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Comparing post-glacial chemical weathering of mafic and felsic rock at Brevik, Åkersberga, Sweden

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Abstract

A field study of postglacial chemical weathering comparing mafic and felsic rock was carried out in the northern archipelago of Stockholm in Brevik, Åkersberga. Rock surface hardness, surface roughness and relative weathering rates were calculated from data collected from three sites. A Schmidt hammer was utilized to measure rock surface hardness by a rebound value, a profile gauge was used to measure rock surface roughness and the relative weathering rates between mafic and felsic rocks were calculated using the measurements from the surface roughness. Mafic and felsic rock are found in close proximity to one another throughout this locality. Evident proof shows mafic rock weathers faster than felsic rock initially, and more specifically mafic minerals weather faster than felsic minerals. The time-averaged rate at which mafic rock surfaces weather faster than felsic rock surfaces dropped by 88 % in 1800 years, during which time the rock rose by 10 meters above sea level assuming post glacial rebound of 5.5 mm/year. The results of this study imply that weathering processes have different rates depending on rock type and environmental conditions and weathering rates vary non-linearly with time.

Contents

Introduction

Weathering is a natural process that alters the mineralogical and petrological properties of a rock mass. It is a process of breakdown that initiates as soon as rocks are exposed at Earth's surface. Rocks weather physically and chemically (Marshak 2015). Physical weathering is caused by thermal stress and pressure relief. Thermal stress can be caused by insolation and frost wedging while pressure relief can be caused by salt weathering and exfoliation. Chemical weathering includes hydration, hydrolysis and oxidation. These processes occur when minerals react with water and air, hydration is when water is being added, hydrolysis when water is dissociated and oxidation when ferric oxides react with oxygen (Scheffers, May, and Kelletat 2015).

Chemical weathering in cold regions was long recognised as almost non-existent due to the low temperatures (Thorn 1992). However, new studies have proved that not only temperature but also moisture content can be a primary control of weathering (Hall et al. 2002). Carbon dioxide was proved to be more soluble at colder temperatures in a study by Williams already in 1949 (Williams 1949). Weathering of a rock surface often leads to an increase in rock porosity and surface roughness. This can form rock features such as surface pitting, rust, voids, joints, onion cleavage, differential relief of crystals and in extreme cases alveolar weathering (McCarroll and Nesje 1996; White, Bryant, and Drake 1998).

Physical properties of rocks, such as porosity, jointing, etc. (Andrén 2009; Kanamaru et al. 2018; Olvmo and Johansson 2002) have an accepted primary control on rock weathering rates as well as chemical rock properties (Beylich and Laute, n.d.; Ruan and Galy 2021). Other studies of weathering includes weathering impact of a rocks optical properties, whether the colour of the rock affects its albedo and causes of thermal stress (Andre, Hall, and Comte 2004; Hall and André 2001), experimental lab studies of rock weathering in climatic chambers (Swantesson 1985), studies on bedrock weathering rates using reference features in alpine areas of northern Scandinavia (Dahl 1967; André 2002; Nicholson 2009) and studies of lithological influence and structural properties on landform evolution (Glasser et al. 1998; Olvmo and Johansson 2002). These are all studies that examined different aspects of weathering through the years.

However, weathering processes are very complex phenomena, and their combined alteration of rocks and minerals are yet poorly understood and very controversial among geoscientists. Previous study sites are often located above the highest shoreline, in alpine, arctic or hot, arid regions (Mustoe 1983; Warke 2000). Hence, there is a lack of studies from periglacial, cold tempered regions, below the highest shoreline that compares weathering features and rates between lithologies. This study aims to contribute to a better understanding of lithological influence in weathering of felsic and mafic rock and their relative weathering rates.

Background

Brevik is located in the archipelago approximately 25 km north of Stockholm, on the east coast of Sweden. Brevik has a cold temperate climate with an annual temperature average of +6°C, and an annual precipitation of 600 mm. Average summer temperatures are +17°C, and winter +0°C (SMHI 2022a).

Brevik is part of the geographical region called Bergslagen in which metasedimentary and metavolcanic rocks belonging to the Svecofennian Province crop out (Gaál and Gorbatschev 1987). The bedrock of Bergslagen is mostly 1.90 - 1.87 Ga. It was variably metamorphosed and deformed during the Svecokarelian Orogeny (Stephens et al. 2009; Johansson and Stephens 2017).

The studied outcrops are located by the shoreline and vary in altitude between 0 and 10 m a.s.l. (meters above sea level). The landscape is situated below the highest shoreline, hence the bedrock was reworked by the latest Weichselian deglaciation which regressed from this area approximately 11 200 a BP (Lundqvist et al. 2021). However, this area was below sea level until 1800 a BP, assuming a post-glacial rebound rate of 5.5 mm/yr. (see below).

The bedrock which crops out at Brevik is predominantly of medium metamorphic grade, i.e. amphibolite facies (Johansson and Stephens 2017). The studied outcrops are mainly mafic and felsic. Mafic refers to rocks rich in dark coloured ferromagnesian minerals with amphibole as its main constituent: the rock is referred to as amphibolite. Felsic refers to rocks rich in light coloured minerals, hence rich in silica, quartz, feldspar and feldspathoids. K-feldspar is the main constituent. However, the rock shows metamorphic banding and can be referred to as gneiss. Gneiss is a metamorphic rock with a banded or foliated structure, typically coarse-grained and often consists mainly of feldspar, quartz and mica (Lundqvist et al. 2021).

