High Pre-Late Weichselian sea-formed caves and other marine features on the Møre-Romsdal coast, West Norway

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The high sea-formed caves and other sea-abrasional and corrosional features found on cliffs facing the sea along the Møre–Romsdal coast are thought to represent a maximum former sea level of 70, possibly 100 m above the present. These maximum marine limits show no relationship or parallelism to the Late Weichselian marine limits, which are on the whole considerably lower, and also show increasing heights northwards along the coast due to the glacio-isostatic compensation. The caves must be older than the last deglaciation, and are thought to have been formed during periods without glacial isostatic depression. Referring to suggested neotectonic uplift rates for Eemian deposits at Fjøsanger, the height of the caves and other marine features connected with them suggest at least an Eemian age, possibly that they are 200,000–300,000 yrs old. Recently dated fossil remains in cave sediments from Skjonghelleren (E. Larsen, pers. comm.) and the estimated sediment-thickness in that cave seem to support this assumption.

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On the Møre–Romsdal coast raised strandlines, terraces and other features associated with shoreline processes are commonly observed, and descriptions of these are found in the literature, especially from the first half of this century (Rekstad 1905, 1907, Kaldhol 1930, 1946, Undås 1942). It was early realized that certain well-developed strandlines increased in height inland, as shown along certain fjords, and that they showed different gradients according to their age. The connection between raised- and tilted shore-lines and glacio-isostatic movements was recognized, as well as the importance of the glacio-eustatic effect. Attempts were made to relate certain shore-lines to certain stages of the deglaciation, but more accurate dating of the shorelines was not possible before the introduction of ^{14}C dating technique, and the actual maximum extent of the Weichselian inland ice on the Møre–Romsdal coast and adjacent continental shelf was a much disputed problem.

Today we know that the Møre-Romsdal coast was overrun by the Scandinavian Weichselian ice-sheet. This was, among others, suggested by the present author as a result of studies on glacial striae, high-positioned erratics and soil profiles on the outer coast, as well as sedimentological and geomorphological studies of the adjacent continental shelf (H. Holtedahl 1955). It was, however, after the introduction of radiometric dating that this view was confirmed. Reite (1968) showed that the fjord districts in Sunnmøre were free from ice during the Allerød Chronozone, and that mountain glaciation increased in importance during a subsequent climatic deterioration, probably in Younger Dryas Chronozone. The latter supposition was later confirmed by Larsen & Mangerud (1981). Later, investigations by Mangerud et al. (1979, 1981) gave a minimum age for the deglaciation of the coastal area of Sunnmøre of about 12,300 yrs B. P. According to Rokoengen (1979) and Bugge (1980) the inland ice reached the outer edge of the continental shelf off Sunnmøre after c. 13,000 yrs B. P., an assumption based on ^{14}C dates of shells in preconsolidated clays.

The presence of an ice-free period – the Ålesund Interstadial – is based on the finds of marine shells in tills in the Ålesund area, giving ages between 28,000 and 38,000 yrs B. P. (Mangerud et al. 1981). If the dating at the outer shelf is correct, the Late Weichselian readvance can have taken place between 28,000 and c. 13,000 yrs B. P. The deglaciation of the shelf after this readvance must have been very fast.

The highest observed post-glacial marine strandlines, terraces etc. on the Møre–Romsdal coast are usually described as the marine limit. According to our present knowledge of the deglaciation, these raised shore features are Late Weichselian in age. There are, however, marine erosional features situated at considerably higher levels on the same coast, especially in the form of caves cut into cliffs facing the sea. Some of these

