase and alkali feldspar – it is normally plagioclase that is predominant. Due to early transformational processes, plagioclase is serisitised (contains small amounts of the mica mineral serisite). The rock species also contains small amounts of muscovite, chlorite, pistacite (?) and traceable amounts of the minerals apatite, zircon, rutile, as well as iron and titanium oxide. Sandstone is mainly cemented by calcite (calcium carbonate). The various layers and lamina in sandstone show variations in both texture (grain volume) and mineral composition, and it is relatively common to confuse the calcite-rich lamina with the more mica-rich lamina that have low amounts of calcite (4.1.1).

Postglacial chemical degradation has led to the rock surfaces in Vingen developing a superficial porous weathering rind of a few millimetres and up to 2–3 cm in thickness. In the degradation zone, various minerals have been dissolved in differing degrees, depending on how resistant they are to chemical degradation. Calcite is the mineral that is least resistant and is entirely dissolved throughout the whole degradation zone. After calcite, the minerals apatite, chlorite and plagioclase feldspar are those that show the highest degree of solubility. In the upper portion of the degradation zone, therefore, apatite and chlorite are frequently wholly dissolved, while plagioclase is partially dissolved and disintegrated because of solubility along serisitized areas. The thickness of the upper zone varies from 0 to 6–7 mm. Uppermost in the degradation zone, muscovite may show early signs of dissolution, with splitting along the cleavage plane. Quartz and potassium feldspar, on the other hand, are highly resistant minerals and show very little indication of dissolution (4.1.2). The chemical dissolution of minerals has caused the rock surfaces to become very vulnerable and non-resistant to further chemical degradation or mechanical stress, the result of which would be the loosening of bonds between mineral grains and a crumbling of portions of the surface, or an exfoliation of the surface layers. In the long term, this would have serious consequences, since the rock carvings are often very shallow in depth.

The annual precipitation in the area's lowlands is 2200–2600 mm. The greatest amount of precipitation normally comes with southerly and southwesterly winds during autumn and winter (4.2.3). The climatic temperature is relatively mild during winter, and near the sea there is normally snow cover only during a few brief periods. The greatest number of days with temperature fluctuations between plus and sub-zero are in January and February, and the typical length of periods of continuous cold is from 5 to 7 days (4.2.1). Multiple freeze/thaw cycles and large amounts of precipitation without insulating snow cover make frost erosion an important degradation process for exposed rock panels.

Wind directions on the coast during the winter season are between the south and west, and in summer the wind often comes from the north. The most common wind direction at ground level, then, is into or out of the fjord (Frøysjøen). Since Vingen is located towards steep, tall mountainsides, the local wind pattern is highly variable, and strong squalls (whirlwinds) are frequently observed, bringing sea spray in across the shoreline (4.2.2). It has therefore been a concern that salt erosion, due to crystallization of salt in the fissures and pores of the rock surfaces, contributes to the degradation of the rock carvings.

Changes in the climate over the past 40 years, however, have led to a reduction in the frequency of sub-zero days in Vingen. For the Ytterøyane reference station (DNMI), the mean average number of days with an observed minimum temperature below 0°C in January has been reduced from 15 to 5. Correspondingly, the average number of days with temperature fluctuations between plus and sub-zero degrees has been reduced as a mean average for January from 11 to 4 days. Changes in the amount of precipitation and number of precipitation days during this period have been relatively minor (4.2.1).

The closest industrial plant with pollutant emissions into the air is the Bremanger smelting plant in Svelgen (700–800 t/yr SO_2), in the air corridor approximately 10 km south of Vingen. The prevailing wind directions normally carry the pollutants outside of the Vingen area, and the emissions will therefore have an impact on air and precipitation quality in this area only during relatively few and exceptional weather situations (4.2.3).

Exposed, untreated rock surfaces are largely covered with lichen vegetation. The exceptions are surfaces that have been recently exposed after covering or exfoliation, surfaces protected from exposure to light, certain surfaces exposed to large amounts of sea spray and surfaces that have been treated or that lie in water courses. Approximately 90 lichen species have been observed on the rock carving panels in Vingen, of which 60 are crustose lichens (4.4.1.2).

Bare surfaces are quickly overgrown with new lichen. It is often pioneer species that begin to establish themselves, but there are also species spread from the surrounding surfaces that are able to establish themselves quickly on these bare surfaces (4.4.1.2). The growth of lichens is a problem both for the documentation of the rock carvings and for making the sites accessible to the general public. Removal of lichen has shown that certain lichen species are also instrumental in the degradation of the rock surface beneath them.

Exposed, untreated rock surfaces with negligible lichen cover are often overgrown with algae and cyanobacteria (blue-green algae). In water courses, these microorganisms form a reddish-brown or dun-coloured coating. A very dark coating is due to a high percentage of cyanobacteria content (point 4.4.1.5). Surface coatings of this kind frequently make it difficult to see the carvings. However, the coatings contain no mineral deposits and in this respect represent no risk to preservation of the carvings.

Lichen-covered surfaces have an abundance of fungi, but also bacteria and algae, throughout the entire porous weathering rind. Fungal hyphae constitute more than 90% of the total biomass in the weathering rind (5.4.3). On surfaces lacking significant lichens, it is usual to find a green layer of algae in the uppermost 2-3 mm of the porous weathering rind. Rock surfaces covered with turf have few microbes in the weathering rind, with the exception of small amounts of fungal hyphae (4.4.1.5). A large amount of biomass in the pores of the weathering rind is in all likelihood detrimental to the consolidation and impregnation of the rock.

The vegetation and cultural landscape in Vingen is maintained by careful management and grazing. Most of the grasslands contain a moderate number of species, and their status is good, with the exception of some relatively small very wet areas. On the hillsides above, heather and deciduous forests are increasing in growth as a result of reduced grazing (4.3 and 4.4). The soil in the previous pasturelands in Vingen is light brown in colour and contains a large amount of organic material. There is great variation in the soil and the pH levels in the upper stratum vary from satisfactory (5.9) to low (4.2) (5.3.1.3).

At Vingeneset the vegetation is dominated by heather heathland, characteristic of poor land management and lack of grazing. Portions of the area are also overgrown by thickets and woods. Today there are only minor areas that are dominated by grassy vegetation, despite earlier extensive grazing and haymaking (4.3. and 4.4). In order to improve grazing conditions, some of the woodland was removed in 1996, and some was sprayed with biocides in 1998, but conditions are still poor in these areas. The examined area at Vingeneset has organic soil of a raw-humus nature, and both the base saturation and pH levels (4.1) are low (5.3.1.3).

Measures such as clearance of woods and fencing at Vingeneset are decisive factors for better grazing conditions, which in turn will be conducive to the transition from the aging heather vegetation that is prevalent today to more grass-dominated vegetation. If these measures are not implemented, the rock art will be corroded by both increased chemical degradation and increased root erosion and root chafing, since thicket and tree vegetation will be able to establish itself in the area.

Factors in and Rates of Degradation

The state of degradation of the stone surfaces is controlled by variations in the texture and mineral composition of the rock species (4.1.2) as well as by variations in climate (5).

Variations in the texture and mineral composition between the strata and lamina of the species results in variation of both the degradation zone‘s depth and porosity. Porosity in the lower portion of the degradation zone normally varies between 5–12% and is due solely to dissolution of calcite. In places where chlorite and plagioclase are also dissolved in the upper portion of the degradation zone, porosity is normally 15–20%, but in certain places may be over 30%. Rock panels with high porosity will be highly exposed to crumbling, especially in places where the plagioclase content is high. Because muscovite is readily split up along the mineral's cleavage plane, rock surfaces that are rich in muscovite will be subject to exfoliation of mica from the surface, even though porosity in such strata is relatively low (4.1.2).

Wherever rock surfaces are parallel with the sandstone's stratification (surfaces facing southwest), the calcite-poor strata and lamina in the upper portion of the degradation zone may have a lower porosity than the deeper-lying, calcite-rich lamina. This may bring about slow drying after precipitation and increase the risk of frost erosion during the winter season. Likewise, the mica-rich strata that are parallel with the rock surface will frequently develop fragile zones. Physical stress, for example during frost erosion or biological growth, will easily lead to fissures and exfoliation along these fragile zones. (4.1.2).

On stone surfaces facing north, the fragile zones that are parallel with stratification are not parallel with the surface and therefore are not as vulnerable to exfoliation. Wherever exfoliation does in fact occur, the fissured surface is often very uneven. This is due both to varying porosity and degradation depth in the individual strata and lamina (4.1.2).

Temperature measurements taken on the stone surfaces show that they are often exposed to relatively rapid and major fluctuations in temperature. An uncovered surface will have a relatively low temperature during long periods of the winter season, for example several sub-zero degrees even though the air temperature is measured at above freezing. These rock surfaces are exposed to many more freeze/thaw cycles, and therefore frost erosion, than would be expected from measurements taken of air temperature (5.1.1). The winters during the past 40 years have been much milder in Western Norway, and this has led to fewer sub-zero days and fewer days with freeze/thaw incidence in Vingen. Frost erosion may therefore have subsided somewhat in scope (4.2.1).

If exposed to strong sunlight, and uncovered, dry stone surface may be subject to a more rapid increase in temperature and reach a higher temperature than the air surrounding it. The surface can therefore be exposed to large temperature fluctuations over a relatively short period of time. This may lead to an accrual of tension that can result in fissuring and exfoliation of the surface (5.1.1). The significance of this process, however, is not substantiated.

The large amounts of precipitation in Vingen are conducive to chemical degradation. On exposed rock surfaces, the average depth for calcite dissolution is 9 mm (total degradation depth) and for chlorite and plagioclase dissolution 1.5 mm. This yields a depth of dissolution of 0.9 μm per year for calcite and 0.15 μm per year for chlorite throughout the postglacial era (10 000 years). Stone surfaces that are located on or near the shoreline, however, have a degradation depth of only 2.5 mm, where only the mineral calcite is dissolved. Direct exposure to sea water and sea spray therefore appears to reduce the rate of chemical degradation considerably, probably due to the high pH value in seawater and because of the fact that calcite is closer to equilibrium in saltwater. Chemical analyses of precipitation in Vingen also show that it is strongly affected by seawater with a relatively high pH value and a high concentration of sea salts. It is probable that this has a generally inhibitory effect on chemical degradation in the entire area (5.2).

Since salt crystals have not been found in the porous degradation zone, salt erosion is probably not a significant degradation process in Vingen. This may be due to the large amounts of precipitation in the area. (5.1.3.3).

The aggregation of organic materials, changes in vegetation towards more heather and stagnation due to reduced grazing and the overgrowing of drainage ditches are all factors that have contributed to acidification of the soil. Heather and other plant species adapted to acid soil can, through discharges of weak acids, intensify the tendency towards acidification of the soil. The pH level at Vingeneset and several other places in Vingen are currently low (4.2). The organic acids also function as ligands (forming complexes with various chemical bonds) that facilitate access to nutrients. Both acid environments and ligands are known to increase the dissolution rate of most minerals (5.3.).

Deeper degradation zones (on average 15.6 mm) in turf-covered rock surfaces than in exposed surfaces indicate that acids and ligands from the soil accelerate chemical degradation. Many exposed stone surfaces will also react with leachate from overlying turf and soil. Surfaces that have been covered with turf for a long time will become highly non-resistant to physical processes when exposed (5.2.4).

Based on observations in the field, five different lichen species were chosen for systematic examination and identification of possible degradation effects on stone species. The results indicate that the species *Ophioparma ventosa* is markedly more aggressive in terms of degradation than the species *Pertusaria corallina*, *Ochrolechia tartarea, Fuscidea cyathoides* and *Lecidea fuscoarta*, which are more difficult to distinguish between (5.2.8). Production of various lichen compounds as well as various productions of oxalic acid in the fungal component may be possible causes for differences in the degradation effect of these lichen species. *O. ventosa* contains the highest number of lichen compounds and appears to produce the most oxalic acid. Another reason for the difficulty in distinguishing between the degradation effects of the various species may be that there are several different fungal species in the weathering rind under each specific lichen species. For *O. ventosa*, DNA analyses show that the majority of hyphae in the weathering rind belong to this lichen and that it is therefore probable that it is the hyphae of this species that have the greatest degradation impact. For the time being, analyses of this type have not been carried out for the other species (5.3).

Since the biological activity inside the degraded rock species is generally high for all of the studied species, it is likely that they contribute to both physical disintegration and chemical dissolution of the rock species. Growth of hyphae in the degradation zone can lead to separation of the mineral grains due to them being raised off the rock surface and infiltrated into the lichen thallus. These mineral grains will then fall off when the lichens die or are removed from the rock surface (crumbling) and a new surface will be exposed. As a new thallus is established, the hyphae in the weathering rind contribute to further physical disintegration and chemical dissolution.

The reason why the marebek (*Verrucaria maura*) species that grow along the shoreline do not appear to affect degradation to any degree may be that they do not produce lichen compounds. In addition, seawater will have a neutralizing effect on any potential oxalic acid production. These lichen species as a whole may have a preservational effect, since the shoreline surfaces are extensively exposed to wave abrasion.

Tests of protection methods?

One effective measure to reduce the number of freeze/thaw cycles, and therefore frost erosion, is to cover the rock panels with an insulating material. Since turf appears to exacerbate chemical degradation, and since it is also inadvisable to disturb it to any extent because of archaeological materials concealed in sub-soil strata, it is desirable to cover the rock panels with another type of insulating material. As a result, insulating materials such as rock wool or stone wool have been used in covering tests. In order to prevent water penetration, the mats were in turn covered with plastic and a tarpaulin (5.1.4).

Test results show that 5-cm thick insulated mats significantly moderate the effects of fluctuating temperature throughout the winter. Further increases in mat thickness of up to 15 cm provide little additional effect. In the course of more long-lasting cold periods with a typical duration of one week and an air temperature of minus 2–3 degrees Celcius, a covered rock surface will fall to the same minimum temperature as the air, with a time lag interval of 1–2 days.

Covering the rocks with plastic-covered mats can prevent natural drying of the stone surface. Moisture beneath the mats results from percolating water and precipitation, or by diffusion of water vapour between the mats and the stone surface. During cold spells this water may freeze and cause frost erosion. Covering with mats is nonetheless very likely beneficial since the number of freeze/thaw cycles are significantly reduced by comparison with uncovered rock surfaces.

These types of mats are easy to apply in terms of both placement and location for subsequent inspection. The plastic covers, however, are not lastingly durable, and the mats are therefore most suitable for short-term covering. For this reason, other more durable types of mats made of polypropylene are being tested.

Wherever it is necessary to remove lichens, gentle methods for doing this should be used. Mechanical methods will easily damage the porous stone surfaces and should be avoided. It must be ensured that chemical methods will not have a corrosive effect on the minerals in the rock species or that the present a toxic risk to people and animals. It was therefore decided to test the effect of Quaternary ammonium salts (Pingo), a biocide, and of ethanol, since neither of these are known to aggressively affect rock species and are relatively harmless and easy to work with. Since light is essential for the growth of lichen photobions (algae component), covering with an opaque material results in elimination of the lichen without using chemicals. Since turf may exacerbate the chemical dissolution of minerals, it was chosen to cover the rock with diffusion-open plastic, a method that is simple to apply. Quaternary ammonium salts (Pingo), ethanol and covering have all been tested both individually and in combination.

Results from the tests show that treatment with ethanol and covering using opaque materials is the most rapid method for removing lichens from stone surfaces. The lichens were dead within one year and gradually loosened from the surface. Without application of cover material, the ethanol treatments would have to be repeated several times before all of the lichen species would die. In certain cases, Quaternary ammonium salts (Pingo) may be just as effective as ethanol under plastic covering, but Quaternary ammonium salts (Pingo) induces increased algae growth if the field is again exposed to light. Tests show that merely covering the rock with opaque material entails a wait of two years before all lichens are dead. Non-lichen inducing fungi, beetles and mica contribute to the breakdown of biomass in the covered test panels. Dead biomass is broken down more quickly by the presence of water (5.4.4).

Even though biomass is removed from the surface, there may still be remaining fungal hyphae in the pores of the degradation zone. The appearance of healthy hyphae in the degradation zone indicates that some are still alive. If this is the case, the lichens will very likely re-establish themselves within a short period of time if the panel remains uncovered. The stone surfaces should therefore remain covered for several years or else be treated again with ethanol after the surface is lichen-free.

A biofilm of cyanobacteria and algae developed in percolating water is relatively easy to remove using ethanol. One year after treatment with ethanol, most of the film is gone and the rock surface has become lighter in colour, often lighter than untreated surfaces outside of the treatment test area. This is because there is generally a large amount of microbial growth in the rock surface's pores, even in the absence of lichen growth.

Proper grazing will prevent the expanded growth of thicket and forest vegetation, which in turn can lead to overgrowth and accelerated degradation of the rock surfaces because of root erosion. Negotiations are currently underway between various authorities and the new grazing rights owner with the aim of ensuring future grazing management and care of the area (8.5.3.2). Efforts here also been made to erect a fence at Vingeneset that will be able to contribute to controlling vegetation through grazing (8.2.2).

Lime treatments on the surface of vegetation have resulted in a rise in the pH value of the soil, a condition that can reduce chemical degradation. Lime treatments can also help establish grass and herb-dominated vegetation, and in combination with grazing prevent the aggregation of organic materials and pollution of the soil. At Vingeneset, where the pH and base saturation levels are particularly low, larger amounts of lime must be applied than in the primary area at Vingen. The effect of raw phosphate is somewhat uncertain, but will probably induce a slight increase in plant growth in Vingen and a higher increase at Vingeneset. The application of phosphates, however, may have an extremely negative consequence on archaeological sources in the subsoil, since the current phosphate content can reveal much about earlier human activity in the area. Measures that entail application of phosphates should therefore be specially scrutinized for each particular area subsection (5.3.1.3).

Reopening old trenches and stream courses has resulted in the drainage of areas that were stagnating and becoming waterlogged. This was also problematic, since the subsoil contains archaeological artefacts (7.1). However, it is an indisputable fact that better drainage in combination with mowing has led to these areas being grazed to a greater extent than before.

1.4.2 The world Heritage area of Hjemmeluft, Alta municipality

Nearly 2000 carved figures are spread throughout 42 sites west of Alta centre, at the head of Altafjord in Finnmark county. The petroglyphs are found primarily on coastal rocks located at various heights above the present sea level. A particular responsibility for the rock art sites in Hjemmeluft, now on UNESCO's list of irreplaceable monuments, prompted examination of the degradation processes here as well. Hjemmeluft, with its geographical location and sandstone bedrock, also offered an interesting basis for comparison with Vingen. The extent of damage to the rock art in Hjemmeluft is slight by comparison with Vingen, but there are notable cases of exfoliation and root erosion, and overgrowth by vegetation is advancing.

The rock species at Hjemmeluft is a precambic fine-grained metasandstone with arcosic wacke composition. Sandstone comprises mainly quartzites, feldspars, serisitized feldspars, muscovites, as well as traceable amounts of amphibole, apatite and ilmenite. A number of fine-grained rock species fragments, primarily of quartzite composition, are also found here. Fine-grained serisitized muscovite constitutes the main matrix between the remaining mineral grains, but in places one also finds dolomite cement (9.3.1).

Postglacial chemical degradation has resulted in the rock surfaces in Hjemmeluft having developed a superficial porous degradation zone, light grey in colour and with an average thickness of approximately 4 mm. It is primarily the dissolution of serisitized plagioclase that creates porosity. In places where the rock species also contains dolomite (Ca-Mg carbonate), the degradation zone is somewhat deeper (9.3.2). A very thin degradation zone on exposed rock surfaces along the shoreline is indicative of the fact that seawater reduces the rate of chemical degradation (9.3.2). Penetrating, crossing fractures and fissures have resulted in many rock surfaces having loose pieces of rock. Increased exfoliation along these fractures is probably caused by the accumulation of water in the cracks and frost erosion (9.3.2).

The area has a climate with both relatively cold winters and warm summer temperatures. The mean annual precipitation 400 mm and precipitation is evenly distributed throughout the year. Although amounts of precipitation are relatively small due to the stable, cold winter climate, the site area will often have a stable, insulating snow cover throughout most of the winter, from December until April. During the transitions from autumn to winter and from winter to spring, frequent plus-to-subzero fluctuations in temperature can occur (9.5.1).

Rock surfaces are exposed to large and rapid fluctuations in temperature. The most vulnerable periods are in autumn and spring when there is no permanent snow cover and often fluctuations between freezing and thawing. During the last 40 years, there has been a general tendency towards more unstable weather conditions in the transition between autumn and winter (December), which has in turn led to an increasing number of freeze/thaw cycles (9.5.2).

Covering rock surfaces with insulating mats is most effective in autumn and spring, which are the periods lacking permanent snow cover. The thickness of the mats appears to be of negligible importance. Periods in which there is movement of water vapour (diffusion) on the underside of the mats results in a large amount of moisture, which will freeze during cold periods (9.5.2).

The climatic conditions in the area result in many similarities between the lichen flora in Hjemmeluft and the lichen flora found in mountainous areas (9.4). The weathering rind is more normally beneath growths of *Ophioparma ventosa* than beneath other lichen species that were examined (9.4).

1.4.3 Comparison of Vingen and Hjemmeluft

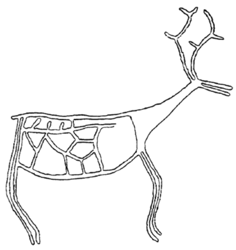
Vingen is located in a coastal climate area, with mild winters and chilly summers. The climate in Alta is more characteristic of the inland, with cold winters and relatively warm summer temperatures. Alta normally has only 15–20% of the amount of precipitation documented in the Vingen area. In Alta there is usually a permanent insulating snow cover during the period from December to April. In Vingen, on the other hand, there are few days with snow cover throughout the winter season. During periods with varying snow cover in November and December, the rock surfaces in Alta are exposed to more frequent, much greater and more rapid fluctuations in temperature than the surfaces in Vingen.

Although the rock species in both Vingen and Hjemmeluft are sandstone, their mineral composition varies quite considerably. While the sandstone in Vingen is primarily cemented by easily soluble carbonate (calcite), carbonates (dolomite) have been observed only occasionally in rock species from Hjemmeluft. In Vingen the rock species contain, in addition, iron-rich chlorites, which are relatively rapidly soluble, and also have a high content of serisitized feldspar. The rock species in Hjemmeluft also contain significant amounts of serisitized feldspar, but they are generally lacking in chlorite. In Vingen, the amount of precipitation is much higher than that of Hjemmeluft. A larger proportion of the minerals in the Vingen rock species will therefore be dissolved more rapidly in the degradation zone, and therefore more deeply and with a generally higher porosity than in Hjemmeluft.

In Vingen, the exposed rock surfaces are threatened by both crumbling and exfoliation. In Hjemmeluft, crumbling is a minor problem for the time being, but exfoliation appears to be a more prevailing process. The cause for this is very likely frost erosion as a result of a large number of temperature fluctuations around freezing point and in periods when there is no permanent snow cover during autumn and spring. Seawater appears to have diminished chemical degradation of rock surfaces near the shoreline in both Vingen and Hjemmeluft.

Climatic differences are the primary reason for the generally major variation between lichen flora in Vingen and that of Hjemmeluft. There are relatively higher occurrences of leafy lichens on the rock surfaces in Hjemmeluft than in Vingen. The lichen species *Ophioparma ventosa* is common to both localities. Lichen species appear to accelerate degradation in both places.

Tests by covering rock surfaces with insulating mats reveal that episodes of freezing and thawing are significantly reduced for surfaces covered by mats. In Alta, mat covers will first and foremost have the greatest impact in countering major, rapid temperature fluctuations during the spring thaw and during autumn/winter before the snow cover becomes permanent. After the snow cover is established, the mats have no extra effect on temperature. In Vingen there are normally only a few, brief periods of snow cover. Therefore, the use of mat covers here will reduce temperature variations in the stone surfaces throughout the winter season.



CHAPTER 2

Trond Klungseth Lødøen and Gro Mandt

BACKGROUND

2.1. Presentation of rock art in Norway – a research history.

The fact that rock art is a particularly vulnerable cultural artefact was already acknowledged by Scandinavian researchers in the early 1900s. Awareness of this fact grew parallel with, and as a result of, the comprehensive and increasingly more exhaustive documentation process that was carried out during the decades prior to and after the turn of the previous century. The first researcher to write about preservation matters was Lauritz Baltzer, who spent a number of years towards the end of the 1880s documenting the rock carvings of Bohuslän, Sweden (Baltzer 1911). Both Gustaf Hallström and Johs. Bøe, who documented the carvings in Vingen during 1913–17 and the 1920s, respectively, noted that many figures were seriously damaged through degradation and exfoliation (Bøe 1932, Hallström 1938). In the series of Norwegian treatises on rock carvings during the 1930s, mention was made that previously documented sites were so overgrown that they became difficult to locate again in the terrain, as well as the fact that a number of figures had deteriorated to the point of oblivion. Moreover, many of the sites of rock carvings were either damaged or ruined because visitors had either painted or marred the figures, and in some cases had scratched in names or dates around them (Engelstad 1934; Fett & Fett 1941; Gjessing 1932, 1936, 1939).

A measure of the extent of degradation was obtained when Anders Hagen carried out a new examination in the 1960s of the Ausevik carvings in Flora municipality in Sogn og Fjordane (Hagen 1969). The site had been documented by Johs. Bøe in the 1930s, and by comparing tracings and photographs from the first examination, it could be documented that a number of figures had been seriously damaged or had become totally imperceptible over the course of these three decades.

An initial survey of the state of Norwegian rock art began in the mid 1970s, partly funded by the Arts Council of Norway and partly by the Ministry of the Environment. A national group headed by Kristen Michelsen of the former Historical Museum of Bergen[1] prepared a report on the damage as well as suggestions for measures to be taken in order to preserve the rock art (Mandt & Michelsen 1981). The report concluded that the state of the rock art throughout the country was critical, and that a number of measures needed to be implemented in order to save the most exposed sites for posterity. A committee appointed by the Directorate for Cultural Heritage in 1991 came to the same conclusion and emphasized in their recommendation titled "*Bergkunst – kulturskatt i krise*" [Rock Art – Cultural Treasure in Crisis], that preservation of rock art was an urgent priority and a national task (Dahlin 1991). The poor condition of the rock art was substantiated by the data presented in the Directorate for Cultural Heritage's "*Plan for Measures to be Taken to Preserve Rock Art*". The report stated that 92.4% of the country's rock art sites were damaged to a greater or lesser extent (Directorate for Cultural Heritage 1995). This in turn led to the Directorate placing preservation issues on the archaeological agenda, with financial support from the Ministry of the Environment, for a nationwide project to preserve rock art, a project that began in 1996 and was planned to last until 2005 (Directorate for Cultural Heritage 2000).

Since the mid-1970s, the efforts to preserve western Norwegian rock art have been multi-disciplinary and have been carried out in close collaboration between experts in the fields of archaeology and conservation from the former Historical Museum of Bergen, now known as the Department of Archaeology and the Bergen

1 From its foundation in 1825 and up until the establishment of the University of Bergen in 1948, the institution was called Bergens Museum and included cultural and natural history. As of 1948, archaeology, ethnography and art history were gathered under the title "Historical Museum", and in 1995 the umbrella organization Bergen Museum was created, comprising both a cultural history and a natural history section.

Museum (Mandt *et al.* 1992; Michelsen 1992). In the mid-1990s, however, the need arose for increased interdisciplinary collaboration in the effort to preserve western Norwegian rock art. The degree of damage to the rock art in the area for which Bergen Museum is responsible is extensive – calculated at 96% in Sogn og Fjordane and 64.5% in Hordaland (Directorate for Cultural Heritage 1995).

In order to acquire better knowledge of the factors involved in the degradation of rock art, and to possibly discern potential key factors in the degradation process, an interdisciplinary project was established at the University of Bergen in 1996/1997, comprising researchers in the fields of agricultural studies, botany, geology, meteorology and microbiology. The Vingen rock carving site in Bremanger municipality, Sogn og Fjordane, was chosen as an area for analysis. This is partly due to the size of the site (more than 2000 figures), and partly due to the dramatic extent of damage owing to many various types of preservation challenges that are present. These include, among others, the poor condition of the rock art, various lichen species' effect on rock surfaces, overgrowth and changes in the vegetation, stagnation and lack of care for the cultural landscape, the effect of continually increasing tourist traffic in the area coupled with a reduction in proper grazing management.

The scientific project, the so-called "Vingen Project", which was included in the National Rock Art Project, involved close cooperation between archaeological and preservation personnel, and was based on the questions and issues generated through many years of preservation efforts in the field and in the laboratory. In order to obtain more universally valid results, a decision was also taken to conduct a number of examinations in Hjemmeluft, Alta municipality, where the rock carvings are of the same type as in Vingen. Several members of the scientific team also participated in the joint Swedish-Norwegian Interreg II project – *Helleristninger i Grensebygd* during 1998–1999.

2.2 Vingen – "… a colossal natural museum for rock carvings" …

The rock carvings in Vingen became public knowledge thanks to a brief article that appeared in the periodical *Oldtiden* in 1912, written by barrister Kristian Bing from Bergen. During an Easter holiday in Nordfjord a couple of years previously, he had heard from local residents that some drawings of animals had been seen in Vingen. Bing was an enthusiastic amateur archaeologist, and once he had seen the site, he quickly concluded that he was in the presence of "… *a colossal natural museum for rock carvings!*" (Bing 1912:36). During Bing's time approximately 100 carved figures were known to exist. But in conjunction with a series of scientific examinations of the sites, not to mention the interest shown in the rock carvings over the years by the families in Vingen and Vingelven, by the end of the 1900s the number had increased to more than 2000. This makes Vingen the largest rock carving site in Southern Norway. The combination of rock carvings, other archaeological cultural remnants, vestiges of culture in the modern era and its location in a uniquely dramatic cultural landscape, makes Vingen a prime example of an area that has been in more or less continual human use for several thousands of years.

2.2.1 Description of the area and the Cultural Landscape

Vingen is located on a small fjord inlet in the innermost recesses of Frøysjøen in Bremanger municipality, north of the municipal capital of Svelgen and southeast of Måløy. Approximately four kilometres northwest of Vingen, on the eastern side of Bremangerlandet, is the towering and majestic Hornelen, which stands as a conspicuous mountain landmark along the main sailing route. With its 860-metre-tall mountain wall jutting vertically out of the sea, it is profiled as Northern Europe's tallest coastal cliff (Ålfot Glacier touring map 1991).

The small and narrow Vingepollen fjord is about one kilometre long and a couple of hundred metres wide and is surrounded by steep 800–900 metre-high mountain inclines. Innermost in the fjord basin, the Vingen falls flow down the precipitous mountainside from their source in Lake Vingen, 420 m.a.s.l. To the north is Tussur Mountain, a dark and steep cliff wall rising directly out of the sea and extending to the westernmost point of the lower terrain at Vingeneset. On the southern side of the fjord basin, a narrow strip of land stretches from the inner basin westwards to the expansive and steep Vehammar mountain ridge located along the mouth of the fjord. Further to the west, towards neighbouring Vingelven, the terrain is steep and rocky and not easily accessed. The landscape of Vingen is characterized by long parallel ridges running east-west, varied by craggy knolls and grassy and bog like areas. Large numbers of boulders and stones of various sizes lying along the foot of the mountain and across the flatter areas – and an extensive section of scree dotted with huge boulders – are the result of both landslides and erratic glacial blocks from the Late Ice Age. In one flat section near the mouth of the fjord basin, there is a small, shallow lake: Vatnet. It is fed by a larger lake higher up in the mountains – Middagsvatnet – but after regulation of the Vingen watercourse (see 2.2.2) water supply is sporadic, and during long periods with little precipitation, Vatnet dries up entirely.

Vingen has been permanently settled from the mid-1600s up until 1936[2], when the area became depopulated. Buildings and homestead sites that belonged to the original Vingen dwellers are located on the shoreline below the large scree area easternmost on the strip of land located on the southern side of Vingepollen. Building foundations, formerly cultivated terraces, stone walls, rock piles and old drainage ditches echo the western Norwegian culture of the past 250 years, when existence was based on maximal exploitation of scarce resources through a combination of fishing and marginal farming. The landscape bears traces of early agriculture, with signs of land clearing, cultivation and early harvests, as well as traces of modern farming in the form of grazing. Several grassy sections – which bear the names Storåkeren, Teigen and Bakkane – show evidence of early cultivation (Fig. 2.2.1-1 and 2) (cf. 4.4.1).

Bøe comments that a large number of the stones in Vatnet are stones from these grounds that were earlier cleared for cultivation of grassy pastureland (Bøe 1932:18). The soil in Vingen is shallow and oligotrophic, and arable land was so scarce that the fishermen-farmers had to add topsoil to embedded stone in order to expand the area for cultivation (Vanberg 1988). One vestige of these so-called ”Vingen-meadows“ is found in the name of one of the rocks inscribed with carvings – ”Kålrabisteinen“ [The Turnip Stone] – in an area where turnips were grown long after the stone had been inscribed with carved figures.

There are only a few modern buildings in Vingen. On the site where earlier Vingen dwellings are located, there are two small cabins, one of them built on the foundation of the old living quarters (Fig. 2.2.1-3). There are also two boatsheds, one of which has been adapted as a field station for the Bergen Museum (”Naustbua”). Further to the west, near the quay, the county governor's office in Sogn og Fjordane built quarters for attendants assigned to supervise landscape conservation in the area; it is currently used for the Bergkunst project (“Vingebu”).

2.2.2 Description of Ownership

When Bing came to Vingen in 1910, the homestead was run as a typical combination holding based on fishing and farming – the dual activities that had long been the very basis of subsistence along the coast. Access to the abundant herring shoals was the reason why people had settled at Vingen in the mid-1600s. In the 1870s, catches were sparse, and this led to crisis and poverty for the people of Vingen. The local population was in debt to local merchants, and many were forced to abandon their properties (Vanberg 1988). In Bing's time Vingen was run by Thue Gullaksen Vingen (Fig. 2.2.2-1). He had 15 children and therefore needed all the land that he could get in order to support his family.

Bing's interests in Vingen were not only limited to the rock carvings. At the time, there were structural changes in Norwegian society, including increased industrialisation and growth. This development was made possible by the advent of water power, and all around the community clusters – often in the steepest, most remotely located areas with tall waterfalls as landmarks – came many speculators interested in investing in hydropower. Bing considered the Vinge Falls and saw the potential for developing the vast water power resources in the mountains between Ålfoten and Vingen. In 1912 he bought the two farms along with their waterfall rights for NOK 4,500, which must have been an enormous sum for Thue G. Vingen, who had purchased Vingen for NOK 600 in 1890. Already in 1916, Bing resold his rights to the waterfalls to shipper H. Kuhnle in Bergen for a greatly increased profit: NOK 50,000 (Vanberg 1988).

Hydropower was not exploited, however, until Vingen was bought in 1964 by Elkem-Spigerverket a/s, Bremanger smelting plant, which was – and is still today – a fundamental company in the municipal centre of Svelgen. The original plans for development of the Vingen watercourse involved building the power station

2 Thue Gullaksen Vingen moved from Vingen to Nesje in Bremanger in 1933 (Vamberg 1988). However, one of his daughters, Inga, and her family ran the Vingen farm up until 1936, when they relocated to Nygård in Skatestraumen (oral account of Helga Vingelven).

Fig. 2.2.1-1. *Vingen in 1913. Among the grassy areas, there are patches of land used for growing potatoes and grain (photo: Hallström). The arable patches have deeper soil than much of the rest of the area, and were tilled on a nearly annual basis.*

Fig. 2.2.1-2. *Haydrying racks were used to dry the harvested grass. (Photo: G. Hallström)*

Fig. 2.2.1-3. *a) the homestead in 1913 (photo: Hallström). b) The buildings as they appear today (part of Naustbua can be seen to the right). (Photo: G. Mandt)*

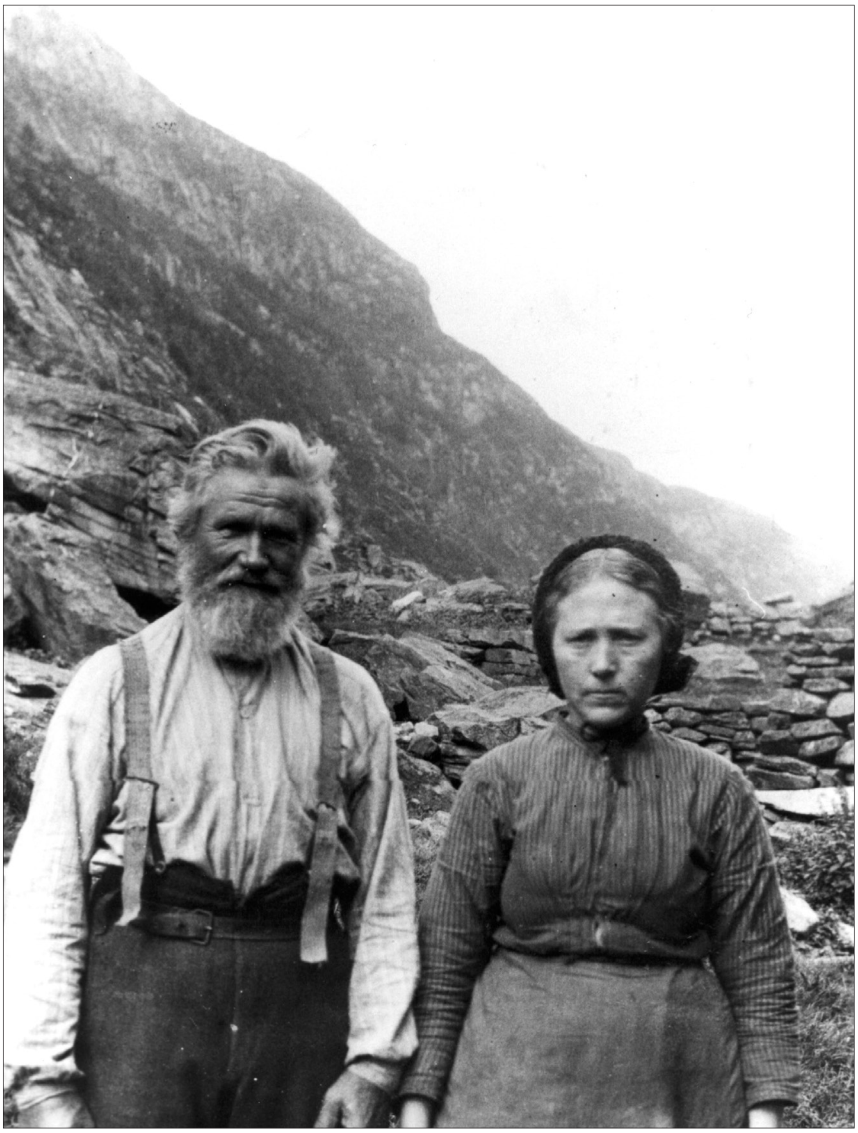


Fig. 2.2.2-1. *Thue Gullaksen Vingen and his wife Johanne in 1913 (photo: Hallström).*

in Vingen itself, adjoining the Vingen Falls. When the watercourse was expanded in the 1960s in order to supply electrical power for the energy-demanding ferrocilicum industry in Svelgen, however, it was no longer an option to expand in Vingen – a fortunate circumstance in terms of the rock carvings.

When Bing bought Vingen, Thue had an obligation to provide tenancy for one retired man. In order to avoid having to assume the custodial tenancy, Bing reached an oral agreement to the effect that Thue's son, who owned the neighbouring Vingelven property, would take over the tenancy obligation in exchange for Thue being able to continue to farm, until such time that a power station was built in Vingen (Helga Vingelven, oral account). This agreement was extended also after Kuhnle had purchased Vingen, and the Vingelven farm has had the grazing rights in Vingen ever since that time.

When Bing sold Vingen to Kuhnle, two plots located farther west in the area – Vingeneset and the area around Vehammaren – were exempted, partly because they were not adjacent to the falls and so were unimportant in terms of hydropower, and partly because there were many rock carvings there. In 1923, Bing transferred portions of the one plot to Bergen Museum as a donation – specifically the rocky expanse of Vehammaren facing north that contained some 200 carved figures. In 1976, Elkem conveyed by deed to the Bergen Historical Museum, without compensation, that portion of their property in Vingen, measuring 54.5 mål [13.5 acres], "*where rock carvings have been found or where there is a possibility for finding them*" (Skåtun 1975). Vingeneset and the area surrounding Vehammaren is still owned by the Bing family.

2.3 The Cultural and Historical Context

2.3.1 The Archaeological Record

Up until the end of 2006, just over 2000 carved figures were recorded in Vingen, spread over approximately 20 sites and 300 larger and smaller panels. The majority of the sites are spread across the 1-kilometre-long strip of land on the southern side of the fjord basin and innermost in the bay (Fig. 2.3.1-1). At Vingeneset towards the mouth of the fjord inlet on the northern side, there are also several major sites, and at neighbouring Vingelven, a few kilometres further west in the fjord basin, there is one large site and several smaller sites.

A large number of the carvings are located on the extended ridges running east-west – most of them on the sides facing north (e.g. Brattebakken, Hardbakken, Vehammaren) – and some of them on the sides facing south (Fig. 2.3.1-2a). There are also rock carvings on some of the larger and smaller knolls, on embedded boulders, and on smaller "liftable" stones. The carvings' placement in terms of compass directions varies from stone to stone, and there are also figures carved on top of the larger stones. On the boulders in the scree there are carvings on both the exposed surfaces and on surfaces between the larger stones. The lowest level at which carvings are located is 8 m.a.sl., the highest at about 20 m.a.s.l.

Fig. 2.3.1-1. Overview showing the shoreline strip of land on the southern side of Vingepollen, as viewed from Tussurfjell. (Photo: T. Lødøen)

The number of figures carved on individual sites varies from approximately 200 on the long ridges to two or three depictions on the smaller stones. The majority of the figures are red deer of various sizes and shapes, many with an intricate lined pattern in the body (Fig. 2.3.1-3). Some of the four-legged animals may represent wolves or dogs, and one is possibly a bear. There are also some sea mammals, a birdlike creature and reptiles (snakes). A good number of human figures also appear – these also in varying shapes – as well as different abstract, geometrical linear patterns, zigzagging lines, multiple curved lines, eye-like figures, ovals, etc. (Fig. 2.3.1-4) Additionally there is a large group of hook-shaped figures of varying design. The carvings are executed by point chiselling along narrow and shallow lines in the surfaces. It is likely that a sharpened stone chisel was used, made of a harder variety of stone than the rock being carved.

Additional cultural monuments other than carvings bear witness to human activity in Vingen in prehistoric times (Fig. 2.3.1-2b). Approximately ten dwelling features are recorded and dated, based on archaeological materials and radiological dating, to the Mesolithic. They appear as round or oval-shaped hollows with low walls of stone or loose earth. In several cases, carved stones of various sizes have been found very near to the building remnants, so nearby that it is reasonable to suppose that they were part of the wall construction.

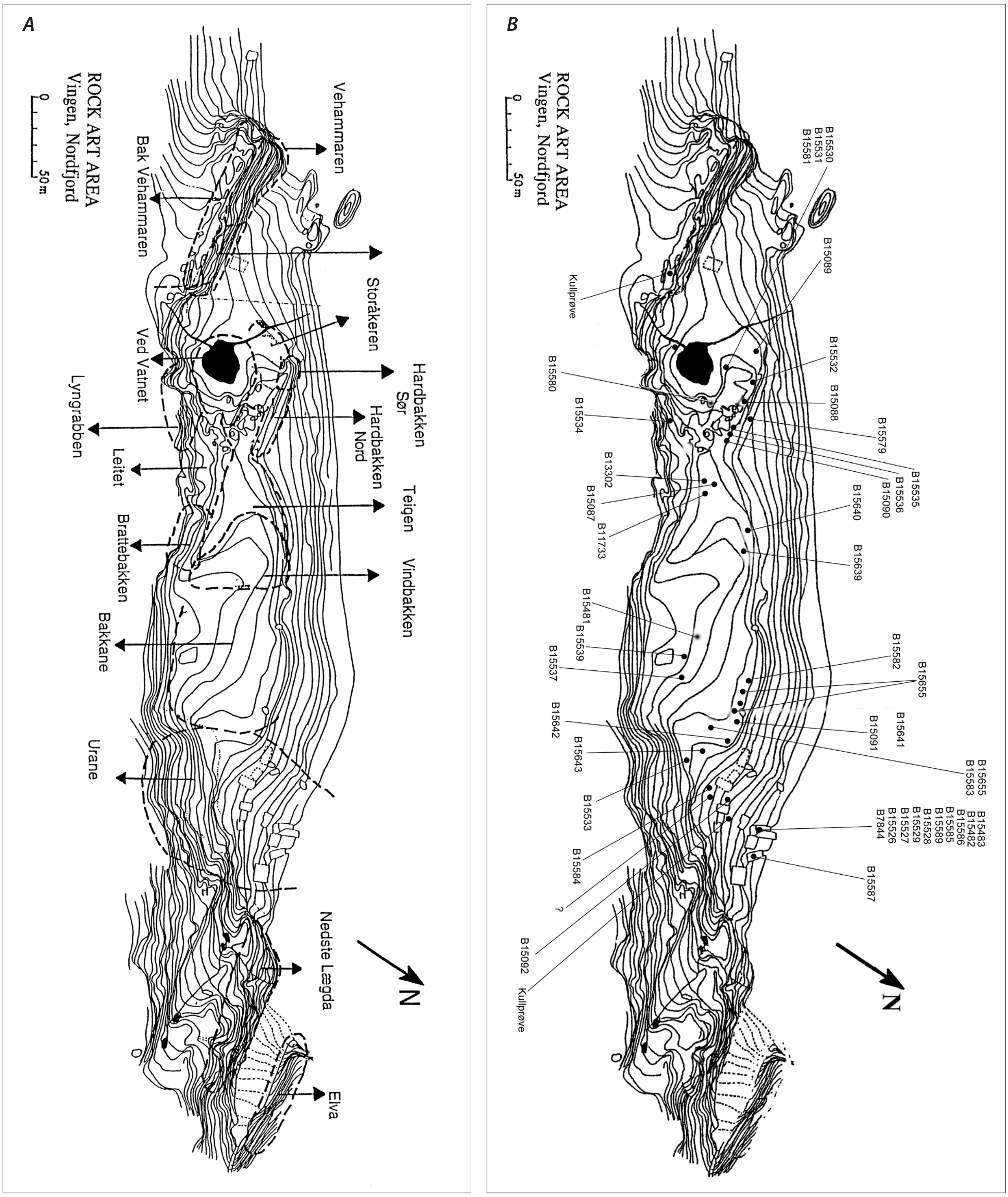


Fig. 2.3.1-2 a) Map showing the strip of land on the southern side of Vingepollen. b) Map with markings (museum numbers) indicating the sites where archaeological materials were found, including individual finds of objects and materials from archaeological excavations. Each number preceded by B represents anywhere between a single to several thousand objects.

Fig. 2.3.1-3. Section from Brattebakken 1. In addition to red deer with body patterns and without horns (female animals?), human figures are depicted, a hook (centre of the drawing) and an concenctric oval design interpreted as female sex organs – a vulva (lower left) (tracing Bakka).

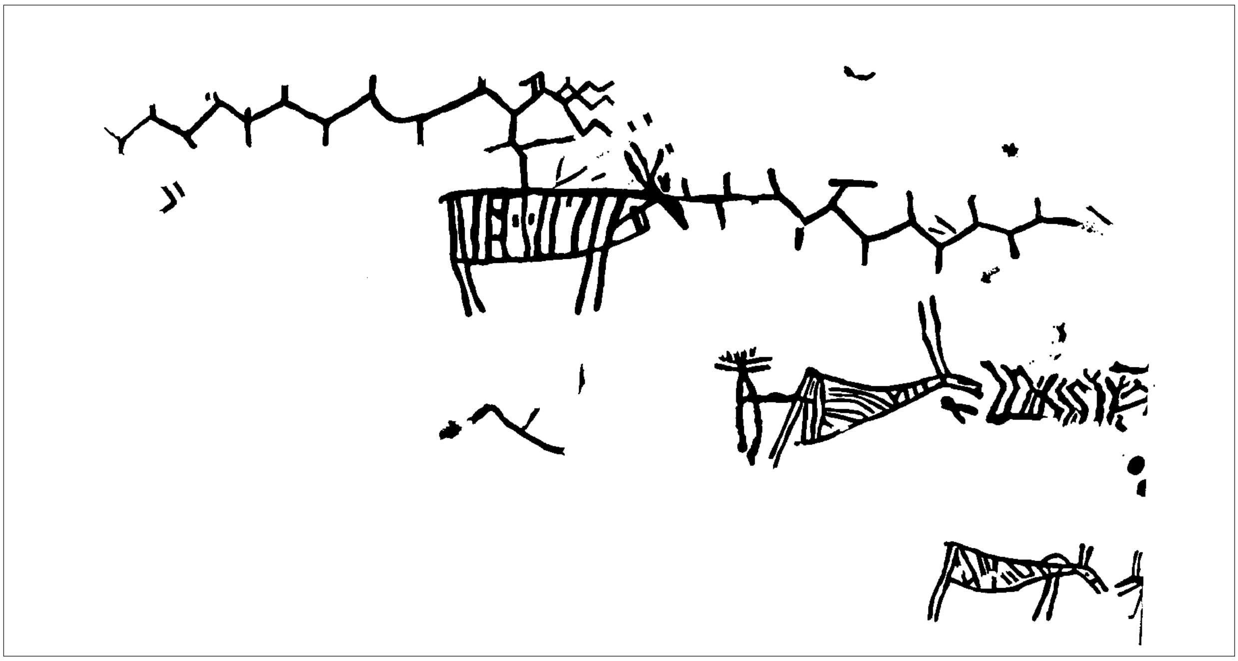


Fig. 2.3.1-4. Section from Brattebakken 1 showing depiction of animals, humans and various zigzag patterns (tracing Bakka).

In many places in Vingen, flint and stone materials, as well as chips and flakes from the production of tools, have been found over a period of years. Some of these were found in drainage ditches, some along the shoreline in Vingepollen, and some in conjunction with clearing in the area of rock art sites, particularly upon removal of moss that had grown and covered the figures on stone surfaces, and in crevices in the rock.

2.3.2 Problems Associated with Dating

One prerequisite for understanding the significance that rock art had in its time – who created the images, why they were created, what activities were conducted in the areas around the sites, etc. – is to date the images themselves. In most cases, the efforts that have been made to date the rock art have been based on typology and development of style and/or on geologically dated shoreline levels. However, by using these methods it has not been possible to determine their situation more precisely within an extended time period of many centuries or millennia. It has therefore been very difficult to acquire a more complete notion of the cultural and societal developments during the periods when the rock art was created. This fact stands in opposition to the nuanced and precisely chronological framework that has been developed for the other cultural remnants, a framework that is based on countless archaeological excavations and other types of investigations. One possible approach for acquiring a better knowledge of the age and meaning of the rock art is to investigate and survey the archaeological material in the subsurface areas immediately surrounding the rock art. (Fig. 2.3.1-2b). Vingen represents a unique opportunity for this type of investigation, partly because of a significant amount of archaeological traces of culture in the soil's subsurface (see 7.4), and partly because the area is undisturbed by more recent installations and activities, with the exception of grazing (see 2.2.1).

The dating of the Vingen carvings is controversial. It was earlier assumed that they were created over a period lasting approximately 2000 years, from about 4000–2000 before the dawn of our historical time. This dating, deduced by Egil Bakka in the 1970s, builds on a combination of stylistic analyses, comparative methods and shoreline datings (Bakka 1973). More recent investigations, however, tend to indicate that the carvings may have been made within a shorter time span towards the end of the Mesolithic, i.e. that they are about 6500–7000 years old (Lødøen 2001, 2003, 2007, 2009; Mandt and Lødøen 2005).

In order to acquire more knowledge about the character and scope of the archaeological material in the subsurface in Vingen, several surveys were carried out in 1998 and 2007, with limited funding from the Meltzer Foundation, the Faculty of History and Philosophy at the University of Bergen, and the Norwegian Directorate for Cultural Heritage. The surveys revealed that there are large deposits of archaeological materials in close vicinity to several of the rock art sites.

Although the surveys were of limited scope, they have indeed provided very interesting finds in terms of the nature and dating of the cultural strata. The finds coincide with several other spot surveys in Vingen, where archaeological materials and cultural strata were found to corroborate dating at the Mesolithic, while objects/contexts from the Neolithic are conspicuously absent. The surveys show that the material deposited in the subsurface is very important in order to place Vingen in its correct cultural and historical context. Among other things, they suggest that the rock art in Vingen dates from the Mesolithic and is therefore considerably older than was previously assumed.

2.3.3 Explanatory Models

Over the years, various interpretations have been proposed concerning the rock art in Vingen. The oldest notion suggests that the images of red deer were made as an invocation for good hunting (Bøe 1932; Brøgger 1925; Bakka 1973). The mountainous area around Vingen is one of the country's most abundant deer regions, and the narrow fjord arm surrounded by steep rocky slopes was considered to be a gigantic trap for stampede hunting on a large scale. It was thought that a group of hunters stampeded the deer out across the steep slopes and down to the water, where other hunters waited in boats ready to bludgeon to death the animals that survived the fall.

This interpretation of a ritual hunting invocation has been modified with the passage of time. As previously mentioned, many motifs other than deer were also carved, including images of humans. These include both women and men (Fig. 2.3.3-1), and the deer images are also differentiated by sex as stags and hinds. In comparison with the traditions of hunters of today or those in our recent past, it can be inferred that

Fig. 2.3.3-1. Section of Bakkane 3 ("Swedish turnip stone"). Of these four human figures, at least two of them are clearly interpreted as females based on the vulva-like depiction on the lower part of the body (tracing Bakka).

the depictions of fertility, death and resurrection may also have been important elements for Stone Age hunters along the Western Norwegian coast.

Many elements in the rock art of Vingen – in terms of both the composition of motifs and placement of the figures – can be interpreted as manifestations of shamanism (Mandt 2000). Shamanism is a religious practice known from hunter-gatherer societies the world over, and is particularly characterized as being conducted in a hallucinatory trance state. When the shaman is in a state of trance, he or she is able to "see" various patterns and figures and can have different bodily experiences, such as being able to fly or to be transformed into an animal. The shaman can transport himself between various cosmic levels - the underworld, earth and heaven – and a journey into the underworld normally occurs via a cave-like passage or something similar. It is tempting to identify the carvings that are found in cavities in the scree and on stones that are concealed beneath large boulders as transcendental places through which the shaman could travel to another cosmic level (Fig. 2.3.3-2). The shaman's journey to the underworld – often described as "the little death" – may also be symbolized through the many depictions of human skeletons in Vingen (Fig. 2.3.3-3).

The cavities between the stones in the scree can also be seen in context with transitional rituals – either in connection with the initiation of shamans or young people's coming of age in the adult world. The narrow passages between the boulders may symbolize the birth canal – with the individual being initiated having to pass through the canal in order to be reborn into a new existence.

Perhaps Vingen was a holy place and a gathering point for groups of people who lived scattered along the coast, on islands or inside fjord arms. It is tempting to see the comprehensive settlement material in Skatestraumen, about 5 km northwest of Vingen, in conjunction with activities associated with creation and use of the rock art (Bergsvik 1999: 2002). Vingen may well have been a place where people congregated at certain times in order to celebrate tribal togetherness, exchange goods and information, perhaps to find a spouse – and most probably also to hunt the highly sought-after red deer. Basic subsistence for the coastal people during the Stone Age was primarily fish and other aquatic resources that could be counted on all year round. Nonetheless, the deer were undoubtedly important and provided welcome products such as food,

Fig. 2.3.3-2. *Human skeletons are depicted in several sites in Vingen. They may symbolize the shaman's entranced journey – "the little death". (Photo: G. Mandt)*

Fig. 2.3.3-3. *In the cavities between the stones in the scree in the easternmost area of Vingen, rock art was found, most often of a geometrical pattern that is difficult to associate with any known object. Could it be that these sites are in some way related to rites of passage? (Photo: G. Mandt)*

hides for clothing and tents, horns, bones and tendons for making tools and weapons. At the same time, deer were perhaps more than a mere useful resource. They were perhaps a metaphor for the tribe, for strength and fellowship and the will to survive.

2.4 Management and Public Administration of Vingen

2.4.1 Cultural Heritage legislation

Cultural monuments dated earlier than 1537 are automatically preserved under the Cultural Heritage Act of 9 June 1978, including the amendments of 3 July 1992. Ever since the first law pertaining to cultural monuments was enacted in 1905 and up until 1990, the five regional archaeology museums[3], have been given custodial responsibility for prehistoric cultural monuments and medieval remains in rural areas, while responsibility for the churches, fortresses, cloisters and city installations has been under the Directorate of Cultural Heritage. After the system for the preservation of cultural heritage was restructured in 1990, and the Directorate for Cultural Heritage acquired directorial responsibility, custodial responsibility for prehistoric cultural relics was transferred to the county administrations[4].

Ever since the discovery of the carvings in Vingen in the early 1900s, archaeological management has been subject to the Cultural Heritage Act. According to § 3, it is forbidden to implement – without the consent of preservation authorities – any *"measure that may result in harm, destruction, excavation, change of location, change, covering, concealment or by any other manner undue spoilage"* to the cultural monument. In § 6, it is stipulated that a 5-metre security zone is to be established around an automatically preserved cultural monument. For Vingen, where the automatically protected rock art sites and remnants are so densely located, this entails in reality that most of the surrounding cultural landscape is part and parcel of the security zone. From the mid-1970s up until 1990, The Historical Museum in Bergen has held a dual management function, since the institution has been both the landowner of the majority of the rock art area and responsible for management as required by law. Since 1990, the managerial responsibility for the management of the cultural monuments in Vingen has been carried out by Sogn og Fjordane county administration.

2.4.2 Rising Tourism

Throughout the 1970s, there was a major rise in visitor traffic and tourism in Vingen. Local authorities and the tourism sector in the area recognized Vingen's potential as a tourist attraction, and regularly scheduled boat excursions to "*die Felszeichnungen*" were set up. The local population came as well. Visits by school classes and boat tourists increased dramatically. This made it necessary to make the rock art accessible to the public, with marked trails, information signs, etc.

The development occurred at the same time as the cultural heritage authorities began to become aware of the poor condition of Norwegian rock art (Michelsen 1992; Mandt 1997; cf.. 2.1). As previously mentioned in the introduction, Johs. Bøe had already observed in the 1920s that many of the carvings in Vingen had been damaged. In his journals from the 1960s and early 1970s, Egil Bakka frequently commented that many of the rock carvings have been preserved only marginally and in several cases he observed deterioration over the period of a decade. In conjunction with the nationwide registration of damage to the rock art (cf. 2.1), professor of geology Anders Kvale described the state of conservation of the rock art in Vingen in 1977 as alarming: "*If nothing is done, the site's value will continue to depreciate year by year"* (Mandt & Michelsen 1981:18).

From the mid-1960s, the Vingen rock art was also subjected to gross vandalism. A number of sites have been marred by felt pen scribblings and painting; many of the figures have been damaged by deep, disfiguring scratches (Fig. 2.4.2-1), and in certain places the fragile weathering shell has been broken, either by trampling the stone or because people have tried to pry loose pieces of the carved rock (Fig. 3.2.2-2).

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3 The Archaeological Museum in Stavanger; The University Cultural and Historical museums, UiO; Bergen Museum, UiB; Tromsø Museum, UiTø, Norwegian University of Science and Technology, NTNU.

4 As of 1 January 2001, responsibility for assigning protected status under the Cultural Heritage Act (the so-called "preservation authority") was transferred from the Regional museums to the Directorate for Cultural Heritage. Archaeological surveys (excavations) and the care and maintenance of findings and documentation continue to be the responsibility of the Regional museums.

Fig. 2.4.2-1. Vandalism in the form of deep scratches across the human figure at Bakkane 4 ("Bakkesteinen). The vandalism was done in 1981 and remains clearly visible today. (Photo: G. Mandt)

2.4.3 Vingen as a protected Landscape Area

Pressure from the tourism sector to make the sites accessible to the public and growing awareness of the damage caused by the large number of tourists made it clear to the cultural heritage authorities that there was a need to protect the rock art in Vingen beyond the mandate provided by the Cultural Heritage Act. Therefore, under the Nature Conservation Act of May 19 1970, Vingen was decreed a protected landscape zone by the Crown Prince Regent's resolution of May 9 1980. The protected landscape area comprises about 50 km^2, and the purpose was *"to conserve a beautiful natural landscape containing important cultural and historical traits (rock carving sites)"* (Rules of conservation for the Vingen protected landscape area). According to § IV of the rules, it is prohibited to make *"technical incursions that may significantly alter the nature or character of the landscape"*, and motorized access (except by motorboat) and camping were proscribed.

In 1981, the first management plan for the cultural monuments in Vingen was established under the auspices of the Historical Museum in Bergen (Auestad 1981), and a number of measures were implemented for protecting and making the sites accessible. Several of the rock art sites were surveyed, walking paths were laid between the sites, and information signs and brochures were made available with information about both the cultural monuments and the various activities that were prohibited in the area. An effort was made to provide information on the vulnerability and poor state of the monuments, in addition to the rules and restrictions that were in force in the protected landscape area. At the same time, the first attempts at conservation were made in Vingen, based on the results of laboratory examinations and from tests carried out in the field during the period 1978-80 in Ausevik, Flora municipality (cf. 3.2.3).

2.4.4 Area Protection Measures

However, neither the protective measures of the Cultural Heritage Act and the Nature Conservation Act, nor the efforts made during the past 20 years to preserve the area and inform the public in Vingen have succeeded in preventing irresponsible behaviour by visitors. Trampling the rock art, open fires and grilling between the sites and vandalism have occurred. (Fig. 2.4.2-1). Ironically, some of the worst cases of vandalism occurred at about the same time as decisions were taken to make the sites accessible to the public.

The increased and, to a large extent, uncontrolled influx of tourists from the 1970s also resulted in the need to reduce grazing in the area, due first and foremost to a concern for the safety of the grazing livestock. Through the years there have been many tragedies involving animals in Vingen caused by irresponsible behaviour on the part of visitors, such as animals being chased into the fjord, or being attacked and bitten to death by loose dogs. (Fig. 2.4.4-1). Reduced grazing led in turn to the previously open and grassy landscape becoming overgrown, and the vegetation is increasingly dominated by heath and other invasive species (see 4.3.1).

Fig. 2.4.4-1. *A dead lamb, very likely the victim of attacks by loose dogs. (Photo: Helga Vingelven).*

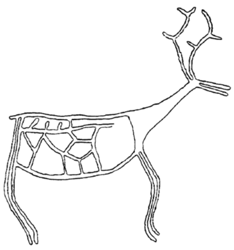
In an attempt to intensify efforts to protect the cultural monuments, in 1996 Sogn og Fjordane county administration took the initiative to implement plans to protect cultural heritage in Vingen, under the Cultural Heritage Act of June 9 1978, no. 50 § 22.4 cf. § 19. As previously mentioned (2.4.1), the county administrations are responsible for the management of cultural monuments at local level. This includes care and management, conservation and protection of the cultural monuments. In 1996, a preliminary area management plan was also developed for Vingen (Mandt & Riisøen 1996). The protection process began by temporarily registering Vingen, including Vingeneset, as an officially protected area in 1996, and by generally prohibiting visitors, with certain exceptions made, primarily for landowners, property rights owners and researchers associated with the Bergkunst project, as well as regulated tourism for a limited period of time during the summer season.

In June 1999, Sogn og Fjordane county administration sent its proposal for public comment involving permanent protection of the area surrounding the automatically protected rock art carving sites in Vingen and Vingeneset (Cadastral farm no. 77/1,2,6, farm no. 78/3, 4 and farm no. 78/5,7). The purpose for preserving the area is

> *"… to protect the rock carvings and the other automatically protected cultural monuments as scientific source materials in the landscape"* (Sogn og Fjordane Fylkeskommune, Kulturavdelinga 1999).

The specific protected area comprises approximately 43 acres, i.e. a significantly smaller area than the Landscape Conservation Area. In this area, no types of activities can be carried out that may alter the character of the area or in any other way have an impact that is contrary to the intent of protection. This includes all types of development or construction such as worksites, piers, houses, cabins or other changes to the landscape. Just as for temporary protection status, there is a general prohibition against traffic, with the same exemptions allowing certain types of access. Managing authorities may grant dispensations in special conditions involving tourism/access. Since 2002 the public area has been confined to a specifically limited area at the most westerly point of Vingen, close to the quay. The county administration is responsible for developing a conservation management plan for Vingen that includes plans for care and management, and it is also responsible for implementing care and management measures that will fulfil the goal of protection (Wrigglesworth 2002).

Protection, according to § 19 of the Cultural Heritage Act, requires a lengthy and comprehensive treatment of each case in question before it is sent to the Directorate for Cultural Heritage for the final administrative decision concerning protection. Sogn og Fjordane county administration sent their final proposal for a protected area (Enclosure H) to the Directorate for Cultural Heritage on 3 May 2001 (cf. 7.5.2).



CHAPTER 3

Trond Klungseth Lødøen and Gro Mandt

DOCUMENTATION AND CONSERVATION

3.1 Documentation

3.1.1 From Tracing Paper to Plastic Foil

The first documentation of the Vingen rock carvings was carried out as early as the summer of 1913 by two representatives from Bergens Museum - archaeologist Jan Petersen and the museum's technical assistant, Olav Espevoll. A number of the figures were copied individually on tracing paper, and photographs were taken[1].

In 1913 and in 1917 the carvings were documented by Swedish archaeologist Gustaf Hallström (Fig. 3.1.1-1). His intention was to publish the Swedish and the Norwegian carvings of the type known as "*veideristninger*" [Stone-Age images]. However, Norwegian archaeologists lead by A.W. Brøgger, former head of The Museum of Cultural History at the University of Oslo, insisted that the Norwegian carvings were to be documented by the Norwegians. Therefore, Hallström's book on Vingen was not published before 1938.

Hallström's documentation comprises tracings on thin, transparent paper, as well as photographs - both overview photos of the site and landscape, and detailed close-ups of individual figures and groups of figures (Hallström 1938). He does not describe each figure, but he does provide relatively precise information about the location of and distance between the groups of figures, and in many cases he measured the height above sea level[2].

In 1925, 1927 and 1931, the Vingen carvings were documented by Johs. Bøe, curator of Bergens Museum, and were published in 1932 in "*Felszeichnungen im Westlichen Norwegen*". Bøe's documentation comprises tracings on parchment, photographs, several gypsum casts, and a verbal description of each figure individually, including damage/state of preservation (Bøe 1932). He has also recorded the levels of the lowest figures in several of the sites[3]. Both Bøe's and Hallström's publications include some 800 numbered figures, which in many cases consist of groups of individual figures.

During the early 1960s, the Vingelven family discovered more carvings in Vingen, and in the 1960s and 1970s, Egil Bakka from the Historical Museum, UiB, documented the images. During these years, the number of rock carvings discovered had practically doubled, i.e. 1500–1600 individual figures. Bakka's most important method of documentation was tracing with a felt pen on transparent plastic foil. This method of tracing had become common at the Historical Museum of Bergen and was widely used in conjunction with, among other documentations, Anders Hagen's new surveys of the carvings in Ausevik in Flora municipality (Hagen 1969, Michelsen 1969).

In his journals, Bakka included thorough descriptions of the carvings, with information on carving techniques, an evaluation of artificial lines as opposed to natural lines, and indications of the state of preservation of the figures and rock surfaces. He made silicone rubber casts of individual figures and groups of figures. He did not take many photographs himself, but in 1976 he took along a professional photographer, Svein Skare, from the Historical museum, who took a number of photographic surveys.[4]

1 The materials are located in the Bergen Museum archives.

2 Hallström's journal notations and comprehensive photo documentation from Vingen is kept in the archives of the University library in Umeå. Copies of portions of the material are kept in the archives of Bergen Museum. It is uncertain where Hallström's original tracings are located – if they were saved at all.

3 Bøe's original tracings and gypsum casts are located in the collections of Bergen Museum.

4 Bakka's documentation materials – journals, tracings and photographs – are kept in Bergen Museum's archive and collections.

Fig. 3.1.1-1. Technical assistant Olav Espevoll, during the documentation of the carvings at the Elva site in 1913, did the photography. The carvings, which are chalk-enhanced, are located on a steep and tall mountainside, and Espevoll needed to secure himself with a safety rope. (Photo: G. Hallström)

3.1.2 Retrieval Problems

Prior to efforts in 1981 aimed at making the rock art in Vingen accessible to the public, various conservation measures, as mentioned above, were implemented (Mandt & Riisøen 1994; Cf. 2.4.3 and 3.2.3). Despite the comprehensive documentation of the rock art that was carried out from the beginning of the century and over the following years, it was discovered that it was difficult to find the previously recorded sites and figures, and because of this, it was also not possible to determine the extent and nature of damage to them. The problem of rediscovering the sites is partly due to the size and complexity of the general area (the large number of sites and figures spread over a large area), and partly due to varying documentation systems, the poor state of conservation of the rock art and the fact that the area was becoming increasingly overgrown with vegetation.

In the publications of Bøe and Hallström, the rock art sites are organized in different ways that are not immediately comparable. Bøe does not use a division into sub-sites, but numbers the figures consecutively from west to east (Bøe 1932). Hallström organized the material into topographical groups, but without a subdivision into sites (Hallström 1938). Both Hallström and Bøe traced most of the figures individually, and only rarely was the location of the figures or groups of figures, on the various rock panels and in relation to one another, provided. Indications of distance and direction between the figures are most frequently lacking or inaccurate. All of these conditions make it difficult to determine where the figures documented by Hallström and Bøe are located – both in relation to each other and where in the landscape they can be found – or more precisely, where one should begin to search for them.

When the first conservation efforts in Vingen began around 1980, no one was fully aware of Bakka's documentation materials. He had only published accounts of the Vingen engravings in minor articles (Bakka 1973, 1979). Photographs of the tracings he made are located in Bergen Museum's photo archive, but it was only after Bakka's death (in1985) that his journal notes from the surveys between the years of 1963–1976 became available for consultation. His descriptions of the figures, as mentioned previously, are detailed and thorough. He gave names identifying the individual sites, and he traced each site separately, numbering the figures. But indications of position, in many cases, are scant or completely absent.

The problems in locating the rock art are exacerbated by the rock species in Vingen being in such a state of deterioration that many previously recorded figures have been severely damaged or have disappeared altogether. The figures are most frequently engraved with shallow and superficial incisions and are therefore difficult to see without plenty of oblique light. Furthermore, rediscovering the figures is made even more difficult because of overgrowth by lichens and by the growth of heath and shrub vegetation that has occurred during the past 30 years because of reduced grazing (Cf. 2.4.4 and 5.3.1.1).

3.1.3 Systemizing Documentation Materials – towards databases

With regard to both the conservation of the rock art and the goal of scientifically examining it anew, it was necessary to collect and systemize all earlier documentation. This work began in 1993 and is practically finished (Lødøen & Mandt *in prep*.). By the end of 2009, only between 1.5 and 2% of the previously recorded carvings have still to be found.

During the work to re-discover and check sites, new figures have been discovered in previously identified sites, and new, previously unknown (minor) sites have been uncovered. The new figures and sites have been traced, photographed and described. In instances when there have been discrepancies with earlier documentation, new tracings have been made. Tracing is done with a felt pen on plastic foil. Because the figures are so difficult to see due to superficial incisions overgrown with lichens, examination is dependent on plenty of oblique light. The most favourable light conditions are provided by early morning sunlight or late afternoon sunlight. In addition, nature can be "helped" by covering the rock carving and the viewer with a black plastic cover, allowing light to enter from the angle that provides the best view of relief on the rock panel. The figures are enhanced with chalk before being traced on transparent plastic foil (Fig. 3.1.3-1). At present

Fig. 3.1.3-1. *Chalk enhancement of the large deer figure no. 4 at Vingeneset site 4. The figure – which is about 2 metres long and the largest registered in Vingen – was discovered during the clearing of heath and peat ground cover in 1996. (Photo: G. Mandt)*

it is difficult to see how tracings can be made without enhancing the figures with chalk. The figures are most often in an advanced state of degradation, and the lines are so narrow and superficial that they are difficult to see through the plastic. Also, many of the animal figures have a complicated, finely lined pattern on their bodies that is almost impossible to document without enhancing the lines. Another problem is that moisture on the rock surface mists the underside of the plastic, so that it becomes no longer transparent.

The "Vingen rock carving area" is divided into a total of 20 different *sites* all named after local place names: Vehammaren, Bak Vehammaren, Lyngrabben, Vatnet, Storåkeren, Hardbakken, Leitet, Teigen, Vindbakken, Brattebakken, Bakkane, Urane, Nedste Lægda, Elva, Hola, Vingeneset, Vingelven, Vingesetra, Fura, Hennøya (see also Fig. 2.3.1-2). The discovery of rock art at Vinge Lake was also reported, but these were probably lost in conjunction with regulation of the watercourse during the 1960s (Helga Vingelven, oral account). Inside each locality, there are different consecutively numbered panels , and the same is true for the *figures* at each site. The documentations of Hallström, Bøe and Bakka have been compared, to the extent that all of them have made tracings (Lødøen & Mandt *in prep*.).

3.1.4 Site Surveying – Measurements and GIS

As part of the documentation of the Vingen rock art, aerial photographs have been taken of the area and a digitalized map has been produced. Additionally, the individual sites will be surveyed and indicated by precise location of plane and height above sea level and will be plotted into the digitalised map underlay. The surveys are important not only in conjunction with scientific examination, including analyses of the rock art's location in relation to prehistoric shoreline levels, but they are also very important in terms of the preservation work. A number of sites in Vingen are in such poor condition that they must have protective covers for varying lengths of time, and in this respect it is necessary to know the exact locations.

3.2 Conservation

3.2.1 Research on Rock Art Preservation

Because of the alarming results of the first rock art project (Mandt & Michelsen 1981), The Archaeological Interim Commission (TAIC)[5] applied for funding in 1981 in order to continue the effort to preserve the rock art. The undertaking was supported first through a grant from the Norwegian Cultural Monuments Council, and later with earmarked funding from the Ministry of the Environment (Mandt 1997:3-4).

The project was placed under the management of the Historical Museum of the University of Bergen. Head Curator Kristen Michelsen, who was in charge of the department of conservation of the Historic Museum, was given a five-year grant to carry out research on the conservation of rock art. Michelsen had followed the effort from its start in 1974. He was interested in the task, and as a chemist with knowledge in the field of geology, he had the necessary interdisciplinary competence. At each of the five archaeological museums, one archaeologist was appointed as a contact. Together with Michelsen, these persons comprised a project group that was to continue the effort to preserve the rock art. The group was to coordinate the measures to be taken and dissemination of the research results.

In the course of the first stage of registration, it became clear that a significant research effort was required before it would be possible to implement conservation measures in a satisfactory manner. Knowledge about rock species, degradation mechanisms and the long-term effects from the use of various methods and measures to stabilize and consolidate the rock panels, needed to be acquired through basic research.