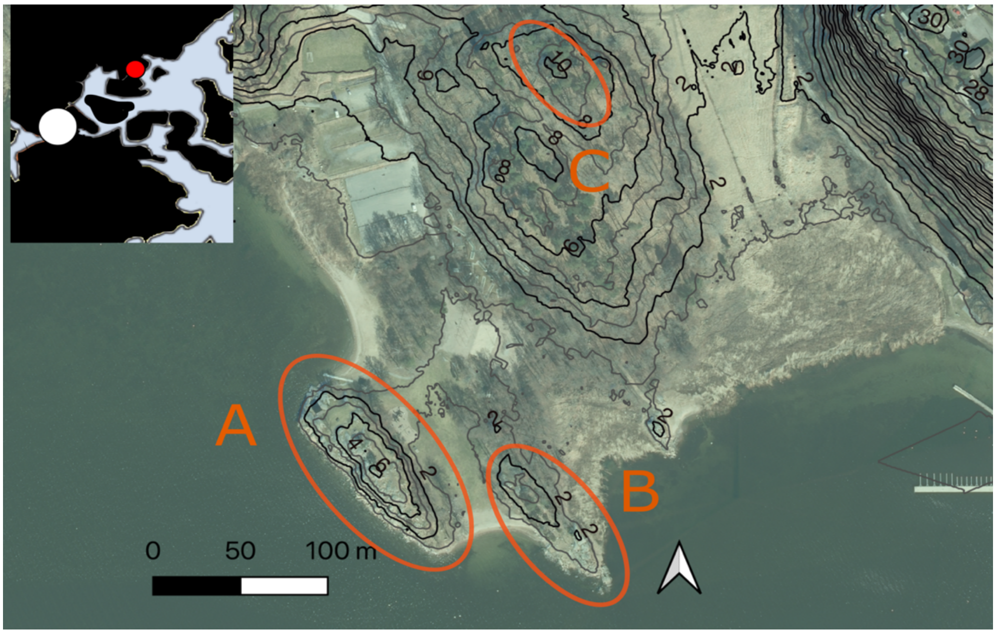

Figure 1. Brevik with the three studied sites of outcrops encircled in orange, A, B and C. Data from these outcrops are collected and measured in situ relation to m.a.s.l. according to this map and a GPS. Map is managed in QGIS with metadata from Swedish surveying and mapping. The inset map shows Stockholm (white dot) and the study area (red dot).

Methods

Four methods were used to characterise the weathering of mafic and felsic rock in Brevik: *field evidence*, *bedrock surface hardness, rock surface roughness* and *relative weathering rate.* These were related to altitude which was calculated in the field using a GPS via the Swedish surveying and mapping app and a physical orthophoto with an elevation grid (*figure 1)*. Maps were managed in QGIS and metadata for orthophoto and elevation grid were downloaded from the Swedish surveying and mapping, provided by SLU (2022). Measurements were collected by in situ relation to m a.s.l, (*figure 2*) and they were considered at 0-1, 1-2, 2-3, 3-4, 4-5, 5-6 and 9-10 m a.s.l. Note the gap in data between 6 and 9 m.a.s.l, this is due to a lack of exposed outcrops.

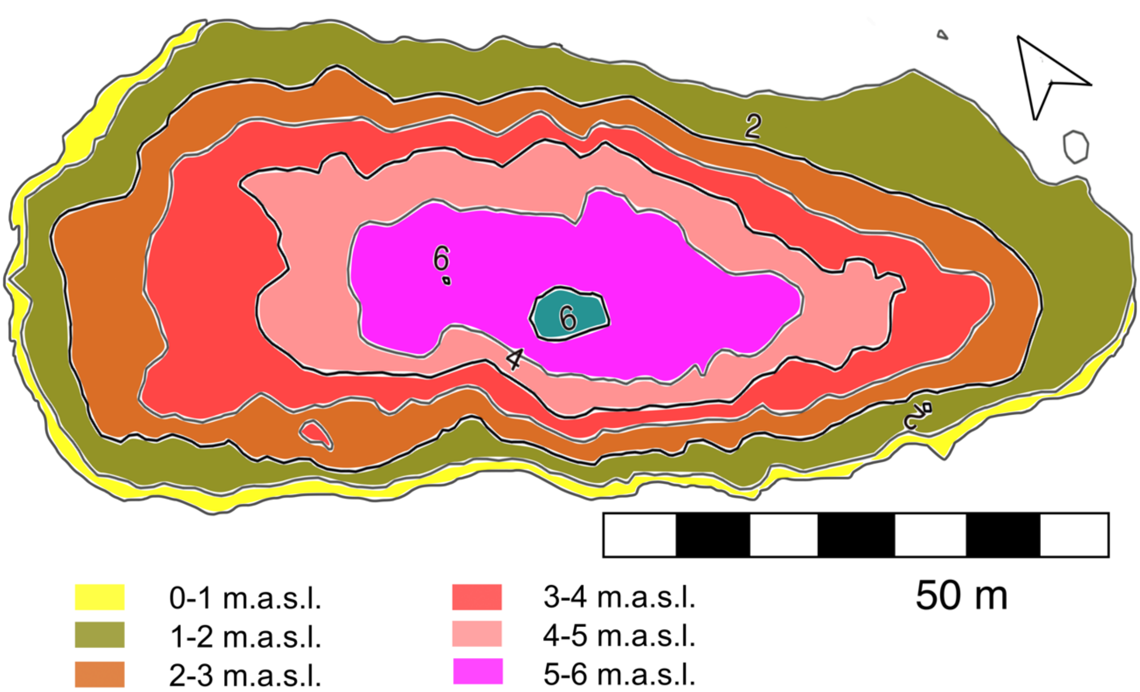

Figure 2. Modified map with elevation grid of the major site A, at the locality. The elevation grid is tinted with different colours to highlight the methodical manner, in which data were collected from certain elevations across the outcrops at all three sites.