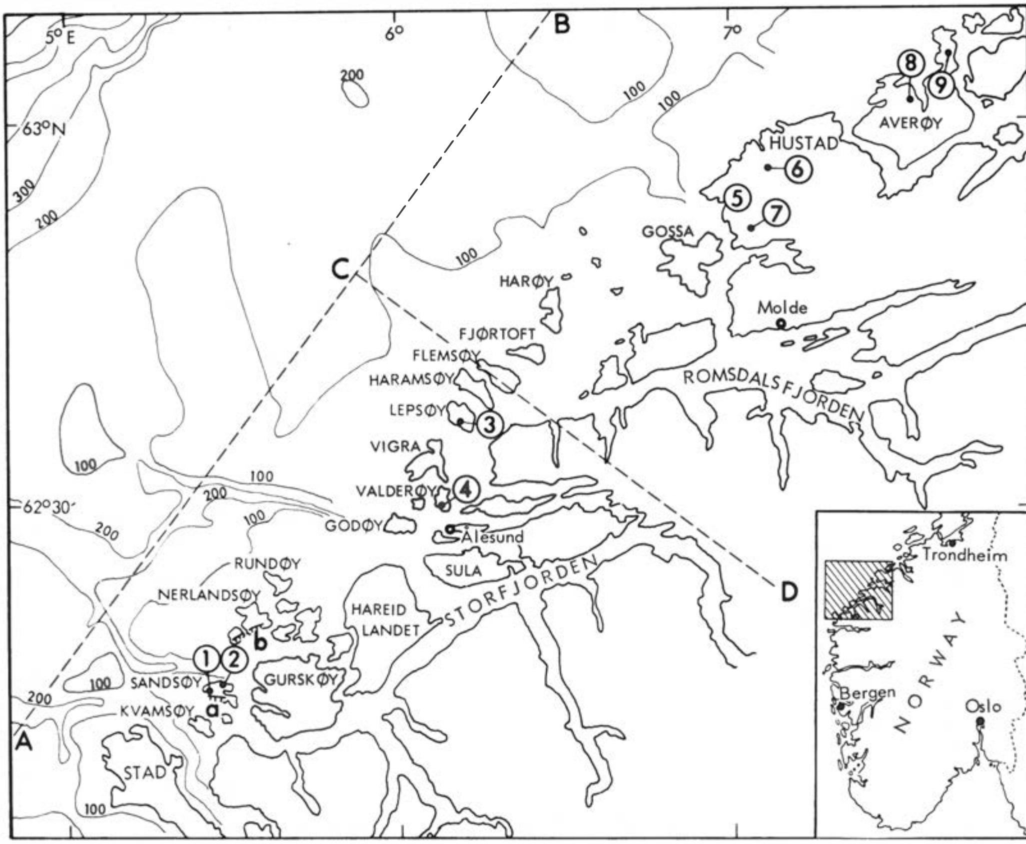

Fig. 1. Situation of the largest caves on the outer coast of Møre–Romsdal, with maximum levels higher than the Late Weichselian sea level. For numbers see Fig. 8. A–B: Direction of Younger Dryas isobase. C–D. See Fig. 8.

have been described (Reusch 1877 a, b, Kaldhol 1930, 1946, Undås 1942, O. Holtedahl 1953, H. Holtedahl 1960), but very little attention has been paid to them in more recent times. In the present paper I have collected data from my own fieldwork, as well as from previously published material, and will attempt a discussion of the origin as well as time of formation of these high sea level features.

Description of caves and other high sea level features

Fig. 1 shows the situation of the largest caves on the outer coast of Møre–Romsdal, with levels higher than the supposed Late Weichselian sea level. All caves have been formed on steep cliffs which rise more or less abruptly from a brim of low land known as the strandflat (Reusch 1894). They are all exposed to an open sea, where wave energy, due also to a considerable depth of water, has been at a maximum. Furthermore, the position and form of the caves are strongly related to rock structures which have acted as lines of weakness, or areas of weakness. Often caves have been excavated at the intersection of fractures, or between fractures and schistosity planes. The rocks along the Møre–Romsdal coast are mainly gneisses, in the southern part lime-silicate gneisses, but basic rocks of various kinds do also occur. The main process in cave formation is wave abrasion; a certain chemical weathering, supposedly due to the action of sea water, is also observed on certain rock surfaces, at the entrance, or inside the caves. The caves are, with a few exceptions, in a position which is protected against erosion by glaciers.

1. Dolsteinhulen, Sandsøy (Fig. 2)

The entrance to the cave is situated on the steep cliff on the southern side of a small, 227 m high mountain knob, forming the most westerly part of the island. The rock type is a lime-silicate gneiss with an east-westerly strike and a vertical dip, cut by almost vertical fractures with an east-northeasterly direction. The cave is formed in one of several parallel clefts, directed by the fractures. The entrance is about 2 m high, and the floor, which consists of talus material, as well as earth and animal manure, is c. 69 m a.s.l. Inside the opening, the floor slopes downwards, while the roof is about level, and 30 m inside the opening the height of the roof is about 20 m above the floor, which here consists of presumably downfallen boulders. The slope leading into the cave is covered by earth and animal manure, and the depth to bedrock is unknown. The floor of the inner part of the cave consists of boulders, but bedrock is present in the back wall. Below the boulders, however, as was described by Reusch, is a very narrow passage which is about 40 m long, and which terminates in a cave cut in bedrock. The lowest part of this inner cave was measured to c. 35 m.a.s.l. by the author (aneroid barometer). The total length of the cave is therefore c. 70 m, the maximum height from floor to roof c. 35 m.

Outside the entrance, on the vertical side-wall of the cleft, are small pothole-like excavations, originally described by Reusch (1877, a, b), and believed by him to be connected with some form of sea-action, either abrasion, or chemical weathering connected with salt water. Similar features were noticed by the present author 20–30 m above the entrance to the cave, i.e. 90–100 m a.s.l.

There is no doubt that the rocky cleft, in which the Dolsteinhulen cave has been excavated, as well as other clefts in the area, are the work of sea abrasion. The cave itself is also a result of sea action. The lowest part of the cave is about 35 m a.s.l., which is well above the Late Weichselian marine limit (c. 20 m a.s.l.), and this could possibly be the floor level at the entrance to the cave. If this is so, the outer part of the cave is covered by c. 35 m of talus, soil and earth.

The maximum height of sea level during the formation was not necessarily the roof of the cave, as obviously large pieces of rock have been removed from the roof. The pothole-like features, found at the entrance of the cave, as well as higher up, and a certain rounding of the walls and roof inside the cave, do, however, point to a former sea level of at least 70 m, and possibly 90–100 m higher than today.

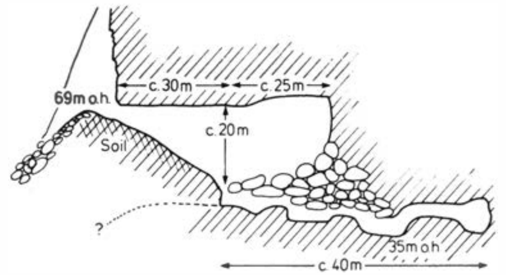

Fig. 2. Longitudinal section of the Dolsteinhulen cave, Sandsøy island.

