

# Red-coated rocks on the seashore: The esthetics and geology of prehistoric rock art in Alta, Arctic Norway

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## Abstract

Research suggests that the World Heritage rock engravings in Alta, Northern Norway, were made along the seashore over a period of 5000 years. The postglacial rebound and consequent land uplift have caused a continuous displacement of the shoreline, now situating the earliest rock art panels up to 26 m above sea level. By examining the rock surfaces at Hjemmeluft and other sites, using field observations and geological analyses, we found that the pronounced red bedrock surfaces in the current seashore zone are composed of inorganic iron films related to a high content of magnetite in the native sandstone. Coupled with an interpretation of regional environmental history, we also found that it is highly likely that the rock art was originally carved on rocks with red iron films, rocks that are now generally gray. Due to the land uplift and subsequent covering of the rock art with lichen, moss, and turf, the red color has waned at the rock art sites. This knowledge may renew interpretation and understanding of the location of rock art in Alta and may have implications for conservation and management.

## KEYWORDS

colors, esthetics, iron films, rock art, rock coatings

## 1 | INTRODUCTION

Prehistoric Scandinavian rock engravings are often painted red to make them more visible to the public, and it is a widespread misconception that this was how they actually looked like when they were made. For the rock art dealt with in this paper, at the UNESCO World Heritage site Hjemmeluft in Alta, Northern Norway, we propose that it was the other way around; bright and clearly visible rock engravings were made on rocks that in prehistoric times were strikingly red-colored, rocks that later have turned gray.

Initially, when rock surfaces are broken by engraving, the affected areas are bright, and the darker the rock surface, the greater is the contrast. This has been valued in prehistoric rock art production throughout the world (e.g., Dorn, 1998, pp. 4–8), and most

notably in areas where desert varnish or other rock coatings form impressive backdrops for highly “readable” rock art (e.g., Newspaper Rock in Utah, USA, Tamgaly in Kazakhstan, and Wadi Umm Salam in Egypt). In some places, rock art remains practically unchanged for thousands of years. In other contexts, the rock art itself, the rock surfaces, and their surroundings have changed dramatically due to natural processes and human action, as for the rock engravings in Alta. They are situated in a highly diverse and changing coastal environment. The postglacial land upheaval has altered the elevation on which the rock art panels are situated, and thereby radically changed the natural setting they are part of.

Landscape traits, including the microtopography of rock surfaces and other esthetic features, have played a crucial role in rock art research in the few last decades (e.g., Bradley, 2000; Chippindale & Nash, 2004;

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Gjerde, 2010a; Helskog, 2010). In this paper, we introduce an esthetic element, previously not explored in Alta, and which we believe to be important for understanding the earliest rock art here: the color red. Discussions and reflections on color in prehistoric societies show a great diversity in how to approach the subject (e.g., Gage et al., 1999; Wreschner et al., 1980). Color may be viewed as a mere decorative element or as a meaningful and representational element, as symbol, analogy, or metaphor for something else (Tilley, 1999; Turner, 1967; Young, 2006). On a profound and general level, colors are means to order, categorize, and communicate aspects of the world (Jones & Bradley, 1999; Young, 2006), and archaeological material and contexts suggest that colors were used to actively convey ideas, beliefs, and identity (Tacon, 1999). Examples include the use of ochre in prehistoric burials (Jones & MacGregor, 2002, p. 8; Wreschner et al., 1980, p. 631), the inclusion of colored rocks in megalithic monuments and the placing of colored artifacts in them (Foreman, 2019; Hensey, 2015; Jones, 1999; Tilley, 1996), the use of pigments in rock paintings and for coloring other objects (Tacon, 1999), and the color variations of Irish Neolithic axeheads (Cooney, 2002). Among the colors, red is often considered to be especially potent, as are white and black. Red is associated with emotions and related to properties of the human body, with flesh and blood, which, in turn, can symbolize fertility, conflict, ancestors and kin, transition, and transformation, with the latter two being especially connected to rituals (e.g., Foreman, 2019; Gage et al., 1999; Jones, 1999; Petru, 2006; Tilley, 1996; Turner, 1967). Red can also denote ambiguity and indeterminacy, and therefore hold magical power (Jacobsen-Widding, 1980).

Returning to the Alta rock art, a major part is found in the Hjemmeluft bay. The engravings were likely produced in the littoral zone (chapter 3), and the current seashore bedrock, a natively gray low-grade metamorphic sandstone (chapter 6.1), is covered with a pronounced red color. Further up in the terrain, where vegetation and lichens are abundant, and where the rock engravings are now located due to the postglacial land upheaval, the color is absent, weak, or patchy, and the rocks are mostly gray. We suggest that the seashore bedrock in prehistory was also red-colored, and that this color afforded esthetic qualities or specific meanings in terms of spirituality, cosmology, ritual practices, or other beliefs or customs, which may have affected rock art

production in prehistoric Alta. The presence of color has mostly escaped attention of rock art researchers in Scandinavia, and the primary aim of this paper is to draw attention to and substantiate that red color was a quality some of the rocks used for artwork in Alta initially held, as well as the visibility and contrast the rock engravings then displayed (Figure 1).

## 1.1 | Geological formation, hypothesis, and methods

Our hypothesis is that the red-colored coating at Hjemmeluft is an iron film, derived from the rock itself, and that acids from lichen and other organic growth dissolve it. Rock coatings, of an organic or inorganic nature, are often defined as results of accretion; elements derived externally are added to the rock surface, which hence form a coating that differs in content and appearance from the rock beneath (Dixon et al., 2002, p. 226; Dorn, 2013, p. 71; Salvatore et al., 2013, p. 138). However, in some cases, elements, in the coatings, can originate from the “host” rock by chemical weathering and reprecipitation (Dorn, 1998, pp. 12–13, 181). Factors required for the formation of rock coatings include the following: bare rock surfaces, absence of fast-growing lithobionts, and that the elemental components of the coating can be transported and fixed to the rock surface in question (Dorn, 2013, p. 72). Reddish surfaces on rocks, often iron films, are a global phenomenon, which have been addressed in many research studies (overview in Dorn, 1998, see also general works on iron mineralogy/geochemistry, reported in Cornell & Schwertmann, 2003), although red coatings on seashore rocks are oddly absent (Dorn, 1998, p. 3). Dorn points out that iron films have not been studied systematically, other than to simply note their existence, perhaps because they are so common (Dorn, 1998, p. 147). This also applies to iron films on seashores.

Methods of investigation include observations and *in situ* chemical analyses (XRF), as well as on samples obtained from the seashore bedrock and other relevant places (microscopy—FTIR and SEM/EDS). Moreover, through studies of the environment and natural history, we hypothesize that the rocks at the seashore at Hjemmeluft were red-coated also when the prehistoric rock engravings were made



**FIGURE 1** The bear to the left was made by Morten Kutchera's Prehistoric Arts and Crafts in 2018 on a red-coated rock sample from the seashore in Hjemmeluft, demonstrating the brightness and contrast of the art held when it was made. The 7000-year-old original to the right, situated at 24 m.a.s.l. in Hjemmeluft, is well preserved, but the difference in color between the pecking marks and the surface has faded away. Photos: K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

(cf. Tansem & Johansen, 2008, p. 82). Subsequently, as the land elevated and vegetation colonized the rock art panels, acids from biological elements and weathering have caused the coating to fade. Emphasizing that the placement of rock art probably rarely was decided by one factor alone, and that a variety of qualities could be required or desired, we propose that the rock's color may have been one such quality. In comparing our findings with the nearby Kåfjord rock art site, we suggest that the sites shared esthetic similarities, previously not noted, namely red-colored rock surfaces.

## 2 | THE ALTA ROCK ART

The Alta rock art consists of approximately 5000 figures distributed within 12 separate open-air sites that differ considerably in extent and numbers, content, and dating (Figure 2). A vast majority of the art is engravings, with a minor body of paintings. Paintings and engravings are not found together, and paintings are not discussed in this paper. The art is mostly defined as Stone Age or hunters/gatherers rock art, also known as the “northern tradition” in Scandinavia. Dominating motifs are humans and animals like reindeer, elk, and bears, and less numerous are dogs and/or wolves, whales, birds, and fish. Boats, fish lines, bows, spears, snowshoes, and hunting corrals are often included in compositions depicting hunting, fishing, or activities interpreted as rituals. Footprints and abstract/geometric patterns are also present. The Alta rock art is generally interpreted as a means of mediation and communication, with the powers and between people, and as expressions of hunting magic, totemism, animism, cosmology, shamanism, and ritual transformation (e.g., Arntzen, 2007; Fuglestedt, 2018; Gjerde, 2010a; Helskog, 1999; Hesjedal, 1990;

Olsen, 1994; Simonsen, 2000). The inner parts of the Alta Fjord where the large sites are found are positioned between the outer coast and the inland of western Finnmark. This intermediate zone is widely understood as a meeting place where groups from an extensive geographical area met to socialize, trade, and perform rituals—and to make rock art (Andreassen, 1985; Gjerde, 2010a; Helskog, 1988; Hesjedal et al., 1996; Hesjedal, 1990; Hood, 1988; Olsen, 1994).

The age of the engravings is suggested to be between 7200 and 200 BC cal (Gjerde, 2010a, pp. 246–252). They are divided into five chronological phases on the basis of morphological similarities at the same elevation above sea level (for Phases 1 and 2, see Figure 3), reflecting shoreline displacement chronology, nearby archaeological material, and comparisons with similar rock art sites (Gjerde, 2010a, pp. 246–254; Helskog, 1983, p. 54, 2011, p. 29).