It became apparent that this was also a neglected field of research in other countries. A great deal of research had been done on the preservation of stone used for construction, but little had been done on rock art panels. It was primarily in Australia and Canada that research had been done on rock species used for prehistoric carvings, and experience from these countries revealed that it was necessary to be especially cautious in the choice of methods, because damage resulting from the use of unfavourable measures does not become apparent until several years later. Michelsen established a close collaboration with the Canadian group, and it

5 An advisory body for the Ministry of the Environment on matters concerning cultural monuments, comprising managing officials from the five archaeological museums.

was agreed that they would cooperate in solving issues they shared in common. For example, the organization of laboratory tests were discussed, and various methods of consolidating rock surfaces were chosen so that the results from test samples showing the effects of various applied chemicals could be exchanged (Michelsen 1981).

Michelsen's work focused on mica schists (Ausevik) and sandstone (Vingen). Tests using different consolidating agents and application techniques were carried out both in the laboratory and in the field (Michelsen 1992:27-32) (Cf. 3.2.4). Up until 1990, comprehensive research and reports were completed regarding the causes of the breakdown of the engraved rock species. During this period, work was also done to identify gentle methods for removing lichens, and various tests were done to divert water flow from the rock art sites (Michelsen 1992). Michelsen outlines the purpose of the project as follows (Michelsen 1981):

- To describe and analyse the processes that are the cause of destruction of various rock species
- To conduct laboratory tests for trial methods of stabilizing rock and repairing damage that has already occurred
- Follow-up of point 2 in the field

3.2.2 Primary Descriptions of Status

Little information exists on the measures that have been taken to preserve the rock carvings in Vingen, except the work Michelsen began at the end of the 1970s. Both Hallström (in 1913 and 1917) and Bøe (in the 1920s) noted that the condition of preservation was poor, and that the rock carvings were difficult to see, partly because of deterioration, partly because many of the sites were overgrown with lichens (Bøe 1932, Hallstrøm 1938). However, no indications were given that *biocides* were used to remove lichens.

It is uncertain to what extent there were systematic searches for rock carvings when ground covering was removed. Hallström refers to Thue Gullaksen Vingen, who revealed that when peat was moved from

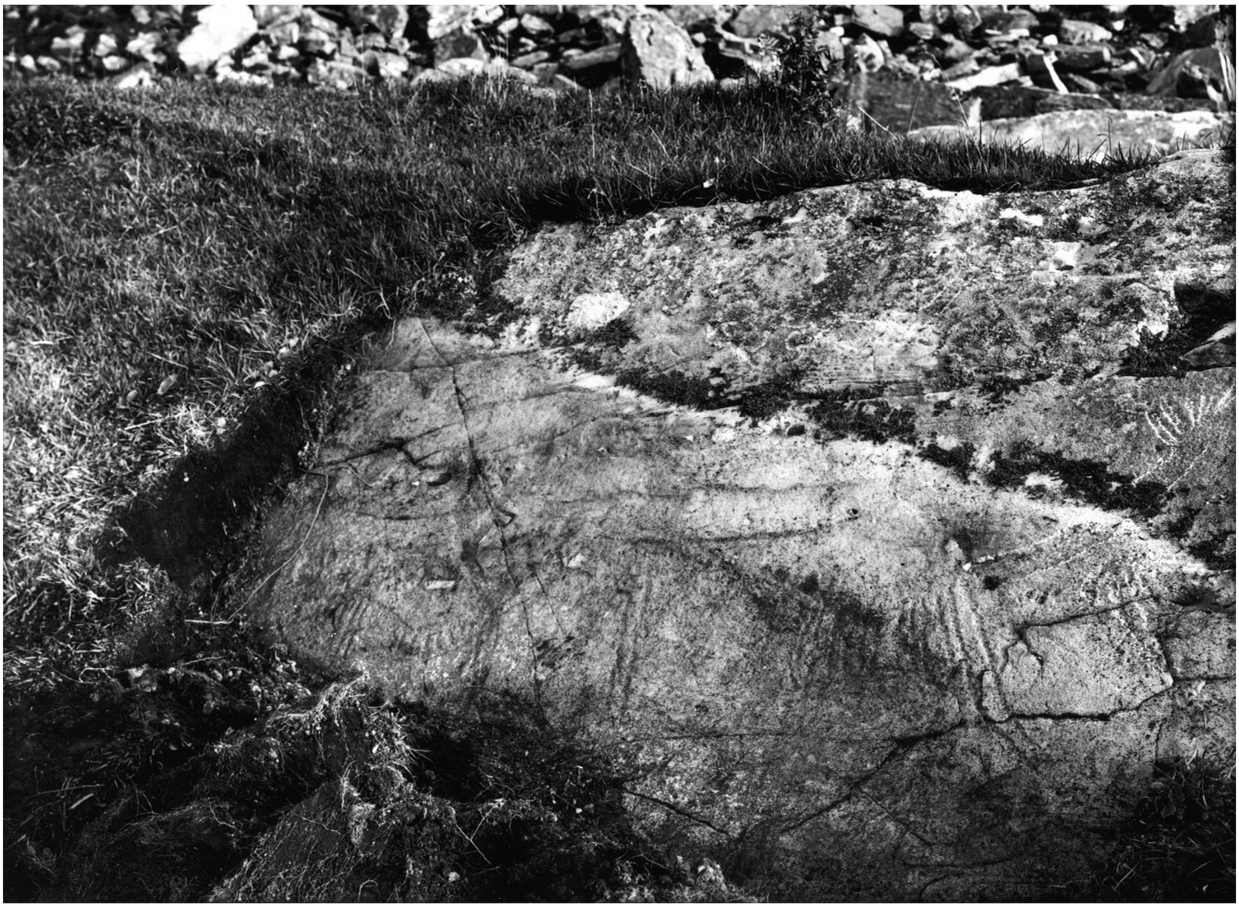


Fig. 3.2.2-1. The Bak Vehammaren 21 site photographed just after the removal of peat growth in 1913. (Photo: G. Hallström)

Vehammaren a few years after the first rock carvings were discovered (in 1884), more carvings were uncovered (corresponding to Hallström's group VI) (Hallström 1938: 416–417 & fig. 116). It is also documented that Hallström removed peat cover from the Bak Vehammaren 21 site in 1913 (Hallström 1938, Fig. 3.2.2-1).

Bøe provides no overview of the number of figures or sites from which he removed ground cover. In some instances, however, he specifically describes removal of ground cover, among other places in conjunction with the "Kålrabistein" [Turnip stone] (Bakkane 3). Two figures on the uppermost portion of the stone had been documented by Hallström, and this was perhaps the reason why Bøe had the turf removed from the entire stone, revealing and documenting a large group of figures (Bøe 1932, no. 485a, Tafel 18). He notes that the rock was in such a poor state that portions flaked off as the turf was removed. This is one of many stones in Vingen that was covered by peat in order to expand the cultivatable land area (Cf. 2.2.1). It is uncertain when the stone was covered with turf.

In the 1960s and 1970s, Bakka had soil removed from several of the larger sites, including Brattebakken 1 and Hardbakken Nord, both in 1963. He also had the Leitet site uncovered (1964) and the knolls at the summit/rear side of Vehammaren (1963). In his journal notes are indications that the state of preservation is poor, and that a number of figures were damaged by natural degradation and vandalism. One example of gross vandalism is known from the so-called "Børslien site" (Leitet 10). With the exception of the upper portion, this site had been concealed by turf until 1963. Already in 1964, one of the animal figures (no. 14) had been smashed by vandals (Fig. 3.2.2-2). Bakka also notes that several rock carvings have been spoilt by visitors who had scratched in names and dates.

Bakka's journal notations reveal that many of the sites were overgrown with lichens, and that the sites that had been exposed for the longest period of time were the most damaged, and were more overgrown than those that had remained covered with turf. No indication is found, however, that any attempt was made to remove the lichens.

3.2.3 The First Protection Measures in Vingen

After Vingen was declared a protected landscape area in 1980, the first preservation measures were implemented in Vingen in 1981/1982, congruent with the effort to make the rock art accessible to the public (2.4.3). The main effort was aimed at preserving particularly exposed and deteriorated sites, and at removing lichens from sites that would be part of the area open to the public. Paths were also laid, some with stone slab walkways, and signs/guideposts were set up.

In order to remove lichens from sites that were to be part of the area open to the public, biocides were used. According to oral information from Michelsen, only *quaternary ammonium salts* (under the product name *Pingo*) (1.4.1)) were used. Initially, the fluid was sprayed onto the image surface; later, it became routine to apply the liquid with a brush.

The first direct conservation in Vingen was done on figures that had been damaged by vandalism and were in danger of being lost. In 1981 there had been several cases of serious vandalism in Vingen, first and foremost by making deep scratches crisscrossing the figures (see Fig. 2.4.2-1). In several places there were gouges, and in some areas this had led to the rock surface loosening from the sub-rock, and portions had been removed (Fig. 3.2.2-2 and Fig. 3.2.3-1).

Chemicals used at the time for conserving stone used in construction proved to be unsuitable for use on rock art species of stone. The best result was achieved in the test using "Trana Weld" (TW) glue, which was shown to have good stability both in the field and in simulated aging tests in the laboratory (Michelsen 1992). Since 1981 this product, now commercialised as Mowilith DM 123S, has been used with various thinners as both a consolidating agent, and as an additive to mortar and a glue used to stabilize loose flakes. Comprehensive conservation measures were taken at the Leitet locality during the first phase. At six of the sites (Leitet 1–5 and 10) that had deteriorated severely, loose flakes were glued in place, damaged edges were insulated and the entire surface was consolidated. At the Bak Vehammaren locality, eight figures were also damaged by gouging and chipping off sections. The loose sections were glued in place using TW/water 1:1, and the damaged edges were insulated with mortar and a 50% TW additive. The measure taken is undoubtedly the reason why what was left of figure 164 is still preserved. Today the insulated borders would be made less apparent, since experience has shown that it is not necessary for the insulated borders to extend outside of the figures.

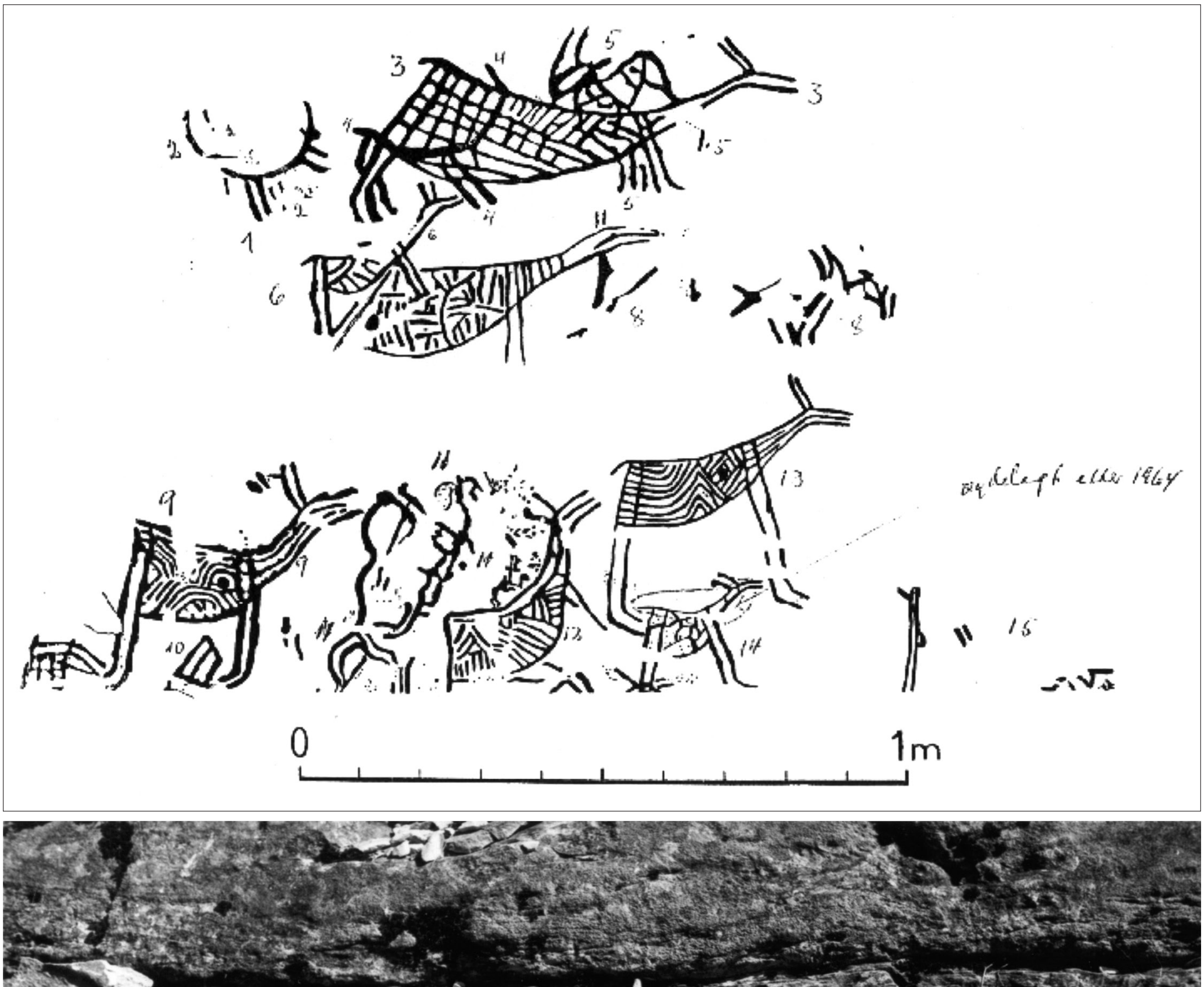


Fig. 3.2.2-2. *Tracing and photo of Leitet 10 showing the damage caused from smashing the surface. (Photo: G. Mandt/ tracing: E. Bakka)*

Fig. 3.2.3-1. *Photo of Brattebakken with the incisions and sections chipped off. (Photo: G. Mandt)*

The unsightly scratches made by vandals were somewhat toned down by applying "desert varnish" (Elvidge and Moore 1980). By making them less obvious, it was hoped that this might prevent other people from being tempted to continue the same type of vandalism.

Two large sites (Leitet 6 and 8, containing altogether 200 figures) were also the victims of serious vandalism in 1981. The sites were found with fresh chips and gouges; they had been spoilt with graffiti applied with a felt-tip pen, and the rock surface was generally in a very poor condition, with many loose pieces. An intensive conservation effort was needed to preserve the sites. Based on the knowledge of the time, it was considered too risky to begin such a comprehensive preservation effort. Instead, it was decided to cover the sites while waiting for the results of on-going research and tests. The sites were covered with two layers of turf, the bottom one surface-down, the upper one with grass turned up, with a total thickness of about 20–30 cm. The turf was taken from the land above and from the hollow near the sites. Currently, the sites are still covered. In 1995, the cover was removed from a small surface area containing two small figures in order to examine the condition of the turf-covered rock. From all appearances, the turf had not set root down to the surface of the rock; the surface was free of lichen growth, but it had turned a reddish brown colour. The site was recovered with the same turf that had been removed.

After 1981–82, no major conservation measures were taken in Vingen until 1991. It was preferred to wait for the results of both the field tests and the laboratory research. The preservation work that had been done was followed up with on-site inspections and was checked several times during the 1980s. These first conservation measures have now been in effect for 20 years, and they appear to be satisfactory.

When conservation work in Vingen began again in 1991, it was the last season before Michelsen was to retire, and it was important for those of us who were to continue the work to have a season working with him in the field. The work was concentrated on emergency conservation measures, i.e. preserving figures that had begun to come loose from the rock surface beneath them. Preventive work, such as diverting water flow from the pictorial surface, was also a priority. In addition, several localities were surveyed and the damage was recorded, described and photo-documented. Since 1994, conservation and documentation efforts have been conducted in Vingen every season up to and including the present time. The work has consisted of preventive measures, such as keeping the vegetation in check, draining water away from the rock art surfaces, and performing emergency conservation wherever it is most needed. Documentation (The Directorate for Cultural Heritage's documentation standard) has been made a priority, and to date, all of the sites have been secured according to Phase 1 specifications. In addition, work has been carried out on developing the methods used (see chapter 5 and 6).

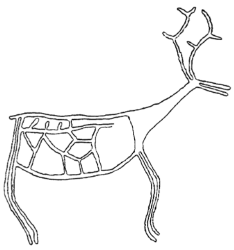
3.2.4 Experiences and Measures Taken 1994–2000

When work resumed in 1994, optimism was relatively high, but after the two first seasons in the field, it became apparent that the problems were far greater than anticipated, and that it would be impossible to solve them based strictly on archaeological conservation expertise. The degree of damage we were facing was extremely complex, and we had too little precise knowledge of the factors involved in the various processes of degradation.

The damage, which has gradually become more and more severe, is not always visible, and it has been shown that other types of damage are discovered as more knowledge is acquired about the rock species. For example, a concealed cavity between the weathering surface and the fresh rock is detected by lightly tapping the surface to produce a hollow sound. A cavity of this kind below the surface results in exfoliation of the weathering skin in thicknesses of between 1–2 cm to eggshell-thin chips. This type of damage is prevalent in Vingen, especially on rock panels facing south, but there is also a great deal of damage to those facing north (e.g. Brattebakken).

Crumbling has also been noted. The characteristic for this type of degradation is that mineral grains lie like sand in the cracks, or may be picked loose from the surface with a fingernail. In Vingen, this type of damage was first recorded on the "turnip stone" in connection with the removal of lichens in 1994. Earlier (1981–82) it was common to spray Quaternary ammonium salts (Pingo) in order to remove lichens, but eventually it became routine to apply Quaternary ammonium salts (Pingo) with a brush. It was found that the liquid penetrated more effectively by "scrubbing" the lichen cover. When the method was applied to remove lichens from the turnip stone (Bakkane 3), it turned out that the surface was "erased", because the mineral grains adhered to the brush and were removed. The method of treatment had to be halted in order to avoid mechanical damage to the figures. However, the figures were in an advanced stage of degradation and were only visible in intense oblique light. The need to stabilize the surface was urgent. Therefore, it was necessary to find another method for removing lichens, and the method chosen was to cover the stone with opaque plastic. Since lichens are a symbiosis between a fungal species and/or an algae/cyanobacteria and need light in order to live, it was hoped that the lichen would die when deprived of light. The result appeared to be good, but there was still a certain amount of uncertainty concerning how clean the surface actually was, how much biomass was still present in the pores and how long the opaque cover should remain on the stone. The stone was partially preserved in 1994, and the most crucial sections remained covered until 1995, when the rest of the stone was conserved. Upon inspection in summer 2000, the stone had acquired a greyish patina, but the image surface appears to be stable.

The image surfaces in Vingen have been conserved only to a small degree. This is due to the hardy growth of lichens and because there is uncertainty as to when the surface is clean enough, and if it is a significant factor that biological material is still present in the weathering rind. Both the conservation method itself and various methods for removing lichens are currently being tested in Vingen (see 5.4.4), and we must wait for the results of these tests before launching into major conservation efforts.



CHAPTER 4

Torbjørg Bjelland, Endre Skaar, Linda Sæbø, Kari Loe Hjelle, Trond Klungseth Lødøen and Pål Thorvaldsen

ROCK TYPE, CLIMATE, AND VEGETATION STATUS (VINGEN)

4.1 The rock type

4.1.1 Origin and composition

The rock type at Vingen is an arkosic metasandstone belonging to the Hornelen Devonian Basin (Fig. 4.1.1-1) and has an age of around 385 million years. Rapid erosion of the recently formed Caledonian mountain chain during the Devonian period resulted in the formation and transport of coarse-grained sediments and their deposition in a basin along the mountain chain. The Hornelen Devonian Basin is the largest of its type in Western Norway, covering an area of 70 x 25 km and a thickness of 25 km (Bryhni 1964). The basin contains a wide range of deposits within an extensive alluvial plain with, for example, braided stream, flood and lacustrine (lake) sediments (Steel *et al.* 1977; 1978). The coarsest sediments were gravels deposited along the margin while the finer sediments filled the rest of the basin (Fig. 4.1.1-2). Vingen is located at the northern margin of the Hornelen Devonian Basin, and the contact between conglomerate and sandstone can be seen at Vingeneset.

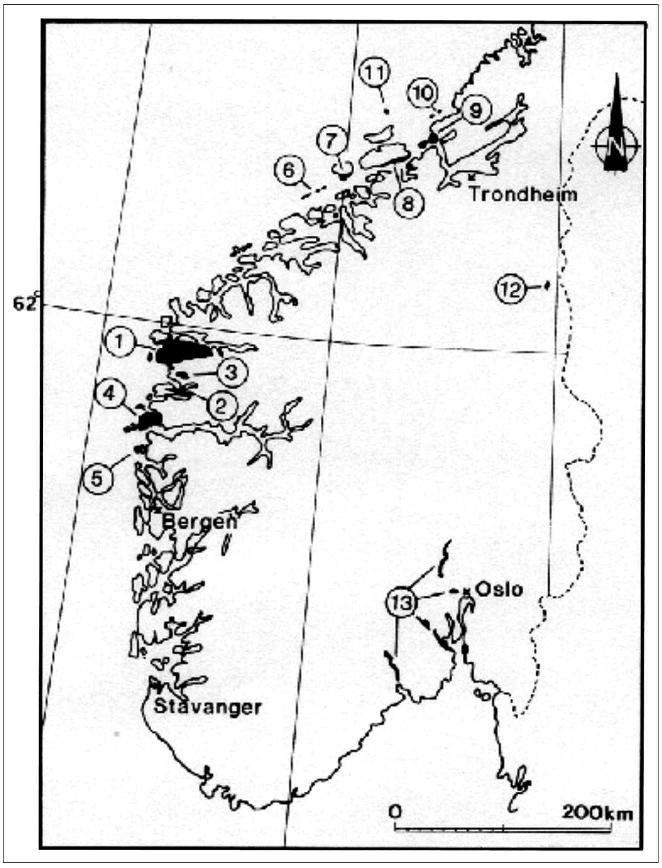
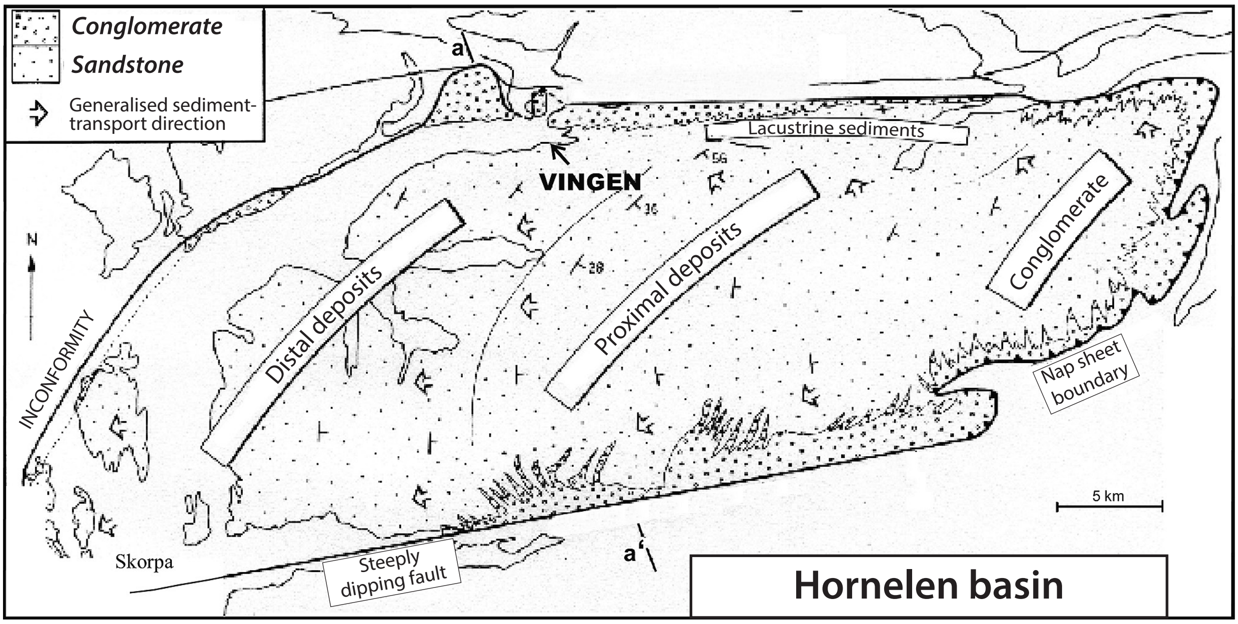


Fig. 4.1.1-1 *Map showing the location of Late Silurian-Devonian sedimentary basins ("Old red sandstone") in Norway. 1-Hornelen, 2-Kvamshesten, 3-Håsteinen, 4-Solund/Bulandet, 5-Byrknesøyene/Holmengrå, 6-Føllingen/Inngripen, 7-Smøla, 8-Hitra, 9-Fosen, 10-Asenøya, 11-Froøyane, 12-Rørangen, 13-Oslo (after Steel et al. 1985).*



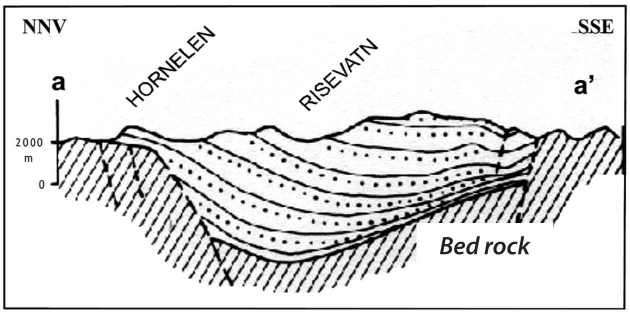


Fig. 4.1.1-2 *Map of the Hornelen basin showing the different types of sediment. Conglomerate was deposited along the basin margins and finer grained sediments filled the rest of the basin. Vingepollen is located at the northern margin of the basin and the boundary between conglomerate and sandstone is on Vingeneset, on the north side of Vingepollen. a-á shows a NNW-SSE cross-section of the Hornelen basin (after Steel et al. 1985).*

Fig. 4.1.1-3 *Crosscutting lamination (cross lamination) is a primary depositional structure in the sandstone.*

Fig. 4.1.1-4 *Band of conglomerate and dispersed pebbles and larger rock fragments on a rock surface on Vingeneset (Vingeneset trial area).*

In the Late Devonian, the sedimentary rocks experienced folding and low-grade metamorphism (Bryhni 1964). This resulted in partial recrystallisation and the growth of characteristic low-grade minerals such as chlorite and epidote. The sedimentary sequence slid westwards on a curved low-angle fault plane during deposition (Bryhni 1964; Steel & Gloppen 1980; Bryhni & Stuart 1985) and this, together with the later folding, resulted in the dip of the layering in the sandstone. At Vingen the primary bedding strikes northeast-southwest and dips ca. 45° south. Many beds exhibit cross lamination (depositional structures consisting of inclined laminae (layers < 1cm)) (Fig. 4.1.1-3). As described in section 2.3.1, rock carvings are found both on rock faces that are parallel to the bedding (south-facing) and on surfaces that cut bedding at high angles (north-facing). The characteristic ridges of rock in the area are parallel to the strike direction.

The sandstone consists predominantly of the minerals quartz (ca. 40–55%) and feldspar (ca. 20–45%) (Table 4.1.1-1). In addition, the rocks contain smaller amounts of mica (ca. 5–10% of muscovite), iron-rich chlorite (ca. 7–12%), epidote (ca. 3–5%) and traces of the minerals apatite, titanite, zircon, rutile, as well as Fe-Ti oxides. The sandstone is mainly cemented by calcite (ca. 5–12%), but locally there is a small amount of quartz cement. Due to the high feldspar content, the sandstone may be classified as arkose (Pettijohn *et al.* 1987).

The grain size in the individual beds and laminae vary from medium to fine (0.500–0.125 mm). Certain beds have small amounts of pebbles (2–4 mm) and large rock fragments. This is particularly common on Vingeneset, at the transition between conglomerate and sandstone (Fig. 4.1.1-4). As previously mentioned, the mineralogical composition also varies somewhat. In particular the total amount of feldspar and the relative amounts of the two feldspar types, plagioclase and K-feldspar. Due to earlier alteration, the plagioclase grains are commonly sericitised (they contain small flakes of mica) (Fig. 4.1.1-5a and b) and are compositionally albites. Beds and laminae richer in clastic mica than adjacent layers are also common (Fig. 4.1.1-5c). Flakes of mica are generally orientated parallel to the bedding. Primary laminae are also defined by concentrations of heavy minerals such as zircon, apatite and Ti-Fe-oxides in thin bands (Fig. 4.1.1-5d). The unweathered sandstone has a dark greyish green colour and little or no porosity. The greenish colour is the result of the content of chlorite and epidote (Fig. 4.1.2-1).

The majority of rock surfaces are cut by northeasterly and southeasterly-orientated fractures partially filled by quartz.

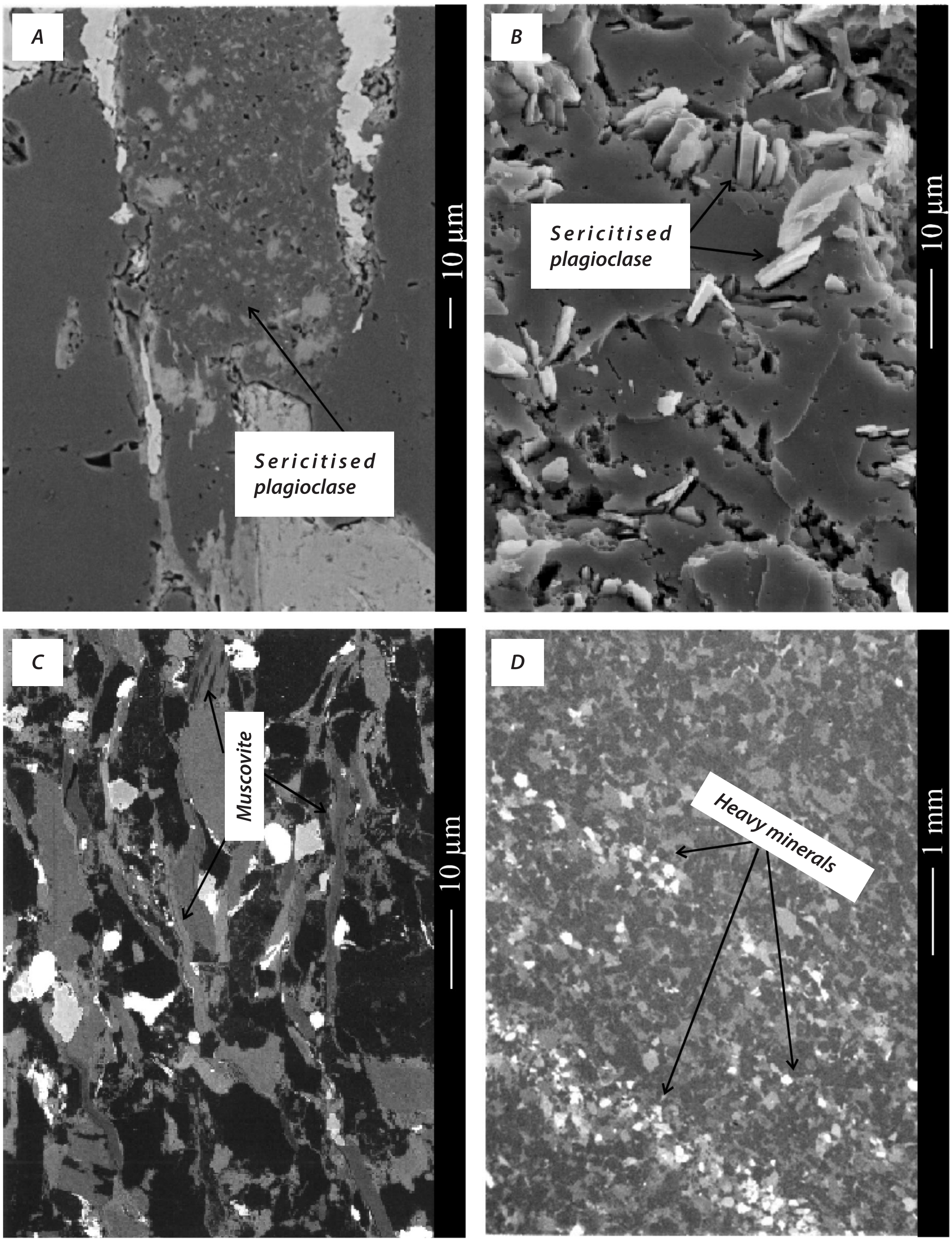


Fig 4.1.1-5 *a) Back-scattered electron (BSE) image of sericitised plagioclase. b) SEM-image of plagioclase with inclusions of sericite. c) BSE-image of sandstone rich in clastic mica. The flakes of mica are orientated parallel to the lamination. d) BSE-image showing primary lamination with concentrations of heavy minerals such as zircon, apatite and Fe-Ti-oxides in thin bands.*

Table 4.1.1-1 Mineralogical composition of Vingen sandstone.

Mineral	Chemical formula (general)	Vol.%
Quartz	SiO_2	40–55
Plagioclase (albite)	$NaAlSi_3O_8$	15–40
K-feldspar	$KAlSi_3O_8$	15–5
Muscovite	$KAl_3Si_3O_{10}(OH,F)_2$	5–10
Chlorite	$(Mg,Fe)_6(Si,Al)_4O_{10}(OH)_8$	7–12
Apatite	$Ca_5P_3O_{12}(F,Cl,OH)$	+
Epidote	$Ca_2(Fe,Al)Al_2Si_3O_{12}(OH)$	3–5
Calcite	$CaCO_3$	5–12
Titanite	$CaTiSiO_5$	+
Trace minerals*		+

** zircon, rutile, iron-titanium oxides.*

4.1.2 Weathering

As a result of postglacial chemical weathering, the rocks at Vingen have an outer porous, commonly bleached weathered zone (Fig. 4.1.2-1 and Fig. 4.1.2-2a). The thickness of this zone varies from a few millimetres to 2–3 cm. The porosity is the result of the partial solution of the different minerals. The degree of solution varies according to the resistance of the individual minerals to chemical attack (Thorseth *et al.* 1997). Since weathering starts on the surface and has been most prolonged, the outermost minerals are mostly dissolved and as a result the porosity is the highest. The porosity decreases beneath the surface of the rocks due to a shorter period of weathering (Fig. 4.1.2-2a).

Calcite is the mineral least resistant to chemical weathering and is therefore dissolved deeper beneath the surface and contributes most to the porosity in the innermost part of the weathered zone (Thorseth *et al.* 1997). At the contact between the weathered and fresh rock calcite has just begun to be dissolved along grain boundaries and along cleavage planes (Fig. 4.1.2-2b). Between 0.5 and 1 mm further out, calcite is, however, completely dissolved. Solution of calcite results in a porosity of 5–12% in the inner part of the weathered zone.

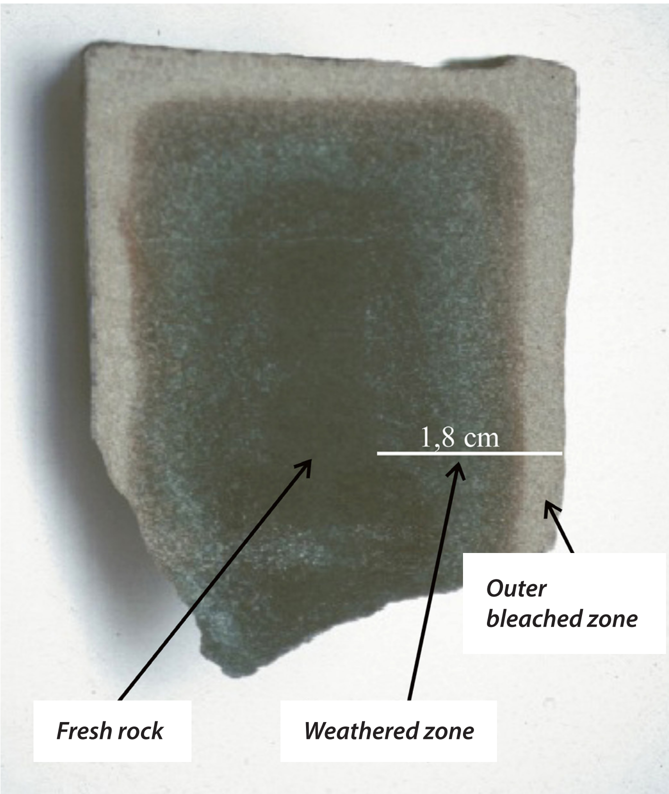


Fig. 4.1.2-1 *Section through the weathered zone into the fresh rock. The weathered zone is ca. 1.8 cm thick. The outer bleached zone is ca. 0.5 cm thick.*

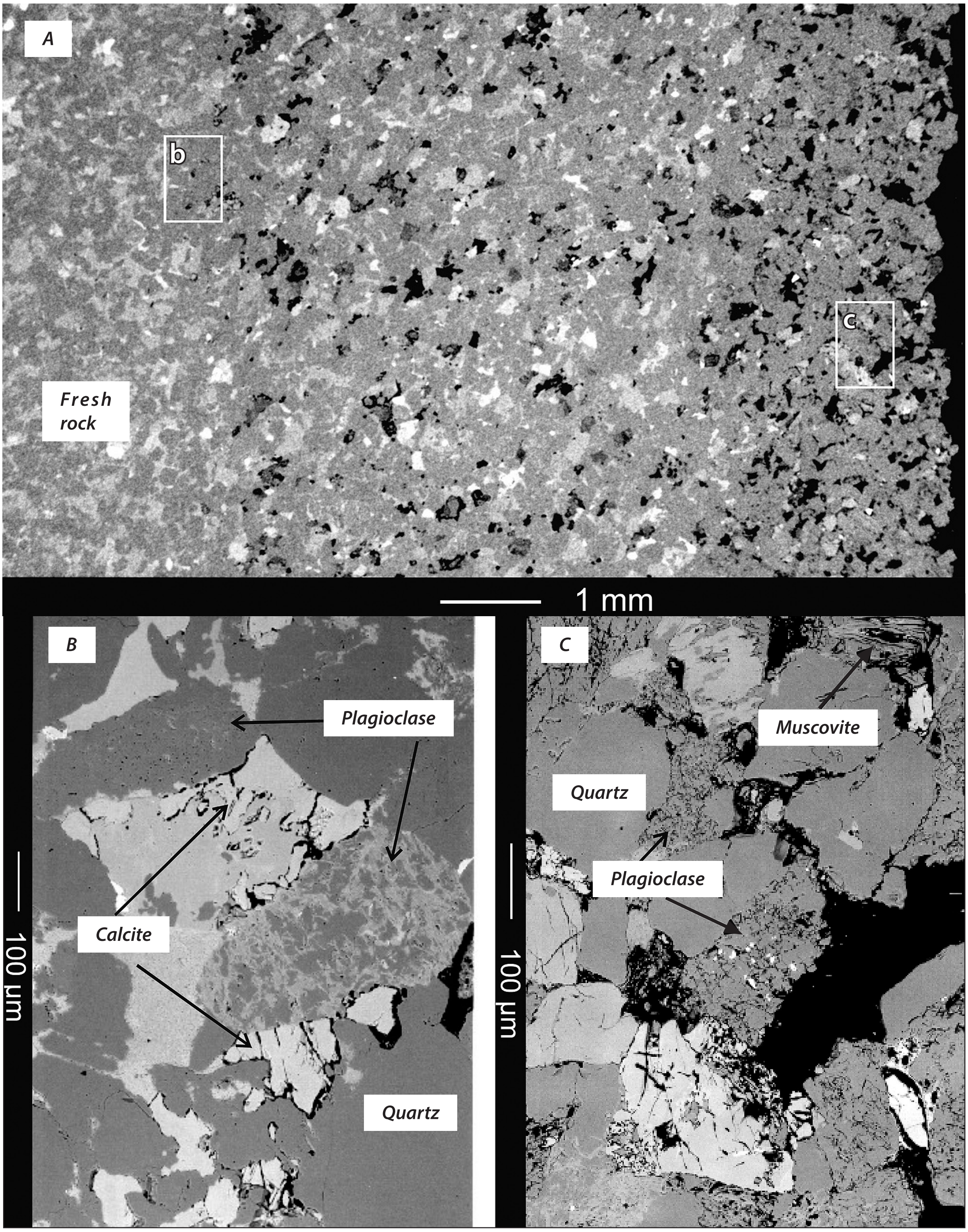


Fig. 4.1.2-2 BSE-images showing a) a section through the weathered zone into the fresh rock. b) nearest the fresh rock, calcite has begun to dissolve along grain boundaries and cleavage planes. Less than 1 mm further out in the weathered zone calcite is completely dissolved. c) In the outermost ~2 mm chlorite is also completely dissolved and plagioclase is partially dissolved. Muscovite exhibits signs of incipient solution and expansion along the basal cleavage.

After calcite, the minerals apatite and chlorite are the most soluble. The rocks contain relatively small amounts of apatite and solution of this mineral contributes little to the development of the porosity. The content of chlorite is higher, however, and is therefore more important. In the outer part of the weathered zone calcite and chlorite are generally completely dissolved. The porosity is therefore higher, commonly 14–20% (Fig. 4.1.2-2). The thickness of the chlorite-free zone is 0 to 6–7 mm. Solution of chlorite results in the outer light grey rind lacking the green colour of the fresher rocks (Fig. 4.1.2-1). As previously mentioned, chlorite in the Vingen sandstone is iron rich (Table 4.1.2-1). Iron-rich chlorite dissolves much more rapidly than magnesium-rich chlorite (Thorseth *et al.* 1997), and this is an important factor in the high degree of solution found here. The solution of apatite normally extends deeper than that of chlorite.

In the outer part of the weathered rind there is significant solution of plagioclase and in places the porosity can exceed 30%. The mineral grains are not completely removed but show clear evidence of solution along the grain boundaries, along certain crystallographic directions and along flakes of mica (sericite) enclosed in the grains (Fig. 4.1.2-2c). Grains of plagioclase are therefore more or less freed from neighbouring grains and partially broken up. Solution of plagioclase generally coincides with the chlorite-free zone. Chlorite is finer grained than plagioclase, however, and complete solution occurs at an earlier stage in the weathering process. Epidote can also begin to dissolve in the chlorite-free zone. Beds and laminae with high porosities will be prone to disintegration into gravel.

Quartz is the most resistant mineral to chemical weathering. It is very stable and shows few signs of solution. Muscovite and K-feldspar are relatively resistant and also show little dissolution. However, in the outermost part of the weathered zone, muscovite is fractured and split open along the basal cleavage (Fig. 4.1.2-2c).

The chemical effects of weathering are fairly well displayed in element maps. Fig. 4.1.2-3 presents element maps of the weathered zone shown in Fig. 4.1.2-2. The maps reflect the solution of calcite in which most of the calcium (Ca) has disappeared throughout the weathered zone. Some Ca remains in the form of epidote and titanite. Phosphorus (P) and magnesium (Mg) have been removed from the outer, most porous part of the zone due to solution of apatite and chlorite respectively. Since chlorite also contains significant amounts of iron (Fe), this element is also depleted in the outer part of the zone. Smaller amounts of Mg and Fe remain in muscovite, epidote and iron oxide. Dissolution of plagioclase in the outer part of the weathered zone is not reflected in noticeable changes in sodium (Na) in the element maps. Concentrations of potassium (K) aluminium (Al) and silicon (Si) also show no change. Quantitative chemical analyses (by XRF) demonstrate, however, a weak depletion in Na in the outer part of the weathered zone relative to the fresh rock (Table 4.1.2-2).

Table 4.1.2-1 *Chemical compositions (weight % oxide) of chlorite, epidote and mica in the sandstone at Vingen (EDS-analyses). The analyses do not report water contained in the minerals.*

	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	FeO^t	Total
Chlorite	1.65	20.22	22.84	33.37	0.31	0.09	0.12	21.34	100.00
Epidote	0.44	0.14	26.20	39.65	0.25	24.34	0.32	8.62	100.00
Mica	0.56	1.78	31.49	50.76	10.53	0.36	0.81	3.31	100.00

FeOt: total iron reported as FeO (divalent iron).

Table 4.1.2-2 *Chemical compositions in weight % oxides (XRF-analyses) of the outer parts of the weathered zones and fresh rocks from four different samples shown in Fig. 4.1.2-2a (sample 1), Fig. 4.1.2-4a (sample 2), Fig. 4.1.2-4c (sample 3) and Fig. 4.1.2-6 (sample 4).*

	SiO_2	TiO_2	Al_2O_3	FeO^t	MnO	MgO	CaO	Na_2O	K_2O	P_2O5	LOI*
Sample 1											
Weathered	70.67	0.73	8.00	2.95	0.02	0.24	1.64	1.46	1.70	0.01	16.39
Fresh	72.49	0.31	9.71	2.36	0.05	1.23	6.87	2.06	2.05	0.07	5.44
Sample 2											
Weathered	71.30	0.73	12.83	4.11	0.03	2.00	1.06	1.13	3.50	0.09	6.83
Fresh	66.28	0.62	11.83	3.96	0.06	2.34	5.15	1.47	3.04	0.15	5.03

Sample 3											
Weathered	74.46	0.46	10.88	2.34	0.01	0.85	0.46	1.07	3.58	0.02	8.86
Fresh	68.24	0.72	15.27	5.31	0.05	3.09	1.17	1.18	4.28	0.16	2.94
Sample 4											
Weathered	75.96	0.41	12.29	2.83	0.03	1.34	0.49	1.58	3.62	0.03	3.47
Fresh	62.71	0.44	10.80	2.90	0.09	1.80	9.54	1.59	3.14	0.10	8.33

** The loss on ignition (LOI) for the fresh rocks is due mainly to the loss of CO_2 from calcite. In the weathered zones the LOI mainly reflects organic material in pores. FeOt: total iron reported as FeO (divalent iron).*

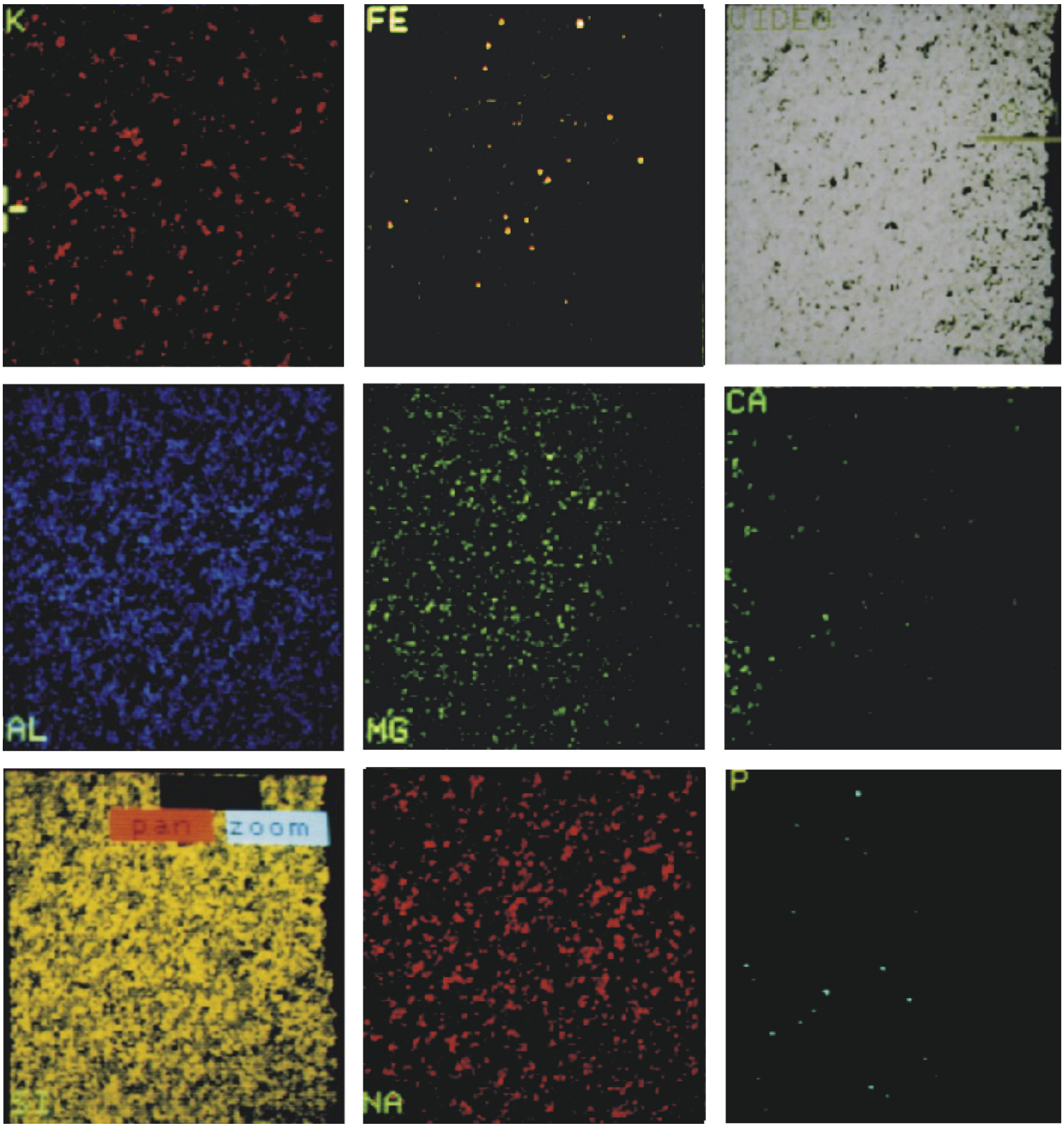


Fig. 4.1.2-3 *Element maps through the weathered zone into the fresh rock (bottom). Most of the calcium (Ca) has disappeared from the weathered zone due to solution of calcite. Phosphorus (P) and magnesium (Mg) is absent from the upper, most porous part of the weathered zone due to solution of apatite and chlorite. Dissolution of plagioclase in the upper part of the zone has not resulted in significant changes in the concentration of sodium (Na). Potassium (K), aluminium (Al) and silicon (Si) also show no change.*

The variation in the texture and mineralogical composition of the rocks is an important factor controlling the degradation of rock surfaces. Due to large variations between different beds and laminae, the outer part of the weathered zone does not always have the highest porosity, even though weathering has been more prolonged here. This is most conspicuous where the rock surface is parallel with the bedding, and where the alternating layers have large differences in calcite content. If the outermost layer was originally poorer in calcite relative to deeper layers in the weathered zone, the porosity will be lower than further beneath the surface (Fig. 4.1.2-4a). Beds with little calcite are generally mica-rich and/or finer grained.

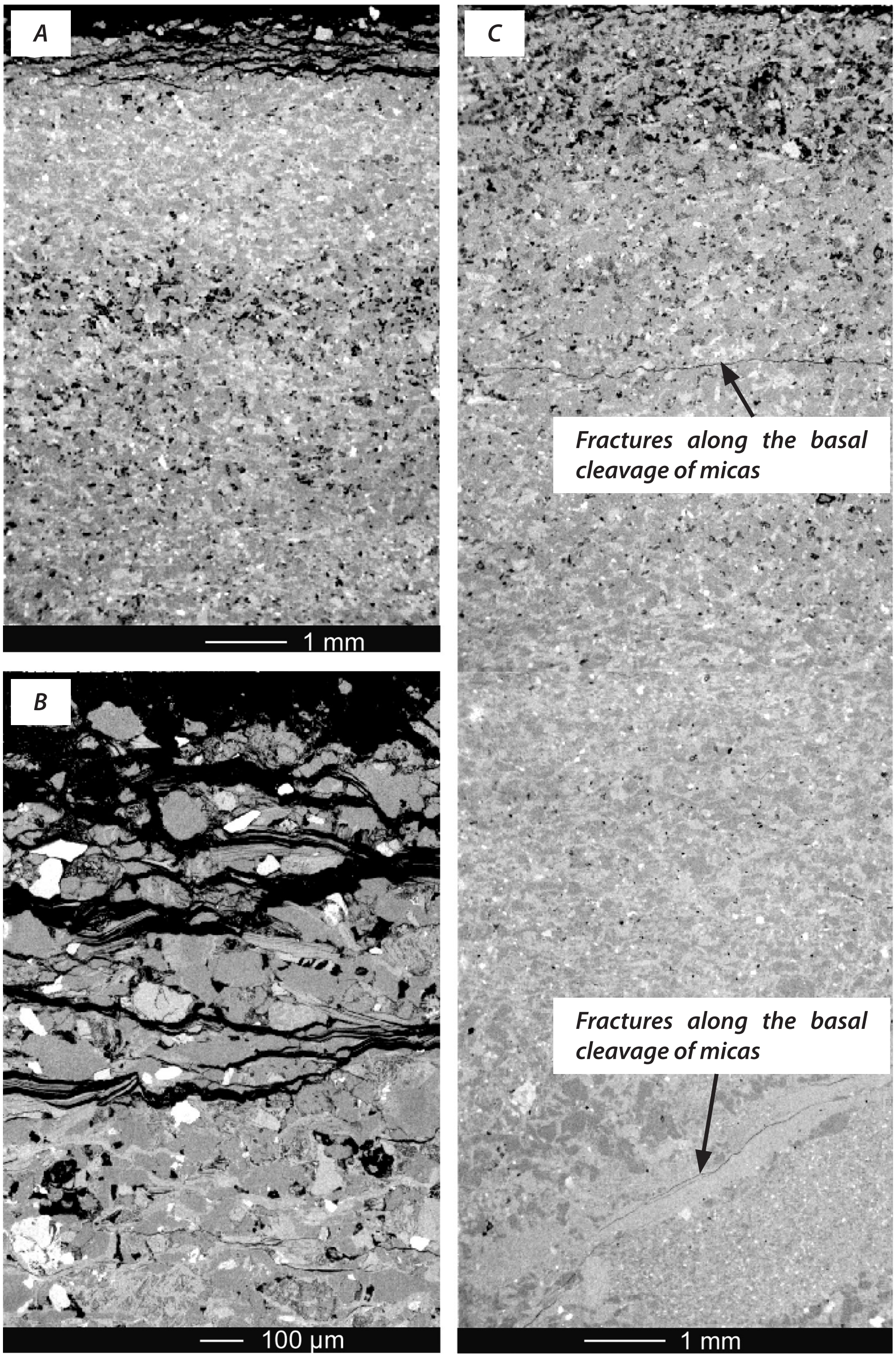


Fig.4.1.2-4 *BSE-images showing the variation in the texture and mineralogical composition of the sandstone. a) A mica-rich outer layer has a lower porosity than the underlying, originally calcite-rich layer. b) Fractures along the basal cleavage of micas in the outer part of the weathered zone results in spalling of the surface. c) Fracturing along flakes of mica deeper in the weathered zone.*

Splitting open of the basal cleavage of micas in the outermost part of the weathered zone commonly leads to the weathered crust flaking off (Fig. 4.1.2-4a and b). Mica-rich beds can also produce weak zones deeper in the weathered crust (Fig. 4.1.2-4c).

A high content of mica is reflected in element maps and chemical analyses by high concentrations of K and Al (Fig. 4.1.2-5 and Table 4.1.2-2). Laminae that are particularly rich in mica generally have less plagioclase and quartz, as reflected by lower concentrations of Na and Si. In certain fine-grained layers, the content of chlorite is higher than elsewhere, but these are dissolved slowly due to their paucity in calcite and consequently have a low porosity.

Physical stress, due to factors that include frost wedging or biological action (5), can lead to fracturing along planes of weakness such as the contact between fresh and weathered rock as well as between individual beds and laminae within the weathered crust (Fig. 4.1.2-4). On south-facing rock surfaces that are parallel with bedding, this commonly results in the surface rind flaking off. On north-facing slopes, the planes of weakness parallel with the bedding are not parallel with the rock surface and flaking is therefore less common. Where spalling does occur, fracture surfaces are very uneven (see Fig. 3.2.3-1). This is probably a result of the depth of weathering varying from layer to layer as a result of different textures (grain size) and mineralogical composition (Fig. 4.1.2-6).

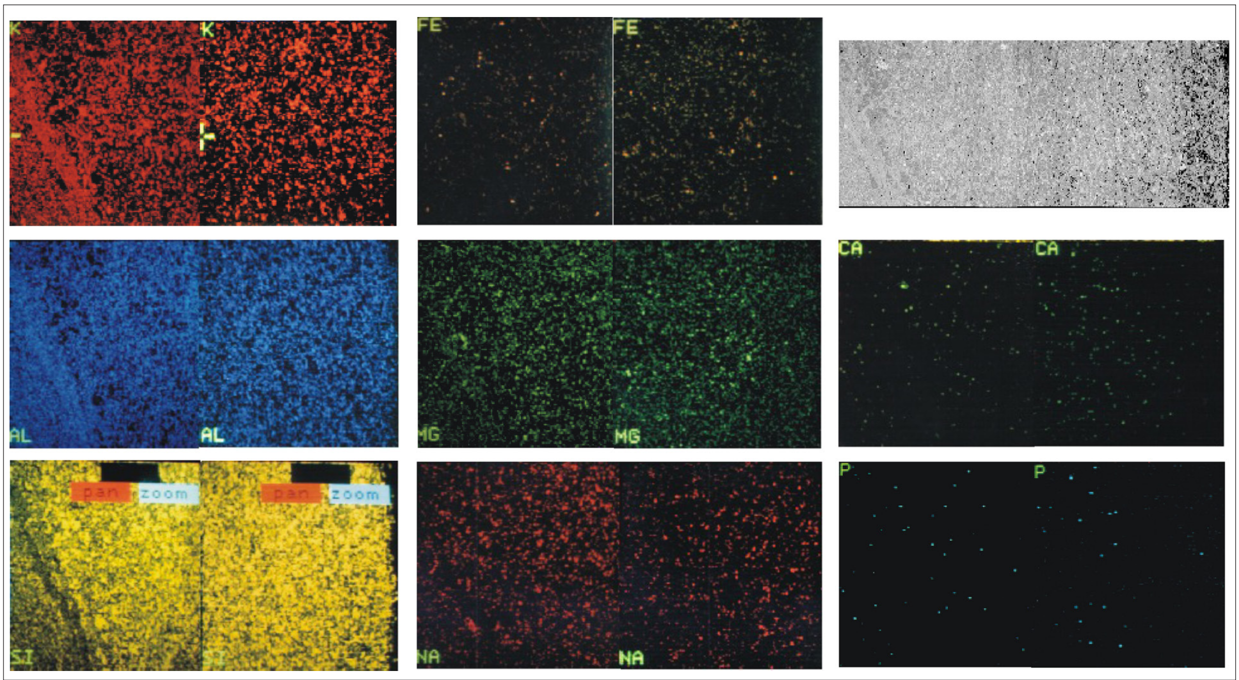


Fig. 4.1.2-5 *Element maps of the section shown in Fig. 4.1.2-4c. The uppermost zone with high porosity probably was rich in calcite (Ca). The rest of the section has a low porosity, indicating a low calcite content. Low contents of Mg and Fe in the upper porous zone indicates dissolution of chlorite. A high content of mica is reflected in high amounts of K and Al. Lesser amounts of chlorite, plagioclase (Na) and quartz (Si) than elsewhere can be seen in the particularly mica-rich lower part.*

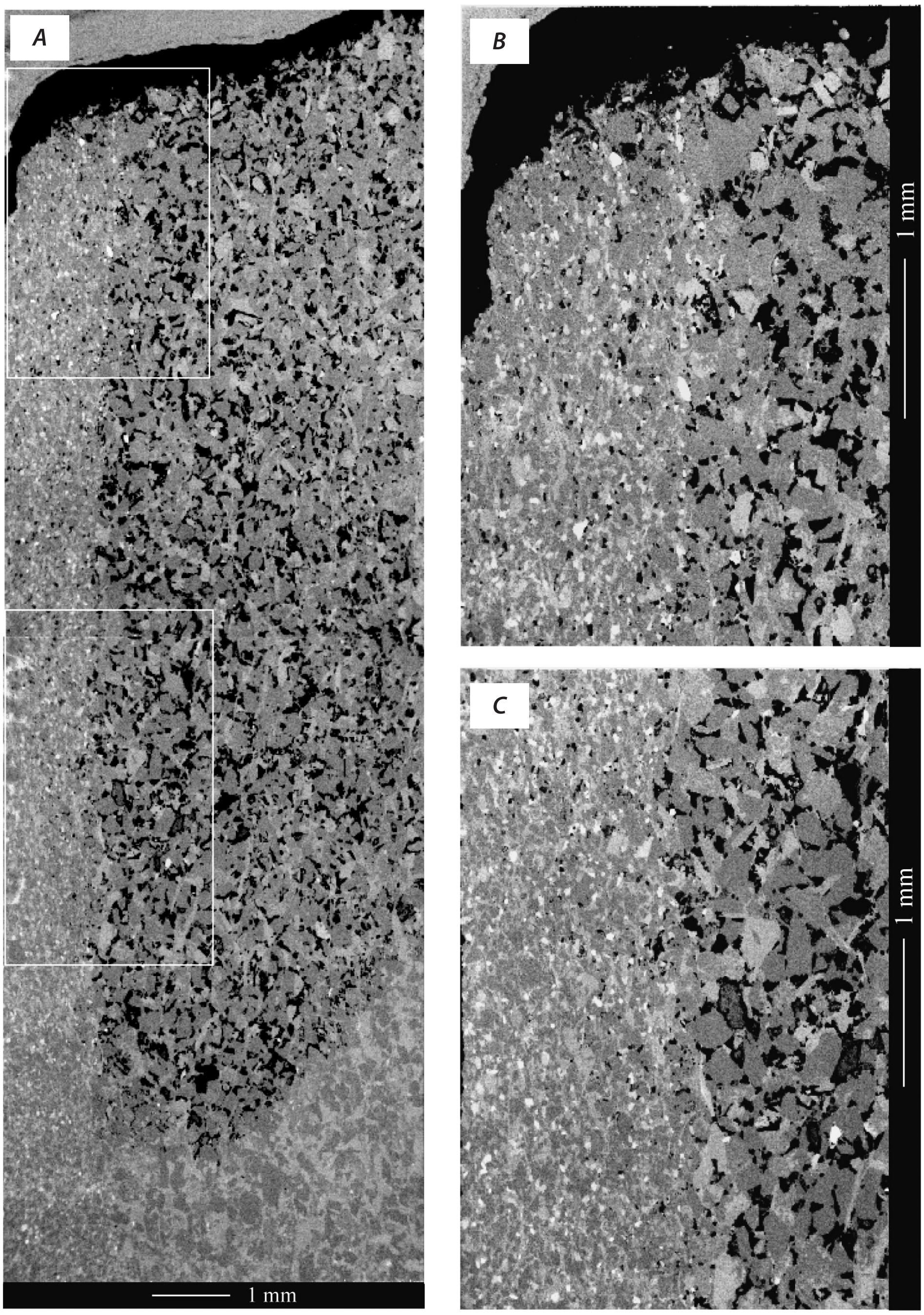


Fig. 4.1.2-6 *BSE-images showing how both porosity and the depth of weathering vary between individual lamina due to differences in grain size and mineralogical composition a) Section through the weathered zone of a rock surface that cuts the bedding with a relatively large angle. b) and c) show details of the marked fields in a.*

4.2 Climate

The climate at Vingen is characterized by its closeness to the open sea and to a large extent by the topography in the area. Throughout much of the year, especially in autumn and winter, the weather is dominated by westerly winds and frequent relatively large amounts of precipitation. In spring and summer there may be periods with strong easterly wind, and then with a marked foehn-effect with unusually high temperatures and dry air. It is also typical for the Vingen area that the pattern of strong winds is almost chaotic, often with strong and short-lived down-winds within limited areas.

The main site is surrounded by high mountains limited amounts of sunlight, although there are variations within short distances. In summer, the mountain Vingekvarven (900 m.a.s.l.), to the east, delays local sunrise until noon, and between October 23 and February 17 the sun is below the horizon all day. (Fig. 4.2-1). Towards the west – southwest (245 deg) the Frøysjøen fjord provides an opening and a glimpse of the open sea.

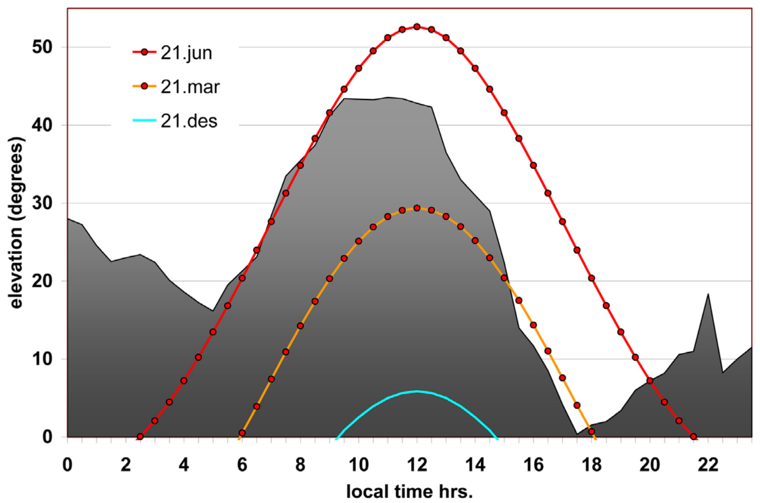


Fig. 4.2-1 Horizon seen from the site of the automatic station at Brattbakken. Sunpaths are drawn for summer solstice, vernal /autumnal equinox and winter solstice.

4.2.1 Temperature

In November 1996, an automatic meteorological station was set up at Vingen (Fig 5.1.2-1). In summer, the temperature may be high on days with clear skies and only weak winds. Then the night temperature is also relatively high, due to back radiation from the steep surrounding mountains. However, frequently cool westerly winds and sea fog give low daytime temperatures even on cloudless days. In winter, the temperature climate is relative mild and below 50 m.a.s.l. snow cover is present only in few and short periods. The most frequent episodes with temperature changes from plus to minus degrees, or minus to plus, are in January and February, and the typical length of a period with temperatures below 0 °C is 5 to 7 days (Table 4.2.1-1).

Data for a longer period (40–50 years) from the nearest permanent climatic stations is used to analyse if there have been significant climatic changes during the project period. Because of the short distance to the open sea and only sparse shielding towards the west, frequent changes between frost and mild periods are common in winter. A comparison of climate in the normal periods 1931–60 and 1961–90 indicates that annual mean temperature in this area has increased over the last 40–50 years. The increase is more obvious in night time than in daytime temperatures. This change is also found in the measurements from the station at Ytterøyane Fyr (61° 34', 4° 41'). Since 1957 there has been an increase in January mean minimum temperature of approximately 2 °C. A corresponding increase in the maximum temperature is 0.5–0.8 °C. Consequently, the number of days with frost (T_{min}< 0°C) in January since 1957 has been reduced from 15 to 5 (Fig. 4.2.1-1), and the number of episodes with daily temperature changes between plus and minus-degrees has been reduced from 11 to 4. Similar but smaller changes in temperatures have been found in the other winter months.

***Table 4.2.1-1.** Normal values for temperature (T), precipitation (RR) and number of days with freezing/thawning episodes (T±) for the station Ytterøyane Fyr (DNMI).*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T	2.8	2.3	3.0	4.5	7.8	11.0	12.5	13.1	11.1	9.1	5.8	3.7
RR	95	71	80	58	54	57	72	91	136	139	130	116
T±	11.3	11.5	9.0	2.1	0	0	0	0	0	0	1.0	6.2

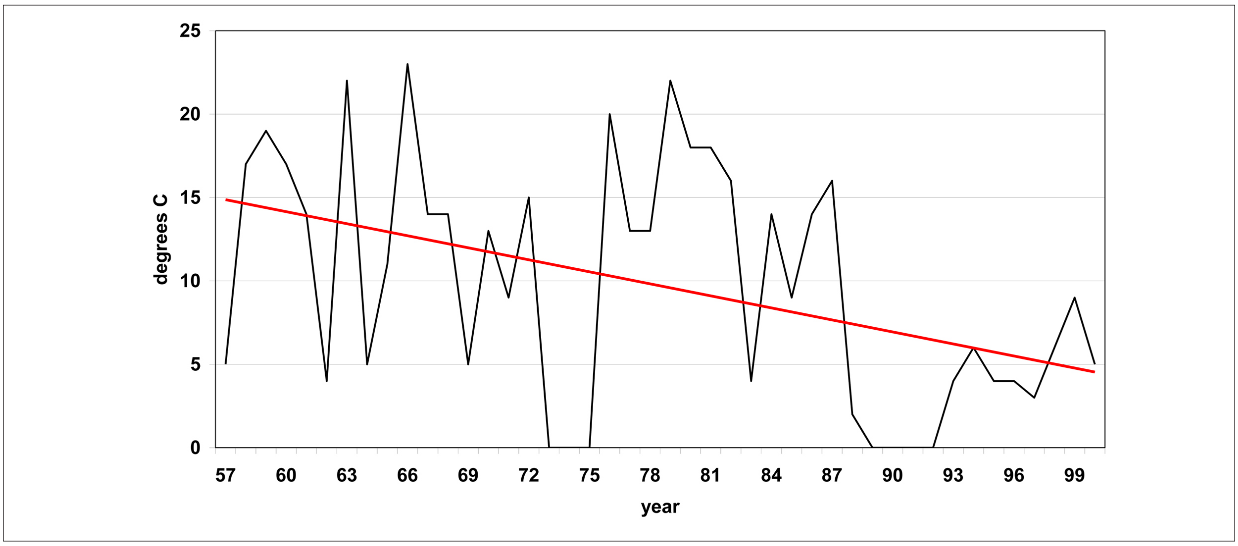


Fig. 4.2.1-1 Number of days with frost (Tmin < 0^{0}C) in January in the period 1957–00. The red line indicate the average trend in this period, from 15 days in 1957 to 4 days in 2000.

4.2.2 Wind

The main wind direction on the coast (Ytterøyane) in the winter is from the south to west. In the summer, northern winds are most prevalent. The most common local wind direction near the ground in the inner part of Frøysjøen is therefore in and out of the fjord. As the station at Vingen is situated close to steep and high mountains both to the north, east and south, the local wind system is very changeable and often difficult to explain from a more large-scale system. In periods with strong winds, powerful whirlwinds may occur, often resulting in a large amount of sea water being sprayed over the land (Fig. 4.2.2-1).

Fig. 4.2.2-1 A frequent situation at Vingepollen; In periods with strong winds aloft there is observed strong whirl-winds near the surface, causing sea water to be sprayed in over land.

4.2.3 Precipitation

The average annual variation of precipitation in these districts is given by normal values from Svelgen and Davik in Table 4.2.3-1. These two stations are situated almost at the same distance from the coast as Vingen, and it is assumed that the average precipitation amounts for the months and year are almost equal. The average annual precipitation in these districts is 2200–2600 mm. In autumn and winter, cyclones with frontal precipitation cross over from the west. The highest amounts of precipitation are therefore recorded in situations with winds from a southerly or a south-westerly direction. Among these three stations, Svelgen has recorded the highest amounts in all months.

A comparison of the normal periods 1931–60 and 1961–90 indicate that annual amount of precipitation has increased by 15% over the last 40–50 years. The strongest increase has been in the autumn, winter and spring (20%), while the increase in summer precipitation has been smaller (5–10%)

The nearest industry producing polluting smoke is the Bremanger melting plant in Svelgen, about 10 km south of Vingen. The present sulphur (SO_2) emissions are reported to be 700–800 tons/year and the sulphur content in the air measured locally is relatively small (Aamlid 1983). Before the governmental demand for cleaning measures in 1974, the amount of contaminating outlets were probably much higher. The direction of the most frequent winds in this area will lead the contaminated air masses outside Vingen, and these outlets will therefore only affect the air quality at Vingen in a very few and special weather situations.

Table 4.2.3-1 *Precipitation normals (1961-90) for the stations Svelgen and Davik*

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Svelgen	229	174	200	123	109	128	155	186	322	326	316	292	2560
Davik	232	166	189	112	90	100	116	147	296	292	294	291	2325

4.3 Vegetation

The macro vegetation of both Vingen and Vingeneset has been shaped by a combination of human activity and the harsh climatic conditions of this region. The climate is heavily influenced by the sea, and is characterised by relatively high winter temperatures and low summer temperatures. The precipitation and air humidity are high. Climatically the locations belongs to the O3 Highly oceanic section, subsection O3h (Moen 1999). This section is characterised by western vegetation types and species that depend on high air humidity. Both plants that are highly frost sensitive and continental plants are absent in this section. Botanically, the investigated area at Vingeneset is within the boreonemoral vegetation zone, while most of the north-facing slopes of Vingen are within the southern boreal zone (Moen 1999). Grasslands dominate the vegetation within the research area of Vingen, while vegetation at Vingeneset can be classified as coastal heathland in the degradation phase, and is dominated by old heather (*Calluna vulgaris).*

The most typical grassland vegetation of Vingen today is found on the former infields, which have been cultivated with great effort by farmers over several generations (cf. 4.4). All of the patches are small and scattered between knolls and mound of stones. Some have been established by building dry-stone terraces. The soils are shallow and poor in nutrients; some patches are well drained, while others are wet and stagnant. The dominant grassland vegetation type can be classified as G4, Common bent – red fescue- sweet vernal-grass grasslands; sub-type G4b: Pignut (Fremstad 1997). Generally, this vegetation type is characterised by widespread species that are low in nutrient demands. Common species in Vingen are *Agrostis cappilaris*, *Festuca rubra, Holcus mollis, Anthoxanthum odoratum, Conopodium majus* and *Galium saxatile.*

Fremstad & Moen (2001) specify five variations of the sub-type G4b, based on the work of Losvik (1993). At Vingen, the presence of the species *Galium saxatile* and *Viola palustris* classifies the Vingen grasslands more precisely to the sub-type variation *C. majus –G. saxatile* (pH 4.7; base-saturation 10%) (Losvik 1993, Fremstad & Moen 2001). As a vegetation type, it is regarded as critically endangered (Fremstad & Moen 2001). The patches in Vingen are small, but all of them are well developed and therefore valuable, especially in the light of their long lasting land use history. Two of the most important species in the vegetation type, *Conopodium majus* and *Hypochoeris radicata,* are considered as regional responsibility species for West Norway.

In our investigation, we wanted to test the soil-chemistry response to CaO and phosphate fertilizing. The applied treatments are also suspected to induce vegetation changes in the *Calluna* dominated patches of Vingeneset, and a survey of the vegetation responses was set up to monitor possible effects. At Vingen 4 grassland patches were investigated. Here, the treatments were expected to maintain the grass-dominated cover and prevent succession towards heathland. The sites of Terrassane, Bakkane and East of Vehammaren can all be classified as G4b sub-type variation *C. majus – G. saxatile*. Occurrence of the species *Cerastium fontanum spp. vulgare* distinguishes the vegetation type in Vingen from the typical variation type as described in the literature (Fremstad & Moen 2001). The patch in Bakkane is influenced by a lack of suitably maintained drainage systems, and as a result is damp and partly stagnant. The fourth location, Bak Vehammeren, differs in soil texture, soil depth, and species composition. This patch is an old hay meadow cultivated from a former marsh. The species composition reveals signs of this, although the grassland species is most extensive. The patch has generally fewer species than the other patches and less bottom layer.

Land use history differs between the patches (cf 4.4). While Vingen was permanently settled, old pictures show that Terrassane contained arable fields used for growing potatoes or grain. The other patches were used as hay meadows. Traditionally, hay meadows were mown once a year in this region, and grazed both in spring and autumn.