Kaldhol (1930) described a rock ledge, or strandline, on the western and southern slope of Sandsøy island, south of the Dolsteinhulen cave. This ledge, which may reach a width of more than 100 m, and can be observed for more than a kilometre, has an undulating surface with its highest parts c. 85 m a.s.l. in the western, and c. 100 m a.s.l. in the eastern part. The ledge is glacially striated, and shows glaciated forms, and is partly covered by till. There is reason to believe that this ledge marks a former sea level and that it was formed before the last advance of the inland ice. It may partly have been formed at the same time as the Dolsteinhulen cave.

2a. Vågehulen, Sandsøy

On the north side of Sandsøy island, on the western slope of the peninsula, east of Wåge, is a marked rocky cleft formed along a fracture with a north-south direction. A cave has been formed at the base of this cleft with the floor at 50 m a.s.l., and the roof at about 58 m a.s.l. The cave is small, with a width of c. 1 m, and only a few metres deep. Talus covers the slope up to the cave. There are no surface features similar to those found in and around the Dolsteinhulen cave, but the cave is no doubt formed by sea abrasion and during a sea level higher than the Late Weichselian one.

2b. High sea level features, Nerlandsøy

On the steep southwestern slope of Nerlandsøy island, facing Skorpa island, there are several caves, of which Skagehola is the largest. This cave has an east–west direction which coincides

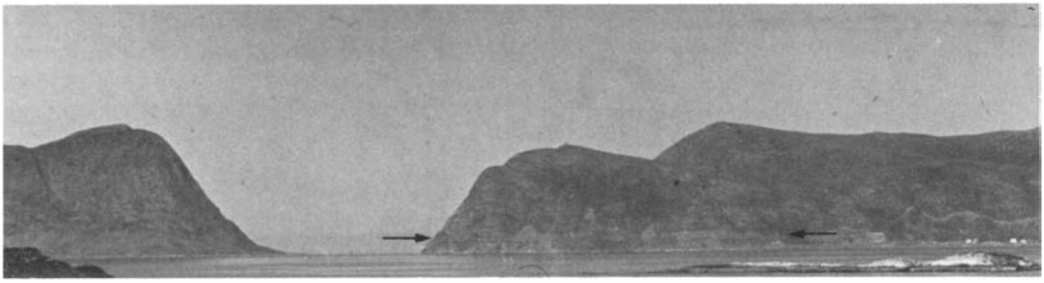

Fig. 3. Nerlandsøy island, with pre-Late Weichselian strand terrace.

with the strike direction of the gneissic rocks. The opening of the cave is almost 7 m broad and 5–6 m high; it is about 25 m deep, and the floor slopes inwards from 15 m a.s.l. to c. 20 m a.s.l. This cave cannot definitely be said to be pre-Weichselian in age, but on the same slope at a level of about 80 m a.s.l. in a niche there are small cavities which most probably are results of sea abrasion or corrosion. Another marked feature, seen along the southern side of the island, is a strandline cut in rock and especially visible in the western part towards Skorpa island (Fig. 3) The rocky ledge varies in width from 10 to 20 m, is situated 40–45 m a.s.l. and is covered by talus, solifluction material and till. Some rounded blocks are observed in this material, but the formation of the strandline definitely predates the last ice advance.

3. Rønstadhelleren, Lepsøy

This cave has been described by various authors (Reusch 1877 a, Kaldhol 1930, Undås 1942, O. Holtedahl 1953). It is situated on the steep cliff which rises abruptly from the narrow and low strandflat on the west side of the island (Fig. 5). Its position and form is closely related to the main fracture systems, which in this case are east-northeasterly and approximately vertical, and coincides with the main strike direction of the gneisses. The cave has been excavated in the backwall of a rocky cleft; it is c. 77 m deep, and c. 20 m broad at the entrance. The form is wedge-shaped, seen in transverse as well as longitudinal section. Talus covers partly the opening of the cave, and at the entrance there is a mound of downfallen material about 9 m high. The top of the mound is 54 m a.s.l. and a slope leads down to the bottom of the cave c. 45 m a.s.l. The floor is covered by earth (and animal manure), except in the inner part, where it is underlain by clay with layers of sand (O. Holtedahl 1953). The floor of the inner part of the cave is about 57 m a.s.l., and the highest part of the roof at the entrance is close to 70 m a.s.l. The inner walls and roof of the Rønstadhelleren cave are rounded and smooth, with cavities and pothole-like features which strongly point to an origin by sea abrasion and possibly corrosion (Fig. 6). Undås (1942) described traces of sea abrasion also outside the entrance to a height of 90 m. As the late Weichselian marine limit is about 38 m a.s.l. at this locality, the cave must have been formed prior to this time and partly during times when sea level was at least 70 m, probably 90 m higher than today.

4. Skjonghelleren, Valderøy

The island of Valderøy, the highest part of which is about 230 m a.s.l., has a very steep western slope, almost vertical in certain places, leading down to a low, and fairly narrow strandflat. The eastern side of the mountain is less steep, also leading down to a well defined strandflat; this strandflat, however, is higher than on the west side, due to some extent to the cover of till. The till has been reworked up to the Late Weichselian marine limit, which is here 41–45 m a.s.l., forming a series of beach terraces.

