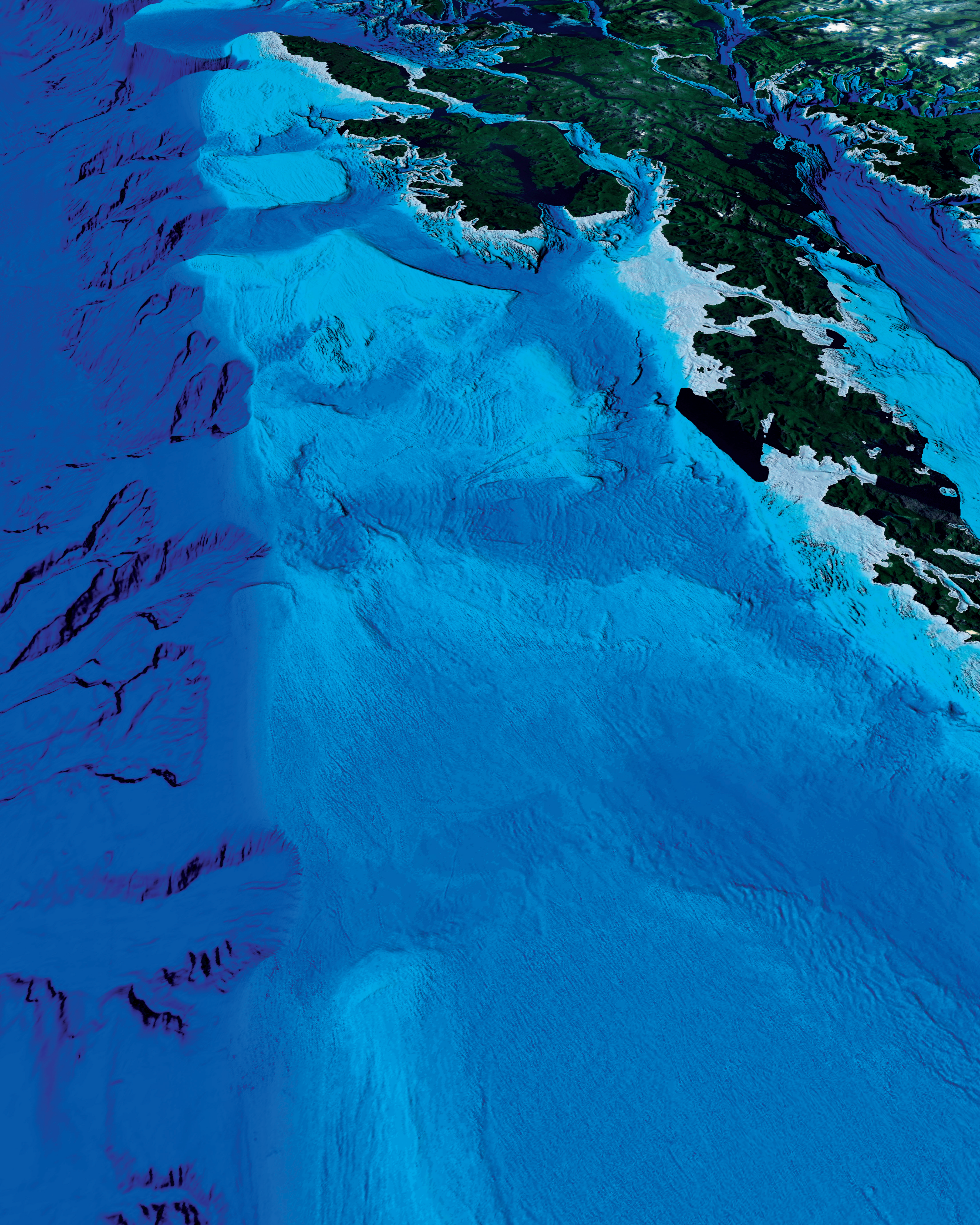

THE SHELF OFF LOFOTEN, VESTERÅLEN AND TROMS

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4.1 THE SEABED – MARINE LANDSCAPES, GEOLOGY AND PROCESSES

4.1.1 Marine Landscapes – Large Fishing Banks and Deep Troughs

The fishing banks off Lofoten, Vesterålen and Troms are internationally renowned as important fishing grounds for cod, halibut and many other species. Investigations by the Norwegian Petroleum Directorate has demonstrated the presence of petroleum resources in the Nordland VI and VII areas off Lofoten and Vesterålen and the Troms II area off Troms.

What are the characteristics of these fishing banks, and how did they develop? If we compare the continental shelf (i.e. the area from the coast to the shelf edge at 200–500 m depth) off Lofoten, Vesterålen and Troms with the shelf in other parts of Norwegian waters, we see that it is particularly narrow and quite unique. Off the island of Andøya, the shelf is less than 10 km wide where the Bleiksdjupet canyon cuts into the shelf. Off Vesterålen and Troms, the shelf is less than 50 km wide. By contrast, off Trøndelag in Mid-Norway, the continental shelf is around 250 km wide. The reasons for these variations in the shelf width are found in their geological history.