Four major sites, Hjemmeluft, Kåfjord, Storsteinen, and Amtmannsnes, contain 99% of the engravings and are situated at the head of the fjord. The sites are different regarding topography and geology, in age span and morphology. This study mainly focuses on the two sites, Hjemmeluft and Kåfjord, located 3 km apart, and on the earliest period of rock art production (7200–5000 cal BP). Hjemmeluft displays 100 panels with ca. 2700 figures, situated from 9 to 26 m above sea level (m.a.s.l.). Kåfjord is one single panel (700 m<sup>2</sup>) with ca. 1500 figures at 18 to 26.5 m.a.s.l. The engravings between 18 and 26.5 m.a.s.l. on both sites are considered contemporaneous (Figure 4). At present, the rock surfaces at the two sites appear quite different: the rock art panels at Hjemmeluft are situated on hard, gray sandstone (Bergh & Torske, 1986) and on red volcanoclastic mudstone at Kåfjord (Bergh & Torske, 1988; further analyses of the rocks are given below). The Kåfjord rock is natively red and thus of interest for comparison with the Hjemmeluft site.



**FIGURE 2** Fennoscandia and the Alta Fjord with rock art sites. For a detailed map on Kåfjord and Hjemmeluft, see Figure 11. Maps: Google Earth and [www.norgebilder.no](http://www.norgebilder.no). Ill. K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



21-26,5 masl 7000-6000 BP (Phase 1)	Kåfjord		Hjemmeluft		
Reindeer					
Bear					
Elk					
Dog/wolf					
Human					
Pattern/abstract					
Foot/hand/snowshoe					
Boat					
Whale/fish					
17-21 masl 6000-5000 BP (Phase 2)	Kåfjord		Hjemmeluft		
	Reindeer				
	Bear				
	Elk				
	Human				
	Pattern/abstract				
Bird					
Boat					

FIGURE 3 Typical figures from Phases 1 and 2 at Hjemmeluft and Kåfjord, arranged after motifs and elevation above sea level. III. K. Tansem, based on tracings by K. Tansem and R. Normann



**FIGURE 4** Some of the rock engravings at Hjemmeluft and Kåfjord. To the left: engravings filled with modern paint at Hjemmeluft depicting elk, reindeer, and a part of a hunting fence. In the middle: authentic rock engravings at Hjemmeluft, showing elks, a dog, and humans with spears, bows, and elk-headed staffs, maybe performing a ritual. To the right: a bear hunting scene from Kåfjord. Photos: K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

The other sites (Storsteinen and Amtmannsnes) also display (patchy) red-colored rock, but the sites are only briefly mentioned here, awaiting further in-depth analyses.

## 2.1 | Location

The majority of the known prehistoric hunter/gatherer engravings in Fennoscandia were created on rocks close to or on the contemporary shore, by the sea, rivers, or lakes (Gjerde, 2010a; Sognnes, 2003, p. 49), and this also applies to the Alta rock art. In recent years, major and minor landscape traits and esthetic features have been addressed when location of rock art is discussed (e.g., Bradley, 2000; Chippindale & Nash, 2004). Gjerde (2010a, p. 404) asserted that no single element can explain the location of Fennoscandian rock art, except for the shoreline, which is a recurrent factor. However, he also maintained another similarity: the rocks with rock art stand out from the rest of the landscape one way or another, up close or from afar. Esthetic and affective properties suggested as to why some places were chosen to make rock art, including proximity to prominent cliffs and mountains, waterfalls or rapids, rocks with features that resemble human faces or animals, and certain acoustic qualities (Gjerde, 2010b; Goldhahn, 2002; Lahelma, 2008, 2010; Lødøen & Mandt, 2010; Rainio et al., 2017). There are rock art sites in Fennoscandia where the geology is clearly different from the surrounding rocks (Sognnes, 2003), but such features have been addressed in a few cases only, also involving color, like on Rødøya and Røsand (rød is Norwegian for red; Sognnes, 2003, p. 204), and for the red rocks along Lake Onega (Gjerde, 2010a, p. 156). Gjerde (2010a, p. 156) suggested that color could be important at the site level, but not a decisive factor on a regional or interregional level.

In Alta, no major landscape traits, except for the location by the sea, have been connected to the location of the art. However, smaller esthetic elements, like cracks, crevasses, patterns embedded in the rock, or other natural formations, have been essential in interpretations, relating motifs and compositions to features in the rocks,

connecting them to the seashore as a place of liminality and transition as recorded in ethnographic sources on Arctic cosmology (Gjerde, 2010a, pp. 91, 118–119; Gjerde, 2019; Helskog, 1999). However, if the red rocks along the current seashore at Hjemmeluft are to have any relevance in the context of this paper, the creation of rock art in prehistoric Alta had to take place on the shore.

## 3 | THE SEASHORE CONNECTION

The raised shorelines in Northern Norway were important in establishing the theory of glacial isostasy and have been investigated by a number of scientists since the mid-18th century (Romundset et al., 2011, p. 2398). Scholars observed the relation between rock art and ancient shorelines early on, and also discussed the possibilities the Holocene land uplift could offer for dating rock art and other archaeological materials (Ling, 2008, pp. 20–22; Sognnes, 2003, p. 192). However, the lack of organic materials for radiocarbon dating in the raised shorelines has caused uncertainties concerning their absolute age. Still, geometrical simulation programs (e.g., Møller & Holmeslett, 2002) can procure local sea level curves showing the overall development (Romundset et al., 2011, pp. 2399–2400). Current knowledge suggests that except for a period during the Holocene Tapes transgression (8000–5000 cal BP) when the land uplift was leveled out by glacial melt water, the sea level has gradually regressed in the Alta area (Møller, 1987). Thus, if the rock engravings were indeed made on the shore, the higher above sea level the rock art is located, the older it is.

Rock engravings can only be dated indirectly, as they do not contain datable materials. Shoreline dating normally provides a maximum date; the rocks emerged from the sea at some point, making it the earliest possible time for the production of rock art. The method has been critically discussed (see Gjerde, 2010a, pp. 249–254; Helskog, 1983, pp. 54–55, for discussions on Alta), and in some cases considered less certain (i.e., Goldhahn, 2017; Helskog, 1983; Lødøen, 2015; Ramstad, 2000; Sognnes, 2003). Whether all the hunter/gatherer rock art in Fennoscandia located in the vicinity

of the sea was created in the littoral zone is certainly debatable (Lødøen, 2015; Sognnes, 2003; Stebergløkken, 2015). However, Alta is one of the sites where relative shoreline dating for chronology suggestions is considered a reasonable assumption (Goldhahn, 2017; Lødøen & Mandt, 2010, p. 22; Ramstad, 2000, p. 60; Sognnes, 2003, p. 94). Future data may, of course, challenge this interpretation.

As for raised shorelines and rock art, there are occurrences in Norway where panels were covered by marine deposits on their discovery (Bakka, 1975; Gjessing, 1938; Hesjedal et al., 1996; Olsen, 1994; Simonsen, 1958, p. 48; overviews in Gjerde, 2010a, p. 402; Ramstad, 2000; Sognnes, 2003). Thus, they must have been submerged during a transgression, which provides a minimum date. This phenomenon has not been recorded in Alta, but excavations on the island Sørøya, 70 km to the north, uncovered four small boulders with water-eroded engravings covered by marine deposits (Gjerde, 2010a, p. 247; Hesjedal et al., 1996, pp. 75–82). The boulders were most likely covered during the Tapes transgression, making the engravings at least 7000 years old (Gjerde, 2010a, p. 250; Hesjedal et al., 1996, p. 82; Olsen, 1994, p. 46). The figures are similar to the earliest engravings in Alta (Hesjedal et al., 1996, p. 200). The shoreline development varies geographically, and in the inner parts of the Alta Fjord, no major transgressions have been recorded after the Tapes transgression, ca. 7000 cal BP. However, there are engravings on different panels at the same elevation (at ca. 18.5 m.a.s.l.) that are clearly eroded by wave or ice action (Figure 5; Gjerde, 2010a, p. 247; Tansem, 2011, p. 56), relating the production of rock art firmly to the littoral zone.

Another key argument for the shore connection is the current absence of vegetation/lichen in the littoral zone; such barren rock surfaces thus offer a vastly better “canvas” than generally overgrown and more weathered rock surfaces above (Bakka, 1975, p. 37; Gjerde, 2010a, pp. 100, 191, 403; Helskog, 1983, p. 55, 1999, p. 74; Mikkelsen, 1977, p. 182). Stripes, cracks, and other features in the rock that could be of importance when making rock engravings (Gjerde, 2010a, pp. 164–169, 279–285; Helskog, 1999; Lødøen & Mandt, 2010, p. 11) would be invisible and thus inaccessible on lichen-covered rocks. Bare rock surfaces hardly occur above the littoral zone at Hjemmaluft and Kåfjord, and only in smaller patches. In practical terms, it is difficult to envisage that prehistoric people undertook large-scale removal of vegetation to make their rock art. The validity of this argument is, however, dependent on whether the present vegetation pattern is a key to the past, to prehistory (further discussion is given below).

The thousands of figures in Alta display an unusual degree of diversity, and the variations within elevation ranges are also substantial. However, there are elements of style that generally distinguish the assemblage of figures and motifs found on different elevations in general. This is most conspicuous on the highest (and earliest) elevations. There are similar, distinctive figure types as much as 3 km apart, at 22.5 and up till 25 m.a.s.l., only at this elevation. Examples include large reindeer corrals, bears associated with dens, rows of bear footprints, elk-headed staffs, fringed drop-shaped figures, and footprints from snowshoes. Some of the larger compositions stretch up to 8 m horizontally, but never more than 2 m



**FIGURE 5** The Ole Pedersen 11C panel at Hjemmaluft, at 18.5 m.a.s.l., contains engravings, such as a human, a circle, and a bird, eroded by water or ice action. The striation marks are also eroded to a greater extent than at other elevations. A reindeer figure is engraved on top, showing no traces of such erosion. This substantiates that the engravings were produced in the littoral zone. Photo: K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

vertically (Gjerde, 2010a, p. 153). A reasonable explanation is that they were made within a specific time period on the contemporary shore. There are some anomalies, with figure types at elevations higher than expected. They are always found on presumably older panels, not seldom as superimpositions, thus implying cases of revisits and reuse. But, in general, current knowledge suggests that most of the rock engravings in Alta now situated between 17 and 26.5 m.a.s.l. were produced on rocks in the littoral zone.