The Skjonghelleren cave (Fig. 4) is situated on the steep western slope facing the ocean. The inner part of the rocky strandflat, from which the cliff rises, is only about 20 m a.s.l. in this area. The position and probably also the development of the cave are very similar to those already described. The orientation is about east-west, following the direction of a main fracture with a northerly dip of about 70 degrees. The rocks are granodioritic gneisses with basic inclusions, strik-

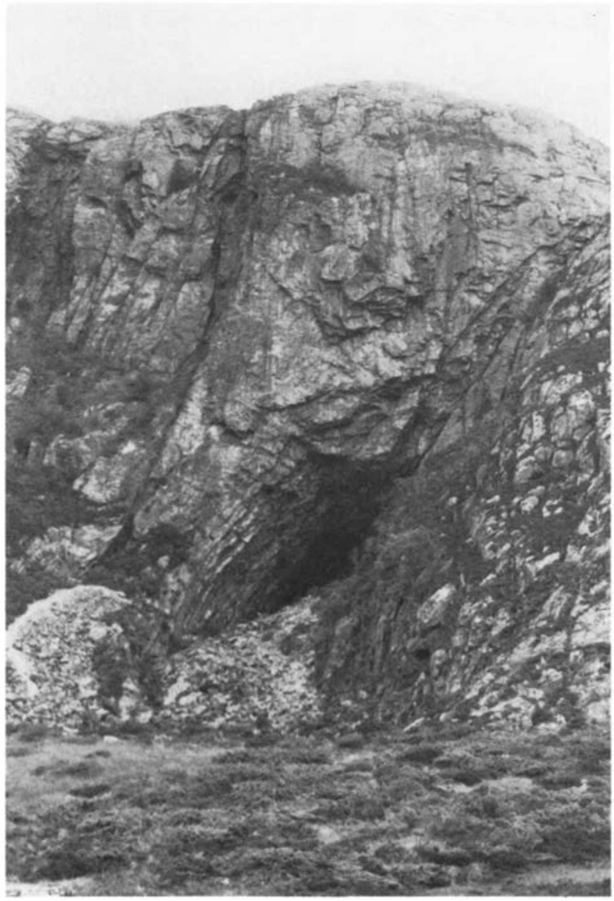

Fig. 4. The Skjonghelleren cave, Valderøy island.

ing north–south and with a slightly easterly dip. The cave has been well described by Reusch (1877 a, b), and only a few details are given here. The entrance to the cave is located at the top of a talus cone where the floor has been measured to a height above sea level of c. 46 m (Kaldhol 1930), and the roof c. 25 m higher. The cave is funnel shaped with the floor rising to more than 61 m a.s.l. in the inner part more than 100 m from the entrance. The position and level of the rocky basement is not yet clear, as great boulders, fallen from the roof, are seen protruding from the floor, which is mainly covered by soil, to some extent consisting of decomposed animal manure, and also because previous and recent excavations have shown thick deposits of sediments below the present floor. These sediments, to some extent consisting of laminated silt and clay of non-marine origin, have been estimated by seismic methods to have a maximum thickness of about 25 m (E. Larsen, pers. comm.). This means that the bottom of the cave at the entrance may be at a level of about 20 m a.s.l. while the roof is around 70 m a.s.l., a vertical span of c. 50 m.

The very interesting finds of fossils in the cave sediments, recently dated by E. Larsen and coworkers (E. Larsen, pers. comm.), will be discussed below.

There can be no question about the marine origin of the Skjonghelleren cave. Its form and position are also clearly determined by the structural pattern of the rocks. Polished forms, presumably due to sea abrasion on the walls and roof of the cave, and also on downfallen rocks at the entrance of the cave, indicate the maximum marine sea level. The present cave is clearly situated above the Late Weichselian maximum sea level, which is 41–45 m at this locality, and it must have been excavated in pre-Late Weichse-