In Vingeneset, heathland, bogs, shrubs and trees dominate the vegetation. The most important species is heather (*Calluna vulgaris*), and this is a species that dominates coastal heathlands. *Calluna vulgaris* is a plant that undergoes cyclical succession, and four phases can be recognised characterizing heathlands; pioneer-, building-, mature- and degenerate phase (Watt 1955, Grimmingham 1972). During the building and mature phase *Calluna* forms a close canopy and is able to suppress its competitors almost entirely. During the late mature phase, and especially the degenerating phase, the canopy opens up, allowing more light to reach the growth, and other species to invade. At Vingeneset, most of the *Calluna* has reached the late mature and degenerative phase, and trees such as European mountain ash (*Sorbus aucuparia*), birch (*Betula*) and juniper (*Juniperus communis*) have become established. Grazing and burning can prevent the cyclical succession.

The coastal heath at Vingeneset varies between wet and dry heath. The wet heath is situated in the flat areas, and Sphagnum- and Trichophorum species indicates wetness. Bogs and wet heaths are situated side by side with no clear distinctions. The dry heath is found on the slopes, especially on the rocks. However, the evergreen *Calluna* was traditionally used as winter fodder in the former agricultural system. *Calluna* is sensitive to trampling, heavily grazing and manure, and explains why grassland vegetation is often found in spots preferred by sheep.

Today, after grazing has been abandoned, the vegetation of Vingeneset is a mixture of different succession stages leading towards forest closure, and is dominated by species that lower the pH. A succession towards heathland and forest closure is also expected to take place in the Vingen part of the area if grazing pressure is reduced. The aims of the experimental treatments in this part of the study are to prevent the ongoing succession from grassland towards heathlands in the Vingen localities, and to induce transaction from heathland to grasslands at the lower plain at Vingeneset.

4.4 Recent history and agricultural land use

A brief examination of early Norwegian agricultural Records (Matrikkel) shows that the agricultural settlement at Vingen is old. In 1665, one family lived in Vingen with 4 cows, without any arable land, and mainly paid its taxes in fish. In 1758 the farm belonged to St Jørgens Hospital, and is found in their property records. No information of agricultural production has been available. The same occurs in 1835, although Vingen was then settled by two families. At the end of the 19th century the statistics provide more information and the records are much more frequent. In the years between 1865–1875, a period when agriculture was modernized and in expansion, two families lived in Vingen. The farms, as a supplement to fishery, sustained 15 people, who had 5 cattle and 11 sheep between them. In the arable fields they grew half a barrel of oats and 1 barrel of potatoes. Oats were not grown regularly every year. The area of natural grassland was measured at 0.8 ha, and it is likely that this includes the arable field. The farms had forests for the maintenance of buildings and for supplies of wood, but not for sale. The farms were regarded as normal in terms of their location, access and farmland quality(!).

After the permanent settlement was abandoned in 1936, the neighbouring farm of Vingelven continued agricultural land use in Vingen for several years. The hayfields were still mown, usually at the end of July (Helga Vingelven, pers. com) and the grass was dried in haystacks in the field and transported home during the winter. In some years the fields were fertilized by farmyard manure, but this was only under special circumstances as this practise was very labour-intensive. According to Helga Vingelven, Vingeneset was mown on a regular basis and maintained as an outlying hayfield during this time. In spring and autumn, the area was grazed by cattle, goats and sheep. Mowing of heather in the outland was also practised, and heather was regarded as a valuable supply of winter fodder. After 1970, the area was mainly grazed by goats and a few sheep for several years, and later only by sheep. The goats started the grazing season as soon as the climatic conditions were favourable. Young sheep without lambs joined the grazing herd a few weeks later, usually between April and May. Finally, the adult ewes and the young lambs were led to the pastures in Vingen. In mid-summer the infields were enclosed while the animals grazed the outland pastures. In the autumn, the animals were once again allowed to graze the infields. In particular, goats grazed during the autumn in Vingen, and the season was extended for as long as possible due to climatic restrictions. Both the grassland area and the steep mountain slopes were grazed, a practise that sustained a mosaic between grass and heath-covered ledges along the mountainsides.

4.4.1 The present lichen flora at Vingen

The lichen flora is essentially the same in Vingen and on Vingeneset. Everywhere there is a variety of habitats, each with its characteristic species. It is principally the interplay between light, humidity, and temperature that controls the distribution of the lichens, reflecting their ecological adaptation. Registration has concentrated on lichens on rocks and faces where rock carvings are present. Lichens growing on trees or soil and in the littoral zone have not been investigated in any detail.

During the course of the last century, different forms of human intervention have affected the lichen population in the Vingen area. The possible effect of pollution from the factory at Svelgen on saxicolous lichens (which grow on rock) and epiphytic lichens (which grow on trees) during the period 1979–1981 has been investigated in the area north of Svelgen (Aamlid 1983). This demonstrated that pollution had affected lichens in the area around the plant. There is less pollution today, and no effects are visible on the lichens in the Vingen area. Whether earlier pollution from the factory has affected the development of the present lichen flora is, however, uncertain.

Activities around, and on, the carved rock surfaces over the last 5–10 years have had a visible effect on the amount and type of vegetation present today. Rock surfaces that have been covered for longer periods, or have been cleaned, have been exposed at different times and it is possible to observe different stages in their re-colonisation. Pioneer species have become established on clean surfaces, but observations in the field indicate that species present on nearby surfaces will also colonise these surfaces relatively quickly.

Apart from surfaces recently exposed due to exfoliation, rock surfaces with a large amount of seepage, surfaces in the shade, surfaces exposed to sea spray, surfaces that have been treated and surfaces that have been recently covered are generally covered by lichens. Crustose lichens predominate on surfaces with rock carvings. Some moss is found on the surfaces, but generally only in larger fractures and depressions. A representative lichen-covered rock surface at Vingen is shown in Fig. 4.4.1-1. At present, about 90 species of lichen have been recorded from the carved rock surfaces at Vingen, of which about 60 are crustose lichens. Foliose lichen occurs in patches, often on the tops of large blocks of rock or individual exposures. Fruticose lichens are rare on the rock surfaces themselves, but are found together with mosses in cracks and depressions and along the edges of surfaces and macrovegetation.

4.4.1.2 The influence of environmental factors on the spatial distribution of saxicolous lichens

Some of the recorded lichens have a characteristic distribution. Loose rocks and surfaces just above sea level are covered by a belt of black crustose lichens belonging to the *Verrucaria* family (Fig. 4.4.1.2-1). These species

Fig. 4.4.1.-1 *A representativ surface in Vingen covered with lichen.*

Fig 4.4.1.2-1 *a) Just above sea level a belt of crustose lichens belong to the Verrucaria family can be found b) Close-up of the black crustose lichen.*

tolerate wave action. Places facing south or towards the sun can lack the typical belt of *Verrucaria*, but it is usually present in shady locations. The orange-yellow lichen *Caloplaca marina* and the grey *Lecanora helicops* occur at more secure heights above the sea. Higher up, where the effects of salt are reduced, the yellow-green, fruticose lichen *Ramalina siliquosa* can be found, generally in more sheltered spots, as well as the characteristic orange lichen *Xanthoria parietina*. The number of lichen species increases rapidly away from the sea.

Certain lichen species grow in the whole area, while others have a more restricted occurrence. Species that develop a large thallus (visible surface lichen) may cover large parts of rock surfaces. *Ochrolechia tartarea* (see Fig. 5.3.2.2-1b) covers large parts of the west-facing rock surface at Hardbakken, while large *Ophioparma ventosa* (see Fig. 5.3.2.2-1c) thalli are found on the southwest facing parts of Vehammaren. Below ledges there are also characteristic species that may cover large surfaces. These are generally sorediate or leprose (with the appearance of fine powder). *Haematomma ochroleucum* is an example of such a species. It has a white, powdery appearance with red apothecia (fruiting bodies). Another leprose species found below overhangs is the yellow-green *Schismatomma umbrinum*. Other species can predominate on a surface even if their thallus is small. For example, on Brattebakken there are small thalli of *Porpidia tuberculosa* in bands parallel with the layering in the sandstone.

The effect of vegetation cover, radiation, microhabitat variables, and maritime influence on the floristic composition of the saxicolous community in Vingen has been studied in detail. Particular emphasis is put on the local distribution of *Fuscidea cyathoides*, *Ochrolechia tartarea*, *Ophioparma ventosa*, and *Pertusaria corallina*. These species were chosen as focal species because they are common in Norway (Santesson *et al.* 2004) and in the study area of Vingen, because they are easily identified in the field, and because valuable knowledge about the lichen-rock interface in Vingen already exists (see 5.3 and 5.4.1), Bjelland & Thorseth, 2002).

The fieldwork was carried out in 1998 and 1999. The data were collected on five perpendicular transects on the southern side of the Vingepollen fjord. The distance between each transect is about 100 m, and the length of each transect varies between 60 and 140 m, as each transect starts at sea level and ends where the grazed field stops and the steep topography prevents further analyses. Along each transect, 20 × 20 cm squares were centred on all specimens of the four focal species (*Fuscidea cyathoides*, *Ochrolechia tartarea*, *Ophioparma ventosa*, or *Pertusaria corallina*, Fig. 5.3.3.3-1). Environmental variables were recorded for the selected specimen in the middle of the square. Squares on the transects not containing any of the four species were not analysed. In each 20 × 20 cm square total percentage cover of all species (lichens, cyanobacteria, bryophytes, and vascular plants) and bare rock were recorded. The data set consisted of 448 squares and 91 species altogether; 77 lichen species (including 7 unidentified species), 1 cyanobacteria species, 11 bryophyte species, and 2 vascular plant species. For each 20 × 20 cm square, 14 environmental variables were recorded. The data were analyzed by different statistical methods (e.g. ordination and logistic regression). For a more detailed description of the analyses, see Bjelland (2003).

Very little of the variation in the lichen community composition is directly relatable to measured micro-environmental variables (9%), although variance partitioning shows that vegetation cover (31%) explains more of the floristic variation than radiation (28%), maritime influence (21%) and microhabitat variables (4.4%). Nevertheless, logistic regression analyses indicate that the microenvironment influences the spatial distribution of the four species.

Different life strategies, or adaptations, may explain why the studied species coexist with different spatial patterns at a local scale. Based on the results of this study, *Ophioparma ventosa* appears to be a micro-environmental specialist (high radiation, low maritime influence) with strong ability to pre-empt space on the rock surface, while *Fuscidea cyathoides* appears to be a generalist regarding habitat preferences, with weak space pre-empting ability. *Ochrolechia tartarea* appears to be a specialist with high tolerance for maritime influence, but a weak ability to pre-empt space on the rock surface. *Pertusaria corallina* appears to be both a habitat generalist and to have a relatively good space pre-empting ability.

Fuscidea cyathoides occurs more or less everywhere in the area and has fewer fungal hyphae within the rock, compared to the other species (Bjelland & Thorseth 2002). This pattern indicates that *Fuscidea cyathoides* rapidly establishes on bare rock, but has a lower ability to resist the competitive effect of other species. It may thus move around in the area over time, in accordance with the "carousel model" (van der Maarel & Sykes 1993). Similar patterns are observed for vascular plants and bryophytes.

The high fraction of unexplained floristic variation, 91%, is suggested to result from (1) lack-of-fit of data to the response model, (2) some influential environmental variables that have not been recorded, (3) local historical factors that affect present-day distribution, and/or (4) apparent randomness in colonisation. The results are in line with the view that the four lichen species particularly emphasised in this study are also able to coexist in a long-term perspective because of different spatial distributions resulting from different strategies with respect to ecology, dispersion, and interaction (Bjelland 2003).

4.4.1.3 Biological diversity within the rock

The lichen-rock interface constitutes more than just the lichen; it is a small ecosystem. A diverse community of bacteria, algae, lichenized and non-lichenized fungi can inhabit the lichen-mineral interface, though fungal hyphae constitute more than 90% of the biomass in the studied samples (Fig. 5.3.2.2-5). No bacteria were noted beneath *Ophioparma ventosa*, probably because this lichen contains usnic acid that has an antibacterial effect (Lauterwein *et al.* 1995).

Until recently, it has been assumed that crustose lichens either cover the surface of the substrate or that they are restricted to the uppermost few millimetres of the substrate on which they grow. However, there are a number of observations of fungal hyphae occurring inside rock covered by epilithic (growing *on* rocks) or endolithic (growing *within* rocks) lichens. These observations come from applications of scanning electron microscopy (SEM), but using this technique alone, it has not been possible to ascertain whether the hyphae belong to the lichen fungus or to any other fungi potentially present in the rock, largely because individual fungal hyphae are difficult to trace through the rock. Bjelland & Ekman (2005) circumvented this problem by using a DNA sequencing approach. They studied (1) the depth to which an epilithic, crustose lichen fungus can penetrate into rock using an accurate identification method, and (2) they assessed the extent of the fungal diversity inside the rock beneath a lichen thallus.

Cores were drilled in Vingen from a rock harbouring the crustose lichen *Ophioparma ventosa* on the surface. The cores were cut vertically, and DNA was extracted from the pulverized rock slices. A series of polymerase chain reactions using fungal-specific primers as well as *Ophioparma ventosa* specific primers were employed to amplify the internal transcribed spacer (ITS) region of the nuclear ribosomal DNA.

The results demonstrate that most of the fungal hyphae within the rock below thalli of *Ophioparma ventosa* belong to this species, and that its hyphae penetrate through the upper part of the weathering rind to a depth of 10-12 mm into the rock. However, the amount of lichen fungus seems to decrease with increasing depth. This means that the thickness of the hyphal layer formed by the lichen fungus inside the rock is at least 7–12 times as thick as the symbiotic (green algal containing) thallus that is visible at the surface of the rock.

Although hyphae of *Ophioparma ventosa* appear to dominate, an additional 13 species of fungi were encountered in the total of c. 54.3 cm^3 of weathered rock that was investigated. One of the unidentified species of the ascomycete Helotiales order (Class Leotiomycetes), Helotiales I, occurs in six of the eight cores. This suggests that this is either a common endolithic species or a symbiont or parasite associated with *Ophioparma ventosa*. The other unidentified Helotiales species, Helotiales II, occurred in only one of the samples. There is an interesting (but admittedly speculative) possibility that these helotialen fungi are related to groups forming ectomycorrhiza with members of the angiosperm family Ericaceae (McLean *et al.* 1999). As the vegetation in the sampling area includes several species in the Ericaceae, this seems possible.

Two different species within the studied cores have been identified as belonging to the ascomycete family Mycosphaerellaceae (Dothideomycetes et Chaetothyriomycetes incertae sedis). Many of the species in this family are plant pathogenic fungi (Crous *et al.* 2001).

Species in the Saccharomycetes and *Penicillium commune* occur in a very wide range of habitats, and it is consequently possible that they could also occur endolithically. The two basidiomycetes found in the cores were 100% identical with two *Malassezia* sequences in the GenBank. Both *Malassezia globosa* and *Malassezia restricta* are know to cause skin diseases, but they have recently also been found in association with soil nematodes in Europe (Renker *et al*. 2003).

Recognizing the possibility that the inside of an ordinary rock can sustain a diversity of non-lichenized and lichenized fungi opens up a series of intriguing possibilities. Firstly, rock-dwelling lichen communities, often forming spectacular, complex mosaics on rock, may be shaped by more species than previously understood, i.e., not only by competition between lichens, but between lichens and non-lichenized fungi. Furthermore, competition between lichens may extend deeper into the rock than has been thought. It is interesting to note that, in this case, the weathering rind contained no detectable trace of fungal hyphae from neighbouring lichen thalli. Secondly, we normally assume that lichen colonisation takes place from above, either through the relichenization of ascospores of the lichen fungus or by lichenized vegetative propagules of the lichen thallus, e.g., soredia, isidia, or simple thallus fragments. However, with hyphae of the lichen fungus firmly settled at considerable depths, the possibility of colonisation (or regeneration) from below cannot be ruled out, assuming that cells of the correct photobiont species are available at the rock surface. Thirdly, biologically mediated weathering of rock, caused by lichen-forming and other fungi, amongst others, is likely to be a more complex phenomenon than expected due to the number of fungal species involved and the depth to which they can penetrate (see 5.4.3). These studies have some limitations and further experiments are needed to assess the generality of our observations. For more details, see Bjelland & Ekman (2005).

The fungal endolithic diversity found by extracting DNA directly from the rock has been compared with the fungal diversity found by extracting DNA from cultures from comparable rock samples. These cultures were made in the laboratory in cooperation with Prof. Rosmarie Honegger (Institute of Plant Biology, University of Zurich). *Ophioparma ventosa* thallus was removed from rock samples before they were crushed into smaller pieces. The small pieces of rock samples were put on agar on Petri dishes with either an antibiotic growth medium or a mineral growth medium (Zurich, October 2004). After 4 months there was growing several cultures in all of the Petri dishes. The cultures were analysed by molecular methods. Altogether 3 different fungal species were identified; 20 sequences were *Helotiales sp*., 2 were *Acremonium kiliense*, and 1 was *Cladosporium cladosporioides*. As *Helotiales sp*. seems to be a very dominant species both from these cultures and from the extractions directly from the crushed rock core samples, analyses are in progress to identify this species to family. These preliminary results indicate that we detect more species by extracting directly from the rock than from the cultures.

In a recent investigation, microbial communities were sampled from both selected crustose lichens and the rock underneath. The four lichens were; *Ophioparma ventosa*, *Pertusaria corallina*, *Rhizocarpon geographicum*, and *Hydropunctaria maura*. By DNA analyses of the microbial communities differences were detected both (1) between lichen species (the entire lichen-rock sample), and (2) between the epilithic lichen and the endolithic substrate (Bjelland *et al.* 2010).

4.4.1.4 The Stone Age lichen flora at Vingen

Macrofossils of lichens are rare because they are poorly preserved in sediments (Sernander 1918; Richardson & Green 1965). Indirect evidence based on other groups of plants has to be used to reconstruct the lichen flora in the Vingen area at the time when the rock art was carved. The vegetation along the coast during the Mesolithic was not the same as today. It was about 4 °C warmer during the summer, and the forest along the coast consisted largely of broad-leaved deciduous trees (Kvamme 1988; Nesje & Kvamme 1991). Also in Vingen deciduous trees dominated the vegetation (ch. 7.2). Since the climate and the vegetation at Vingen during the Mesolithic were different from today, it is likely that the lichen flora was also different.

The sea level has also varied, and during the period the rock art was carved it is believed to have been higher than it is today. The zonation of the lichen flora must therefore have been displaced landwards relative to the situation today. After the last ice age, the lichen flora on surfaces and rocks in the Vingen area responded to the climatic change, and it is uncertain which species constituted the zonation and which was predominant on the individual surfaces. Species of *Verrucaria* which grow on surfaces at the water's edge have, however, a characteristic ecology. From what we know of the ecology of these species today, there seems no reason to believe that they did not grow there when the rock was decorated.

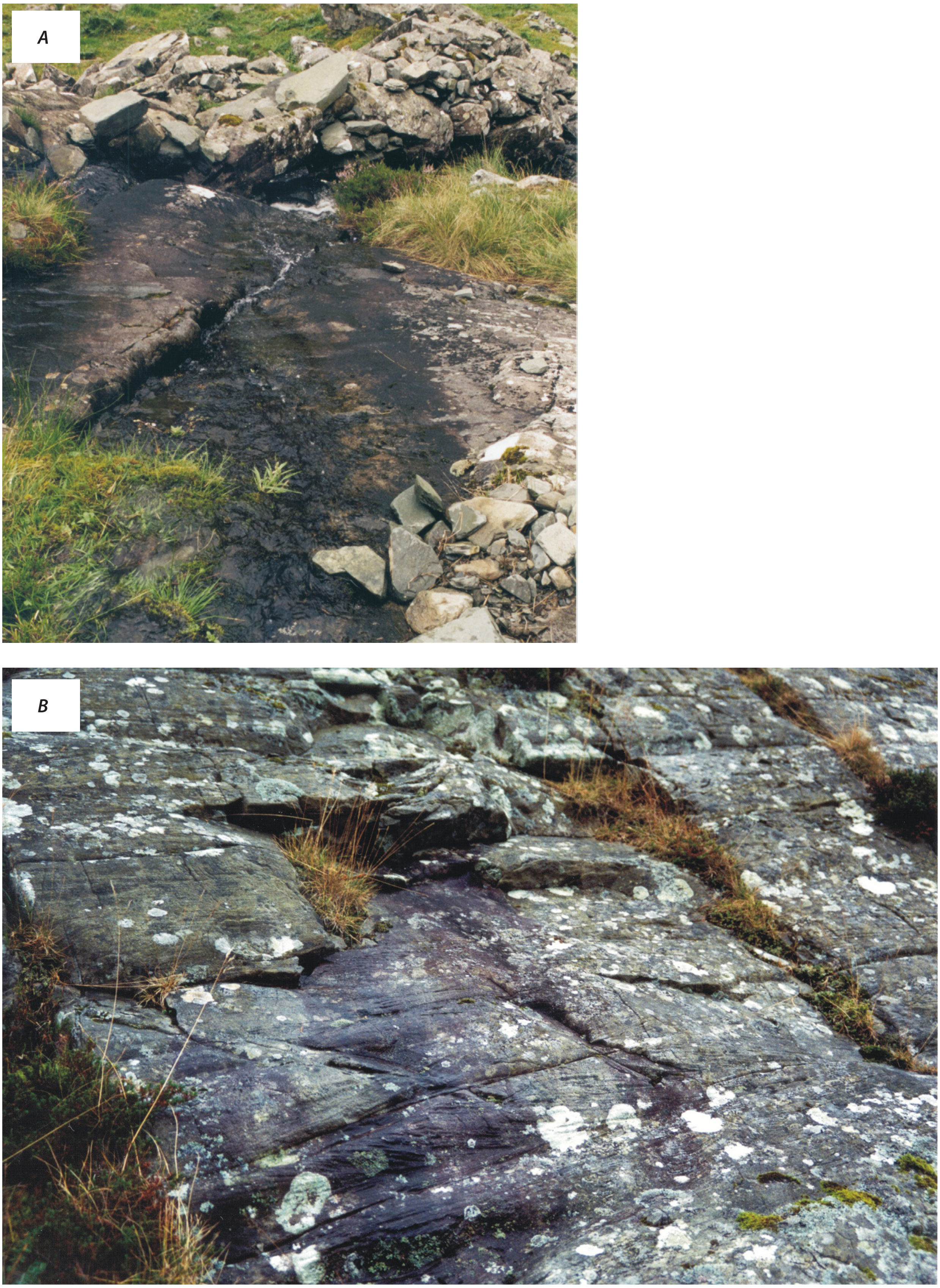


Fig 4.4.1.5-1 *Rock surfaces where water seeps over are discoloured by a reddish brown to brownish black coating. The pictures show water seeping over a rock surface west of Lyngrabben (a) and at Hardbakken (b).*

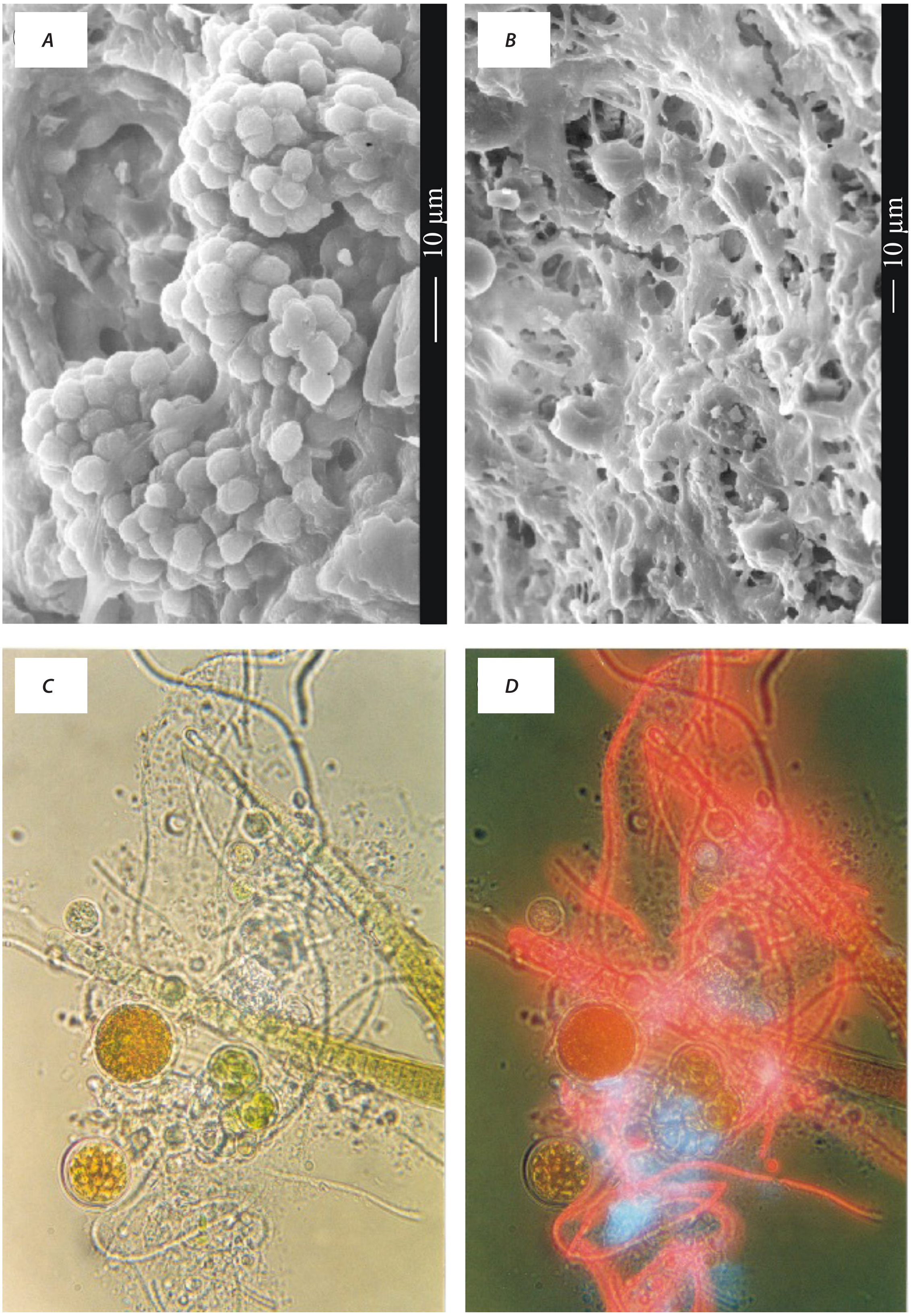


Fig 4.4.1.5-2 ***a) and b)*** *SEM -images of biofilm causing a dark coating at surfaces under the influence of water seepage. Examinations in microscope with transmission light and d) fluorescence proofs that the coating is caused by algae and cyanobacteria.*

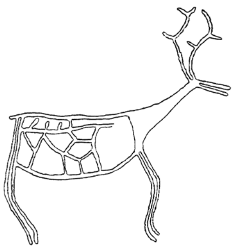
4.4.1.5 Rock surfaces not covered by lichens

Exposed, lichen-free rock surfaces are populated by different microorganisms. This is particularly evident where water seeps over surfaces (Fig. 4.4.1.5-1), where the surfaces are generally discoloured by a reddish brown to brownish black coating or biofilm of algae and cyanobacteria (blue-green algae) (Fig. 4.4.1.5-2). Very dark coatings are the result of a larger proportion of cyanobacteria. On other lichen free rock surfaces, a green layer of algae in the outermost 2–3 mm of the porous weathered rind is common. Generally, fungal hyphae are abundant within the pores.

Below a ledge behind Vehammaren there are *Trentepholia*-algae. These occur as a reddish brown coating on the rocks and can resemble leprose lichens.

With the exception of fungal hyphae in pores in the weathered rind, surfaces covered by turf have little microbial growth.

No DNA analyses have been made of fungal hyphae, algae, cyanobacteria or other microorganisms growing on and or within lichen-free surfaces in Vingen. As a result, they have still not been identified.



CHAPTER 5

Torbjørg Bjelland, Kari Loe Hjelle, Trond Klungseth Lødøen, Endre Skaar, Linda Sæbø and Pål Thorvaldsen

DEGRADATION AND REMEDIAL MEASURES

The degradation rate of rock surfaces is controlled by the composition of the rocks themselves as well as the local environment. How weathering is affected by variations in the rocks is dealt with in chapter 4. Here we discuss the significance of the environment.

Three types of weathering process are generally recognised: Physical, chemical and biological. Biological processes involve both physical and chemical processes and could well be included under these headings. However, we have chosen to separate these from the purely inorganic processes. The most important environmental factors for physical, chemical and biological processes are probably the availability of water and the temperature, both factors of the local climate. In addition, light is an essential factor in the majority of biological processes and important for the colonisation of organisms on rock surfaces.

Postglacial weathering has resulted in rock surfaces that are porous and therefore accessible to water and biological activity. This forms the basis for increased mechanical as well as chemical degradation, since a larger surface area of rock and mineral grains are exposed to these processes. The rock surfaces are fragile and easily damaged. They can withstand little mechanical stress or further chemical dissolution without the loosening of individual mineral grains, the surface rind fragmenting into gravel or breaking off in flakes. Spalling, even of thin flakes, is particularly dramatic since the rock carvings are generally very shallow (see section 3.1.2). In the longer term, fragmentation of the surfaces will have serious consequences for the rock art.

Measures designed to limit degradation must remove or minimise the different factors promoting physical, chemical and biological weathering. Since weathering is a complex process, the limitation of one factor can result in the augmentation of others. Possible remedial measures should therefore always be tested for their beneficial and possible undesirable effects.

5.1 Physical processes

5.1.1 Mechanical fracturing and fragmentation

Physical weathering is fracturing and fragmentation of rocks due to purely mechanical processes. The causes of this are stresses induced by rapid changes in temperature, the expansion of water during freezing (frost wedging) and the growth of crystals of salt (salt wedging) in cracks and pores in the rock (Thorseth *et al.* 1997).

Variations in temperature may cause expansion (during heating) and contraction (during cooling) of rocks. Since rocks are poor conductors of heat, the surface expands and contracts more than the interior and leads to stresses that can result in fracturing.

When water freezes, the volume increases by about 9%. This can lead to the build up of high stresses in the rock, and finally to fracturing. Frost wedging is particularly active in areas with abundant surface water and frequent freeze-thaw cycles.

The force exerted by growing salt crystals within pores and cracks can also lead to fracturing and fragmentation of the rocks. Salt wedging is most common in deserts due to evaporation of groundwater, but can also take place in coastal areas due to seawater.

5.1.2 Methods

The standard measuring program for the automatic meteorological station included air temperature, air humidity, wind and precipitation (Fig. 5.1.2-1). The purpose of these measurements was to record local- and micro-climatic parameters that may describe effects or the influence on actual demolishing processes on a rock surface with carvings.

Fig. 5.1.2-1 The automatic meteorological station at Vingen.

Fig. 5.1.2-2 Mats placed on a field with rock carvings at Brattbakken.

From 1997, the measuring program was enlarged with measurements of temperature and humidity on a rock surface, temperature a few cm under the rock surface, and temperature and humidity on the rock surface under mats with different properties (Fig. 5.1.2-2). Also, samples of precipitation were taken every 14 day for chemical analysis of content of pH, SO_4, NO_3, NH_4, Ca, K, Mg, Na and Cl.

In addition to the standard program for measuring and storing hourly data, a program for measuring and storing data every 1 min. was run in special weather situations. The purpose of this was to obtain a measure of physical properties and processes in and at the rock surface on a smaller time-scale, for example in situations with strong insolation, wet/dry surface, snow cover etc. From 1999, the station was equipped with a GSM mobile telephone.

By comparing these measurements by long-time measurements of meteorological parameters from permanent meteorological stations in the district, we may discover if there has been a change in the climate over the last 40–50 years that may have had an influence on – and perhaps enforced – the destruction of the rock surfaces in this area.

5.1.3 Uncovered surfaces

5.1.3.1 Air- and rock temperature

The temperature at a rock surface is usually very different from the air temperature. In addition to great absorption of sun radiation, the temperature at the rock surface is dependent on physical processes as heat flux in the rock and evaporation of water at the surface. Figure 5.1.3.1-1 and 5.1.3.1-2 give temperatures in the air (TL), at the rock surface (TS1) and 4 cm below the surface (TS2) in two periods with clear sky and almost no wind. The first figure shows that the air in spring is relatively cold, while the rock surface is strongly heated by radiation. The temperature is decreasing downwards in the rock and the heat flux is therefore directed from the surface, both downwards in the rock as well as upwards in the adjacent air layer. The second figure shows that late in the autumn the situation is almost the opposite. Because the sun is below the local horizon all day. there is a radiative cooling of the rock surface during the whole day, and the temperatures at the surface are therefore lower than both in the air above and in deeper rock layers. In these situations, the temperature at the surface may therefore be below the freezing point, even with plus degrees in the air.

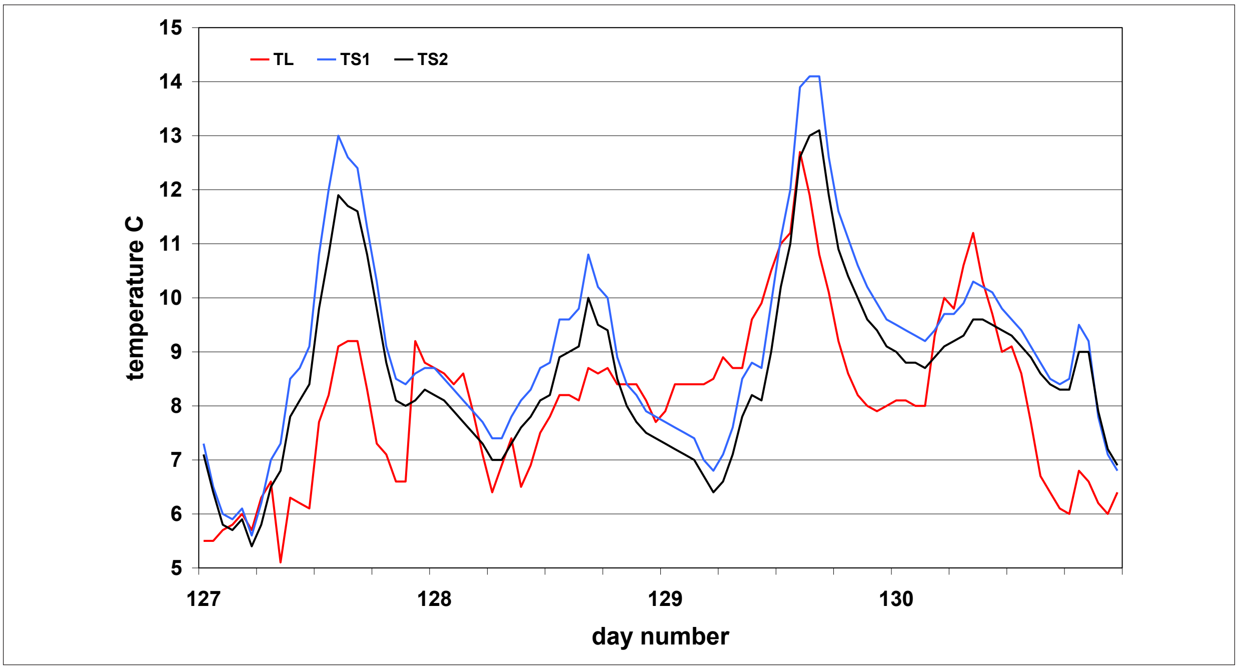


Fig. 5.1.3.1-1 Temperature in the air (TL), at the rock surface (TS1) and 4 cm below surface (TS2) in a period with clear sky in spring, May 7–10 1998

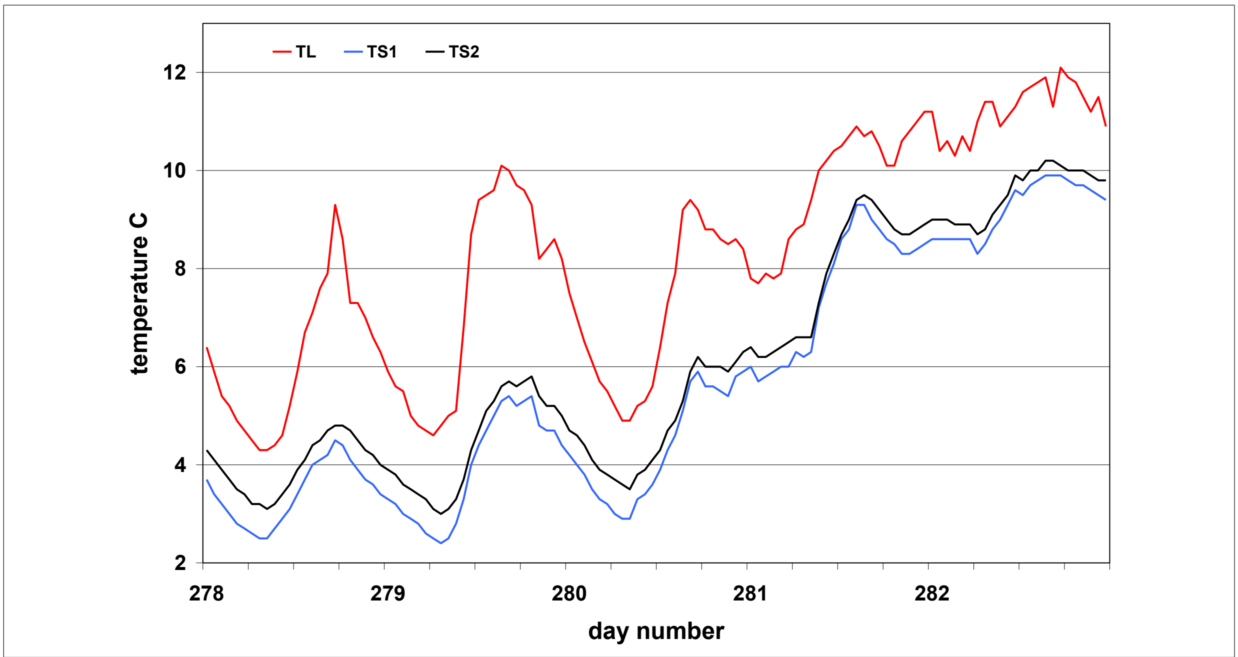


Fig. 5.1.3.1-2 Temperature in the air (TL), at the rock surface (TS1) and 4 cm below surface (TS2) in a period with clear sky in autumn, October 5–9 1998

Quite often, especially in the spring and autumn, there are strong easterly winds in the Vingen area, with warm and very dry air (foehn). These situations may last for days and with a relative air humidity of less than 60% – the lowest recorded is about 30%. In these periods there is an increasing temperature gradient in the upper rock layer and a relatively high temperature difference between the air and the rock surface. The consequence of the drying of the surface in such periods is obviously less heat conductivity in the rock, compared to 'wet periods' with rain, and the rock surface is therefore more frequently exposed to rapid temperature changes.

5.1.3.2 Energy balance in rock surfaces

Physical processes that may cause cracking of the surfaces of this type of sandstone rock are expansion and contraction of the rock surface layer, caused by rapid temperature changes, and/or by freezing/thawing of water in the small cracks and pores in the surface. In the analysis of the recordings, special attention is therefore given to winter episodes with rapid temperature changes between plus and minus degrees, and in summer to days with strong insolation and major temperature gradients in the rock surface.

At a rock surface, the main factors in the energy balance may be given by a simple formula;

$$Q_{net} = H + LH + G$$

where Q_{net} is the net radiation at the rock surface, H is the heat flux between surface and air, LH is the flux of latent heat of water vaporization to/from the rock surface and G is the heat flux to/from the deeper layers of the rock.

In periods with high insolation values (high Q_{net}) the temperature at the surface will increase rapidly, and the heat flux will be directed both upwards to the adjacent air (+H) and downwards in the rock (+G). If the surface is wet, a part of the energy will be used for evaporation (+LH). When the radiation balance is negative ($-Q_{net}$), the air temperature is often higher than at the rock surface, and the heat fluxes will be directed from air to the rock surface (-H) and upwards in the rock (-G). If the air humidity is close to saturation, the cooling by the rock surface may lead to temperatures below the dew point of the air and dewfall or icing on the rock surface (-LH).

Weather situations that may be typical at Vingen on a summer day are illustrated by the recordings on August 15 2000 (Fig. 5.1.3.2-1 and 5.1.3.2-2). The day before was sunny with relatively high temperatures. Early in the night, there is little wind and the air temperature (TL) is relative high. The net radiation is negative and consequently the temperature at the rock surface (TS1) is 3–4 °C below the temperature of the adjacent air. In the morning, before sunrise, the air temperature falls rapidly and reaches its minimum at about 0900, roughly the same time as the minimum in the rock surface. There are scattered clouds and relative high values of insolation during the day, but from the figure it may seen that the sun does not reach the station area before 1230. Then the sea breeze is already established and air from the open sea keeps the air temperature quite cool (TL_{max}= 14.7 °C). However, the rock surface is getting much warmer with maximum temperatures close to 20.5 °C on this day. After about 1700 the cloudiness increases, the radiation balance become negative and the temperatures fall rapidly. Most of the time with negative net radiation, the temperature flux in the rock is directed upward towards the surface.

The flux of evaporation energy to or from the rock surface in this period is illustrated in Fig. 5.1.3.2-2. The figure gives variations in vapour pressure in the air (e_a(air)) and in the saturation pressure of water vapour at the rock surface (e_s(surf)). The difference between these two values (diff(e)) indicates that there is no flux of water vapour energy from the air to the rock surface during this period. If the surface is wet, a part of the positive net energy at the surface will be used for evaporation.

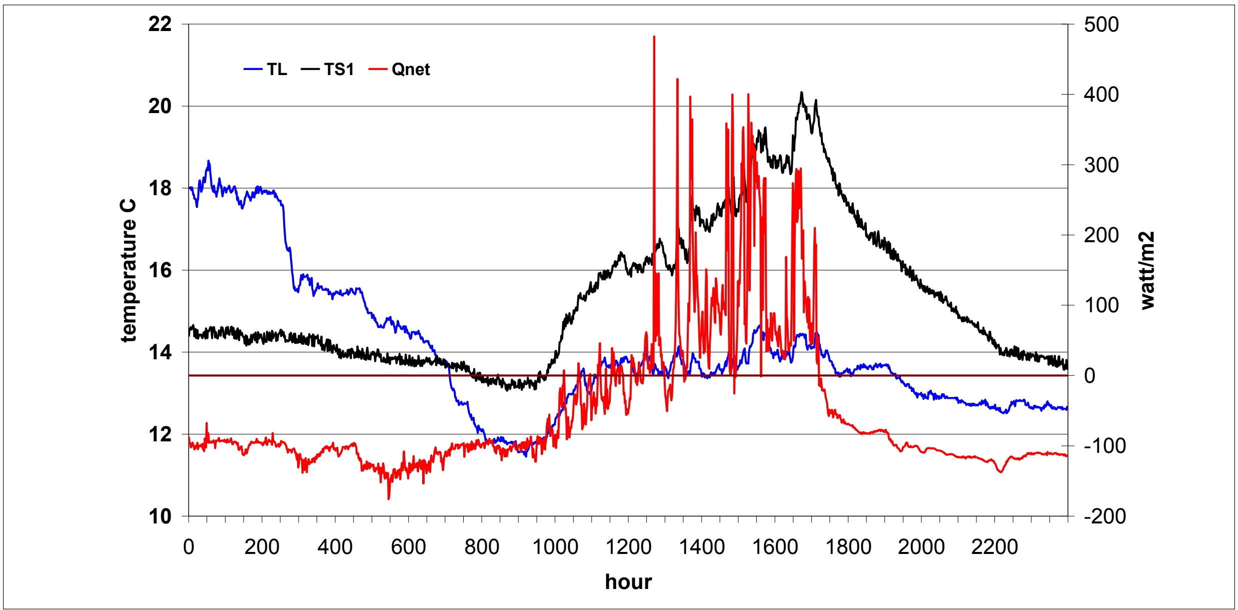


Fig. 5.1.3.2-1 Temperatures in the air (TL) and at the rock surface (TS1), and net radiation (Qnet) on a summer day, August 15 2000, at Vingen.

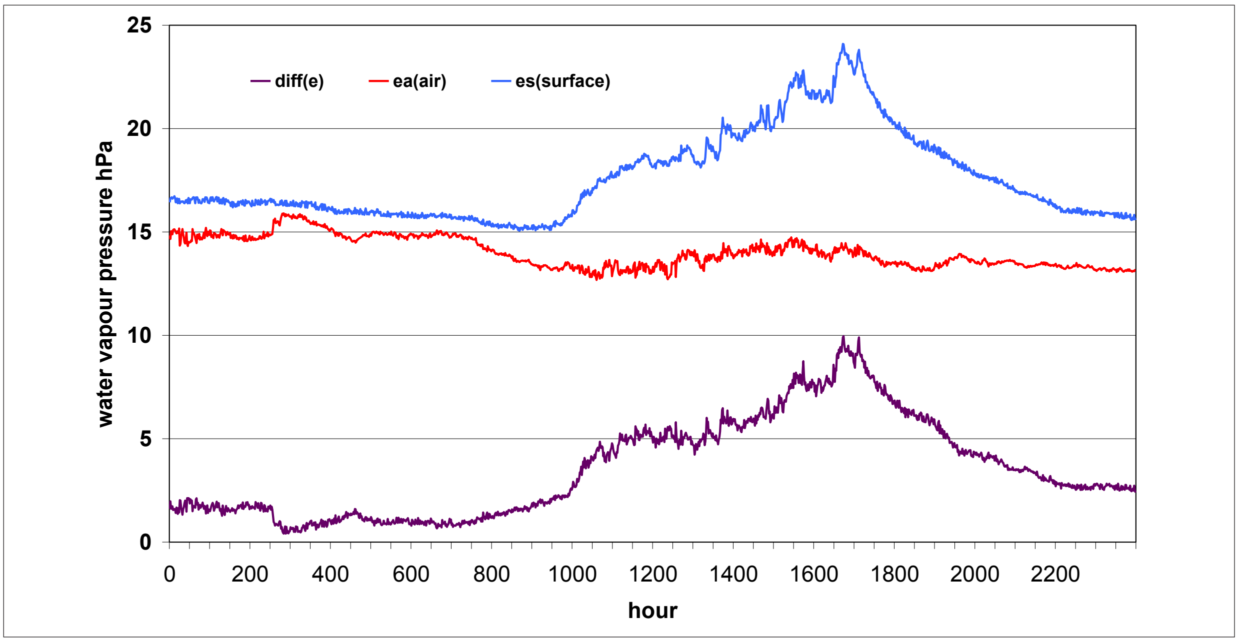


Fig. 5.1.3.2-2 Water vapour pressure in the air (ea(air)), saturation pressure at the rock surface (es(surface)) and the difference (diff(e)), on a summer day, August 15 2000, at Vingen.

In periods with no rain, the measurements of humidity at the rock surface may not be entirely reliable. The upward facing surface of the humidity sensors used (ref.) has a radiative quality that is very different from the rock surface, and contact with the underlying surface was probably rather poor. The temperature at the surface of the sensor may therefore be different from the temperature at the rock surface. Therefore, the humidity measured, especially in periods with a negative net radiation, may be somewhat different from the real humidity situation at the rock surface.

The surface layer of the rock (10–15 mm) is porous to some extent, and will absorb water supplied to the surface. This "absorbed water" will have an effect on temperature variations in the layer as both the heat capacity and thermal conductivity increase and the water is also available for evaporation. A wet surface thus counteracts thermal variations in the surface layer. This means that when the surface is dry, the upper layer is more exposed to rapid temperature variations and greater temperature gradients.

The figures illustrate that the local air temperature at Vingen (TL) is largely dominated by advected air masses either blowing in from the sea or down from the surrounding mountains. The temperature in the rock surface (TS1) is on the contrary more decided by radiation and surface wetness and by the thermal conductivity in the upper rock layer. In periods with a positive net radiation ($+Q_{net}$), the surface temperature is often higher than the air temperature, with the opposite occurring in periods with negative net radiation.

An important factor for temperature conditions in the rock surface layer is whether the surface is bare or covered with lichen. The results from direct measurements of surface temperatures with an infrared thermometer (Rotronic Pyrotron) on different types of lichen cover are given in Tab 5.1.3.2-1. The rock surface had an inclination of 45 degrees and was facing south (190 degrees), and the sun radiation was close to normal on the surface in the measurement period (Fig. 5.1.3.2-3). With clouds and only scattered sun radiation, the temperature differences between covered and a clean reference surface was minor. In bright sunshine, the difference was at the most about 10 °C, and the highest temperature measured was 42.1 °C. The clean surface had the lowest temperature in both situations. Lichen is obviously an effective thermal insulator, shielding the surface against rapid and great temperature variations in situations with strong radiation.

Table 5.1.3.2-1 *Average temperatures (°C) at a lichen covered surface and at an uncovered clean rock surface in an overcast situation (17 measures) and in bright sunshine (19 measures), done July 27. 2000.*

	Uncovered rock	**Parmelia saxatilis**	**Lecidea lapicida**	**Pertusaria corallina**	**Rhizocarpon geographicum**	**Schaereria fiscocinera**
overcast	21.5	22.4	22.8	22.1	22.4	22.8
sunshine	28.9	38.5	32.2	31.0	31.3	31.9

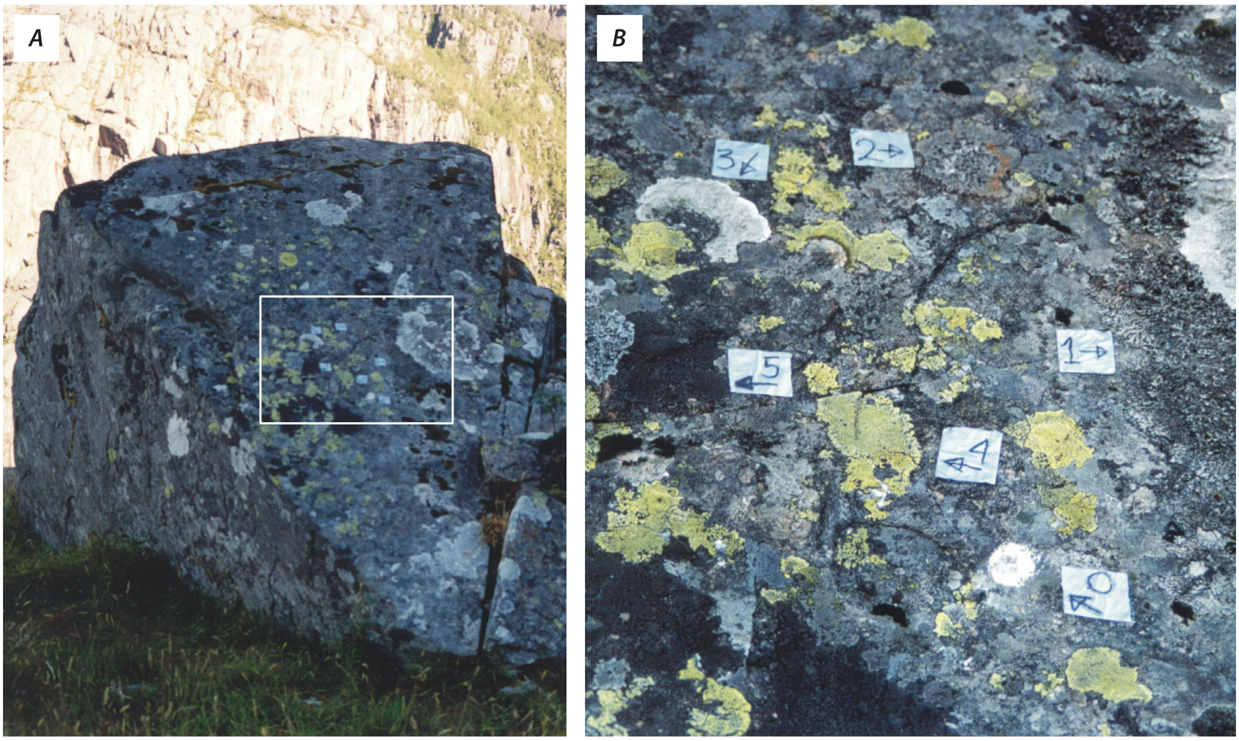


Fig. 5.1.3.2-3 *a) Direct measurements of temperature of rock surface covered with different types of lichen. The inclination of the framed area of the south facing surface is 45 degr. b) Close-up of framed area in a) 0: clean surface, 1: Parmelia saxatilis; 2: Lecidea lapicida; 3: Pertusaria corallina; 4: Rhizocarpon geographicum; 5: Schaereria fuscocinerea.*

5.1.3.3 The effect of sea water and -salts

Demolition of rock surfaces by sea salt crystals is obviously demonstrated in windy coastal areas with little precipitation (Boggs 1995). Drifting seawater is collected in pores in the rock surface and crystals of sea salt are liberated when the water evaporates. By successive episodes with drying of seawater the salt crystals will increase and finally the tension from the growing crystals will crack small fragments from the rock surface. This process is probably not of any great importance at Vingen because of frequent episodes with rain. Consequently, salt crystals are not shown in the analysis of the pores in the cracking zone of collected rock samples (ca. 90). On the contrary, sea salt may lead to a lower freezing point and fewer episodes with ice cracking of the surface (also 5.2.1).

5.1.4 Measures: Covering with insulating mats

Autumn 1998 three insulating mats with different thickness was placed on the rock Brattbakken to test the effects of the mats on thermal and humidity conditions on a covered rock surface. The insulating material was rock wool and the dimension of the mats was 1.2 x 1.2 meter and with thickness 5, 10 and 15 cm. To avoid rain and running water down the rock surface a plastic cover was stretched over each mat and peat was removed from the upper edge of the rock. Sensors for measuring temperature and humidity were placed at the rock surface under each mat (Fig. 5.1.4-1). In October 1999, the three mats were replaced with one large rock wool mat, 3 x 2.2 m, 10 cm thick, and the sensors were placed at different distances from the edge of the

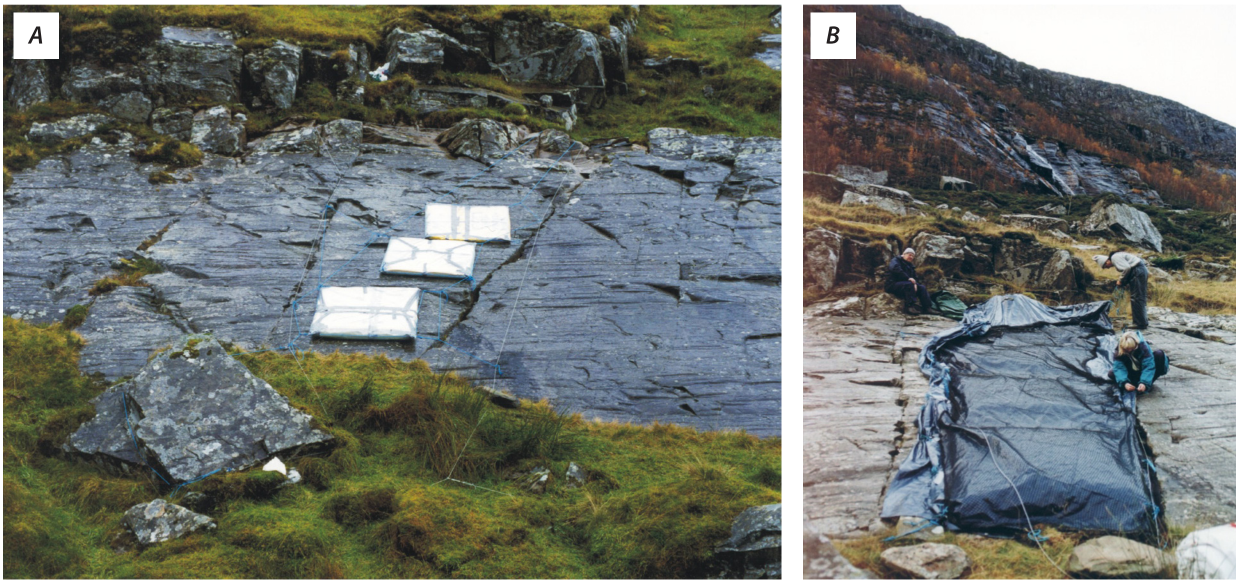


Fig. 5.1.4-1 Autumn 1998 a test field on Brattbakken was covered by insulating mats to test the effect on the rock surface temperature. a) Temperature and humidity were recorded under building mats of 1.2 m² and with three different thicknesses (5, 10 and 15 cm). b) To shield the mats from rain and surface water under the mats, they were coated with plastic covers and ditches were dug at the upper rim of the rock.

mat, (15, 70 and 110 cm.). Finally, in August 2004, measurements of temperature and humidity were made at two new localities, Bakkane 1 and Bakkane 2. The insulating material was now Plastazote laid over a Gore-Tex type membrane.

The temperature recordings only detected minor differences in the thermal insulation effects between the different types of mats. The main effect of all the mats was a smoothing of temperature variations and a reduction in the number of rapid temperature changes between plus and minus degrees.

Covering a rock surface with a mat brings about a change in the temperature conditions of the covered surface by reducing the heat loss to the atmosphere. In addition, a mat is an effective obstruction to the transport of humidity and it thus prevents evaporation of water from the rock surface. There is obviously some transport (diffusion) of humidity in the small openings between the mat and the rock surface. This transport is directed inwards in periods when the temperature under the mat is below the air temperature.

Fig. 5.1.4-2 shows the temperature variations in the air (TL), at the uncovered rock surface (TS1) and under two of the mats (TM2, TM3) 10 and 15 cm thick respectively, in the first three weeks of January 2000. In this period, the air temperature varied between +9 and -3 °C and the figures indicate that at this time of the year there are no diurnal periodic effects on the air temperature. In addition to variations in cloud cover, the main influence on local air temperature obviously comes with local winds, transporting air from a relatively warm sea in west, or from cold snow covered mountains in an easterly direction. In most of this period, the uncovered rock surface has a lower temperature than the air with a temperature difference of 4–5 °C. Under the mats, the temperature variations are smoothed and much smaller than at the uncovered rock surface.

The climate in this area is oceanic and typical average temperatures in wintertime are plus 2–3 °C. Temperature variations are usually relatively small and slow. In a few periods recorded air temperature was below 0 °C and minimum temperature lower than minus 2–3 °C. The recordings show that a covered rock surface will reach almost the same minimum temperature as the air, but with a delay of 1–2 days. Under the mats the temperature variations are smoothed and the episodes with freezing/thawing are significantly reduced.

Because of the smaller and delayed temperature variations under a mat cover, there will obviously be more frequent periods when the temperature in the air is higher than at the covered rock surface. As the air humidity is usually relatively high (westerly winds) there will be an inward transport (diffusion) of humidity under the mats. Although in shorter periods and before the temperature under the mats comes below freezing point, there may be an opposite temperature difference and an opposite transport of humidity, the humidity recordings under the mats indicate that in most of the cold periods (temperatures below 0 °C) there will be water present on the rock surface under the mats.

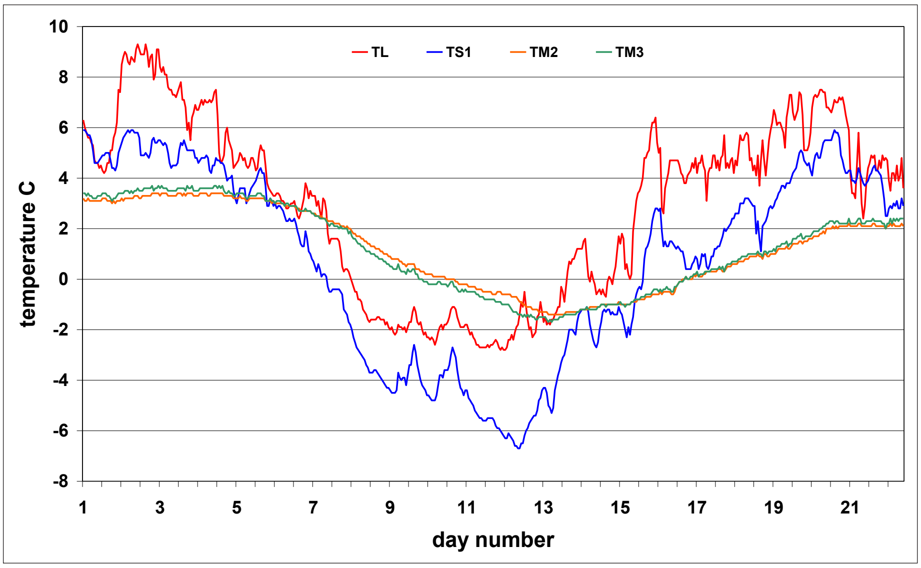


Fig. 5.1.4-2 Temperatures in the air (TL), at rock surfaces, uncovered (TS1), and covered with two types of mats, 10 cm rock-wool (TM2) and 15 cm rock-wool (TM3), in a period with frost at Vingen, January 1–21 1999.

5.1.5 Conclusions

In the relatively mild and humid winter climate at Vingen, with frequent episodes with temperature changes between plus and minus, and with relative large amounts of precipitation, the freezing and thawing of water is probably a main cause of the cracking of the rock surface. The investigations indicate that the temperature at an uncovered rock surface falls rapidly in periods with negative net radiation. Therefore, in the winter, rock surfaces may frequently have a relatively low temperature, for instance several degrees below zero, even when temperatures above zero are recorded in the air. An uncovered rock surface is therefore much more frequently exposed to episodes with freezing and thawing than can be read from any recordings of the air temperature. Exceptions of this are found in the relatively few and short periods with snow cover. With snow cover, the rock surface will have a temperature close to 0 °C.

In summer, on a clear and sunny day, an uncovered and dry rock surface may have a more rapid temperature increase and reach a much higher temperature than the adjacent air. The rock surface will be exposed to rapid temperature changes and tensions which may lead to the cracking and peeling of the upper layers. However, the importance of this process is uncertain (Thorseth et al. 1997). Lichen may moderate temperature variations to some extent, partly because the lichen acts as a shield and an insulator against direct sunshine, and partly because the drying of the surface is reduced. On a large rock surface the lichen cover will be quite uneven, and the effect of lichen on the rock surface temperature is therefore limited.

An effective measure to reduce the number of freezing/thawing episodes, and consequently frost cracking, is covering the rock surface by an insulating mat. Tests indicated that a mat with a thickness of 5 cm will reduce the temperature variations considerably. Only minor additional effects were found by using thicker mats. During a cold period of one week with air temperatures about minus 2–3 degrees, the temperature at the covered rock surface will become approximately the same as in the air, but with a time lag of 1–2 days.

Temperature measurements with different distances from the edge of a larger mat indicate that at a solid rock the "horizontal" temperature transport under a mat cover is negligible at distances of more than approximately 20 cm from the edge of the mat.

Covering a rock surface with a mat also prevents natural drying of the surface. Humidity/water under the mat is supplied from running surface water, precipitation, or by diffusion of humidity in the small openings between the mat and rock surface. In long periods (weeks) with temperatures below 0 °C this water will freeze and probably cause cracking of the rock surface. The transport of humidity is obviously reduced the greater the distance from the edge of the mat, but during a whole winter no improvement is found in the humidity conditions under a larger mat. However, covering of a rock surface with insulating mats is probably a useful measure, as the number of freezing/thawing episodes are reduced in comparison to uncovered surfaces.

Over the last 40–50 years, the winter climate in Western Norway has gradually become milder and wetter. However, variations from one year to another may be significant, and some winters will probably still have several relatively long periods with frost and many freezing/thawing episodes.

Since no salt crystals are shown in pores in the upper layer of the rock, cracking by salt crystals is probably not an important disintegration process at Vingen. The reason for this may be the large amount of precipitation in this area.

5.1.6 Further investigations

5.1.6.1 Solar radiation and rock surface temperature

At the main test field at Vingen, with the automatic climatic station, the sun is below the horizon for most of the winter. Most of the rock surfaces with measurements of temperatures at the uncovered surface and under mats are facing a northerly direction. At Vingeneset the sun is above the horizon even in mid-winter, and most of the rock surfaces are facing a southerly direction. The temperature variations both in the air and on the rock surfaces may consequently be different from what is recorded at Brattbakken. Therefore, temperature recordings were also made here at the Vingeneset test field from 2002.

5.1.6.2 Temperature and humidity on a covered stone surface

The inclination of the test field at Vingeneset was almost 45 degrees to the south. Two temperature sensors were placed under each of two mats of 10 cm rock wool covered with plastic. The recordings indicate that the temperature at the rock surface under the mats in a way reflects the general annual temperature variations in the rock. In the winter time temperature variations under the mats are much smaller than in the air and only in very short periods below 0 ^{o}C. Temperature variations in the air, generally caused by shifting in wind directions and different advective air masses, are only to some extent affecting the temperature conditions under the mats. In April–June the net radiation is on an average positive, and the heat gain in the rock is obvious. As the temperature increase in the ocean surface water in spring is much slower than in the rock, the raise in average diurnal air temperature is consequently far behind the rock surface temperature.

5.1.6.3 Variations of temperature under a peat cover

Temperature sensors were also placed in the peat of a small bog and in turf from a small and shallow area with grass and heather. The depth of the sensors was approximately 10 cm below the surface. The effect on the temperature of these two covers is very similar to the effect of an insulating mat. In winter, the temperature variations are much smaller than in the air and no periods with frost are recorded. In particular, the bog is relatively "warm" during the cold periods, due to the high water content in the soil. In April–June the high water content of the bog soil reduces the temperature increase, while the dryer turf is now on average the "warmest".

5.1.6.4 Variations of temperature under a black plastic cover

In periods with the highest insolation, a black plastic cover with no insulation provides an increase in temperature conditions on the rock surface. There is no significant effect on the temperature at night or in the winter. It is obvious that humidity is transported in under the mat. A non-insulated mat may therefore increase the risk of the rock surface being cracked by freezing.

5.2 Chemical processes

5.2.1 Solution of minerals and rocks

Chemical weathering encompasses solution of the primary minerals, due to reaction with water and ions (H_2O, H^+, OH^-) so that chemical bonds are broken. Some of the dissolved material can be reprecipitated in the form of new, more stable minerals, while the rest is removed in solution. Chemical weathering therefore leads to changes in the mineralogical and chemical composition of the rocks, and also their physical properties.

In addition to water molecules, natural waters contain different amounts of other components. Rainwater dissolves CO_2 and pollutants in the atmosphere. Pure water in equilibrium with the atmosphere has a pH of about 5.7. In coastal areas, precipitation is strongly influenced by the composition of seawater. Rainwater and surface water also take up dust and sand deposited on vegetation and rock surfaces, chemicals from the soil, and ions derived from minerals undergoing solution. Fresh water can therefore vary considerably in chemical composition.

Both the amount of water that comes into contact with minerals and its chemical composition is significant in terms of the rate of solution of individual minerals (Thorseth *et al.* 1997). For instance, the rate of solution of aluminosilicates (e.g. mica, feldspar etc.) is lowest at neutral pH, but accelerates in both acid and alkaline environments. A high content of effective ligands (e.g. organic acids) in the water will also increase the rate of solution, even at neutral pH.

Soil has a high content of carbonic acid and ligands (complex humus products and simple organic acids) (see also 5.3.1). These substances can increase the chemical solution of minerals and rocks both due to their effect on the pH and/or the formation of complexes.

5.2.2 Methods

The amount of precipitation was recorded as part of the standard routine for the weather station (see 5.1.2). Every fortnight, samples of the accumulated precipitation were analysed for pH, Na, K, Ca, Mg, SO_4, NO_3, NH_4 and Cl. When compared with analyses of precipitation from other stations, the chemical analyses can provide information regarding sea salts and eventual pollution from industry.

In order to investigate the significance of different local environments for chemical weathering, samples have been collected systematically from both exposed rock surfaces and surfaces covered in turf or soil. A total of 90 rock samples were collected both at Vingen and from Vingeneset. Rock surfaces were examined to see if there were differences in the depth of weathering between shoreline exposures, seaward-facing surfaces and surfaces further inland. As noted earlier, most surfaces are more or less covered in various species of lichen (4.3.2). The rock samples from Vingeneset are from surfaces partially and diffusely overgrown by different lichens (5.4.3). The samples from Vingen were mainly collected beneath specific species of lichen. Even surfaces near the sea are partially covered by different lichens. In the case of turf-covered surfaces, the effect of different thickness of turf has been investigated.

5.2.3 Precipitation: Amount and chemical composition

The majority of the precipitation falls in the autumn and winter in connection with cyclones and weather fronts moving in from the west. A comparison of measurements at several stations shows that precipitation is strongly influenced by the local topography. With westerly winds, the mountains in the east (Ålfotbreen 1380 m.a.s.l.) amplify the precipitation and locally result in high daily precipitation. Fig. 5.2.3-1 shows a comparison of the daily precipitation recorded at Svelgen and Vingen.

Chemical analyses of precipitation at Vingen were carried out on samples accumulated over a period of 14 days. The closest "background" station that NILU operates in the region is at Nausta in the Naustdal valley, about 30 km south of Vingen. At this station, situated about 20 km from the fjord, chemical analyses were carried out of precipitation accumulated over 7 day periods. Fig. 5.2.3-2a and b compare the pH of the precipitation at these two stations during the period 11.8.98 – 4.5.00. There is a marked difference in the values between the stations over the whole period, with higher pH in the precipitation at Vingen. Assuming that the relative proportion of salts is the same as in seawater and that the salts have the same rate of deposition from the atmosphere, the difference in pH may be adequately explained as a consequence of different distances from the ocean and therefore different concentrations of salts in the precipitation. This is emphasised by a comparison of the analytical results for chlorine and magnesium as shown in Fig. 5.2.3-3a and b and Fig. 5.2.3-4a and b.