#### 4 | THE HJEMMELUFT SEASHORE, PAST AND CURRENT

The seashore is where sea and land meet, a place in a permanent state of transition at all temporal scales, an environment defined by change (Kneib, 2002, p. 1268). It is the area extending from the lowest level uncovered by the low spring tides to the highest point washed or splashed by waves. The intertidal zone is often divided into the upper, the middle, and the lower littoral zones. The supralittoral zone is the area above, where salt spray influences the environment (Knox, 2001, p. 1). Together, the upper littoral zone, which begins where barnacles occur in quantity, and the supralittoral zone define the littoral fringe (Knox, 2001, p. 23). Over long geological timescales, astronomical tides can be affected by the size, depth, and shape of the ocean basins, and tidal amplitude changes were substantial during the last ice age and after deglaciation. From 7000 BP, however, the supraregional amplitudes have closely reflected the present-day tidal ranges, although local changes might have occurred (Haigh et al., 2020). The highest and lowest astronomical tide in Alta is currently 148 cm above and –192 cm below mean sea level. Mean high water is 75 cm, and mean low water is –109 cm. Weather effects can be substantial, adding or subtracting





**FIGURE 6** Living conditions at the Alta seashore fluctuates daily and through the seasons. Temperatures can reach  $-25^{\circ}\text{C}$  in the winter and  $25^{\circ}\text{C}$  in the summer. High tide in February and low tide in July at Hjemmeluft. Photos: K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

several decimeters to these amplitudes. This means that the average difference between high and low tide is nearly 2 m, but at regular intervals, it exceeds 3 m (Kartverket).

Life in the tidal zone persists in a highly unstable environment and the organisms that live here are able to survive both exposure to air and submersion in seawater (Figure 6). The environment is especially harsh in the littoral fringe, which draws the boundary between the littoral habitat with species that live in waters of high salinity, such as black tar lichens (*Hydropunctaria maura*), and the terrestrial habitat with less salt-tolerant lichens, mosses, and vascular plants (Fjellberg et al., 2010, p. 28; Knox, 2001, p. 24).

The habitat systems in the littoral fringe are dependent on tidal amplitude, wave action, topography, angle, substrate hardness and roughness, solar radiation, rain, and runoff, as well as air temperature and salinity (Hayward & Ryland, 2017, pp. 1–13; Knox, 2001, p. 42). All these factors influence the presence of biofilms, which are assemblages of microorganisms colonizing hard surfaces immersed in water from the Polar Regions to the tropics. Intertidal biofilms are predominantly composed of photosynthetic organisms and can give rock surfaces a dark green or red appearance, influencing the settlement and colonization by larger organisms (Thompson, 2007, pp. 85–86). Generally, the lower littoral zone on the rocky seashore



**FIGURE 7** Example of the littoral zonation in Hjemmeluft. At the lowest brown and red algae, followed upwards by the barnacle belt, tar lichen, the barren zone and finally the transition to terrestrial vegetation and lichens. Photo: K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

at Hjemmeluft is populated with brown and red algae, and it continues upwards with the barnacle belt, black tar lichen, and biofilms, before a barren belt marks the transition to terrestrial vegetation, lichens, mosses, and vascular plants. This is not a consistent pattern. For instance, on bedrock facing south or west, where the environment is dry due to solar radiation, black tar lichen is generally absent or infrequent, whereas it is abundant in the same height range on the northern and eastern side of the rock.

When compared with most other areas along the Alta seashore, the littoral zone at Hjemmeluft offers a less hospitable environment for vegetation, which can be related to its sandstone geology and the hard, smooth rock surfaces that make it difficult for organisms to settle. Thus, the boundary between the two main habitats, where neither littoral nor terrestrial life is present in abundance, is generally broad at Hjemmeluft (Figure 7). The vertical range is some places up to 2 m.a.s.l., but horizontally, it can stretch for several meters, depending on the rock surface angles. As pointed out by Dorn (2013, p. 72), rocks with no or little organic growth is a prerequisite for the formation of inorganic coatings, such as iron films, and red-coated rock surfaces are found at the current seashore at Hjemmeluft within this barren belt.

## 5 | ENVIRONMENTAL HISTORY

Over the last 7000 years, as the land rose, rock art previously located at or near the seashore was successively covered by vegetation. Like all long-term processes governed by climate, this was not a linear development and organic growth and weathering would have progressed irregularly. The details of such processes are currently not possible to reconstruct. However, we may look at known climate shifts and vegetation history to get an idea of how the landscape has transformed over the millennia, inquiring whether there have been conditions that could question our main hypothesis—that the rocks along the seashore had a red coating also when the rock art was made.

## 5.1 | Climate history

The climate in Alta is subarctic, with no permafrost. Winters are cold (mean temperature in January is  $-13.4^{\circ}\text{C}$ ), summers are relatively warm (mean temperature in July is  $12.3^{\circ}\text{C}$ ), and precipitation is low, presently c. 550 mm/year (data from [climate-data.org](http://climate-data.org) and [Norwegian Meteorological Institute](http://www.met.no)). The climate in the inner parts of the Alta Fjord has features of a continental climate, because the moderation of air temperature from the North Atlantic Ocean and the Gulf Stream is less pronounced than in outer coastal areas. Seawater temperature in the inner Alta Fjord is also controlled by local climatic processes (Eilertsen & Skarðhamar, 2006, pp. 534–537; Mankettikkara, 2013, p. 110). The outer coast is ice-free year-round, but parts of the inner Alta Fjord may freeze during winters.

Prehistoric climate change estimates in northern Fennoscandia often cover large areas, and the Alta area has hardly been subjected to local climate development studies. Thus, climate history assessments in Alta must be based on studies from adjacent locations. The Holocene Thermal Maximum had its peak by 8000–7000 cal BP (Mauri et al., 2015; Seppä et al., 2009). Some estimates show that the temperature could have been as much as  $2\text{--}3^{\circ}\text{C}$  higher in both summer and winter as compared with recent conditions (Mauri et al., 2015, pp. 114–115), whereas others are more modest (Seppä et al., 2009). In the mid-Holocene, 6000 cal BP  $\pm$  250, temperatures were  $1.0^{\circ}\text{C}$  and  $1.7^{\circ}\text{C}$  warmer in summer and winter, respectively as compared with the recent preindustrial period (Sundqvist et al., 2010, p. 605). The temperature fluctuated but declined rather steadily toward the recent past (Seppä et al., 2009, p. 526), with, for example, a colder period between 4000 and 3000 cal BP (Seppä et al., 2009, p. 531, Mauri et al., 2015). The climate was wetter 7000 years ago, followed by a decrease in precipitation, especially in summer, whereas winter precipitation was somewhat higher than that at present (Mauri et al., 2015). During the Little Ice Age (AD 14–1900), glaciers in the Arctic generally reached their largest extent since the colder period by 3000–4000 cal BP, indicating the severity of this cold spell (Nesje et al., 2007). Since then temperatures have increased. In summary, the climate was warmer during the Holocene

Thermal Maximum, and since then fluctuating, with colder and warmer spells, but not fundamentally different from the recent past.

## 5.2 | Vegetation history and soil pH

The inner areas of the Alta Fjord represent a northern branch of the middle boreal zone in Fennoscandia. Mixed pine–birch forests were well established already by 8000–7000 cal BP, but birch increased in relative abundance by 4000–3000 cal BP due to a somewhat colder climate (Hyvärinen, 1985; Sjøgren & Damm, 2018). The mixed pine–birch forests have prevailed to the present, but it is unknown to which degree they might have been affected by human impact (e.g., cutting of trees and animal grazing) in the actual rock art areas. However, from historic photos, it is known that Alta was less forested in recent modern times than today (Figure 8).

Due to the rocky nature of the landscape within the Hjemmeluft site, a relatively open pine–birch forest is now found in depressions, small valleys, and re-entrants with preserved moraine material and a thin soil cover. Such landscape features also drain water from inland moors and lakes. The rockier parts of the site, where the rock art is located, are covered by thin turf and moss, with occasional shrubs and trees, or are barren, except for substantial lichen growth. Over millennia, there may have been fluctuations in the nature, extent, and thickness of the turf, moss, and lichen cover. However, the general tendency is ample increase, as many rock art panels were found below layers of turf that were removed upon discovery. One can argue in a similar way as regards lichen, though species types and rates of formation may have changed over time. In recent years, as observed, recolonization on previously cleaned and barren rock surfaces has been fast (Bjelland, Hjelle, et al., 2010, p. 105).

Local soil pH variation is dependent on bedrock, hydro-geochemistry, and topography across different vegetation types (Valentine & Binkley, 1992). Thus, soil pH in boreal forests, with generally noncalcareous bedrock (as in our case, see below), may vary from 3.5 to 6.4 (Giesler et al., 1998), underlining the general acidic nature of such soils. In our case, changing vegetation over the



**FIGURE 8** Historic photos show that Hjemmeluft earlier was completely deforested due to small-scale farming, grazing, and the need for firewood. To the left: in 1941, when this photo was taken, the forestation of Hjemmeluft was minimal. All the buildings seen in the photo were destroyed by fire at the end of World War 2. To the right: the present situation is quite different; trees and shrubs cover large areas on the site. The white spots between the trees in the middle right are cleaned rock art panels in the rockier parts of the landscape, which also represent prehistoric seashore lines. Photos: M. Valier, courtesy of T. G. Eggan, [Krigsbilder.net](http://Krigsbilder.net), and K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



millennia likely has affected soil pH near rock art, but there can be little doubt that pH generally has been rather low.