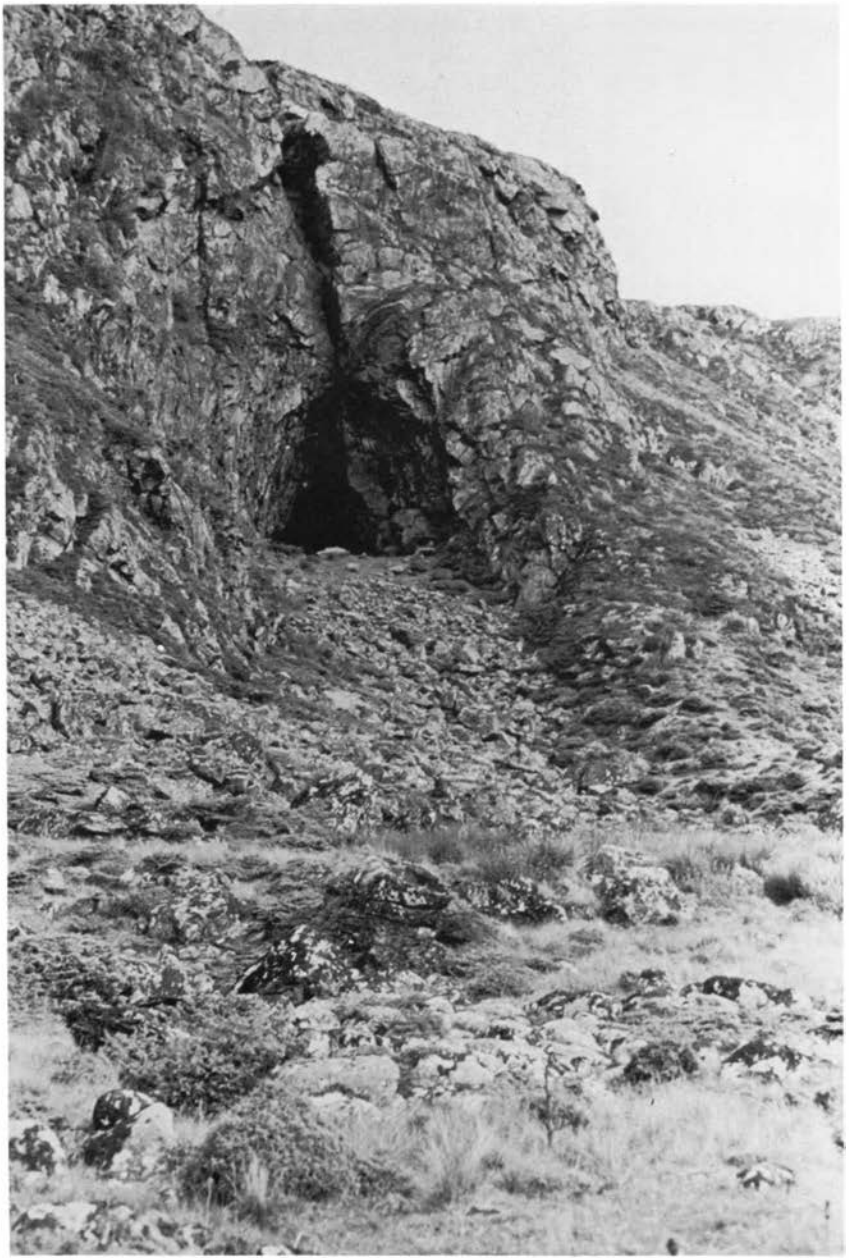

Fig. 5. The Rønstadhelleren cave, Lepsøy island.

lian time, when sea level reached a maximum stand of at least 70 m above the present.

5, 6, 7. The Hustad caves

In the Hustad area, further north along the coast, there are several observations of high, supposedly sea-formed caves. At *Gulberget,* which is an isolated rocky hill remnant on the wide strandflat on the Hustad peninsula, with a maximum height of 160 m, the steep slope towards northwest, west and southwest has been strongly attacked by the sea, resulting in a series of clefts. According to Undås (1942), one of