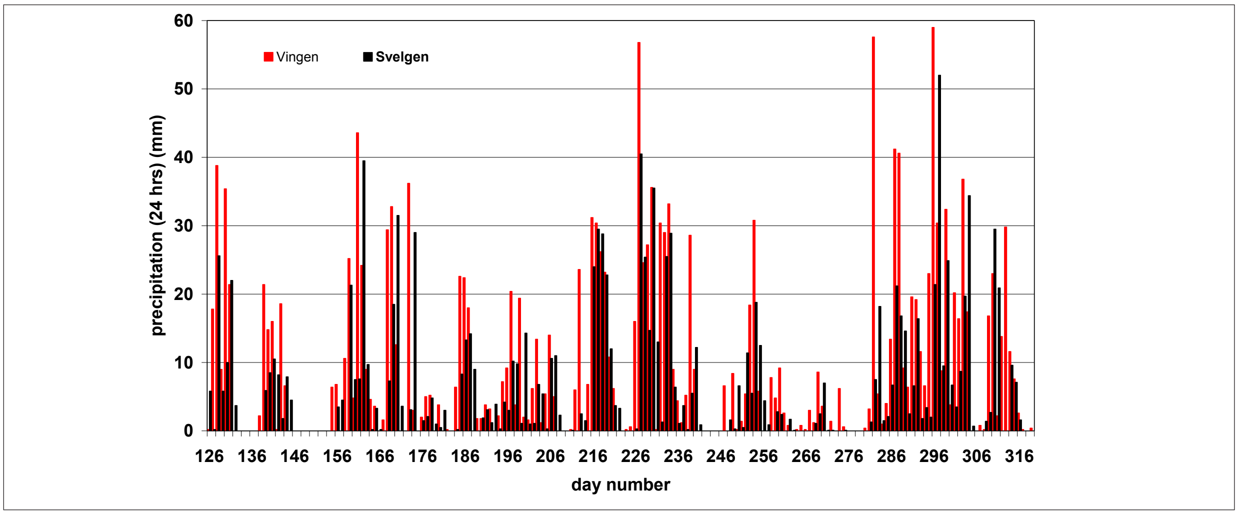
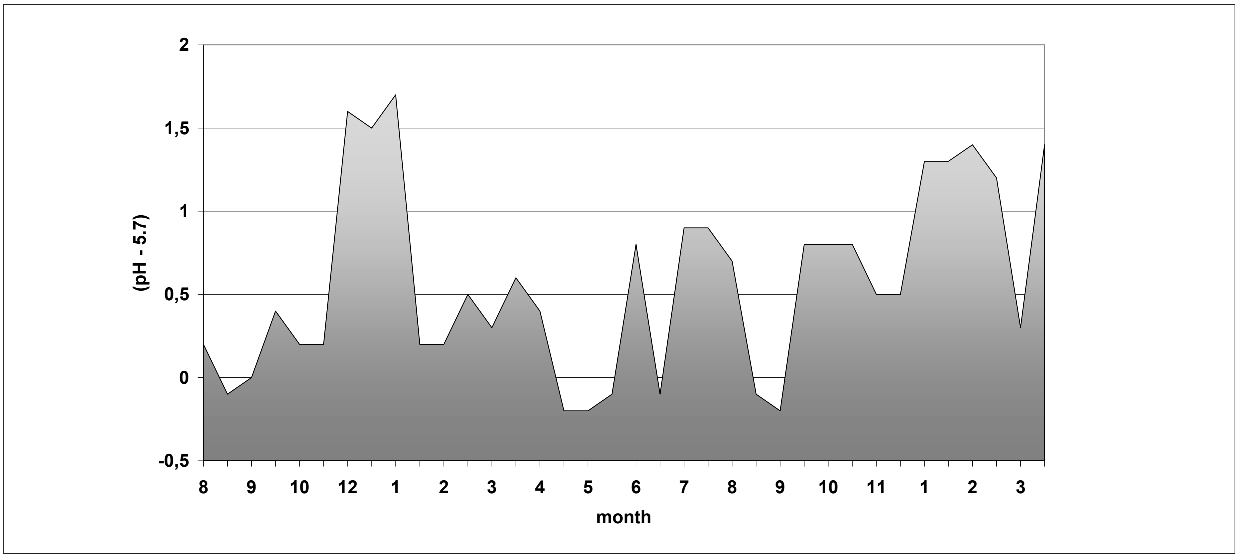


Fig. 5.2.3-1 *Daily precipitation amounts at Vingen and Svelgen. May 6 – November 13 1998.*



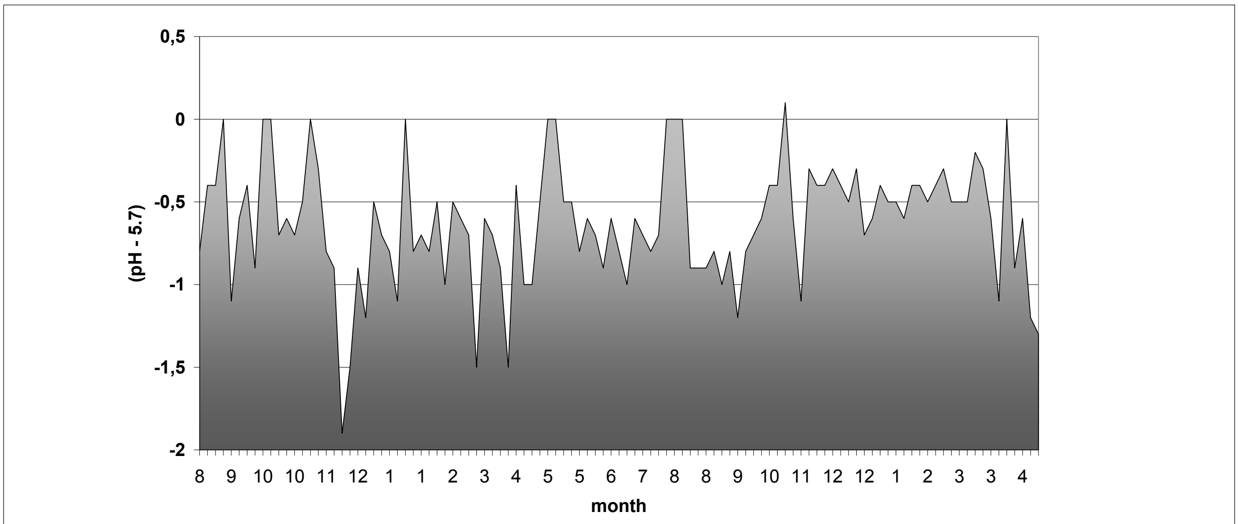
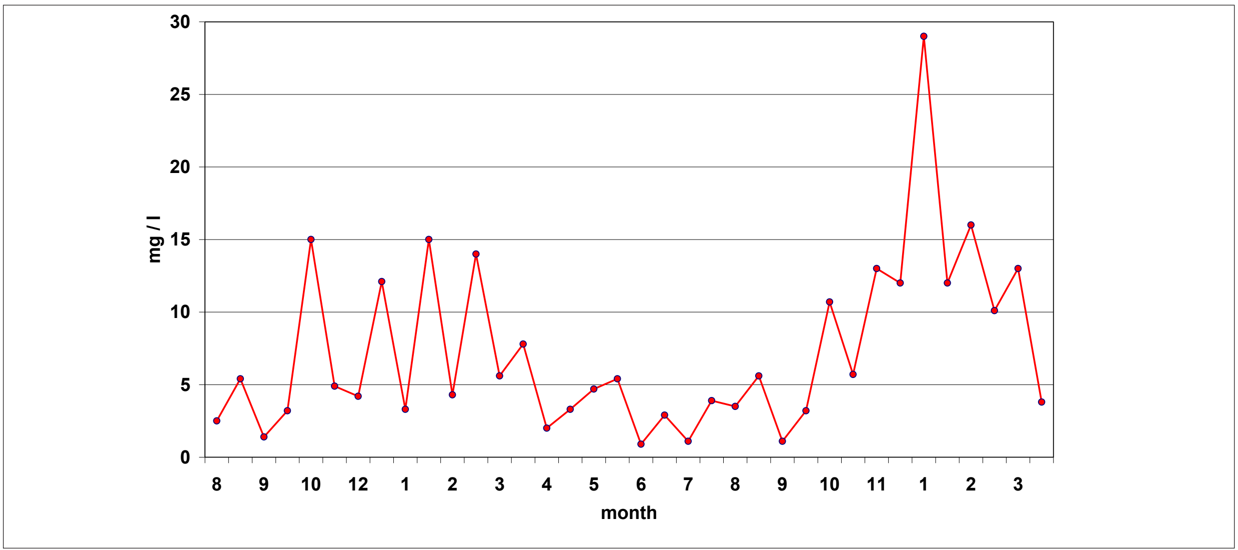


Fig. 5.2.3-2 a) and b) *A comparison of pH-values of precipitation measurements at Vingen and Naustdal. The numbers given are average values of 14 days at Vingen and 7 days at Naustdal.*



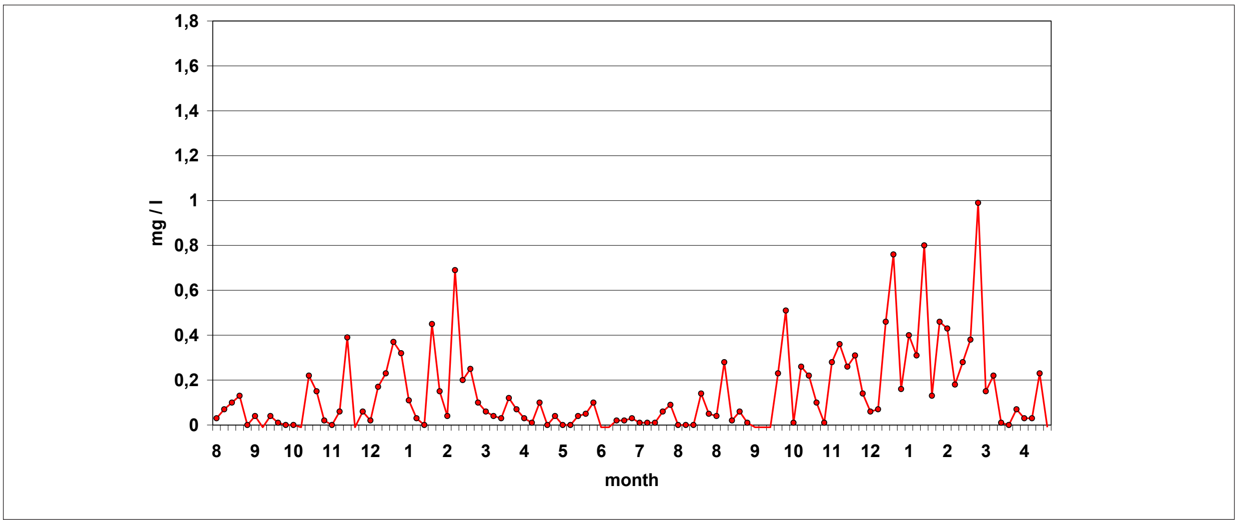


Fig. 5.2.3-3 a) and b) *Comparison of content of Chlorine (mg Cl/l) in precipitation measurements at Vingen a) and Naustdal b), in the period August 11 1998 – May 4 2000.*

5.2.4 Effects of different environmental factors

In Figs. 5.2.4-1 and 5.2.4-2 the depth of weathering (as given by the solution of calcite and chlorite) are plotted as groups according to locality and environment. Groups 1–3 are samples from Vingeneset, group 1 being samples from rock surfaces near the sea, group 2 are from exposed surfaces diffusely overgrown by various lichens further inland, and group 3 are surfaces covered by a thin (10–15 cm) layer of turf of raw humus character (see 5.4.1). Surfaces in groups 2 and 3 have both been used as test sites (see 5.4.1 and 6.2). Groups 4–9 are samples from Vingen. Group 4 are rock surfaces close to the sea, groups 5–9 are samples from exposed surfaces beneath particular lichens, *Lecidea fuscoatra, Fuscidea cyathoides, Ochrolechia tartarea, Pertusaria corallina* and *Ophiopharma ventosa* (see also 5.4.1) and group 10 are samples from surfaces above Vehammaren that were covered by a thick (40–50 cm) layer of turf or soil.

5.2.4.1 Exposed rock surfaces

Since calcite is least resistant to chemical attack, it is this mineral that defines the maximum depth of weathering. With the exception of rock surfaces near the sea and surfaces overgrown by the weathering-enhancing lichen *O. ventosa* (see 5.3.2), the average depth of weathering on exposed surfaces is 8.9 mm on Vingeneset and 9.3 mm at Vingen. If we assume that the rate of solution of calcite has been constant through the postglacial

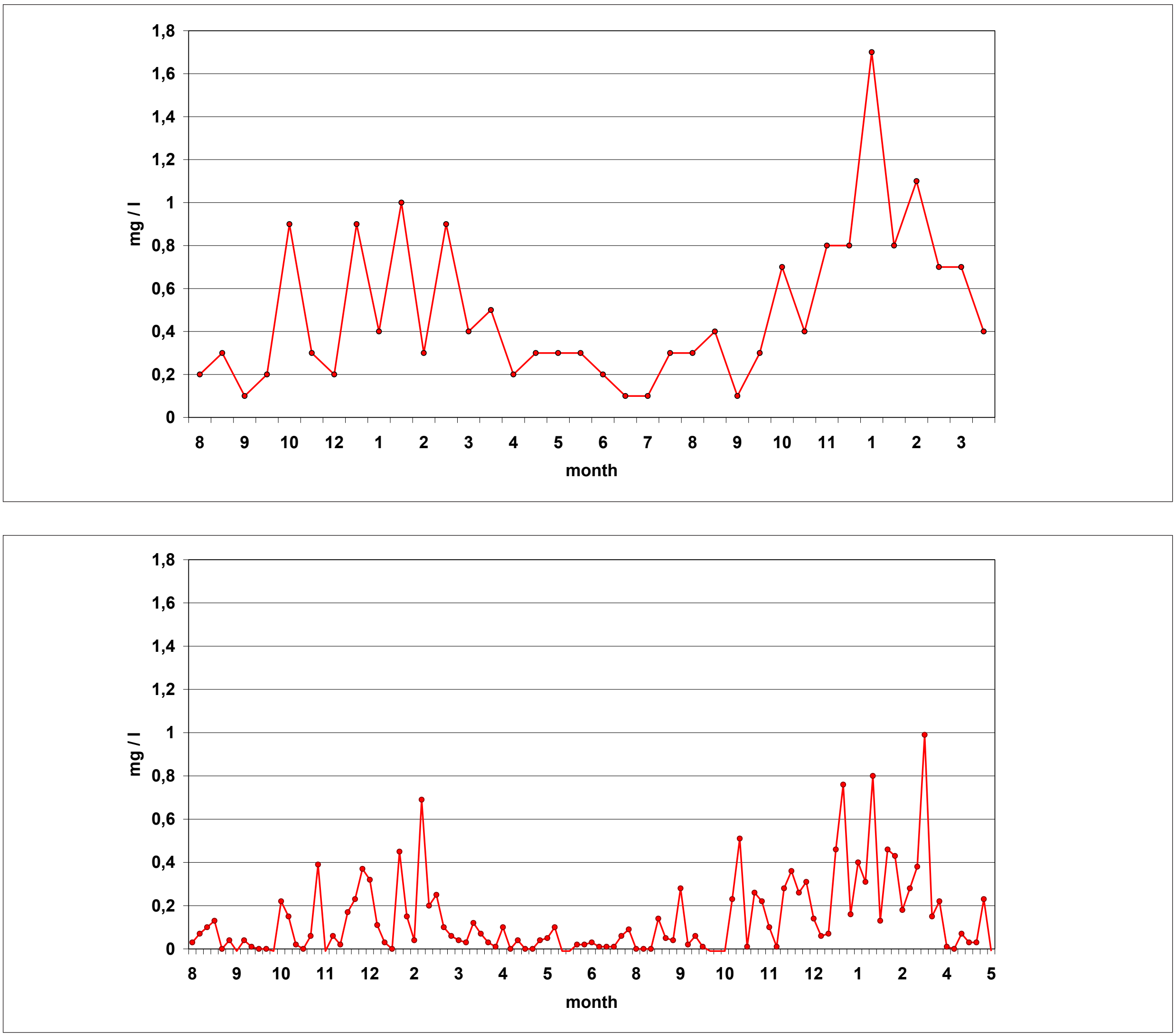


Fig. 5.2.3-4 a) and b) *A comparison of content of Magnesium (Mg mg/l) in precipitation measurements at Vingen a) and Naustdal b), August 11 1998 – May 4 2000*

period (~10 000 years) the data suggest that the weathered surfaces have developed at a rate of around 0.9 μm per year. The depth of solution of chlorite is around 1.5 mm (see also 5.4.1), which gives a rate of solution of 0.15 μm per year. Since many surfaces have probably lost the outermost skin due to fragmentation or exfoliation, these are minimum rates. The values nevertheless indicate that the growth of the calcite-free zones is about 6 times faster than the chlorite-free zones. Clear evidence of solution of plagioclase coincides with the chlorite-free zones, suggesting a similar rate of solution for both of these minerals.

Chemical weathering of the exposed rock surfaces is due to reaction with precipitation and surface water. In addition, there is the weathering due to the growth of lichen (see 5.4.1). As shown earlier, the amount of precipitation is high at Vingen. The relatively high pH and salt content can, however, have inhibited weathering. Samples from Vingen were collected from many different surfaces. The pronounced variation in the depth of weathering, even underneath the same species of lichen, is principally the result of variations in the mineralogical composition and texture of the rocks (see 4.1). Samples from Vingeneset, from more uniform surfaces, show less spread.

Exposed rock surfaces at or facing the shore have a thinner weathered crust, averaging 2.4 mm (5.2.4.2). Turf-covered surfaces on the other hand are more deeply weathered than corresponding exposed surfaces (5.2.4.3).

5.2.4.2 Exposed surfaces near the sea

To investigate the effect of exposure to seawater. five samples were collected from the shore to a height of about 8 m a.s.l. along a shore-facing surface on Vingeneset, as well as a sample from a shore-facing surface just above the quay at Vingebu. and two samples from a similar surface above the quay at Vingen (Fig. 5.2.4.2-1). The shore samples were collected between the low and high tide marks where the rock surface is in daily contact with seawater. The other surfaces are only in contact with seawater in the form of spray in connection with gales.

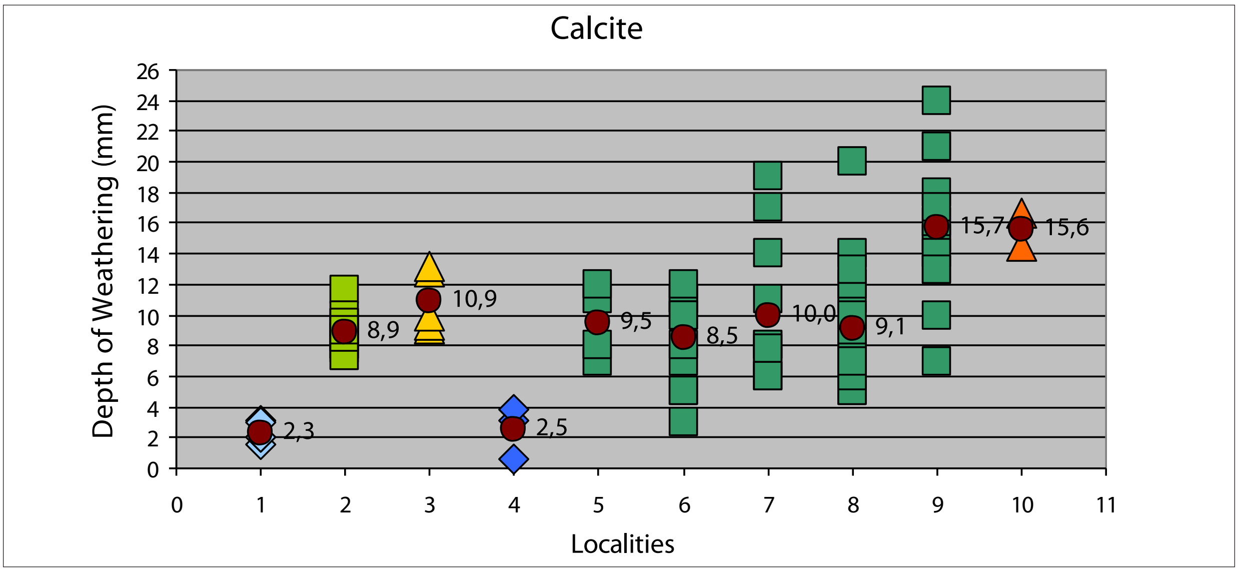


Fig. 5.2.4-1 The total depth of weathering (calcite solution) for samples collected from different localities and environments on Vingeneset (nr. 1-3) and at Vingen (nr. 4-10). (nr.1-exposed rock surface near the shore on Vingeneset; 2-exposed surface with unspecified lichen on Vingeneset; 3-surface with a thin covering of turf on Vingeneset; 4-exposed surface near the shore at Vingen; 5-9 exposed surfaces with particular types of lichen at Vingen (5-L.fuscoatra, 6-F.cyathoides, 7-O.tartarea, 8-P.corallina, 9-O.ventosa); 10-surfaces with a thick cover of turf at Vingen (●=average value).

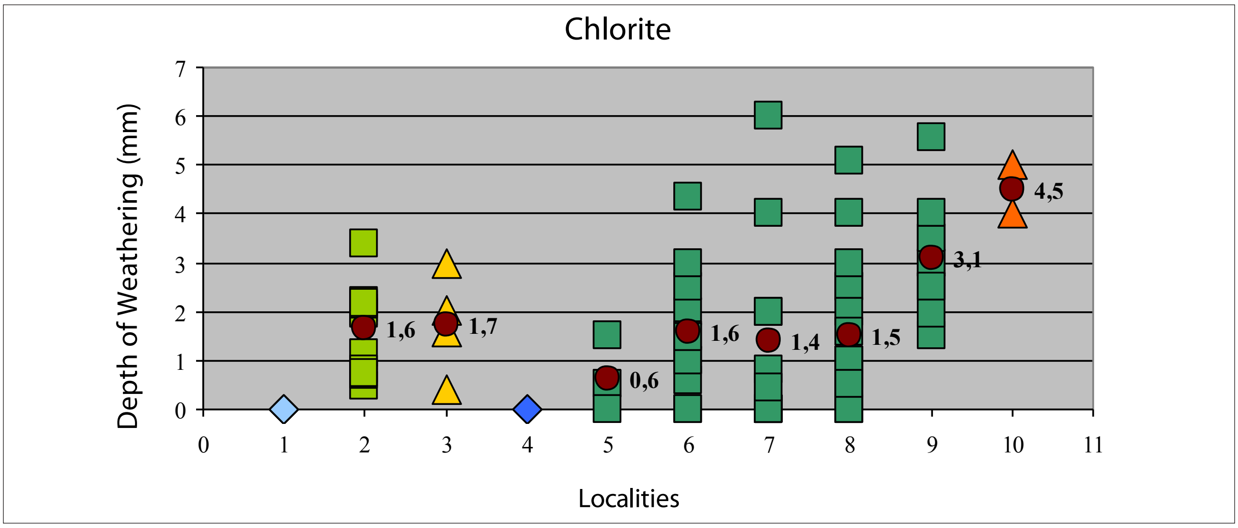


Fig. 5.2.4-2 Depth of solution of chlorite in rock samples from different localities and environments on Vingeneset (nr. 1-3) and at Vingen (nr. 4-10). (nr.1-exposed rock surface near the shore on Vingeneset; 2-exposed surface with unspecified lichen on Vingeneset; 3-surface with a thin covering of turf on Vingeneset; 4-exposed surface near the shore at Vingen; 5-9 exposed surfaces with particular types of lichen at Vingen (5-L.fuscoatra, 6-F.cyathoides, 7-O.tartarea, 8-P.corallina, 9-O.ventosa); 10-surfaces with a thick cover of turf at Vingen (●=average value).

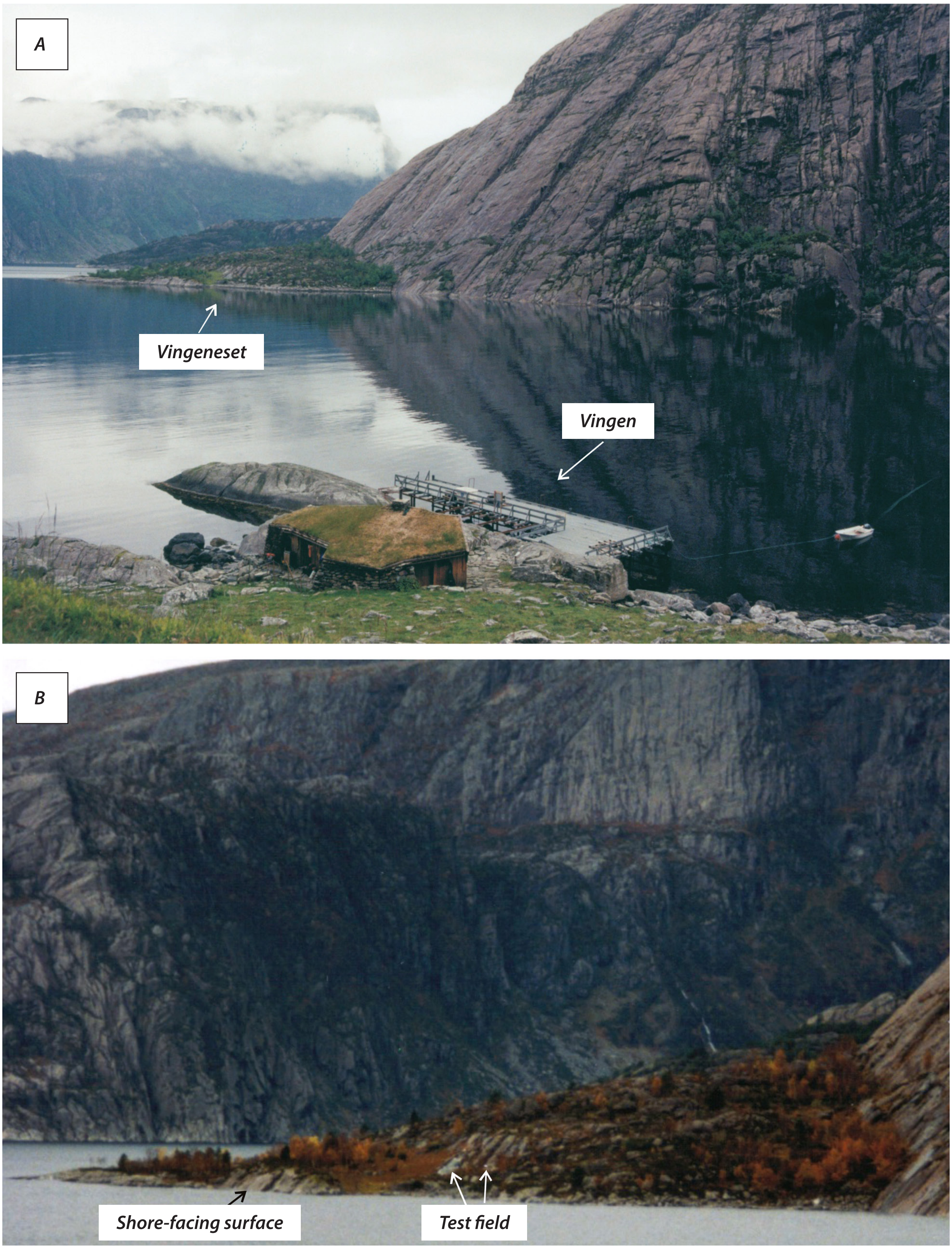


Fig. 5.2.4.2-1 *a) To investigate the effect of seawater on weathering samples were collected from surfaces near the coast both on Vingeneset and at the quay at Vingen. b) On Vingeneset five samples were taken from a surface facing the sea along a profile from the shore up to a height of about 8 m a.s.l. (at the line of trees). Samples from surfaces further inland and used as a trial area are from a lower topographic level than the samples from the top of the sea-facing surface.*

The samples from the profile on Vingeneset show a weak increase in the depth of weathering from 1.5 mm at the shore to 2–3 mm in samples from the higher parts of the rock surface. In the samples from Vingen, the depth of weathering is about 0.5 mm at the shore and 3–4 mm on the rock surface at the quay. The deeper weathering at the shore on Vingeneset (1.5 mm) relative to that at Vingen (0.5 mm) can be a consequence of the larger grain size in the samples from Vingeneset.

One of the reasons for thin weathered crusts near the shore can be continual abrasion by waves. This seems to be unlikely, since *Verrucaria maura* (see 4.3.1) and the other species of lichen that grow on the surfaces appear to be unaffected. An alternative explanation is that seawater reduces the rate of chemical weathering. This seems likely, as seawater has a higher pH than rain and surface water and is closer to equilibrium with calcite, the most soluble of the minerals in the rocks. Salt lowers the freezing point of water and the rock surfaces will be less susceptible to frost action (se 5.1.3.3). This will probably also reduce the rate of chemical weathering.

Due to the change in sea level since the last ice age, rock surfaces near the shore have not been exposed to rain and surface water for as long as topographically higher surfaces. It may be surmised that this would be reflected in different depths of weathering. On Vingeneset the depth of weathering of rock surfaces further inland is on average 8.9 mm. These surfaces are, however, topographically lower than sample nr.5 (with a depth of weathering of 2 mm) in the sea-facing profile, but are more sheltered from sea spray (Fig. 5.2.4.2-1b). This indicates that sea spray can be the main reason for the reduction in chemical weathering on exposed surfaces.

5.2.4.3 Turf-covered rock surfaces

The surfaces investigated on Vingeneset were covered with a thin layer of turf (10–15 cm of humus) on their lower edges. Beneath the turf, the average depth of weathering is 10.9 mm (group 3). This is more than on the exposed rock surfaces, where the average depth of weathering is 8.9 mm (group 2). Surfaces covered by a thicker layer of turf (around 50 cm) behind Vehammaren in Vingen are weathered to a depth of around 15.6 mm. This is clearly deeper than on exposed rock surfaces in the same area (groups 5-9) that on average are weathered to a depth of 9.3 mm. The outer chlorite-free zone also extends deeper beneath thick turf than elsewhere.

There may be several reasons for the deeper weathering beneath turf than on exposed rock surfaces. One reason may be less erosion due to reduced mechanical stress. Another could be that turf accelerates chemical weathering. If the difference, which can be as much as 6 mm beneath thick turf, was the result of physical processes, then rock carvings would not remain on any exposed surfaces. It therefore seems likely that some of the difference is due to weathering being enhanced by the presence of turf. This may be a consequence of organic acids that reduce the pH and are effective in forming complexes, both of which are well known to accelerate rates of mineral solution. When such strongly weathered surfaces are uncovered they will be especially susceptible to physical processes.

5.2.5 Experimental dissolution of Vingen sandstone

During the project period good knowledge about the weathering of the Vingen sandstone in field has been reached. As described above, analysis have shown that the weathering of the sandstone increases in contact with turf- and heather vegetation, lichen growth/microvegetation and/or exposure to acid seepage water. On the contrary, contact with seawater results in very little weathering. These observations lead to certain insecurity. For instance, there is an interaction between the different weathering factors, and in practise they are difficult to separate. For how long have the surfaces been covered by turf? How has the vegetation of lichens changed over the last 10,000 years? Is wave erosion the cause for the lack of weathering rinds observed near the sea? Or is the chemical composition of the seawater favourable for the preservation of the minerals of the sandstone?

Due to these questions, the need arises to explore the weathering of the sandstone under controlled conditions. Experimental dissolution of the Vingen sandstone was therefore carried out to investigate the effect of inorganic and organic acids, different pH and seawater on the mechanism and dissolution rate of the sandstone.

5.2.5.1 Experimental set-up

Batch experiments were performed using autoclaved polypropylene reactors. Fresh 1cm^3 cubes of unaltered sandstone were placed in 200 ml sterile solutions with different pH (1–6.5) of HCl and oxalic acid (10^{-3} M), and sterile filtered seawater. The pH of the solutions were measured and adjusted once a month. To prevent photo oxidation, the containers were kept dark at room temperature (21^{o}C) during the experimental run. Samples were taken after 3 months, 6 months, 12 months and 18 months of reaction time. Thin sections were prepared of the cross sections of each sample. Thin sections were analysed in SEM/EDS.

5.2.5.2 The effect of different pH

The analyses reveal that the rate of weathering increases with decreasing pH, with a minimum at near neutral pH. Dissolution due to contact with inorganic acids results in the development of a weathering rind similar to the one observed after weathering in nature, where a total dissolution of calcite occurs. The thickness of the calcite depleted zone increases with time and by decreasing the pH from a minimum at near neutral pH. After 1 month of reaction time at pH 1 (HCl) a 1.58 mm thick rind where calcite is dissolved appeared at the sample surface. After 18 months of reaction the rind was 3 mm deep at pH 1. After 18 months of reaction at pH 6.5 only partial dissolution of calcite grains was observed in a < 100 mm thick rind.

5.2.5.3 The effect of oxalic acid

Dissolution of calcite is insignificant after reaction with oxalic acid solutions. The calcium from calcite reacts with the oxalate from the solution to form Ca-oxalate crystals at the sample surfaces. However, the dissolution of the mineral plagioclase seems increased compared to reaction with inorganic acids at the same initial pH. After 18 months of reaction at pH 1 in oxalic acid, a 0.615 mm thick rind was observed at the sample surface. In the zone plagioclase is partially dissolved, whilst calcite, chlorite and alkali feldspars are unaffected.

5.2.5.4 The effect of sea water influence

As in nature, reaction with seawater results in minimum dissolution of the sandstone samples. The reason is probably due to seawater having a higher pH than rain and surface waters, and therefore being in more equilibrium with calcite.

5.2.6 Rates of dissolution and the effect of seawater

In cooperation with the University of Stockholm, a system was set up in the autumn of 1999 for the collection of water draining from a rock surface near the quay at Vingen. Water samples have been collected periodically (every 14th day) for chemical analysis (ICP-MS). These data, together with chemical analyses of the precipitation, may provide important information regarding rates of mineral dissolution, as we want to quantify the weathering as the elemental difference between the run off water and the precipitation.

5.2.7 A measure of the weathering – Comparison of moulds from 1925 and 2001

Around 1925 Espevold and J. Bøe made gypsum moulds of many of the rock carvings in Vingen. These moulds are kept at Bergen Museum. To measure the weathering and to find how much the surface has changed during the last 75 years, two moulds were chosen and compared with silicon moulds from 2001. We also wanted to investigate if surfaces exposed to turf weather faster than exposed surfaces when the turf is removed.

The moulds we chose were made of two carvings we know had been exposed to different conditions in Vingen. Carving A has probably never been covered by vegetation, and from Bøe's notes it says that "The carving is wide and distinct with point chiselling". Carving B was covered with turf when Espevold and Bøe discovered it around 1925. In Bøe's notes from 1925 he says that "The carving has been covered by turf and is very well preserved".

5.2.7.1 Methods

The forms were 3D scanned using a scanning method developed by a Swedish company called Metimur. The method is objective and documents the different levels of the moulds with high precision (2/10 mm). The results of the documentation are data files with points containing three-dimensional coordinates (X, Y and Z). These data are treated and visualised in Fledermaus.

5.2.7.2 Results

The results of the scanning process show that weathering occurs on the entire surfaces, not only in the carvings. The measurements obtained by the scanning process are minimum measurements of the changes, since no reference area where no weathering has occurred exists.

Carving A (uncovered)

The visualised 3D image of the two moulds (from 1925 and 2001) shows major changes over the last 75 years. The carving has become less defined, the pit marks less visible, while the surrounding surface is less smooth and has more defined rock structures. This is observed although today's moulding technique is much more detailed than in 1925. Analysis in Fledermaus shows that erosion has occurred along the boundary between the carving and the rock surface. Also, details in the carving have disappeared and the result is a much wider and shallower carving.

Carving B (covered by turf in 1925)

The biggest change is observed in this figure. In general, the carving is more blurred. Especially, the neck, the head, the front legs and the back part of the figure are difficult to see. The entire surface is very uneven due to a loss of quartz grains in the upper surface. Analysis in Fledermaus shows that erosion has occurred along the boundary between the carving and the rock surface. Details in the carving have disappeared, and the result is wider carving with shallower pit marks. The uneven surface is very prominent, and this indicates that physical degradation is a serious problem on the surface.

5.2.8 Evaluation and conclusions

The outer, most porous zone on exposed rock surfaces, where chlorite is totally dissolved and plagioclase is partially dissolved, is on average 1.5 mm thick, but large variations in thickness are found. Since the rock is plagioclase-rich, this zone is susceptible to fragmentation as only quartz, alkali feldspar and possibly muscovite hold the rock together. Even a solution of a few micrometers along the grain boundaries of these resistant minerals will result in a total loss of adhesion and loosening of the grains. Although the zone is thin, this can have dramatic consequences for the rock art, as it is very shallow. With regard to preservation of the rock art, the chemical weathering is approaching a critical level.

The large amount of precipitation at Vingen promotes chemical weathering. Direct exposure to seawater appears to significantly reduce the rate of chemical weathering, probably due to the high pH of the seawater and the fact that it is closer to equilibrium with calcite. Chemical analyses of precipitation show that it is strongly influenced by seawater with relatively high pH and high concentrations of salts. This probably inhibits chemical weathering relative to precipitation free of salts.

Turf appears to accelerate chemical weathering, possibly due to the presence of various organic acids that result in chemical complexing and effectively reduce the pH. Rock surfaces that have been covered in turf for an extended period will be very susceptible to physical degradation. Carvings on these types of surfaces will disappear faster than carvings on corresponding exposed surfaces after the turf is removed.

5.3 Biological processes

5.3.1 Macro-vegetation

The interactions between agricultural land use, vegetation and soil chemistry are the main basis of this part of this study. Grazing has been an important ecological factor in these areas for many years, but is now threatened by cessation. Cessation of grazing leads to the accumulation of organic matter. During decomposition organic acids is released, which lowers the soil pH and increase nutrient supply. This initiates a forest succession that will gradually change the vegetation composition. In all likelihood, a succession in these costal areas through several stages will move towards a mature association between heather and Scots pine *(Pinus sylvestris)*, including deciduous species such as birch *(Betula spp)* and rowan *(Sorbus spp)*. A development of this kind should be avoided, as this will lower the soil pH and also complicate the accessibility to the rock carvings. Also, trees and scrubs will develop extensive root systems that may affect the rock carvings, as their roots may expand into rifts and crack off pieces of the bedrock. To minimize degradation of the bedrock and accelerated destruction of the rock carvings, it is considered to be highly important that the soil and environment is kept as close to a neutral pH as possible.

5.3.1.1 Decomposition of *Calluna vulgaris*, soil chemistry and acidification

One of the most important species in this area is *Calluna vulgaris,* which covers large areas, especially at Vingeneset. A general soil acidification in the presence of this species is believed to be one of the main problems related to macro-vegetation and the degradation of rock carvings in Vingen and Vingeneset. Acidification accelerates the solubilization of minerals in the soil (especially Fe) and enhances mineral leaching; podzolization occurs, which creates a soil profile with an acidic, nutrient-poor upper layer. This is the most common soil profile in Norway. Soil acidification from *C. vulgaris* is suspected to be induced both by the chemical character of the canopy drip and by chemical compounds released during the decomposition of organic matter. Furthermore, soil acidification is also closely associated with the type of humus produced in heathlands. In a similar investigation where CaO and phosphate was experimentally introduced to a heather-dominated mountain heathland, Erstad & Steffensen (1999) showed that cover of Ericaceous species including *C.vulgaris* is reduced by liming.

A number of organic and inorganic compounds are released during the growth and decomposition of plant material, the most important of which are lipids and various phenolic compounds which comprise up to 40% of the shoot dry weight. Phenols are structurally similar to alcohols, but are stronger acids (pK_a <11). Furthermore, through various chemical reactions during the degradation of phenols, much stronger acids are produced. In soil extractions from British heathlands, residues of phenols such as p-methoxybenzene, benzoic and salicylic acids were found (Leake et al. 1989). These compounds will make the soil both toxic and acidic. Bruckert & Jacquin (1973) measured *C. vulgaris* canopy drip to have a pH of 3.5. Correspondingly, Fisher & Yam (1984) found mean pH values over the year between 4.25 and 4.5, linking the deviation in these results to both environmental and methodological differences. Fisher & Yam (1984) also tested the iron-mobilization capacity in extracts from *C. vulgaris* leaf and plant litter in different seasons and plant ages. Solubization of iron in the upper soil profile is the stage that initiates the podzolization process. They found that that the iron-mobilization capacity in the extracts depended upon plant age, season and soil condition. The results showed that actively growing plants at pioneer stage produced significant higher iron-mobilization rates than older plants. Furthermore, plant extracts were more active in plants from wet heathlands than plants from dry heathlands. Fischer & Yam (1984) concluded that their study indicated that iron-mobilization under *C. vulgais* was more likely to be a consequence of the acidity and mineral release characteristics of the canopy and litter, than any exceptional ability of its throughfall alone to mobilize iron.

A second important aspect in this question is connected with the type of humus that is typically produced in heathlands. During the decomposition of organic matter, acids are released and the pH is reduced. Generally, the content of organic matter is substantially higher in grassland soils than in forests or heath soils (Stevenson 1982). In the grasslands, humus is synthesized in the rhizophere, which is more extensive under grass than under forest vegetation. This type of humus is called mull humus. In heathlands, materials from dead plants accumulate on the soil surface and form an organic-rich layer. Only the uppermost mineral soil layer becomes stained with humus, which leads to a high C:N ratio in the upper layer (Anderson & Hetherington 1999). The litter from heather contains large amounts of cellulose and lignin, and small amounts of nitrogen. The high aliphatic and polyphenolic content in the litter inhibits microbial attack and contributes to the development of mor (raw) humus, which characteristically decomposes slowly and maintain a structure of vegetable material (Ponge 2003). This leads to the accumulation of organic matter, and the litter layer in heathlands can be of substantial thickness. Mull humus in grasslands and mor humus under heathlands and forests differs in the content of humic and fulvic acids. Mull humus has a humic: fulvic acid ratio that is higher than 1, while the opposite is typical for the latter type. Peat also contains more humic than fulvic acids. Fulvic acids contain more functional groups (especially COOH) of an acidic nature than humic acids. The total acidities of fulvic acids (900–1400 meq/100g) are considerably higher than for humic acids (400–870 meq/100g). The formation of mor humus and the action of fulvic acids is like the effect of canopy drip, which is strongly suspected to affect the soil podzolisation in heathlands. It is likely that these are additive effects that are effectual at the same time.

Concerns have also been expressed as to whether ericoid associated mycorrhizas may have an environmental impact that accelerate degradation processes. Ericoid mycorrhiza is a group of more than 200 strains of endophytic organisms that live symbiotically in the roots of *Ericales* host plants (*Vaccinium, Calluna, Rhododendrum etc*.) Plants infected with *Ericoid mycorrhizas* are found to grow successfully on mor humus soils in which low pH and high organic acid levels combine to exclude many other species. In highly acidic organic soils, N mineralization rates are low, and mycorrhizal infection may significantly contribute to plant N nutrition (Harley and Smith, 1983). It has been shown that the ericoid endophyte trough enzymatic production is able to degrade complex organic substances to provide its host plants with access to sources of otherwise unavailable N. The symbiotic relationship between the fungi and the plant thus facilitates the growth of ericaceous plants in acidic mor humus, and induces resistance to toxic metallic ions by reducing inflow, although the underlying mechanisms are not clearly understood (Leake at al. 1989). The rate of mycorrhizal infection in *Calluna* roots is found to be depressed with the deposition of acids and/or ammonium (Yesmin et al 1996), and therefore decreases with atmospheric nitrogen deposition in peat soils.

It has been demonstrated that the endophyte *Hymenoscyphhus ericae*, which is often associated with *C. vulgaris* in heathlands, has a considerable saprotropic potential. Growing in sclerophyllus litter of high C:N and C:P ratios, the plant benefits from the association with this fungi species, which mobilizes crucial nutrients as N and P through its activity and makes them available for plant growth (Read 1991, Cairney & Burke 1998). Therefore, in organically enriched acidic soils with N and P shortage, *Ericales* is competitive to other plant species due to the association with the endophyte.

How this symbiotic relationship interacts under Norwegian climatic relationships and the amount of mycorrhizal infection are unknown. The concerns are linked to whether some of the extra-cellular enzymes produced by the mycorrhiza serve as acids in soil or otherwise accelerate the degradation process. Little research on these relationships has been carried out, making it difficult to assess the possible environmental effects at this time. But the question is interesting, and should be investigated. However, plant-mycorrhiza associations are a common feature of all vegetation types, and therefore cannot be avoided in nature. Today, in connection with the issues addressed in this investigation, we have no reason to suspect that ericoid mychorriza acts negatively, although it seems to be very effective in various aspects.

However, the presence of *C. vulgaris* acidifies the environment and thus induce soil podzolisation trough canopy drip and litter, and indirectly through aggregation of mor humus. This implies that the expansion of *C. vulgaris* into the Vingen area should be avoided, and that it is desirable to induce a transition from heathland towards grasslands at Vingeneset.

Nitrogen, potassium and phosphorus are often the nutrients that limit growth in plants. Only a small portion of phosphorus in the soil is available to plants. The highest amount of phosphorus is available at pH levels of between 5.5. and 6.5. In acidic soil, much of the phosphorous is found in complex compounds with iron and aluminium, and is precipitated. At pH levels higher than 6.5 some of the phosphorus will be bonded as calcium phosphate. Ca-phosphate is still more readily available than minerals of Fe-phosphate and Al-phosphate. It has been shown that phosphorus deficiency can increase the exudation of protons and organic acids from the roots of several species (Schilling *et al.* 1998, Neumann & Römheld 1999, Wallander 2000). At high pH (>6.5) this may liberate phosphorus from Ca-phosphate. At lower pH organic acids can liberate phosphorous, among other ways, by ligand exchange (Neumann & Römheld 1999). In addition, the exudation of protons and organic acids from the roots of plants can absorb phosphorus in the form of apatite, which is found in small amounts in most rock species (Wallander 2000). These kinds of organic acids have a major impact on degradation and podzoling of soil (Lundström 1994, Hansen et al. 1999). These biological processes, along with precipitation that filters down through the soil, are factors causing eluviation of base cations and natural acidity in our soil.

Liming raises pH, increases the soil's ability to retain base cations and thus improves access to important plant nutrients. At the same time, there will be reduced amounts of aluminium, iron and manganese oxy-hydroxides that inhibit plant growth. Moreover, liming will increase activity in soil microbes, which in turn induces a more rapid and complete decomposition of litter. By adding raw phosphates we expect to be able to inhibit the strongly acidifying effect of seeking for phosphate. Both lime (bulk dolomite) and raw phosphate are relatively poorly soluble. Therefore, the full effect of liming and fertilizing may not be expected to become apparent for some years.

Against this backdrop, a study was set up to investigate how the present situation could be altered in Vingen and especially Vingeneset, to prevent further soil and environmental acidification. The investigation was set up to monitor the possible response at both sites on soil chemistry, humus and vegetation composition after treatments involving CaO liming and P fertilizing.

5.3.1.2 Experimental design and methods

The experimental treatments were carried out in both the heathlands at Vingeneset and at the grasslands of Vingen. Because of archaeological priorities, the treatments could not be performed as desired to ensure sufficient material for statistical analysis. Consequently, the result of the investigation is restricted. This is an extremely heterogeneous environment that requires a large number of experimental repetitions and controls in order to produce a statistically reliable answer in the studies of effects on vegetation.

In the experiment we wanted to test the effects of CaO chalking and phosphorous fertilizing. The plots were established in June 1996, when four grassland patches and one heathland patch were made available for the investigation. These were divided into 2x2m squares, and treatments listed in table 5.3.1.1. were given. At the Vingeneset experimental site the 2500 kg Cao and the 60 kg phosphate treatments were omitted, as the patch was too small. Likewise, at the Behind Vehammaren site the 2500/0 and 5000/0 treatments were left out and all treatments involving phosphate, in order to avoid effects on archaeological methods. The rock-phosphate brand that was used was Israelfosfat (Hydro Agri). The chemical content was 14.99% P, 34.3% P_2O_3, 39.1% Ca, 0.04% Cl and 0.0016% Cd. The lime used was a coarse dolomite type with a content of 59% CaO. Before the treatments, soil samples were taken from all sites at 0–5 and 5–20 depths where possible. For each site, two samples from each depth were taken, except for Bakkane and East of Vehammaren. Elsewhere, when the soil dept was insufficient, the sample was divided into two parts (an upper and a lower part, respectively, representing 0–5 and 5–20 cm soil depth).

Further soil samples were collected in 1999 and 2005, and all of the samples were analysed according to standard methods and the base saturation was calculated. A vegetation survey was performed annually over three years between 1996 and 1999, and again in 2004.

Table 5.3.1.1. *Experimental treatments in Vingen and Vingeneset*

	Rock-phosphate, kg pr. ha		
CaO, kg pr ha	**0**	**60**	**120**
0	0/0	0/60	0/120
2500	2500/0	2500/60	2500/120
5000	5000/0	5000/60	5000/120

5.3.1.3 Results; the soil and macro-vegetation response to CaO liming and P fertilizing in the grasslands of Vingen and Vingeneset

The results in this chapter is based directly on results from analyses of the soil-samples and they are only briefly tested and discussed because the expertise in soil-chemistry unfortunately chose not to contribute to the project in the final stage, as mentioned in the preface. The text in this chapter is therefore mainly a translation of work of Hovstad & Øpstad (2001) published in an earlier version (Thorseth & al 2001:93pp). Because of several changes in personnel and shift in methodology over the years, the data from the vegetation part of the study is insufficient and therefore difficult to draw any conclusions from based on available tests. Furthermore, at the Vingeneset site the experimental squares were covered by soil and peat accidentally during some archaeological restoration work nearby, and this part of the study was interrupted before 2004.

Vingen

Table 5.3.1-2 shows the results from pH, base saturation level, and Ca-Al readings in soil samples taken in 1996 before soil treatments, and in 1999 and 2005. Before the treatments, soil analyses showed that all of the sites except Bakkane had low values for both pH and base saturation. The values are almost consistent to what would be expected in soils with this vegetation type (Losvik 1993, Fremstad & Moen 2001), but the pH values are a little low, especially in the former arable field at Terrassane.

The earlier arable infields in Vingen have poorly developed brown soil. The topsoil in many places is very shallow, and there is a high content of organic material. The soil in the "Bakkane" section has a relatively high loss on ignition, but here the decomposition of organic material has occurred under good conditions and the organic material is humified.

Table 5.3.1.2. *pH, base saturation (%) and Ca-AL in soil samples from grassland patches at two levels. The results are grouped according to CaO treatments.*

1: East of Vehammeren		**Level 0–5 cm**			**Level 5–20 cm**		
Year	CaO treatment	pH	Base saturation, %	Ca-AL	pH	Base saturation, %	Ca-AL
1996	0	4.6	25.8	45.2	4.3	16.9	37.7
	0	5.0	34.9	74.2	4.8	20.3	58.9
1999	2500	5.7	51.6	128.4	5.4	44.0	99.3
	5000	6.1	68.6	163.2	5.8	52.6	148.2
	0	5.1	37.7	84.9	4.8	33.0	86.9
2005	2500	5.5	53.8	123.4	5.6	51.2	131.1
	5000	5.7	65.6	161.3	5.8	58.8	166.9

2: Terassane		**Level 0–5 cm**			**Level 5–20 cm**		
Year	CaO treatment	pH	Base saturation, %	Ca-AL	pH	Base saturation, %	Ca-AL
1996	0	4.3	15.6	14.8	4.3	8.7	7.2
	0	4.8	26.6	25.5	4.8	15.6	10.6
1999	2500	5.7	59.3	65.8	5.2	26.0	17.6
	5000	6.0	69.3	85.8	5.4	31.0	25.6
	0	5.0	25.9	28.4	5.2	20.2	24.7
2005	2500	5.7	55.2	50.6	5.8	41.5	47.9
	5000	6.1	67.8	105.3	6.1	57.8	73.5

3: Bakkane		**Level 0–5 cm**			**Level 5–20 cm**		
Year	CaO treatment	pH	Base saturation, %	Ca-AL	pH	Base saturation, %	Ca-AL
1996	0	5.9	59.8	175.1	5.6	54.9	150.2
	0	5.5	58.1	168.2	5.5	55.0	172.1
1999	2500	5.8	63.4	196.3	5.6	58.2	182.6
	5000	6.0	69.8	188.4	5.7	63.1	205.3
	0	5.6	59.4	161.0	5.3	50.5	142.0
2005	2500	5.6	66.4	156.8	5.3	45.0	144.6
	5000	5.7	65.4	154.5	5.3	52.3	164.0

4: Behind Vehammaren		**Level 0–5 cm**			**Level 5–20 cm**		
Year	CaO treatment	pH	Base saturation, %	Ca-AL	pH	Base saturation, %	Ca-AL
1996	0						
	0	4.3	22.5	37.3	4.2	16.7	30.6
1999	2500	5.0	41.5	86.4	4.5	23.1	44.2
	5000	5.1	45.0	92.2	4.5	24.0	45.4
	0	4.3	24.0	44.7	4.3	18.7	42.3
2005	2500	5.1	44.1	111.9	4.9	32.8	83.1
	5000	5.3	52.8	127.5	5.1	39.5	114.5

The "Bakkane" section has the desirable pH and base saturation also on the non-limed quadrates. For permanent grassland and grazing it is considered desirable to have a pH somewhere between 5.3 - 5.8 and with highest demand for pH when there is little organic material in the soil. Liming has resulted in increased pH in the soil. The change in pH as a result of liming is significant for both strata in all sites in Vingen. The largest increases in pH were found in the sections "East of Vehammaren" and "The Terraces" (Terrassane). These two blocks also have the lowest content of organic material in the soil.

pH affects the soil nutrient conditions through several different mechanisms. One such important mechanism is the competition between H^+ and nutrient cation for negative charge space on the surface of soil colloids. The degree of base saturation expresses the relationship between the amount of adsorbed nutrient cation and the soil's overall ability to adsorb cation. Acidic soil with a low content of adsorbed H^+ has a low base saturation. In all blocks except "Bakkane", the base saturation degree is low, and this is closely connected with the pH levels in the soil. A good base saturation degree in mineral soil used for agriculture is 60-80 %, a little lower for organic soil (50-70 %).

Soil must be regarded as a buffer system with a certain ability to withstand fluctuations in pH. Liming results in an alteration in the equilibrium between ions adsorbed to soil colloids and ions in the soil's liquid content. Adsorbed H^+ is replaced with Ca^{2+} or Mg^{2+} and is distributed in the liquid of the soil. There it reacts with different bases or is washed out. The effect of liming on pH depends on the ability of the soil to act as a buffer. Soil with a high content of organic material has a high buffering ability, and a lot of lime is needed to raise pH. Lime that is spread on the surface will slowly percolate down through the soil (Hagem 1933). Some lime will be washed away on the surface, and some of the lime will be part of chemo-biological reactions or will be bonded in the uppermost layer of the soil. Therefore the effect of the lime will be greatest in the upper layer, as shown in Table 5.3.1-2.

Lime penetrates down into the humus types of soil to a lesser degree than it does into gravel and sandy soil. Humus is highly adsorbent, and more lime will be needed, as a result, in the uppermost layer of the soil. In the mineral-rich soil in the "Bakkane" and "East of Vehammaren" blocks, the effect of liming at depths of 5-20 cm is evident.

Table 5.3.1.3. *Result of chemical analyses of soil samples for some minerals in grassland sites 1996 (before treatment) corrected for volume weight.*

Site	**Level (cm)**	**Mg-AL** (mg/100g)	**P-AL** (mg/100g)	**K-AL** (mg/100g)	**K-HNO3** (mg/100g)
East of Vehammaren	0-5	25.5	4.4	20.5	28
	5-20	17.9	3.0	11.3	23
Terrassane, western part	0-5	20.5	7.9	19.2	21
	5-20	7.0	6.0	4.4	10
Terrassane, eastern part	0-5	13.2	6.2	11.8	17
	5-20	5.6	5.6	3.0	7
Bakkane	0-5	23.9	5.9	23.1	27
	5-20	19.7	4.8	14.9	19

Table 5.3.1-3 shows the values of some minerals in soil samples before treatment. Liming leads to an increase in adsorbed Mg and Ca (Mg-AA and Ca-AA) as well as easily soluble Mg and Ca (Mg-AL and Ca-AL) in the soil (Table 5.3.1-4). This effect from liming is significant in both layers 1 and 2. There is also a tendency toward an increased Mg and Ca content in plant matter, but the variation in material is wide. In all likelihood, access to Mg and Ca is not a limiting factor for plant growth in Vingen. At Vingeneset, on the other hand, the Mg and Ca content in plant matter is very low.

Table 5.3.1.4. *Soil content of some analysed minerals in level 0–5 cm in 2005. The values are corrected for volume weigths and represents means of all squares within same CaO treatment.*

Site	**CaO treatment**	**Mg-AL** mg/100g	**P-AL** mg/100g	**K-AL** mg/100g	**K-HNO$_3$** mg/100g	**Na-AL** mg/100g
Aust for Vehammaren	0	32.7	8.2	23.7	31.9	19.3
	2500	42.8	6.1	17.9	26.0	20.9
	5000	56.0	5.8	23.5	31.4	18.3
Terrassane	0	17.4	7.7	11.8	18.9	12.3
	2500	29.5	6.4	8.0	16.4	15.3
	5000	39.3	7.1	10.0	17.9	13.2
Bakkane	0	31.4	4.4	20.1	27.5	22.2
	2500	30.5	4.2	18.6	29.0	20.7
	5000	29.5	3.8	18.4	24.8	23.3
Bak Vehammaren	0	32.2	11.3	27.9	35.3	22.7
	2500	45.6	7.6	20.0	24.9	25.1
	5000	55.8	6.8	18.7	18.6	22.2

The copper level in plants can easily be affected negatively by liming, and there is a tendency toward a decrease in amounts of copper in the plant material, although the difference is not significant. In Vingen an average of 7.31 mg Cu/kg TS was found for plant material located in the quadrates that had not been limed. For samples with 250 and 500 kg CaO, the results found were 6.46 mg Cu/kg TS and 6.59 mg Cu/kg TS. In Vingen, the copper content in the plant material is within a normal range, whereas at Vingeneset it is a little low (2.85 mg Cu/kg TS on the average). At less than 5 mg Cu/kg TS copper deficiency, the growth and development of grassy plants will be inhibited (Aasen 1997). Copper is an element in haemoglobin and several enzymes, and a low copper level may result in stunted growth and discontentment in domestic livestock. Grazing on heather with high copper content can help to ensure that copper intake needs are met.

In Vingen there is a tendency that lime-treated quadrates have less moss-growth than untreated quadrates. On the other hand, there is no clear tendency towards increased ground cover in the categories of grassy or herb plants. The lime-treated quadrates were judged to have acquired a deeper green colour, and this indicates better access to nutrients. A quantitative assessment of grass growth in a grazed pastureland is difficult, and we are unable to draw any certain conclusions concerning how lime and raw phosphates have affected grass growth in Vingen. Earlier experience nonetheless shows that careful lime treatments on acid soil results in increased growth.

The addition of raw phosphates has resulted in an increase in P-AL in both layer 1 and layer 2 in Vingen. In Vingen, the P-AL value averaged 9.27 mg/100g at 0 kg lime, 8.36 mg/100g at 250 kg lime and 7.24 mg/100g at 500 kg lime in layer 1. We normally expect that liming will lead to a slight increase in P-AL values. Increased pH improves access to phosphorus since fewer phosphates are bonded in clay colloids, iron and aluminium hydroxides and accelerated breakdown of organic materials (Øgaard 1994). At the same time, lime can bond P in different forms of calcium phosphate that are not easily soluble. The effect of liming for access by plants to phosphorus, in other words, can be both positive and negative. Calcium phosphate is dissolved by ammonium lactate (AL), and application of calcium phosphates therefore has little effect on P-AL. Raw phosphates are easily soluble at low pH, and this may be part of the reason for the negative relationship between lime and P-AL.

Table 5.3.1.5. *Loss of ignition (% of dry matter) at two levels at the Vingen localities before the treatments (1996), after three years (1996) and 9 years (2005).*

Site	1996		CaO treatment	1999		2005	
	0–5 cm	5–20 cm		0–5 cm	5–20 cm	0–5 cm	5–20 cm
East of Vehammaren	35.3	25.3	0	39.1	27.6	39.9	34.7
			2500	31.2	30.1	34.4	27.5
			5000	36.9	29.8	35.2	25.7
Terrassane	13.3	7.8	0	15.8	7.6	13.2	8.4
			2500	15.5	8.0	14.4	7.4
			5000	15.3	7.9	13.8	7.2
Bakkane	34.1	17.8	0	40.8	35.5	41.6	31.1
			2500	39.8	32.9	41.8	28.5
			5000	42.6	33.5	38.1	27.5
Behind Vehammaren			0	84.3	84.7	85.9	83.6
			2500	82.3	85.2	79.9	65.8
			5000	80.3	85.7	79.4	65.0

The analysis for loss of ignition is an indicator for changes in humus content in the soil samples. For the Vingen localities the result shows no significant changes in this parameter, indicating that decomposition of humus has not increased (Table 5.3.1-5). In a mineral soil such as grassland, this is as expected. For the Bak Vehammaren plot, the initial values for this parameter are missing.

Vingeneset

At the Vingeneset localities, the soil samples that were taken before lime and fertilizer treatments in 1996 (Table 5.3.1-6 show that these plots have a rather acidic soil. The sample area is located at Vingeneset on organic soil characterized by raw humus. The raw humus stratum contains both decomposed organic material and living and dead plant materials that bind the soil together in a matted structure. The high organic content explains the high loss on ignition at Vingeneset (Table 5.3.1-7).

Lime penetrates down into the humus types of soil to a lesser degree than it does into gravel and sandy soil. Humus is highly adsorbent, and more lime will be needed, as a result, in the uppermost layer of the soil. The results in Table 5.3.1.6 show that the effects of liming at 5-20 cm depth are negligible in the raw humus soil of Vingeneset. The pH value and base saturation degree in the soil samples from Vingeneset show that at 500 kg lime per 1000m2 there is no significant change in the state of the soil. There is a major need for lime treatments on the latter soil type.

Table 5.3.1.6. *pH and base saturation (%) in soil samples from coastal heathland patches at Vingeneset in 1996, 1999 and 2005 at two levels.*

Site	Year	CaO treatment	Level 0–5 cm pH	Base saturation, %	Ignition loss (% of dry matter)	Level 5–20 cm pH	Base saturation, %	Ignition loss (% of dry matter)
Vingeneset	1996	0	4.1	22.5	94.1	3.9	18.7	81.0
Vingeneset	1999	0	4.2	27.6	88.2	4.1	21.5	85.3
		5000	5.3	56.3	58.5	4.3	26.8	52.1
Vingeneset	2005	0	4.3	27.5	85.6*	4.2	22.6	60.3*
		5000	5.3	55.3	75.1*	5.1	39.0	54.2*

Liming leads to an increase in adsorbed Mg and Ca (Mg-AA and Ca-AA) as well as easily soluble Mg and Ca (Mg-AL and Ca-AL) in the soil (Table 5.3.1.7) This effect from liming is significant in both layers 1 and 2. There is also a tendency toward a rise of Mg and Ca content in plant matter, but the variation in material is broad. The access to Mg and Ca is very likely not a limiting factor for plant growth in Vingen. At Vingeneset, on the other hand, the Mg and Ca content in plant matter is very low.

Table 5.3.1.7. *Soil content in Vingeneset of some analysed minerals in level 0-5cm in 1999 and 2005. The values are corrected for volume weights and represents means of all squares within same CaO treatment.*

Site	**CaO treatment** kg/ha	**Mg-AL** mg/100g	**Ca-AL** mg/100g	**P-AL** mg/100g	**K-AL** mg/100g	**K-HNO$_3$** mg/100g	**Na-AL** mg/100g
Vingeneset, west 1996	0	16.1	19.6	4.1	13.7	15.0	
Vingeneset, east 1996		28.1	12.7	3.4	3.7	11.0	*
Vingeneset 1999	0	35.2	54.2	8.3	18.4	16.1	14.7
	5000	76.6	119.7	6.0	15.1	13.8	11.5
Vingeneset 2005	0	26.9	56.0	5.0	21.3	21.8	15.1
	5000	63.8	121.0	4.4	17.4	19.6	15.0

At Vingeneset lime has no significant effect on P-AL, but liming does have a tendency to yield lower P-AL values. In soil samples from Vingeneset, there is a negative relationship between added raw phosphates and easily soluble Mg and Ca in the soil. This is not the case, on the other hand, in the soil samples taken at Vingen.

5.3.1.4 Discussion and achievements

Lime treatments on the surface of the vegetation resulted in a rise in pH in the soil at test quadrates in both the upper soil stratum (0-5 cm) and the substratum (5-20 cm). The increase in both the pH and base saturation degree has been highest in the test sites where there is a moderate content of organic material in the soil. Current knowledge of soil chemistry indicates that lime treatments will reduce degradation. The most important reason for this is that the added lime reacts with H^+ in soil liquids. The added lime also affects the biological processes and composition of vegetation. Liming can aid in maintaining grass and herb-dominated vegetation and, in combination with grazing, prevent accumulation of organic materials. In this respect, liming has a more indirect effect on pH and degradation. Liming will also have a positive effect on grazing since forage production increases and the nutritional content of plants will be generally improved. When deciding whether to apply lime treatments in Vingen and Vingeneset, the results from other areas of the rock art project must be taken into account.

The question concerning the application of phosphorus is complicated. Raw phosphates do not appear to have any appreciable effect on important soil parameters such as pH and base saturation degree. During the past decade, several studies have been carried out which show that mykorrhiza fungi exude enzymes and organic acids in order to gain access to heavily insoluble nutrients (particularly phosphorus) found in mineral and organic materials (Gahoonia & Nielsen 1992, Carney & Burke 1998, Schilling *et al.* 1998, Neumann & Römheld 1999, Wallander 2000). This is an important factor in degradation that occurs in soil (Lundström 1994). We do not know how significant these processes are for Vingen. The phosphorus content in the soil in Vingen is relatively high. It is uncertain what effect the addition of raw phosphates will have for plant growth and grass crops (Cf. Krogstad 1998). A slight increase in yield in Vingen and a higher crop yield in Vingeneset are likely to be the result. In Vingen alone, the addition of raw phosphates does not result in an increase in phosphorus content in the plant material that has been analyzed. At Vingeneset, however, there is a tendency for phosphate content in plant material to increase when raw phosphates are added.

Reopening old open trenches and stream courses has resulted in the drainage of areas that were stagnating and becoming waterlogged. Better draining/dryer soil has led to better grazing in these areas. Grazing pressure has varied somewhat during the project period. Strong grazing pressure is desirable so that there will be more thorough grazing in the marginal zones and in the lower portions of the hillsides above. This will be able to inhibit increased establishment of heather, bushes and forest vegetation.

5.4 Micro-vegetation

5.4.1 Lichens

During preservation and conservation of the rock carvings in Vingen, we observed that the degree of weathering differed beneath different lichen species. Based on this and existing literature dealing with lichens that protect rock surfaces, it was necessary to investigate which lichen species damage and which possibly protect surfaces at Vingen.

Even though much has been written about the problem of lichens and cultural heritage, there is little literature that confirms or rejects the specific assumptions. A large number of the studies on lichens and biodeterioration of rocks are from the Antarctic or from historical buildings and monuments in the Mediterranean area. Until we published our results (Bjelland & Thorseth 2002), there were no published studies of the weathering effect of lichens from sites in northwestern Europe . In recent years, this topic has received increasing attention in Scandinavia, as we now seem to be losing an important part of our old cultural heritage – the rock carvings. As weathering is strongly related to atmospheric, hydrospheric, and biospheric conditions, the relative importance of the various weathering processes differs with climatic and vegetational conditions. Due to the large climatic and vegetational changes in Europe during and after the last ice age, the style and intensity of weathering has also changed through time throughout Europe. Therefore, it is not possible to transfer results and conclusions regarding weathering in one climate to another (Bjelland 2002).

5.4.2 Methods

As previously mentioned, there are several factors that are of significance for weathering. In order to reach definite conclusions about the effects of specific lichens it is necessary to investigate many rock samples with the same lichen species. Four common species of crustose lichens were selected: *Fuscidea cyathoides, Ochrolechia tartarea*, *Ophioparma ventosa*, and *Pertusaria corallina* (Fig. 5.4.2.2-1). A few samples of *Lecidea fuscoatra* were also collected. Observations in the field suggest that these species represent a wide range in aggressiveness. The number of duplicate samples for each species varies because it is difficult to find representative rock surfaces or loose rocks without any rock art. The cores were drilled from rock surfaces that probably have been subaerially exposed since the deglaciation 10,000 years ago. The selected rock surfaces had different inclinations, and were situated at 6-20 m above sea level.

A number of parameters (25/23) were measured or recorded for each sample. Analyses of the weathered zone and the fresh rock were carried out to determine changes in the bulk chemical composition. In addition, secondary minerals precipitated in the lichen thallus and in the weathered zone were determined, the surface features of weathered minerals were studied and the depth of weathering of individual minerals, the porosity and the amount of biological material were determined in the weathered zone. The data were analyzed by different statistical methods (e.g. multivariate analysis).

Multivariate analysis is an important tool in biological research today. To summarize the samples investigated all the measured parameters were used in a multivariate analysis. PCA (Principal Component Analysis) reduces multivariate data to a few components that account for the majority of the variation in the material. Based on the measured variables, the samples are ranked so that the differences between them are maximized. The axes point in the direction of greatest total variation. The first principal component is the variable that best accounts for the variation between samples. In PCA biplots, the samples that lie at the ends of the axes will have greatest significance for differences in the data, while samples that lie near the centre of the diagram will be of minor importance. Variables are marked with vectors in the diagram. These point towards the maximum variation between samples. Their lengths are proportional to the degree of variation in the material that can be accounted for by the variable. Vectors that point in the same direction indicate positively correlated variables, vectors that are at right angles indicate no correlation, and vectors that point in opposite directions indicate negatively correlated variables.

Twenty-two variables were used in the PCA (depth of dissolution of apatite, chlorite, calcite, lichen chemicals, grain size and the chemical composition of the rock). To simplify, only 10 of the variables are shown in the figure (Fig. 5.4.2.2-2 and 3).

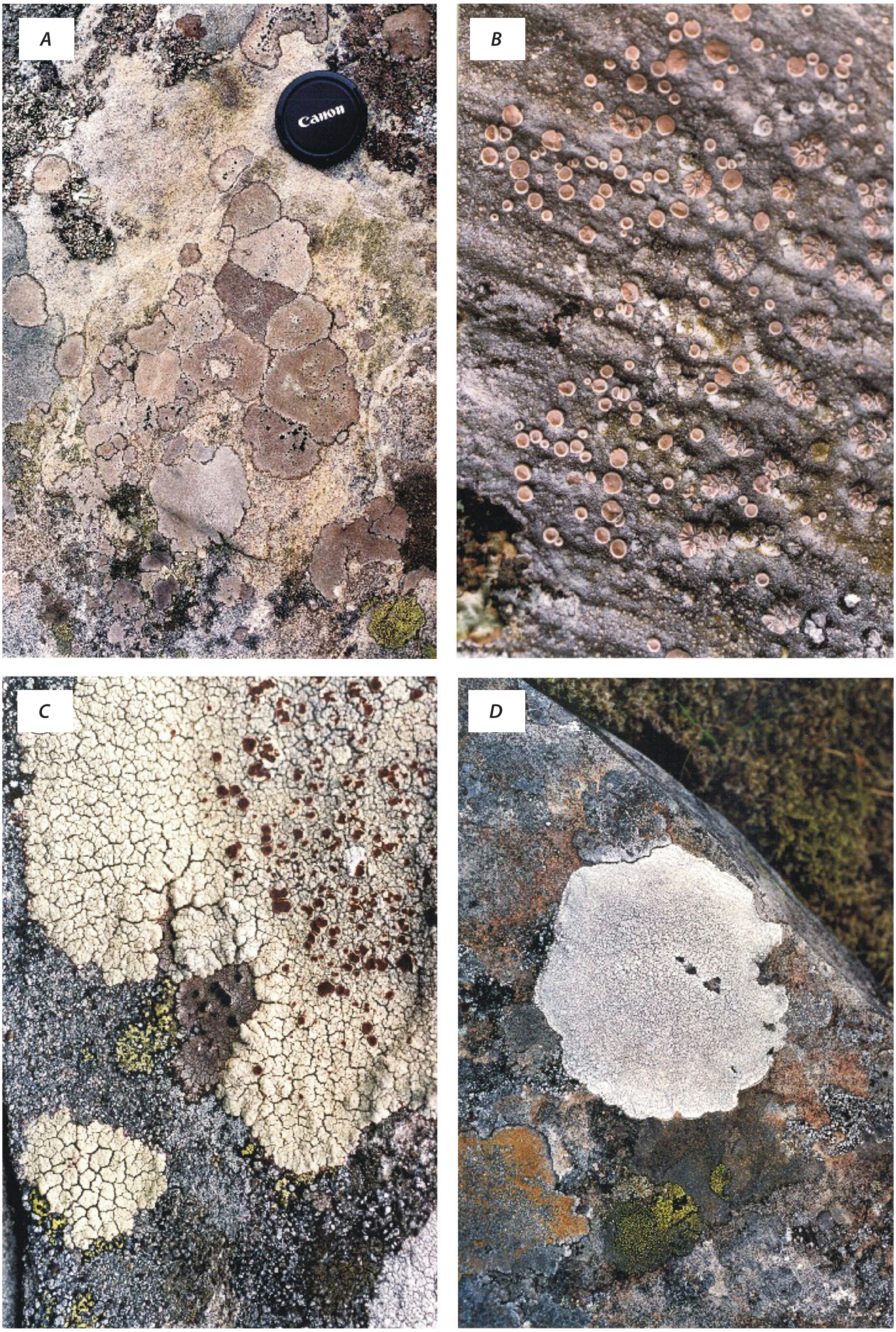


Fig. 5.4.2.2-1. *a) Fuscidea cyathoides, b) Ochrolechia tartarea, c) Ophioparma ventosa, and d) Pertusaria corallina.*

5.4.3 Weathering effect of lichens

The general description of the weathered rock presented in section 4.1.2. also applies to the weathered zone beneath lichen. The bedrock at Vingen is an arcosic metasandstone in which quartz (45–55%), plagioclase (15–40%), and K-feldspar (15–5%) are the dominant minerals. Other minerals present are muscovite (5–10%), Fe-rich chlorite (7–12%), epidote (3–5%), and accessory minerals (e.g. apatite, zircon, sphene, iron and titanium oxides). The detrital grains are mainly cemented by calcite (5–12%), but occasionally quartz-cement occurs. The grain size in the different beds and laminae generally range from medium to fine (500–125 µm), but silty laminae (<63 µm) are also present. The detrital muscovite grains are generally orientated parallel to the lamination. The plagioclase is albitic in composition, and usually contains numerous inclusions of minute sericite crystals. The unweathered sandstone is dark greenish grey and virtually impervious. The greenish tint is due to the chlorite and epidote content.

Geochemical analyses of the fresh, unweathered sandstone samples reflect the variation in the mineralogical composition of beds and laminae. However, the principal component analysis (PCA) does not show any separation of the studied species (*Fuscidea cyathoides*, *Lecidea fuscoatra*, *Ochrolechia tartarea*, *Ophioparma ventosa* and *Pertusaria corallina*) due to the compositional variations.

Macroscopically, the weathering is visible as a 2–24 mm thick porous, grey to beige rind (Fig. 5.4.3.2-2). The porosity, which decreases down through the weathering rind, reflects the degree of dissolution of the minerals in the rock. As calcite is the most susceptible mineral to chemical weathering in the sandstone, the porosity in the lower part of the weathering rind (5–12 vol%) is caused by the dissolution of calcite alone. After calcite, apatite and chlorite are the least stable minerals. In addition to calcite, apatite and chlorite are frequently completely dissolved in the upper part of the weathering rind and the porosity is therefore higher in this part (12–20 vol%). Plagioclase shows partial dissolution at the same depth as chlorite and apatite. The

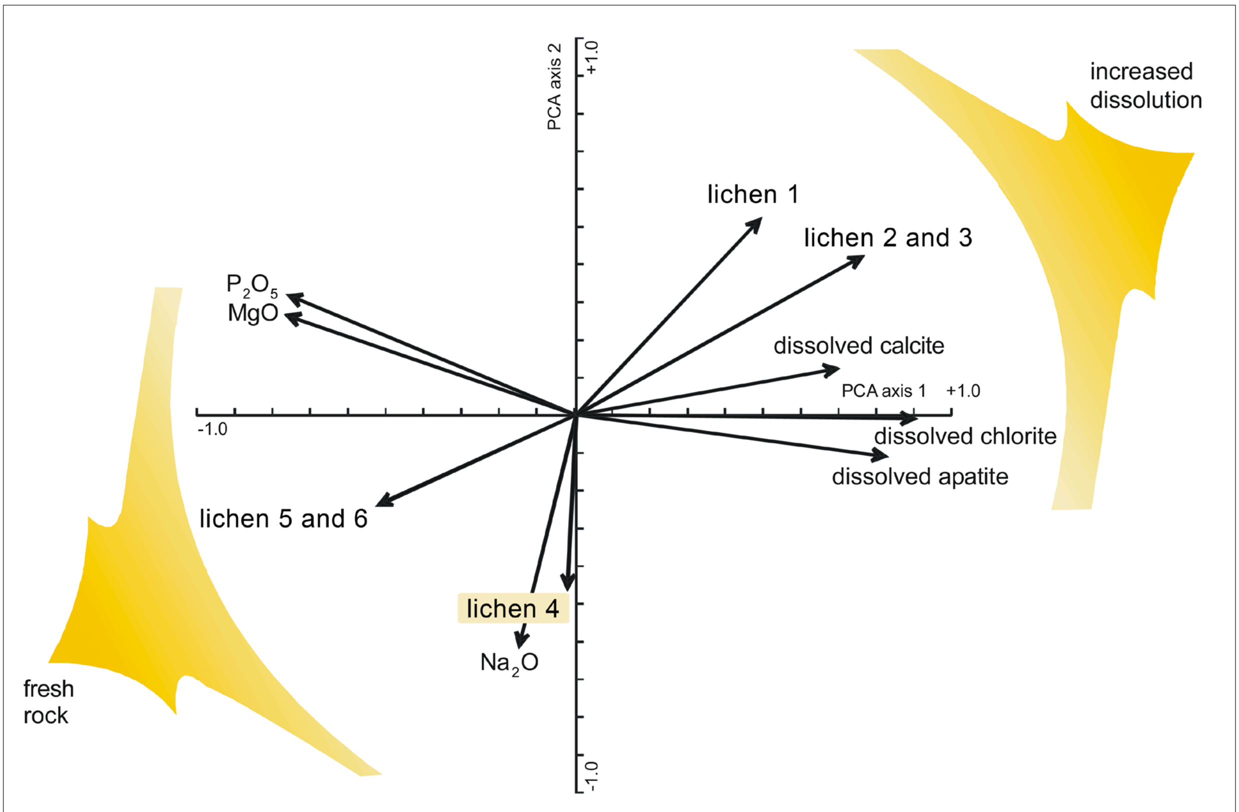


***Fig. 5.4.2.2-2.** PCA-ordination of the different variables measured in each core covered by Fuscidea cyathoides, Ochrolechia tartarea, Ophioparma ventosa and Pertusaria corallina along PCA-axis I and II.*

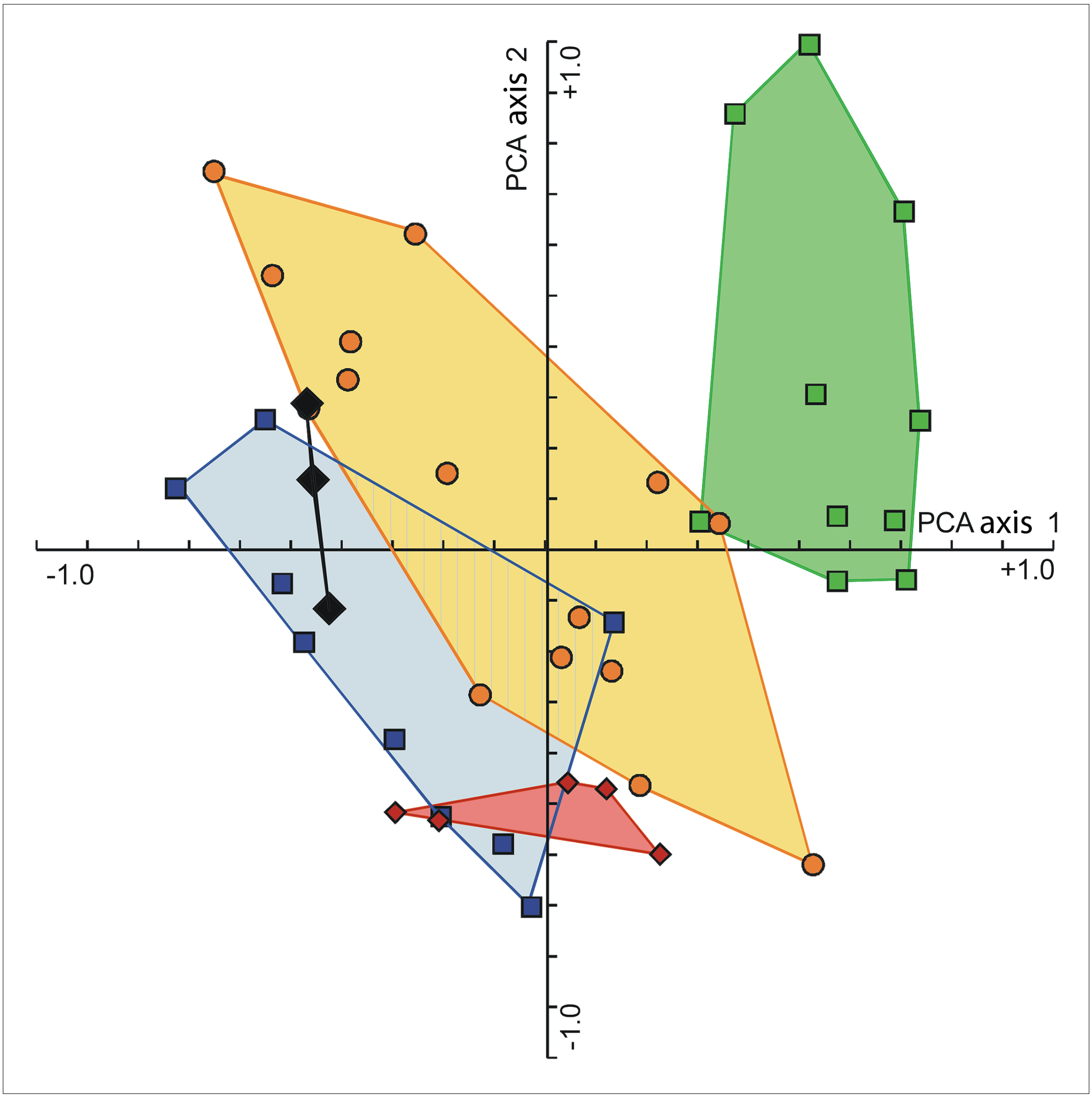


Fig. 5.4.2.2-3. *Distribution of cores covered by Fuscidea cyathoides, Ochrolechia tartarea, Ophioparma ventosa and Pertusaria corallina along PCA-axis I and II.*

plagioclase grains are dissolved along grain boundaries, crystallographic planes, and around the internal mica grains (sericite), and show numerous etch marks and dissolved channels in the surface. Plagioclase grains are hence more or less detached from the other mineral grains and are partly crumbled. Due to the dissolution of plagioclase, the porosity in plagioclase-rich surface layers may be as high as 32 vol%.