### 5.3 | Seashore history

Apart from displacement due to the postglacial uplift, the seashore may also have been subject to changes in salinity and pH of seawater, affecting lichen and other vegetation in the semi-barren littoral zone, that is, where the rock art most likely was originally made. The mean salinity of surface water in the inner parts of the Alta Fjord is now 3.31‰ in winter and 2.54‰ in summer. This difference is due to the freshwater discharge from Alta River and general runoff, notably during snowmelt (Mankettikara, 2013, p. 106). Similar variations are found across the North Atlantic Ocean (Furevik et al., 2002), albeit at a generally slightly higher level of salinity. Salinity levels must have been higher during periods with less supply of freshwater, thus perhaps contributing to a reduction of less salt-tolerant vegetation along the seashore. Conversely, with a high influx of fresh water during the Tapes transgression (c. 8000–6000 cal BP), salinity levels may have declined. Historical salinity fluctuations/levels are not known, but may, at times, have outweighed the present fluctuations between summer and winter in Alta. Nevertheless, it is reasonable to suggest that general historical fluctuations may have been roughly within the present limits, and that former effects on vegetation would not have been fundamentally different from today.

The role of seawater pH must be considered, because oxidation of iron-rich compounds—likely contributing to the red coating of the rock along the seashore—may develop faster in alkaline environments (Cornell & Schwertmann, 2003, pp. 435–474). The present pH of seawater generally ranges between 7.5 and 8.4 (Chester & Jickells, 2012). Although the current tendency is acidification of the world's oceans, it is unlikely that a general lowering of pH from preindustrial times will have much effect on oxidation and life along the seashore in Alta. There are no historical records available from Alta, but over the last c. 40 years, the pH in Arctic waters (Greenland Sea) has dropped from c. 8.2 to 8.1 (upper 200 m), with a tendency to further drop due to current climate change (AMAP, 2018). Locally, the acidic runoff from small moors and bogs—and generally from rock covered by turf and other vegetation—may affect pH along the seashore. However, this likely takes place only where larger quantities of runoff (creeks, etc.) reach the seashore.

### 5.4 | The current and past seashore

There is a distinct temperature gradient from south to north along the Norwegian coast, with southerly limits for some northerly species and vice versa. Yet, similar species are found widely on the seashore along the entire coast (Oug et al., 2010, p. 17), for example, tar lichen, brown, green, and red algae, and other organisms like barnacles, common mussel, and sea snails (Hayward & Ryland, 2017). This implies that life on the seashore is resilient, enduring a wide

variety of environmental conditions. Similarly, lichens have an ability to tolerate extreme environmental conditions (Werth, 2011, p. 192), and they have colonized habitats in which few other plants and animals can survive (Gadd, 2017, p. 172). It is thus highly probable that the bedrock above the intertidal zone in Alta may have been colonized by lichens 7000 years ago, in a growth pattern not fundamentally different from today; however, the lichen species may have differed (Bjelland, Skaar, et al., 2010, p. 58).

Although many factors are yet uncertain, from the above discussion on climate, vegetation, salinity, pH, and resilient organisms along the seashore, we postulate that the seashore environment in Alta has not altered over the last 7000–8000 years in ways that have changed living conditions fundamentally in the barren belt between terrestrial and marine life. This implies that we regard life along the present seashore as a valid key to the past, that is, to when the rock art was created.

## 6 | THE ROCKS

Having demonstrated that the environment along the seashore in Alta has not fundamentally changed through the millennia, we now take a detailed look at the geology of the area, followed by our own investigations of the nature of the red surfaces in the current seashore zone (chapter 7).

### 6.1 | Geology at Hjemmeluft

The Hjemmeluft site consists of a very smooth, ice-scoured low-grade metamorphic sandstone with marked glacial striations. It is a part of the upper member of the Skoddavarre Sandstone Formation, which belongs to the Raipas Group, a c. 2 by Precambrian tectonic window within the Caledonides of Norway. The sandstones are of fluviomarine and alluvial origin, and the most widespread lithofacies in the rock art area is a heavy mineral-laminated sandstone, along with more massive beds (Bergh & Torske, 1986). Here, the compact sandstone can be classified as an intermediate between a feldspathic graywacke and an arkosic wacke, usually with less than 10% matrix/cement (Bergh & Torske, 1986, p. 12; Bjelland, Lødøen, et al., 2010, p. 164).

Rounded quartz is the principal component (70%–80%), followed by sericitized plagioclase (albite; 5%–15%), K-feldspar (microcline; 5%–15%), clasts of muscovite (10%–15%), and fine-grained rock fragments, mainly quartzite. Trace amounts of minerals such as amphibole and apatite are also present. The matrix is normally composed of sericitized muscovite, but in some places it also contains dolomite (Bjelland, Lødøen, et al., 2010, p. 164). A most conspicuous trait of the sandstone, and as described later, very important for the development of reddish iron films on the surface, is heavy mineral laminations. The laminae vary in thickness from 0.2 up to 10 mm, and mostly occur in 2–10 cm thick sets. They consist of magnetite, zircon, rutile, tourmaline, and a little hematite,

with magnetite by far being the most abundant. Trace amounts of such minerals are also distributed throughout the sandstone (Bergh & Torske, 1986, pp. 9–10). It is important to note that iron is present only as iron oxides, with magnetite by far being the most important.

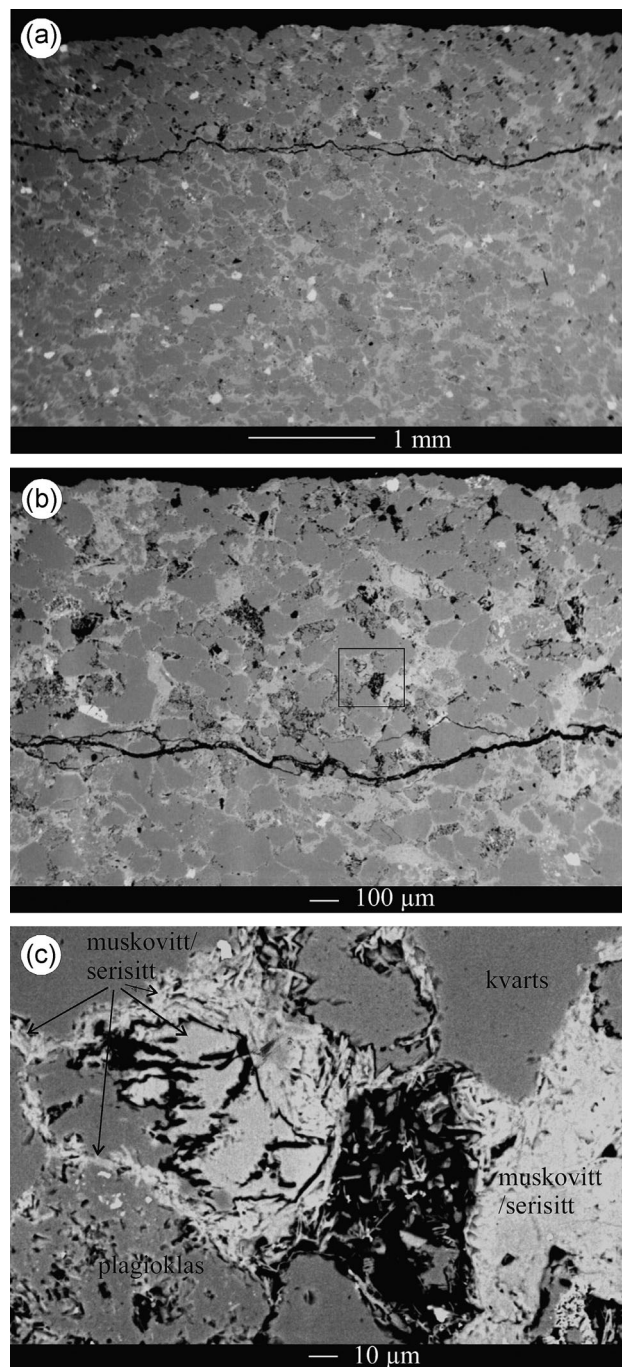
The color of fresh, unweathered sandstone is dark gray. When exposed, to the atmosphere, with or without microbial activity, light-colored, bleached weathering rinds develop, with a thickness up to c. 1 cm. The thickness is dependent on time of exposure after the last ice age and the nature of the slightly acidic lichen/moss/turf/soil cover. Weathering rinds are characterized by increased porosity, mainly due to the dissolution of sericitized feldspar. When occasional traces of more easily dissolved dolomite are a part of the matrix, the rinds are normally thicker (Bjelland, Lødøen, et al., 2010, pp. 167–179). More important, weathering rinds are very thin (<0.1 mm) or practically absent in the current intertidal zone (Bjelland, Lødøen, et al., 2010, p. 167). There are several reasons for the near absence of weathering rinds along the present seashore, and the most important fact is that these rocks obviously have been exposed to the atmosphere for the shortest period of time and have very little biological growth (Figure 9).

## 6.2 | Geology at Kåfjord

Whereas the gray sandstone at Hjemmeluft develops a reddish surface color in the intertidal zone, the rock art at the Kåfjord site is located on a rock that is natively reddish (Figure 10). The rock is a strongly laminated volcanoclastic or tuffaceous mudstone in the transition zone between the Precambrian Kvenvik Greenstone Formation and the Storviknes Sedimentary Formation, both of similar age as the sandstone at Hjemmeluft (Bergh & Torske, 1988, p. 227; Melezhik et al., 2015, p. 273).