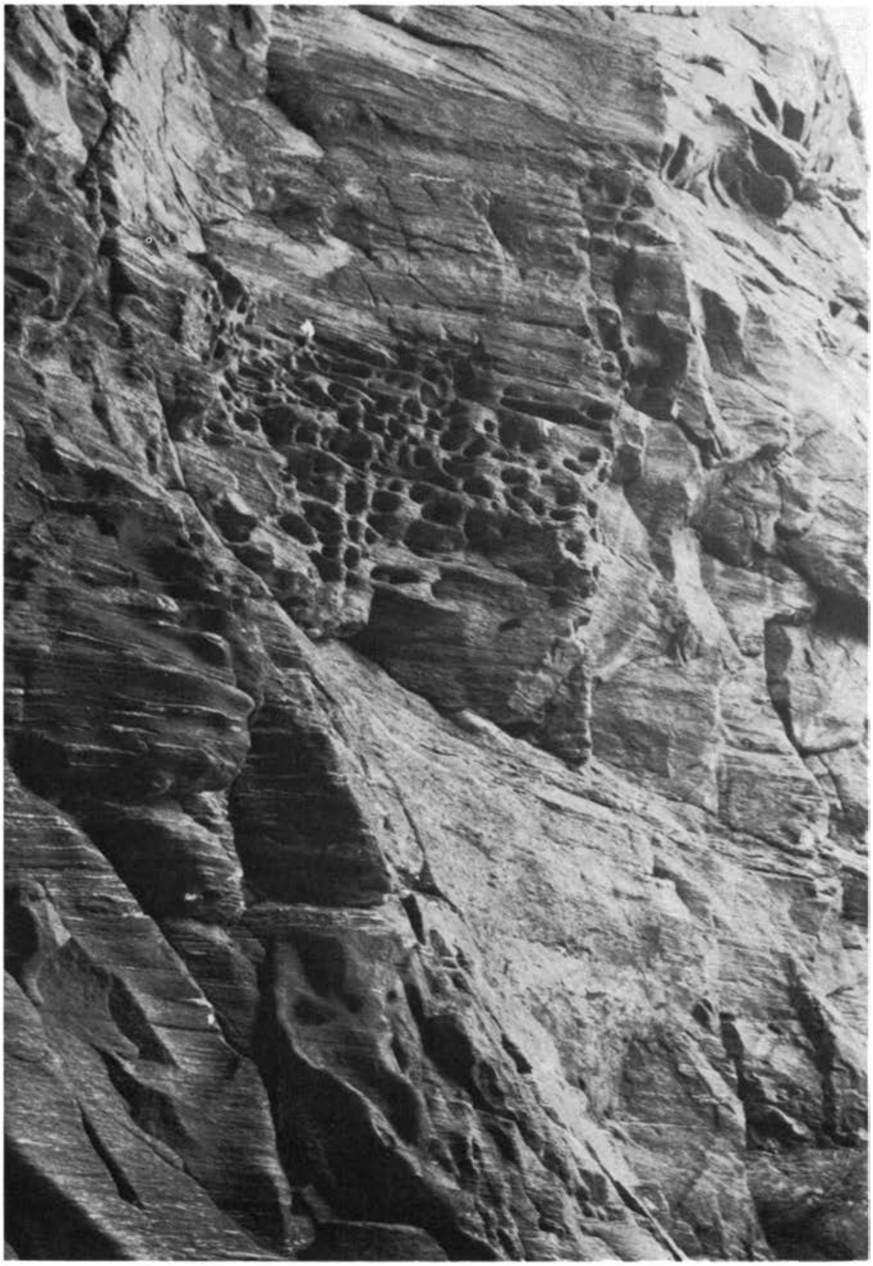

Fig. 6. Cossosion marks and rounded surfaces at the entrance of the Rønstadhelleren cave, Lepsøy island.

these clefts is filled with till, which has not been influenced by the sea in Late Weichselian time, and is therefore thought to be older than the last ice advance. Two small caves are described by Undås at levels of 78 and 80 m respectively, which is higher than the Late Weichselian marine limit of about 57 m a.s.l.

Further to the north-east, south of the *Hustad* village, another high positioned cave is present on the northwestern slope of a mountain ridge, which is an extension remnant of the mountain Raudtuva. The cave is formed in gneiss along a distinct east-southeasterly fracture, with a steep northerly dip. As with most other caves described, the entrance is situated on top of a talus cone, which here is at a level of c. 67 m a.s.l. From this mound the floor slopes down into the cave, where the height is about 60 m a.s.l. The cave is about 20 m deep, and the width about 3 m. The roof is estimated to be at 70–75 m a.s.l. The walls and roof inside the cave show rounded forms and differential wear due to a very heterogenous gneissic rock, presumably as a result of marine abrasion (Fig. 7). According to Undås (1942) the Late Weichselian marine limit is about 65 m in this area, and therefore the cave does not necessarily need to be pre-Late Weichselian in age. However, the similarity of the cave with other sea-formed caves which are definitely pre-Late Weichselian strongly point to an age greater than the last ice advance.

South–southeast of Gulberget, near the southwestern corner of the Hustad peninsula, is another rocky mountain remnant protruding above the strandflat, where high positioned caves and sea-abrasional forms have been described (Undås 1942, Kaldhol 1922). The features are located on the northern slopes of the small hill *Åsmulen*. Again fracture-controlled clefts have been cut by sea abrasion, and in one case (Båsen), a cave 25 m long, 4–5 m high at the entrance, and 2 m broad, forms an extension of a 40 m long cleft. In the other case (Oksbåsen), the 12 m long cleft ends in a pothole-like feature with a width of 5–6 m. The floor of these features are at 62 and 60 m a.s.l. respectively, while rocky walls show signs of sea abrasion up to a level of 70–75 m. Rounded, typical beach pebbles and stones were found by the author in the innermost part of the Båsen cave. The Late Weichselian marine limit is somewhat uncertain, according to Undås between 66 and 71 m, but there seems to be every reason to regard the features as formed before the last ice advance and during a sea level which was somewhat higher.

8. *Trollhola, Averøy*

The island Averøy, west of the town Kristiansund, has in its northern part a well developed strandflat, which in many places terminates in steep cliffs leading up to the hilly and mountainous parts of the island. Some of these cliffs show distinct signs of sea abrasion, especially in the form of caves. The cave Trollhola has been developed on the western slope of Søfstadberget, a hill with a maximum height of 213 m, situated west of Nekstadfjorden. Like the other described caves, it has been developed along fractures; in this case a main east-northeasterly fracture which forms the boundary between gneiss and more basic layers. The entrance to the cave is situated on the top of a talus accumulation at a height of about 88 m a.s.l., and the floor inside rises from about 76 m a.s.l. at the bottom near the entrance mound to about 90 m a.s.l. in the inner part, where another smaller cave continues. The main cave is about 35 m long, 4 m broad, and the floor is soil-covered with sand and some downfallen blocks. The walls of the cave show definite signs of sea abrasion, and these are present up to a level of at least 90 m a.s.l. The Late Weichselian marine limit is not known at this locality, but the cave is definitely higher, and therefore older.

9. *The Bremsnes cave, Averøy*

This cave is formed along a distinct north-easterly fracture zone on the southern side of Bremsneshatten, a 130 m high remnant hill situated on the strandflat southwest of Kristiansund. The entrance to this cave is about 80 m a.s.l., and situated on top of a talus accumulation. From the entrance the floor of the cave slopes down to a level of about 67 m a.s.l. The cave is about 80 m long, from 4 to 12 m broad, and according to Undås (1942) the floor of the main cave is between 72 and 77 m a.s.l., while a secondary cave further inside has a floor level of 82 m a.s.l. The floor of the cave has, especially in its outer part, a great amount of downfallen rocks; at the foot of the talus accumulation inside the cave a few morainic boulders were also observed. The Late Weichselian marine limit is, according to Undås, about 77 m a.s.l. in the area, and the cave might therefore be Late Glacial in age. The lack of rounded beach-pebbles inside the cave, the presence of morainic material, and the great amount of rocks fallen from the roof, do, however, point to an older age.

