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A Holocene lacustrine rock platform around Storavatnet, Osterøy, western Norway

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Abstract: A recently discovered lacustrine rock platform at low altitude exists along a 10 km^2 lake on the Osterøy Island near Bergen, western Norway. The lake was converted to a reservoir in 1920 and therefore is subject to frequent changes in level above and below the previous natural level of 151.5 m a.s.l. The rock platform, up to 20 m wide, is developed in strongly foliated metamorphic Proterozoic and Palaeozoic bedrock. Overhanging notches and small caves are developed along bedrock fractures in some places along the platform, which typically tilts 5 to 10 degrees towards the lake and is veneered with angular debris from the cliffs. The study area was deglaciated at the Pleistocene/Holocene transition 10 000 ^{14}C yr BP, and the tilting of the glacial rebound was complete about 6000 ^{14}C yr BP. The west-coast climate in Norway during the latter part of the Holocene, with high precipitation and frequent freeze-thaw cycles during winter, resulted in highly fluctuating lake levels. These conditions are consistent with the conclusion that the platform was formed by frost weathering. Mass movement from the steep slopes, together with ice-push during ice breakup, was responsible for transportation of the debris. Because the platform around the lake is essentially at the same level, it must have been formed between the mid-Holocene and AD 1920.

Key words: Holocene, rock platform, lacustrine, frost weathering, western Norway.

Introduction

Rock platforms are found mainly in marine environments and usually described as the result of marine abrasion (Trenhaile, 2002). Late Weichselian rock platforms are common along the fjords of northern Norway and described as formed mainly by frost weathering just outside the Younger Dryas glacier terminus (Marthinussen, 1960; Rasmussen, 1981).

Descriptions of lacustrine rock platforms are relatively rare. On the North Island, New Zealand, with an oceanic climate, Allen *et al.* (2002) interpreted the formation of a lacustrine rock platform to subaerial weathering with wetting and drying cycles as the main process together with wave action. Lacustrine rock platforms are usually found in periglacial or alpine environments. The most famous shorelines of this kind are the so-called parallel roads of Glen Roy in Scotland, where three shorelines were formed along the shores of dammed lakes in response to ice advance and retreat during the Loch Lomond Stadial (Younger Dryas) (Sissons, 1978; Dawson, 1980). In the Jotunheimen Mountains in southern Norway, Matthews *et al.* (1986) reported on the rapid formation of a rock platform, up to 5.3 m wide, formed by frost weathering in a lake dammed by a 'Little Ice Age' glacier between AD 1650 and 1850. Shakesby and Matthews (1987) discussed the process of formation of the rock platform formed after the 'Little Ice Age' around the same lake. In a general comment, Trenhaile (1980) stated that the morphology of rock platforms is strongly influenced by lithology and structure. Very little attention has previously been paid to this relationship.

This paper describes a previously unreported, prominent rock platform around a lake at low altitude (150 m a.s.l.) on Osterøy Island, 25 km northeast of Bergen, western Norway. It focuses on the relationship between the morphology of the rock platform and the bedrock structures, and the time and mode of formation.

Location

Osterøy Island is at 60°30′N, just inland from the coast of western Norway. It is bounded by narrow, up to 645 m deep fjords (Figure 1). Storavatnet, with a natural lake level of 151.5 m a.s.l., is centrally located on the island, surrounded by 500–868 m high mountains. The lake consists of two connected elongated lake basins, Vestrevatnet and Austrevatnet, which are respectively 5 and 7 km long. Since AD 1920, the lake has served as reservoir for a hydroelectric project and has thus been

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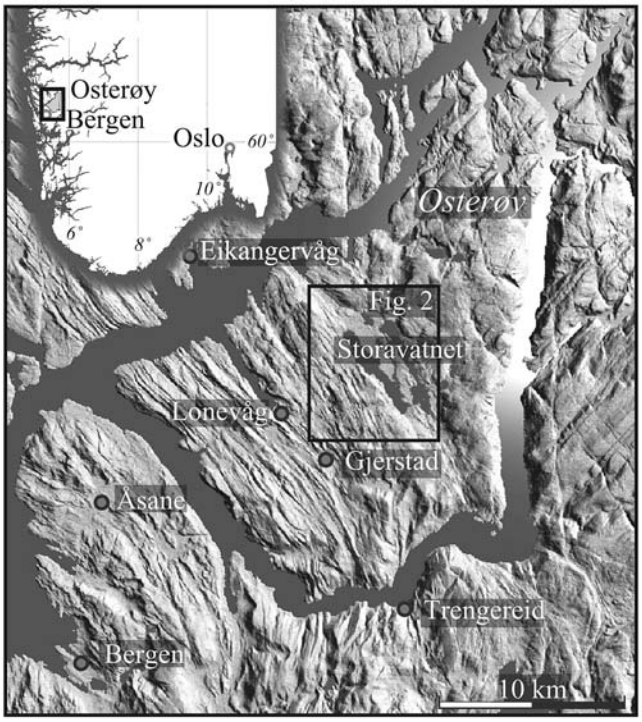