The low-grade metamorphic, red mudstone appears in a narrow zone (c. 60 m broad), which is bordered by dull gray mudstones. It is a very fine-grained rock and contains thin (2–10 mm), greenish laminae rich in chlorite, developed due to variations in redox conditions during sedimentation (Sæbø, 2003, p. 9). More important, the stone has a high content of evenly distributed, secondary crystals of magnetite (5% or more), easily recognizable with the naked eye and a compass needle (Storemyr, 2013, pp. 4–5). There are also trace amounts of fine-grained hematite in the rock (Sæbø, 2003, p. 9), a trait that explains the native, reddish color. Weathering rinds are thin, 1–5 mm, with a lighter red color than the fresh rock. Rinds have not been investigated microscopically, but they are probably a result of the dissolution of selected minerals (Storemyr, 2013, p. 7), as well as micro-cracking caused by frost (Storemyr, 2013, pp. 31–32). In the intertidal zone, where weathering rinds are thin or absent, and the rock surfaces are clearly more reddish than that at the elevated rock art panel.

Despite extensive work, by the authors and others, involving field walks and trial excavation, no rock engravings have been found on the gray bedrock beside the red mudstone zone (Figure 11).



**FIGURE 9** SEM images, with progressively higher magnification, of a cross-section through a weathered rock surface from above the littoral zone at Hjemmeluft. The images show that the upper zone is porous (black spots) with a fissure toward the “fresh” rock (a, b), and that plagioclase is sericitized (c). Ill. Bjelland, Skaar, et al. (2010, p. 171)

## 7 | INVESTIGATION OF RED ROCK SURFACES AT HJEMMELUFT, KÅFJORD, AND BEYOND

To explain why the sandstone at Hjemmeluft has a strong reddish surface color in the intertidal zone, observations and analyses were performed. These were aimed at understanding both the nature of





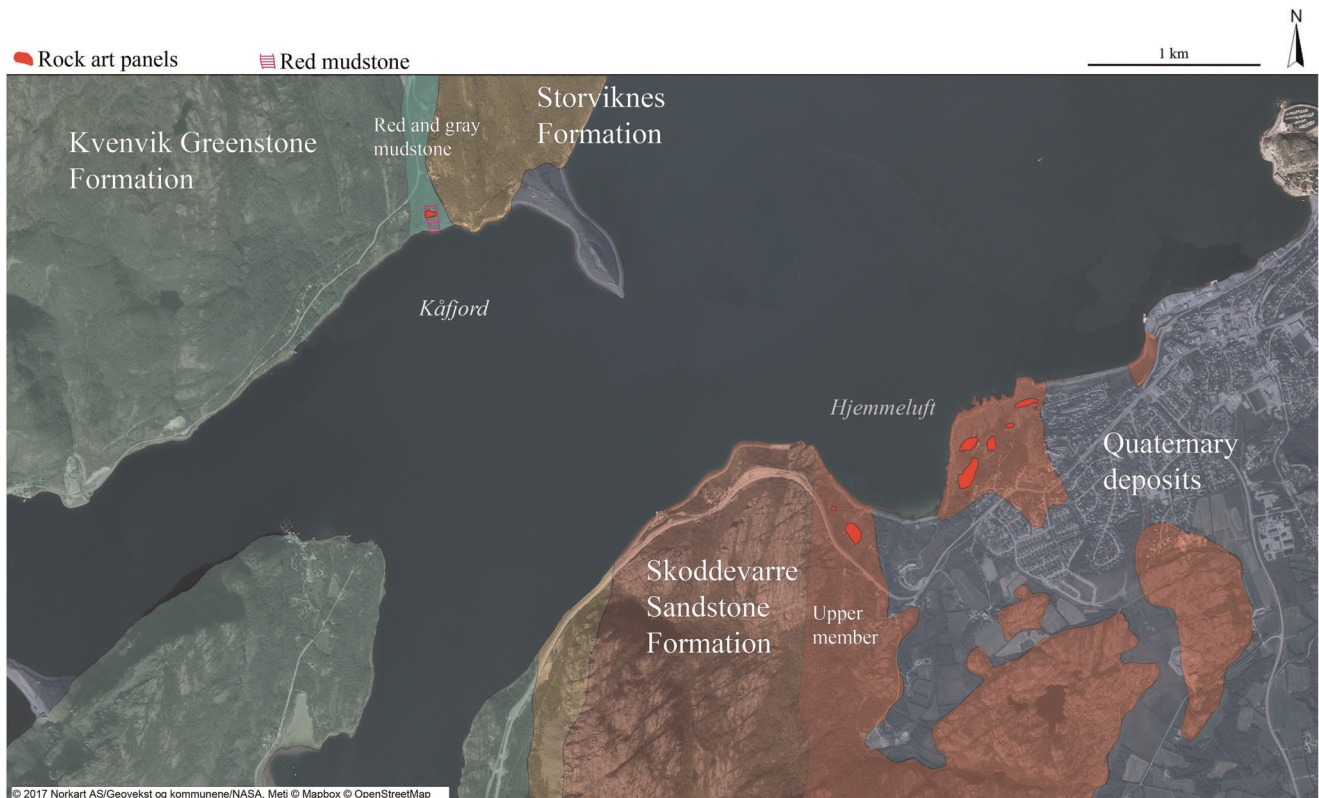
**FIGURE 10** The Kåfjord panel. Photo: K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

the coloration and its distribution, also beyond the Hjemmeluft (and Kåfjord) sites. As stated above, our primary hypothesis is that the surface color is of an inorganic origin, an iron film, and strongly related to chemical weathering of magnetite present in the rocks. Moreover, an additional hypothesis is that biological growth and associated acidification and weathering lead to removal of the iron film.

## 7.1 | Methods

Field walks were undertaken within the entire rock art landscape in the Alta region and to various outcrops without rock art in the Skoddevarre sandstone formation. A boat survey trip was made along the shores of the Inner Alta Fjord to observe whether similar, strongly red-colored rocks were found on other lithologies. Samples of red-colored rock surfaces, mainly from Hjemmeluft, were analyzed by stereo microscopy (by Christine Bläuer) and SEM/EDS (Zeiss Supra 55VP Field Emission Scanning Electron Microscope [FE-SEM] equipped with a Thermo Noran Six Energy-Dispersive Spectrometer [EDS] system; by Ingunn Thorseth). Analyses of red-colored surfaces were additionally performed with a Bruker ALPHA FT-IR Spectrometer (by Christine Bläuer), whereas analyses of iron content were done in the field using a handheld XRF (Niton Xlt3 GOLD D2 with a silver anode 50 kV, 0–200  $\mu$ A X-ray tube; by the authors). Further information on analysis protocols is given below.

Moreover, as a part of interpretation for the public, we performed an interesting experiment to visualize how fast red-colored surfaces on the Hjemmeluft sandstone can lose the red color when exposed to an acidic environment. We used a substance that is known to public as Coca Cola Classic, with a pH of about 2.37 (Reddy et al., 2016, p. 256). The experiment is reported here for demonstration purposes only; oxalic acid or HCl should have been used.



**FIGURE 11** Geological formations and distribution of rock art panels in Kåfjord and Hjemmeluft. Geology based on Bergh and Torske (1986, 1988). Map: Norkart AS/Geovekst. Ill. K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



## 7.2 | Local–regional distribution of red-colored rock surfaces

Smaller patches of red-colored rock surfaces are not uncommon in the current intertidal zone in the Inner Alta Fjord. It can be found on Precambrian metasandstones, mudstones, gabbros, pyroxenites, and other rocks (cf. *Geological Survey of Norway*). There is a clear connection between types of rock and red coatings, as they appear and disappear with one lithology replacing another (Figure 12). Many red-colored, smaller spots associated with runoff can be seen on rocks away from the shoreline. In such cases, it is obvious that the color originates from leaching of iron sulfides (especially in gabbros and pyroxenites) or from small bog iron ore deposits. This is, presumably, mainly normal rust (i.e., iron (oxy)hydroxides).

There are also patchy, red-colored areas at the seashore by the younger rock art site Amtmannsnes in Alta. This rock art is made on a slightly metamorphic arkosic sandstone of the Komsa formation, bordering the Skoddavarre formation (cf. *Geological Survey of Norway*), with abundant biotite. Initial observations indicate that leaching of iron from biotite might be responsible for reddish rust formation, given that there is a clear (field) relationship between reddish color and the distribution of biotite.

The Skoddavarre sandstone formation is generally covered by turf, moss, lichen, and forest above the littoral zone. However, in the patches where vegetation or turf is absent, the surface is normally weak to modest red-colored. This can especially be seen on dry cliffs exposed to the sun and in cracks and crevasses with little or no biological growth. There are no spots with rust formation from leaching of iron sulfides or biotite, because sulfide and biotite have not been detected in these rocks (c.f. Bergh & Torske, 1986; Bjelland, Lødøen, et al., 2010, p. 164). Moreover, our own observations, also with stereo microscopy (see below), indicate that the color is rarely related to algae (e.g., the often strongly reddish *Trentepohlia* sp.) or red lichen. The color of the surface cannot be scratched away with a fingernail and is generally not as sparkling as for algae (and lichen).

## 7.3 | Observations along the shoreline at Hjemmeluft

In the intertidal zone at Hjemmeluft, there is a strong relationship between the intensity of the reddish coloration and the distance from the lower littoral zone. In the lowermost locations, just above the zone with black tar lichen, the coloration is most intensive, looking like a tightly attached, extremely thin film (as observed in “cross-section” by recently cracked stone). The color varies from deep reddish-brown, partially shiny on smooth surfaces to purplish at surfaces with minute cracking (due to ice-picking or mechanical weathering). More important, these are the zones without weathering rinds. The red color is thus like a “paint” on a nonporous surface.