Field evidence

Photographic field evidence of postglacial weathering differences between felsic and mafic rocks were collected. This evidence includes photographs of observations and features where dissimilar weathering within lithologies were observed. Rock surface features such as, pitting, cavities, voids, onion skin weathering, oxidation and postglacial striae are reported in the study. Observations of foliation, minerals assemblages, lichens and moss growth at certain elevations and hollowness below rock surface are also depicted at the site. Outcrops were occasionally soaked in water to make postglacial striae and other features more evident for recognition in photographs (*figure 6a, b)*.

Bedrock surface hardness

The mechanical hardness of mafic and felsic rock was measured using a N-type Schmidt hammer. The instrument measures the distance of rebound from a piston of a controlled impact on a rock surface. Giving a value of resistance between 10-100 R, referred to as R. The N-type is the version used most by geomorphologists (Nicholson 2008; Hall 1997; Matthews and Winkler 2022). It can provide data on a range of rock types from weak to very strong with compressive strength that range from c. 20 to 250 MPa. Harder rocks have a higher rebound value.

A Schmidt hammer is originally designed to measure mechanical hardness of concrete, hence a flat smooth surface. This makes the Schmidt hammer extremely sensitive to discontinuities in a surface. Hence, fissile closely foliated and laminated rocks cannot easily be investigated. It is therefore important that the Schmidt hammer is used with care such are, making sure measurements are carried out on flat as possible surfaces and avoiding lichens. Using it at on a horizontal plane with less than 10° declivity, at a 90° angle towards the rock (Goudie 2006).

These constrains were all followed during this study where 60 different rock surfaces were examined across site A, B and C: 31 mafic and 29 felsic. At each examined outcrop, 50 rebound values were sampled, four times at each elevation. The measurements were carried out during April and May when air temperatures were fluctuating between 3-15°C.

Rock surface roughness

Surface roughness is measured using a profile gauge across a horizontal surface of felsic rock. K-feldspars are observed to correspond to the high points and amphibole to the low points. By pressing the profile gauge against a rock surface, the profile gauge reflects the profile of the rock surface. The profile is traced on a paper (figure 3) where maximum difference, *d*, between the lowest and highest surface along the profile is measured (*figure 4)*. Seven rock surfaces are analysed between 0-10 m a.s.l. Four profiles at each surface are depictured for a mean value.

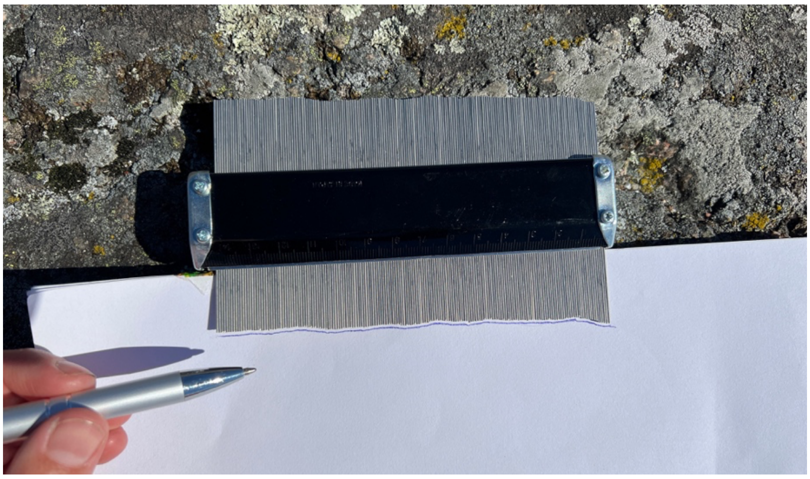

Figure 3. Rock surface is being transferred from the profile gauge to a paper. The profile can be analysed later to establish the maximum difference between high and low areas.

Relative weathering rate

Relative weathering rates between mafic and felsic rocks were calculated using their difference in surface lowering. Relative rate is not the same as absolute weathering rate. An absolute rate is fixed by time while the relative rate is calculated in proportion to another rate. Using the surface roughness data where amphibole is interpreted to be consistent with the lowest surfaces, and K-feldspar consistent with the highest surfaces along the profile.

The relative rate of chemical weathering between amphibole and K-feldspar is calculated by plotting difference, *d*, in height (*figure 4)* as a function of time, *t*. Time is the number of years a rock has been exposed to weathering. Due to post-glacial rebound a rebound rate of 5.5 mm/yr was used (SMHI 2022b). Dividing surface elevation, m a.s.l, with 5.5 mm/yr equals number of years the rock has been exposed to weathering. Dividing the plotting difference, d, with the calculated time, t, for the corresponding elevation, we get a relative weathering rate between amphibole and K-feldspar.

Figure 4. The profile gauge where *d* equals the plotting difference between maximum and minimum lowering along profile.

Results

Field observations

In this section field observation are described and displayed as photographs. Difference in *surface lowering* between felsic and mafic rock were observed at all sites and all seven elevations studied, all of different significance:

- Porphyritic gneiss where K-feldspar crystals had greater elevation than the mafic matrix.
- Felsic vein cutting through a mafic rock, resulting in great surface lowering of the mafic rock, compared to the feldspar vein (*figure 5 a*).
- Mafic veins cutting through a felsic rock, resulting in great surface lowering of the mafic vein compared to the gneiss (*figure 5 b)*.