Figure 1 Map of Osterøy island and vicinity. Note the strike-parallel 'ridge and valley' topography developed on the rocks belonging to the Bergen Arc System.

subject to raised and lowered levels ranging between 142 and 154 m a.s.l. (Tysse, 1995). This means that the natural processes responsible for the formation of the shoreline ceased in 1920.

The maximum width of the lake is 800 m and the irregular shape limits the fetch to 2–3 km. Soundings in both lake basins reveal structurally controlled deep and narrow trenches, with depths generally over 60 m and a maximum measured depth of 111 m in Vestrevatnet and 128 m in Austrevatnet (Figure 2a). The irregular bottom topography suggests a very thin bottom sediment cover in contrast to the fjords of western Norway where thicknesses of 100–200 m are common (Aarseth, 1997). The surface area at normal lake level is 10 km^2 and the total drainage area before 1920 was 60.7 km^2, including the lake itself.

Bedrock geology

A variety of metamorphic rocks are exposed in the field area (Figure 2a). The Vestrevatnet shorelines expose the early Palaeozoic and possibly late Proterozoic Myking Complex, which is dominated by well-foliated micaschists and amphibolites with additional layers of quartz schists and bodies of serpentinite and saussurite gabbro (Henriksen, 1979). The rocks are intensely deformed and recrystallized under uppermost greenschist to lower amphibolite facies grade. The amphibolite and micaschists are kneaded and mixed to the extent that they form a tectonic mélange. These rocks form part of the Major Bergen Arc of the Bergen Arcs System (Kolderup and Kolderup, 1940).

Rocks of the Myking Complex are in tectonic contact with various gneisses of Proterozoic ages immediately east of Vestrevatnet (Figure 2a). To the east are basement gneisses belonging to the Western Gneiss Region. The foliation is generally steep (45–90°) with mostly westerly dips along the shores. Locally, the foliation has been refolded during Devonian deformation. One set of limbs of the folds typically shows low dips, commonly observed in the gneisses around Austrevatnet. Steep fracture zones transect the rocks, notably along NE–SW and NNW–SSE trends (Figure 2a). The fracture zones are best developed in the gneisses, where they can be up to 20 m in width. In such zones, the gneiss is more easily eroded.

Climatic conditions

Osterøy Island at present has a typical west coast climate, which is similar to that of Bergen described by Spinnangr (1942). The precipitation is both orographic and frontal, and most intense during autumn and winter months and least in May. The nearest weather station with precipitation records is at Gjerstad (Figure 1), at 60 m a.s.l., located only 5–10 km SW of the lake. Mean annual precipitation in the years 1975–83 was 2200 mm yr^{-1} versus 2250 mm yr^{-1} in Bergen for the period 1961–90. Precipitation in the mountains bordering the lake may be of the order of 20–30% higher (E. Skaar, personal communication 2002).

The winter climate in the Bergen area is very unstable and the winter precipitation in western Norway correlates well with the oscillating NAO index (Nesje *et al.*, 2000; Nesje and Dahl, 2003). Cold weather conditions, with subzero temperatures, very seldom last more than 8–10 days near sea level. During such conditions, temperature inversion prevails, resulting in temperatures up to 10°C lower in a similar topographic depression at Åsane (Figure 1) close to Bergen (Tangen, 1976). These conditions presumably apply also to the Storavatnet area each year when the lake becomes ice-covered. During the 1990s the lake was totally ice-covered only a few times, although bays and other shallow parts froze every winter.

A brief history of the Late Weichselian and Holocene in the area

The history of the last (Weichselian) glaciation in western Norway is relatively well known due to many finds of sediments below till or in isostatically isolated marine caves (Mangerud, 1991). Late Weichselian subtill sediments containing marine molluscs have been dated and provide evidence of open fjords during the Allerød Interstadial. Such findings are reported both NW (Eikangervåg) and S (Trengereid) (Figure 1) of the island (Mangerud, 1977). Whether the entire Storavatnet area was free from glaciers during that time is not known, but most likely Vestrevatnet, farthest away from the highest mountains, had no ice. During the latter half of the Younger Dryas Stadial the fjord glaciers advanced to a position 35 km west of Storavatnet and formed the distinct Herdla Moraines (Aarseth and Mangerud, 1974).