Further up, the coloration is more patchy. This is clearly related to lichen growth and weathering rinds: the more lichen, of various species, the more weathering and less reddish color. Often, there is a zone without reddish color just beside lichen. Moreover, the reddish color is usually weaker within glacial striations. This is, presumably, because glacial striations are mechanically slightly “broken up” (higher porosity) as compared with nearby, smoother rock. The nature of the striations, as well as weathering rinds, seems to create an optical effect on coloration; light is more unevenly dispersed as compared with smoother surfaces and thus less intense. Just above the intertidal zone, where lichen, moss, and turf predominate, the weathering rinds are thicker and the reddish color of the rock surface wanes. But, on close inspection, it is usually possible to see small spots of weak reddish color when biological growth is absent. At all levels in the intertidal zone, there is a most conspicuous relationship between heavy mineral laminae and adjacent rock: The reddish surface color by the heavy mineral laminae is always more intensive, indicating that magnetite, which is by far the predominant Fe component of the laminae (see mineralogical analysis in Section 6.1), is strongly related to the reddish color.



**FIGURE 12** From the left: iron films/rock coatings on rock surfaces along the shore on the eastern side of the Alta Fjord, patchy red-colored areas at the seashore at Amtmannsnes, and red coatings on bare rock surfaces far from the seashore in the Skoddevarre mountain area. Photos: P. Storemyr and K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

## 7.4 | Observations at cleaned and lichen-covered rock art surfaces at Hjemmeluft

Due to the shoreline displacement, the rock art at Hjemmeluft is now located well above the intertidal zone (chapter 3). The panels were covered by turf, moss, and lichen upon their discovery in the 1970s, which have been cleared and cleaned in many stages. Earlier, cleaning involved mechanical removal of turf, moss, and lichen, and recurrent covering with various types of mats (to inhibit biological growth). The mechanical methods have been replaced in recent years with regular (often annual) treatment with 70% ethanol (pH = 7) to inhibit biological growth (Bjelland & Helberg, 2006, pp. 82–84; Tansem, 2011, pp. 54–55). Thus, most surfaces with rock art are now completely barren, with pH near neutral—a contrast to a former, slightly acidic microenvironment, below lichen and moss.

Interestingly, these barren surfaces display patchy and weak, but clear reddish coloration, which may have slightly intensified over the last few years (according to studies of historic photos). It is clearly most vigorous in areas with heavy mineral laminae. The coloration is nearly absent at places with runoff from (slightly acidic) moss and turf, indicating that pH is an important factor in color formation: the more alkaline, the faster it seems to form.

The photographic rock art documentation from Alta (Tromsø University Museum and Alta Museum), produced in the 1970s, indicates that the patchy, reddish coloration was never totally lost beside lichen and other organic growth (Figure 13). However, there are clear relations between near-total loss and some few types of lichens that seem to include various types of map lichens (*Rhizocarpon geographicum* sp.), as well as *Aspicilia* sp., *Porpidia* sp., and *Fuscidea* sp. (T. Bjelland, Personal Communication, April 10, 2019). Presumably, this relationship is due to types and strength of organic acids (especially oxalic acid) and other compounds produced by the lichen.

## 7.5 | Observations at the Kåfjord site

Despite the fact that the volcanoclastic mudstone at the Kåfjord rock art site is natively reddish, it is possible to observe similar traits in

surface colors as the Hjemmeluft site, as in the barren, intertidal zone, the red color is more intense than that on the currently cleared and cleaned rock art site itself, higher up in the landscape. As mentioned above, weathering rinds are more pronounced at the rock art site than in the intertidal zone (cf. Sæbbø, 2003; Storemyr, 2013).

## 8 | ANALYSES

Analyses were done in three stages. First, a preliminary work involving stereo microscopy, FTIR, and XRF was carried out, which aided in differentiating visually between red-colored surfaces with a presumed inorganic versus organic origin. Second, SEM/EDS was undertaken to understand the (mineralogical) nature of the red films in the intertidal zone at Hjemmeluft. Third, in-situ XRF measurements of iron were undertaken to understand the distribution of inorganic red films at Hjemmeluft, both in the current intertidal zone and at the rock art locations. This included (1) the relationship in iron content on rock with and without red films and (2) the relationship in iron content on rocks with and without heavy mineral laminae.

### 8.1 | Preliminary stereo microscopy, FTIR, and XRF on the sample surface

Three samples with red-colored surfaces were analyzed: (1) from the intertidal zone at Hjemmeluft, assumed to contain an inorganic reddish surface layer; (2) from a vertical cliff with no lichen at Skoddavarre, at c. 150 m.a.s.l., also assumed to contain an inorganic surface layer; and (3) a sandstone pebble in a moraine by Alta museum/Hjemmeluft (c. 30 m.a.s.l.), assumed to contain red algae.

The surface of sample 3 is of an organic nature, as confirmed by FTIR done directly on the surface of the stone (many CH bands). XRF on the sample surface indirectly confirmed its organic nature, as it contained less iron than a fresh cut through the rock (1.4 vs. 1.7 m%). FTIR did not detect iron-containing minerals on surfaces in any of the samples, presumably because the surface layers are thin and irregular (see also the SEM results below). However, XRF showed that



**FIGURE 13** When this rock art panel at Hjemmeluft, Bergbukten 4A, was discovered, some parts were buried under dirt and turf, whereas others were covered by lichens. The left photo, from 1977, shows how the panel appeared after the turf was removed and before the lichens were cleaned off. The rock engravings are marked with chalk. To the right: the rock surface has a patchy red coloration on the area previously overgrown with lichen, whereas the surrounding rock has a more even coloration. The bright lines and marks are results of vandalism. Photos: K. Helskog and K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



sample 2 contained much more iron in the surface layer than on fresh rock (2.6 vs. 1.2 m%, respectively), indicating inorganic surface films. XRF on sample 1 did not give definite results (2.1 vs. 2.0 m%, red surface vs. fresh rock), though the surface layer was clearly inorganic (no CH bands in FTIR; Figure 14). A further test by microchemistry (with 10% heated HCl on red material scratched from the surface) showed that sample 1 contained much  $\text{Fe}^{3+}$  (yellow solution, cf. Feigl, 1960; see Arnold, 1984), whereas on the fresh surface, it was difficult to differentiate between  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$ . This indicates oxidation of primary  $\text{Fe}^{2+}$ -bearing minerals, in our case, primarily magnetite, by far the most important Fe mineral in the rock.

In conclusion, these preliminary tests aided in differentiating between reddish surfaces of inorganic and organic origin in the field. They confirmed that our field observations were correct, especially that sample 3 had a surface with (yet undetermined) algae/organic growth. Such surfaces with “sparkling” red color cannot be observed in the intertidal zone or associated with rock art further up in the terrain.

## 8.2 | SEM/EDS on sample surfaces

Six new samples, akin to sample 1 (see above), were subsequently collected in the intertidal zone at Hjemmeluft. Of these, the visually representative samples, SEM 2, SEM 4, and SEM 6, were selected for imaging and elemental analyses by SEM/EDS (Figures 15 and 16). The analyses of nonprepared surfaces showed thin, irregular, amorphous-looking surface layers or films (thickness c. 1–2  $\mu\text{m}$ ) and nanospheres, both strongly enriched in iron, covering quartz (mainly) and other minerals in the surface zone (see mineralogy in Section 6.1). The layers and spheres also contained small proportions of Si and Al. For Si, it is likely that signals from underlying quartz played a role, for Al, it can be a result of adsorption in the iron-rich layer from weathered, underlying minerals. Porous iron films are known to have excellent adsorption capacities (Cornell & Schwertmann, 2003, pp. 253–296).

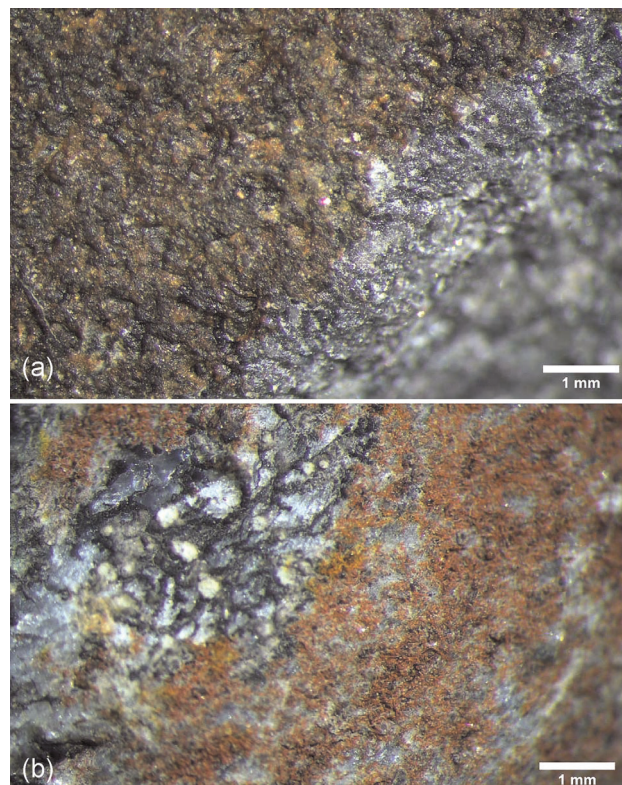
SEM images were consistent in terms of the appearance of the iron-rich surface layers and nanospheres, and organic components were not identified. This, however, does not rule out that bacteria may play a role in the formation (cf. Dorn, 2009, p. 172). Given the extremely thin and irregular nature of the films and spheres, poor crystallinity, and/or small crystallite size, it is not surprising that the FTIR analyses (see above) were unable to identify mineral phases. Thus, further analyses are needed to determine mineral phases, for example, by micro XRD or synchrotron methods (XAFS). However, it would be surprising if normal rust, that is, iron (oxy)hydroxide (goethite,  $\alpha\text{-FeO(OH)}$ ) and/or metastable ferrihydrite (iron hydroxide with varying water content and an elusive chemical formula; cf. Cornell and Schwertmann, 2003, pp. 23–27) are not the main mineral phases.