The veins observed between 0-3 m a.s.l differed greatly between centimetres to decimetres in surface lowering. Veins at higher elevation tended to have less difference in surface lowering. Hence a trend of decrease in difference between mafic and felsic vein surface lowering was recognised.

Figure 5 a) Photograph display a felsic vein cutting through mafic rock where mafic rock has weathered more than the felsic vein, observed at 3 m a.s.l at site A. b) Right photo displays the inverse feature where an amphibole vein has cut through a felsic rock, the vein has weathered substantially more than the felsic rock and surface differences are up to two decimetres, vein is observed at 0-1 m a.s.l. at site A.

Postglacial striae were visible in some felsic outcrops but evident in all mafic outcrops (*figure 6a,b)*. Felsic rock tended to have a rougher, angular surface where striae could be recognised when the outcrop was soaked in water and sunlight reflecting upon it. Mafic rock tended to have a smoother and even surface where striae were visible while dry, but even more evident if soaked.

Figure 6 a) Photograph display a wet outcrop of mafic and felsic rock where evident striae appear in both, however the striae is more prominent in the mafic rock, at site B. b) Wet mafic outcrop shows evident striae with a felsic vein cutting through, at site B.

Pitted surfaces were observed scattered across all outcrops on all three sites, A, B and C. They were observed on both mafic and felsic rock although the quantity of observed pitted surfaces was by far greater on mafic rocks. Clusters of pits were depicted by the very sea level up to 6 m a.s.l. at suites A and B. Pitted surfaces appeared along joints, voids or on plain surfaces, on the very top of an outcrop, by the steep sides or below a bulge of the rock. At site C, 8-10 m a.s.l. pits appeared more random and scattered than clustered along the rock surfaces.

Figure 7 a) Photograph exhibits a felsic outcrop with a pitted surface at 3 m a.s.l. b) Display of a pitted surface in a mafic rock outcrop, note pitting occurs scattered along a set of joints.

Onion weathering features were observed as patches of the rock surface which appeared to weather off like layers of an onion, hence it is referred to as onion weathering. These features are recognized first around 2 m a.s.l and they appear predominantly on mafic outcrops. They are scattered about the outcrops but has a common trend of either facing west, south or in a zenith position of the rock. Sizes of these onion weathering features vary between >30 cm (*figure 8a, b)*. Outcrops where with these onion features were recognised retaining patches of hollow sound, occasionally in-between features, where surface looked intact. Onion features appeared from 2 m a.s.l, the hollow patches started appearing at 3 m a.s.l and increased up to 6 m a.s.l. Patches of onion features were also recognised at site C, outcrops 9-10 m a.s.l under moss and a thin layer of soil, approximately 1-7 cm thick.

Figure 8 a) Photograph displaying onion weathering features of lowered, rounded and flat patches scattered across a mafic outcrop with shoe as scale, at 5-6 m a.s.l. b) Mafic outcrop with onion weathering features at 3 m a.s.l. at site A.

Oxidation, rusted surfaces, appeared most prominently at site A and B, closer to the sea. The steep sides of outcrops tended to be in a more oxidated state then oxidation along a flat surface. Oxidated surfaces appeared as red and brown tinted patches on top of outcrops with a variety of size between 0,5 cm – 20 cm across. These patches occasionally appeared in combination with onion weathering features. By the steeper sides, across bulges or along foliation planes of some outcrops, rock weathered of like thin flakes that easily could be chipped off or crumbled (*figure 9a, b)*. Oxidation of rock surfaces were observed in mafic outcrops from approximately an altitude of 2 m a.s.l. and up.

Figure 9 a) Photograph display mafic outcrop with an oxidated surface where flakes easily can be chipped off, 3-4 m a.s.l. b) Oxidated mafic bulge of an outcrop where oxidated and chemical weathering during repeated cycles have weathered the surface.

Lichens and moss were recognized growing on both felsic and mafic rock, lichen is the first visible biological matter that starts to grow on rock surfaces. Lichens start growing on mafic outcrops between 0,5-1 m a.s.l. and moss at 2 m a.s.l. at site B *(figure 10 b)*. Felsic outcrops appeared more resistant to lichens and moss growth at corresponding hight. Lichens first appear growing in joints and voids in the rock surface before it starts to cover the outcrop. Moss appears mainly on the north-eastern side of site A and B. Since site C is located further from the shore and sheltered by a birch and oak forest, moss can grow thicker and cover more of the outcrops of both felsic and mafic rock (*figure 10 a)*.

Figure 10 a) Outcrop at site B where lichens can be indicated growing at approximately 0,5 - 1 m a.s.l. and increase with elevation, a shoe as scale. b) Photograph display a felsic outcrop at site C with onion skin features, surface was covered with 2-7 cm bio mass but uncovered due to examination of surface, folding rule as scale.

Amphibole clusters were observed at 5-6 m a.s.l. at site A. This feature was only recognized at this particular outcrop (*figure 11 a).* Crystals of amphibole appeared in clusters of 0,5 – 3 cm across, in a quartz and K-feldspar vein. *Weathered cavities*/voids with an approximate diameter of 5-20 cm across were found at 2 -10 m a.s.l. at site A and C. Voids appeared along joints and were scattered mostly one by one or occasionally two to three. One outcrop had several weathered voids gathered along a felsic vein in an outcrop at 2 m a.s.l at site A facing the sea (*figure 11b)*.