On the eastern slope of Bremsneshatten, another cave was observed which has been cut along a fracture in an east-west direction. A rocky cleft 25 m long leads into the cave, which is 6 m long, 1 m broad, and about 5 m high. The entrance to the cave was 70 m a.s.l., and the inside of the cave had a smooth and polished surface, presumably due to sea abrasion. The position of the cave is clearly below Late Weichselian sea level, and the age may therefore be Late-glacial.

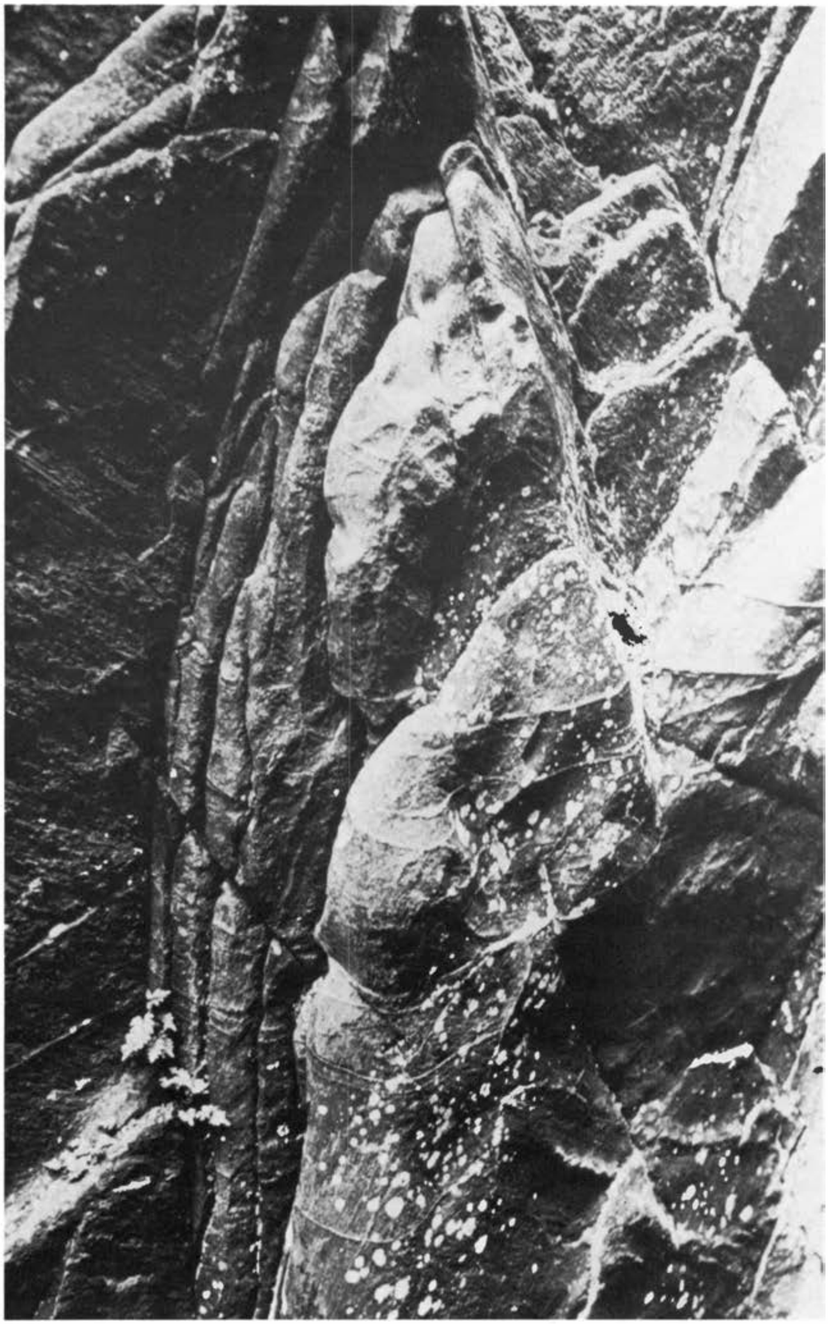

Fig. 7. Rounded surfaces of wall in cave at Hustad, supposedly due to marine abrasion.

The origin and age of the caves and their relation to sea level

The caves above the Late Weichselian marine limit have some common features. They have all been cut into cliffs exposed to the open sea, in rocks weakened by fractures, and in positions protected from ice erosion. In general the direction of glacial striae along the outer coast between Kristiansund and Stad are northwesterly

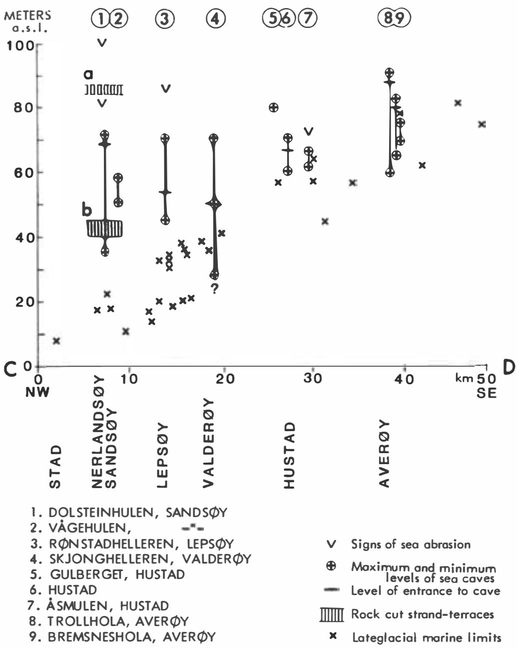

Fig. 8. Maximum and minimum levels of described sea-formed caves, levels of other signs of sea abrasion (corrosion?), rock-cut strand terraces, and Late Weichselian marine limits projected on plane normal to Younger Dryas isobases. See also Fig. 1. a: terrace at Sandsøy, b: terrace at Nerlandsøy.