Quartz is the most resistant major mineral to chemical dissolution in the bedrock, and shows few signs of dissolution, except for some etch marks. K-feldspar and muscovite also show minor dissolution. At the rock surface however, muscovite shows frequent fracturing along the basal cleavage.

In spite of the heterogeneity of the sandstone and weathering factors other than today's individual lichen cover, the results indicate differences in the degree of weathering beneath the studied lichen species. The weathering is deepest beneath *Ophioparma ventosa*. The mean weathering depth beneath *Ophioparma ventosa* is 18.4 mm (dissolution depth of calcite), while it is 13.8, 12.8, 10.0, and 9.5 mm beneath *Pertusaria corallina*, *Fuscidea cyathoides Ochrolechia tartarea*, and *Lecidea fuscoatra*, respectively. The mean dissolution depths of apatite (2.93 mm) and chlorite (4.32 mm) are also highest beneath *Ophioparma ventosa*. Furthermore, a higher porosity and a lower Na_2O content in the weathering rinds beneath *Ophioparma ventosa*, indicate a higher dissolution of plagioclase, than beneath the other species. *Fuscidea cyathoides*, *Lecidea fuscoatra*, *Ochrolechia tartarea*, and *Pertusaria corallina* are more difficult to separate with respect to compositional differences in the weathering rind. However, the PCA analysis indicates that *Pertusaria corallina* could be a more aggressive species than *Fuscidea cyathoides*, *Lecidea fuscoatra*, and *Ochrolechia tartarea.*

The contact between lichen and substrate is very intimate (Fig. 5.4.3.2-3). Fig. 4 shows SEM-BSE micrographs of a transverse section through a representative lichen-mineral interface before (Fig. 5.4.3.2-4a), and after (Fig. 5.4.3.2-4b) staining with Pb-citrate. Mineral grains or fragments are embedded in the interior of the thallus and fungal hyphae penetrate into the sandstone. At the uppermost part of the weathering rind the pores are filled with hyphae, giving the false impression of a very low porosity in the upper weathering zone (Fig. 5.4.3.2-2). The abundance of hyphae decreases inwards in the weathering profile (Fig. 5.4.3.2-5). Deeper within the weathering rinds hyphae are still abundant in the pores, but are not as compact as in the upper part. Only a few or a single hyphae can be seen in the pores at the bottom of the weathering rind. Fungal hyphae seem to occur throughout the porous rind, independent of weathering depth.

Fig. 5.4.3.2-2. *A transverse section through a Ophioparma ventosa lichen-rock interface (Scale=1mm).*

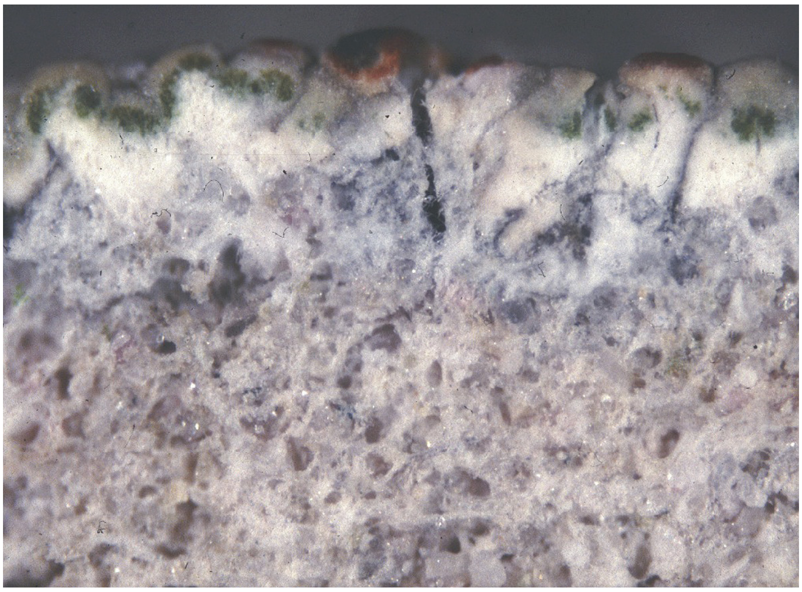


Fig. 5.4.3.2-3. The contact zone between a crustose lichen and the rock is very intimate and it can be hard to decide where the lichen thallus stops and where the rock begins. The image shows the contact between Ophioparma ventosa and the bedrock.

Ophioparma ventosa and *Pertusaria corallina* usually have a thicker thallus (~ 2.0 mm) than *Fuscidea cyathoides*, *Lecidea fuscoatra*, and *Ochrolechia tartarea* (~ 1.0 mm). Fungal hyphae are also more abundant in the uppermost part of the weathering rind beneath *Ophioparma ventosa* and *Pertusaria corallina*, in comparison to the other two species.

Besides penetrating the pores within the weathering rind (Fig. 5.4.3.2-6), fungal hyphae have also penetrated into individual mineral grains through fractures and etch pits and channels. The close attachment of fungal hyphae on mineral surfaces may lead to biophysical disintegration (Fig. 5.4.3.2-7). The BSE image in Fig. 5.4.3.2-8 shows how fungal hyphae have penetrated into a muscovite grain below an *Ophioparma ventosa* thallus. Fungal hyphae penetrating mica (biotite and muscovite) and pores in plagioclase were observed beneath all the studied species. Mica is especially susceptible to physical weathering owing to its closely spaced and perfect cleavages. Where the rock substrate contains abundant mica grains, oriented parallel to the rock surface, a lifting of the "surface" is frequently observed. Mineral grains or fragments embedded in the interior of the thallus also indicate biophysical disintegration of the rock surface (Fig. 5.4.3.2-4). A higher degree of fragmentation of mineral grains beneath *Ophioparma ventosa*, and to a lesser extend *Pertusaria corallina*, compared to *Fuscidea cyathoides, Lecidea fuscoatra*, and *Ochrolechia tartarea*, may indicate an increased biophysical weathering due to the high amount of hyphae. However, as physical and chemical processes interact and enhance each other, it is difficult to distinguish the effect of each mechanism, especially in the disintegration of plagioclase. The results show that there is a positive correlation between the degree of weathering and species that penetrate more deeply into the rock and which have a greater amount of fungal hyphae in the weathered zone (Fig. 5.4.3.2-9).

Furthermore, there is a relationship between the degree of weathering and the acids and reactive chemicals produced by the lichens. It is well known that lichens generate oxalic acid and other reactive chemicals which can influence the rate of dissolution of minerals (Bjelland & Thorseth 2002). The studied species produce different types of lichen compounds (Fig. 5.4.3.2-10). *Lecidea fuscoatra* and *Ochrolechia tartarea* generate gyrophoric and lecanoric acids, *Fuscidea cyathoides* produces fumarprotocetraric acid, *Pertusaria corallina* produces thamnolic acid, while *Ophioparma ventosa* produces divaricatic, thamnolic, and usnic acids. Some lichen compounds are restricted to or mainly occur in special parts of the thallus. Bjelland *et al.* (2002) demonstrates for the first time that in addition to the presence within the thallus, some of the major lichen compounds also occur within the rock beneath the lichens (*Fuscidea cyathoides*, *Ochrolechia tartarea*, *Ophioparma ventosa* and *Pertusaria corallina*), and are thus directly in contact with the mineral surfaces within the weathering rind. If the lichen compounds act as proton sources or as ligands, they may therefore contribute to the chemical weathering of the rock. However, only divaricatic acid was detected within the weathering rind

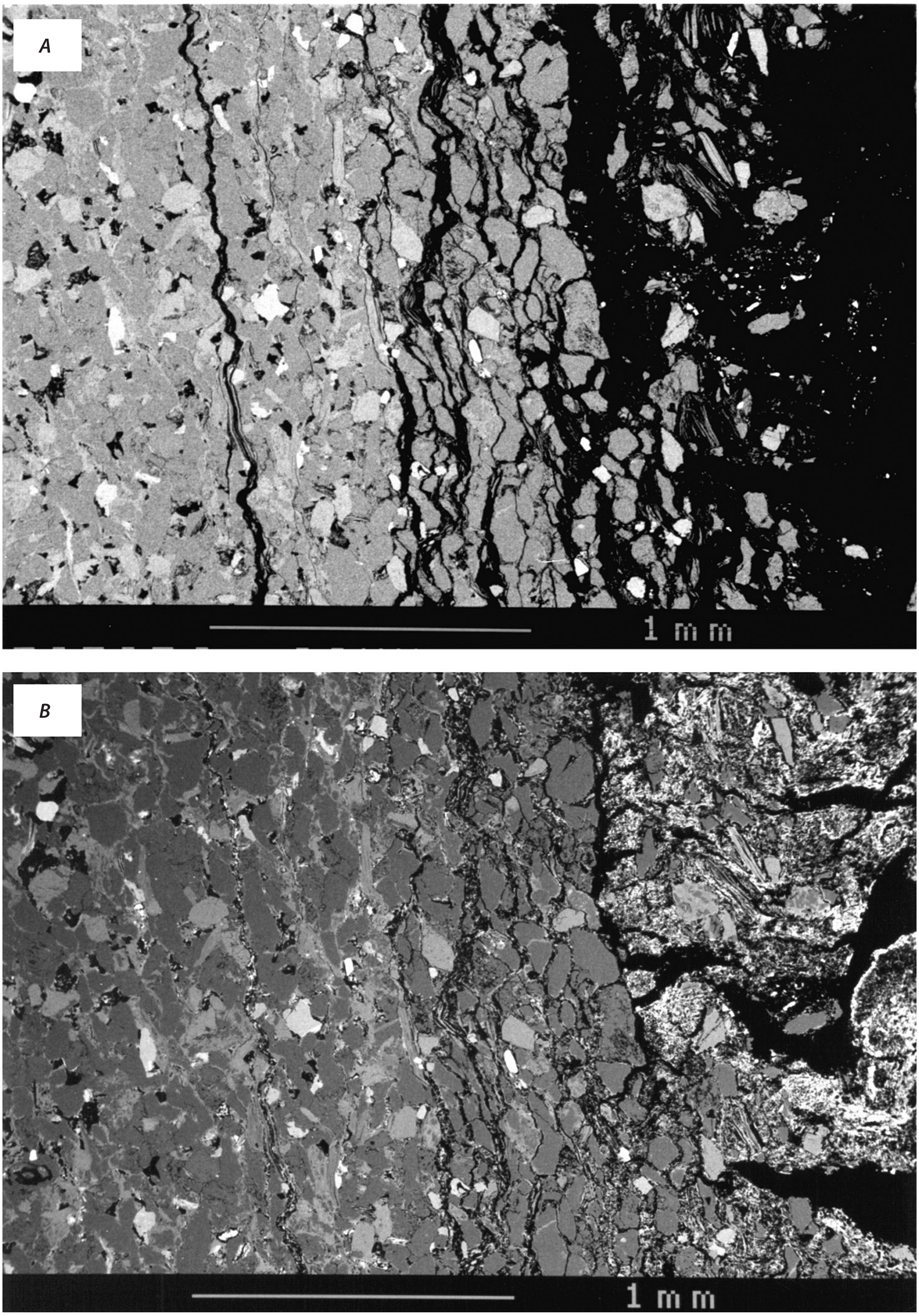


Fig. 5.4.3.2-4. *SEM-BSE images showing how fungal growth in the upper weathering rind can result in disintegration of the upper surface, and further lead to integration of mineral grains in the thallus. a) The lichen rock interface in Lecidea fuscoatra before (a) and after staining with Pb-citrate.*

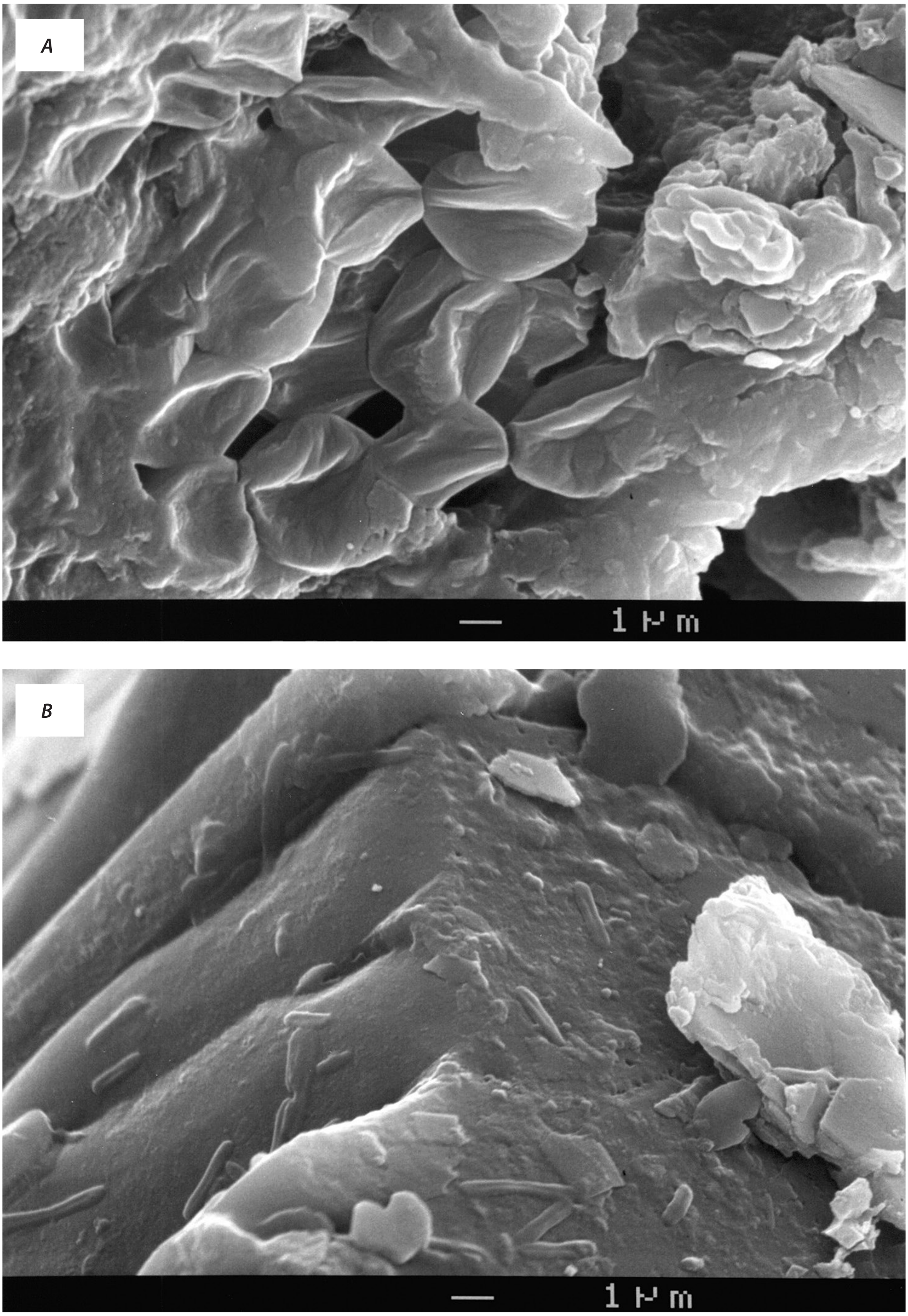


Fig. 5.4.3.2-5. Algae (a) and bacteria (b) are only found in small amount in the weathering rind beneath lichens.

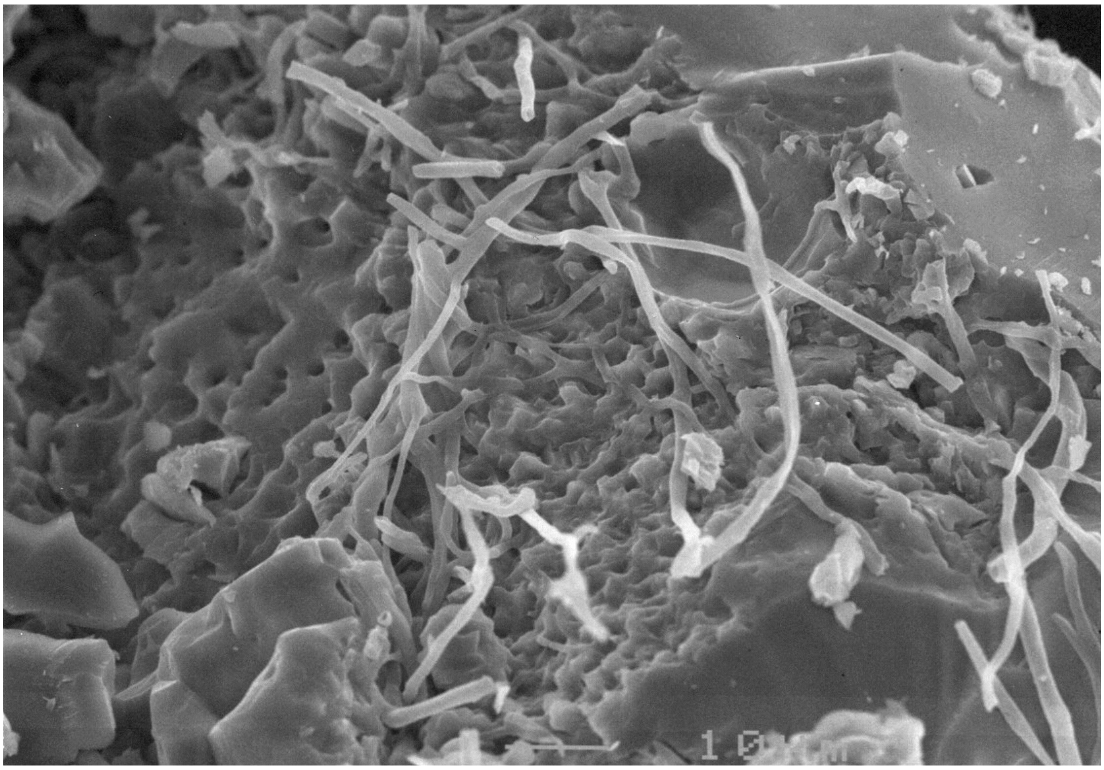


Fig. 5.4.3.2-6. *SEM-image showing etch marks in quarts. The fungal hyphae are closely attached to the mineral surface.*

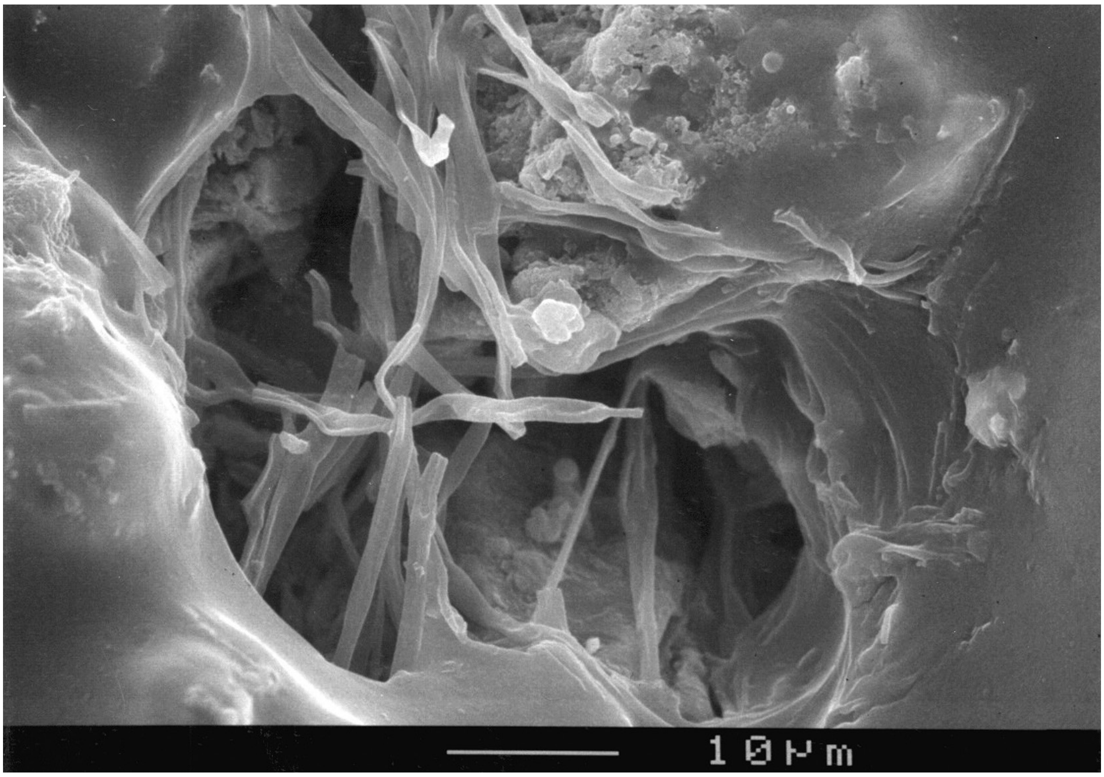


Fig. 5.4.3.2-7. *SEM image showing fungal hyphae penetrating a pore.*

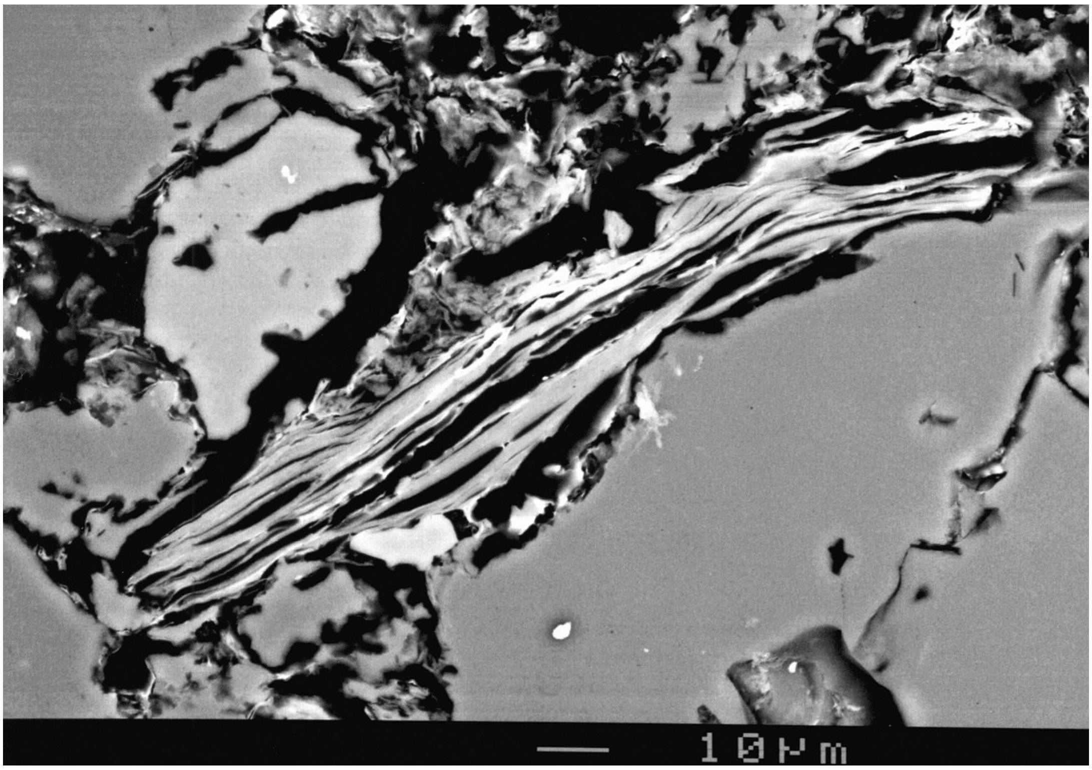


***Fig. 5.4.3.2-8.** SEM-BSE image showing fungal hyphae infiltrating a muscovite grain in the upper part of the weathering rind.*

beneath *Ophioparma ventosa*, whereas thamnolic and usnic acid seem to be restricted to the thallus (Bjelland *et al.* 2002). No lichen substances were found in the weathering rinds beneath *Pertusaria corallina* and *Fuscidea cyathoides*, whereas gyrophoric and lecanoric acids were found in the weathering rind beneath *Ochrolechia tartarea* (Bjelland *et al.* 2002). Even if it was not possible to detect all the lichen compounds in the weathered rock samples, their occurrence cannot be excluded. The concentration may have been too low to reveal the presence of precipitated crystals. Furthermore, it is not known if the lichen compounds only dissolve into the circulating water from precipitated crystals on hyphae in the lichen thalli, or if the endolithic hyphae produce lichen compounds directly on the mineral surfaces within the weathering rind. If so, micro-reaction zones with high concentrations of lichen compounds may develop and cause efficient biochemical etching of the mineral surfaces.

Oxalate salts may precipitate extracellularly on the surface of thallus, within the thallus, and at the lichen-rock interface. Ranges of metal oxalate precipitates are known to occur within lichens; including calcium, copper, magnesium, manganese, and iron oxalate (Adamo & Violante 2000, Chen *et al.* 2000). There seems to be a direct relationship between the form of oxalate in saxicolous lichens and the mineralogy and chemistry of the substratum (Purvis *et al.* 1984). Only one type of metal oxalate precipitate was found in the studied samples in Vingen; whewellite, the monohydrate form of Ca oxalate (Fig. 5.4.3.2-11). Whewellite has however been documented in all studied species at Vingen, but the content differs between the species, as well as within and between thalli of the same taxon (Bjelland *et al.* 2002). The whewellite peaks in the XRD spectra are clearly much stronger for *Fuscidea cyathoides* and *Ophioparma ventosa* than for *Ochrolechia tartarea* and *Pertusaria corallina*, suggesting a higher oxalic acid production in the former species. There were only few differences in whewellite occurrence between the thallus edge and centre samples in the four species. Differences within and between species in oxalate amount are in accordance with other studies, Holder *et al.* 2000, Prieto *et al.* 2000).

Compared to the other species, *Ophioparma ventosa* produces more types of reactive chemicals (lichen compounds and oxalic acid). The results indicate that differences in content of lichen compounds are a

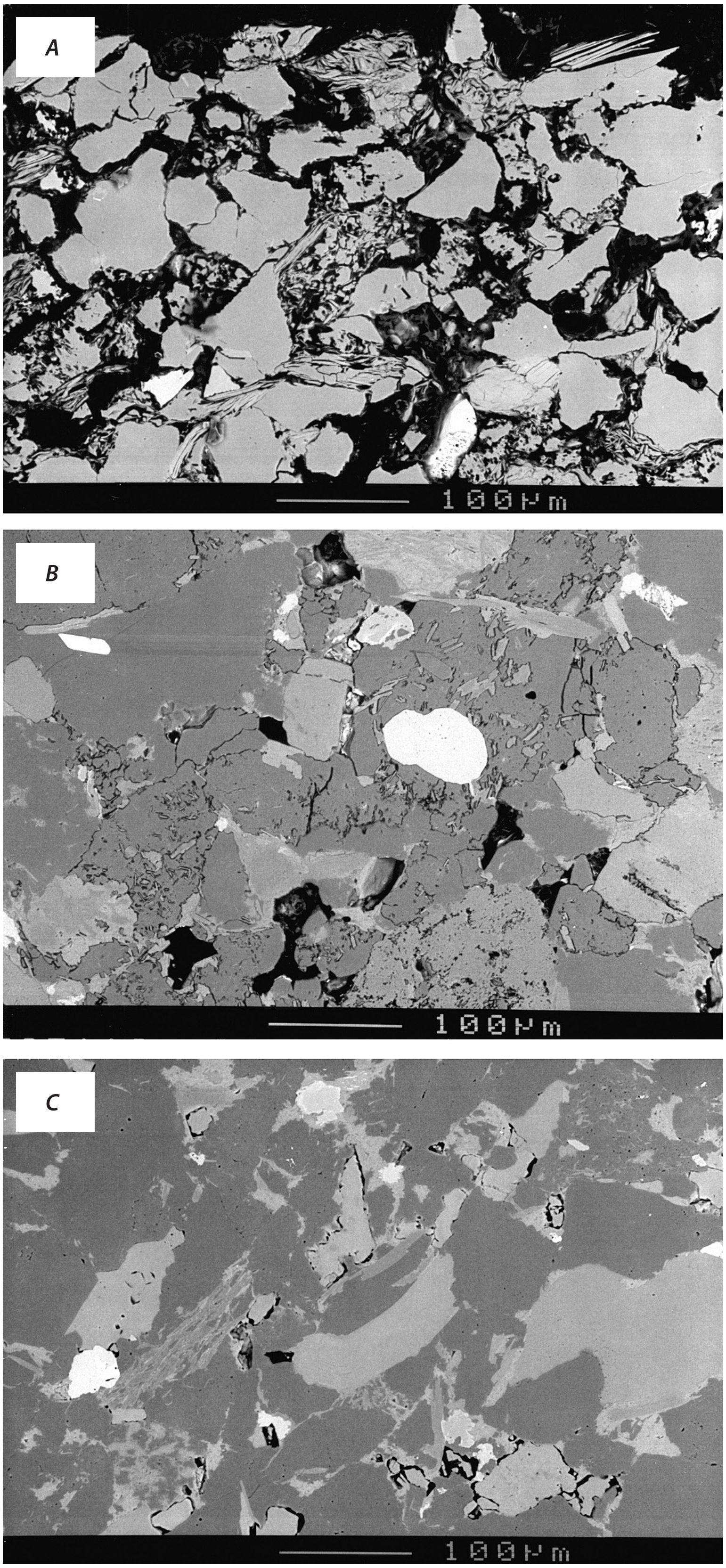


Fig. 5.4.3.2-9. *BSE-image of the weathering rind beneath Ophioparma. ventosa. a) in the upper part, b) in the centre and c) in the transition zone between weathered and unweathered rock.*

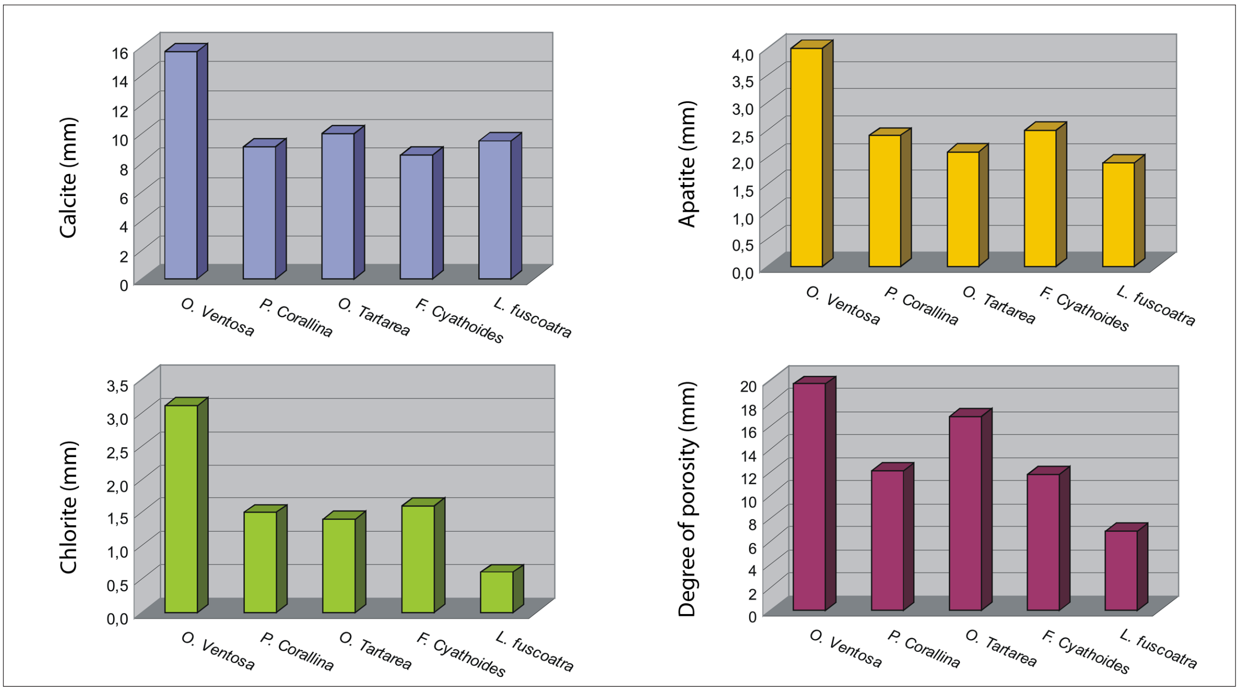


Fig. 5.4.3.2-10 Mean dissolution depth of calcite, apatite and chlorite, and mean degree of porosity (upper 2–3 mm), beneath different lichens.

more likely explanation for the variations in chemical weathering, than differences in oxalic acid production. However, further experimental studies are needed to determine the weathering effect of the different lichen compounds in the studied lichen species.

As previously mentioned, the weathering at the shoreline is very shallow (5.2.4.1), even though *Verrucaria* species cover the majority of the surfaces (se 4.4.1). One of the reasons for this may be that these species do not produce aggressive lichen compounds and therefore cause less chemical solution. It is not known for certain if these species produce oxalic acid. Any acid produced by lichens at the shore would in any case be neutralised by seawater and therefore have little influence on weathering. The growth of lichen along the shore may also protect the rock against abrasion. Lichen thalli that infiltrate the rock surface will prevent the uppermost sand grains from being abraded by waves. If the shore is strongly exposed to wave action, the lichen will probably protect rather than promote erosion.

As there are no comparable lichen-free reference surfaces at Vingen, it is not possible to determine if a rock surface that is encrusted by lichens weathers more slowly or faster than an identical but lichen-free surface. Differences in the degree of weathering between species indicate, however, that lichens have an effect on the degradation of rocks. The study clearly indicates that lichens weather their rock surface both physically, through the expansion and contraction of fungal hyphae, and chemically, through the production of elements such as lichen compounds and oxalic acid. In addition, the water-holding capacity of lichens may in general increase the chemical dissolution and frost wedging of lichen-covered rock surfaces. On the other hand, the thallus and the endolithic fungal hyphae also keep the partly fragmented rock surface together and protect it from abrasion and erosion. However, when the thallus dies, loose mineral grains and fragments from the upper lichen-mineral interface will be removed and a new surface will be exposed and available for colonisation and biodegradation. It is therefore likely that lichens generally increase the weathering processes, except in locations with extremely high abrasion, where they may protect the surface (Bjelland & Thorseth 2002, Bjelland 2005).

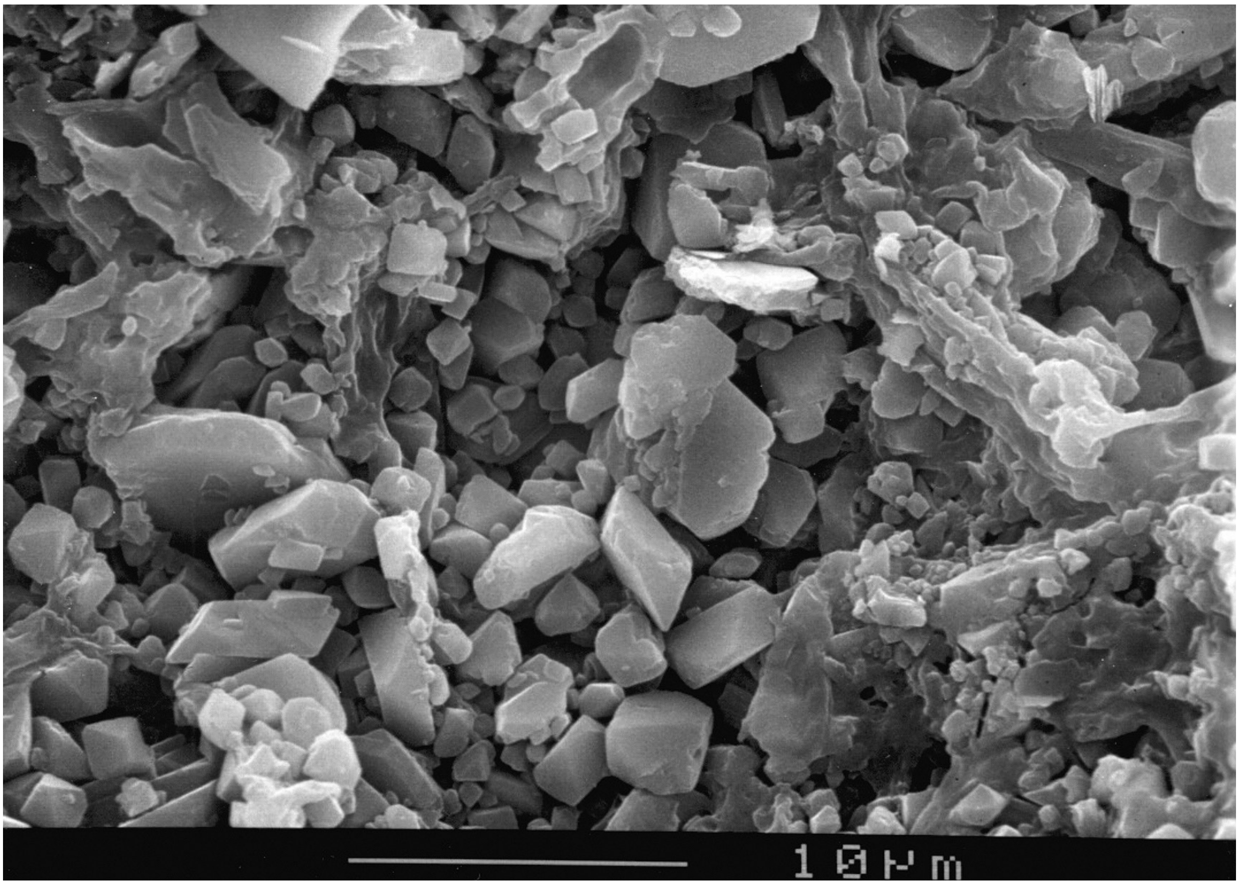


Fig. 5.4.3.2-11. *Ca-oxalate crystals in a Ophioparma ventosa thallus.*

5.4.3.1 Relationships between the weathering effect and ecology in saxicolous lichens

The results from studies in Vingen imply that there is a relationship between how competitive crustose lichen species are within a community and their weathering effect. At Vingen, crustose species such as *Ophioparma ventosa* and *Pertusaria corallina*, with a thick thallus on the surface as well as an extensive and deep fungal layer within the rock, seem to be both more competitive and more aggressive than species such as *Fuscidea cyathoides* and *Ochrolechia tartarea,* with a thin thallus and few fungal hyphae within the rock. However, this is not the case for species with other growth forms, as foliose species, with a relatively small amount of fungal hyphae within the rock, are able to overgrow and compete out crustose lichens.

Unlike *Pertusaria corallina*, which is a habitat generalist, *Ophioparma ventosa* is a habitat specialist, often growing at sites with high radiation and low maritime influence. Observations from Vingen indicate increasing depth of the weathering rind with increasing distance from the sea (Bjelland *et al.* 2001). Since *Ophioparma ventosa* grows at a greater distance from the sea than the other species, one cannot exclude that the apparent weathering effect of *Ophioparma ventosa* may be caused by other factors. Further, as *Ochrolechia tartarea* can grow much closer to the sea compared to the other species, this could have an influence on the apparently lower weathering effect of this species. However, in the study of weathering (Bjelland & Thorseth 2002), samples from all species were collected randomly within the same area at Vingen. A comparison of samples of all four species from the same rock surface and the same stratigraphic sandstone layer, where the rock composition is almost homogeneous, also shows a deeper weathering rind beneath *Ophioparma ventosa* than beneath the other species.

Little is known about the correlation between concentrations of biomineralisation products and environmental factors in lichens. It was not possible to find any clear relationships between the amount of oxalate in the studied crustose lichens and any environmental conditions. It is suggested that if the release of oxalic acid in lichens needs a high initial pH, as in non-lichenized fungi (Burnett 1976), some of the variation in oxalate content within species may be due to the variation in calcite content in the sandstone. However, further analysis with a better control of the composition of the substratum beneath each studied thallus and the microenvironmental conditions, such as light and runoff exposure, sea spray, and other factors related to their microhabitat, were therefore necessary in order to be able to explain the observed differences in oxalate content within and between species.

As regards lichen compounds, some biological roles have been proposed – protection against other plants, protection against UV light, permeability of the cell wall of the photobionts, chelating agents, stress metabolites, and hydrophobic properties to prevent the saturation of the medulla (Huneck & Yoshimura 1996), although how the lichens control the production remains more or less unclear. It is well known that there is a correlation between the concentration of e.g. usnic acid and the light intensity of a habitat (Rundel 1969). If *Ophioparma ventosa* mostly grows on sites with high radiation at Vingen, it will have a high production of usnic acid. It is likely that specimens with a high production of lichen compounds and oxalic acid will enhance the weathering process more than specimens with a low production of these organic acids.

To follow up these results and further investigate which factors control the organic acid production in saxicolous lichens, a total of 60 rock cores were drilled from one rock surface at Vingen in 2003. To get enough material for the analyses, two rock cores were drilled from each individual thallus from the selected species *Fuscidea cyathoides*, *Ophioparma ventosa*, and *Pertusaria corallina*. *Ochrolechia tartarea* was not growing on this rock surface. The occurrence of oxalic acid and different lichen compounds in individual thalli and the corresponding weathering rinds were analysed by HPTLC (high performance thin-layer chromatography). In addition, the mineralogical and geochemical composition of the substratum beneath each studied thallus were analysed by SEM (scanning electron microscopy) and XRF (X-ray fluorescence spectroscopy). To find if there is a correlation between the concentrations of biomineralisation products in lichens and environmental factors, the microenvironmental conditions and other factors related to their microhabitat, was measured. So far, the results have not indicated any correlation.

Physical weathering by lichens can be influenced by environmental factors. Species with fast vertical growth have more impact than those with a very slow growth rate, and old lichens are in contact with the substratum longer than lichens with a short lifespan. The growth rate of lichen thalli is, however, subject to considerable variation. This variability may be due to small-scale concentrations of nutrient availability, such as bird droppings, as well as variations in microclimate (Hawksworth & Hill 1984). The growth rate and lifespan of the four studied species at Vingen is not known, but it seems that *Fuscidea cyathoides* has a more rapid turnover than the other species. It rapidly establishes on bare rock, but has to "jump" further if the competition increases, and sooner or later it becomes common in the community. Small propagules are an advantage regarding dispersal for species with this strategy. Of the four species studied at Vingen, *Fuscidea cyathoides* has the smallest propagules. The ascospores in *Fuscidea cyathoides* are 9.5–13(14) x 5–5.5(6) µm (Purvis *et al*. 1992), while those in *Ochrolechia tartarea* and *Ophioparma ventosa* are (35)40–70 x 20–40 µm (Purvis *et al*. 1992) and (30)40–50(55) x 4.5–5 µm (James & Brightman 1992), respectively. *Pertusaria corallina* is mainly dispersed by isidia at Vingen, which are larger than the other species' ascospores (1100 x 200–300 µm) (Tønsberg 1992). Similar patterns, as described for *Fuscidea cyathoides*, have been found for vascular plants, and are called the "carousel model" (van der Maarel & Sykes 1993, Palmer & Rusch 2001). A rapid turnover may explain why *Fuscidea cyathoides* has fewer fungal hyphae within the rock compared to the other species.

This work thus indicates that there may be at least an indirect relationship between weathering effect and ecology in saxicolous lichens, but whether this is a specific strategy for nutrient requirements still remains unclear.

5.4.4 Remedial action

5.4.4.1 Removing lichens

When archaeologists obtain permission from The Norwegian Directorate for Cultural Heritage to remove the lichen cover to either document the rock carvings, to carry out conservation, or to show them to tourists, the lichens should be removed with a method with few negative effects, both on the bedrock and regarding the environment. Mechanical methods will easily lead to damage of the porous rock surface and should be avoided. Chemical treatment must not cause solution of the minerals in the rock or the poisoning of people and animals. We have therefore chosen to test the effect of Quaternary ammonium salts (Pingo) and ethanol, both of which are known to be non-aggressive, safe and easy to apply. Since light is essential for the growth of the photobiont (the algal/cyanobacterial component of lichens), covering surfaces with opaque material will kill lichen without recourse to chemicals. Since turf can result in increased dissolution of minerals, we decided to cover surfaces with microporous plastic sheets, a method that is both practical and simple to carry out. Quaternary ammonium salts (Pingo), ethanol and covers have been tested individually and in combination on five trial areas:

1. Quaternary ammonium salts (Pingo) and black plastic covers
2. Quaternary ammonium salts (Pingo) alone
3. Ethanol and black plastic covers
4. Ethanol alone
5. Only covers of black plastic

The trial areas were established during the month of August, 1997, and were located above Vehammaren partly on solid rock and partly on loose blocks. The areas were selected to be representative of the decorated surfaces with respect to the predominant species of lichen, the type of surface and location in the general area (Fig. 5.4.4.1-1–5).

All of the methods, particularly treatment with Quaternary ammonium salts (Pingo), have been employed earlier at Vingen, but there has been some doubt as to their effect. Even though the different methods apparently are effective in removing the lichen on the surface, little is known about their effects beneath the rock surface. Because the biomass partially blocks pores in the rock it is uncertain whether the fluid penetrates sufficiently to kill all life. This may be the reason for the experience that lichens re-establish themselves relatively quickly. Quaternary ammonium salts (Pingo) can also function as a nutrient and promote the growth of microorganisms. It is also uncertain how long surfaces need to be covered in order to kill lichens, and whether they simply become inactive and survive the treatment.

The trial areas were inspected every year with respect to:

- Are the photobiont (the algal/cyanobacterial component of lichens) and/or mycobiont (the fungal component of lichens) still alive?
- Degree of activity of other microorganisms within the weathered zone.
- How quickly are new lichen thalli re-established?
- Can any undesirable effects on the rocks be detected?

In August of 1998, all of the lichens in the two areas that were covered or treated with Quaternary ammonium salts (Pingo) or ethanol were dead. In the area that was treated with ethanol and covered with plastic, there was abundant mould. Large numbers of the beetle *Aridius nodifer* were observed on this area. This family lives on mould (Lindroth 1993) and probably contributes to the decay of the organic material.

In 1998 there was still appreciable lichen, apparently alive, on the area that had only been treated with Quaternary ammonium salts (Pingo). In addition, the area had taken on a greenish colour, indicating increased growth of algae. However, all lichen had died on the area only washed with ethanol. On the area covered with plastic, but otherwise untreated, many of the lichens were still alive. The observations suggest that a period of one year is too short for all the effects of the methods to emerge.

In June of 1999 all lichen on the three trial areas covered by plastic were dead. Some of the species had loosened from the surface and could easily be brushed away. Contrary to 1998 there were lichens living on the two uncovered areas that had been washed (in 1997) with ethanol or Quaternary ammonium salts (Pingo). There was still mould on the area that had been treated with ethanol and then covered by plastic, but there were fewer beetles than in 1998.

In 2000, lichens on the covered areas were still dead (Fig. 5.4.4.1-1–5). These areas were drier and most of the mould had disappeared. Much of the lichen, especially those with thick thalli, had fallen off the rock surface.

These observations show that a single treatment with ethanol or Quaternary ammonium salts (Pingo) is insufficient to remove lichen permanently. On surfaces not covered by plastic, treatment by Quaternary ammonium salts (Pingo) or ethanol has to be repeated several times to ensure that all lichen is killed. After three years, it appears that a combination of treatment with Quaternary ammonium salts (Pingo) or ethanol *and* covering with plastic is the most effective method for the removal of lichen. However, Quaternary ammonium salts (Pingo) results in increased growth of algae.

After 2–3 years without treatment or cover on the test panels, the re-colonisation of lichens could easily be observed. In particular, the crustose species *Trapelia coarctata* was an early colonizer on the surfaces. Some of the lichen species on “the edges” on the test panels were also still alive, but all the species that had been under the plastic cover were dead. In addition, algae started to grow on the surfaces, especially in the area between the covered and uncovered zone, and on the surface close to the ground. There was a smaller amount of fungal hyphae in the weathering rind treated with ethanol or Quaternary ammonium salts (Pingo) without cover, than in those with a cover.

In order to test how efficiently ethanol kills the fungal hyphae within the rock covered by lichens, two additional tests were carried out in the laboratory together with Prof. Rosmarie Honegger (University of Zurich). *Ophioparma ventosa* thalli were removed from rock cores before being crushed into smaller pieces. We set up two different tests. Some of the small pieces of rock were treated with

1. Ethanol and then put on agar in 8 Petri dishes (4 with antibiotic medium and 4 with mineral medium), and others were treated with
2. Ethanol and water before they were put on another 8 Petri dishes (4 with antibiotic medium and 4 with mineral medium).

We grew them on different mediums in the Petri dishes in order to test if there were any differences. Fungal growth was observed only after one week. After seven months, the cultures were analysed by molecular methods. There were several cultures growing in 5 of the 8 Petri dishes with samples treated with only ethanol (1); 6 sequences were *Helotiales sp*, 1 was most probably *Ophioparma ventosa*, and 1 was unidentified.

Cultures were growing in all of the Petri dishes with samples treated with both ethanol and water (2); 24 sequences were *Helotiales sp*., 1 was *Mollisis minutella*, 1 was *Cladosporium sp*, and 1 was unidentified.

When the lichen was removed from the rock surfaces, water was added to the (dry) lichen thallus to activate photosynthesis (in the algae/cyanobacteria), and then we sprayed it with ethanol. This will kill the whole lichen more efficiently. The lichen thallus on the surface cannot survive without the photobiont (algae/cyanobacteria). As we had removed the thalli from the samples before we did this test, these samples did not contain the algae. The results thus indicate that ethanol seems to reduce the fungal growth better than those samples treated with both ethanol and water.

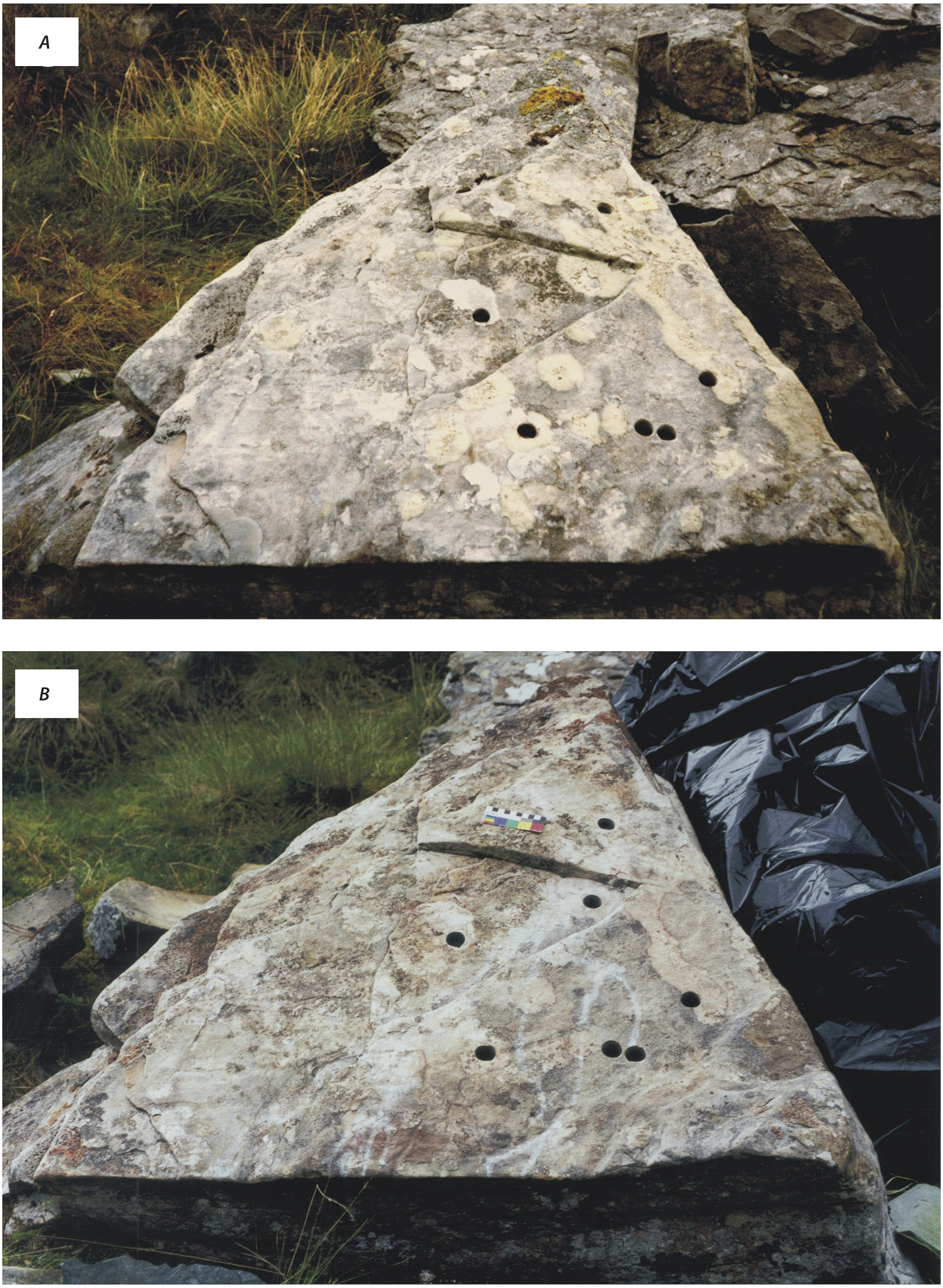


__Fig. 5.4.4.1-1.__ Rock surface treated with Pingo and cover of black plastic. a) Before treatment in 1997. b) Inspection in 2000.

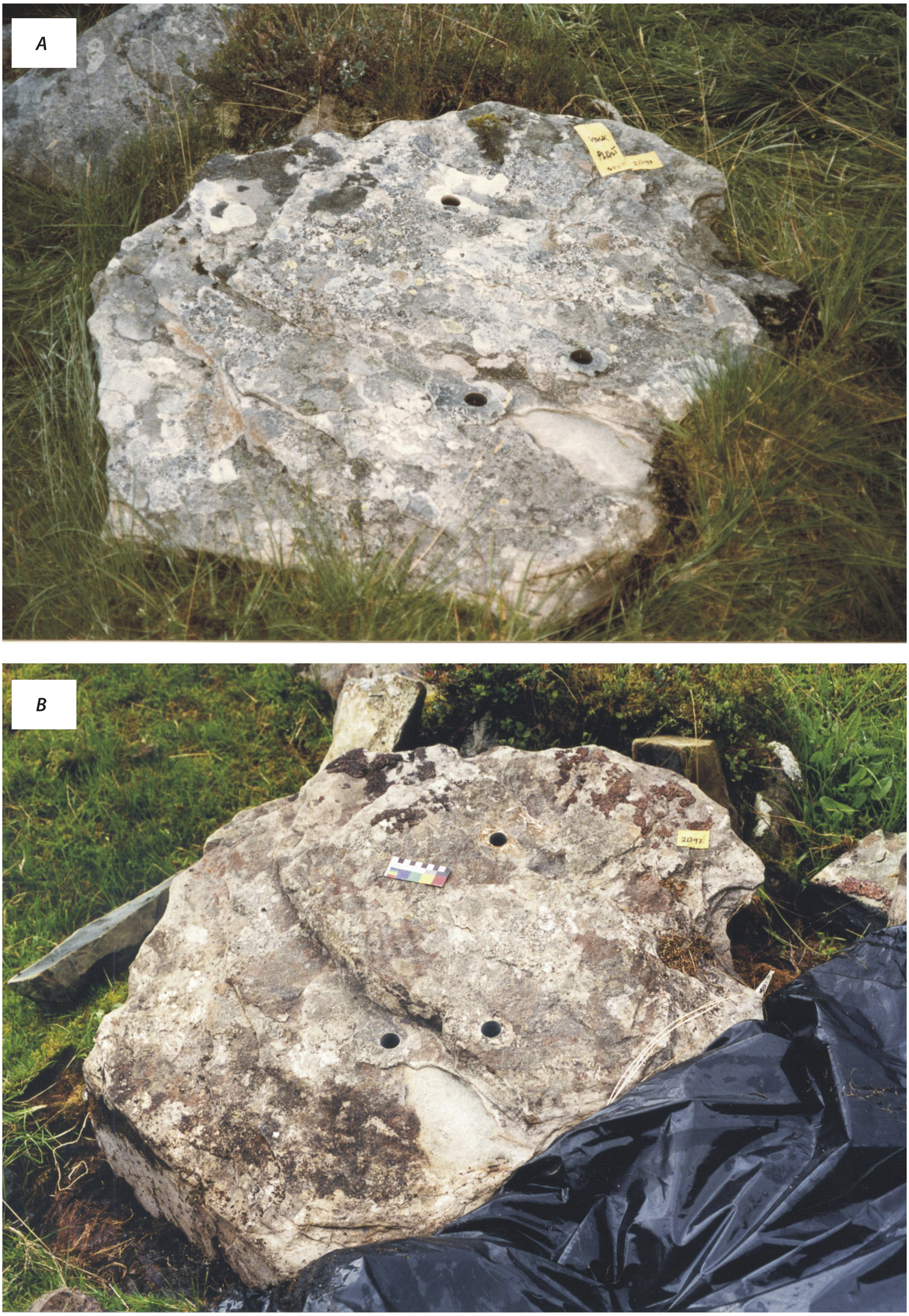


Fig. 5.4.4.1-2. *Rock surface treated with ethanol and cover of black plastic. a) Before treatment in 1997. b) Inspection in 2000.*

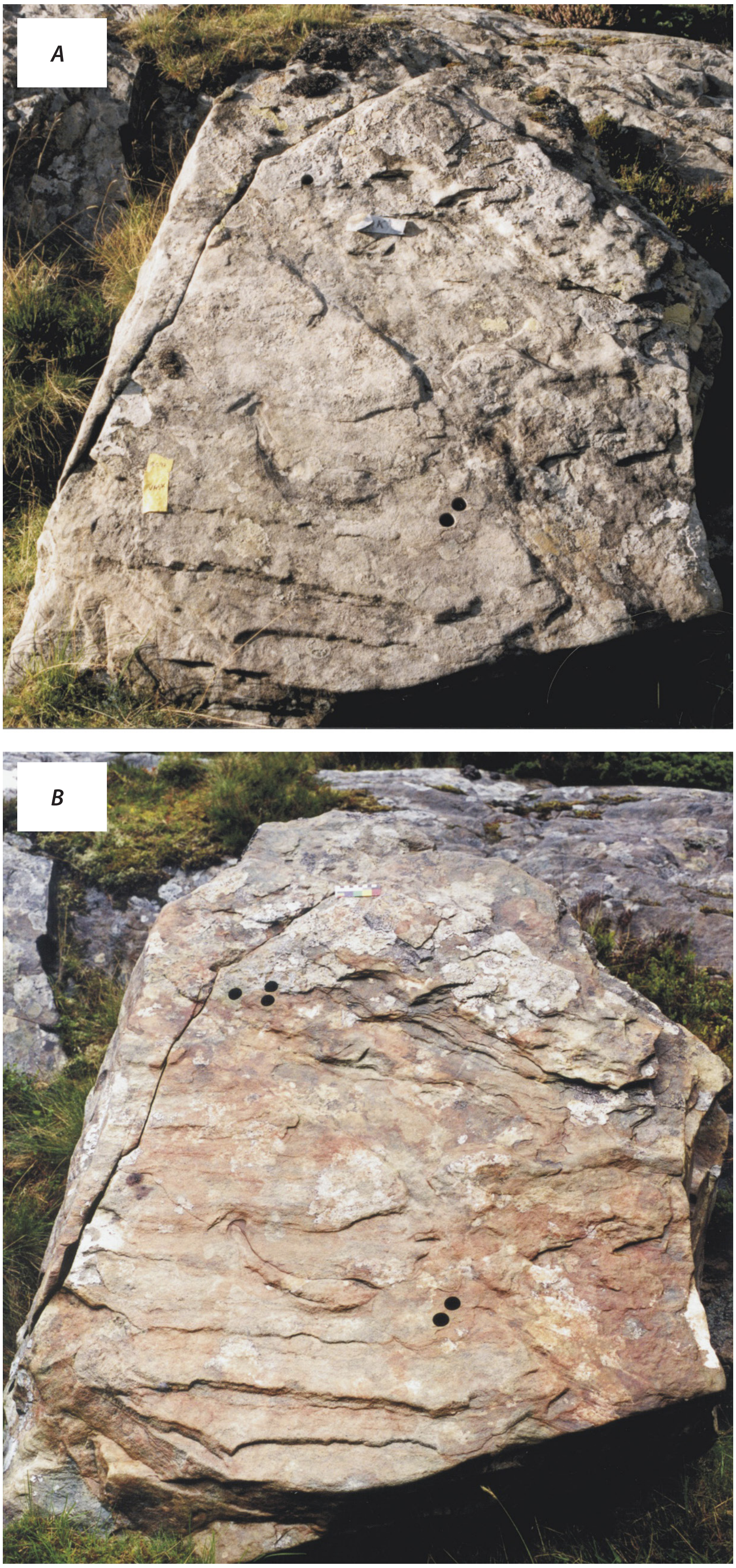


Fig. 5.4.4.1-3. *Rock surface treated with Pingo. a) Before treatment in 1997. b) Inspection in 2000*

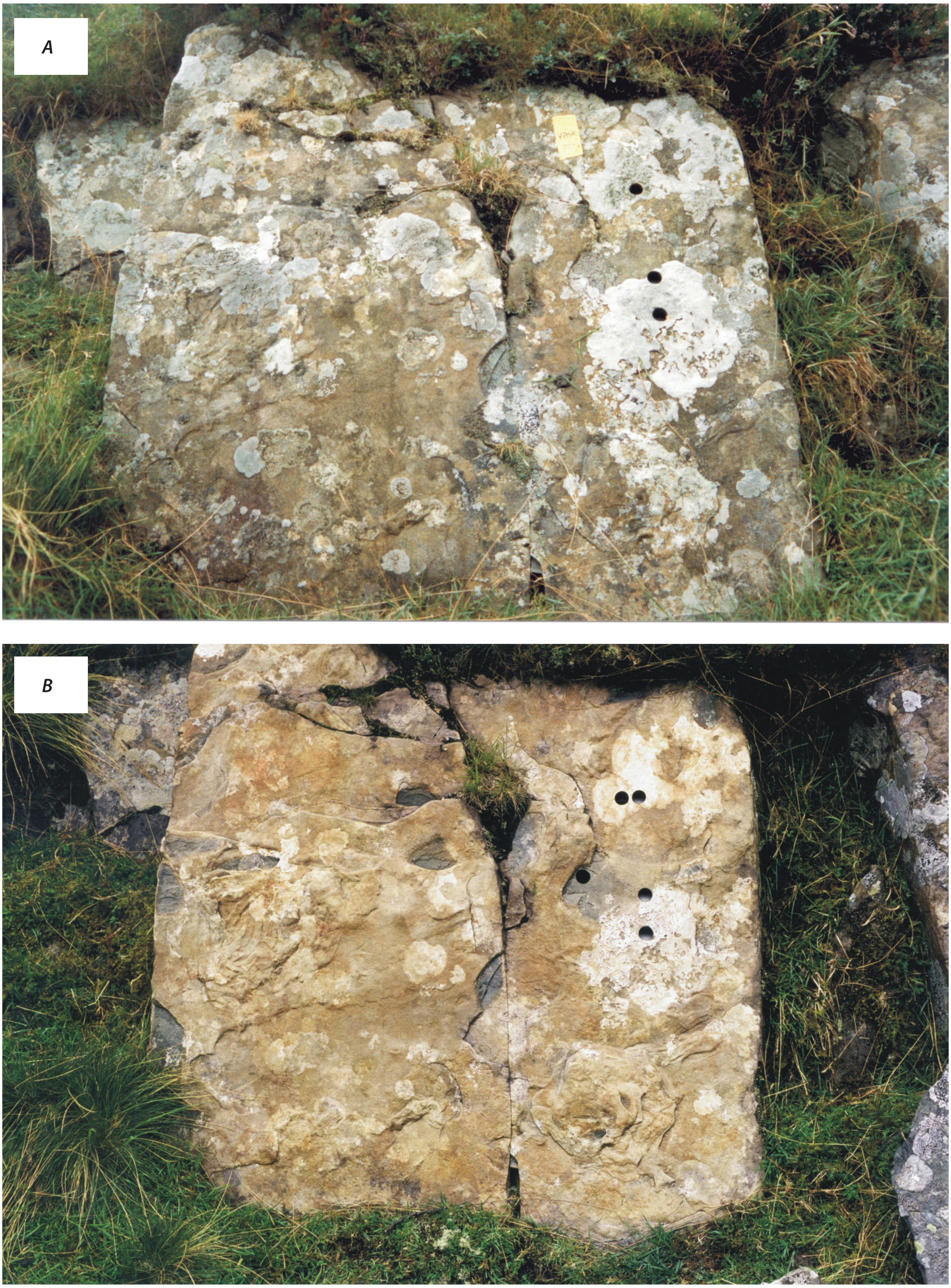


Fig. 5.4.4.1-4. *Rock surface treated with ethanol. a) Before treatment in 1997. b) Inspection in 2000.*

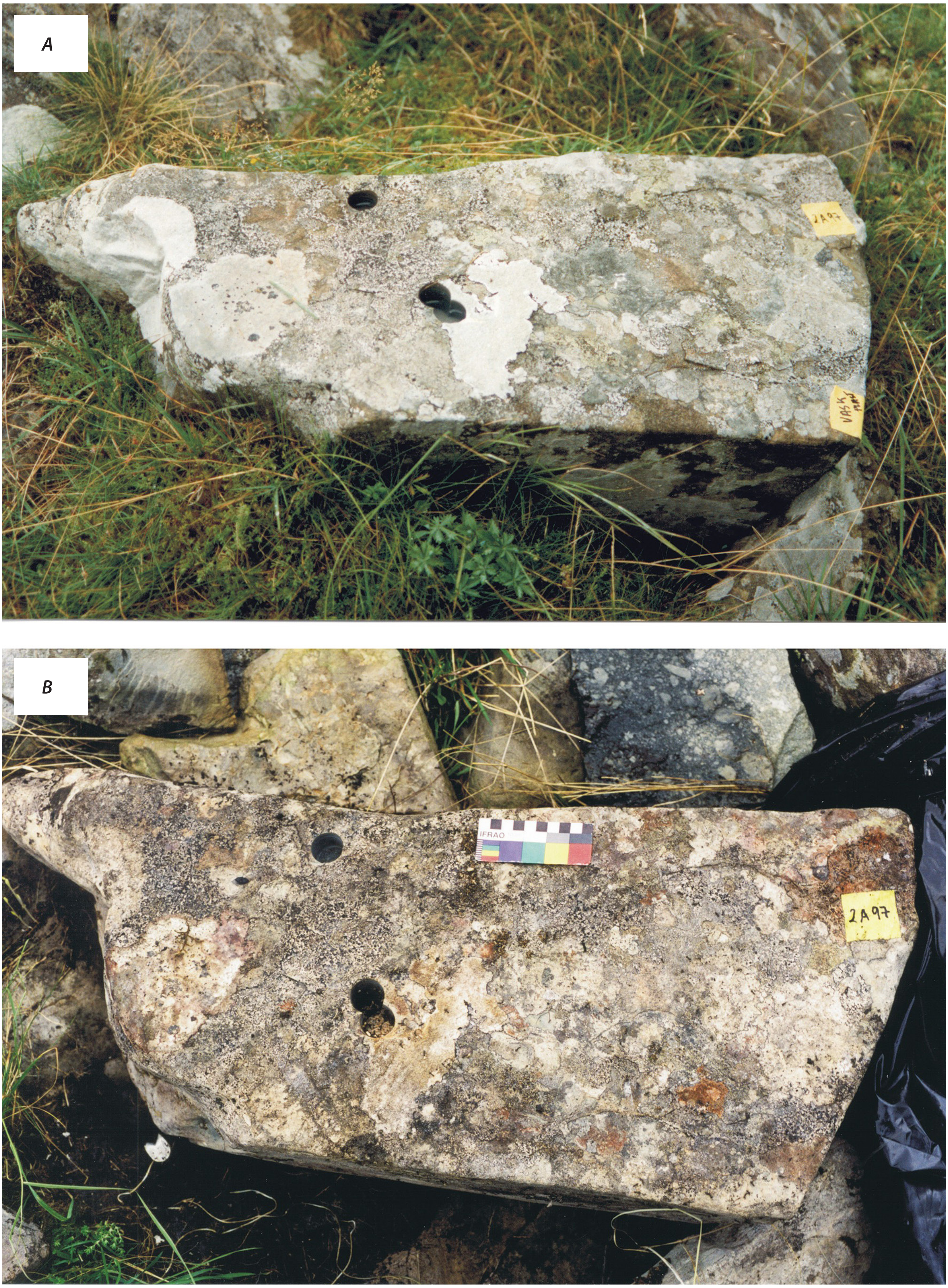


Fig. 5.4.4.1-5. *Rock surface with a cover of black plastic. a) Before treatment in 1997. b) Inspection in 2000.*

In the light of our results, the best way to remove lichens from rock art panels is as follows:

1. Before you start to clean a rock carving surface it is important to make sure that an expert in botany has checked that there are no redlisted (rare and threatened) species (especially lichens and mosses) growing on the surface.
2. Carefully brush the rock surface clean (PS! Don't use a steel brush, use a soft brush!).
3. Spray the rock surface with water until the lichen is wet (this is necessary to activate (photosynthesis) the lichen). Wait about one hour.
4. Spray the rock surface with ethanol (70–96%). It is important that the surface gets properly wet. The spraying can be repeated several times a day.
5. Cover the surface with black plastic (0.15mm). Wait one year.
6. Carefully brush the rock surface clean.
7. Spray the rock surface with water (if the lichen is dry). Wait about one hour. Spray the rock surface with ethanol (70–96%).
8. Cover the surface with black plastic (0.15mm). Wait one year.
9. Carefully brush the rock surface clean.
10. Spray the rock surface with ethanol. The spraying can be repeated several times during a year until the lichens are removed.
11. Continue to spray the rock surface with ethanol at least twice a year to avoid re-colonisation of lichens on the surface and within the pores.

5.4.4.2 Juvenile development of saxicolous lichens

Colonisation and survival of a lichen population involves series of life cycle stages; dispersal of propagules, attachment to the substrate, germination, juvenile development, growth and reproduction. The reproductive strategy of a lichen is either asexual or sexual. The sexual way to reproduce involves dispersal of the mycobiont (the fungal component of lichens) by ascospores. In this case, the mycobiont has to make contact with a suitable photobiont (the algal/cyanobacterial component of lichens) to re-establish the lichen thallus. The asexual strategy involves simultaneous dispersal of both bionts in vegetative diaspores, such as soredia and isidia, or by thallus fragments. The reproduction of vegetative diaspores is generally considered advantageous for rapid colonisation. However, field observations from Vingen indicate that lichens rapidly establish again with small lobes on a lichen-free surface, even if the lichen cover was removed from the surface the year before.

No studies have focused on the ontogeny and rate of development of saxicolous lichen species. It is normally assumed that lichen colonisation takes place from above, either through the re-lichenization of ascospores of the lichen fungus or by lichenized vegetative propagules of the lichen thallus, e.g., soredia, isidia, or simple thallus fragments. However, with hyphae of the lichen fungus firmly settled within the rock at depths counted in millimetres, the possibility of colonisation (or regeneration) from below cannot be ruled out, assuming that cells of the correct photobiont species are available at the rock surface. As poikilohydric microorganisms (whose water status varies passively with surrounding environmental conditions), lichen mycobionts and photobionts can survive extreme temperature stress periods unharmed in a state of dormancy (Kappen 1993).

One *Ophioparma ventosa* thallus and one *Pertusaria corallina* thallus were totally removed from the rock surface in 1999 in order to see how fast and if they were able to re-establish from this spot on the rock surface. Also, one *Ophioparma ventosa* thallus was partly removed. The thalli were removed mechanically without any chemicals. The results show that small areoles are established only after one year. After five years the areoles is growing together and makes small thalli. Comparing with other tests in Vingen, this indicates that the lichens more easily re-establish on a rock surface if it is not treated with chemicals. This is probably due to the fact that there are still fungal hyphae within the rock that are able to re-establish if there is a suitable photobiont available.

To test if this hypothesis is correct, a further 4 rock samples from *Ophioparma ventosa* were collected to use in a lichen re-establishment test. This part of the project is being carried out in cooperation with Prof.