According to Aarseth and Mangerud (1974), the orientation of the Younger Dryas isobases in this area is very close to N–S with a gradient of 1.3 m km^{-1}. The final deglaciation of the fjords took place at the transition between Younger Dryas and the Preboreal chronozones (Aa and Mangerud, 1981). The marine limit on Osterøy is marked by a delta at Gjerstad (64 m a.s.l.) (Figure 1). The gradient of the marine shoreline at the time of deglaciation was 1 m km^{-1} according to diagrams in Aa and Mangerud (1981). This gradient rapidly decreased to about 0.53 m km^{-1} at 9400 ^{14}C yr BP (Krzywinski and Stabell, 1984) and 0.18 and 0.12 m km^{-1} at 5900 and 5300 ^{14}C yr BP, respectively. The isobases are thought to have had a constant ~N–S orientation since Younger Dryas (Kaland, 1984)

The climate history of the Holocene is established through observations of several proxies, such as marine biostratigraphy

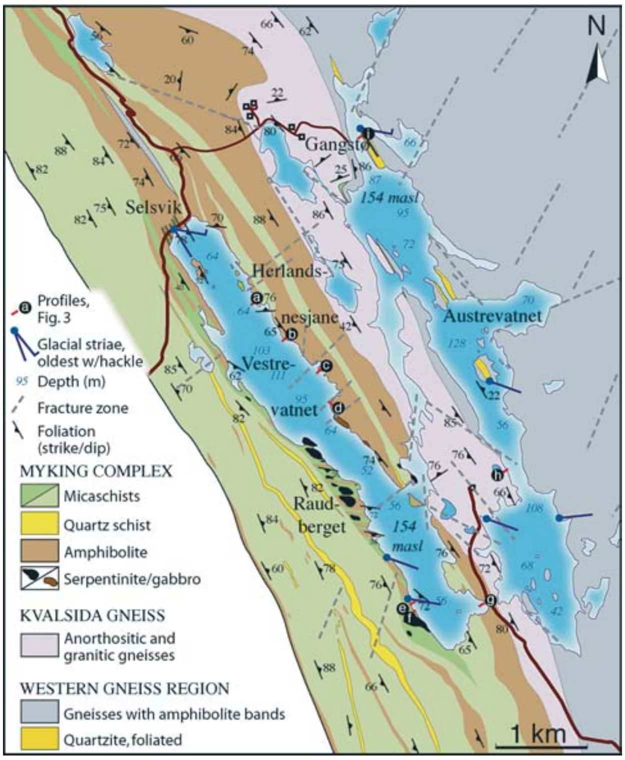

Figure 2(a) Bedrock map of the Storavatnet area (modified from Henriksen, 1979). Glacial striae, maximum water depths from echosounder profiles and location of profiles on Figure 3 are indicated.

Figure 2(b) Caves in micaschist, developed along fracture zones perpendicular to the shoreline. Note that some of the caves are located in fracture overlap zones. A cave parallel to the coastline, that can be crawled through, connects the two caves in the middle of the picture. Location just SE of Figure 3b.

Figure 2(d) A 7 m wide rock platform developed in foliated amphibolite (Figure 3a). The platform itself is very rugged due to the steep foliation, and only veneered with angular debris in more protected areas. The lower part of the cliff is a small notch.

Figure 2(e) Weathered blocky debris from gneissic rocks below the rock platform. Note 1 m scale near the lake surface. Location 300 m SE of Figure 3i.

Figure 2(c) Shoreline developed in amphibolite. Small bays are incised along fracture zones, and the rock platform is well developed on the intervening rock tumps. The summits of these tumps are thought to be remnants of an older platform. Location as for Figure 3c.

(Mikalsen *et al.*, 2000), glaciology (Nesje *et al.*, 1991) and snow avalanche colluvium and pollen (Blikra and Selvik, 1998). The glaciers in western Norway are believed to have disappeared during the climate optimum. A recrudescence started by 6000 ^{14}C yr BP, but larger glaciers did not form until 3700 to 3100 ^{14}C yr BP (Nesje *et al.*, 1991). This was probably related to lower temperatures, but was mostly the result of higher winter precipitation.

Methods

The main method for mapping the morphology of the shoreline has been levelling with an automatic level mounted on a tripod and using the current lake level as a temporary benchmark. Most of the levelling was carried out during the summer of 2002. Lake level was calibrated every day from the local hydroelectric project benchmarks, drilled in bedrock at 0.5 m vertical intervals at Selvik, at the N end of Vestrevatnet (Figure 2a).