Tectonic plate boundaries and glaciers
About 60 million years ago, the North Atlantic crust cracked and a volcanic seabed formed in what later became the Norwegian Sea (see chapter 3). The boundary between the new seabed and the old continent, that continental Norway is still part of, runs more or less along

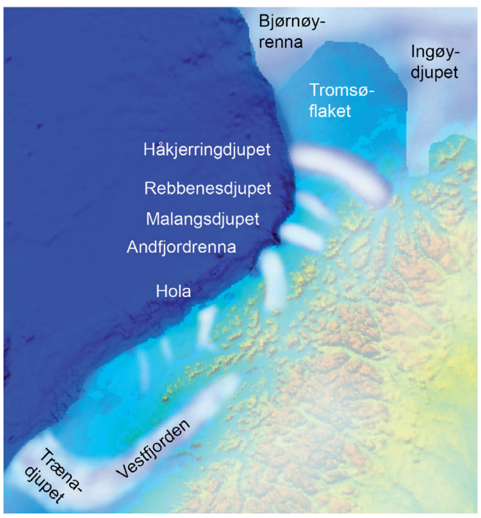


Figure 1. The largest ice streams from Northern Norway followed Ingøydjupet and Vestfjorden/Trænadjupet. ID – Ingøydjupet; TD – Trænadjupet; H – Hola; AFR – Andfjordrenna; MD – Malangsdjupet; RD – Rebbenesdjupet; TF - Tromsøflaket.

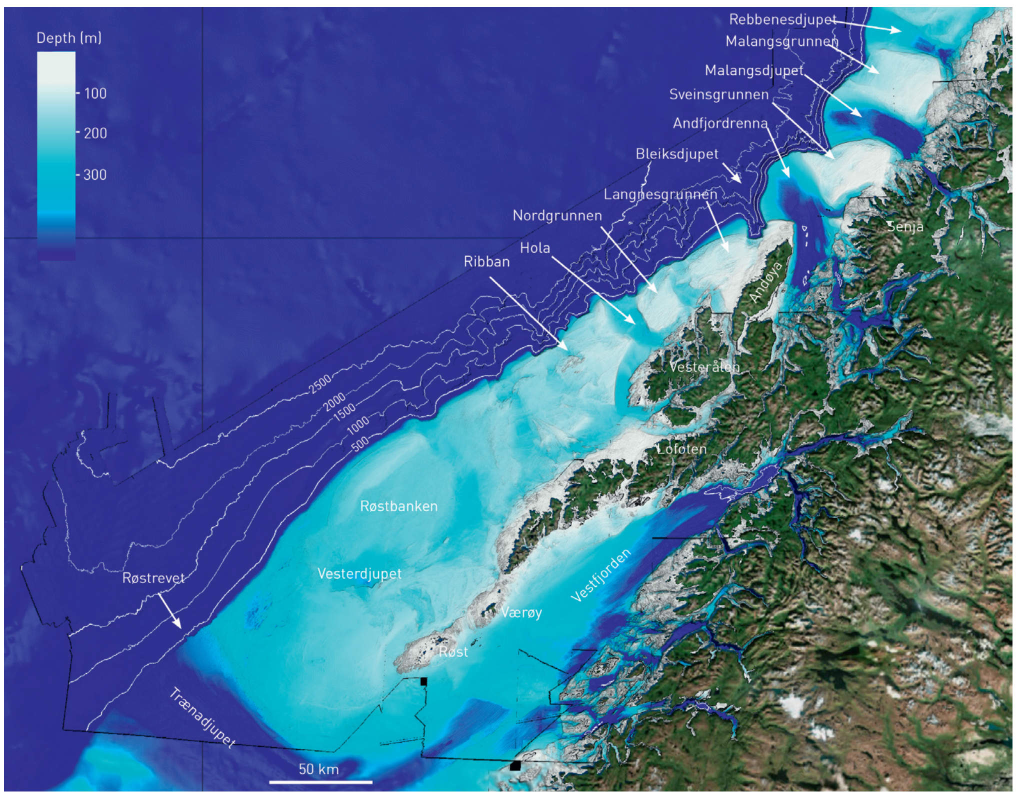


Figure 2. Overview of troughs and banks off Lofoten, Vesterålen and Troms.