## 8.3 | Handheld XRF at Hjemmeluft

To determine the field relationship between iron content at red-colored surfaces and adjacent gray sandstone at the Hjemmeluft

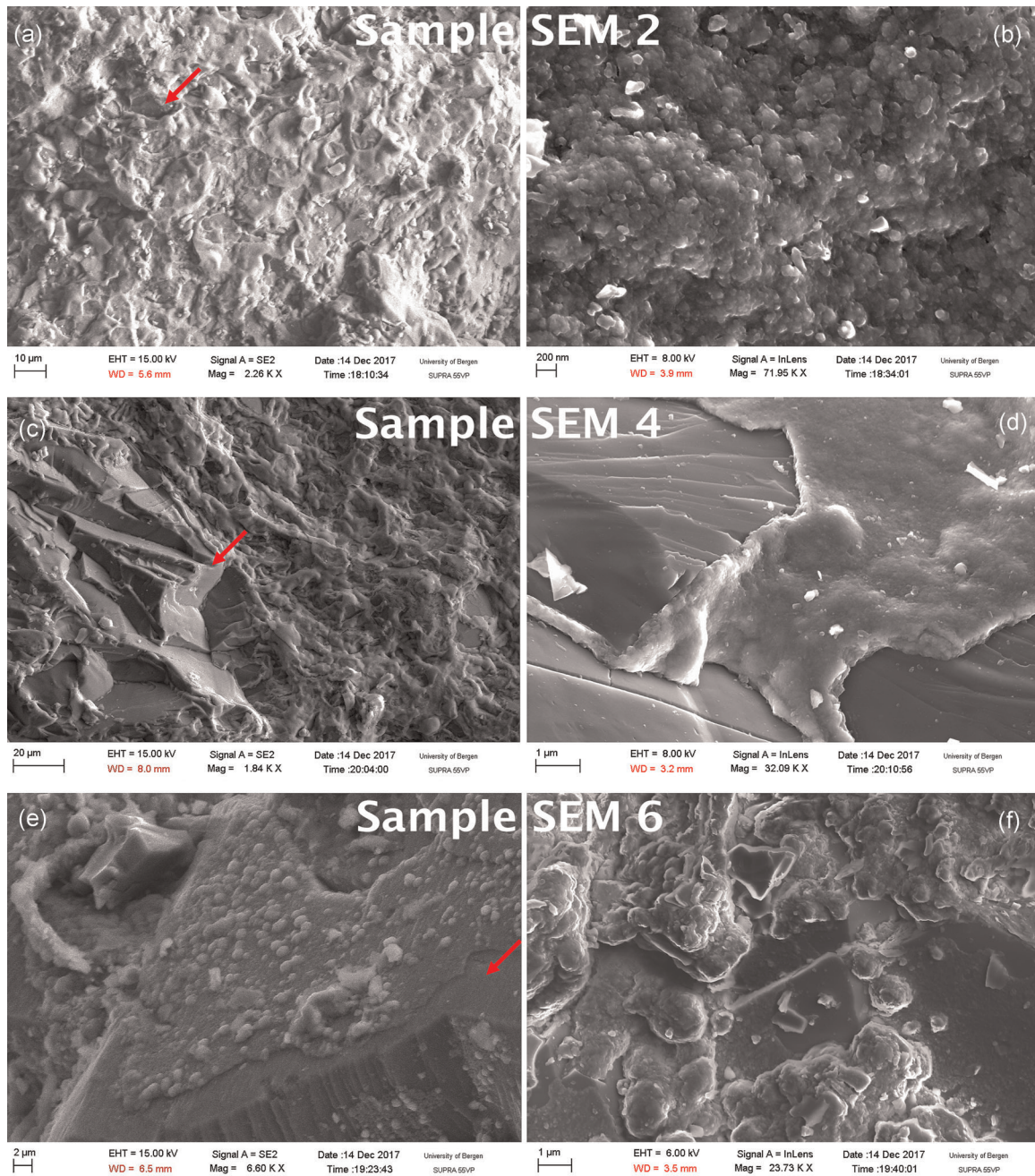
site, 504 handheld XRF measurements were carried out. After initial soundings, measurements were concentrated to three selected areas and rock surfaces at the shore and two of the rock art panels where red patches were most visible. The measurements were sorted, and those that were judged as irrelevant were removed, as were measurements directly on heavy mineral laminae (with very high Fe content). We were left with 173 measurements from the rock surfaces by the seashore, and 212 from rock art panels.

The analyses showed a marked increase in iron content at reddish surfaces beside heavy mineral laminae, and there was otherwise a consistent trend: Gray (“fresh”) sandstone surfaces, sometimes with patchy reddish color, always had a lower Fe content than strongly reddish surfaces (average red 2.62% with standard deviation 0.47 vs. average gray: 1.81% with standard deviation 0.37). At the cleared and cleaned (with ethanol) rock art sites Bergbukten 1 and 4A, a much less pronounced trend was recorded. Patchy reddish surfaces had, as expected, just a slightly higher Fe content, hardly statistically relevant, than gray sandstone surfaces nearby (average red 1.84%; gray 1.69%).



**FIGURE 14** Analyzed samples and stereomicroscopic images of the red coating on the same samples. (a) From the Hjemmeluft seashore (inorganic mainly). (b) From a vertical cliff at Skoddavarre, 150 m.a.s.l. (inorganic mainly). It should be noted that the coating in sample 1 is less patchy than in sample 2. This is probably due to the much smoother rock surface in the seashore zone (sample 1). Photos: C. Bläuer and P. Storemyr [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]





**FIGURE 15** SEM images of samples SEM 2, SEM 4, and SEM 6. (a) Iron film, with arrow indicating a quartz crystal below, (b) amorphous layer with nanospheres rich in iron, (c) iron film, with arrow indicating a quartz crystal below, (d) amorphous iron film over quartz, (e) amorphous iron film, with arrow indicating quartz, and (f) amorphous iron film over quartz. Photos: I. Thorseth [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

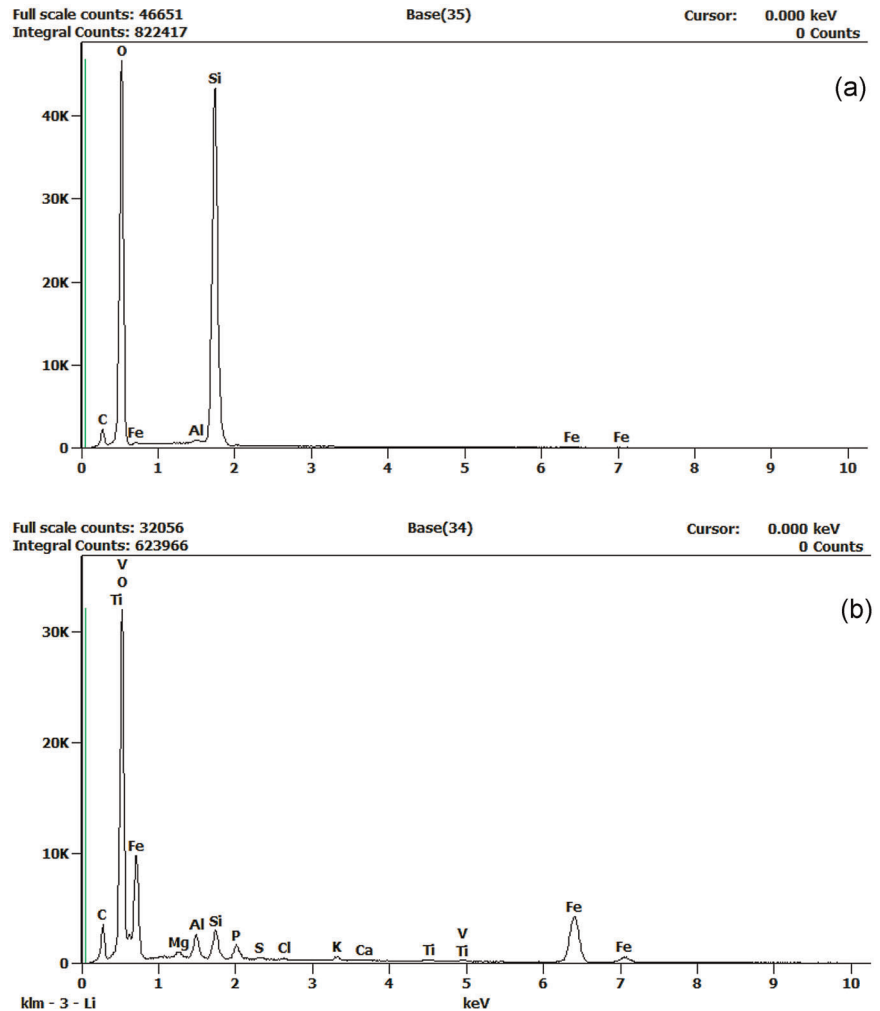
## 8.4 | “The Coca Cola experiment”

A small piece of native rock with a well-developed iron film was collected from the Hjemmeluft seashore. The piece was divided into two parts, and one of them was placed in a container with Coca Cola and the other was kept outside. The acidic liquid was replaced every week, and after a few weeks, the color was perceptibly weaker. Within 5 months, the color had faded considerably (Figure 17).