Figure 11 a) Photograph exhibits what appears to be clusters of crystalized amphibole in a quartz vein, amphibole might be cutting through the quartz vein, or crystalized in voids in the vein. Surface lowering between quartz and amphibole is evident, outcrop appears at 5-6 m a.s.l.at site a. b) Photograph display several weathered cavities/voids between 10-20 cm across at 2 m a.s.l. They appear in a mafic outcrop along a felsic vein at site A.

Foliation, in both mafic and felsic outcrops were observed at site A, B and C. Foliation was steeply inclined and most easily seen on vertical faces (*figure 12 a)*. Weathered out layers of amphibolite occurred when foliation was perpendicular to the rock surface (*figure 12 b)*.

Figure 12 a) Photograph of a felsic rock where foliation of amphibole and K-feldspar minerals is evident, 1 m a.s.l. b) Display of a foliated amphibole vein, cutting through felsic an outcrop. Amphibole have experienced significant weathering and appear as sheets, at 0,5 m a.s.l.

Bedrock surface hardness

Schmidt hammer rebound values on felsic rock gave a mean trend of values decreasing with hight above sea level from 60-36 R. Rebound data shows approximately constant values between 0-4 m a.s.l. where mean values are between 58-60 R (range 38.5-69.5 R). Rebound data between 4-10 m a.s.l have a slightly decreasing trend where mean values are 60-36 R (range 69.5-17.5 R). Note the gap in data between 6-9 m a.s.l. Rebound values from the highest elevated outcrops, site C, show the lowest rebound value (*figure 13).*

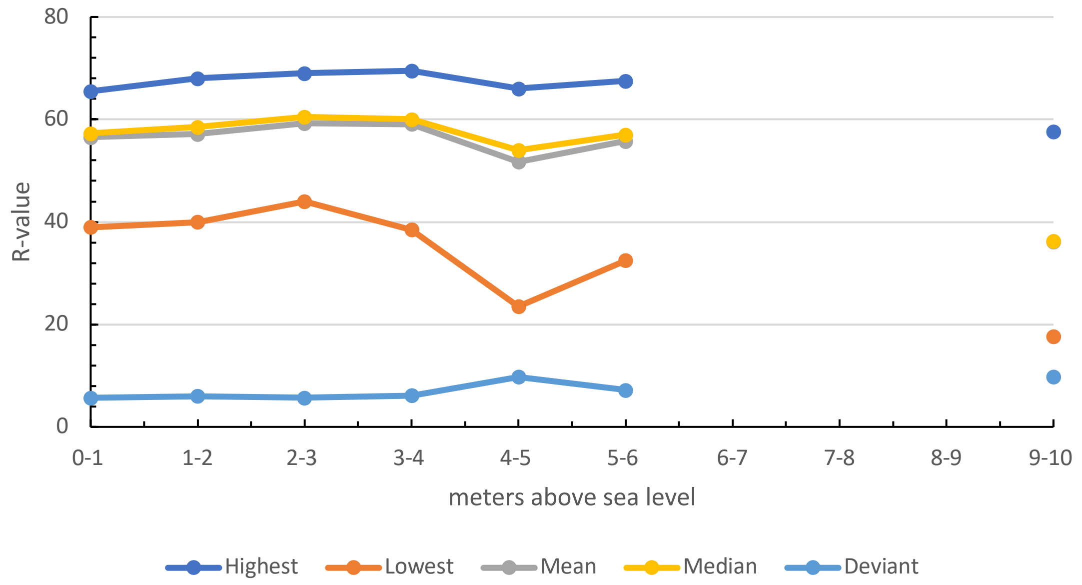

Figure 13. Diagram of rebound values, R, of felsic rock surfaces, measuring the surface hardness in a rock. Diagram depict values of R decreasing with height above sea level.

Rebound values of mafic rock also show a decreasing value with height above sea level with a mean range from 52-37 R. Rebound data between 0-3 m a.s.l depicts the biggest drop in rebound in mafic rock with mean values of 52-39 R (range 59.5-21 R). R values between 4-10 m a.s.l. shows a lighter decrease in mean values of 44-37.5 R (range 59.5-18.5 R). Note the same gap in data between 6-9 m a.s.l. which makes the decreasing angle even smaller. Rebound values from the highest elevated outcrops, site C, show the lowest rebound values in mafic rock, although 2-3 m a.s.l show similar R values (*figure 14).*