At some locations ($n = 19$), only the front and rear elevations of the rock platform were levelled. At others ($n = 9$), more detailed profiles of the entire shoreline were measured (Figure 3). Directions of any glacial striae were recorded when found (Figure 2a). In addition to the existing bedrock geology map, scale 1:20 000 (Henriksen, 1979) geological structures were mapped in detail at certain locations. Ten profiles were obtained across both parts of the lake with a high-frequency recording echosounder (Simrad EY, 70 kHz) to measure the maximum depths and find areas suitable for coring. Owing to an incomplete ice cover during the winter 2001–2002, no coring was carried out.

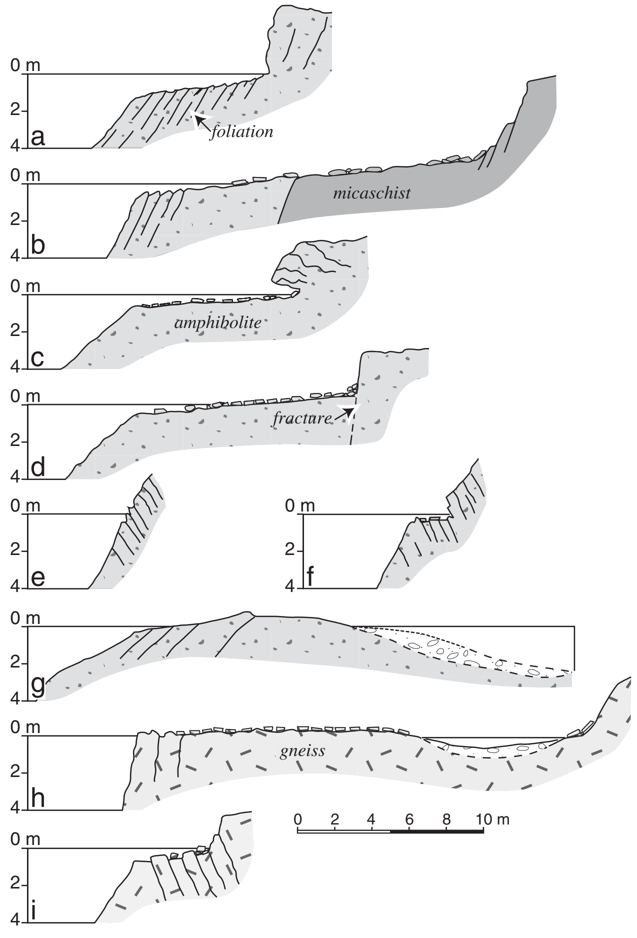

Figure 3 Profiles across the rock platform from nine selected locations: (a–i). For locations, see Figure 2a. Natural lake level (151.5 m a.s.l.) is given as 0 m. Bedrock, foliation, fractures and debris on the platform are indicated.

Morphology of the rock platform

Micaschists

The most continuous rock platform is developed in micaschists along the northeastern shore of Vestrevatnet. The micaschist is mechanically (and chemically) the weakest rock in the area, although the presence of garnet and amphibole, and particularly the numerous quartz pods, increase its resistance to weathering. Foliation is well developed with a consistently steep southwesterly dip, enhancing mass movement along the dip slope (Figure 4). Large slabs of micaschist are found on the rock platform in some areas, but generally the micaschist shorelines produce little debris resting on the platform.

The general width of the rock platform is 2–5 m in the micaschist areas and the platform tilts at ~10° towards the lake. The surface of the platform is smooth, but quartz inclusions form small irregularities. Caves exist in two areas but only in micaschist. The caves narrow inwards and some are possibly more than 5 m deep (Figure 2b). The locations of the caves are largely controlled by fracture location and geometry. Most caves follow fractures that are orientated at high angles to the coastline. Some of the caves have developed at fracture overlaps, which are generally known to be high-strain areas with multiple subordinate fractures (e.g., Huggins *et al.*, 1995; Rykkelid and Fossen, 2002), again facilitating weathering.

Where the coastline is at right angles to the foliation, the cliff above the rock platform sometimes has overhanging parts resembling a wavecut notch. The overhanging micaschist wall has quartz pods protruding from the rugged surface due to selective weathering (Figure 5). The fact that the notches are not parallel to the strike of the foliation of the micaschist must be due to the anisotropic mechanical strength of the bedrock.