to north-northwesterly (H. Holtedahl 1955). The surface features formed by marine abrasion and corrosion are only present in protected places, where they have escaped ice erosion. This supports the assumption that the features were formed before the last ice advance.

Fig. 8 shows how the Late Weichselian marine limits increase in height along the coast from south to north, due to the coastline cutting the isobases. It can also be seen that the highest pre-Late Weichselian sea levels, estimated from signs of sea abrasion in caves and otherwise, do not have the same trend along the coast, but are as high, or higher, in the southern part as in the northern part. This means that while the Late Weichselian strandlines were formed during the deglaciation at a time when the crust was depressed isostatically due to the ice load, the pre-Late Weichselian strand features, including the caves, were formed partly when the crust was not influenced by the load of glaciers, i.e. during an interstadial or interglacial.

It is seen that the roofs of the caves which are definitely above the Late Weichselian marine limit are between 70 and 80 m a.s.l., and the floors in some cases, as far as it can be estimated, almost 40 metres lower. Presumably the caves were eroded under varying sea levels.

As was previously mentioned, the re-advance of the inland ice after the Ålesund Interstadial can have taken place between 28,000 and c. 13,000 yrs B.P. The caves must be older than this readvance, and actually Mangerud et al. (1979) suggested that they might be of Ålesund Interstadial age, in which case one had to assume a strong isostatic depression of the crust during parts of that interstadial. This again would suggest a pre-Ålesund Interstadial glaciation of greater dimensions than the post-Ålesund Interstadial glacial advance, a suggestion which is unlikely.

Landvik (1982) has described the peripheral part of a sub-till sandur on Godøy island west of Ålesund. ^{14}C dating of shells in correlated glaciomarine sediments has given an age of c. 35,000 yrs B.P. If this date is correct, a re-advance of the inland ice has occurred during the Ålesund Interstadial. During the sandur deposition, a marine transgression is described from 11 m a.s.l. to at least 25 m a.s.l., and possibly to about 50 m a.s.l. The Skjonghelleren and Røndstadhelleren caves, which are situated reasonably close to Godøy island, have been excavated during sea levels partly considerably higher than 50 m a.s.l., and can therefore scarcely be connected with the Ålesund Interstadial. This conclusion also agrees with the previous assumption that the high strand features were formed when the earth crust was not isostatically depressed.

A situation with a 'stable' crust would be expected during an interglacial. The highest eustatic sea level during the last interglacial is approximately 5 m higher than at present (Bloom et al. 1974, Fairbanks & Matthews, 1978, Harmon et al., 1978).

At Fjøsanger, Bergen, Mangerud et al. 1978 have estimated the Eemian transgression at 30–45 m a.s.l., and as an explanation of this high level they have postulated a minimum net uplift of 10 m, and possibly as much as 40 m. This uplift is partly thought to be a result of an isostatic compensation for glacial erosion, but mainly a result of a long term neotectonic uplift. If the uplift is thought to be 10 m in 125,000 years (0.08 mm/year), an uplift of 80 m would have taken 1 million years, while an uplift of 40 m during 125,000 years would give an uplift of 0.32 mm/year, and a 80 m uplift would have taken 250,000 years.

If the caves on the Møre coast were formed during the Eemian, an uplift of 0.64 mm/year might be suggested, eight times as fast as at Fjøsanger. On the other hand, if the uplift were to equal the velocity at Fjøsanger, the caves would be 1 million years old. There is, however, no reason to expect the same uplift velocity in these two localities, but a conclusion must be that the features are at least Eemian in age, probably much older.

Recent excavations in the Skjonghelleren cave (E. Larsen pers. comm.) have given some interesting results bearing on the problem of age.

In the upper 6 m of the deposits there have been found zones with laminated silt and clay alternating with zones containing coarser material, especially stones dropped from the roof. The laminated silt and clay is supposed to have settled subglacially in a small pond formed inside the cave when the ice covered the area (Reusch 1913, Undås 1942), the coarse material during periods when the cave was open. A great deal of fossil bones of mammals, fish and birds have been found, suggesting that the cave during its open phases was inhabited by mammals (fox etc.). ^{14}C datings of bones found c. 1.5 m below the surface have given an age of approximately 28,000 years B.P. This preliminary dating suggests an Ålesund interstadial age for the fossil remains, and considering the very slow depositional rate (c. 0.053 mm/year and the possible sediment-thickness of c. 25 m, the cave must be at least Eemian in age, possibly 200,000–300,000 yrs old. This is not in disagreement with the assumed age based on the assumed rate of tectonic uplift described above.

As the caves are present on cliffs forming the backwall of the extensive strandflat, the assumed high age of the caves will throw new light on the age of this coastal feature.

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