## 9 | DISCUSSION

Reddish surfaces on rocks range in composition/origin from inorganic (e.g., oxidation of iron-bearing minerals), to biogeochemical (with the aid of bacteria), and then to purely organic (e.g., algae), which can be found in virtually all environments. When generally inorganic in composition/origin, such reddish material on surfaces is termed an iron film. Recalling that the nature of the iron-rich layers in our case is generally inorganic and looks like a film (SEM), we will adopt this

**FIGURE 16** EDS on sample SEM 4. (a) Recording on quartz below the iron film, (b) recording on the iron film. The presence of Al, Si, and P should be noted. All other EDS recordings on samples SEM 2 and SEM 6 were consistent with sample SEM 4. III. I. Thorseth [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

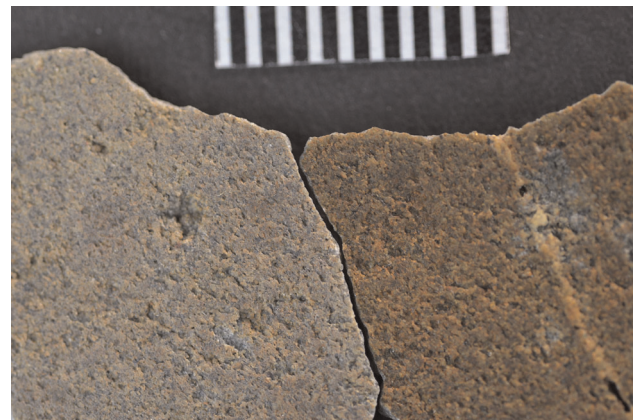


terminology. Furthermore, it is important to recall that inorganic oxidation of  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$  is rapid above a pH of 5 (Dorn, 2009, p. 172).

It is likely that the thin iron films in the intertidal zone at Hjemmeluft, as well as at Kåfjord, and in higher terrains without lichen are a result of the same processes that take place in soil profiles (see Cornell & Schwertmann, 2003, pp. 435–474). In our case, with magnetite by far as the most important original Fe mineral, goethite ( $\alpha\text{-FeO(OH)}$ ) is the most common stable end product at northern latitudes under aerobic conditions, formed via metastable ferrihydrite. The formation of lepidocrocite ( $\gamma\text{-FeO(OH)}$ ) is common under anerobic conditions in clayey soils in the north, and thus less likely in our case. Hematite ( $\text{Fe}_2\text{O}_3$ ) and maghemite ( $\gamma\text{-Fe}_2\text{O}_3$ ) are more commonly associated with film formation in subtropical and tropical regions (Cornell & Schwertmann, 2003, pp. 435–474).

Our observations and analyses have not proven the mineralogy of the iron films, but they have suggested that the films consist of goethite and/or ferrihydrite, which is corroborated by the literature overviews given by Cornell and Schwertmann (2003, pp. 435–474). The reason why metastable ferrihydrite may be a part of the iron films is that its transformation to more stable goethite can be blocked by adsorbed impurities (Carlson & Schwertmann, 1981). There are marked color

differences of the iron films, ranging from deep reddish, brownish, and violet/purple to orange. Presumably, the differences are a result of the nature of the sandstone substrate, the thickness and extensiveness of the films, the depth of the weathering rinds, as well as the impact of waves in the intertidal zone, “smoothing” the surface. Color



**FIGURE 17** The result of the Coca Cola experiment. The piece of rock dipped in Coca Cola for 5 months on the left. Photo: K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



differences may likely also result from differences in composition of the films (e.g., Al content) and degree of crystallinity, as well as difference of shape and size of crystallites.

The elevated rock art surfaces at Hjemmeluft have, until recently, been overgrown by lichen, moss, and other vegetation, and one of the key elements of weathering is lichen growth (Bjelland et al., 2002, p. 430; Chen et al., 2000). Such weathering can be both physical (hyphal penetration, expansion, and contraction of lichen thallus or swelling salts originating from lichen activity), causing mechanical disruption, and chemical (excretion of various organic acids; Bjelland et al., 2002; Chen et al., 2000). Dorn (2013, p. 80) also pointed out that lithobionts, in general, can dissolve inorganic accretions chemically and prevent the formation of coatings.

Even if the Coca Cola experiment cannot be judged as overly scientific, it demonstrated that the iron film on our specimen paled rather quickly when exposed to this relatively strong acidic liquid. Of course, in later experiments, oxalic acid should be tested. Any iron films on the rocks in question would, presumably, also have been dissolved in the slightly acidic environment established by vegetation and soil formation (Bjelland et al., 2002; Chen et al., 2000, p. 130; Gadd, 2017, p. 174).

As mentioned above, over the last two decades, most of the Hjemmeluft rock art has been regularly treated with ethanol to kill lichen and keep the surfaces clean (Bjelland & Helberg, 2006; Tansem, 2011). The absence of lichen may have been a contributing factor in improving the visual aspect of the patchy and rather weak red coating, or possibly may have even contributed to its recent formation. It is important to recall that biological growth and chemical weathering have created a light-colored and very porous weathering rind on rocks exposed for several thousand years after the last ice age. Thus, the formation of the reddish color will, presumably, give a “weaker” visual appearance than on a “fresh” rock with little porosity, as along the current seashore.

The main question posed is whether the current, barren seashore zone is rather similar to the one existing when the rock art was created thousands of years ago. On the basis of our analysis and discussions of climate, vegetation, and seashore history, the inorganic nature of the reddish color of the current barren seashore, as well as the patches of reddish color that have survived among lichen at the currently elevated rock art locations, it is highly likely that the “present is the key to the past,” that is, the barren seashore locations were also strongly red-colored by iron films thousands of years ago.

## 10 | CONCLUDING REMARKS

The data supporting the view that most of the rock art production in Alta as well as in many other Fennoscandian hunter-gatherer rock art sites was connected to the littoral zone are overwhelming, and contrary evidence or even suggestions on the matter are scarce. Although the current data on the postglacial seashore displacement in Alta are incomplete, and more research are needed to procure more accurate development patterns, a relative seashore chronology has been established. Combining this current knowledge with

geological analysis and studies of environmental history, we have suggested that the seashore at Hjemmeluft thousands of years ago was visually similar to that of today. Covered with red iron film or native red, the rocks in Hjemmeluft and Kåfjord, respectively, held common features that may have been a significant factor influencing the choice of location for rock art production and resulting in clearly visible bright rock engravings contrasted with the red rocks.

Postglacial uplift and weathering had two impairing esthetic consequences at Hjemmeluft. First, the red iron films vanished when the land rose and vegetation was established. Second, the bright pecking marks normalized, adopting the same gray color as the surrounding rock. At the Kåfjord site, the engravings also faded and acquired a similar appearance as the “host” rock’s color. Due to the special rock properties at Kåfjord, the panel is red to this day, but the color in the seashore zone was probably more intensively red when the rock art was made, due to similar processes as at Hjemmeluft.

Studies on how environmental changes affect the sites (Figure 18), as we have done here, may procure insights and raise questions, and instead of being narrowed down, the potential for new ideas and understandings of rock art is widened. The four major sites in Alta, including Hjemmeluft and Kåfjord, display several differences when they are compared, which indicates that identical geology and topography were not a prerequisite in general, and that each site had its own qualities. The search for formal parallels between rock art sites in general, often covering large areas, may easily obscure the individual qualities the sites hold, and thus also what in fact may have been local preferences and traditions. Applying an idiosyncratic perspective, where a number of qualities, also color, are taken into account, represents an alternative and, in our view, a more productive focal point for interpretations of rock art.

We have proposed that the red color was one of the principal esthetic qualities that inspired people to make their marks on these particular rocks, regardless of any deeper purpose or meaning behind it. Apparently, not every red rock surface was appealing as a place for rock art creativity in Alta; maybe the cliffs were too steep, surfaces too uneven, access too difficult, or the rock had other decisive qualities. The red rocks at Hjemmeluft and Kåfjord were favored again and again over a substantial period of time. These sites offer gently sloping, smooth rock surfaces, where the strikingly red colors and the green, black, and red laminations, as well as cracks, depressions and features resembling small landscape traits, add life and drama to the “canvas” in the littoral zone, creating a powerful backdrop for the bright, initially almost white, figures. Our findings visualize how the rocks and the art may have appeared to the people who created the engravings, which again may influence our perception and interpretation of the Alta rock art.

This new knowledge may also spur renewed discussions and ideas on how to manage, conserve, and disseminate rock engravings in Alta and elsewhere. A key point is authenticity, crucial to all aspects of heritage management. To make them easier to discern for the public, some of the rock engravings at Hjemmeluft are painted red and the rock surfaces on which they reside are gray. As shown by our research, it was rather the other way around. The color, visibility, and contrast that the rock art held have changed inevitably through natural





**FIGURE 18** A young boy living in the Hjemmeluft area, Helge Pedersen, engraved his name on the seashore rocks in 1948, and more than 70 years later, the letters and numbers are still bright and clearly visible against the reddish “background” rock. He also engraved his initials, HP, at 20 m.a.s.l. in the same year. The difference between them is not only in the color of the rock’s surfaces, but also in the engraving’s brightness. The engravings from 20 m.a.s.l., affected by lichens and weathering, have blended with the surrounding rock and lost the contrast and brightness displayed by the seashore engravings. Photos: K. Tansem [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

processes, which cannot be revised; however, the mindsets to present, preserve, and perceive it can change. One may argue that this disruption of authenticity is of little or no consequence; the rock art’s initial appearance is lost anyway. Still, and apart from the fact that it can be harmful, especially on removal (Bjelland & Helberg, 2006, p. 64), the paint is a foreign element that may alienate the rock art from its natural environment and make it appear as something it never was.

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#### CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

#### AUTHOR CONTRIBUTIONS

Karin Tansem: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, visualization, writing original draft, and writing review and editing.

Per Storemyr: conceptualization, data curation, formal analysis, investigation, methodology, visualization, writing original draft, and writing review and editing.

#### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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