In micaschist areas along the western side of Vestrevatnet the shoreline is discontinuous, and where it is present the rock platform is < 1 m wide, with a small overhanging cliff parallel to the strike of the foliation. Here glacial striae are often found on bedrock slopes leading up to the rock platform. In some areas the glacially polished bedrock is very smooth with no trace of a rock platform (Figures 3e and 6).

Debris on the micaschist rock platform varies from larger rock slabs from the cliff behind through cobbles to gravel in

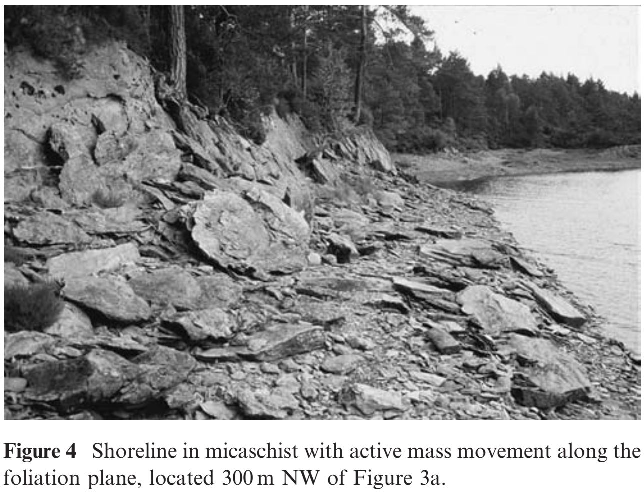

Figure 4 Shoreline in micaschist with active mass movement along the foliation plane, located 300 m NW of Figure 3a.

Figure 5 Rock platform and overhanging notch in micaschist some 50 m SE of the caves on Figure 2b. Quartz inclusions and an amphibolite mound on the rock platform demonstrate the differential weathering. In the background (between the two white flagpoles) a higher beach has developed during high lake stands after AD 1920.

more protected areas or small depressions on the platform. The smaller particles are relatively soft and subangular. At more exposed parts the micaschist platforms totally lack detritus (Figure 5).

Amphibolite

Amphibolite inclusions in the micaschists protrude a few cm, demonstrating that the steeply dipping amphibolite is more resistant to weathering on a horizontal surface (Figure 5). The amphibolite has a strong and regular foliation at mm to cm scale, defined by parallel amphibole and chlorite grains and domains enriched in amphibole and plagioclase. The larger weathering products on the rock platform reflect a more effective disintegration of the planar-foliated amphibolites. The bedrock surface on amphibolitic rock platforms is more rugged compared to micaschist surfaces close by (Figure 2d).

Generally, rock platforms on amphibolite dip more gently than the ones on micaschist, some dipping less than 5° towards the lake. Where joint systems intersect zones of amphibolite, the coastline is broken up into small bays and protrusions leaving erosional remnants as small hills where the rock platform is very well developed (Figure 2c). A notch has developed on one of the amphibole protrusions in an area of nonplanar foliation, but joints behind the notch suggest unstable conditions. The rock detritus on the adjacent platform consists of angular schists of amphibolite (Figures 3c and 7).

Banded gneiss

The rock platform on gneissic rocks along Austrevatnet has greater variations both in width and continuity than along Vestrevatnet even though the bedrock types appear more homogeneous. The vertical distance between the outer and inner parts on the gneissic rock platforms are relatively small even on the widest platform in Austrevatnet (Figure 8). The coarser banding has resulted in larger blocky debris. At low lake levels the slopes below the rock platform are often strewn with blocky and cubic gneissic blocks (Figure 2e). The angular debris is more homogeneous around Austrevatnet, with particle sizes usually from cobbles to boulders (Figure 2e).

Fractured gneiss

A 16 m wide rock platform is developed in fractured gneiss (Figures 3 h and 9). It is formed along a NNW–SSE trending fracture zone where spacing is on the cm or dm scale. Here the fracture networks seem to play the role that the foliation otherwise has, and resulting debris size appears to be controlled by local fracture density. The great width here is partly caused by a cove on the inside, allowing the weathering to attack from two sides.

Quartzite

The narrow zones of quartzite tend to have higher fracture densities than the gneisses. This has made the quartzite zones less resistant to erosion than normally would be expected of the hardest rocks in the area. The rock platform is therefore also developed in the quartzite in places, although it is usually < 1 m wide.

Serpentinite

Several smaller bodies of ultrabasic serpentinite are found along the southwestern side of Vestrevatnet (Figure 2a). The serpentinites are not foliated and there are only incipient signs of weathering or rock-platform development on these bodies even where intersected by fracture systems.