Rosmarie Honegger (University of Zurich). In 2005, first the *Ophioparma ventosa* thalli were removed from the samples, pieces of the weathered rock were then added algae (the photobiont of *Ophioparma ventosa*) and put on Petri dishes. After one week, the fungal hyphae were growing around the algae, but they were not penetrating them. Due to problems of keeping the samples wet enough in the Petri dishes, new samples were made and put outdoors on the roof of the University of Zurich in March 2005. Lichens grow slowly, so this part of the project is still not complete.

5.4.4.3 Removal of biological coatings

Biocoatings on water seepages is removed relatively simply by using ethanol. One year after washing, most of the coating had gone and the rock surface had a lighter colour, usually lighter than the surfaces around the treated area. This is due to microbial activity within pores in the rock, despite the lack of lichen.

Considering our results the best way to remove biological coatings from rock art panels is as follows:

1. Spray the rock surface with ethanol (70–96%). The spraying can be repeated several times a day.
2. Cover the surface with black plastic (0.15mm). Wait one year.
3. Carefully brush the rock surface clean.
4. Spray the rock surface with ethanol.
5. Cover the surface with black plastic (0.15mm). Wait one year.
6. Carefully brush the rock surface clean.
7. Spray the rock surface with ethanol.
8. Continue to spray the rock surface with ethanol at least twice a year to avoid re-colonisation of microorganisms/lichens on the surface and within the pores.

5.4.5 Natural decomposition of organic material on the rock surfaces

Mites have been observed in several places in the outermost pores in the sandstone. In narrow cracks, they are abundant and easily visible to the naked eye (Fig. 5.4.5-1 and 2). Individuals are about 0.6 mm long. The species found at Vingen is *Ameronothrus lineatus* and it occupies terrestrial, limnic, and marine habitats (Schulte *et al*. 1975). This species lives largely on cyanobacteria, algae, and fungal hyphae (Schulte 1976).

Ameronothrus lineatus is only observed on surfaces with smaller amounts of lichen, for instance surfaces treated earlier with ethanol, in seepages, and on a rock surface beneath an impregnated step. Even if the lichen is dead and the biological material is partially or completely degraded, there are large amounts of algae and fungi on the rock surface that mites can feed on. So far, no systematic and comparative studies have been carried out on different lichen species and their content of mites. It is uncertain why *Ameronothrus lineatus* is not found in connection with any living lichen thallus already studied in connection with the other analyses at Vingen. One reason may be that certain lichens contain chemicals that deter mites from feeding on them (Lawrey 1986).

5.4.6 Evaluation and conclusions

Lichens have an effect on the degradation of rocks, such as leading to fragmentation, causing textural and chemical changes to the rock and to its component minerals. In spite of heterogeneous rock, and the fact that the studied weathering rinds are the result of complex interactions of physical, chemical, and biological weathering processes during the postglacial period, the results show that some lichen species are clearly more aggressive with regard to weathering than other species in a lichen community. The lichen *Ophioparma ventosa* appears to be a significantly more aggressive species with regard to promoting weathering than the species *Pertusaria corallina*, *Ochrolechia tartarea*, *Fuscidea cyathoides*, and *Lecidea fuscoatra*, whose effects are difficult to distinguish from each other. There is a positive correlation between the degree of weathering and species with high amounts of hyphae within the rock. Differences in content of lichen compounds seem to be a more likely explanation for the variations in chemical weathering, than differences in oxalic acid production. The results imply that there is an indirect relationship between weathering effect and ecology in saxicolous lichens. It is also suggested that lichens generally increase the weathering processes, except at locations with extremely high abrasion, where they may protect the surface.

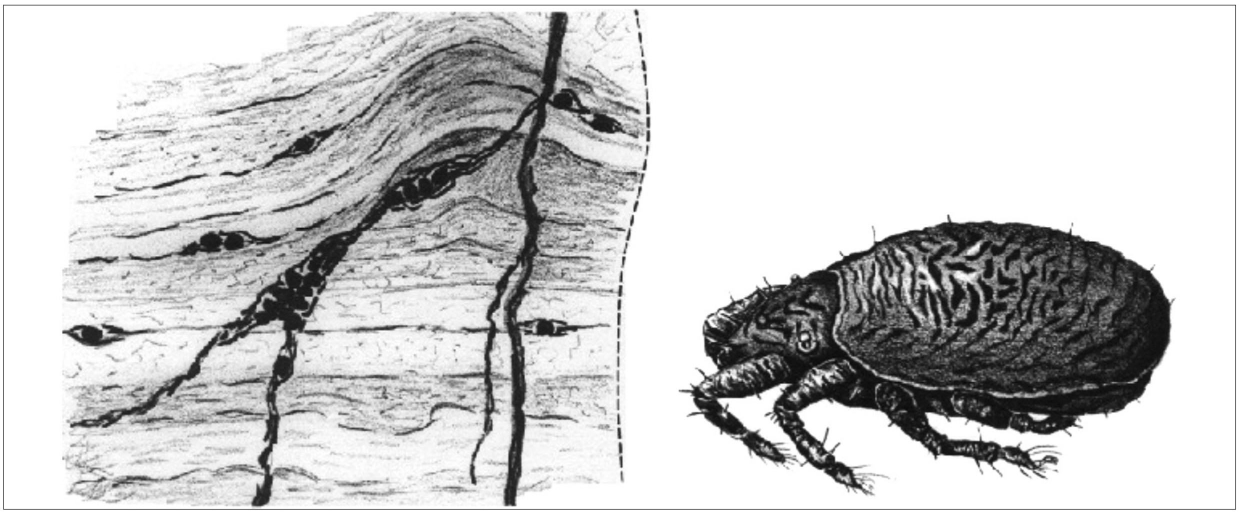


Fig. 5.4.5-1. The mite species Ameronothrus lineatus is often observed sitting in cracks and pores on lichen-free rock surface. (Drawing Beate H. Ingvartsen)

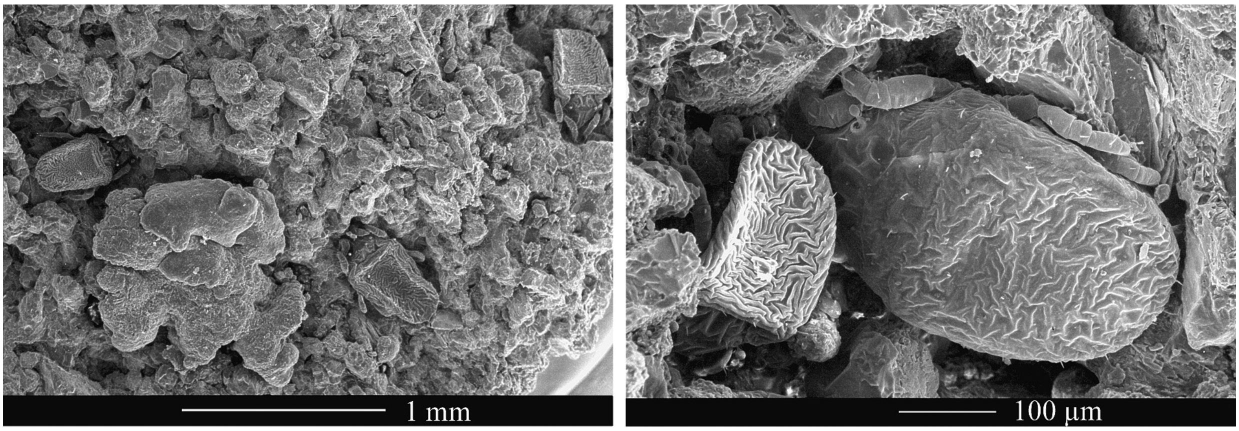


Fig. 5.4.5-2. SEM-images of mites.

At Vingen, the *Verrucaria* species on the shoreline appear to be protective, since coastal areas are otherwise exposed to wave abrasion. Also, this species does not produce aggressive chemicals, and in addition seawater will have a neutralising effect on any oxalic acid produced.

If it is necessary to remove lichens from a rock carving surface, it should be done with care and with a follow-up plan. Every time a crustose lichen cover is removed, the upper millimetre of the rock surface is removed (5.3.3). It is therefore very important to avoid re-colonisation on a newly cleaned/exposed rock carving surface. Mechanical methods may damage the rock surface, and should be avoided. The effect of treatment with Quaternary ammonium salts (Pingo), ethanol, and covering with opaque material, alone and in combination, has been tested. The results show that treatment with ethanol and covering with opaque material are the quickest and best methods for removing lichen from rock surfaces. Lichens die within one year and gradually loosen from the surface. Without covering, the treatment must be repeated several times in order to kill all species of lichen and the fungal hyphae with the weathering rind. Quaternary ammonium salts (Pingo) in combination with covering are as efficient as ethanol, but result in increased growth of algae if the surface is exposed to light. Covering the surface with opaque material can kill lichen within two years. Non-lichenized fungi, beetles and mites contribute to the degradation of biological material on covered surfaces. To avoid lichen re-colonisation either from the fungal hyphae within the weathering rind or from above (lichen diaspores), a clean rock surface should be continuously sprayed with ethanol and/or covered with black plastic.

Biocoatings related to water seepage are relatively easily removed using ethanol, and after one year most of the coating has been broken down and the discoloration has disappeared. To avoid re-colonisation of microorganisms, the rock surface should be continuously sprayed with ethanol.

5.4.7 Perspectives

Similar comparative studies from other sites are required to be more specific about the weathering effect of different lichen species. Experimental studies of the dissolution effect of lichen compounds are needed to better understand the weathering processes in which lichens are involved. It will be important to find whether the organic acids are produced within the weathering rind or if they only dissolve into the circulating water from the epilithic lichen thalli. There is also a strong need for further studies on the physiology and the entire ecology of more saxicolous lichen species, including studies on the factors which control the production of organic acids, lichen dispersal, establishment, and nutrient requirements, to be able to relate the weathering effect and the ecology of a lichen species.

5.5 Vegetation history in relation to acidity/preservation

The production of rock carvings is supposed to have taken place between ca. 5000 and 4200 BC (Chapter 2.3.2 and 7.1). The pollen diagrams from both Vingen and Vingeneset (chapter 7.2), show that the carvings were produced in a period of open deciduous forest in Vingen and at Vingeneset. Birch (*Betula*) and hazel (*Corylus*) were the dominant tree species at Teigen prior to human activity in the Mesolithic, whereas birch dominated the area surrounding the investigated bog at Vingeneset at this time. Also hazel and rowan (*Sorbus*) are growing at Vingeneset, and from ca. 6000 BC, alder (*Alnus*) became important in the vegetation, probably reflecting the humid conditions by the bog. The presence of hazel indicates high pH, and alder, with its ability to produce nitrogen, resulted in rich soils. At both sites deciduous forest regenerated in the openings left by people in the Late Mesolithic. The presence of hazel in the area, and especially in Vingen in the Late Mesolithic and Neolithic, indicates a relatively high pH in the following thousands of years. A gradual leaking of soil nutrients probably occurred, and ca. 1100 BC, about 3000 years after the production of rock carvings had ended, the deciduous forest at Vingeneset was replaced by mixed pine (*Pinus sylvestris*) and birch forest with rowan (*Sorbus*) and juniper (*Juniperus communis*) as well as areas still dominated by alder. This change, from easily decomposed leaves to low decomposition of pine needles, probably had a more serious effect on soil pH than the previous out-wash of nutrients. A further step towards acidification took place ca. 600 years later when the heathlands began to develop (cf. chapter 5.3.1). For about 2500 years, heather (*Calluna vulgaris*) has been important in the vegetation at Vingeneset; in the first hundred of years in a mixture with pine, birch, rowan and alder. It is still unknown whether heather also dominated the vegetation in four areas of Vingen before more intensively grazing/land-use practices resulted in grasslands rather than heathlands. The presence of microscopic charcoal during the last ca. 700 years at Vingeneset indicates burning of the heathlands, which probably had a more positive effect on the soil pH.

5.6 The Vingeneset test area: The significance of temperature, water and light for the rate of denudation

5.6.1 Background

The effect of the environmental parameters of temperature-water-light on the biological activity on and within the rocks, as well as the other physical and chemical weathering processes, were investigated on a sizable trial surface on Vingeneset.

Light is essential for the growth of pioneer organisms such as algae and cyanobacteria, both alone and in symbiosis with fungi (lichen). Nitrogen-fixing cyanobacteria are particularly important pioneer organisms. These create a foundation for the growth of fungi and bacteria. Reducing the amount of light available should decrease the amount of biomass created. Other organotrophic microorganisms that live on organic material will then predominate. These will break down and oxidize most of the existing biomass.

Another essential environmental factor for biological activity is water. If the availability of water is restricted, then all biological activity, and the associated degradation, will be limited. The same will be the case for chemical solution unrelated to microbial activity and for frost action, if the temperature varies around the freezing point.

5.6.2 The disposition of the trial surface

The trial area on Vingeneset consists of a rock surface of some 20 square meters that is parallel to the sedimentary layering and slopes 45° towards the south-southeast (Fig. 5.6.2-1). The surface was divided into four rectangular areas, and each of these was again divided into four squares of about 1 m^2. The trial area is surrounded by several panels with rock art (e.g. *Vingeneset* 4 and *Vingeneset* 2).

The trial area has been used to investigate the effect of light by comparing covered and exposed squares. The importance of physical processes due to temperature changes has been taken into account by employing 5-cm thick insulating mats as covers. The mats are restrained by thick tarpaulins and nets (Fig. 5.6.2-1b). The effects of water are investigated by comparing areas with and without seepage, both covered and exposed. Seepage is created by laying turf on the upper side of the surface. Trial area AI is a covered surface without seepage, AII is exposed and without water seepage, BII is exposed with seepage and BI is covered and with water seepage (Fig. 5.6.2-1c).

The insulating mats are plastic-covered. They easily mould to the underlying surface and are relatively simple to handle during later inspections and sampling. To stabilize the covers through stormy winters, the tarpaulins and nets are fixed to thin cables, one on each side of the mats, which are attached tautly to bolts fixed in the rock. In addition, the edges of the mats are held down by sand bags (Fig. 5.6.2-1b). To prevent water flowing freely between the trial areas, they were isolated by strips of silicon about 1cm high. Larger cracks crossing the rock surface were also sealed with silicon.

5.6.3 The initial condition of the trial area

The trial area was carefully examined by archaeologists to make sure that the surface had no rock art. Next, a technical curator investigated the surface and lichen samples were collected to determine the species present, and rock samples for geological and microbiological investigations.

About 25 species of lichen and some species of moss were recorded on the trial surface. The area was relatively heterogeneous with respect to the distribution of lichens. Parts of the surface were nearly completely covered by lichen, while other parts were more or less bare (see Fig. 5.6.3-1). Crustose lichen with relatively thin and small thalli predominate, but there are patches of lichen with larger and thicker thalli.

The rock surface exhibits dispersed larger particles of gravel and rock fragments (see Fig. 4.1.1-5). The eastern part of the trial area was weakly discoloured due to seepage of water from the overlying turf (Fig. 5.4.2-1). The depth of weathering is around 9 mm, typical of exposed surfaces in the Vingen area (see 5.2). Prior to the trial, the surface was already damaged due to weathering. Several loosened but still undetached crusts are connected with fractures and rosettes of lichen. Between squares BII2 and BI2, a large area of the surface has flaked off (Fig. 5.6.2-1a). In the upper part of square AII1, a large flake has disappeared alongside a

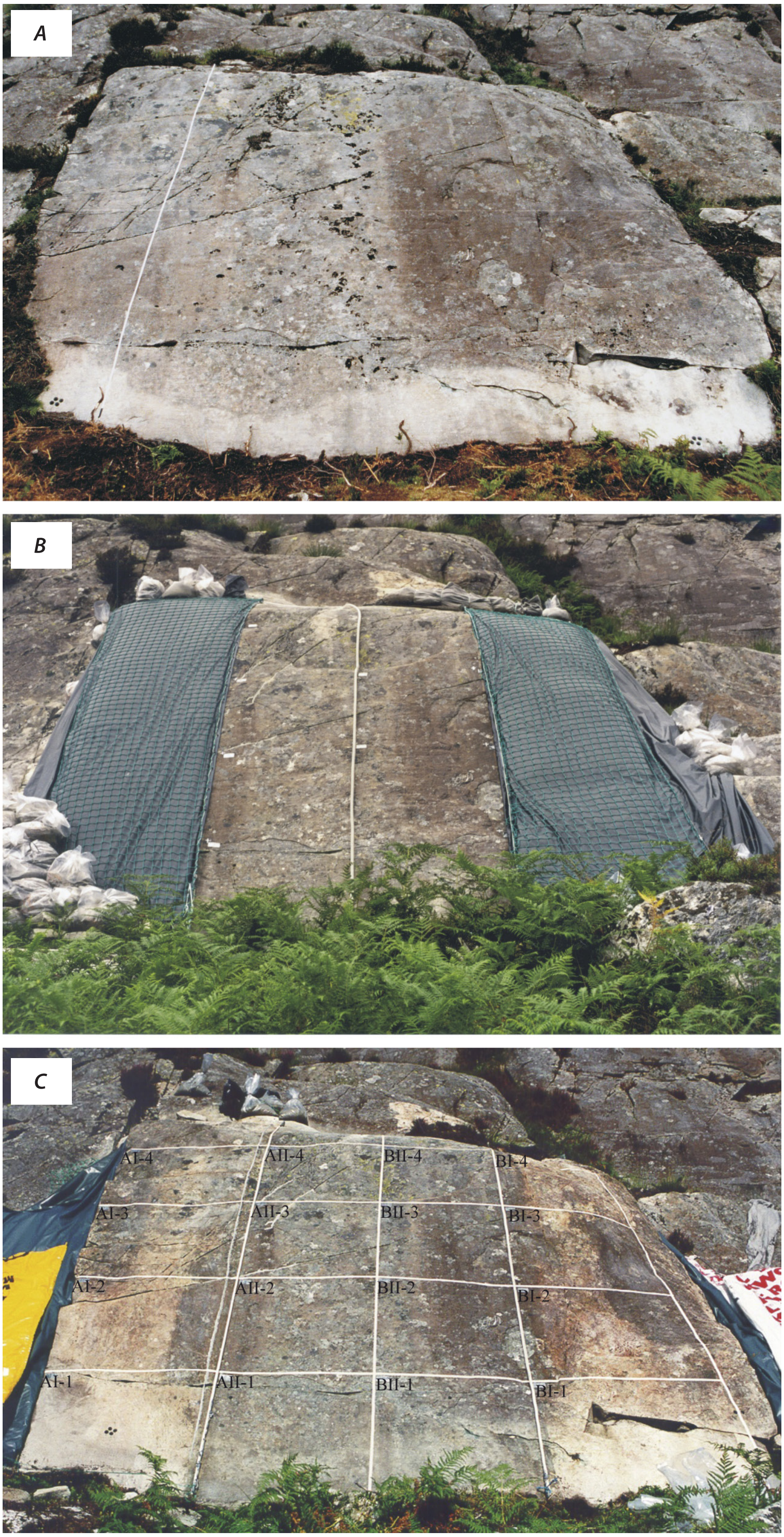


***Fig. 5.6.2-1** a) Trial area on its installation in 1997 and b) after covering. c) Uncovered on inspection in the summer of 2000. AI: covered without water seepage (square AI1-4), AII: left exposed without water seepage (square AII1-4), BII: left exposed with water seepage (square BII1-4), BI: covered with water seepage (square BI1-4).*

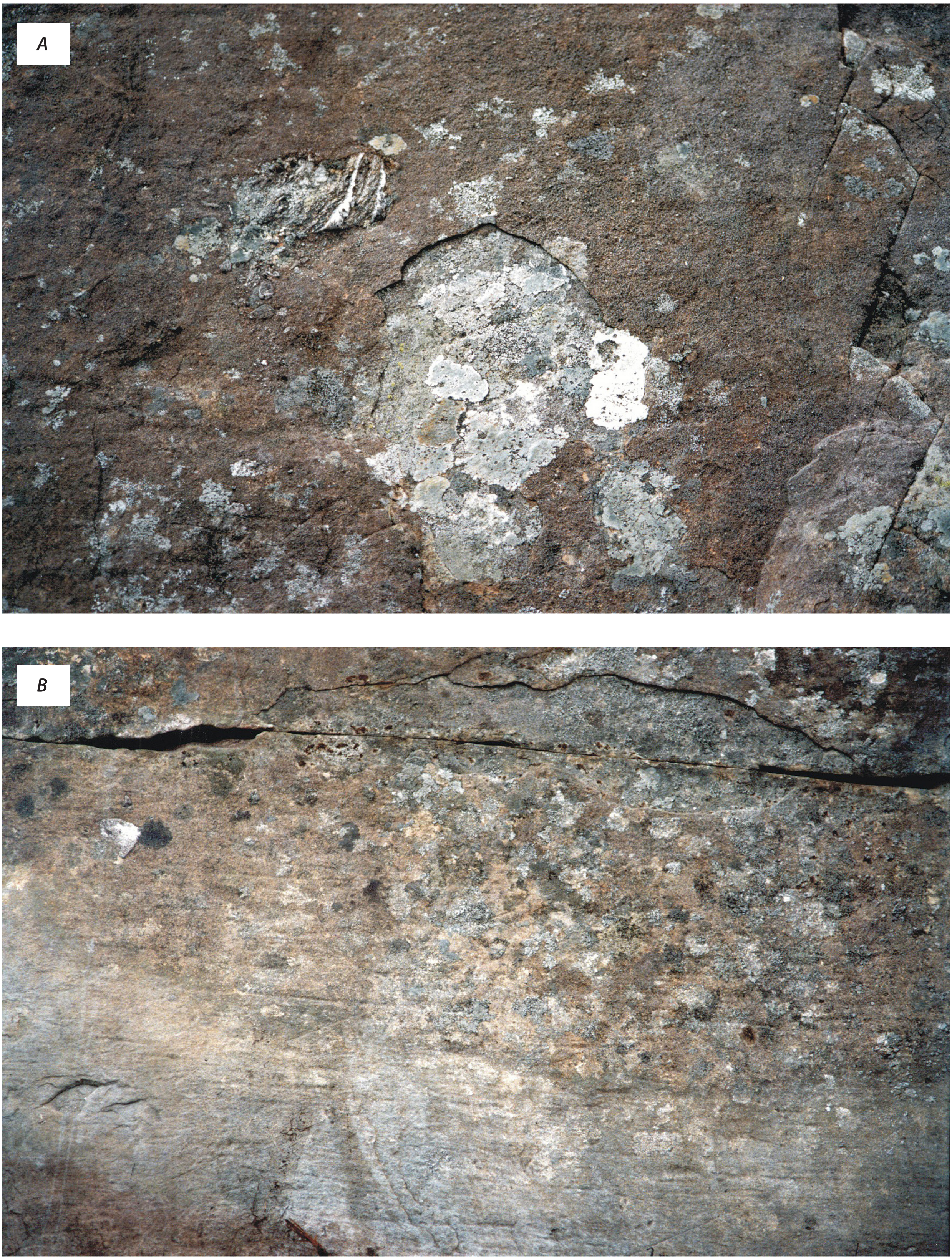


Fig. 5.6.3-1 *Typical damage due to weathering present at the initiation of the trial area. a) A relatively large surface layer has flaked off between squares BII2 and BI2. b) Flaking adjacent to a fracture in the upper part of square AII1.*

nearly horizontal fracture (Fig. 5.6.2-1b). In several places, the outer part of the weathered rind has bulged up beneath rosettes of lichen. This probably is the result of a high content of organic material. The extent of the prior damage to the rock surface has been mapped for comparison with its subsequent development.

5.6.4 The effect of insulation and water seepage

After the trial area was established in August of 1997, the rock surface has been inspected yearly with respect to i) the growth and destruction of pioneer organisms such as lichen, algæ and cyanobacteria (blue-green algæ); ii) growth of other micro-organisms; and iii) degree of weathering and the extent of any damage.

5.6.4.1 Biological material

After being covered for one year (1998) the majority of the lichens were still alive. However, many were strongly discoloured and commonly had a slimy surface, and were overgrown by various fungi (Fig. 5.6.4-1). Two years later (in 1999), the majority of the covered lichen (in areas AI and BI) was apparently dead. The degradation of the biomass was more advanced in areas with water seepage (BI) than those without (AI).
After three years (in 2000) the biological material on the covered surface with water seepage (BI) was almost

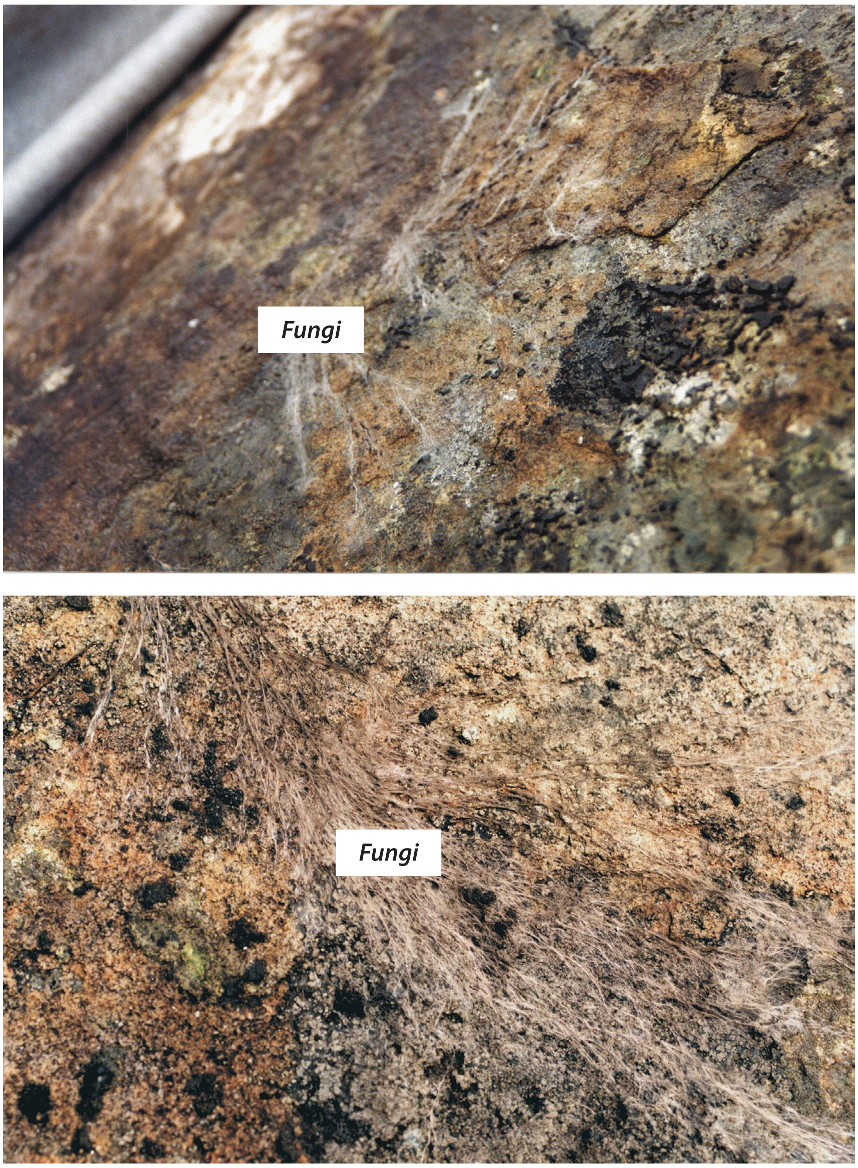


Fig 5.6.4.1-1 The lichen thalli are overgrown by various fungi.

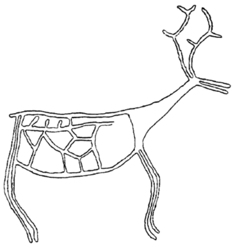
completely broken down, also throughout the weathered crust. In the area without access to water (AI), however, the fungal hyphæ were only destroyed on the outer surface. Farther down in the weathered crust they were apparently still intact. Due to the destruction of the biological material, both areas of the surface had become lighter coloured.

5.6.4.2 Weathering

As could be expected, changes in the thickness of the weathered zone from year to year were not detected, since chemical solution is an extremely slow process. This a long-term aim of the trial; only after a period of 10–20 years with regular sampling will it be possible to compare and investigate the progress of chemical solution and the consequences of isolation and water seepage. In the short term, it is possible to observe the effect of isolation and water seepage on the physical weathering (e.g. frost wedging). As noted above, flaking of the surface was apparent prior to the initiation of the trial (Fig. 5.6.4-1). To date, no increase in flaking has been recorded in any of the different areas. It is possible, however, that crusts which have loosened but are still in situ have increased in lateral extent but this is difficult to document.

5.6.5 Future investigations

The trial surface should continue to be inspected regularly with respect to the reduction in biomass and the condition of the rock surface. Comparison with the damage recorded initially will make it possible to determine the rates of degradation in the different areas of the surface.



CHAPTER 6

Kjartan Gran

METHODS, PRODUCTS AND MATERIAL TESTING

6.1 Covering

Various types of coverings are used as protection against frost upheaval in the weathering zone of the rock surface and to remove and prevent the establishment of micro-vegetation. Frost erosion is a significant degradation factor in many rock art localities, and tests using covering materials have shown that fluctuations in temperature are diminished and that damage during critical frost spells is held in check by protective coverings during the periods when the area is not covered by snow.

The National Rock Art project has enabled us to test different types of covering materials and to develop and customize suitable products to meet our needs in covering rock art (Fig 6.1-1). Detailed investigation concerning insulation properties and technical property has contributed to the results and made it possible to use several specific products for this purpose today.

Fig. 6.1-1. *Protective periodic cover at Ausevik, Sogn og Fjordane (Photo: K. Gran)*

6.1.1 Insulation

For several seasons, we have recorded temperatures beneath different types of covering, and this is being continued at several locations to make sure that the covers are providing effective protection.

In connection with the development of covering materials, temperature measurements have been taken beneath different artificial insulating materials to gauge the actual insulating effect in proportion with variations in air temperatures. The measurements have shown that insulating materials made of glass wool and rock wool as thin as 5 cm provide good protection against fluctuations in temperature. PE foam insulation has practically the same effect down to a thickness of about 4 cm. In Sweden tests have been conducted using natural materials such as clay and fine-grain gravel/sand as covering materials. The purpose of the tests was to prevent frost and to identify materials that diminish the chemical degradation of the rock panel under protective cover. These tests are still ongoing, and concrete results are not yet available in terms of the suitability and effectiveness of these materials.

Several different analyses of deterioration profiles have led to the conclusion that the use of peat turf as a protective cover applied directly to the surface of the rock cannot be recommended since water percolating down through the peat will result in an accelerated dissolution of easily soluble minerals in the rock surface. Peat turf will also serve as genial soil for other growths and will result in roots, etc. penetrating the surface of the rock.

6.1.2 Materials and construction

The technical properties of the materials are very important to achieve a functional, long-lasting cover. It is equally important to adapt the covering and use of materials to local conditions and to the specific item being covered. In addition to the primary objective – that the covering will secure and avoid causing damage to the rock – other properties, such as durability, functionality, weight and price are important parameters that must be assessed globally. It is important to select durable materials so that the protective coverings will function according to the purpose and provide protection over time.

The choice of covering materials and their physical shape is specific for each task and at each site, and there is a need for individual planning and adjusted fittings. Based on the results of practical tests, it was decided to use reinforced PVC (polyvinylchloride) foil as a covering material. As an alternative, PE (polyethylene) foil that does not contain undesired chlorides may be used. PE foil, on the other hand, is much stiffer than necessary and must also be coated with flame retardants to make it self-extinguishing. To the extent that there is uncertainty concerning how harmful the chemical flame retardants may be, this is an argument for not using PE foil.

The coverings must be practically shaped and the operation well planned so that field work is made as uncomplicated as possible. Practical design is particularly important if plans are made to cover sites in wintertime and if covers must be removed and replaced annually.

Coverings can generally be distributed in three layers:

The bottom layer is placed against the rock surface, applied in principle to protect the surface against mechanical damage when laying out the insulation and in theory to create a drainage zone for removing condensation from the rock surface. The bottom layer can consist of a composite of "breathing" textile, a membrane and a fibre cloth/geotextile combined with a net-like fabric that lies on top and creates an air space beneath the insulation layer. Use of a fibre cloth/geotextile alone may result in leading water in beneath the cover. Special consideration must be given to the risk of this occurring and its possible effects.

The insulating layer is placed over the bottom layer and is designed to protect against frost cycles. Various tests have been conducted with specific types of material and practical shapes of insulating mats used for protective covering for shorter and longer time periods. Experience has shown that glass wool and stone wool are well suited as covers, since the insulating properties are good and the material joins well with the rock surface. The disadvantage is that the insulation is vulnerable to moisture and compression, which in turn reduces its insulating property. Ready-made mats for use out of doors – "winter mats" – protect insulation to a certain extent, but the plastic around the insulation is easily damaged and broken down by ultraviolet rays (UV rays) from sunlight (Fig. 6.1.2-1).

Fig. 6.1.2-1 *Three layers of covering, Bakkane I, Vingen, Sogn og Fjordane (Photo: K. Gran)*

Based on these experiences, specially ordered, fabricated glass wool insulation that is welded into durable foil and delivered in handy sizes has been used.

Polyethylene mats withstand the effects and pressure of moisture better than glass wool and stone wool, and without a reduction in the insulating property. Insulating mats are more rigid and are not as adaptable to the terrain, but they can be shaped by bending and welding them together. It is important to be aware of the fire hazard associated with polyethylene, since the material is basically combustible. The material can be ordered in a fire-retardant variety, but it must be assessed in each case whether or not this is desirable and necessary.

The top layer is placed uppermost, designed to protect and retain the insulation and bottom layer. The top layer and fixtures must be adjusted to fit the insulating layer. When using mineral wool/glass wool that is welded into foil, the top layer in some cases may consist only of the fixtures/fastening devices mounted directly on top of the insulating layer (Fig. 6.1.2-2).

For long-term covering, the insulating layer can be covered with a tarpaulin/foil that encompasses the entire area or is distributed in sheet sections in handy sizes which can overlap one another and be fastened individually. The tarpaulin/foil must be fastened tightly, for example by applying weights or using wire fastened outside of the covered surface. The top layer should be adapted individually to the site and can be fabricated according to a model corresponding to the exact measurements and shape of the site.

Because of the shape of the rock carving site and location, it may be necessary to specially adjust cover materials and fixtures so that protection is optimal. Whenever covering requires the removal of turf and other material or entails other types of physical measures, the planning and execution of the cover itself, as well as the method used, must be done in consultation with archaeological specialists and supervising authorities pursuant to applicable regulations.

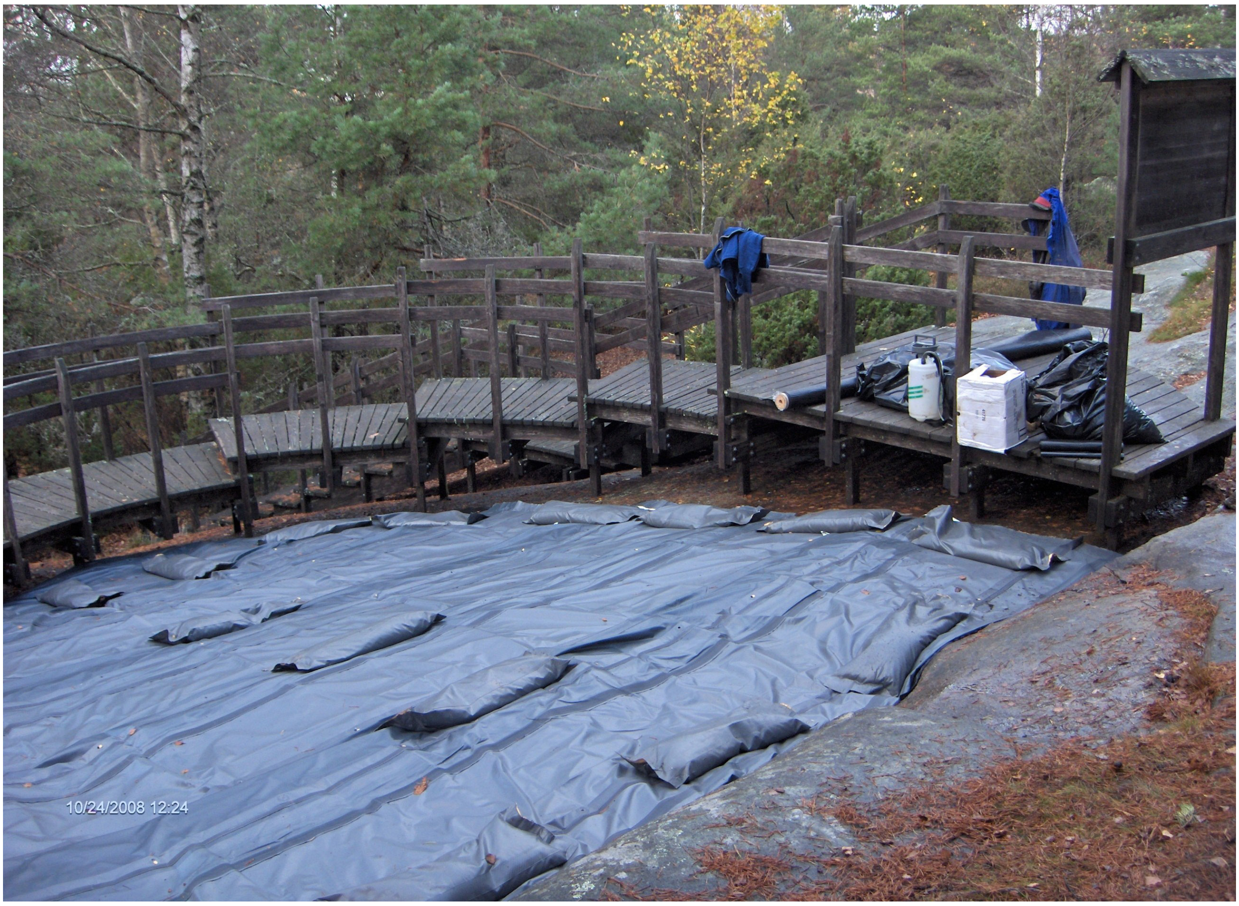


Fig. 6.1.2-2 Spesial designed foil for covering. Manufactured in PVC with insulation inside, Begby, Østfold (Photo: K. Gran)

It is important that the covering materials are sufficiently linked into one another and are anchored with weights or fastened directly into the ground. Experience has shown that it is demanding and heavy work to have to replace covering materials and sandbags that are unable to withstand the stress of weathering over time. Spoilt plastic, insulation and leaking sand from sandbags also represent stress factors on both the natural environment and the rock art sites. It is important to think long-term and practically when selecting the fastening methods and the materials to be used. Plastic materials such as sandbags, plastic strips and rope must be frost- and UV resistant. Wire and fastening materials made of metal must be of rust-resistant steel or stainless steel (not galvanised). Steel must not be used in combination with aluminium.

Bags for sandbags are now made of specially manufactured PVC cloth that is able to withstand outdoor exposure. Good results have also been obtained by using rubber tubes for tiers, filling them with sand and using plastic strips. These sacks are currently in use in various localities in Norway.

6.1.3 Short time covering / periodic covering

It is particularly important to plan the covering operation so that the work involved in covering and uncovering can be performed efficiently during the entire period when the work is to be done.

When the surfaces are uncovered, it is necessary to have sufficient storage facilities for the covering materials. If the materials cannot be stored near the site, appropriate transport must be available for removing the materials from the area and bringing them back when needed.

Sandbags may be an alternative to fastening down the covers. This can entail a lot of heavy and demanding work involving carrying, placement/collection of materials twice yearly. If periodic or winter covering is planned to continue over a long period of time (more than 10 years), it may be advisable to designate permanent points for anchoring the covers. This may be done, for example, by using proper equipment fastened into crevices

Fig. 6.1.3-1 Sesonal covering at Helgaberg, Hordaland (Photo: K. Gran)

outside of the panel or by bringing stone blocks or similar materials to the panel and drilling holes to anchor fasteners. In this event, planning must take into account that the insulating mats must be adapted to the site.

Information about the measure should be posted locally and disseminated to users in the immediate vicinity and to any other potential visitors.

6.1.3.1 Periodic covering, case stories

In Vingen and Ausevik and at other sites in Bergen Museum's jurisdiction district, periodic covering is sometimes used for removing micro-vegetation. In these cases, low-quality materials are frequently used. In some cases this has resulted in disintegration of the materials and the spread of pieces of plastic and insulation out across the area. Based on the results from the National Rock art project, only high quality products are currently in use.

In Ausevik in Flora, specially designed insulation mats have been in use for more than five years, and thin sheets of PVC foil are used to cover larger areas in order to remove micro-vegetation before starting restoration work.

In Hardanger and Etne, thorough on-site surveys have been conducted at the sites of Bakke in Jondal, Bruteigsteinen and Helgaberg in Etne for the purpose of planning periodic covering at sites here.

Measurements were taken of all sites and these data, along with continual assessments, have provided the basis for the planned coverings and choice of materials for these tasks. During the late autumn of 2005, all three sites were covered for the winter.

In Jondal, the site has remained open during the summer, but will be covered again in wintertime. People from the local historical society do the practical work of covering the rock art in the autumn and uncovering it in the spring.

At Helgaberg the cover has remained in place, and is functioning well (Fig. 6.1.3.1-1).

6.1.4 Long term covering

The University of Bergen has used long-term covering for several years. In the 1970s, 80s and 90s, the areas were covered with peat turf. This method is no longer recommended due to the possible negative effect in the form of degradation of specific minerals caused by the turf over time. It is possible that turf covering and poor map references have resulted in the loss of some figures because they have been impossible to find.
Sometimes a combination of glass wool insulation and peat turf has been used, but with no protection from roots, resulting in the infiltration of roots into the insulation layer, as well as roots growing into and eroding the disintegrated surface layer on the rock.
Even later use of prefabricated winter mats (insulation mats with PE plastic sheets) has led to disintegration of the plastic and the littering of the surrounding area with small pieces of plastic and insulation.

Based on earlier experience and testing, important general guidelines have been established. This kind of protective covering must be suitable to lie in place for several decades with a minimal amount of side effects and required maintenance. It is especially important that the materials used are able to withstand climatic fluctuations over time. In order to adapt the materials to the surroundings, the colour and surface characteristics are essential for the choice of material.

It will be advantageous if the protective covering can be shaped in such a way that it permits researchers to check the site at intervals during the period it is covered. Monitoring of the climate on the rock surface using temperature and moisture sensors will also provide valuable security for future conservation of the site.

6.1.4.1 Case stories

At Ausevik, several tailor-made insulation covers were laid out on two panels in 2004. The insulation mats are welded into covers of thick, reinforced PVC foil and the mats are mounted overlapping each other.

Fig. 6.1.4.1-1 *Permanent cover, Vingeneset 4, Vingen, Sogn og Fjordane (Photo: K. Gran)*

Vingen
Bergen Museum decided to cover the two panels in Vingen Bakkane 2 and Vingeneset 4 on a permanent basis. Preparations for covering have been accomplished over a long period of time, and investigations have been conducted at Vingeneset 4. At Bakkane 2, direct conservation measures have been implemented to secure loose bits of rock on the surface. During the summer of 2003, further clearing was done around both sites and holes were drilled for sinking anchor bolts to attach the wires that will secure the protective cover on Vingeneset 4. The covering was completed in 2004, and the top layers of the specially adapted tarpaulins made to dimension were fitted exactly to cover the sites. Against the rock surface is a layer of breathing fabric, ”Sympatex”, which was sewn inside a coarse-gauge fibre cloth/geotextile that will serve as protection for the ”Sympatex” fabric. As an insulating layer, 4–5 cm of insulating polyethylene ”Plastazote” matting has been applied. The insulation layer is welded together into one large mat without transient seams. For Bakkane 2, the insulation layer was shaped around the rock on-site in order to ensure a perfect fit.

Although the covering process has been time-consuming, the overall result is considered to be extremely good. The specially dimensioned tarpaulins were delivered by Protan AS in Bergen and have been of good quality and precise fit. What remains to be done is to find a solution to the drainage problem in the terrain above and directly below Vingeneset 4. In 2005, despite a lot of wind and poor weather conditions throughout the winter, the coverings remained well secured and in position. The cover over Bakkane 2 was somewhat displaced, and specially produced sandbags were placed around the edges, a measure which, according to plan, was to have been taken in 2004.

The protective coverings at Bakkane 1 and 2 (Fig. 6.1.4.1-2), as well as at Vingeneset 4 (Fig. 6.1.4.1-1), are still in good condition (2008) and have apparently achieved the desired objective.

Fig. 6.1.4.1-2 *Permanent cover, Bakkane 2, Vingen, Sogn og fjordane (Photo: K. Gran)*

Fig. 6.1.5-1 *Climatic monitoring, Kåfjord, Finnmark (Photo: K. Gran)*

6.1.5 Climate Monitoring

The test sites for insulation materials in Alta and Vingen have been monitored by a climate station (4.2.1, 5.1.2) designed to measure temperature and moisture beneath various types of insulation. Measurements in Alta are still running but in Vingen the measurement series was terminated in 2003.

The measurements from Alta and Vingen provide the basic information on insulation properties. Furthermore, a simpler but more flexible system of temperature monitoring is used. Small temperature detectors are used individually and placed with sensors under the insulation as well as exposed to the open air to compare the temperature difference (Fig. 6.1.5.1-1).

Data loggers for temperature measurements can be used to determine the insulation effect. This is recommended as a part of the safeguarding and covering program.

6.2 Consolidation with Mowilith

Mowilith DM 123 is used as glue and consolidant for rock surfaces at several rock art sites in the Bergen Museum jurisdiction area. The largest interventions have been made in Vingen and Ausevik. Here Mowilith DM 123 has been used for different purpose from the beginning of 1980 until early in 2000.

6.2.1 Background information

In the 1970s and 80s several efforts were made to inhibit the disintegration that was observed throughout the 1900s. In this period different products were also tested to find useful chemicals for gluing and consolidating. (Michelsen 1992). Based on the results of this work, the product Trana Weld was used for gluing and consolidating rock art in both Vingen and in Ausevik. Trana Weld was originally an additive to cement based on different polymers such as PVC and PVA.

Fig. 6.2.2-1 Conservation and re conservation with Mowilithe and sement 1998–2002, Ausevik, Sogn og Fjordane (Photo: K. Gran)

Later Trana Weld was replaced by Mowilith DM 123 S since Trana Weld was no longer available on the market. Mowilith DM 123 S is a copolymer emulsion of vinyl acetate, ethylene and vinyl chloride stabilised with cellulose derivatives and surfactants. The product is originally used as binder in latex and acrylic paint but was at that time evaluated as having the same technical properties as Trana Weld.

6.2.2 Method

Diluted Mowilith was used earlier to consolidate porous surfaces. The idea was to allow Mowilith to penetrate the crust and thereby strengthen it. Mowilith diluted with water (up to 90% water) was brushed onto the surface of the areas to be consolidated. The application continued until all the pores were filled and no air bubbles could be observed. Subsequently all superfluous material was wiped off and the surface was cleaned.

Concentrated Mowilith and dilutions up to 50% added water are used for gluing loose pieces and securing cracks and cavities; it is also sometimes injected into cavities and cracks. Mowilith mixed with sand or cement is also used as mortar for securing cracks and exfoliated edges.

The use of extensive safeguarding using Mowilith and other efforts up until the mid-1980s were in some cases quite intrusive and dominating. After 1990, the methods changed and conservation interventions are now less visible and less intrusive (Fig. 6.2.2-1).

The conservation strategy has changed, and is now more focused on ethical and small-scale interventions. Edges and exfoliations are conserved and safeguarded through minimal interventions which are less visible. In larger cavities and fallouts the edges and sides are filled and secured without filling the whole area as was previously done.

6.2.3 Practical work

Until 2003 conservation measures were taken using Mowilith in Vingen and Ausevik. In Vingen, Bakkane 1 was the last site conserved with Mowilith in 2003 and subsequently permanently covered in 2004. From 1995 until 2002, intensive conservation measures were implemented in Vingen and in Ausevik. On the whole, this entailed renewed conservation and repair of new damage on previously conserved sites, but certain new sites were also conserved.

6.2.4 Testing of Mowilith

Since 2003 and up to 2008, no direct conservation has been carried out using Mowilith or other types of adhesive in Bergen Museum's area. There are several reasons for this. Through the rock art project, there has been a national focus on securing rock art, and this has entailed, among other aspects, a discussion concerning background documentation and the effects of using Mowilith. There has also been greater focus on preventive methods, and this has led to a change in priorities in terms of conservation work.

It is also important to note that a possible incompatibility may exist between the use of Mowilith and the use of ethanol to counteract lichen growth. Mowilith will swell and can lose its effectiveness in the presence of large concentrations of ethanol. As a result, glued flakes may come loose or be torn off.

Field tests have begun in order to acquire better documentation on the effects and suitability of Mowilith.

6.2.4.1 Investigations on Mowilith in Vingen

Mowilith DM 123 S has proven to have good stability both in the field and in simulated ageing tests in a laboratory (Michelsen 1992). Nevertheless, consolidation of the surface images in Vingen has only been achieved to a minor extent. This is due to the hardy growth of lichens and because there is uncertainty as to when the surface is clean enough, or as to the significance of the fact that biological material is still present in the weathering skin. It is also uncertain how much time the agent needs, and if length of time varies in accordance with porosity and the size of grains in the rock species. The question also exists whether the consolidating agent leads to the proliferation of microorganisms, and how long breakdown time is for the material. When lichen vegetation is removed from a rock art surface, its re-growth must be inhibited. It is therefore desirable to find out whether rock surfaces consolidated with Mowilith are able to withstand treatments using ethanol, or whether other biocides should be used instead on such surfaces.

Based on these questions, a test site was established in 1998 for the purposes of testing Mowilith. The test surface was treated with ethanol annually and covered with black plastic to remove lichen vegetation, and samples were taken from the rock species in order to check the amount of biomass in the pores of the weathering skin. In the spring of 2001, the test surface was consolidated using Mowilith. Both two and six months after consolidation a sample of rock was taken. At the Leitet locality, the rock surface had been consolidated in the early 1980s, and the result appears to be satisfactory. In 2001, samples of rock were also taken from this surface.

Mowilith is very difficult to observe in SEM because it presents no visual contrast. Thin ground sections from rock samples impregnated with Mowilith along with an untreated rock sample for purposes of comparison were prepared at the Norsk Hydro Research Centre in Bergen. During preparation, all porosity was coated with blue epoxy, and the thin ground sections were polished without using cleansing agents. In ordinary thin ground polishing, the residual cleansing agent can often settle in the pores of the test sample, making it difficult to distinguish from the consolidating agent.

Analyses appear to indicate that Mowilith does not penetrate the entire weathering skin as previously presumed. Mowilith fills in most of the pores in the upper 0.5 cm of the weathering skin, whereas the pores remain empty in the lower layer of the weathering skin adjacent to the non-weathered rock. This tends to indicate that a vacuum should be used when consolidating in order to ensure that the consolidating agent penetrates throughout the entire weathering zone. Analyses and observations show that Mowilith is still found in the surface of the mineral grains in the pore walls of the upper portion of the weathering skin 20 years after consolidation was performed. There are no indications of increased algae growth or increased amounts of biomass in the samples.

Rock samples treated with Mowilith are examined before and after treatment with ethanol, and observations in SEM show that the plastic emulsion swells in contact with alcohol. This means that the rock surfaces consolidated with Mowilith cannot be treated with ethanol in order to inhibit re-growth of lichens. The effects of biocides on rock surfaces treated with Mowilith should be investigated.

6.2.4.1 Investigations on Mowilith in Vingen

In 2001, an attempt was made, using Mowilith, to glue cracks and loose pieces of rock on a test surface for consolidation/conservation. By the autumn of 2002, portions of the surface were consolidated. During the application of the consolidating agent, it was observed that the agent apparently did not penetrate the weathering skin, but instead “ran off”. The test site was inspected the same autumn, and it appears that Mowilith also functions well in Hjemmeluft.

6.2.4.3 Follow-up

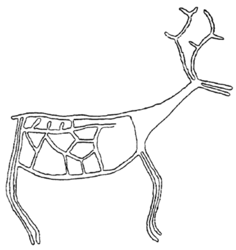
The test sites have not been in use since 2003. In the future, they will be good items for reference and can be used in conjunction with new test samples or for sampling later.

6.2.5 Further work

In 2004, a collaborative project was started to test the use of conservation agents on various types of rock. Museum of Archaeology, University of Stavanger (MA-UiS) coordinated the testing of various cement adhesives and additives for cement used as consolidating agents on sandstone (from Vingen), phyllite (from Stavanger) and on granite (from Østfold). This is a collaborative effort shared by MA-UIS, the Company Halliburton and UiB. In addition, it is also desirable to test 2–3 traditional consolidating agents used in, among others, building stones. In conjunction with this, it is natural to contact various research institutions in Europe that have acquired experience in this area, particularly with Italy, since contacts have already been established with professionals there. Cooperation within the Co-financed European RANE (Rock Art in Northern Europe)-project, as well as evaluation of earlier experiences and tests in Sweden was also helpful.

Tests will be performed through laboratory experiments involving the use of methods for accelerated ageing and the placement of test items in selected testing sites.

Fig. 6.3.1-1 *Testpanel for paint, 4 years after paynting*



CHAPTER 7

Kari Loe Hjelle og Trond Klungseth Lødøen

ACTIVITY, SETTLEMENT AND VEGETATION IN PREHISTORIC TIMES

7.1 Archaeological investigations

During the last decades, several investigations seeking to sample and collect archaeological material of importance for rock art have been undertaken in the Vingen area. In addition to test excavations and palaeobotanical sampling, systematic examinations of brooks, unvegetated soil, and debris have been carried out. Hollow spaces in the many scree slopes in the area have also been explored. A number of investigations have been carried out because abrasive turf and soil that partly covers surfaces with rock art, has been necessary to remove in order to complete primary documentation of the many carved panels and reduce weathering, others in order to document the general distribution of archaeological material in the area. Most investigations have provided valuable stratigraphic information, and led to the discovery of substantial numbers of artefacts of importance for the interpretation of the rock art and its context.

Test excavations have been undertaken in the immediate vicinity of some of the rock art panels, i.e. immediately below or adjacent to the carvings. These have not resulted in any clear pattern of a regular deposition of archaeological material linked to the different rock art localities, since some investigations led to the discovery of stone artefacts or cultural layers and some did not. But of course, this does not rule out the possibility of deposition of perishable artefacts of wood or bone, etc. The striking result from these investigations is that all the rediscovered archaeological material, including radiocarbon dates of charcoal from cultural layers, dates to the Late Mesolithic.

Specific for the area, apart from the rock art, is the presence of highly visible, circular depressions, interpreted as houses or dwelling features. A total number of nine certain dwelling structures have been documented so far. These have a diameter of less than 5 meters, and are constructed of surrounding stone and gravel walls. They are located between boulders and rock art panels, some of which are in clusters, while others are more isolated. None of these have yet been completely excavated, but test excavations have revealed the presence of cultural layers and provided highly homogenous archaeological material, clearly indicating a Late Mesolithic origin. In addition to the presence of waste flakes, blades, and conical cores, microblades struck from conical cores are common, which is in accordance with material documented elsewhere in Vingen. The dating is further substantiated by the dominance of characteristic Late Mesolithic raw material categories such as quartz, quartzite, rock crystal, mylonite, and flint

Excavations in the vicinity of some of the dwelling structures have revealed the presence of middens containing concentrations of archaeological material, and high amounts of fire-cracked rocks. The artefacts from the middens are similar to those of the dwelling structures and there is reason to believe that the midden deposits are related to the structures. Further analyses of the midden material and some of the dwelling features indicate patterns of temporal occupation, indicating that the dwelling features were emptied or cleared from time to time. The contents present in the different dwelling features today must therefore be seen as remains from the final occupation phase.

Altogether, this work has led to a more updated picture of the archaeological remains in Vingen, apart from images in solid rock. An overwhelming amount of archaeological material typical for the Late Mesolithic (6500–4000 BC) has been documented, with a dominance of waste flakes, blades and conical cores, together with microblades struck from conical cores, and the characteristic raw material categories such as quartz, quartzite, rock crystal, mylonite and flint (Lødøen 2001; Lødøen 2003). In addition, tools for the production of rock art have been documented in the proximity of the carvings (Lødøen 2003). The dating to this period is further supported by results from radiocarbon dating, and a cluster of results towards the end of this period (5000–4200 BC).

Many structures complementing the picture have also been documented, from smaller fireplaces and smaller stone structures, to larger dwelling features. The latter type has only been subject to modest investigations; however, their permanent character, with the presence of rock art on their surrounding stones and their content of typical Late Mesolithic artefacts seems to indicate that most archaeological remains in Vingen are contemporary. Middens associated with some of the dwelling features, containing fat cultural layers and fire-cracked rocks have also been documented. In addition, cultural layers have been found in the vicinity of many panels.

Material from both earlier and later periods is strikingly absent, and the absence is supported by radiocarbon dating. It is therefore likely that both archaeological artefacts and images have been part of the same process and should be dated to the Late Mesolithic, and probably to the latter half of the Late Mesolithic as indicated by the radiocarbon results. The archaeological investigations have gained the necessary support from several scientific disciplines and palynological, pedological and geological analyses are still being carried out in order to explore less visible relations between the images and the archaeological material underneath the turf and in the rock art environment. Archaeological analyses and correlation work are still being carried out in Vingen, and a synthesis of all excavated material and its relation to the images is under preparation.

7.2 Pollen analytical investigations

The people, who lived in Vingen and utilized the area in connection with the rock art and ceremonies related to them, may also have influenced on the vegetation of the area. Today, Vingen is an open landscape with grasses, herbs and dwarf shrubs resulting in a clear visibility of the bedrock and the areas of rock art. The farming activity that took place in the 19th and 20th centuries has been important in the formation of the vegetation in the area today. For how long has this open landscape been the case in Vingen, and what was the situation before the treeless landscape of today? These questions are important in order to be able to understand people's perception of Vingen and their view of the landscape.

The activity in Vingen hopefully left traces on the vegetation that are visible in a pollen diagram, which in the next step may be used to date periods of human activity in the area. Furthermore, knowledge of the vegetation may give indications of whether the area was utilized by hunters/gatherers or whether also some farming activity already took place in the area in the Neolithic. Agriculture – including the cultivation of cereals and grazing of domesticated animals – is easily recognized in pollen diagrams, both through the cultivated species themselves, and through herbs growing in cultivated fields and pastures. To trace the impact on the vegetation after people making rock carvings in the Mesolithic is more difficult, although high activity resulting in trampling and need for open space as well as wood for fire, would probably result in changes in vegetation composition and structure which hopefully can also be reflected in a pollen diagram. Fireplaces produce microscopic charcoal particles which are found in pollen samples and the presence of several people when the rock art were produced may have resulted in destruction of the vegetation cover and erosion. This may have resulted in an increased input of minerogenic particles – silt and sand – into the bog, which again may be traced through the measure of loss-on-ignition in the peat. Through the combined analysis of pollen and loss-on-ignition we aim to identify periods of human activity at Vingeneset.

In relation to the preservation of rock art and how the soil affects weathering of the rock, knowledge on past vegetation may add information to nutritional status of the soil in different time periods. Plants have different requirements in terms of environmental factors such as temperature, acidity and humidity, and different vegetation communities result in different soil types. One aim of the pollen analytical investigation has therefore been to identify changes in vegetation through time that would result in changes in soil acidity.

Pollen analytical investigations have been carried out at Vingeneset and at Teigen (Fig. 7.2-1), with the aim to obtain information on the vegetation during the period when the rock carvings were made, to identify and date periods of human activity in the area, and to get information on changes in vegetation that would result in acidification of the soil in Vingen. This last topic is discussed in chapter 5.5.

7.2.1 Vingeneset

7.2.1.1 Investigated sites and methods

The only bog in Vingen is found at Vingeneset. Here, a survey along transects was carried out to identify the deepest part of the bog (Fig. 7.2.1.1-1 and 7.2.1.1-2). The stratigraphy was investigated and described with the aim to identify charcoal and thereby traces of human activity. A core covering the depth of 0–130 cm was sampled from the bog, using a PVC tube with a diameter of 110 mm (core I). Due to a hiatus 18 cm below the surface in this core, probably reflecting peat cutting, a new core covering the upper 34 cm was sampled at the edge of the bog, using a PVC tube with a diameter of 160 mm (core II). Both tubes were pressed into the bog and then dug up.

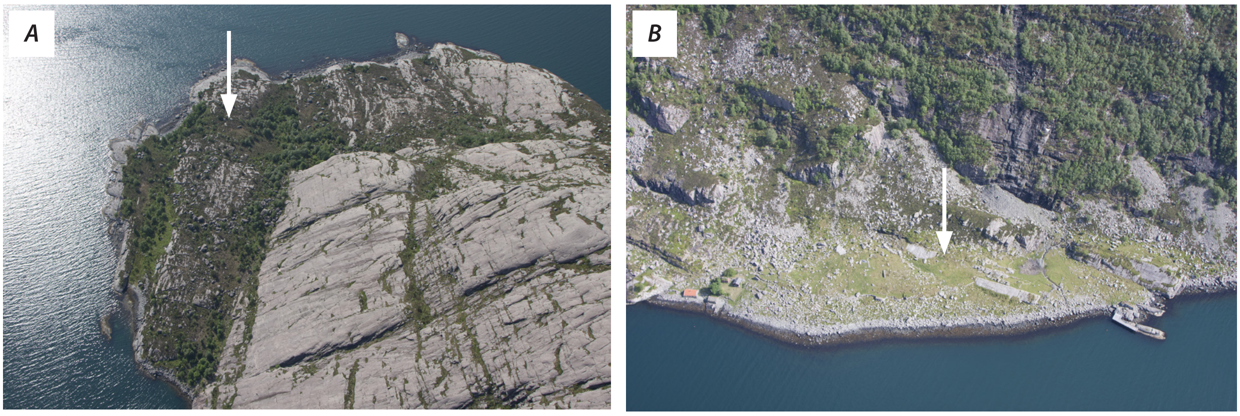


***Fig. 7.2-1.** Pictures showing the investigated sites at a) Vingeneset and b) Teigen in Vingen. Photo: Trond Lødøen*

In the laboratory, pollen samples of 1 cm^3 were taken from the different tubes. The samples were processed using standard procedures with acetolysis and HF-treatment (Fægri and Iversen 1989). Identification of pollen is based on the key in Fægri and Iversen (1989) and the reference collection of modern pollen at the University of Bergen. Nomenclature follows Lid and Lid (1994). At Vingeneset, loss on ignition was measured. The samples were dried at 110º C for eight hours and thereafter ignited at 550º C for five hours. The results are given as % of dried weight.

The results are presented in pollen diagrams (Fig. 7.2.1.2-2, 7.2.1.2-3 and 7.2.2.2-1). To the left is a depth column. This is followed by loss on ignition (percentage of organic material); radiocarbon dates; layers; local pollen zones which indicates the main step in the development of the vegetation at the site; a total diagram showing the relationship between unidentified pollen, trees, shrubs, dwarf-shrubs and herbs; and the different pollen types present in percentage of sum pollen (the number of terrestric pollen counted in each sample). Thereafter follow the curves for spores (ferns and mosses), water plants (aquatic pollen), non-pollen palynomorphs and microscopic charcoal. These are calculated in percentage of sum pollen + the microfossil in question.

7.2.1.2 Vegetation development at Vingeneset

Chronology

Eleven radiocarbon dates from Vingeneset were obtained from peat and two dates from plant macro remains (twigs) (Table 7.2.1.2-1). The age-depth relationship (Fig. 7.2.1.2-1) indicates that the two dates based on plant macro remains differ from the dates based on peat. The macro remains dated in the 117–118 cm level turned out to be older than the peat dated at 120.5–121.5 cm, whereas the plant macro remains in the 104.5–105.5 cm level gave younger dates than two peat datings from higher levels. Some old macro remains may have

Fig. 7.2.1.1-1. Field work at Vingeneset in 1999.

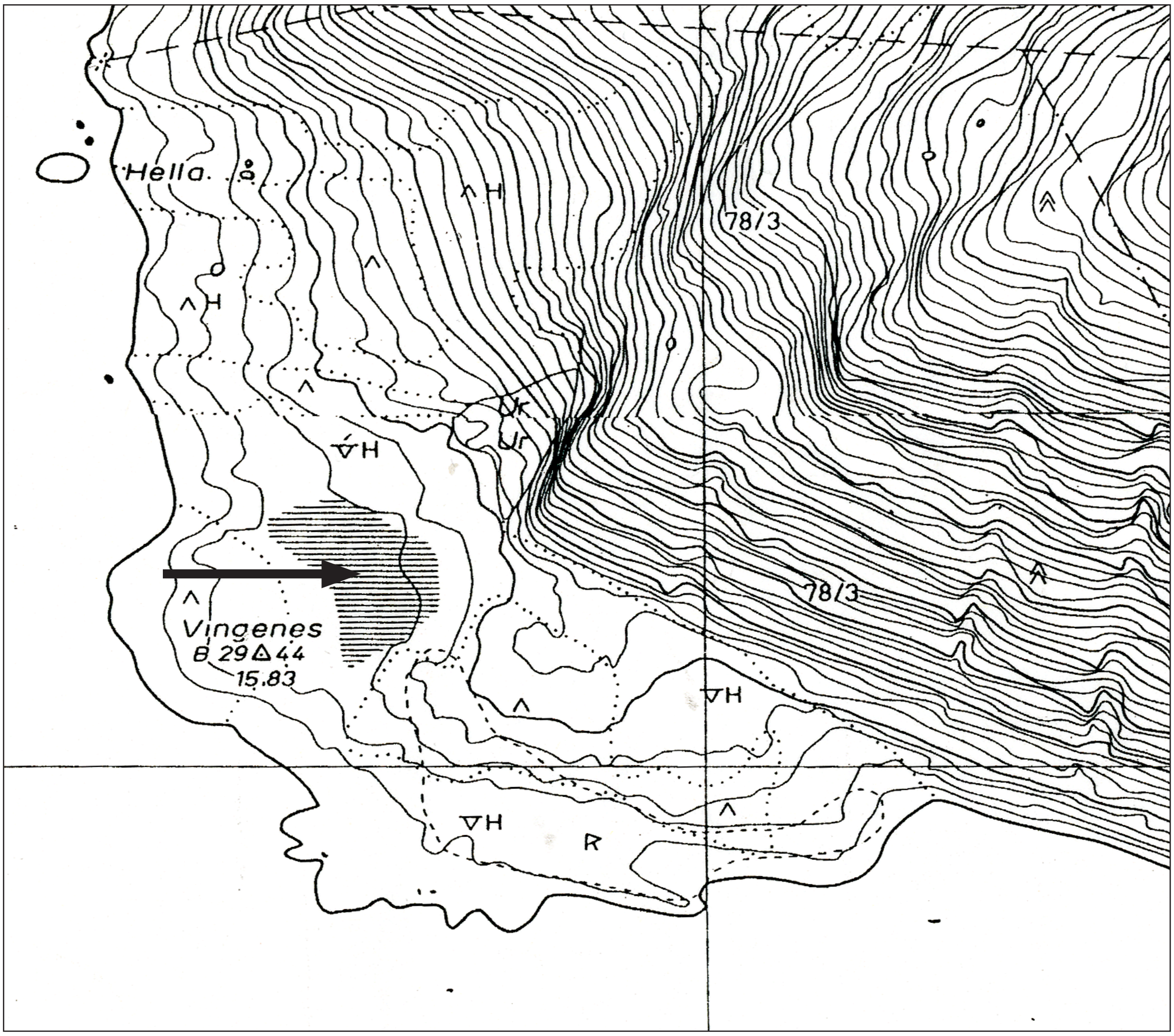


Fig. 7.2.1.1-2 Map showing the topography at Vingeneset and the position of the investigated bog.

Table 7.2.1.2-1. Radiocarbon dates taken in relation to pollen analytical investigations at Vingeneset and Teigen. All samples are taken from the collected tube in the laboratory, except the two dates from cultural deposits at Teigen, collected from the profile wall in the excavated trench. The dates and calibrations have been carried out at the National Radiological Dating Laboratory at NTNU in Trondheim.

Site	Lab. Ref.	Dybde (cm)	Dated material	14C age BP	Calibrated age, one sigma
Vingeneset Core I	T-16381	29.5–30.5	Peat	2420 ± 45	535–410 BC
	T-16382	49.5–50.5	Peat	2870 ± 80	1150–925 BC
	T-16383	59.5–60.5	Peat	3120 ± 85	1455–1285 BC
	T-15159	94.5–95.5	Peat	4710 ± 90	3630–3370 BC
	T-15158	99.5–100.5	Peat	5295 ± 80	4245–4000 BC
	TUa-4081	104.5–105.5	Macro remains	4410 ± 40	3075–2940 BC
	T-15157	109.5–110.5	Peat	5840 ± 65	4790–4625 BC
	TUa-4082	117–118	Macro remains	7730 ± 50	6565–6465 BC
	T-15156	120.5–121.5	Peat	7365 ± 60	6220–6135 BC
	T-14859	131–132	Peat	7930 ± 95	7010–6600 BC
Vingeneset Core II	T-19052	17.5–18.5	Peat	425 ± 70	AD 1425–1515
	T-19330A	18.5–19.5	Peat	660 ± 80	AD 1275–1390
	T-19053	31.5–32.5	Peat	2280 ± 75	405–215 BC
Teigen, Vingen	T-16811	74–75	Peat	4665 ± 85	3540–3345 BC
	TUa-5158	Top cultural deposit	Charcoal	5960 ± 50	4910–4785 BC
	TUa-5159	Bottom cultural deposit	Charcoal	5980 ± 45	4930–4800 BC
	T-16812	89–90	Peat	6255 ± 80	5275–5085 BC
	T-16813	108–109	Peat	6815 ± 120	5750–5590 BC

been redeposited in the first case, whereas younger roots or macro remains trampled down into the peat may have influenced the upper date. Following this, the chronology of the site is based on the radiocarbon dates of peat. For the youngest part of the peat the chronology is based on core II.

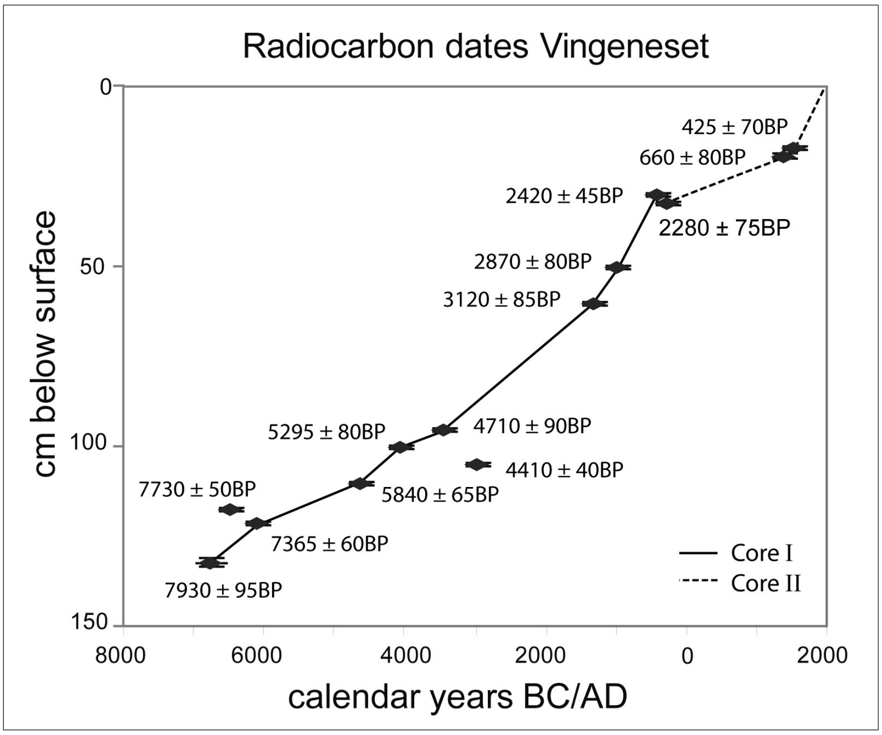


Fig. 7.2.1.2-1. Age-depth relationship at Vingeneset based on calibrated BC/AD years and one sigma range. More information on the dates is given in Table 7.2.1.2-1.

Pollen diagrams

The vegetation development covered by the two pollen diagrams from Vingeneset (Fig. 7.2.1.2-2 and 7.2.1.2-3) have been divided into seven pollen assemblage zones; V1-V7.

Pollen zone V1 (Open birch forest with hazel; Middle and Late Mesolithic, ca. 7000 – ca. 5800 BC): Pollen zone V1 represents the first period of peat accumulation in the bog. The zone is dominated by birch (*Betula*), some hazel (*Corylus avellana*), willow (*Salix*) and dwarf shrubs such as bilberry (*Vaccinium*) and some crowberry (*Empetrum*) and heather (*Calluna vulgaris*). Grasses (Poaceae) and several herbs are present, indicating an open forest at the site. Cow-wheat (*Melampyrum*) is the dominating herb species, growing in the forest bottom together with dwarf-shrubs. The relatively high values of *Corylus* indicate that hazel was growing at Vingeneset. The lowermost sample analysed has high values of microscopic charcoal, which may indicate the presence of people in the area around 7000 cal BC.

Pollen zone V2 (Open birch-alder-hazel forest; Late Mesolithic–Early Neolithic, ca. 5800 – ca. 3700 BC): Birch (*Betula*) continues to dominate the pollen composition in the first part of pollen zone V2, followed by high values of alder (*Alnus*). Hazel (*Corylus avellana*), rowan (*Sorbus*), aspen (*Populus*) and guilder-rose (*Viburnum*) were all growing in the area; values below 10% for pine (*Pinus sylvestris*) probably reflect long distance transport. Dwarf-shrubs; bilberry (*Vaccinium*), crowberry (*Empetrum*) and heather (*Calluna*), are present together with herbs like cow-wheat (*Melampyrum*), which has high values in the first part of the pollen zone, meadowsweet (*Filipendula*), common sorrel (*Rumex* sect. *acetosa*), tormentil (*Potentilla*) type, sedges (Cyperaceae) and grasses (Poaceae). There are fluctuations in the loss-on-ignition during zone V2, indicating disturbances in the vicinity. A small decrease in organic material takes place in the beginning of the zone, followed by an increase before a new, and larger, decrease takes place in the upper part of the zone. This reflects deposition of minerogenic material in the peat, probably as a result of disturbances and erosion in the surroundings of the bog. Marked decreases in *Alnus* and *Sorbus* and increase in *Vaccinium*, *Calluna vulgaris* and Cyperaceae, may be vegetation responses to this disturbance. The increase in dwarf shrubs is followed by an increase in *Betula* before *Alnus* again gets the highest pollen percentages. Microscopic charcoal has values around 20% throughout the pollen zone, with highest values in the lower and upper parts of the zone. In layer 5 also macroscopic charcoal is observed. Archaeological remains dated to the Late Mesolithic as well as a concentration of radiocarbon dates from archaeological contexts within the time period 5000–4200 BC (ch. 2 and ch. 7.1), coincides with the period of highest minerogenic input into the bog. However, based on the relatively high values of herbs and dwarf shrubs together with high values of charcoal and minerogenic material indicating erosion, human activity seems to have taken place in the area also at the end of the Mesolithic/ transition to the Early Neolithic time period.