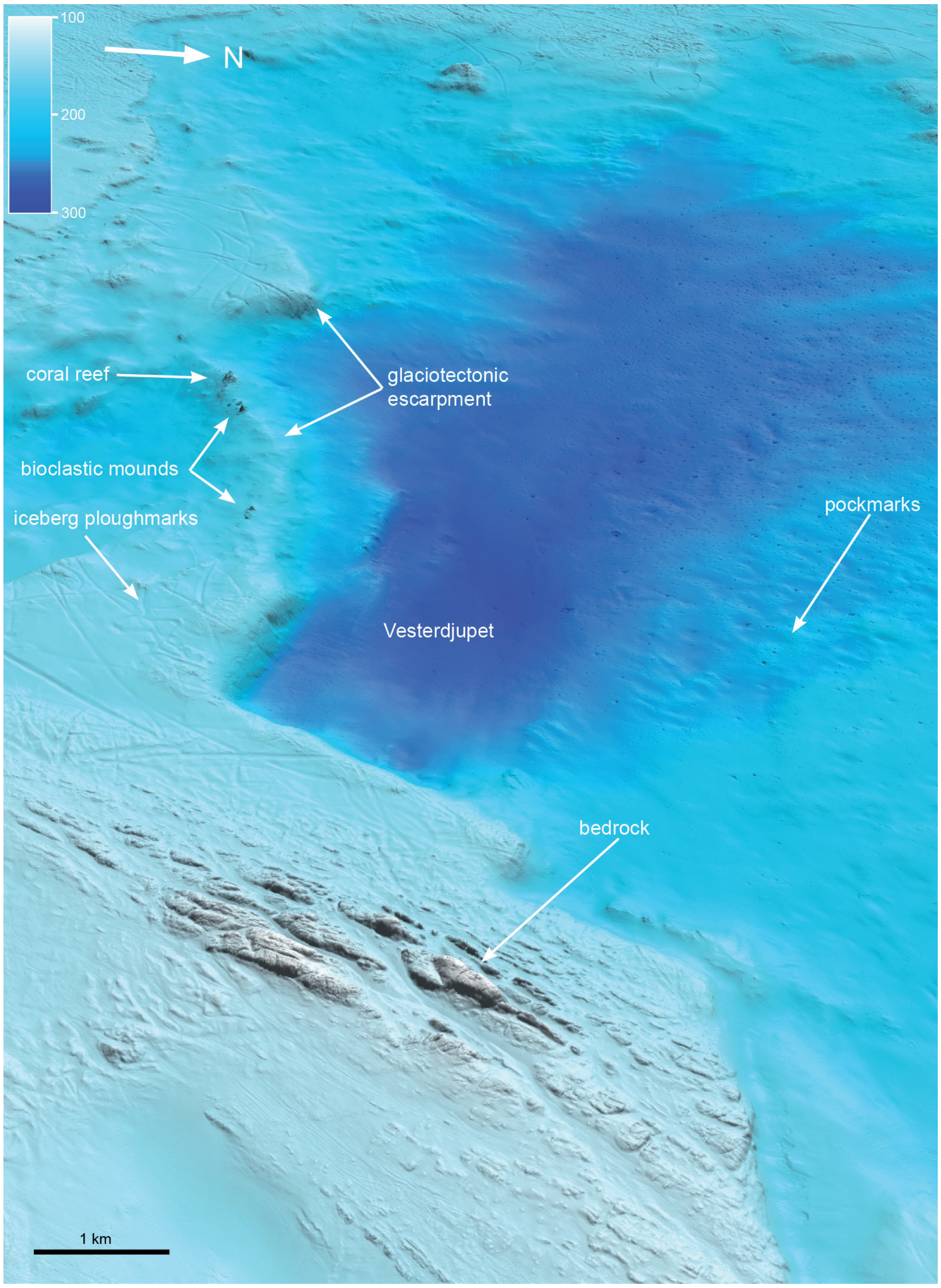


Figure 3. 3D view of the Vesterdjupet basin which was formed by ice that removed slabs of the seabed while moving westwards. The glaciotectonic escarpments delineate the basin margin. Muddy sediments with pockmarks dominate in the basin. The bedrock ridge is 50 metres high. Note coral reefs and bioclastic mounds on the ridge along the southern margin of the basin and iceberg ploughmarks in the shallower areas.

the border between the continental slope and the deep-sea plain. The presence of this boundary is one important reason why the continental shelf is at its narrowest off Lofoten, Vesterålen and Troms.

Another important reason is that only limited parts of the ice masses that covered Scandinavia and large parts of the Barents Sea drained through these areas (figure 1). The main drainage occurred through Vestfjorden/Trænadjupet, and Ingøydjupet/Bjørnøyrenna. This means that this part of the shelf was never subject to extensive erosion or deposition of thick tills, and only a thin layer of sediments was deposited by the ice. Meanwhile in central Norway, the ice masses moved onto the continental shelf and deposited sediments more than 1000 m thick on the outer shelf.