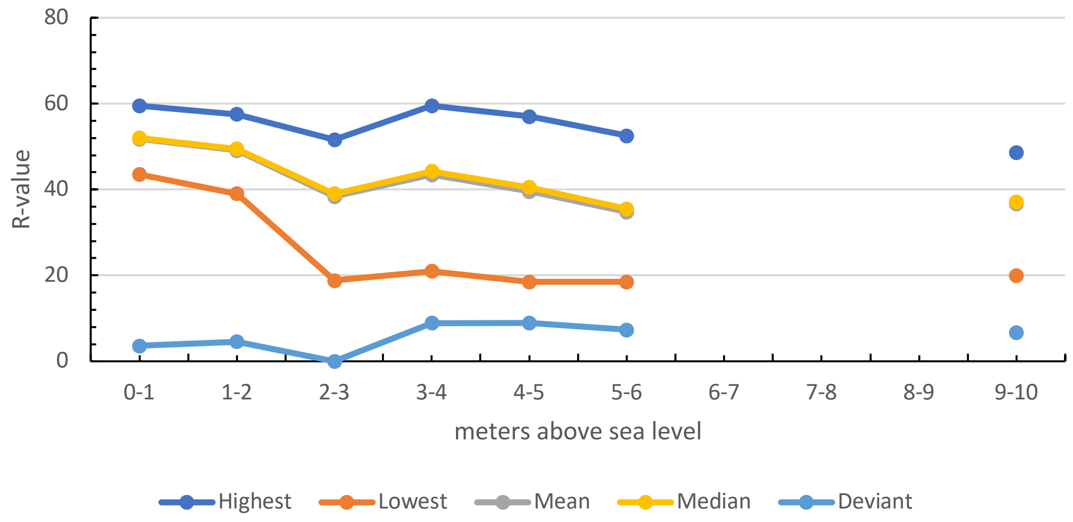

Figure 14. Diagram depicting a range in rebound values between 59.5-21 R in mafic rock surfaces. A drop in R value appear between 2-4 m a.s.l that correlates with values from the highest outcrops at 9-10 m a.s.l. at site C.

Mafic rock has a lower rebound value on all corresponding elevations compared to felsic rock surfaces. The range between mafic and felsic values vary between 69.5-35 R. Where felsic rebound values depict low and steady decrease while the mafic trend is decreasing more fluctuant (*figure 15)*.

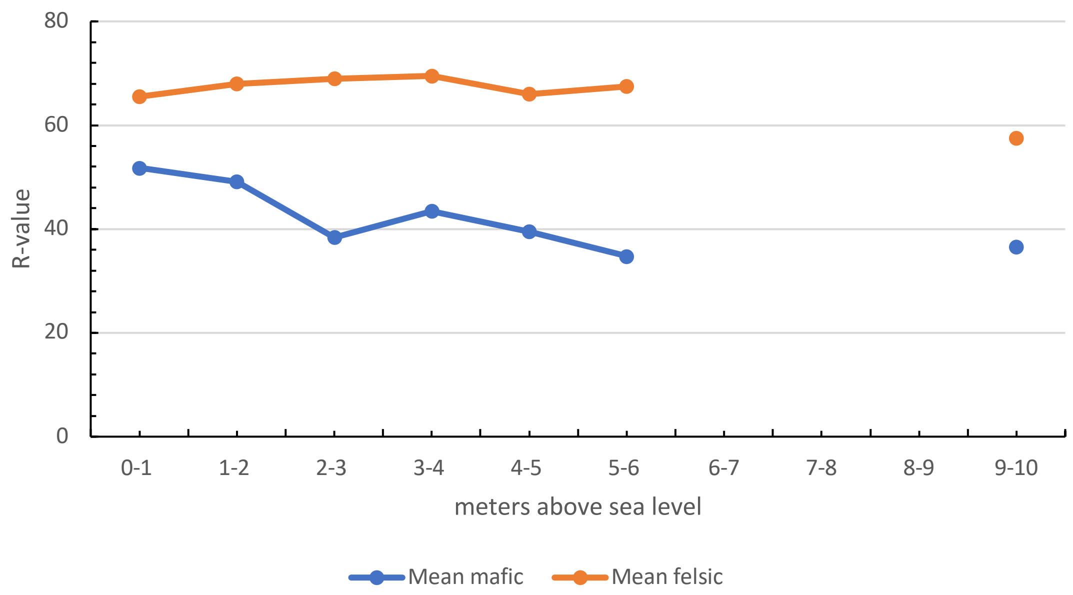

Figure 15. Diagram comparing mean R-values of mafic and felsic rock where mafic rock surface hardness is lower than felsic at all height. Both mafic and felsic rock show a decrease in R-value with height above sea level.

Rock surface roughness

The roughness of both mafic and felsic rocks increases with height above sea level. The difference between felsic and mafic rock surfaces varies approximately linearly with altitude at 0-5 m a.s.l. from 2 to 8mm. The difference increased to 7-15mm at 5-6 m a.s.l, *(figure 16)*. These data were measured at site A where 5-6 m a.s.l. corresponds to its highest peak where the outcrop could be exposed to enhanced weathering due to higher wind velocities, sun, rain and sea spray from almost all latitudes. The roughness decreases from 6-10 m a.s.l. Outcrops at 9-10 m a.s.l are collected at site C *(figure 1*) which is situated further inland, protected by birch and pine trees, soil and moss.