Pollen zone V3 (Birch-alder forest; Early Neolithic – Bronze Age, ca. 3700 – ca. 1500 BC): In this zone, deciduous forest dominates the vegetation also on the bog, and the forest may have been denser than in the previous zones. Birch (*Betula*) continues to be the most important tree species, but also alder (*Alnus*) and rowan (*Sorbus*) were growing on the bog or in the immediate surroundings. Hazel (*Corylus*) has a marked increase in the transition to zone V3, followed by decreasing percentages throughout the zone. Hazel was still growing in the area, but became less important close to the site during this time period. Aspen (*Populus*) and guilder-rose (*Viburnum*) were present, together with heather (*Calluna vulgaris*), cow-wheat (*Melampyrum*), meadow-sweet (*Filipendula*) and grasses (Poaceae). Continuous and relatively high values of microscopic charcoal indicate presence of people in the area.

Pollen zone V4 (Open birch-pine forest; Bronze Age, ca. 1500 – ca. 500 BC): An opening up of the vegetation and change from birch (*Betula*) dominated forest to dominance of pine (*Pinus*) is taking place in the first part of zone V4. Alder (*Alnus*) gets higher values in the start of the zone, followed by lower percentages. Increased percentages of juniper (*Juniperus*), heather (*Calluna*), cow-wheat (*Melampyrum*), grasses (Poaceae), goldenrod (*Solidago*) type and nettle (*Urtica*), and presence of ribwort plantain (*Plantago lanceolata*), are all indicators of opening-up of the vegetation. Probably also some grazing took place. Charcoal has lower values than before, and no clear charcoal layer was identified in the bog. This may be an indication that clearance by burning did not take place, or that the bog itself was not cleared.

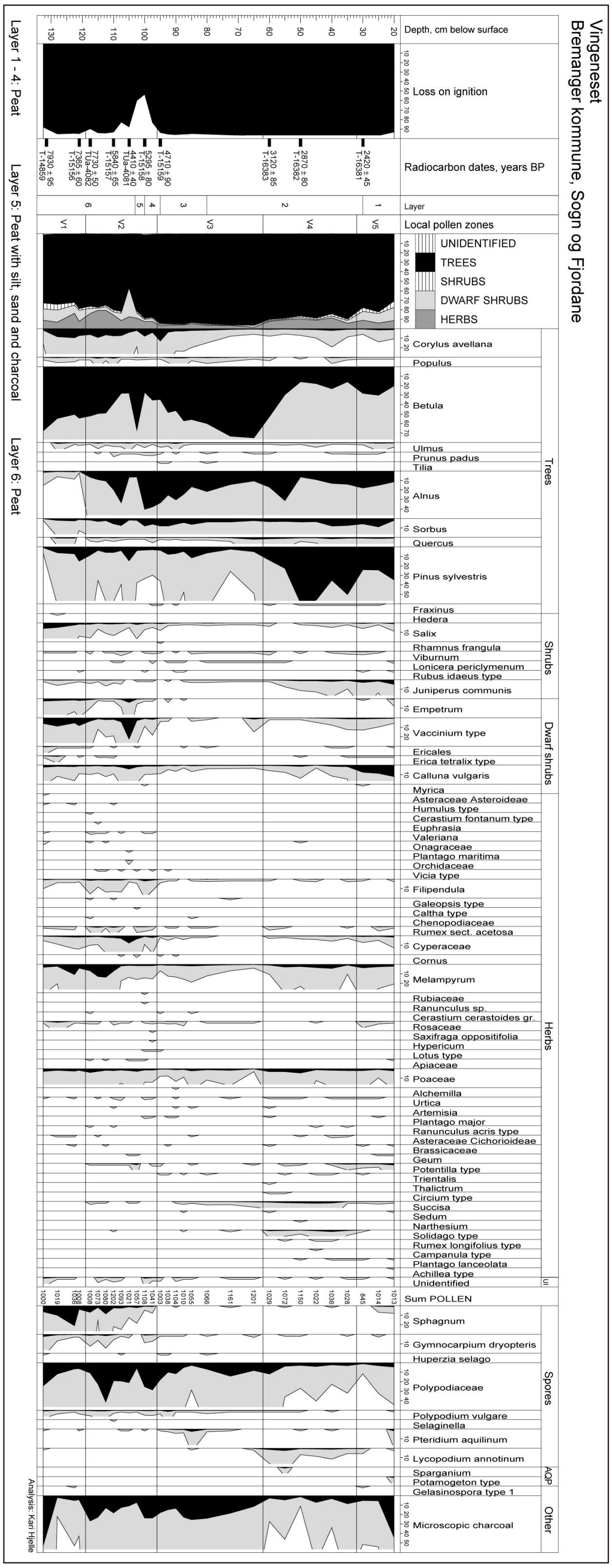


Fig. 7.2.1.2-2. Pollen diagram from Vingeneset, Core I. Black column shows the pollen percentages, grey the percentages × 10.

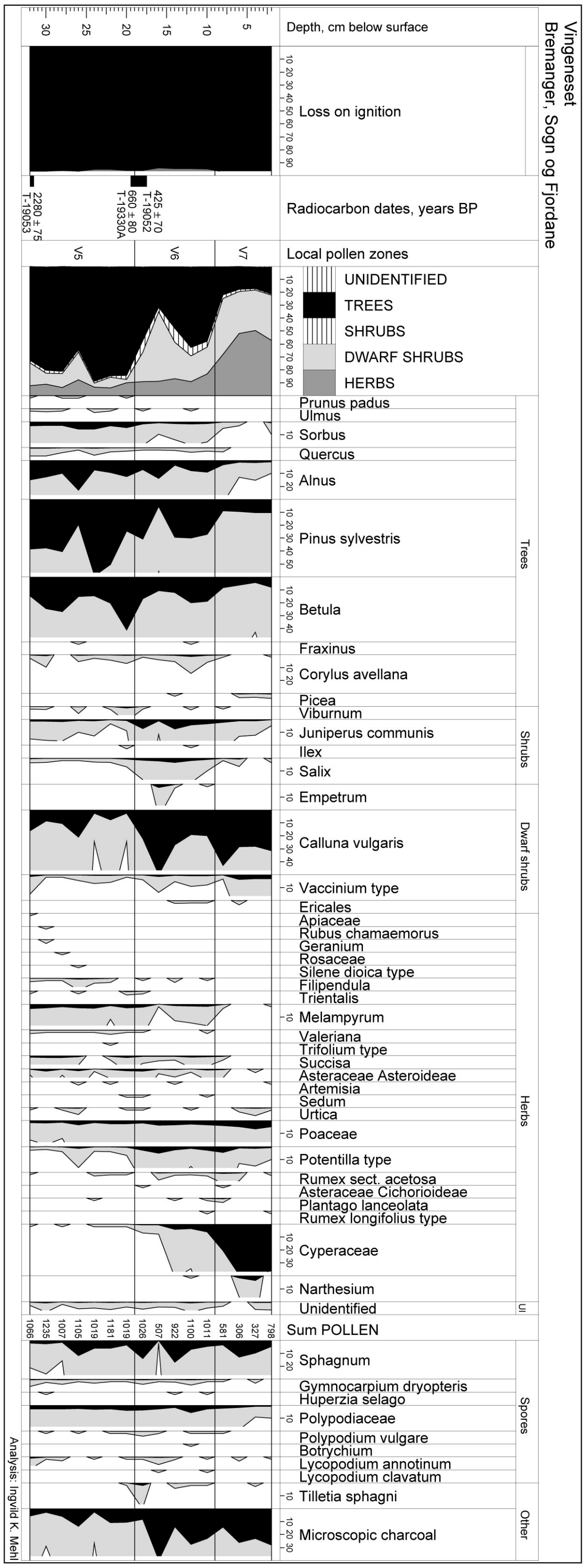


Fig. 7.2.1.2-3. Pollen diagram from Vingeneset, Core II. Black column shows the pollen percentages, grey the percentages × 10.

Pollen zone V5 (Heathlands with birch and pine; Iron Age and Medieval time, ca. 500 BC – ca. AD 1400): A decrease in pine (*Pinus*) and increase in heather (*Calluna*) and juniper (*Juniperus*) is taking place at the transition between zone V4 and V5. Although *Calluna* has been continuously present from zone V1 and therefore also has been growing at Vingeneset from the Mesolithic, zone V5 probably reflects the start of heathland development at Vingeneset. Relatively low amounts of charcoal do not indicate local burning in relation to this development, but burning may have taken place in the surrounding vegetation on drier ground.

Pollen zone V6 (Open heathlands; Medieval and Post-Medieval time; ca. AD 1400 – ca. 1800): A further decrease in tree pollen and increase in juniper (*Juniperus*), heather (*Calluna*), tormentil (*Potentilla*) and microscopic charcoal is taking place in zone V6. This shows the expansion of heathland vegetation and maintenance through burning and grazing.

Pollen zone V7 (Heathland and bog; ca. AD 1800–2000): A decrease in all tree species and increase in sedges (Cyperaceae) and bog (*Narthecium*) reflect the local development at the bog. Open heathland vegetation dominated the vegetation at Vingeneset, although some trees of birch (*Betula*), alder (*Alnus*), pine (*Pinus*) and rowan (*Sorbus*) were present. The pollen zone probably reflects the open vegetation at Vingeneset documented in photos from the early 20th century and dominating until today (Fig. 7.2-1).

7.2.2 Teigen

7.2.2.1 Investigated site and methods

At Teigen, a trench of 0.5 × 1 m was excavated (Fig. 7.2.2.1-1). The stratigraphy in the resulting profile wall reveals a development from peat to deposition of cultural layers, followed by a new period of peat accumulation. In the middle of the youngest peat, a thin layer of charcoal is visible. In the upper ca. 30 cm the peat is mixed, reflecting cultivation activity. A PVC tube was pressed into the peat by the profile wall and pollen samples from the sequence indicated on Fig. 7.2.2.1-1 have been analysed. From the profile wall, charcoal for radiocarbon dates were sampled directly from the top and bottom of the cultural deposit. Pollen samples were taken from the PVC tube in the laboratory, following the methods described in chapter 7.2.1.1.

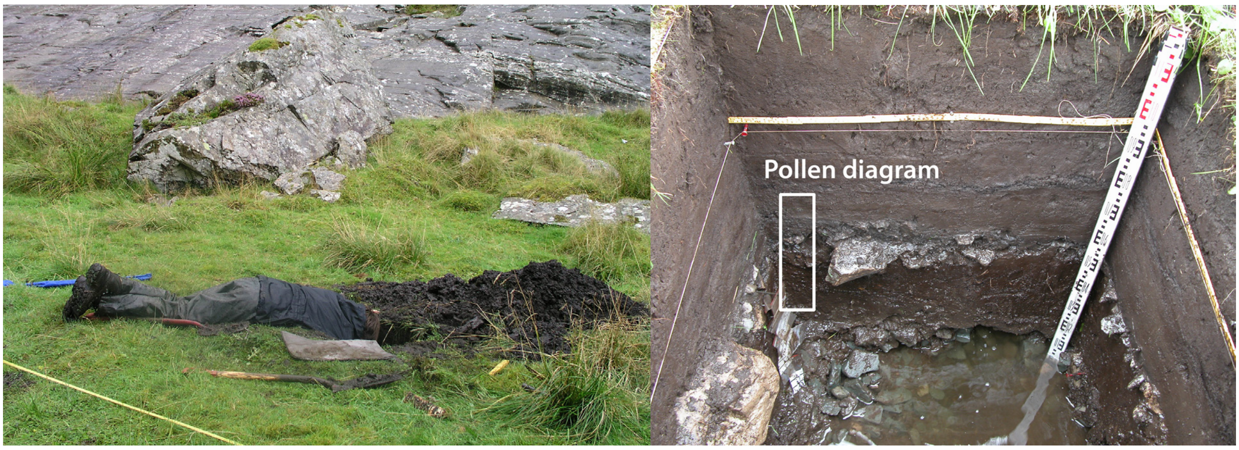


Fig. 7.2.2.1-1. *Field work and stratigraphy at the investigated site at Teigen in Vingen.*

7.2.2.2 Vegetation development at Teigen

Chronology

Five levels have been dated in connection with the pollen diagram from Teigen (Table 7.2.1.2-1). These show peat accumulation in the Late Mesolithic, until ca. 5000 BC, followed by deposition of cultural layers. According to the radiocarbon dates of charcoal from the bottom and top of these deposits, the activity took place during a short time period around 4900–4800 BC. The cultural deposits are overlain by peat which reflects abandonment of the activity at the site. The bottom cm of the peat is dated to ca. 3500 BC, which indicates a hiatus or period of low accumulation after the local activity had ceased.

Pollen diagram

The pollen diagram from Teigen has been divided into five pollen assemblage zones; T1–T5 (Fig. 7.2.2.2-1).

Pollen zone T1 (Open birch-hazel forest; Late Mesolithic; ca. 5700 – ca. 5300 BC): Open deciduous forest dominated by birch (*Betula*) and hazel (*Corylus*), with some rowan (*Sorbus*), European bird cherry (*Prunus padus*), willow (*Salix*) and guilder-rose (*Viburnum*) was growing in Vingen. Several hazel nuts found in the peat further support the local existence of *Corylus*. Low percentages of oak (*Quercus*) and elm (*Ulmus*) probably reflect trees growing in some distance to the site. Meadowsweet (*Filipendula*) is the dominating herb species, showing the humid conditions by the sampling site. Relatively high values of nettle (*Urtica*) give an indication of nitrophilous conditions and the possibility of people being present. Grasses (Poaceae), cow-wheat (*Melampyrum*), daisy family (Asteraceae Cichorioideae) and tormentil (*Potentilla*) type, all indicate the presence of open vegetation where also juniper (*Juniperus*) may have been growing. Presence of people is further indicated in the relatively high values of microscopic charcoal in all samples as well as in the presence of greater plantain (*Plantago major*), an indicator of trampling, in the upper part of the zone.

Pollen zone T2 (Birch dominated vegetation; Late Mesolithic; ca. 5300 – ca. 5200 BC): High values of birch (*Betula*) characterises pollen zone T2, whereas the percentages of hazel (*Corylus*), willow (*Salix*) and guilder-rose (*Viburnum*) decrease. This may reflect forest clearance followed by local birch expansion.

Pollen zone T3 (Late Mesolithic; ca. 5200 – ca. 4900 BC): The zone represents the upper part of peat below the cultural deposits. Birch (*Betula*) continues to be the dominant tree species throughout the zone, but also hazel (*Corylus*) and rowan (*Sorbus*) have been growing close to the site. Meadowsweet (*Filipendula*) reaches its highest values in this zone. Together with grasses (Poaceae), and herbs like common valerian (*Valeriana*), cow-wheat (*Melampyrum*), nettle (*Urtica*), tormentil (*Potentilla*) type, northern dock (*Rumex longifolius*) type, common sorrel (*Rumex* sect. *acetosa*) and daisy family (Asteraceae Cichorioideae), meadowsweet (*Filipendula*) shows the presence of open herb communities. Fern spores, both Polypodiaceae and polypody (*Polypodium vulgare*), have higher values in zone T3 than in the previous zones. Microscopic charcoal is increasing in the upper part of the zone, indicating human activity in the vicinity.

Pollen zone T4 (Birch-hazel-pine; Late Mesolithic; ca. 4900 – ca. 4800 BC): According to the two radiocarbon dates from the bottom and top of the cultural deposits (Table 7.2.1.2-1, Fig. 7.2.2.2-1), the zone represents accumulation within a relatively short time period around 4900 – ca. 4800 BC. The two pollen samples from this zone indicate a change in the nearby vegetation in relation to the previous zone. Increases in European bird cherry (*Prunus padus*), hazel (*Corylus*), guilder-rose (*Viburnum*) and pine (*Pinus*) occur, whereas the percentages of birch (*Betula*) decrease. Also, there are lower values for grasses (Poaceae) and nettle (*Urtica*) in zone T4 than in T3, which may indicate that hazel was favoured by people and expanded at this time, that clearance of birch resulted in increased pollen deposition from surrounding trees, or that plant remains in refuse from the human activity influence the pollen assemblages. The high amount of both macroscopic and microscopic charcoal reflects the human impact taking place during this zone.

Pollen zone T5 (Mixed deciduous forest with pine; Early and Middle Neolithic; ca. 3600 – ca. 3200 BC): Pollen zone T5 represents peat accumulation after the utilization of the investigated site ceased. The date of the bottom part of the peat to 3540–3345 BC (Table 7.2.1.2-1) indicates either a hiatus at the end of/after the activity reflected in zone T4, or it reflects slow accumulation after the abandonment. Birch (*Betula*) seems to have been the first species to expand into the abandoned areas, followed by hazel (*Corylus*). An increase in elm (*Ulmus*) and alder (*Alnus*) and more than 20% of pine (*Pinus*) may indicate that all these species were growing in Vingen in the time period. The presence of both hazel and elm shows that areas of rich soil still existed in Vingen in the beginning of the Neolithic. Ribwort plantain (*Plantago lanceolata*), together with grasses (Poaceae) and herbs like the daisy family (Asteraceae Cichorioideae and Asteraceae Aster), common sorrel (*Rumex* sect. *acetosa*), tormentil (*Potentilla*) type and nettle (*Urtica*), may indicate that the area was used for grazing of domesticated animals in the Neolithic. On the other hand, the herb composition is quite similar to the pollen assemblages from the Mesolithic and the evidence for an economic change is weak. The local area seems to have been dominated by shrubs and trees, indicated both in the dominance of tree species and in the low values of grasses. Relatively high values of microscopic charcoal throughout the zone indicate that people continued to utilize the area, although their activity at the investigated site had ceased. In the upper part of the pollen diagram a further increase in *Alnus* indicates the presence of alder thickets close to the site.

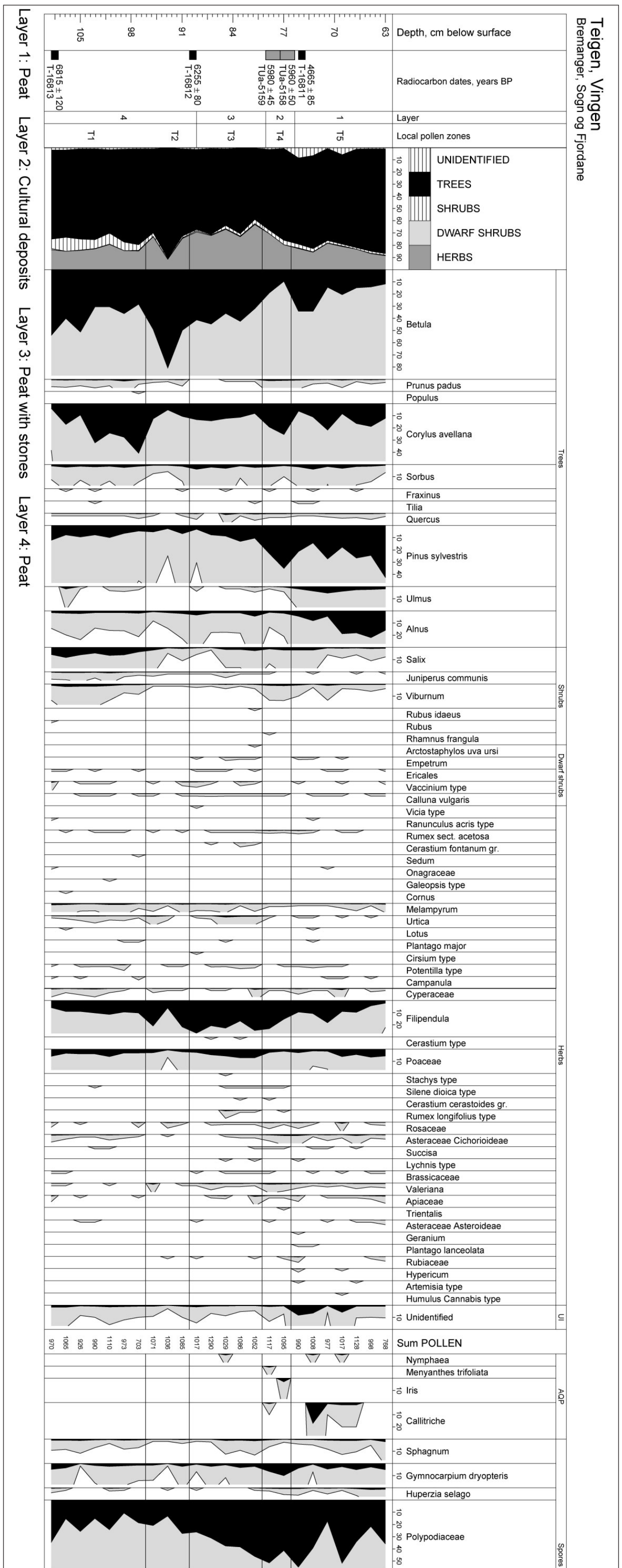


Fig. 7.2.2.2-1. *Pollen diagram from Teigen. Black column shows the pollen percentages, grey the percentages × 10. Charcoal for the two radiocarbon dates from layer 2 are taken from the same stratigraphical layer in the profile wall.*

7.3 Human activity in Vingen based on the palaeobotanical data – a summary

The pollen diagrams from Vingeneset reveal the vegetation development from ca. 7000 BC to the present day, whereas the time period from ca. 5700 BC to ca. 3200 BC is presented in the diagram art Teigen in Vingen. This means that the pollen diagrams from both areas cover the period when the rock carvings are supposed to have been produced; the Late Mesolithic and especially the time between 5000 and 4200 BC. Cultural deposits accumulated at the investigated site in Teigen and erosion into the bog at Vingeneset support high activity in the area within that time period. However, the amount of microscopic charcoal in the diagrams from Vingeneset and Teigen indicate the presence of people in the area throughout the Mesolithic.

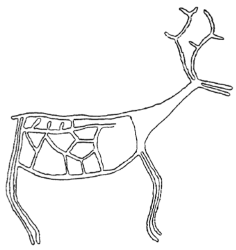
A forested landscape of different deciduous trees, quite different from the open landscape we see today, greeted the people who arrived in Vingen in the Late Mesolithic. Our fascination of the grey bedrock may however have also been the same for people living at that time. Depressions were probably covered by soil and vegetation, whereas the bedrock used for carvings was uncovered, making great contrasts in the green forest during summer time. Berries such as blueberry (*Vaccinium myrtillus*) and raspberry (*Rubus idaeus*) were growing in the area in the Mesolithic, and together with hazel nuts (*Corylus avellana*), the berries were probably collected by people living in or visiting Vingen and Vingeneset during the summer.

At both sites, forest expansion is indicated in the pollen assemblages from the Early and Middle Neolithic and peat accumulated both at Vingeneset and at Teigen. Human impact is, however, indicated through the continued presence of microscopic charcoal, grasses and some herbs. Archaelogical excavations by the nearby Skatestraumen show settlement in the region from the Mesolithic into the Early and Middle Neolithic time periods (Bergsvik 2002). This means that people were present in the area although the main activity in Vingen seems to have come to an end. The next period of local activity in Vingen is dated to the Bronze Age, with forest clearance and grazing, followed by heathland development in different steps during the Iron Age and Medieval time (see also Hjelle *et al.* 2010). This shows the presence of people in Vingen in a time period not recorded in the archaeological data.

7.4 Future investigations

The two investigated sites indicate that Vingen was quite forested at the time the rock art were created. At Teigen we have the possibility to analyse samples higher up in the core and thereby get information on the further development through the Neolithic as well as dating of what may be forest clearance at the site either in the Late Neolithic or in a later period. In a forested landscape, the pollen source area of an investigated site is quite limited, ca. 20–50 m from the site. This means that we should look for new sites for further pollen analytical investigations. Having several local pollen diagrams, we will have the possibility to make landscape reconstructions from Vingen for selected time periods. These reconstructions may make the basis for hypothese testing; how large were the areas covered by woodland in the Mesolithic and later periods? In which periods did forest clearance take place and for what purpose? The large number of photos from the early 20th century provides a great possibility to test landscape reconstructions based on pollen data, and thereby verify reconstructions for earlier time periods. A further discussion of the vegetation development in Vingen will be published elsewhere (Hjelle and Lødøen, in prep.).

From Djupedalen (Fig. 7.4-1), in the vally behind Vingelven, sediments and peat from an overgrown basin have been collected, loss-on-ignition measured, and five levels radiocarbon dated. Pollen analyses from these sediments will provide data for a wider region surrounding Vingen, and contribute towards a better understanding of the environment, vegetation development, and causes of the changes that have taken place in the area in different time periods.



CHAPTER 8

Trond Klungseth Lødøen and Gro Mandt

FUTURE ADMINISTRATIONS AND MANAGEMENT OF THE AREA

8.1 Ethical recommendations – Premises for Preservation

The Norwegian Cultural Heritage Act of 1978 establishes the task of preserving and managing cultural monuments and cultural environments both as a source of knowledge about the past and as a source for people's experience and enjoyment now and in the future. The law defines the actions that are illegal and unacceptable in terms of the conservation of the automatically protected cultural monuments. Cultural Heritage Management, with the Directorate for Cultural Heritage as the spearhead, has the formal responsibility for administering laws and regulations, adopting resolutions and seeing to it that the latter are implemented. Cultural Heritage Management, however, entails much more than merely administering the Cultural Heritage Act.

The task of managers is to ensure that cultural monuments are protected and conserved for the edification and enjoyment of people today as well as for future generations. But this also involves an aspect of "consumption". Cultural monuments are not the property of researchers, no more so than they are the property of the local population or the nation. They are a common cultural heritage for all of humanity. Individual countries, however, through their statutes, have designated themselves to "manage" on behalf of humanity the cultural monuments that are located within the given country's borders. Knowledge about cultural monuments that is produced by researchers must be disseminated to the public that is outside of the halls of academia. And cultural monuments must – to the extent that is in harmony with preservation – be made accessible to the public.

Making cultural monuments in the field accessible to the public is a relatively recent phenomenon in Norway, one which gained ground concurrently with radicalizing and democratizing tendencies in the 1960s and 1970s (Hygen 1999:26). Ever since the 1980s, measures aimed at enlightening the public and providing public access have been defined as important tasks for archaeological professionals, and in the 1990s, the relationship between and consequences of custodial care, conservation, maintenance and accessibility were continually discussed items on the agenda for cultural heritage management. (*ibid*.29)

In her doctoral dissertation "*Fornminneforvaltning i praksis [Cultural Heritage Management in Practice]*" Anne-Sophie Hygen (1999:15-33) defines the terms "conservation" "preservation" and "use" of cultural monuments. She regards the three terms as mutually integrated aspects of the same concept, namely: how conservators of cultural heritage are to relate to relics of the past, and which ideological and practical consequences are entailed by including and using these terms in cultural heritage management (*ibid*.:15). She submits that the approach adopted for management will inform and govern the decisions that are taken, as well as the practical measures that will result from these decisions:

> *"If the initial approach entails, for example, long-lasting conservation, it will have different consequences than if the initial approach were accessibility and use, even though conservation can include use, and use can include conservation, etc. In the handling of each individual cultural remnant, it is necessary to clearly define the approach that one is taking, and then to analyze, assess and select, in a conscious and determined manner, the suitable, correct and ethically acceptable consequences of the choices made" (Hygen 1999:33).*

One issue that arises is the manner in which *conservation* of cultural monuments will – or can – direct the *management* that entails *use* – i.e. making accessible to the public. How can managing authorities ensure that access will not lead to *abuse* or *consumption* of the non-renewable resource that the cultural monument represents?

If one proceeds under the premise that management must be guided by the goal to preserve, then conservation will *always* have first priority at the expense of all other concerns. One initial requisite for conservation is that it has a *long-term objective* – namely that cultural monuments are to be conserved not only for those living today, but also for future generations. Therefore, a requirement for long-term conservation is that public use of the monuments – in the sense of public access and dissemination of information – should not be based on *short-term commercial interests* – i.e., that they are *items for consumption* rather than for active experience.

The *limits of endurance* of cultural monuments and the surrounding cultural landscape should be the primary managerial criteria for decisions regarding how they should be administered. Concern for the materials' limits of endurance applies not only to making them accessible, but also in terms of documentation, preservation and research. This may entail, for example, that cultural monuments are isolated and taken "out of circulation" for periods of time, meaning that monuments may need to be closed to the public, rock art panels may need to be concealed under protective coverings, etc. Another requirement for responsible conservation of cultural monuments is that preservation is done in an ethically justifiable manner – denoted by Hygen as *integrity* (1999:17)*:*

> *"In an ethical sense, one can say that any encroachment on cultural monuments represents at the same time an encroachment on the inviolability of people of the ancient past, that is to say, on our fellow human beings from antiquity. This applies to all of us, whether we are researchers, stewards or otherwise. In our strivings, even with the best managerial intentions, we can very easily succumb to the temptation to assume an authoritarian and imperialistic role.*

Integrity, then, is involved in the type of *encroachment* that is carried out, and the manner in which it is carried out, as well as the type of *measures* implemented around the cultural monument to protect it or to make it accessible.

According to the Cultural Heritage Act, it is not only the individual cultural monuments, but also the entire cultural environments – defined as *"areas encompassing cultural monuments as a part of a larger whole or a context"* – that must be protected (Act Concerning Cultural Monuments 9 June 1978, § 2). As far as Vingen is concerned, this involves protection of the ancient coastal landscape in which petroglyphs and other cultural remnants from prehistoric and more recent times are located. Through responsible maintenance of the cultural landscape, the cultural monuments themselves are protected, primarily because landscape management prevents overgrowth and stagnation of the land.

8.2 Cultural Landscape

Grazing is an important element in the care and management of the Vingen landscape. The financial return for sheep and goat farming today is poor, and in the future it may become difficult to find local animals to graze the area. Up until now, grazing animals from the neighbouring Vingelven farm have been used. The conflict between grazing livestock and public access, as well as the lack of agreements regulating this, make the situation today untenable. Authorities responsible for cultural monuments and farmers must work together to find solutions that can ensure grazing and conservation of Vingen and Vingeneset. This must be consummated through a written agreement with the owners of the grazing livestock. The agreement must ensure sufficient grazing and supervision of the grazing animals. In order to achieve this, it appears necessary to offer financial remuneration to the owner of the grazing animals. The owner must also be assured that the animals are not harmed or unnecessarily disturbed by human activity in the area.

8.2.1 Management of agricultural landscapes

The long-term objectives for management of the original cultural landscapes in Vingen and at Vingeneset are identical: to maintain and promote a cultural landscape with vegetation that best preserves the rock art and the other cultural remnants in the area. This kind of objective will also conserve the cultural landscape and the biological values associated with it. Because of differing uses for the two areas, they have developed differently and today are quite different from one another in terms of vegetation. This will call for the use of different means in order to achieve the objective. Before these means and methods are implemented, there are certain general conditions that must be satisfied and assigned as areas of responsibility for managing officials:

1. Precise objectives must be formulated for the care and management of both areas. At the same time, a control system must be established that will guarantee that the measures taken effectively contribute to achieving these objectives in the short and long run.
2. Management must be seen in a long-term perspective. Sporadic ”all-out efforts” lacking proper follow-up will only make matters worse, and expenditure will be wasted. By long-term perspective, we mean at least 50 years in the future.
3. It is necessary to take into account that hired manpower will be needed to attend to care and management of the area in the future. This entails that long-term agreements must be made with land owners and suitable personnel to carry out the management operations. If care and management activities are to be realistic, the measures that are implemented must be cost-effective.
4. Normal consideration for animal protection must be observed. Animals must be given sufficient grazing area for foraging and moving about. There must be access to fresh water, particularly in dry periods.

Vingen

For Vingen there are several detailed care and management plans that outline measures for restoration and long-term care of the area (Austad 1981, Schei 1996). The most recent one was developed in 2002 on commission by Sogn og Fjordane county administration (Wrigglesworth 2002). This report provides a detailed review of a number of subareas at Vingen and proposes management measures that coincide with what is necessary in order to fulfil the long-term objectives. Therefore, it is not expedient to propose new measures for this area at the present time.

Grazing pressure during recent years has been too low to have the desired effect on heather vegetation. As a result, new agreements should be drawn up with the land owners for increasing the number of grazing livestock in the area, or for extending the grazing season.

Vingeneset

The primary objective for care and management at Vingeneset is to transform the surfaces in immediate proximity to the cultural monuments from heather cover to grass cover. This will stop the podzolizing process, along with the resulting acidification of the soil. This will entail that the current raw humus must be decomposed. The process requires lime treatments that will both accelerate the decomposition process and hinder acidification by humus acids that are liberated. Liming using dolomite results in an increase of both the pH factor and the degree of base saturation in the soil. In addition, both calcium and magnesium are added. By adding lime, the humus acids in the acid soil form complex ligands and thereby improve aeration in the soil. This in turn stimulates more efficient organisms to participate in the decomposition process and dark brown soil is developed over time. In order for this process to take place, it is necessary to halt the production of organic materials that are difficult to break down, so that one can avoid the accumulation of a thick layer of litter. The most effective means for achieving this is to introduce grazing livestock and maintain a grazing pressure over time that is sufficiently high to prevent heather from re-establishing itself in these areas. The process must be initiated by removing old heather cover either by clearing or burning. This is also necessary to have an effect on where the animals will graze. In an area as large as Vingeneset, animals will not graze in a uniform concentration over the entire area. They will gradually select limited areas that they frequent regularly and will establish a permanent grazing pattern. This grazing pattern, such as it is today, must be altered so that the animals concentrate their grazing to a greater degree in the area immediately around the cultural monuments. Implementation of such a plan entails burning off and removing old heather cover on the surfaces where more intensive grazing is desired. This will promote germination from the seed bank in the earth and stimulate grass growth on these surfaces. The animals' grazing pattern will thus be affected so that they include these areas in their grazing, and high grazing pressure will be obtained in areas where grazing-tolerant grassland vegetation will develop, hindering the reestablishment of heather in these same areas. In order to achieve the desired development, it is important that heather cover is not burned off outside of the primary areas for which one wishes to alter the vegetation. Later on, when the grazing pressure has been managed and grass cover has been established in these areas, one can then burn off larger areas of heather cover. In this event, grazing pressure must be increased, or the area must also be grazed during the winter.

8.2.2 Restoration phase

During 2005 a fence was set up around the target area at Vingeneset to keep animals from leaving the area. During the summer of 2006, there were a number of sheep grazing inside the area. The livestock mainly concentrated their grazing in and around the forested mountainsides on the steep slope up towards Tussurfjellet. On this slope there is considerably more grass and herbs than down on the flatland, and the animals seemed to find ample grazing here. In the uppermost portion, the vegetation is rich in herbs, and the heather is not as course as in the low-lying areas. However, there are stands of bog asphodel (*Narthecium ossifragum*) which can cause hepatogenous photosensitization (alveld) in sheep. If the animals are to be led to graze in the low-lying areas, it will be necessary to initiate measures to improve grazing conditions as described above.

1. Removal of unwanted vegetation.

If objectives are to be achieved, management measures must be adopted in order to make Vingeneset an attractive grazing area for domestic animals. Vegetation on the lower-lying, flat portion of Vingeneset consists of poor, old heathland which is gradually becoming overgrown with juniper, sallow, birch, rowan, aspen and pine. The quality of forage for grazing, in the current state of the area, is so poor that neither sheep nor goats will graze in this part of the general area. All species of trees that have attained a certain height must be removed. Mechanical removal using a scythes, pruning shears and axes is very labour-intensive and expensive. It is nevertheless a very suitable method in the immediate areas surrounding and above the monument sites. This method must be combined with liming/grazing if it is to have a lasting effect. Trees must be removed with chain saws.

Burning off heather is the most cost-effective method of removing old vegetation. When this is done in a professional manner during winter, with black frost in the soil, the heather is effectively removed, the ashes act as a fertilizer, and the seed bank in the soil is activated. The fertilizing effect may be further activated by following up with liming. Heather burns at a temperature of 550–600°C, but the thermal effect down through the frozen soil penetrates only a few centimetres. Normally plants germinate both from the roots and from seeds in the soil. When heather fires are controlled by experienced persons, very good control over the burnt area is ensured. Professional heather burning is radically different from the sporadic heather fires that occur during springtime droughts, causing major damage to the underlying soil. The heather fire on Helga Vingelven's property in 1951 was of this type.

According to Helga Vingelven, heather burning has not been used as a form of vegetation management in Vingen in living memory. The farmers needed the heather for winter forage, and heather gathering was a regular and important part of the hay harvesting season. Some people immediately react negatively to the use of heather burning, fearing that it may harm the cultural monuments. The risk of such damage is minimal. If the archaeologists first record and mark the cultural monuments/rock carvings, the people responsible for burning vegetation will be able to contain the fires at a sufficient distance from the sites. As an extra safety measure, the rock art sites can be covered with inexpensive, non-flammable, insulating mineral wool mats. Only a limited area of vegetation is burnt off at one time. At the University of Bergen/Heathland Centre, there are personnel with the proper competence to accomplish heather burning at Vingeneset.

The transition from the prevailing types of vegetation to a new and stable mosaic of vegetation will take a long time, perhaps as much as 10 years. The costs of the conversion will primarily come during the first two years. Extra work must be expected to counter the growth of ferns, especially common bracken (*Pteridum aquilinum*), which may be a recurrent problem in the first years following clearing and surface scorching. It is not expected that bracken will pose a major problem, since measures will be taken to stimulate decomposition of raw humus and the development of a brown earth profile.

2. Liming

In lime treatments, carbon is added to the soil in the form of $CaCO_3$. This foreign carbon may, in theory, disturb the radiocarbon dating in the event it should penetrate into strata in the sublayers of the soil. However, it is standard procedure, when conducting radiological dating, to remove foreign carbonates with the aid of salt acids. Thus, the radiological tests would not be affected.

Increased pH results in a better environment in which more resilient, grazing-tolerant species of grass can establish themselves and grow. However, it will take many years before the course heather branches disappear simply by liming, and it must be expected that lime treatments will have to be repeated at intervals of only a few years. Grazing is necessary in order to ensure the long-term effectiveness of heather removal and liming.

3. Grazing

During the restoration phase, grazing pressure must be high so that it can reduce the growth of plant material. This can be achieved through a combination of increased numbers of grazing livestock and extended grazing seasons during both spring and autumn. The animals must have extra supervision during this restoration phase, and it must be expected that financial remuneration must be made to animal owners during this period of time. It is not possible to determine an exact number of animals for the area at Vingeneset; here, one must proceed by trial and error and adjust the grazing pressure as needed.

Different grazing livestock will have different effects on the vegetation. Today the area is being grazed by a small flock of Norwegian dalasau. The effectiveness of this grazing plan must be evaluated during the 2007 grazing season. It is necessary to assess whether the desired effect is being achieved by the current grazing regime or whether the number of animals should be increased/exchanged with other types of domestic animals. If the area is to be grazed during the winter, it will become important to find areas with heather of high nutritional quality. Heather is an important part of winter forage. In order to establish such areas, systematic heather control and re-establishment of heather must be accomplished, either by burning off old heather or by clearing. These management measures must be implemented before the area is opened for winter grazing.

In our opinion, a cultural monument area such as Vingeneset should be grazed by light-footed animals able to digest course forage. Goat grazing is a long tradition in the area, but also feral sheep (the old Norwegian year-round grazing sheep) are very suitable to graze this terrain. The more common breeds of sheep are also suitable. Both sheep and goats require little tending, and feral sheep in particular will be able to graze the area on a year-round basis. Goats graze more intensively on heather and leafy plants than sheep. The weakness of sheep is the risk of hepatogenous photosensitization. Feral sheep lamb outdoors, and it is uncertain to what extent newborn lambs may be preyed upon by eagles in this area. Here it will be necessary to proceed by trial and error. The main grazing season during the first years should therefore be supervised by shepherds.

8.2.2.2 Brief Overview of Vegetation/Pastureland

Vegetation on the lower flat portion of Vingeneset consists of poor, old heathland which is gradually becoming overgrown with juniper, sallow, birch, rowan, aspen and pine. The quality of forage for grazing, in the current state of the area, is so poor that neither sheep nor goats will graze in this part of the area.

The deciduous forested area on the steep incline up towards Tussurfjellet is considerably richer in grass and herbs than the lower plain, and animals will find suitable forage here. In the upper portion, the vegetation is rich in herbs, and the heather is not as course as in the low-lying areas. There is good summer grazing here. However, there are stands of bog asphodel also in this area.

Another problem in Vingeneset is the poor supply of water. Vingeneset is known for drought conditions in the summer. The only known stable water supply is Hamreskar Pond, about 400 mas.

8.3 The Rock Carvings

8.3.1 The Tyranny of Diversity

Each new generation of explorers who visited Vingen throughout the 1900s were overwhelmed and fascinated by the abundance and diversity of the rock carvings. Bing predicted that many more petroglyphs would be found in Vingen that the approximately 100 figures that were known to exist during his time (Bing 1912:36). Already during the course of the next couple of decades his prediction became reality. Through the investigations of Gustaf Hallström and Johs. Bøe – which entailed, among other things, the removal of rock cover on new panels and stones – the number discovered increased many times over (see point 2.1 and 3.1.1). In Bøe's publication on Vingen, some 800 figures are described (Bøe 1932), and Hallström operates with a corresponding number. Bøe presumed that the original number of figures must have been significantly greater, and he imagined that practically every single stone and rock panel on the southern side of Vingepollen had been engraved with petroglyphs (*ibid.).*

An anecdote from Egil Bakka's investigations in the 1960s illustrates that the extent of the discoveries sometimes led to a certain amount of frustration. While Bakka was busy documenting one of the largest discoveries of new sites, Hardbakken (containing more than 200 figures), one of his local assistants, Helga Vingelven, began to search for petroglyphs on the surface of another large, turf-covered rock panel, Brattebakken. Sure enough, as the turf was removed, new figures appeared! When she excitedly informed Bakka of the discovery, he quipped dryly: "Oh no, not even more of them!" (Helga Vingelven, oral account).

By the end of 2006, after several years of recording and fresh documentation in conjunction with the conservation effort, the sum total of previously recorded and new discoveries in "Vingen's petroglyph area" had amounted to well over 2300 individual figures (Lødøen & Mandt *in prep*.).

8.3.2 The Vulnerable Rock Carvings

The numerous and varied rock carvings spread across rock panels and knolls, as well as smaller sites spread over a wide area, represent one of the traits that makes Vingen special in both a national and international context. At the same time, this abundance creates problems in terms of management because the petroglyphs are so vulnerable that they require the utmost protection against human tampering.

Documentation and damage surveys of the Vingen carvings, efforts that have been conducted intensively during the auspices of the Directorate for Cultural Heritage's National Rock Art project, have shown that a significant number of figures, and indeed entire sites, have been destroyed or severely damaged. This is not a new observation. In the 1920s Bøe (1932:25) complained that *"eine ausserordentlich grosse Anzahl der Bilder [an extraordinarily large number of the images]"* are more or less damaged as a result of weathering. Bakka's journals from the 1960s and 1970s also reveal that many of the images are damaged, and in several cases he indicates that the degree of damage had worsened even during the period of time of his investigations in Vingen. The fact that the state of damage becomes worse over time is a lesson we have corroborated from the 1980s and up until the present time.

As described in Chap. 5, the poor state of preservation is due to a combination of many factors, first and foremost the natural weathering processes, but also reduced grazing as a result of changes in farming practices, and intentional or unintentional damage caused by humans. In an attempt to repair the most serious damage and thereby ensure the intrinsic value of the petroglyphs, a large number of measures have been implemented over the past 20 years to protect and preserve the sites (Cf. 3.2.3). Nevertheless, the condition of many of the sites in Vingen is so poor that it is only a question of time before major portions of the rock surfaces will disintegrate.

Even with intensive conservation efforts, it will never be possible to restore the rock panels to their original durability. Therefore, the petroglyphs must be cared for in the same manner as objects in a museum. Inside the display cases and storage rooms of museums, an optimal preservation environment is created for the objects, including regulation of light and climate most conducive to the nature of the object being preserved. Correspondingly, attempts must be made to create an outdoor environment for the petroglyphs that will retard deterioration. This can be accomplished through various preventive measures, such as for example diverting water away from the surfaces of rock panels, keeping them free of vegetation growth, preventing dramatic fluctuations in temperature, and by placing protective covers over the petroglyphs for various periods of time (Cf. 3.2.3).

If the petroglyphs are defined as belonging in a museum context, this also entails regulation of public access to the damaged and vulnerable materials. As with museum objects, petroglyphs will not be able to endure physical handling by the public. Even the slightest pressure on panels where the weathering surface is in the process of exfoliation will lead to irreparable damage to a non-renewable cultural resource. Out of concern for the vulnerability of the petroglyphs, one of the most important preventive measures to protect the petroglyphs in Vingen is therefore to regulate and limit traffic in the immediate vicinity.

8.3.3 Documentation Standards of the Directorate for Cultural Heritage

A first step in the conservation effort entails a thorough and detailed documentation of the petroglyphs and an assessment of their state of deterioration. This data will form the basis for an evaluation of the various measures that must be implemented in order to responsibly manage and care for the cultural monuments.

Assessment of the damage to the petroglyphs began in 1991 and continued during the period of 1994-96 (Cf. 2.1 and 3.1.1). From 1996 and up until 2000, much work has been invested in filling out the Directorate for Cultural Heritage's Documentation standards for rock art in all of the Vingen sites. Altogether, three different versions of the form have been used, in addition to the county variant that was used during the first year. More than 50 working weeks have been devoted to the project and about ten different persons have been involved. In the year 2000, this work was almost finished. What remains to be recorded are individual, newly discovered sites, sites that have not been rediscovered, and sites that have been permanently covered over.

The current version of the Documentation standard (which is very similar to the 1997 version) is 36 pages long and is mainly based on checklists where the alternative that best describes a given situation is marked with a cross. In addition, there are separate spaces for clarifying observations, problems or other matters, if desired (Riksantikvaren 1998). This is a radical change from the 1996 edition, which consisted to a much greater degree of open spaces in which to write descriptions (Riksantikvaren 1996a). Furthermore, the 1996 version of the form was much shorter – only 12 pages – and came with 8 pages of detailed instructions. The experience from having worked with these two versions over a lengthy period of time has made clear the advantages and disadvantages of both, and it may be tempting to review the forms in detail in order to point out the contrasting aspects (as was done, incidentally, for the 1996 edition, in a letter sent to the Directorate for Cultural Heritage). Space does not allow going into such detail here, however. Instead, some basic problems involving the Documentation standard will be addressed, based on the experiences from Vingen.

In conjunction with archaeological and conservation research, it is valuable to document the rock art, its natural and cultural context and its physical condition. Therefore, we have given priority to closely examining each site. The figures have been located and studied, when necessary with the aid of artificial light, and they have been compared with earlier tracings. Discrepancies, whenever they occur, have been recorded through drawings, or at least chalk-enhanced and photographed. In cases where sites have not been traced previously, priority has been given to having this done. After the figures themselves have been documented, an effort has been made to identify any damage present, and to photograph and draw these in the same manner (Cf. 3.1.3). These basic procedures have yielded the material needed for filling out the Documentation standard forms. Archive references are filled in subsequent to the field work.

While the surveys of figures and their condition by means of tracing, photographing, sketching and written descriptions have been experienced as interesting and meaningful in themselves, reactions to the work associated with the Documentation standard have been mixed. The standard provides the input for the Rock Art database, which is intended to be a tool for use by managing authorities. However, the objectives of the Directorate for Cultural Heritage have not always been clear in the minds of those working in the field. There has been uncertainty relating to the objective that the database is to serve, to what extent and how it will function, and how many new versions of the Documentation standard one can expect in the future. The instructions for the newest versions of the form have been scant, with only brief comments given at intervals.

Uncertainties of this type have caused a certain amount of frustration concerning what constitutes relevant information for the database. For example, there has been some confusion concerning how large an area around the site should be taken into consideration, in terms of describing both the natural surroundings and the cultural artefacts. ”Archaeological contexts” in Vingen can include everything from the rock art sites in the immediate area to the Stone Age remnants at the far end of the area, or even farther, to include the petroglyphs and settlement locations in other areas of Nordfjord. By the same token there has been speculation as to how large an area is to be documented in terms of vegetation around the sites.

Even more to the point is the confusion associated with the very term “site”. In the instructions accompanying the 1996 edition, “site” is defined as

> *”a collection of figures, clearly delimited in the terrain on a rock surface/loose boulder. The rock art site is to be considered as a continuous portrayal of figures or a scene. The site is to be considered a unit in the terrain and if the site's distance from the nearest neighbouring site is more than 50 m.”* (Riksantikvaren 1996b:1).

A definition of this type is impossible to apply in Vingen, where the rock carvings are distributed across a large number of scattered stones and rock panels usually spaced less than one metre from one another. We ”solved” this problem by totally ignoring the Directorate's definition, using instead the system of divisions into localities and sites that is described above (3.1.3; Lødøen & Mandt *in prep*.). Nevertheless, there was still uncertainty as to how this was to be incorporated into the form. It can be debated, for example, how a huge boulder with engravings on one side should be considered – whether it is the boulder itself or the carved panel surface that constitutes the site, and secondly how many of the boulder's surfaces are to be taken into account when filling out the form.

The limit set for what is considered relevant information is very important for the amount of time invested, both in the field and in follow-ups. It is therefore important that this concern is addressed.

The issue of relevance and purposefulness has been particularly pressing in relation to sections 2.7 and 2.8 of the Documentation standard. These paragraphs require that the number of figures are counted, based on given categories (Riksantikvaren 1998:11-14). In relation to Vingen, this has been shown to be practically unfeasible. Whether a figure depicts a “four-legged land animal” is not always evident; to a much lesser degree whether it is a “Deer” or a “Reindeer”. It is no simpler to decide whether a ”Hook figure” or a ”Stick figure” is being described, or to what extent a jumble of lines in various shapes and sizes represents a “Line figure” or the remnants of a “Four-legged animal”, or for that matter, perhaps the remnants of a “Frame and lattice” figure or of an “Oval figure” filled with a pattern. Very frequently, it is necessary to resort to the category “Nondescript figure”.

Indeed, it is difficult to understand why these sections are included on the form at all. Information of this type is not likely of any special interest to management authorities. To the extent that the database is to be used in archaeological research, it is practically indefensible to include this quantification of figures. In Vingen, where so many people have worked concurrently, it has been shown repeatedly that different people see different things. The information that is recorded on the forms is therefore of a very subjective nature and is hardly suitable to providing an overview of anything at all. It is suggested, therefore, that sections 2.7 and 2.8 be removed from the form. As an alternative, it should be possible to link existing tracings to the database, even if it involves linking several different tracings from one and the same site. By doing this, everyone will have the opportunity to evaluate the figures themselves.

Subjectivity and arbitrariness are also a general problem with the Documentation standard, particularly in the most recent version. This problem has been illustrated in cases where people who have worked on adjacent sites have written contradictory descriptions of the terrain and vegetation. In the 1996 version of the form, subjectivity became apparent when information was provided through written descriptions. It made obvious the personal, subjective aspects that emerged from the evaluations that were done. The most recent version, through its alternative categories to be ticked off, gives the impression of being neutral and scientific. The evaluations, however, are just as subjective – a fact that researchers should bear in mind when they use the database. Subjectivity has a particular impact when the state of various sites, or the changes in a site over time, are to be compared. This is one of the reasons why photographs and drawings have been given priority in the work at Vingen, and why at the same time frequent use has been made of the open Comments spaces on the form. Hopefully, the various supplementary forms of documentation will counterbalance some of the misconceptions that can result from the completed forms.

Experiences from Vingen show that many of the problems associated with the Documentation standard stem from the goal to standardize information. Each site and each figure is unique and is thus difficult to pigeonhole in categories. In this respect, the problems are insolvable, since standardized information is a requisite for the database. For users, however, it is important to be aware of the kinds of challenges that have been faced in the field, and of the implications that these may have for the final product (database).

It should also ben noted that reactions to the Documentation standard and the database are not entirely negative. The course offered by NIKU during autumn 2000 in the use of the database contributed to an especially optimistic view. The course made it clear that the database was functional, and aspects of the form that seemed strange and impractical became more comprehensible. The purpose of both the Documentation standard and the database became clearer to us. In general, there has been understanding and enthusiasm for the objective of collecting information about rock art.

In the future, however, a greater effort should be made to keep those who are assigned to do the work continually updated on the objectives and state of affairs, and to make a more concerted effort to include these people in discussions. Only by doing this can misunderstandings and dissatisfactions be avoided, and problems can be solved as they arise.

8.3.4 Documentation of Damage

In the area managed by Bergen Museum, damage to rock art sites is normally documented by indicating the damage on copies of tracings or by freehand sketches, and by photographic documentation.

Colour and symbol legends that are used for drawing in damage on tracings are included in sections of the form used for documentation of the rock carvings at Vingen. When this work began, there was no standard for colours and symbols for use in damage assessment. Colours and symbols were therefore selected by students who worked filling out the Directorate's Documentation standard and eventually developed into a standard that was used by everyone documenting rock art in the Bergen Museum's area of operation. Red shading, for example, is used to denote cavities; blue designates quartz veins, and green marks delaminated edges. The system has varied somewhat, depending on the availability of the different colours in the field.

In August 2000, representatives from Tromsø Museum visited the field, and experience with damage documentation was exchanged. As a part of the collaboration between Bergen Museum and Tromsø Museum, it was agreed that Bergen and Tromsø would both use the same colour and symbol scheme and would devise a standard legend. Discussions led to a consensus on the colours and symbols that were to be used. It is important that the colours contrast, so as to avoid confusion of overlapping lines. As it turned out, Tromsø had made notes of things that were not marked on the damage assessments in Bergen, such as weathering. The reason for this is primarily that there are other types of weathering damage to sites in Tromsø Museum's area of operation. A standard legend of symbols and colours will simplify the reading and interpretation of damage assessments, regardless of the area of the country where they are prepared.

8.3.5 Photographic Documentation

Comprehensive photo documentation of the rock carvings in Vingen has existed ever since the early 1900s (Cf. 3.1.1). Since the end of the 1970s, photos have been taken in black and white, colour, and slide format. Entire sites and detailed close-ups of figures have been photographed, and in order to avoid the problem of being unable to rediscover the sites, an extra effort has been made to take location photos.

8.3.6 Care and Management Plan

In June 2000, work began on filling out the Directorate for Cultural Heritage's care and management plan for localities in the area that Sogn og Fjordane county administration had originally proposed as a public area, in conjunction with hearings on land preserves. The forms were completed for Storåkeren, Ved Vatnet, Lyngrabben and Hardbakken Sør, but so far not for Vehammaren 2. On the other hand, the form was completed for the Leitet locality, since it borders on Lyngrabben. For the 2001 season, the area open to the public was changed and basically limited to Hardbakken Nord, with access via a trail directly from the quay. Using this route avoids sending visitors through the best pastureland where access to fresh water is optimal.

The work involving the care and management plan for Vingen was planned for completion during the autumn of 2001. One problem relating to the writing of a care and management plan for the rock art sites in Vingen has been the uncertainty in terms of the selection of localities that are to be part of the public area, as opposed to those that will be closed to/protected from public access. The areas were not designated by the summer of 2000, and it became necessary to fill out the forms with two possible alternatives in mind. Follow-up measures will depend on whether the sites are to be opened to the public, and also whether this will affect adjoining sites. Sites that are located on or near hiking trails, for example, will be at risk of being trampled, even though they are not included in the proposed public area, such as the Leitet locality.

Good damage surveys are an important requisite for developing and following up a care and management plan. Surveys of this kind provide the basis for an assessment of the extent of damage and preservation measures. They also provide a more rapid projection of how much time will be needed for care and preservation work. Part of the work associated with the care and management plans includes making damage assessments whenever they do not already exist. In Vingen, a great deal of work was invested in recording thorough damage documentation for each site in the various localities. In addition, overview sketches and freehand sketches were made, and the sites were photographed.

The point concerning when the management measures will be implemented will most often be a point in time prior to filling out the Directorate for Cultural Heritage's Documentation standard. In this respect, it is possible to go as far back in time as is necessary. The number of columns for Future measures (active sites, category 1) can be increased to indicate earlier dates/years if necessary. Moreover, a historical account for the site will be covered by the care and management plan, and the same is true of the literature relating to the site. It is more important to record plans for the site in the care and management plan to a greater extent than has been done previously. There is also the option of including enclosures that are found to be necessary and useful. The long-term objective is to develop a care and management plan for all localities in the rock carving area of Vingen.

8.3.7 The Difficult Choice

Protective coverings are considered to be a good solution for many sites in Vingen. This applies to several of the sites that are most damaged (Cf. Fig. 5.1.4-1). This method will help to keep lichen growth in check, and the sites can thus be "stored" until new conservation techniques will hopefully be developed in the future. Testing of various protective cover methods will therefore remain an important task in the future years (see 5.4 and 6.1). Two sites at Leitet – 6 and 8 – have been covered since 1981 (Cf. 3.2.2), and these sites will serve as important references in the work involving tests and evaluation of the effects of protective covering.

Many of the sites that are on small, "liftable" stones are also suitable subjects for protective covering. The reason for this – in addition to the fact that many are damaged – is the risk that they may be removed by trespassers[1]. Before they were covered, the sites were surveyed and logged in order to facilitate finding them again. Out of concern for preservation, several of the smallest decorated stones were removed and placed in storage in the museum during both the 1920s and 1990s.

For many of the most damaged sites in Vingen, protective covering is not a suitable preservation method. This is due in part to the size of the sites, to the angle of inclination (almost vertical mountainside), and in part

1 Local rumour has it that small stones engraved with carvings taken from Vingen have been set in the masonry of fireplaces in private homes, and a notice in the newspaper during the early 1990s reported that a rock carving from the Vingen field had been offered as a gift to Lervik in the Shetland Islands.

to the location – or a combination of these factors. The petroglyphs that are most damaged are on panels facing southwards, where the stratification is parallel with the surface, and where large cavities ("hollows") have been detected under the weathering zone. Many of these sites are nearly vertical panels in the westernmost section of the area. Here they are exposed to extremely harsh weather brought by westerly gales, and tests of short-term protective covering have demonstrated that only a few strong squalls are enough to blow off the covering materials. This is the case in the larger sites at Vehammaren 1 and 2, as well as site 3, which is located on the side of Vehammaren facing westward. Behind Vehammaren, the circumstances apply primarily to sites 2, 3, 6, 7, 9, 10, 13, 14, 15 and 19. Furthermore, it will be difficult to cover Storåkeren 1, 2 and 3, Teigen 1, 7, 8 and 10, and all of the sites at Lyngrabben and Vindbakken 1. The same is true for the sites in Urane, Nedste Lægda and Elva. At Vingeneset, these circumstances apply particularly to sites 11 and 12 (Fig. 7.3.7-1).

At many of the petroglyph sites in Vingen, degradation is so extensive and has advanced to such a degree that the question has been raised of whether or not it is possible – or justifiable in terms of cost – to save them at all. The issue is whether there are sufficient resources – financial, human, temporal – to complete the demanding measures necessary to preserve the worst damaged sites for prosperity, in their original state, and in their original locations. Or should we allow nature to take its course and permit the most deteriorated sites to "return peacefully to ashes", while we assign priorities to preserving sites where deterioration has not yet reached the point of no return? If we choose the latter alternative, it must at least be under the condition that heroic efforts should be made to document the sites "sentenced to death" through all available methods of documentation – tracings, castings, photography, etc. – in order to preserve the knowledge content of the images in the best possible manner. But where does one draw the line between a site that can be justified as preservable and one that should be allowed to disintegrate into oblivion? Are the degree of deterioration and damage the only decision criteria, or should the intrinsic cultural and historical potentials be taken into account? What, in the latter case, are the basic criteria? Is it rarity, unique traits or particularly beautiful art work, the technique of execution, placement in the landscape, proximity or distance from other categories of motifs, relationship to other cultural monuments – or a myriad of other factors – that should be the basis for the decision regarding whether or not a petroglyph merits conservation?

Another question that will certainly arise when discussing the use of resources is whether only sites designated as publicly accessible should be assured survival. Or should resources also be invested to preserve those sites – for example in Vingen – that must be protected to the greatest extent possible from access by the public, and will thereby remain accessible only to a few professional specialists?

Vingen is hardly the sole area facing this problem. Therefore an agenda appears to be set for a discussion concerning ethical guidelines for the task of conserving rock art and making it accessible to the public. Which institutions should be responsible for taking the decision concerning the petroglyphs' continued existence or non-existence: the regional museum? The county administration? Or perhaps the municipal administration? It may be claimed that professionals in the field – those who are in close contact with the cultural monuments and who are therefore most familiar with the extent of damage and cost requirements – are the individuals best suited to making such decisions. However, the increasing number of other participants and interested parties in the work involving rock art have introduced a number of factors outside of the concerns of professional conservationists, and these factors may well be given consideration by political and funding authorities.

8.4 The Remaining Archaeological Material

During the course of the work to document, preserve or care for the rock art in Vingen, archaeological materials have been unearthed that offered grounds to believe that they may have been related to the production of the rock art. These have often been various tools made of stone and residual materials from the production of the tools, but there have also been cultural strata containing charcoal remnants. Documentation of this archaeological material, which according to *The Act Concerning Cultural Monuments* is entitled to the same conservation as the rock art itself, has been in many cases sorely lacking. The reasons for this are numerous. It is likely that this owes partly to the fact that examiners of the sites did not have proper routines for handling or taking into account archaeological materials as they performed various types of conservation work, partly to the fact that they did not have sufficient knowledge concerning what they were looking for, and partly due to insufficient resources.

8.4.1 Disputes among Professionals

In the mandates associated with the Directorate for Cultural Heritage's funding for the conservation of rock art, little leeway is provided for examination of the substratum. Nevertheless, there are many cases where the work undertaken during the rock art project, or in other measures related to conservation of the rock art, has inexorably led to conflicts relating to other archaeological materials. This has resulted when cutting back edges of turf, removing vegetation and maintaining drainage ditches. Cases also show that petroglyphs that are partially covered by earth and vegetation must be uncovered in order to prevent them from being exposed to damage by upheaval caused by roots or deep frost as a result of water saturating the soil surrounding the sites. When the surrounding soil contains archaeological materials, these measures can lead to the loss or disruption of irreplaceable source material. Once the contexts of these materials has been disturbed, having lain untouched in the soil for thousands of years, the result is often that all of the source material is lost to erosion, the dissipation of organic materials, or by the breakdown of charcoal. Conversely, findings of such materials can lead to delays in or even preclusion of conservation measures for the rock carvings. If better knowledge of the extent and nature of archaeological materials in the substratum is acquired, such conflicts can be avoided or at least reduced in frequency.

It is obvious, of course, that the many rock art images are more readily accessible than archaeological material concealed beneath a thick layer of turf and soil. In many cases, however, it is precisely because of this proximity that sub-soil materials are also highly accessible, far too accessible, and thus exposed to at least the same risk of destruction and damage as the rock art itself. It is somewhat alarming, therefore, that greater emphasis has not been placed on the preservation of substratum material as well, since it is important for an understanding of the rock art and the prehistoric activities around the petroglyph sites. An incongruity is created between preservation of the images, which to an increasing extent are removed from their contemporary context, and preservation of the very material that can serve us in our research aimed at chronologically situating and interpreting the petroglyphs. As a result, the effort to conserve should not entail the rock art alone, but should also include the underlying source material. The question, therefore, is how we can conserve both of these categories of archaeological material within the constraints of the Directorate's budget for the conservation of rock art.

8.4.2 Important Source Material

The archaeological material in the substratum represents such an important reference source for the rock art that its loss would simultaneously entail the loss of the very basis for being able to properly understand its meaning. As an example, this material may represent an important potential for being able to precisely date the rock art. One usual approach to dating rock art, at least for ritualistic hunting figures such as are found in Vingen, is to proceed based on a geological dating of the shoreline level and the assumption that the rock art was produced in the shoreline zone. The lack of proper geological data in many places, however, has resulted in a highly approximate determination of these dates and has thus been unable to situate materials more precisely than within a time range of several hundreds of years. In addition, it is not known with any certainty whether the rock art actually was produced in the shoreline zone. Even within the shoreline zone, there may have been many metres' deviation between the mean water level, high water mark or higher levels that still may lie within what is considered the shoreline zone. If these factors are taken into account, the framework for determining dates becomes even more unstable, in many cases opening for a time segment deviation of several thousands of years. These factors have combined to make the use of rock art problematical when formulating syntheses for an overall picture of our prehistory. This is in sharp contrast to the far more nuanced and fine chronological framework that has been developed for other cultural material, a framework that has been built up through the results of countless archaeological investigations. By including the archaeological material from the sub-soil, such as objects and radiological dating of the cultural layers, it is also possible to contribute to the development of a more finely meshed chronological framework for the rock art.

Archaeological material from the subsoil at petroglyph sites will also be a unique source for obtaining a better understanding of the meaning of the rock art, and will help in clarifying the activities that occurred in proximity to the sites and which may have been a part of the process through which the petroglyphs were produced.

8.4.3. Investigative Surveys – test excavations

In order to acquire important information intersecting rock art and other archaeological materials, and in order to survey the nature and extent of potential deposits in the immediate proximity of the rock art sites, several problem-oriented investigations were undertaken by the Institute of Archaeology, University of Bergen, in areas of Hordaland and Sogn og Fjordane. The overall objective for the investigations has been to attempt to approach a solution to central issues concerning rock art, such as placement in chronology, what it expresses, how it was made, and the significance it may have had in the contemporary age during which it was created.

With funding from the Meltzer Fund, among others, several investigations were conducted at several points in Vingen in 1998. These uncovered extensive archaeological material deposited in the vicinity of several of the rock art sites. The event prompting one of these investigations was that materials had been found during clearing work as ground cover was cut back around the edges of a small stone on which an animal figure was depicted in the Bakkane locality. In the soil, which was very rich in charcoal content, several flakes of rock crystal, quartzite and quartz were found. Tests conducted in the vicinity of this site revealed the presence directly beneath the turf of an undisturbed, 20–30 cm-compacted cultural layer containing large amounts of heat-shattered stone, chips and tools from the Early Stone Age. Radiological datings of the charcoal from the cultural layer situate this material towards the Late Mesolithic.

The results coincide with several other spot investigations in Vingen where materials from the Mesolithic were found and where their age was confirmed through radiological datings of the cultural layers, whereas materials/contexts from the Neolithic are conspicuously absent. These results stand in contrast to earlier datings performed by Egil Bakka in the 1970s. On the basis of hypothesized shoreline displacement for Outer Nordfjord, he had suggested a time segment within the lower and middle Neolithic, with possible origins towards the end of the Late Mesolithic (Bakka 1973; 1979; 118). The essential point here is that the material from the subsoil indicates that the rock art is significantly older than previously assumed and that it therefore has a different cultural and historic contemporary context (see 5.5).

During the summer of 2000, minor investigations were conducted in front of a rock art site at Vingeneset, where the largest of the animal depictions in Vingen is located (Cf. Fig. 3.1.3-1). The carving, located on a steeply inclining rock surface, was discovered in 1996, concealed behind a curtain of turf and non-compacted material. In order to determine the type of carving it was, the turf was removed and some of the loose soil and rock was dug out from the lower edge of the engraving. Already at this point in time it became clear that the loose rock and soil contained archaeological artefacts. One such finding was a chiselled quartzite core.

Since the discovery, the rock carving has been covered with insulation mats and a tarpaulin, all held in place by sandbags pending conservation at a later date. This type of protective cover, however, has proved to be insufficient, since gales have several times torn off the tarpaulin. The desire for a better method of protection by fastening the cover to rock and the mountainside triggered archaeological investigations of the subsoil area in front of the rock carving. The investigation revealed that beneath the ground, approximately 1 m in front of the site, there was a longitudinal ridge that ran parallel to the rock panel on which the carving was located. In the gap between the ridge and the panel. a 10–20 cm-deep, unusually well preserved cultural layer that was thickly rich in charcoal, and that contained chiselled stone artefacts. What is sensational in this context is that the cultural layer was concealed beneath a layer of larger stones in the bottom of the hollow, and then all of the material was covered with mixed shoreline sediments. Upon closer examination, it is believed that the stone cover and gravel sediment must have been placed there during the past 200–300 years in order to provide underlay for expanding hayfields, a practice for which evidence has been found in other places in Vingen. In addition, we know from both oral and written sources that earth and stones were used to fill hollows and to cover embedded stones in Vingen in order to create more land for grazing, cultivation or haying (Cf. 2.2.1).

Comparisons of this cultural layer with other cultural contexts in the barren landscape of Vingen leads one to conclude that it is settlement and agriculture during the most recent centuries that is responsible for helping to preserve prehistoric cultural layers beneath covers of stone and soil. This leads to the hope that palynological analyses of the cultural layer will also be able to determine the types of organic materials that were deposited in proximity to the rock art.

The important point is that these sources must be properly protected. If not, exposure of the cultural layer may leave it prey to processes that break down the charcoal, so that the sources that may be used for interpretation and dating of the rock art will be lost.

8.4.4. Test Excavations and Research Potential

The examples that are included here show that it is not only a case of finding isolated objects, which in themselves are important per se, but more generally of deposits of archaeological materials that might better be compared to remnants of settlements, and that are natural to consider in context with the rock art. The investigations also show that in the immediate vicinity of the rock art site, there is a stratified, radiologically datable layer containing archaeological materials that will be important for the development of a more detailed chronological framework and for providing a better basis by which to analyze the meaning of the images depicted. Naturally, it is not possible to hastily posit direct links between the rock carvings and the archaeological material in the subsoil, but the material does represent an important research potential that should be given better protection. In order to develop a more unified conservation policy and a better overall protection of the archaeological source categories that are discussed here, it will be paramount in the future for the other archaeological materials to be placed on the agenda in a context with the rock art, including the development of clearer guidelines specifying how the other archaeological materials are to be taken into account through conservation strategies, rather than ignored!

8.5 Presentation to the public – Dilemma or Management Based on Preservation's Premises

8.5.1 Preservation and Use – Conflict or Compromise?

Throughout the whole of the 1990s, management of Vingen was marked by conflict. Various users and interest groups were on a collision course when considering the interrelated issues of "protection - use - consumption" of the cultural monuments. Both local authorities and the tourism sector wanted to exploit and develop Vingen's potential as one of the county's prime tourist attractions. Those assigned to protect – and who have the task of preserving – the cultural monuments have repeatedly warned that the damaged and extremely vulnerable cultural monument area in Vingen is at risk of being spoilt, or at worst destroyed. The warning, however, appears to be difficult to accept.

Under the provisions of both the Cultural Heritage Act and the Nature Conservation Act, the protection of Vingen should, in a formal sense, be well assured (Cf. 2.4). However, the so-called "right of free access" – i.e. people's right to free movement in outfields and by boat on the sea, conferred by the Act concerning Outdoor Recreation of 28 June 1957[2] – coupled with the fact that Vingen has been defined in various contexts as outlying land, rather than as cultivated pastureland and hayfields, have been used as instruments for opening the area to free traffic and organized tourism.

In Bremanger and the adjoining municipalities, local outdoor recreational interests are largely related to the ocean and coastal areas, and boats are practically common property. For many different user groups, Vingen has therefore become an attractive place to visit. The local population has a long tradition of going to Vingen to enjoy their Sunday afternoon coffee on the shore. Throughout the years, Vingen has been a popular

2 The new Act Concerning Outdoor Recreation that was adopted by the Norwegian parliament in June 1996 does not entail any significant changes from the old law. Committee hearings and the debate in parliament, however, offer no doubt that the Parliament views the right of free access to all as an separate right of individuals and small groups, and that commercial outdoor activities cannot be pursued under the shelter of the right of free access, but instead require the permission of the land owner (Åsen 1996).

destination for school class outings in a wide radius. The good fishing in Vingepollen attracts sports fishermen as well as professional coastal fishermen. Norwegian and foreign boaters on holiday and who seek cultural and historical attractions have also been tempted to tie up at the large pier, built by the municipality in 1992, where boats have been able to remain for days without paying a fee. The hiking trail over the mountain from Svelgen has been used frequently by both local hiking associations and visiting hikers. The increasingly better organized and active tourist sector has left its unmistakable mark on Vingen over the past decades.

Neither protection mandates nor conservation rules have prevented irresponsible behaviour on the part of the public, such as trampling and deliberate vandalism to the rock carvings, open fires and grilling, and disregard for the leash law. Another contributing factor in tempting the public to do as they please is undoubtedly the area's wilderness location, in an isolated area without permanent residents or permanent supervision by wardens. The unrestricted and largely uncontrolled traffic has not only resulted in damage to the rock art and other cultural vestiges, but also in a sharp reduction in the most important protective measure for the cultural landscape – grazing by small livestock –, which in turn is harmful to the cultural monuments, because the previously open and grass-dominated landscape is becoming overgrown (Cf. 2.1 and 3.1.1).

The rock carvings, other archaeological traces of culture, the cultural monuments of more recent date, the old coastal landscape and the dramatic natural surroundings combine to make Vingen a unique example of an area with 6000–7000 years of almost continual human presence. It is understandable, then, that the public wants to visit Vingen, and it is understandable that local interests want to show off "their own" cultural posterity.

Problems arise when commercial interests, along with the general notion that one has special rights by virtue of time-honoured traditions, come into conflict with conservation of the vulnerable cultural monuments. The agenda is thereby set for culture-(tour)ism's classic dilemma: long-term conservation versus short-term commercial gains. One can be often tempted to pose the question as to whether it is *possible* to manage cultural monuments on preservation's premises. Or is it a fact that managing authorities in some (many?) cases, must compromise their notions of conservation because (other) politically governed interests in society become a prevailing, restrictive authority?

8.5.2 When Preservation Controls Accessibility – One Example

It has frequently been foreign tourists who have shown the greatest respect for the restrictions on free traffic in the unique cultural area that Vingen represents. They are accustomed to the rigid restrictions on access to valuable cultural and historical monuments that cultural authorities in their home countries have imposed.

8.5.3 Vingen at a Crossroads?

8.5.3.1 Protection of an Area – a Tool for Preservation?

The temporary protection of the Vingen area that was enacted by Sogn og Fjordane county administration in February 1996 started a process that will hopefully result in the preservation of the cultural monuments through reduced and regulated use (Cf. 2.4.4). In the proposal for permanent protection of the area (pursuant to the Act Concerning Cultural Monuments § 19, cf. § 22) that was sent by the county administration to the Directorate for Cultural Heritage on 3 May 2001, a framework was established that seems to be capable of meeting the requirements for management – and accessibility – of Vingen on the premises of conservation.

In their comments, county administrators note that consultative statements have generally been positive with regard to protection of the area, and that they have acknowledged the need for protective measures in order to conserve the cultural monuments. Some reservations were expressed, depending on the perspective of the various consultants concerning protection and use of the monuments in Vingen.

The proposal to protect the area underscores the purpose: to preserve the Vingen rock carvings and the other automatically protected cultural monuments as scientific sources of material in the landscape. The county administration sees the overall objective as being to preserve the primary material on the site itself. The rock carvings and other cultural vestiges are not to be removed and placed in protective storage in a museum.

Aside from certain exceptions, heavy restrictions are placed on traffic in the area and the measures or activities that can be carried out – among other things, that nothing can be implemented that may alter the nature of the area or work against the purpose of protection:

> *"The determined interests in favour of using Vingen for tourism and outdoor recreation, along with the negative experiences from the period before temporary protection was enacted, have made it necessary to control traffic within the entire landscape area encompassing the rock carvings. It is necessary to exercise legal authority to regulate traffic and activity so that the latter may not lead to a risk of damage to the petroglyph sites and in order to ensure care and management, intensive grazing and other measures conducive to the conservation and improvement of the environment surrounding the rock carving sites"* (proposal for protection p. 4).