Figure 6 Glacially polished stoss side where the foliation of the amphibolite is dipping in the opposite direction to the slope (Figure 3e). Only incipient weathering has taken place and no rock platform is developed. Scale = 1 m. Location as for Figure 3e.

Figure 7 Notch developed on the hill to the left on Figure 2c (Figure 3c). The foliation is nonplanar and the debris on the rock platform is platy and angular. Scale = 1 m.

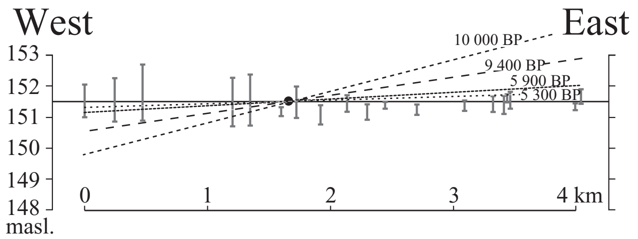

Figure 8 The heights of outer and inner parts of the rock platforms projected onto a W–E profile. Natural lake level and present outlet from the lake (dot) are indicated. Tilt of early-Holocene shorelines is stippled.

Higher rock platforms

At a few locations on the east side of Vestrevatnet, as well as at Selvik in the northernmost bay, there is an undulating rock bench 2–2.5 m higher than the pronounced rock platform (Figures 2c and 3d). In places, this bench has parallel east–west trending grooves thought to be of glacial origin. The width of the bench is up to 10 m. It is found on both micaschist and amphibolite and thought to represent the remnants of an older rock platform most probably formed during the Allerød Interstadial when the threshold at the river outlet might have been higher. The large, relatively horizontal rock surface covered by bogs between the two parts of the lake and along the northwestern side of Vestrevatnet, at an elevation of 8–12 m above the natural lake level, is subject for a separate study (Aarseth and Fossen, 2004).

Processes responsible for formation of the rock platform

The cliffs around Vestrevatnet show a general steeper and often overhanging lower part formed like a notch, just above the inner part of the rock platform (Figures 2d, 5 and 7). This is the area where the most active erosion processes took place. Rock platforms along coasts and larger lakes normally have notches (Bird, 1968) and are covered by well-rounded debris. The debris on the platform in Storavatnet is angular, except for the smallest particles which are generally subangular. The wave energy therefore, is too small for active abrasion here. Wave transport is detected only at a few places where disc-like, amphibolitic pebbles, <10 cm in diameter, are washed laterally onto a micaschist platform. Debris of different lithologies around the lake is angular or subangular and mostly slabby on platforms developed on Palaeozoic rocks and blocky in areas of basement gneiss.

Figure 9 Rock platform developed in nearly vertically foliated and heavily fractured gneissic rocks (Figure 3h). Note figure for scale.

These facts points to *in situ* frost wedging as the main cause for the formation of the rock platform. In some narrow zones of intensely fractured micaschist, chemical weathering must have played an important role, but here the coastline usually comprises small bays where most of the platform is buried under a cover of debris. Variations in thickness of lake ice, in addition to fluctuations in lake levels, were responsible for the sloping cross-section of the rock platform. The west-coast climate probably prevented a stable lake level as well as an even ice thickness on Storavatnet during the Holocene. Precipitation from the Atlantic, produced by successive fronts, caused the lake to rise many times during each winter. A narrow outlet channel also contributed to a relatively rapid rise of lake level. During high-pressure conditions with temperature inversion, freezing at the contact between the lake ice and the rock platform took place. Thus, the freezing happened while the lake level was still relatively high, and the first area to freeze would be the contact between the lower part of the cliff and the lake ice, making this area particularly susceptible to frequent frost wedging. The 'undercutting' of the cliff should be most effective in densely fractured and foliated rocks, and where the strike of the foliation parallels the coastline. The steeply dipping foliation would have enhanced mass movements and been responsible for removal of most of the rock material. On the rock platform itself lake ice will have frozen in contact with the submerged rocks. After frost wedging of the foliated rocks developed, the ice would have ripped off pieces as the lake rose.

Removal of debris from the rock platform

Effective erosion of the rock platform is dependent on removal of the debris from the platform. As wind is unable to generate waves large enough to move particles exceeding gravel size around the lake, other erosional processes must be considered. At least once every spring there is a period when the ice breaks up and the lake is only partly covered with ice of variable thickness. Wind-induced stress is responsible for drifting ice on the lake, which can be effective in pushing large particles (Raukas, 2000). Farmers in the area have reported intense ice-pushing damaging their dry-stone walls made up of relatively large boulders. They have received compensation for this now that larger reservoir fluctuations are occurring. This mechanism is also indicated by the present distribution of large rock slabs in areas where gentle slopes are exposed at low lake stands (Figure 2e).