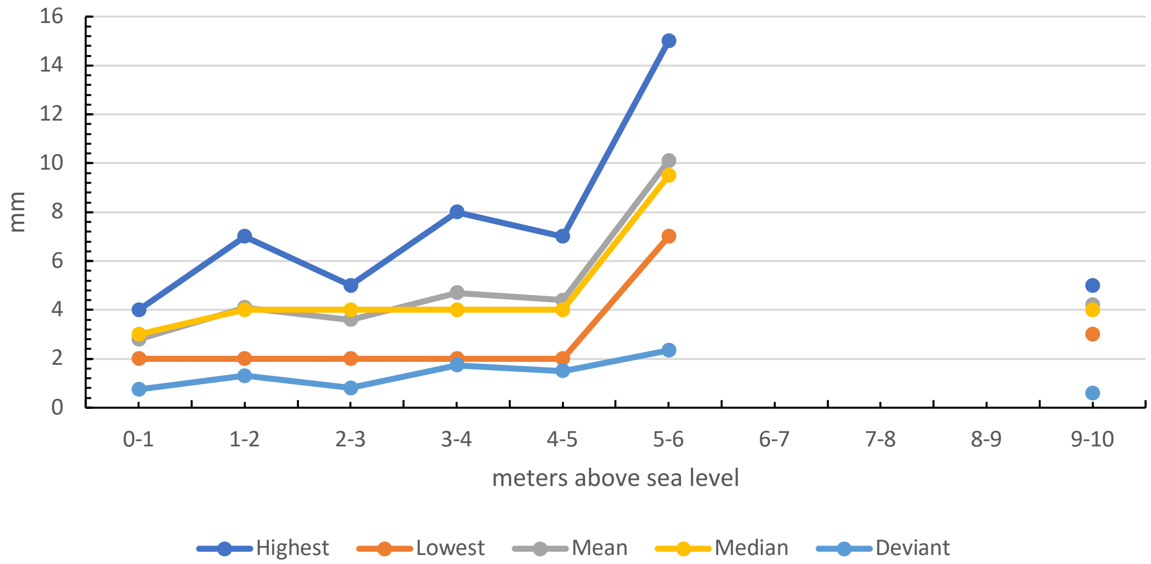

Figure 16. Diagram comparing surface roughness by lowering differences between felsic and mafic rock at different elevation. Trend shows an increase in roughness with height above sea level. 5-6 m a.s.l. corresponds to the highest surface on site A, whereas 9-10 m a.s.l are data from outcrops by site C, inland, protected by forest and biological cover, see figure 1. Note the gap in data between 6-9 m a.s.l.

Weathering rate

The relative weathering rate is calculated using surface roughness difference, d, between mafic and felsic rock, divided by time. Years of exposure at 1 m a.s.l is calculated with rebound rate 5.5 mm/yr (SMHI 2022a) equation:

$$t = \frac{1000}{5.5} \approx 180\ years$$

Implying that rocks at 1 m a.s.l have been exposed above sea level for 180 years, 2 m a.s.l. for 360 years, 4 m a.s.l for 540 years etc.

The key finding is that mafic minerals weathers initially faster than felsic rock but that trend slows down at 3-4 m a.s.l. when the outcrops have been exposed to weathering for about 540 years (figure 17). The relative weathering rate between mafic and felsic rocks continues decreasing gradually throughout the data (*figure 17).* The relative weathering rate is not an absolute rate, it is calculated using the surface roughness data, where the difference d (*figure 4*) is divided by the time that the examined outcrop has been exposed above sea level. These calculations result in the relative weathering rate between mafic and felsic rock, hence the difference between them, not an absolute rate.

The highest relative weathering rate appears closest to sea level and has a relative rate of 22 μm/yr the first 180 years. Between 180- and 360 a BP the relative weathering rate decreases to 19,5 μm/yr. The rate continues to decrease to 540 a BP to 9 μmm/yr. Between 720-900 a BP the relative weathering rate increases to almost 14 μm/yr, remembering this outcrop is the highest and most weathering exposed outcrop at site A. Between 1080-1800 a BP the rate continues to decrease to a rate of almost 3 μm/yr, note this is a nearly 800-year gap.

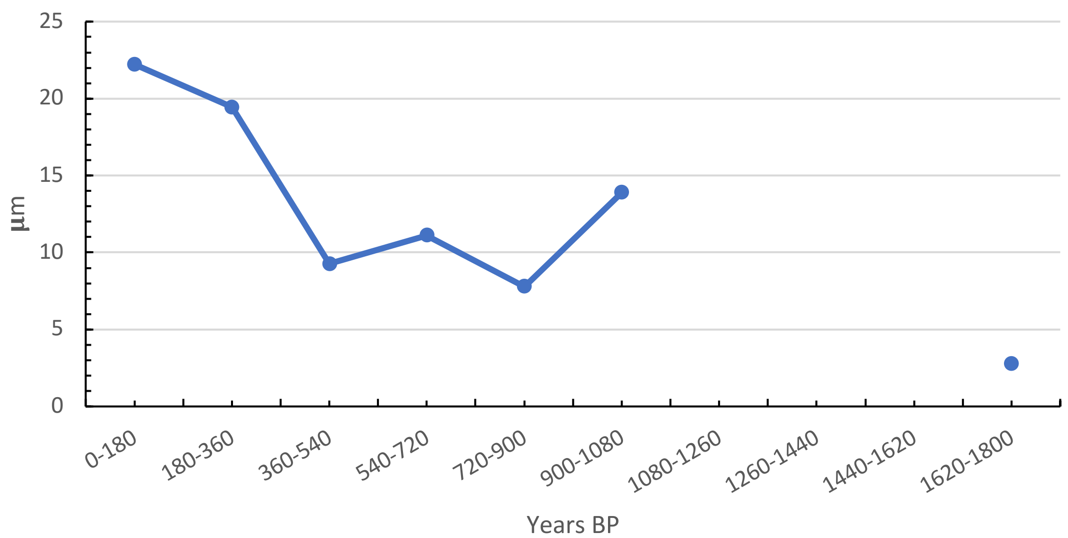

Figure 17. The relative weathering rate between mafic and felsic rock decreases with time. Mafic rocks have a much faster weathering rate the first 180 years. At 540 years the trending difference in weathering rate between mafic and felsic rocks starts to even out, and the trend of relative rate continues to smoothly decrease.