Owners and others with special user rights may make use of the area as previously, provided it is in accordance with the objective to protect and with the regulations regarding protection. This pertains especially to measures associated with active and intensive grazing, work in conjunction with documentation, conservation and research on cultural monuments, and fishing by registered professional coastal fishermen.

Protection entails that the public may have access to a limited area in Vingen where they can view a representative selection of rock carvings, cultural landscape and cultural monuments of more recent date. The public area, defined as a museum area with regulated traffic within a specified period of time, will be more specifically described and delimited in conjunction with the county administration's further planning.

Despite the fact that the county administration finds it undesirable to place restrictions on people's right of free access, overall consideration of the need to protect the cultural monuments outweighs the desire to make the entire rock art area and the surrounding landscape accessible to the public. However, it has been proposed that the hiking trail between Vingelven and Vingen can be used when the public area is open.

Pertaining to Elkem ASA's hunting rights in the mountains above Vingen, an arrangement that has led to conflict in terms of grazing in Vingen because the hunters have gone through the protected area, it will be required to come to an agreement between the parties involved.

The county administration considers it important and necessary to establish long-term and permanent regulations for the cultural monument area in Vingen. Specifications for completion of the various measures that are described in the proposal to protect will be integrated into the regulations that are to be drafted in conjunction with the development of Care and management plans.

8.5.3.2 Animal Health and Preservation of Cultural Monuments – Two Sides of the Same Coin …

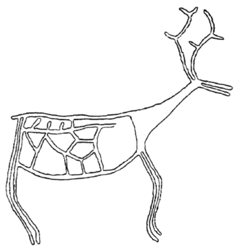
Legal protection of the area will set the premises for conservation through limitations on traffic, regulated public access and intensive care and management through grazing. The decisive issue in the coming time will be how the positive stipulations embodied in the framework of the protection mandate will be followed up in practice.

Throughout the second half of the 1990s, at least one annual meeting has been held between the various parties having interests in Vingen: cultural monument management authorities represented by the county administration and the Directorate for Cultural Heritage, the University of Bergen, landowners and research and conservation authorities, parties at the municipal level, the tourism sector, local private parties and owners of grazing rights. The meetings have resulted in a number of basic disagreements concerning measures and implementation of efforts to conserve and at the same time provide public access to Vingen. This applies, among other things, to agreements concerning grazing, definition and delimitation of a public area, a ceiling on the number of permitted visitors, stewardship and supervision during and outside of the tourist season, etc. In other words, there are many concerns that must be addressed before conservation of the Vingen cultural monument area will be adequately ensured.

In the view of the district veterinarian, certain requirements must be met in order to create a better climate for the livestock in Vingen, and thereby for the livestock owners as well: a binding contract must be negotiated with animal owners concerning grazing conditions; visitors to the area must be limited to 40 persons per week (= two tourist groups totalling 40 persons) in order to avoid disturbing the livestock; no additional dispensations must be made during the grazing season for visitors other than these tour groups; effective stewardship must be organized; and a decision must be made regarding what to do about the large pier. The Directorate for Cultural Heritage outlined three possible solutions for Vingen:

1. Grazing animals in the area in parallel with organized tours. The condition is proper supervisory control and approval from veterinary authorities.
2. Organized tours as planned, and removal of grazing animals from the area. The condition is proper supervisory control and manual grass harvesting. The conservation project will suffer.
3. The grazing animals are returned to the area, and Vingen is closed to visitors. This requires proper supervisory control and creates a problem for the tourism sector. Difficult to follow up/unforeseen consequences that may result from illegal trespassing.

The process that has now resulted in the agreement between the county administration and the livestock owners reflects the concerns that the co-participants in the "Vingen project" have emphasized throughout the project period: by giving priority to safe and beneficial living conditions for the grazing animals, it is possible to provide the best possible platform for conservation of the cultural monuments. In other words, it has been corroborated that animal health and preservation of cultural heritage are two sides of the same coin in a cultural landscape for which grazing is a prerequisite for the preservation of traces of culture from prehistoric and more recent times. It is hoped that this view will be maintained in future efforts, and that it will be one of the foremost guiding thoughts in the work to care for and manage the cultural monuments in Vingen.



CHAPTER 9

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HJEMMELUFT, ALTA MUNICIPALITY

9.1 Background

Investigation of the rock art in Alta has a relatively short history. The first rock art were discovered as recently as 1973. In that year, figures were found in Bossekop and in Hjemmeluft. Since that time, additional figures were discovered in Hjemmeluft, and in 1977, figures were also found at Amtmannsnes and again in 1978 at Kåfjord (Helskog 1988). These four areas are located in the basin of Altafjord and constitute the largest known concentration of rock art in Northern Europe. Since 1985, the rock art sites in Alta have been included as the fourth Norwegian cultural monument on UNESCO's World Heritage List of worldwide cultural monuments for preservation.

The investigations in Alta that are discussed here were carried out in the specific area comprising the Hjemmeluft sites. The area may be roughly characterized as a relatively wide bay on the western outskirts of Alta urban centre, at the foot of Bæskades. It is bordered by Alta fjord to the north and Europe Motorway 6 to the south. The area is characterized by flat, barren rocks and rocky knolls in grass and heather-covered flat lands. There are stands of birch spread throughout the area, and in certain portions the groves are rather dense.

Within this area, there are some 2000 known rock carvings. They are concentrated in sections of the area at various elevations on both sides of the bay. The most commonly found motifs are animal, human and boat figures. Reindeer, moose and bear are the most prevalent animal figures, in addition to a few depictions of birds and fish. Human figures appear alone, or they are depicted in interaction with animal figures in what appear to be hunting and ritualistic scenes, or in various human interactions that have been interpreted as dances or rites. The boat figures are depicted with crews or unmanned; they occur in groups or individually and are part of what may be interpreted as hunting or fishing scenes. Apart from these motifs, there are other, less visible depictions or abstract patterns such as networks of horizontal and vertical lines and wavy patterns. The figures were created by point-chiselling, probably using the sharpened tip of a harder rock species than the bedrock, whereby the motifs are worked up through numerous chisel marks made in the surface of the stone (Helskog 1988).

Just as in Vingen, dating of the Hjemmeluft rock art is problematical. Nevertheless, there are convincing arguments for associating the rock art in Hjemmeluft to the prehistoric shoreline level, thus making it relevant to date the art in a context with the postglacial land upheaval. The rock carvings are located within four separate elevation zones that respectively show stylistic and formal similarities between about 8 and well over 26 m above sea level today, and that are separated from one another by broad zones containing no rock carvings. A factor that corroborates the relationship between the rock art and the prehistoric shoreline elevation is that stylistic traits correspond with the elevation over sea level on both sides of the bay. It is inferred, therefore, that the rock art was created on barren rock panels near the water, where the rock was free of lichens, moss and vegetation. As the land rose in relation to sea level, the rock art was gradually carried farther up and away from the shoreline. Based on the shoreline displacement data and the probability that the oldest rock carvings are located highest in the terrain, the four phases may have corresponded with the following time segments (Helskog 1988):

Phase 1: 4200 to 3600 B.C.
Phase 2: 3600 to 2700 B.C.
Phase 3: 2700 to 1700 B.C.
Phase 4: 1700 to 500 B.C.

In addition to the rock carvings themselves, archaeological excavations and tests in the area have unearthed prehistoric materials and tools indicating settlement and correlating in time with the datings of the rock art. Moreover, several remnants are known to exist in the area, and these can very likely – based on elevation above sea level, form and size – coincide in time with the dates of the phases listed above.

9.2 Analyses and methods

Early in the project, it was suggested that investigations at Hjemmeluft similar to those at Vingen would be advantageous. A comparison of the two localities would be interesting since the rock type is the same (sandstone) while the climate is different. In 1997 an inspection was carried out to determine the general condition of the rock art with respect to the type and degree of damage, growth of lichen, etc.

In 1997, an automatic weather station was commissioned at Hjemmeluft (Bergbukten 4A). The standard records are the same as those at Vingen and include air temperature and humidity, wind speed and precipitation. The amount of precipitation was not recorded during the winter months due to problems with freezing. In this period it is possible, however, to obtain data on precipitation from the permanent meteorological stations. In the autumn of 1998, a trial area like the one in Vingen was established at Hjemmeluft, with the aim of testing the effects of different thickness of matting on the temperature of the rock surface (Fig. 9.2-1). During the course of the project, samples were collected in order to determine the composition of the rock and the extent of its weathering, and mapping of lichen on the surfaces at Hjemmeluft decorated by rock art was also carried out. The majority of the rock samples were collected from the area around the weather station, but some were collected on the opposite side of the bay (Fig. 9.2-1 and 2). Samples were also collected along a section from the shore to the lowest of the paths (Fig. 9.2-2).

9.3 The rock canvas

9.3.1 Origin and composition

The rock type at Hjemmeluft is a massive, Precambrian metasandstone belonging to the Raipas Group, exposed within a basement window (Fig. 9.3.1-1). A basement window is an area where basement (Precambrian) rocks are exposed due to erosion of overlying rock units. The sandstone exhibits structures that indicate that it was originally deposited as sand in an ocean (rhythmic bedding) or on a beach (wave ripple marks). The sandstone is fine grained and principally composed of rounded grains of Quartz, feldspar, sericitised feldspar, relatively large clasts of muscovite, as well fine-grained rock fragments, mainly quartzite (Table 9.3.1-1).

Table 9.3.1-1. *The mineralogical composition of the metasandstone at Hjemmeluft.*

Mineral	**Chemical formula (general)**	**Vol.%**
Quartz	SiO_2	70–80
Plagioclase (albite)	$NaAlSi_3O_8$	5–15
K-feldspar	$KAlSi_3O_8$	5–15
Muscovite	$KAl_3Si_3O_{10}(OH,F)_2$	10–15
Dolomite	$CaMg(CO_3)_2$	0–25
Trace minerals*		+

* amphibole, apatite, ilmenite (iron-titanium oxide)

Trace amounts of accessory minerals such as amphibole, apatite and ilmenite are also present. The feldspar is principally plagioclase (albite) and K-feldspar (microcline). Fine-grained muscovite (sericite) forms the matrix between the grains of the other minerals. In places the cement is dolomite. The sandstone is generally laminated, the lamination being defined by alternations of laminae rich in Fe-Ti oxide and oxide-free laminae (Fig. 9.3.1-2). On the basis of the relatively high content of matrix the sandstone can be classified as intermediate between a feldspathic greywacke and an arkosic wacke (Pettijohn et al., 1972).

Fig. 9.2-1. *a) Views of Hjemmeluft. The weather station is located on the western side of the bay. b) The trial area with insulation matting lies just above the weather station. The majority of the rock samples investigated were collected around the weather station. Additional samples were collected from the peninsula on the opposite side of the bay.*

Fig. 9.2-2. Rock samples were collected at regular intervals from a) the shoreline and b) up to the lower path.

Steep fractures cross the majority of surfaces with rock art (Fig. 9.3.1-3). Three principal orientations of fractures have been recorded; 102/48° N-NE; 010/68°W and162/40°E. Subvertical fractures with lesser lateral extent are oriented at ~050°.

9.3.2 Weathering

As a result of postglacial chemical weathering of the least resistant minerals, the rock surfaces at Hjemmeluft have developed an outer porous and bleached rind (Fig. 9.3.2-1). In the 12 rock samples investigated so far, the thickness of the weathered zone varies from about 2 to 7 mm, and the average thickness is 3.9 mm. Generally, it is the solution of sericitised feldspar that creates the porosity of the rock surfaces (Fig. 9.3.2-2). Exceptions are places where the rock contains carbonate, where the weathered zone is thicker than elsewhere. On the coast, there is practically no weathered zone at all (0.1 mm). It is not clear whether this is due to salt spray or postglacial uplift (see also 5.2).

As noted above, the rock surfaces are cut by fractures with different orientations and extents (9.3.1). Adjacent to fractures, the weathered crust is commonly detached from the rock beneath over areas of several cm^2 in extent, and in several places the weathered crust has flaked off (Fig. 9.3.2-3). This is probably the result of water lying in the fractures and saturating the pores in the weathered rind. During frosts this will result in fragmentation and flaking. As a result, sections containing rock art have disappeared (Fig. 9.3.2-4), while others are threatened by flaking nearby (Fig. 9.3.2-5) or by detachment of the weathered crust. Scars from flaking are commonly hidden beneath a covering of lichen (Fig. 9.3.2-6). Crosscutting fractures have resulted in the partial detachment or loss of large flakes. This is particularly serious where this occurs close to individual pieces of rock art, and in places parts of carvings are missing as a result (Fig. 9.3.2-7).

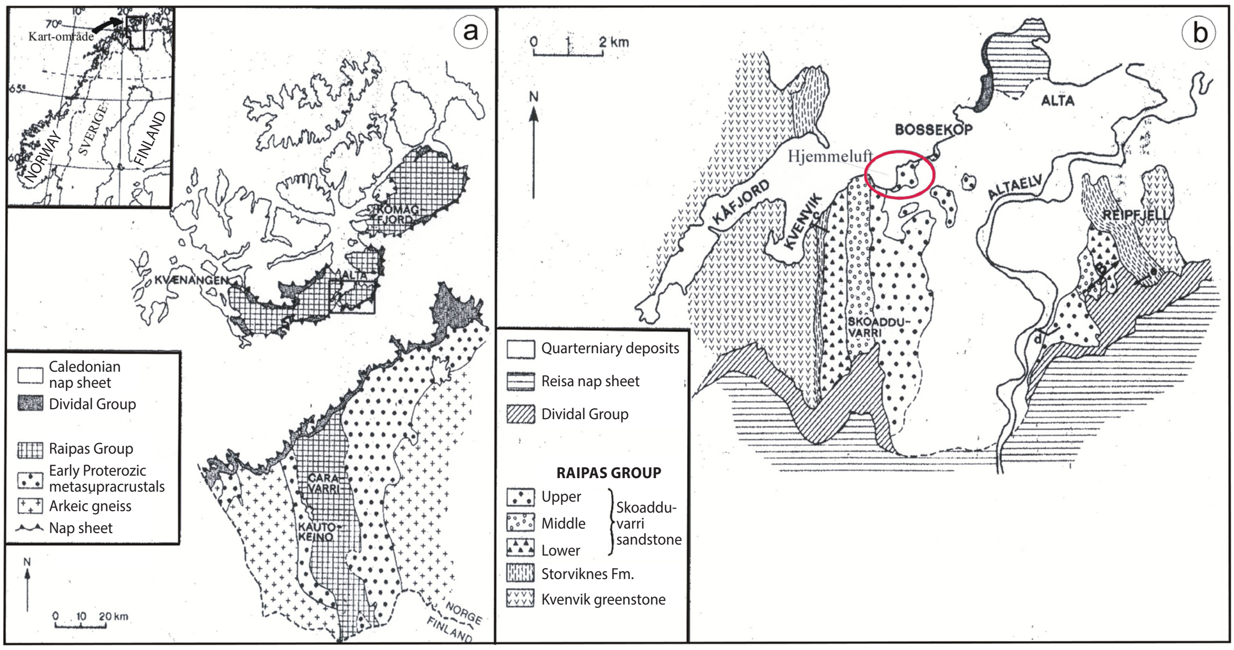


Fig. 9.3.1-1. *a) Geological map of V-Finnmark. B) Geological map of the Alta-area illustrating the Skoadduvarri sandstone dispersed on both sides of the Alta-valley. The Hjemmeluft-area is marked by red colour. (Modified from Bergh & Torske, 1986).*

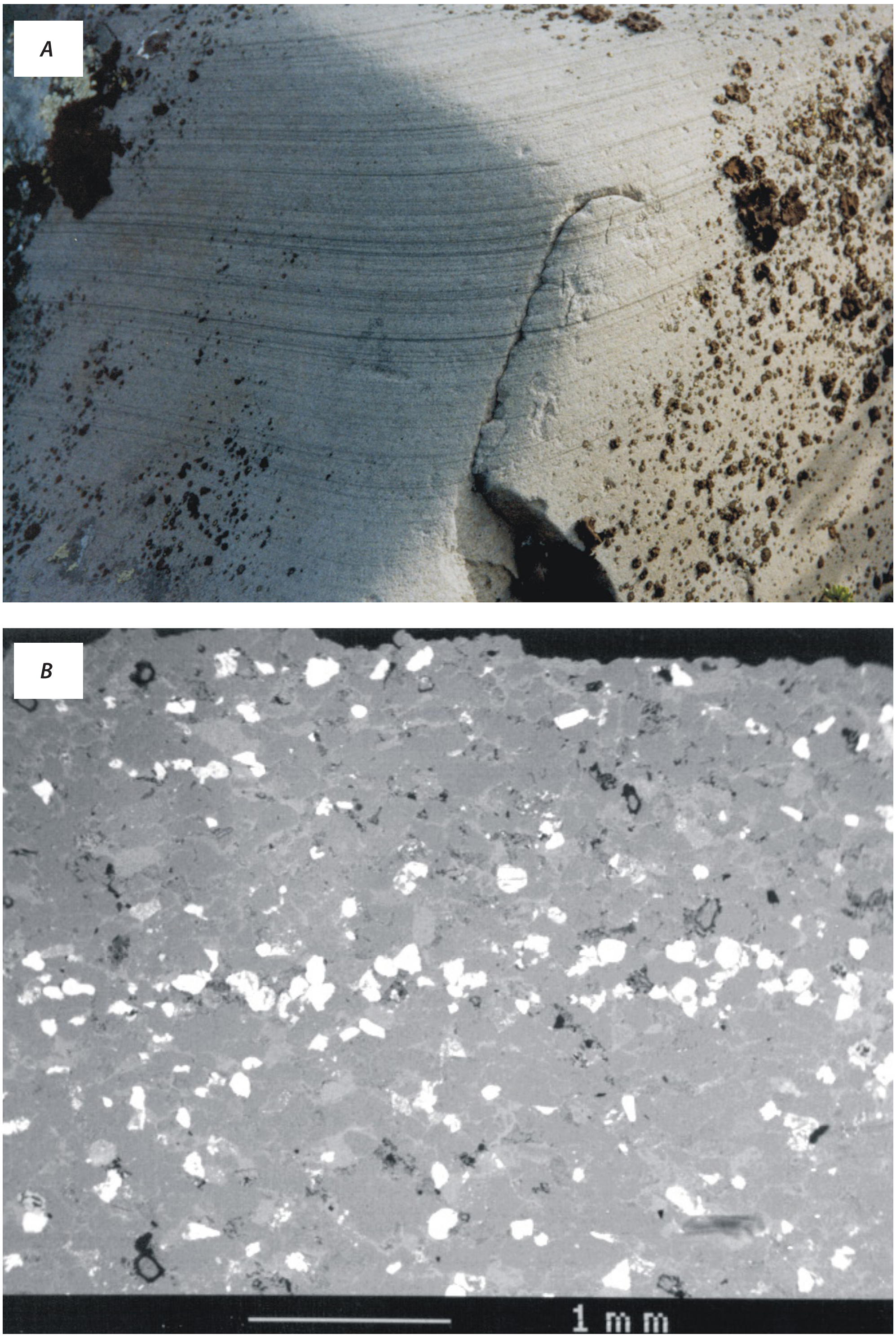


Fig. 9.3.1-2. *a) Alternation of laminae with different contents of Fe-Ti oxide. b) SEM/BSE-image of laminae rich in Fe-Ti oxide.*

Fig. 9.3.1-3 *Steep fractures cross the majority of rock surfaces decorated with rock art. The fractures have three principal orientations; 102/48 N-NE; 010/68 W and 162/40 E. Fractures with lesser lateral extent are subvertical and trend ~ 050°*

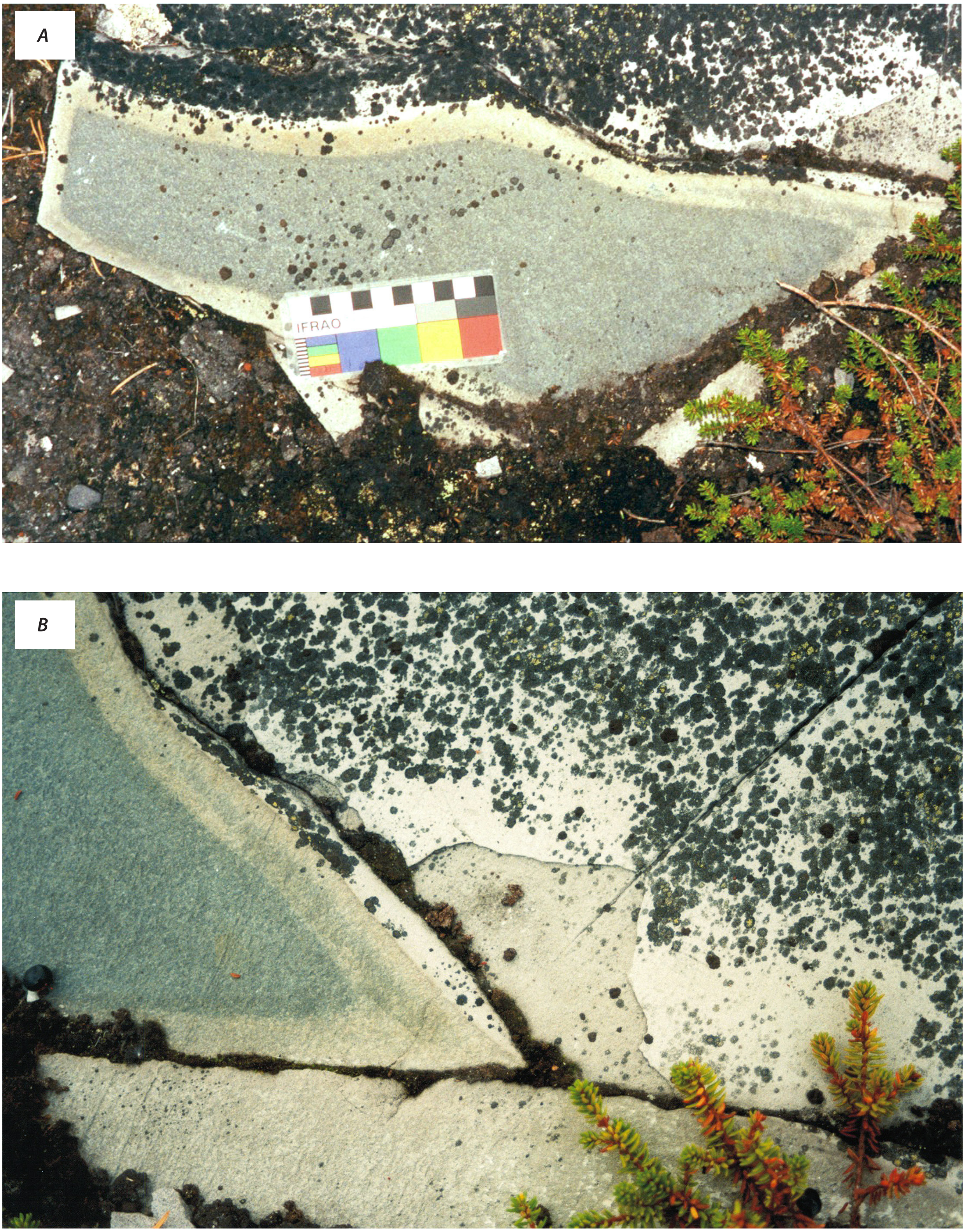


Fig 9.3.2.1 The lichen colonization on newly exposed rock surfaces is fast. The pictures show the changes on a rock surface from 1997 (a) to 2000 (b).

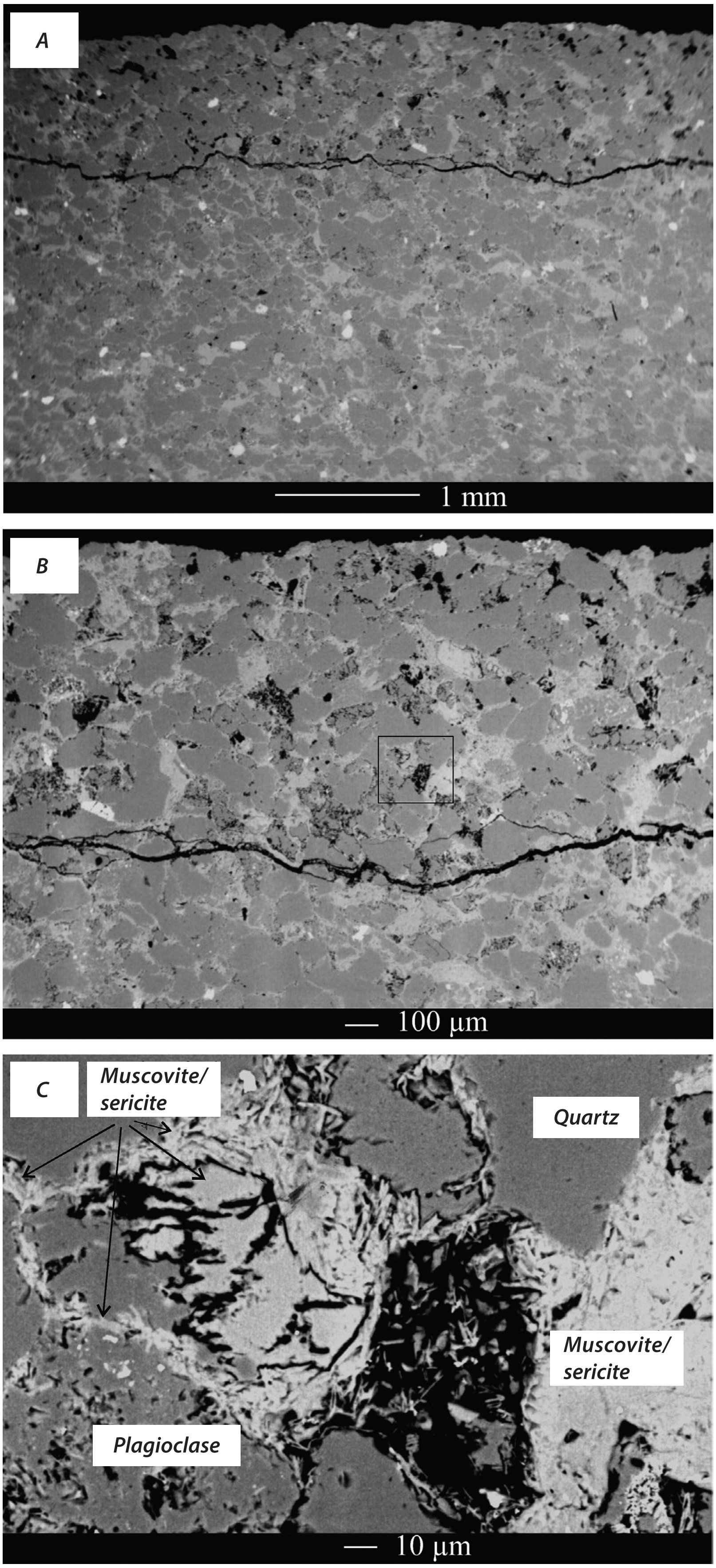


Fig 9.3.2-2 *Cross section through the weathering zone*

Fig 9.3.2.3 *Crosscutting fractures have resulted in the partial detachment or loss of large flakes*

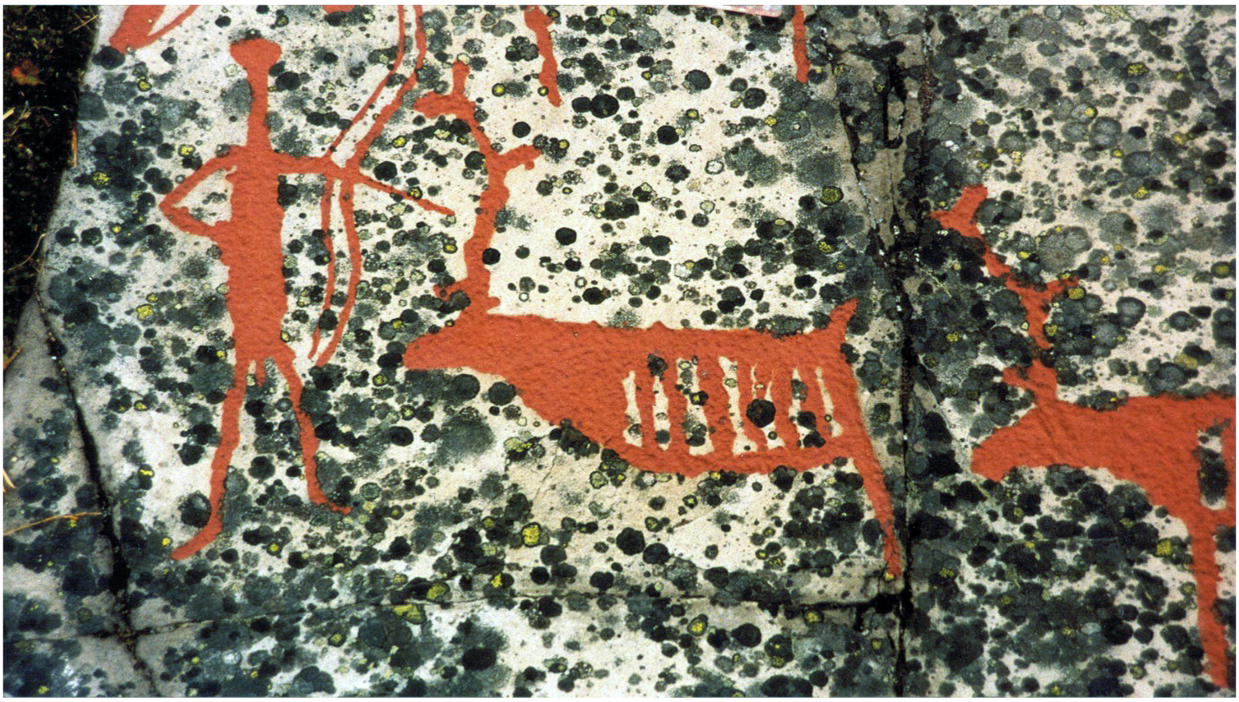


Fig 9.3.2.4 *Parts the image in the middle has been lost due to cracking and exfoliation*

Fig 9.3.2.5 *Flaking of the weathering zone along fractures in the vicinity of rock images*

Fig 9.3.2.6 *Scars from flaking are commonly hidden beneath a covering of lichen*

Fig 9.3.2.7 *In areas with crossing fractures large pieces of the rock are missing*

9.4 The current lichen flora at Hjemmeluft

A general recording of lichens on surfaces with rock art has been carried out at Hjemmeluft. Different stages in a succession can be seen as the surfaces have been exposed at different length and or previously been treated with chemicals. Fig. 9.4.1-1 shows the extent of lichen colonisation on a surface during a period of three years. As the picture documents, newly exposed rock surfaces are quickly covered by lichens. Fig. 9.4.1-2 shows a surface that has been exposed for 20 years. Surfaces that have been exposed for longer periods are totally covered in lichens. Different stages in the succession at Hjemmeluft have also been described by Bjerke (1999).

A representative lichen-covered surface in the area investigated at Hjemmeluft is shown in Fig. 9.4.1-3. On these surfaces there is a large amount of foliose lichen among the crustose lichen. One common and easily recognised foliose lichen is the yellow-green *Arctoparmelia centrifuga*, which forms characteristic concentric rings. In addition, there are also some umbilicate lichen, including *Umbilicaria hyperborea*, *Umbilicaria proboscidea*, and *Umbilicaria torrefacta*.

Other common foliose lichens on the rock surfaces are *Melanelia stygia*, *Parmelia omphalodes*, and *Parmelia saxatilis*. The only fruticose lichen that is present on the surfaces is the brown-black *Pseudephebe pubescens*. *Pseudephebe pubescens* is tightly branched, and forms small and irregular but widely dispersed mats.

The crustose lichen *Ophioparma ventosa* has also been recorded on surfaces at Hjemmeluft, but is not as abundant as in the Vingen area (Fig. 9.4.1-4). In places there are large areas covered by a black thick and characteristically crustose lichen; *Allantoparmelia alpicola* (Fig. 9.4.1-5). Other crustose lichens that are easy to recognise are species that belong to the yellow crustose map lichens, for instance *Rhizocarpon geographicum* and *Rhizocarpon macrosporum*. A number of other species in this family, such as *Rhizocarpon alpicola* and *Rhizocarpon eupetraeum*, have also been recorded. These have, however, a brown-grey colour and are not easy to identify in the field. Other recorded crustose lichens include *Aspicilia laevata*, *Lecidea fuscoatra*, and *Rinodina atrocinerea*.

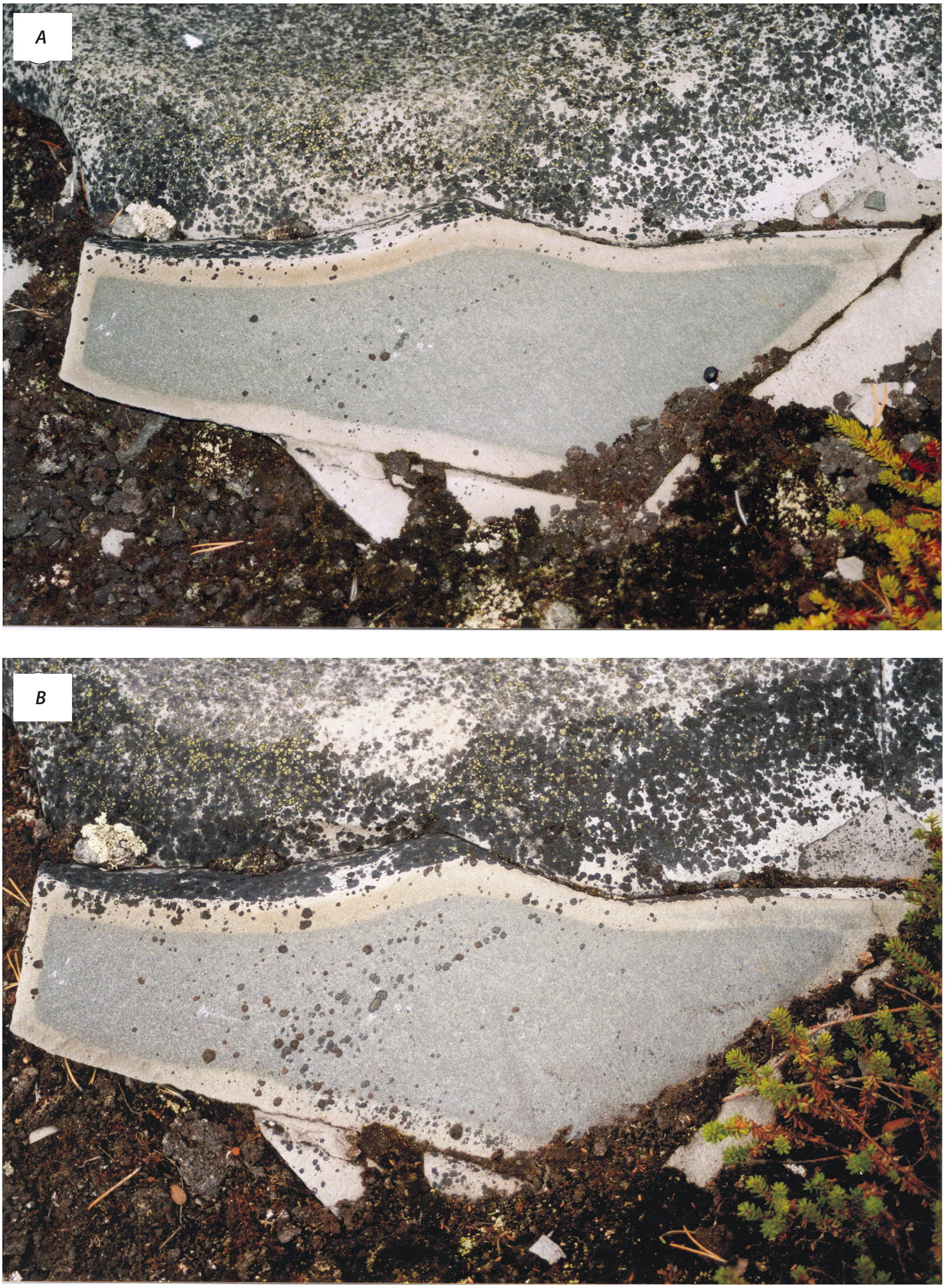


Fig 9.4.1-1 a and b High amounts of foliose lichen among the crustose lichen at Hjemmeluft, Allta

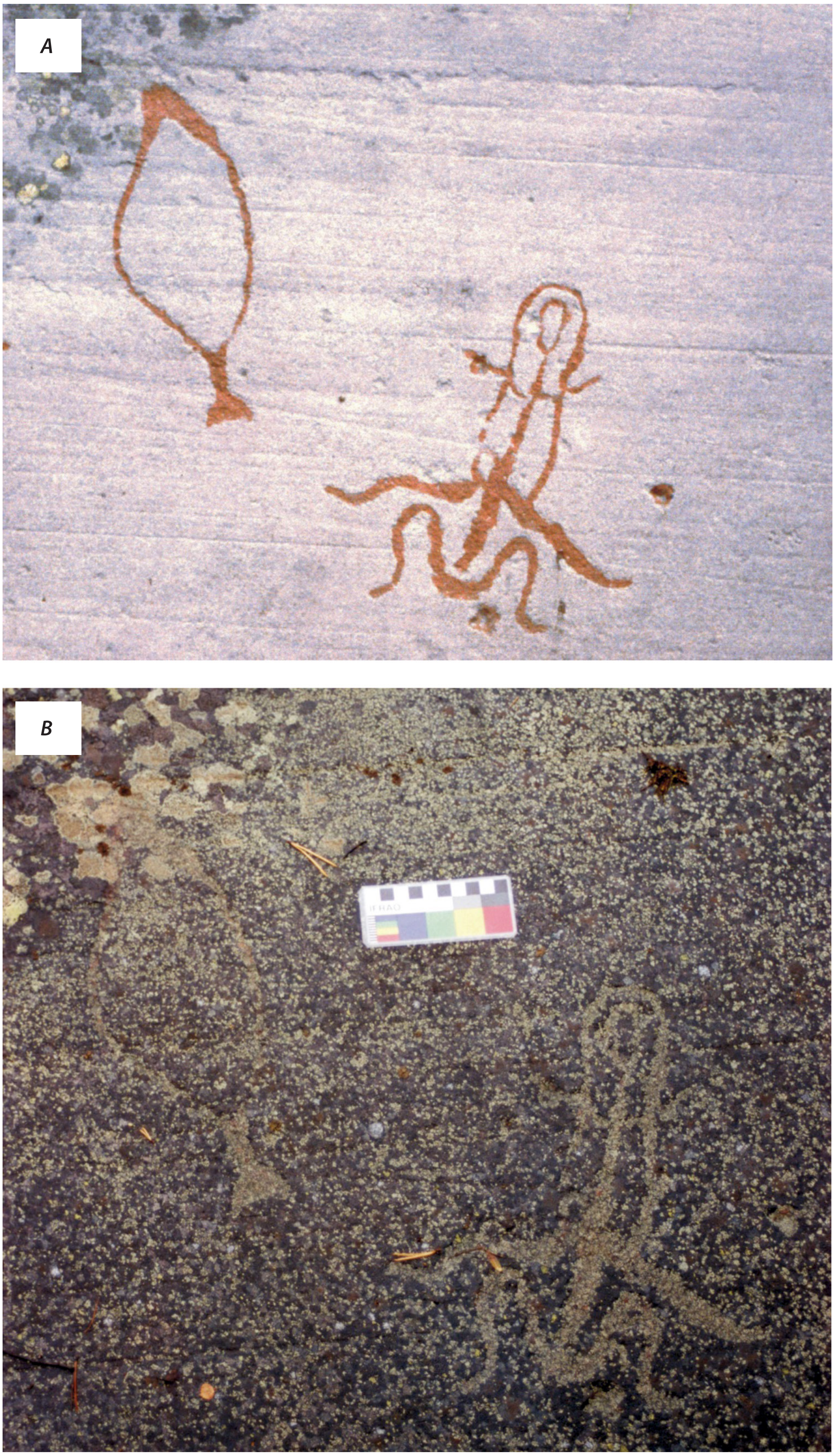


Fig 9.4.1-2 Lichen colonization of a rock surface after 20 years. a) Clean rock surface in 1981 (photo: J. Mikkelsen). b) The same rock surface in 2000.

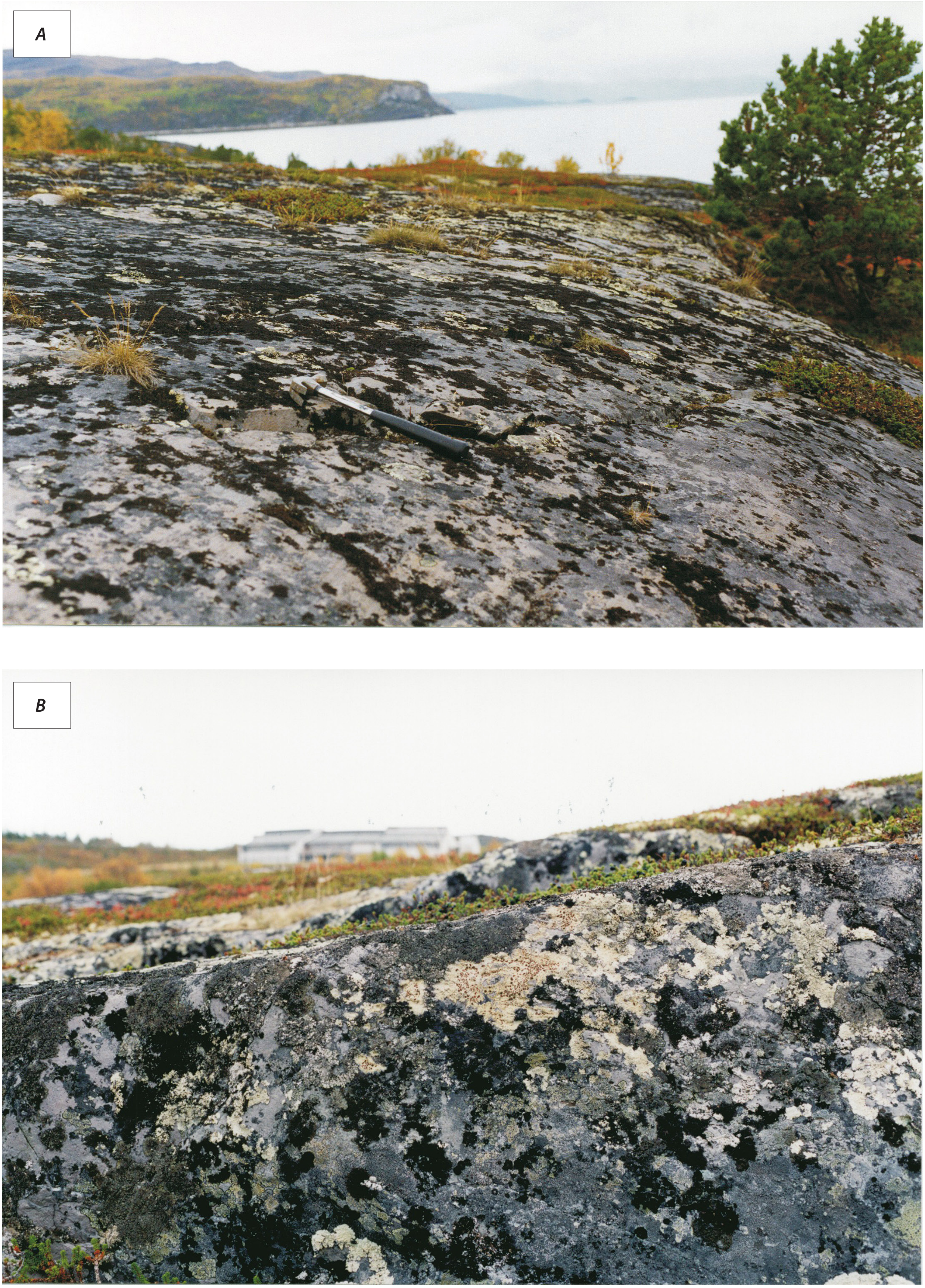


Fig 9.4.1.3 High amounts of foliose lichen among the crustose lichen at Hjemmeluft, Allta

Fig 9.4.1-4 *Ophioparma ventosa on a rock panel at Hjemmeluft*

Fig 9.4.1-5. *Some areas are heavily dominated by the black thick crustose lichen; Allantoparmelia alpicola*

In cracks and depressions between surfaces there are some lichens that generally do not appear on the surfaces. Examples of these species include the fruticose lichens *Bryocaulon divergens*, *Cladonia rangiferina*, *Cladonia stellaris*, *Ochrolechia frigida*, and species in the *Stereocaulon spp*. family, as well as the foliose lichen *Cetraria nivalis*.

9.5 Weathering effects of lichens

The crustose lichen *Ophioparma ventosa* and the foliose lichen *Arctoparmelia centrifuga* were selected to investigate the rock beneath lichen thalli with respect to weathering and infiltration with biological material. Since equivalent analyses were carried out beneath *Ophioparma ventosa* at Vingen, this species was also investigated at Alta. The foliose lichen *Arctoparmelia centrifuga* is very common in the area and was therefore selected as an interesting species in this study.

Different lichen growth forms are attached to the substrate in different ways. Crustose lichens are tightly attached to the substrate with their lower surface, which are typically ecorticate, while foliose lichens are leaf-like and typically attached to the substratum with rhizines. Fruticose lichens are hair-like, strap shaped or shrubby, and are attached to the substratum only by the thallus base (Bjelland 1997). Very few samples have been investigated, but the results show that the depth of weathering is slightly greater under O*phioparma ventosa* than beneath *Arctoparmelia centrifuga*, 4 and 3 mm respectively. More samples are needed, but the results are in accordance with other studies, which indicate that crustose lichens are more effective in the degradation of the rock than the two other growth forms.

9.5.1 Climate

The field at Hjemmeluft (69°57'N, 23°13'E) is situated close to the sea but, mainly because of the northern position, the climate is nevertheless very cold in winter and warm in summertime. The normal mean temperature in January and July are respectively -8.7 and 13.4 °C. Normal annual precipitation is 400 mm, distributed almost evenly throughout the year. The growing season is short, from the end of May to the start of September, and in the rest of the year there is snow cover in shorter or longer periods. Even if the precipitation amounts are small, the winter climate is permanently cold and the fields are covered with a stable snow cover for most of the winter from December to April. In the transition periods between autumn and winter and between winter and spring, there may be frequent temperature variations between plus and minus degrees, as shown in Tab. 9.5.1-1.

Recordings of temperature at the permanent meteorological station at Alta indicate that the average number of days with frost in October has decreased over the last 40 years, from 18 to 14 days. For November and December, only minor similar variations are found in this period, as shown in Fig. 9.5.1-1. The number of days with freezing/thawing episodes in October and November has only small year-to-year variations, but a smaller increase in the number of these episodes is found in December. This may be explained by a trend towards a more unstable temperature climate in this month. A similar temperature development is found for the months of April and May.

Table 9.5.1-1 *Normal values of monthly precipitation amounts, number of days with snow cover and days with freezing/ thawing episodes (T±) at Alta.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	32	25	23	17	20	33	54	49	38	39	34	36
Snowcover	30	28	31	28	7	1	0	0	1	10	22	28
T±	5.8	4.9	9.1	14.3	9.3	0.2	0	0.1	2.0	12.6	11.8	12.0

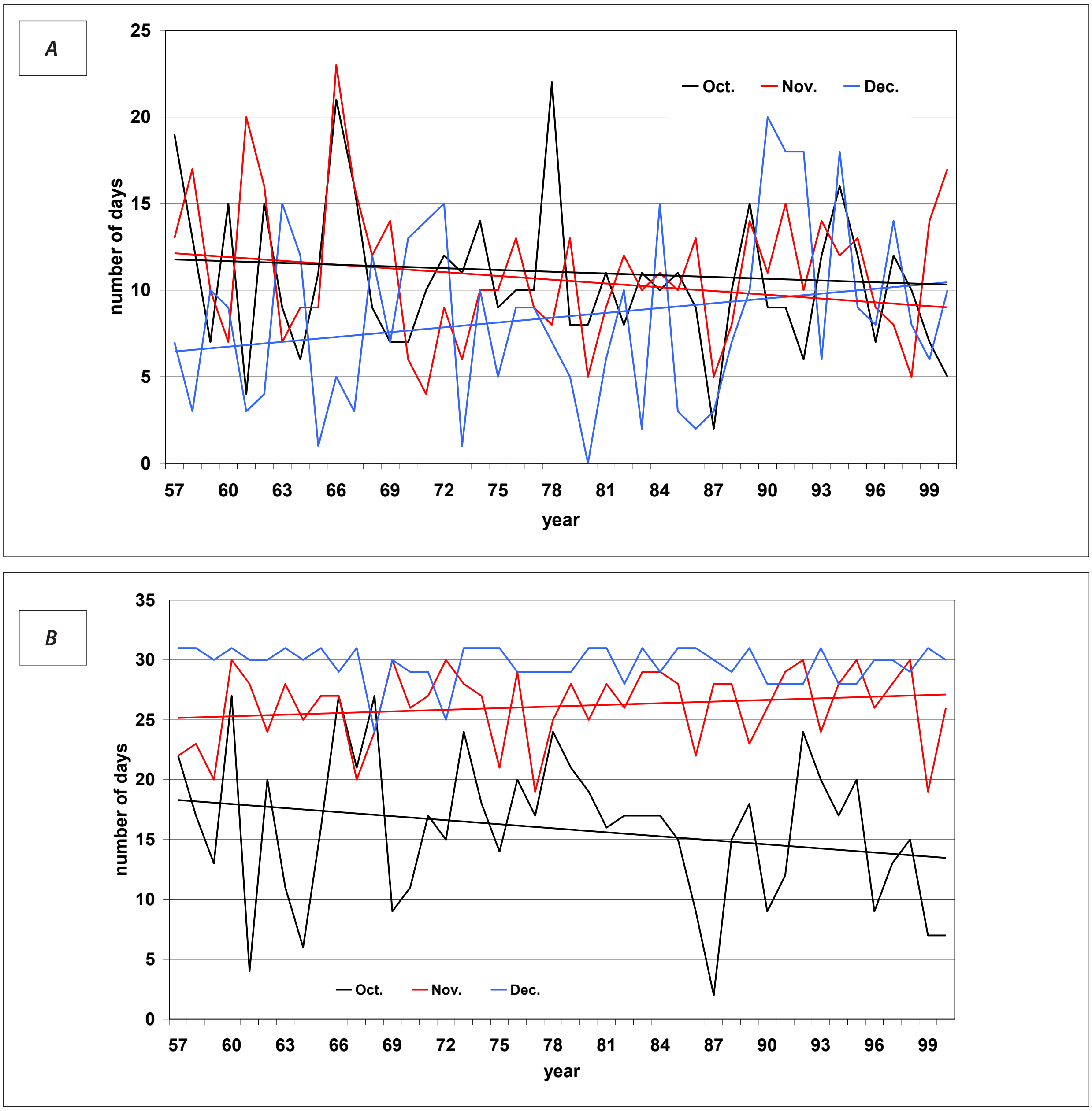


Fig. 9.5.1-1a) and b) *Number of days with frost (T < 0ºC) and with freezing/thawing episodes at Alta in the months October, November and December, 1957–00. For each month (graph) is drawn a line indicating the trend of the variations in the numbers in this period.*

9.5.2 Climate investigations

An automatic weather station was installed in Hjemmeluft in 1997. The standard program of measurements was mainly identical to the program in Vingen, and included measurements of air temperature, humidity, wind speed and precipitation (Appendix A). From the autumn of 1998, additional measurements were made of the temperature and humidity under the mats. Close to the station on a rock field, 3 rock wool mats measuring 1.2 x 1.2 m and 5, 10 and 15 cm thick were installed, and sensors for measuring temperature and humidity were placed on the rock surface under each of the mats. Also, the temperature was recorded on an uncovered rock surface and on the rock approximately 4 cm below. In September 2000 one of the mats (10 cm) was replaced with a Plastazote mat.

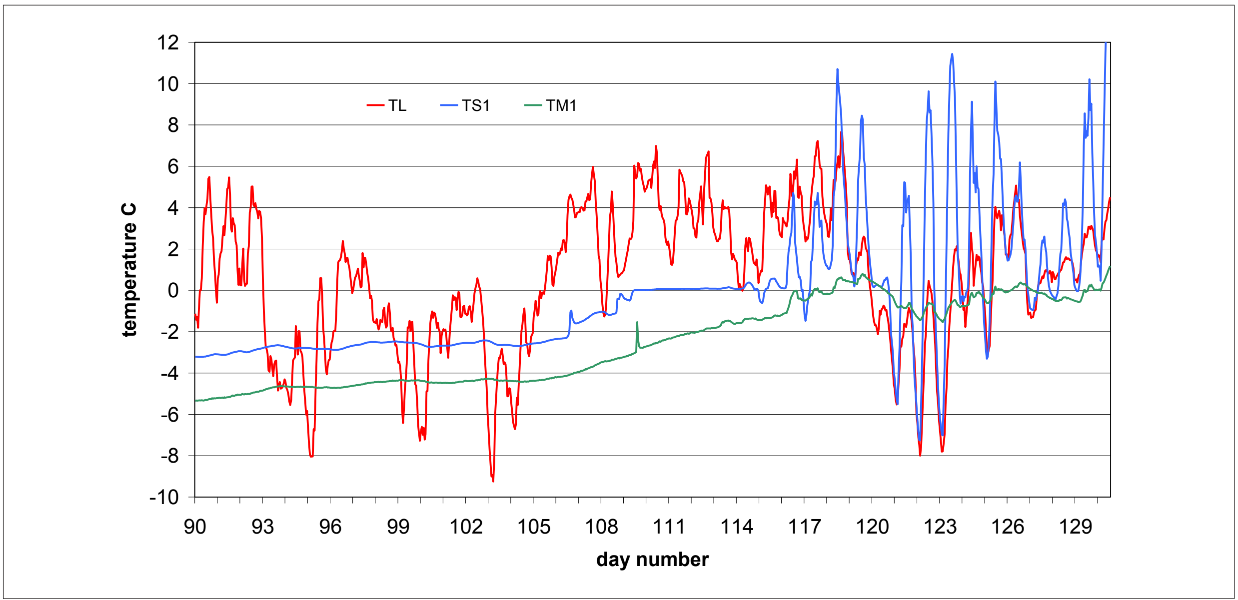


Fig. 9.5.2-1 Temperature measurements in air (TL), at uncovered rock surface (TS1), and at rock surface covered with a 5 cm rock-wool mat (TM1), in the period March 31–May 20 1999. The rock surface has snow cover until April 19 (dno 109), and all snow is melted May 25 (dno 115).

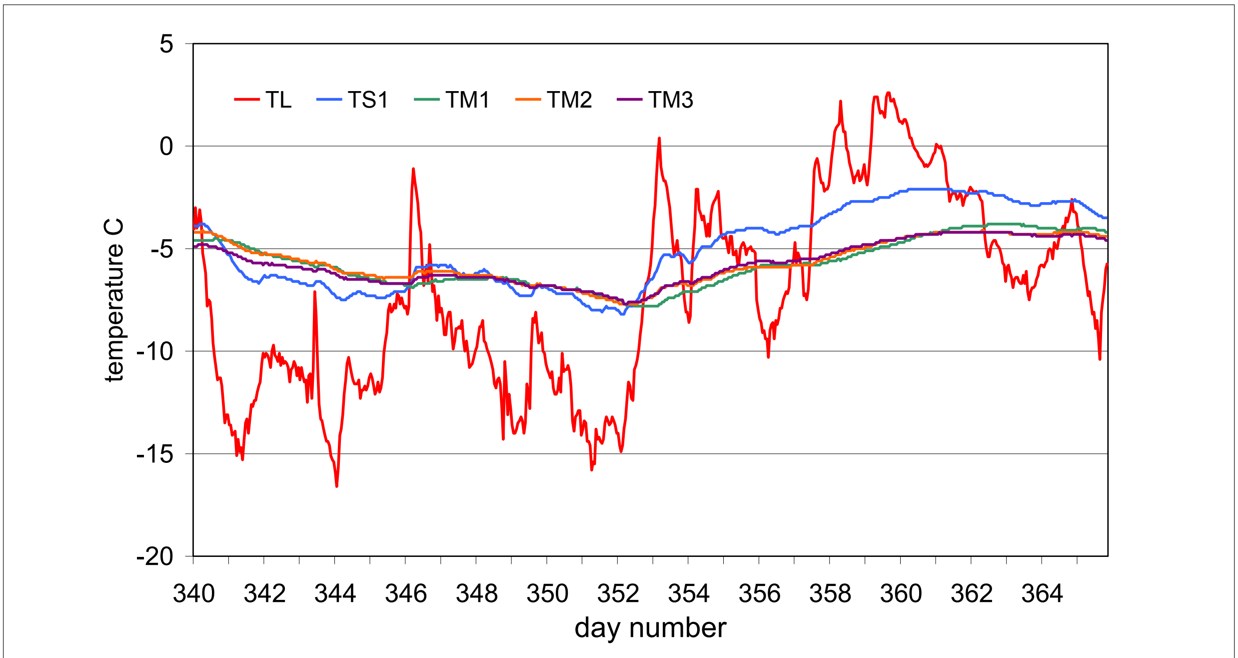


Fig. 9.5.2-2 Measurements of temperatures in air (TL), at uncovered rock surface (TS1), and at rock surfaces covered with 5 cm rock-wool (TM1), 10 cm rock-wool (TM2), and 15 cm rock-wool (TM3), in the period December 6 – December 31 1999. The rock surface is partly covered with snow.

The variations of local temperature in the winter are much higher and faster than at Vingen, and it is not unusual to find temperature variations of more than 20 °C in 24 hours. Most episodes with freezing/thawing at Alta are found in November/December and in March/April.

Despite relatively small amounts of precipitation, the field will be covered by snow for most of the winter, but in October–December and April–May, when we find the most frequent variation in temperature between plus and minus degrees (Tab. 9.5.1-1), the fields are snow-free for certain periods of time.

Fig. 9.5.2-1 shows a comparison of temperatures in the air (TL), on an uncovered surface (TS1) and on a rock surface covered with a 5 cm mat (TM1) for the period from 31 March (dn 90) to 10 May (dn 130) 1999. In the first part of the period, there is snow cover and obviously very little influence of the air temperature on the temperatures of the rock surfaces under the snow cover. On 19 April (dn 109) the snow has obviously started to melt, and the temperature on the uncovered rock surface is almost stable at 0 °C in 4–5 days. When all the snow has melted away, the temperature on the rock surface varies between -8 °C at night and 10–12 °C in the daytime. The diurnal temperature variations under the mat are much slower, and when all the snow has melted, only 1–2 degrees. Temperatures at the same points in a period in November 1998 are shown in Fig. 9.5.2-2. Now there is no heating of the surface from sun radiation, and without snow cover the temperature variations, both in the air and on the uncovered rock surface, are mainly from advected air masses. Under the mat (TM1) the temperature variations are relatively small and lower than 0 °C even when the temperature in the air is plus degrees.

In the autumn of 2000, the weather varied with the first frost in the beginning of November and with only poor snow cover in the rest of the year. The temperature effect of the mats on the surface temperature of the rock was obvious, although no significant difference was found between the different types of mats. The variations in temperature on the uncovered rock surface were between 0 and -10 °C, and the unequal snow cover had an significant effect on the temperature of the uncovered rock surface only for shorter periods. The variations of the temperature under the mats were much smaller, but following the same pattern with a time lag of approximately 2 days. In this period there is an indication that the 5 cm-mat has a poorer isolation effect than the other mats, although on the whole the differences are relatively small.

9.6 Summary and conclusions

This area has a climate with both relative cold winters and high summer temperatures. Average annual precipitation is 400 mm and the precipitation is evenly distributed throughout a year. For most of the winter, from December to April, the fields have a permanent insulating snow cover. In the autumn and spring, the air temperature frequently changes between plus and minus degrees and the rock surfaces are exposed to major and rapid temperature variations. Most frequent episodes with freezing and thawing are found in the autumn and spring when there is no permanent snow cover. Over the last 40 years there has been a trend towards more unstable weather type in the transition period between the autumn and winter (December), which has resulted in an increasing number of these types of episodes during this period.

9.7 A comparison with Vingen

9.7.1 Climate

There are major differences between the climates in these two locations, as illustrated by the monthly temperature normals shown in Table 9.7.1-1. Vingen is situated in an area with a coastal climate with mild winters and cool summers, and the temperature normals are 2.8 and 13.1 °C for January and August respectively. The climate in Alta is of a more continental type with cold winters and relatively high summer temperatures. The temperatures normals for December and July are -8.7 and 13.4 °C respectively. In January, the average temperature is 11.5 °C lower in Alta than on the coast of Western Norway, while it is almost one degree higher in July. In Vingen, the most frequent freezing/thawing episodes are found in mid-winter (January), while in Alta similar episodes are most frequent in late autumn (October–November) and in early spring (April–May). It is also typical for the two climates that temperature variations in short periods (days) in Alta may be much greater than in Vingen.

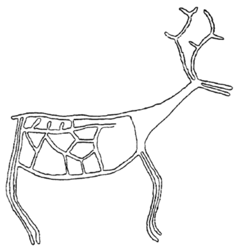
Table 9.7.1-1 Temperature normals for Ytterøyane and Alta.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Ytterøyane	2.8	2.3	3.0	4.5	7.8	11.0	12.5	13.1	11.1	9.1	5.8	3.7	7.2
Alta	-8.7	-7.9	-5.2	-0.6	4.8	10.0	13.4	12.0	7.2	1.6	-3.6	-7.0	1.3

The average amount of annual precipitation in Alta is only 15–20% of is the amount recorded in the Vingen area, distributed fairly evenly over 93 precipitation days in a year. In Vingen the precipitation varies more throughout the year, with the largest amounts in the autumn and winter, and an average of 213 precipitation days. In Alta, a stable and cold winter climate gives a permanent snow cover during the period from December-April. Snow cover is an effective thermal insulator, and it prevents major and rapid temperature variations in the rock surface. In Vingen there are normally only a few days with snow cover during the winter, and in cold periods the temperature variations may be higher on a rock surface than in the air.

9.7.2 The temperature effect from covering by mats

From the tests made with different types of mats, it was found that the number of episodes with freezing and thawing at the rock surface under the mats was reduced considerably. In Alta, the temperature effect of a mat cover is obvious in spring in the snow melt period, and in the autumn before the snow cover becomes permanent. In the period with a permanent snow cover, no significant effect from a mat cover has been found. In Vingen, only short periods with snow cover may occur during the whole winter from October to April, and a mat cover will consequently be useful throughout the whole season.



CHAPTER 10

Trond Klungseth Lødøen and Gro Mandt

EXPERIENCES AND RESULTS

10.1.1 Objectives and Achievements

During the years the "Vingen project" has existed, several of the project's objectives have been achieved, while others including various measurements and analyses of test sites will have to run over a period of several additional years before measurable results can be obtained. This underscores the importance of long-range planning and continuity in the effort.

During the first phase of the project, it was natural to place primary emphasis on assessing the *degradation factors*, because any remedial measures taken must be based on knowledge about the degradation processes. At the same time as we acquired an awareness of the present state of degradation and more knowledge about the deterioration processes, we also gained experience based on tests of the measures taken, and this resulted in the formulation of new, more specific questions and issues. One of the advantages of the Vingen project is that co-workers who have been associated with different institutes of the University of Bergen have been given access to advanced analytical equipment and methods for use in research.

Several of the methods have also proved to be very informative for testing various *conservation measures*. The results of the Vingen project provide clear indications of what can and cannot be implemented in terms of isolated conservation methods and specific measures. We now already have a sound basis for evaluating different conservation measures, and the development of methods and equipment/tools that can improve and promote efficiency in the future will remain an important concern. This applies, for example, to *protective covering,* for which various types of materials are being tested. This seems to be a beneficial method for preserving damaged or particularly vulnerable sites in both the short and the long term. The sites will therefore be able to lie "in storage" until new and better conservation methods are developed in the future. When it comes to direct treatments applied to the rock panels, we are of the opinion that it is necessary to remain cautious – perhaps for many years to come – towards implementing any major conservation measures, and that instead it is necessary to limit measures to the *emergency conservation* of particularly damaged sections in order to prevent further damage.

10.1.2 Interdisciplinary Collaboration

The collaboration that has been established for the "Vingen project" between archaeological/conservation professionals and the other scientific disciplines involved has fully demonstrated the importance of this type of interdisciplinary cooperation in the effort to preserve the rock art. The collaboration has been one of the University of Bergen's premises for the rock art conservation project from the outset during the 1970s, and it has been further corroborated during the project period. Tasks and measures related to degradation and remediation have been planned and carried out in close cooperation between the different disciplines. The archaeological/conservation issues have been the basis for the actions which have been implemented, and the scientists have contributed with their insight and experience, in addition to completing analyses for the testing of newer and older methods of conservation.

10.1.3 Competence Development and Recruitment

The knowledge and experience acquired during the Vingen project has proved to be directly applicable to other areas of Norway, as well as to rock art sites in foreign countries. Although the collaboration between natural science personnel and archaeology/conservation specialists in the University of Bergen's project has primarily focused on Vingen and to a certain extent on Alta, some of the co-workers in the project have had additional tasks relating to other rock art localities. For example, there has been a need for scientific expertise in conservation matters involving other parts of the area served by Bergen Museum (Hordaland, Sogn og Fjordane, Sunnmøre), especially in the fields of geology and botany. Some of the co-workers in the project have participated in the interdisciplinary, Norwegian-Swedish collaboration INTERREG II A, and geologists and botanists in the Vingen project are represented in the "*Norwegian professional group for rock art conservation*", an advisory, interdisciplinary group recently appointed by the Directorate for Cultural Heritage and given the task, among other things, of collecting and coordinating results from the physical measures taken to preserve the rock art.

In the continuing effort to identify methods and measures that can preserve and work preventively in the long run, we consider it crucial that this group competence within the framework of the rock art project be maintained – not only out of concern for the rock art located in Bergen Museum's area of operations, but sites elsewhere throughout the country. With this in mind, it is therefore very uplifting that the Directorate for Cultural Heritage took the initiative, at the end of 2001, to prolong the *interdisciplinary natural science competency* in the field of rock art conservation that has been built up through the Vingen project.

In terms of retaining acquired competence and recruiting new personnel into the professional field of *rock art conservation*, the rock art project does not face as bright a future. We consider it alarming that during the years the Directorate's national rock art project has existed, not enough effort has been made to retain the competence built up in the field. On a national basis, the existing knowledge today is highly limited, and in the long run, professionals in the field of rock art will face difficult problems, since permanent employees with a high level of competence are already approaching retirement age. During the years that the University of Bergen has been involved in the Directorate's rock art project, it has been relatively easy to hire and train archaeology students in the various phases of conservation work. However, as these students – who are highly capable – complete their degrees, they will naturally be attracted by job opportunities that last longer than a few months' field work during the summer. Unfortunately, it has proved to be more of a problem to hire people (students or postgraduates) with a background in conservation, partly because the pool from which to recruit is small, and partly because budgets have set limitations. In summary, therefore, there is an urgent need to build up and retain competence in the field of rock art conservation on a nationwide basis.

10.2 Restructuring of the Project

Over a period of several years, a process of reorganization has been implemented at the University of Bergen involving Bergen Museum and the Institute of Archaeology. The reorganization was completed on 1 January 2002, and entails, among other things, that the teaching institute has been separated from Bergen Museum both administratively and financially. Along with a number of other fields in the areas of cultural history and natural history, the externally financed museum activities involving archaeology will be organized under Bergen Museum, while the new Institute of Archaeology will fall under the Faculty of Humanities. For several years, those of us who have worked to preserve rock art in Bergen Museum's area of operation have discussed the possibility of integrating the natural science portion of the "Vingen project" with the archaeological sub-project. Reorganization has made these plans realisable. The main rationale is – as shown above – that scientific competence is needed and necessary in other contexts and in other localities than Vingen's. Although the two projects have always cooperated closely and well together, we consider that it would facilitate coordinating measures if the two were "under the same roof". The most natural restructuring would be to organize the project under the auspices of Bergen Museum, which is defined as an interdisciplinary institution and which, in addition, has management responsibility pursuant to the Act concerning cultural monuments. The project will be organized in accordance with a model that is established for large, externally funded projects at Bergen Museum, entailing a main project and several sub-projects, a project manager and a steering committee. In this way, the more research-oriented portions of the project, such as environmental monitoring, research into factors causing degradation and development of methods, will be included in one sub-project, while documentation, care and management planning, etc. will be part of another.

10.3 Future Work Entailed in the Project

10.3.1 Short-term Goals and Measures to be Taken

Since solid, basic knowledge concerning the deterioration process has now been acquired, as well as experience with these types of issues and related research, it is very important that these factors and problem areas be further investigated. One important task for the remainder of the project period, therefore, will be more comprehensive and concentrated efforts relating to the use of materials and practical implementation of various methods and measures. Emphasis will be placed on the testing of various types of protective covering materials and the establishment of procedures for practical implementation: material testing; trials on protective covering; testing of types of paints/solutions; techniques for cast moulding.

The project will follow up and complete the natural scientific examinations that have not yet been completed: surveys/measurements of climate; test sites for the removal of lichens; protective covering; the effects of grazing and liming on the chemical parameters of the soil and on vegetation. It is desirable to begin laboratory studies of mineral dissolution in order to gain a better knowledge of the mechanisms at work in lichen degradation, and of the effects of seawater and turf. By conducting an experiment to study the nutritional intake of lichens, it will be possible to simultaneously acquire better knowledge concerning the degradation of lichens.

During the coming years, the project will also focus on the formulation of the scientific results obtained through the "Vingen project" in "understandable" language that will communicate to laymen. It is important that the results are made accessible to the various agencies within the field of conservation of cultural monuments, so that the knowledge may be of practical application in the field when conserving the rock art.

10.3.2 Considerations for Long-Term Measures to be Taken

One important tool in the effort to preserve rock carvings and other cultural monuments in Vingen into the distant future is the *care and management plan* which is in preparation and which, according to the deadline set, is to be completed on the 1st of February[1]. As part of the plan, schemes will be devised for the follow-up and supervision of the cultural monuments. This is of paramount importance for long-term preservation. It is pointless to invest major amounts of resources in various preventive measures if these are not followed up at frequent intervals. It has been documented, for example, that there is a rapid rate of overgrowth and degradation in Vingen, and this underscores the importance of continual grazing.

Over the period of many decades, it has been repeatedly pointed out that the state of damage in Vingen is alarming. As we have delved more deeply into the problem, we have seen the damage more clearly and we have become aware of damage that we would previously not have been able to discern. It has become increasingly clear that *documentation* in as many different ways as possible is the best form of ensuring the future existence of the rock art, a view that the Directorate for Cultural Heritage has also adopted for the conservation effort. Many of the rock art sites are in such poor condition that it is doubtful they can be preserved for posterity at all. If they are on the path to no return, then thorough and manifold documentation is the only possibility we have for preserving the potential knowledge of the sites for future generations. In this respect, testing of new methods for documentation will be an important task for the coming years.

The large extent of damage entails that the stewards of cultural monuments will have to make difficult decisions in terms of *prioritizing* conservation measures to be taken. In many cases, this may be a question of deciding whether it is justifiable to sacrifice time, money and labour in an attempt to try to conserve the sites in poorest condition. On what criteria should these priorities be based? The issue opens for an ethical discussion at national (and perhaps even international?) level.

Another area that has presented problems in relation to the preservation of the rock art is the pressure from *the tourist sector* and local authorities to make the sites accessible to the public. The ambitions of local parties, in most cases, to turn the rock art into a tourist magnet overwhelmingly exceed the maximum tolerance levels that the stewards of cultural monuments must necessarily set if they are to do their jobs properly as

1 The care and management plan is being written by Melanie Wrigglesworth, M.A., on commission from Sogn og Fjordane county administration.

conservationists. The stage is set for conflict, and in this respect, we strongly urge discussion – to include among other things the subject of priorities – at the highest levels of power!

The national Bergkunst project ends in 2005, and signals received from the Directorate for Cultural Heritage indicate that the institutions will have to assume supervision and responsibility for "their" rock art localities. Of the five regional or managing museums, four are associated with universities. From all appearances, it seems that the universities will be in an extremely difficult financial situation during the years to come, with increasingly less funding from the government. At the same time, there is a discussion over the issue of commissioned work carried out by the universities, whereby external funding for all types of commissioned tasks/research is stipulated as a prerequisite. This prerequisite will also apply, according to all indications, to activities relating to the conservation of rock art. As a result, the prospects are rather dismal for the conservation of rock art after the Directorate for Cultural Heritage's funding has terminated. It is highly unlikely that the institutions will be given extra funding to continue the conservation work that will be required after the end of the project in 2005.

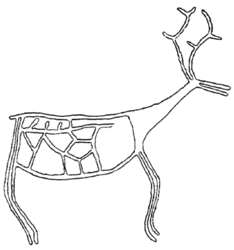
Premises:
A number of conditions are indicated below that must be present for responsible conservation. These premises are:

- **Interdisciplinary** cooperation comprising archaeology, conservation technology and various disciplines within the natural sciences, primarily botany and geology, supplemented with other fields of study as needed.
- **Competency development** including training of archaeologists and conservation technicians.
- **Collaboration** and networking, both nationally and internationally.
- **Continual follow-up** of the rock art sites/conservation measures taken.

Organization
We assume that resources are not available for building up comprehensive, interdisciplinary teams in all of the archaeological institutions. It is therefore suggested that *a national, interdisciplinary competency group*, comprising the full range of professional fields as listed above, be established at one of the regional/managing archaeological museums. At the other archaeological museums, one or two persons (preferably representing archaeology and conservation technology) should be appointed to cooperate with the competency group.

The competency group should be responsible for:

- Establishing and developing collaboration with the other museums, with the county administration and with funding authorities.
- Cooperating with research institutions, both at home and abroad.
- Building the required competence through courses, seminars and meetings, targeting all of the personnel involved.
- Developing a plan of action for the preservation of sites and the dissemination of knowledge about the rock art.



CHAPTER 11

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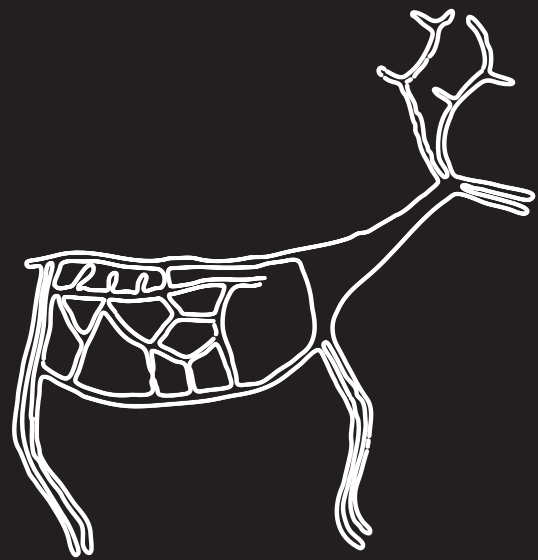

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