Period of shoreline formation

Exact dating of landforms caused by weathering and erosion is always difficult. For Storavatnet, a maximum date for the rock platform can be suggested. The rock platform appears fresh and glacial striations have been found only on the slopes below the front of the platform. This makes a postglacial age clear, giving a maximum date very close to the Pleistocene/Holocene locene transition at 10 000 ^{14}C yr BP (Aa and Mangerud, 1981).

On Figure 8, the heights of the rock platforms have been projected onto a plane perpendicular to the isobases. The present river outlet is close to the middle of the profile. Marine shoreline gradients at various times are indicated. The westernmost lake level was 1.6 m lower and the easternmost level 2.6 m higher at the time of deglaciation of the lake area. The erosion of the shoreline presumably began all around the lake immediately following deglaciation. There is no evidence, however, for active rock-platform formation on the easternmost locations above the present natural lake level. On the westernmost rock platforms, one cannot exclude some platform formation at lower levels, although the lowest parts are less than 0.8 m lower than the natural lake level and the glacial striae appear to be fresh below the platform (Figure 6). Formation of the rock platform would require a stable lake level over a relatively long period, but the change in shoreline gradient was rapid during the first few thousand years (Kaland, 1984). The areas close to the projected hingeline at the lake outlet, however, have experienced a stable lake level for a longer time if we assume no erosion at the outlet itself (Figure 8). The climate in the Preboreal and the Boreal climatic zones was considerably warmer and drier than during the Atlantic and Sub-Atlantic (Nesje and Dahl, 1993). This presumably would result in fewer freeze-thaw cycles around Storavatnet. Since about 6000 ^{14}C yr BP the shoreline gradient of less than 0.1–0.2 m km^{-1} is considered sufficiently stable for rock-platform formation to have occurred.

The shoreline formation terminated when the lake was converted into a reservoir in 1920 and frequent lake-level oscillations above and below the natural lake level occurred. From that time zones of intensely weathered micaschist above the natural lake level were abraded and beaches developed up to 154 m a.s.l. (Figure 5).

Conclusions

The recently discovered rock platform around Storavatnet is interpreted as a shoreline formed by frost weathering along the natural lake level prior to the conversion to a reservoir in 1920. The frost weathering was enhanced by frequent freeze-thaw cycles and lake-level fluctuations caused by unstable winter weather conditions. Shoreline widths are controlled by bedrock fractures and foliation. A maximum width of *c.* 20 m is found on amphibolites and fractured gneissic rocks with strongly inclined foliation. Minimum widths are found on glacially polished stoss sides with the foliation dipping into the bedrock surface, and on serpentinite rocks.

Caves are developed in fracture overlap zones. Beach notches are formed by frost weathering at several places in less foliated micaschist and amphibolites. Owing to undercutting by frost weathering, clasts were removed by down-dip mass movement and by ice-push from drifting ice during ice-cover breakup. The shoreline was formed mainly after the termination of the oblique glacial rebound about 6000 ^{14}C yr BP. In strongly chemically weathered zones, shoreline development has continued since 1920, giving rise to wavecut beaches above the natural lake level during high reservoir levels.

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References

Aa, A.R. and **Mangerud, J.** 1981: Glacialgeologi og vegetasjonsinnvandring i Indre Nordhordland, Vest-Norge. *Norges geologiske undersøkelse* 369, 33–75.

Aarseth, I. 1997: Western Norwegian fjord sediments: age, volume, stratigraphy, and role as temporary depository during glacial cycles. *Marine Geology* 143, 39–53.

Aarseth, I. and **Fossen, H.** 2004: Late Quaternary, lacustrine cryoplanation of rock surfaces in and around Bergen, Norway. *Norwegian Journal of Geology* 84, 125–37.

Aarseth, I. and **Mangerud, J.** 1974: Younger Dryas end moraines between Hardangerfjorden and Sognefjorden, western Norway. *Boreas* 3, 3–22.

Allen, J.C., Stephenson, W.J., Kirk, R.M. and **Taylor, A.** 2002: Lacustrine shore platforms at Lake Waikaremoana, North Island, New Zealand. *Earth Surface Processes and Landforms* 27, 207–20.

Bird, E.C.F. 1968: *Coasts*. Canberra: Australian National University Press, 246 pp.

Blikra, L.H. and **Selvik, S.F.** 1998: Climatic signals recorded in snow avalanche-dominated colluvium in western Norway: depositional facies successions and pollen records. *The Holocene* 8, 631–58.