Discussion

Weathering types

Chemical and physical weathering are active at all of the sites of this study, in one way or another. Site A and B are both located in direct contact with the sea (*figure 1*). Outcrops are exposed to insolation, abrasion and the salty sea spray from Östersjöns brackish water etc. Figure 7 b displays a photograph of a *pitted surface* along a joint in a mafic outcrop. Joints are developed by physical weathering but become wider due to chemical weathering acting along the joint (Blatt, Tracy, and Owens 2006). The scattered pits are due to chemical weathering where salt crystals by repeated cycles go through hydrolysis and hydration accentuating minor differences in the relief of the rock surface. These pits occur due to the expansion and contraction associated with halite precipitation.

The *onion skin features* also appear due to a combination of chemical and physical weathering process (*figure 8 a, b*). These features are generally facing the sun where fluctuating temperatures cause expansion and contraction of the rock surface. Chemical process such as hydrolysis accelerates and extend these weathering features.

Biochemical weathering (*figure 10 b)* is the main process operating at site C. Outcrops are located 200 m offshore, where outcrops are protected by a birch and oak forest. They are also covered by a thick layer of soil and biomass. This inhibits the physical weathering processes, such as abrasion and insolation seen at sites A and B. Promotion of chemical and physical weathering by biological processes is a positive feedback mechanism (Dahl 1967). This feedback occurs because soil retains water, salt and hosts a variety of organisms which secrete organic acids, promoting faster chemical weathering (Scheffers, May, and Kelletat 2015).

Differential weathering

Mafic rock is more susceptible to weathering by physical disaggregation and chemical dissolution than felsic rock. Figure 5a and b displays mafic rock surfaces being weathered preferentially relative to felsic rock surfaces. This can be seen from the weathering profile in which mafic layers have weathered 100-250 mm deeper than felsic layers. This happens because mafic minerals are more chemically reactive than felsic minerals in accordance with Bowen's reaction series (Marshak 2015). Another contributory cause may be that K-feldspars, which are the dominant minerals in the felsic layers, are mainly bigger than amphiboles, which are the dominant minerals in the mafic layers (*figure 12 a*). This means that the surface area of the amphiboles is bigger than for the K-feldspars.

Mafic rocks are softer compared to felsic rocks. The diagram in figure 15, show mafic rocks have a lower rebound value compared to felsic rock, meaning mafic rock surfaces are not as hard as felsic rock surfaces. Another indication that mafic rock surfaces are softer can be seen in figures 6 a and b. Here mafic rock surfaces exhibit glacial striae whereas the felsic rock surfaces do not. A further indication of the susceptibility of mafic rocks to chemical weathering is the occurrence of pitted surfaces, voids (*figure 11b*), and onion skin features in mafic rocks (*figure 7-8*) and not in felsic rocks. Lichens also start to grow and weather mafic rocks at an earlier stage compared to felsic rocks. Figure 10 a show that lichens start to weather the mafic rocks at 1 m a.s.l. and the felsic rocks at 2 m a.s.l.

Oxidation is another type of chemical weathering acting only on mafic outcrops. This mainly affect mafic rocks because amphiboles contain iron which readily oxidizes to form iron oxides during chemical dissolution (Scheffers, May, and Kelletat 2015). *Oxidation* were only observed on mafic outcrops and was extensive on parts of the rock facing the sea (*figure 9 a, b*). This could imply that salt from sea spray accelerated chemical weathering making the rock more susceptible to oxidation.

Changes in differential weathering

Differences in the type of weathering affecting felsic and mafic rock surfaces appear to change with time at Brevik. Initially mafic rock surfaces weather faster than felsic rock surfaces. However, with time weathering of felsic rock surfaces takes over.

For example, figure 13-15 show how felsic rebound is relatively stable, for the first 1000 years after rising above sea level, at 65 – 67 R (corresponding to a variation of ~2%). During the next 800 years, rebound value drops by 15% (*figure 13*).

It is also apparent from figure 16 that weathering differences between mafic and felsic rocks change with time. From 0 - 6 m.a.s.l., differences in surface roughness between mafic and felsic rocks increase from 2-4 to 7-15 mm, whereas from 6 to 10 m.a.s.l., differences in surface roughness decrease again from 7-15 to 3-5 mm.

A final observation is seen in figure 10 b. Here, a felsic rock surface at 10 m a.s.l. shows onion skin weathering which was only observed on mafic rock closer to sea level at site A and B. However, onion skin weathering at site C was probably promoted by biochemical processes given that the rock surface was covered by 2-7 cm of soil and biomass.

Relative weathering rates

Initially, mafic rock surfaces weather 22 μm/yr faster than felsic rock surfaces (*figure 17*). However, this differential weathering rate decreases to 2.7 μm/yr 1800 years after the rock surface rises above sea level (*figure 17*). This 88% drop of differential weathering rate occurs in stages, the initial drop by 38 % during the first 1000 years and a further 80% during the following 800 years. This could indicate the importance of biochemical weathering given an approximate correspondence to the point at which rock surfaces become vegetated.

Conclusion

When comparing postglacial differential weathering of mafic and felsic rock at Brevik, mafic rocks weather faster than felsic rocks initially. The rate at which mafic rock surfaces weather faster than felsic rock surfaces dropped by 88 % in 1800 years, during which time the rock rose by 10 meters due to post glacial rebound. This implies that weathering processes have different acceleration rates depending on environmental conditions. Far from the shore, hydrolysis and root wedging are key processes effecting both mafic and felsic rock, whereas closer to the shore, salt weathering and insolation are key processes effecting mainly mafic rock. Interestingly, results from this study indicate that weathering is a complex phenomenon the rates of which vary non-linearly with time.

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