Dawson, A.G. 1980: Shore erosion by frost: an example from the Scottish Lateglacial. In Lowe, J.J., Gray, J.M. and Robinson, J.E., editors, *Studies in the lateglacial of northwest Europe*, Oxford: Pergamon Press, 45–53.

Henriksen, H. 1979: Structural geology and metamorphism on northern Osterøy. Unpublished thesis, University of Bergen, 478 pp.

Huggins, P., Watterson, J., Walsh, J.J. and **Childs, C.** 1995: Relay zone geometry and displacement transfer between normal faults recorded in coal-mine plans. *Journal of Structural Geology* 17, 1741–55.

Kaland, P.E. 1984: Holocene shore displacement and shorelines in Hordaland, western Norway. *Boreas* 13, 203–42.

Kolderup, C.F. and **Kolderup, N.-H.** 1940: *Geology of the Bergen Arc System*. Bergen: Bergen Museums Skrifter.

Krzywinski, K. and **Stabell, B.** 1984: Late Weichselian sea level changes at Sotra, Hordaland, western Norway. *Boreas* 13, 159–202.

Mangerud, J. 1977: Late Weichselian marine sediments containing shells, foraminifera, and pollen, at Ågotnes, westen Norway. *Norsk geologisk Tidsskrift* 57, 23–54.

—— 1991: The last ice age in Scandinavia. *Striae* 34, 15–30.

Marthinussen, M. 1960: Coast and fjord area of Finnmark with remarks on some other districts. In Holtedahl, O., editor, *Geology of Norway*, Oslo: Norges geologiske undersøkelse, 416–29.

Matthews, J., Dawson, A.G. and **Shakesby, R.A.** 1986: Lake shoreline development, frost weathering and rock platform erosion in an alpine periglacial environment, Jotunheimen, southern Norway. *Boreas* 15, 33–50.

Mikalsen, G., Sejrup, H.P. and **Aarseth, I.** 2000: Late Holocene changes in ocean circulation and climate: foraminiferal and isotopic evidence from Sulafjord, western Norway. *The Holocene* 11, 437–46.

Nesje, A. and **Dahl, S.O.** 1993: Lateglacial and Holocene glacier fluctuations and climate variations in western Norway – a review. *Quaternary Science Reviews* 12, 255–61.

—— 2003: The 'Little Ice Age' – only temperature? *The Holocene* 13, 139–45.

Nesje, A., Kvamme, M., Rye, N. and **Løvlie, R.** 1991: Holocene glacial and climate history of the Jostedalsbreen region, western Norway; evidence from lake sediments and terrestrial deposits. *Quaternary Science Reviews* 10, 87–114.

Nesje, A., Lie, O. and **Dahl, S.O.** 2000: Is the North Atlantic Oscillation reflected in Scandinavian glacier mass balance records? *Journal of Quaternary Science* 15, 587–601.

Rasmussen, A. 1981: The deglaciation of the Coastal Area NW of Svartisen, Northern Norway. *Norges geologiske undersøkelse* 369, 1–31.

Raukas, A. 2000: Rapid changes of the Estonian coast during the late glacial and Holocene. *Marine Geology* 170, 169–75.

Rykkelid, E. and **Fossen, H.** 2002: Layer rotation around vertical fault overlap zones: observations from seismic data, field examples, and physical experiment. *Marine and Petroleum Geology* 19, 181–92.

Shakesby, R.A. and **Matthews, J.A.** 1987: Frost weathering and rock platform erosion on periglacial lake shorelines: a test of a hypothesis. *Norsk geologisk Tidsskrift* 67, 197–203.

Sissons, J.B. 1978: The parallel roads of Glen Roy and adjacent glens, Scotland. *Boreas* 7, 229–44.

Spinnangr, F. 1942: Temperature and precipitation in and around Bergen. *Bergens Museums Årbok* 9, 1–30.

Tangen, P.O. 1976: *Kartlegging og analyse av vind og temperaturklima i BOB's utbyggingsområde Lid/Flaktveit i Åsane*. Report of the Geophysical Institute, Division B, Meteorology, University of Bergen.

Trenhaile, A.S. 1980: Shore platforms: a neglected coastal feature. *Progress in Physical Geography* 4, 1–23.

—— 2002: Rock coasts, with particular emphasis on shore platforms. *Geomorphology* 48, 7–22.

Tysse, H. 1995: *Kamp om kraft. Herlandsfoss kommunale kraftverk*. Bergen: John Grieg A/S.