Wide fishing banks and deep troughs

Even though the massive icecap that covered Scandinavia mostly avoided the shelf off Lofoten-Vesterålen-Troms, this does not mean that ice was not important in shaping the marine landscape here. Erosion from ice advancing towards the shelf edge from a local icecap in the Lofoten-Vesterålen area played an important role. If we image the shelf bathymetry between Lofoten and Troms using a colour scale ranging from 50 to 350 m, we can clearly see large and relatively flat banks separated by deep troughs (figure 2).

The Vesterdjupet basin in the middle of Røstbanken northeast of Trænadjupet (figure 4) is more than 100 m deep and covers an area of around 500 km2. The depression is asymmetric - with fairly steep basin boundaries in the southeast (up to 10° - 15°) becoming more gently sloping in the northwest (figure 3). At the southeastern margin, we also find a bedrock ridge, rising as much as 50 m above the surrounding seabed. The asymmetric depression of Vesterdjupet was formed by what are called "glaciotectonic processes". The base of the ice sheet covering Røstbanken stopped moving at some point in time and froze to the seabed. As the ice sheet started to move again, the parts of the seabed that were stuck to the ice were ripped off and transported westwards.

Andfjordrenna is a good example of a glacial trough. It starts in Andfjorden and continues for 90 km all the way to the shelf edge. The trough has been dug out by glaciers moving repeatedly westward from the inland towards the sea, and being deflected northwards instead of crossing the Vesterålen islands. On the seabed, there are numerous elongated ridges and depressions (figure 4A) which were formed by the ice as it moved towards the shelf edge. At the shelf edge, where Andfjordrenna ends and the deep sea begins, the trough forms a curved fan. This is because the glacier deposited most of its dug-out debris on the shelf edge, where large icebergs calved. Andfjorden is special in that its outer parts are underlain by sedimentary rocks and not old crystalline bedrock, which is normally the case in Norwegian fjords. The boundary between the old crystalline bedrock to the sedimentary rocks appears as a transition from a rougher terrain to a more even landscape with elongated ridges (figure 4B).

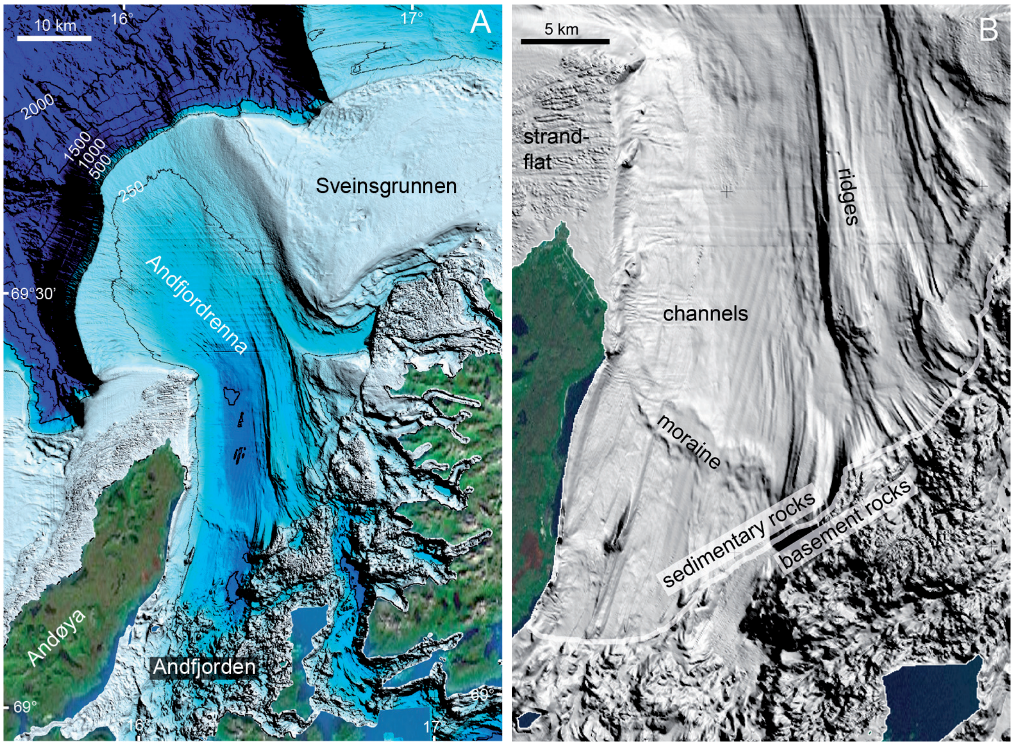


Figure 4. A – Andfjorden and Andfjordrenna form an approximately 90 km long depression starting at the shoreline and ending at the shelf edge. The shaded relief image has been made with a low attitude "sun"to highlight the marine landscape. B – The boundary between sedimentary rocks (covered by fluted tills) and old crystalline bedrock (basement rocks) is obvious in Andfjorden.

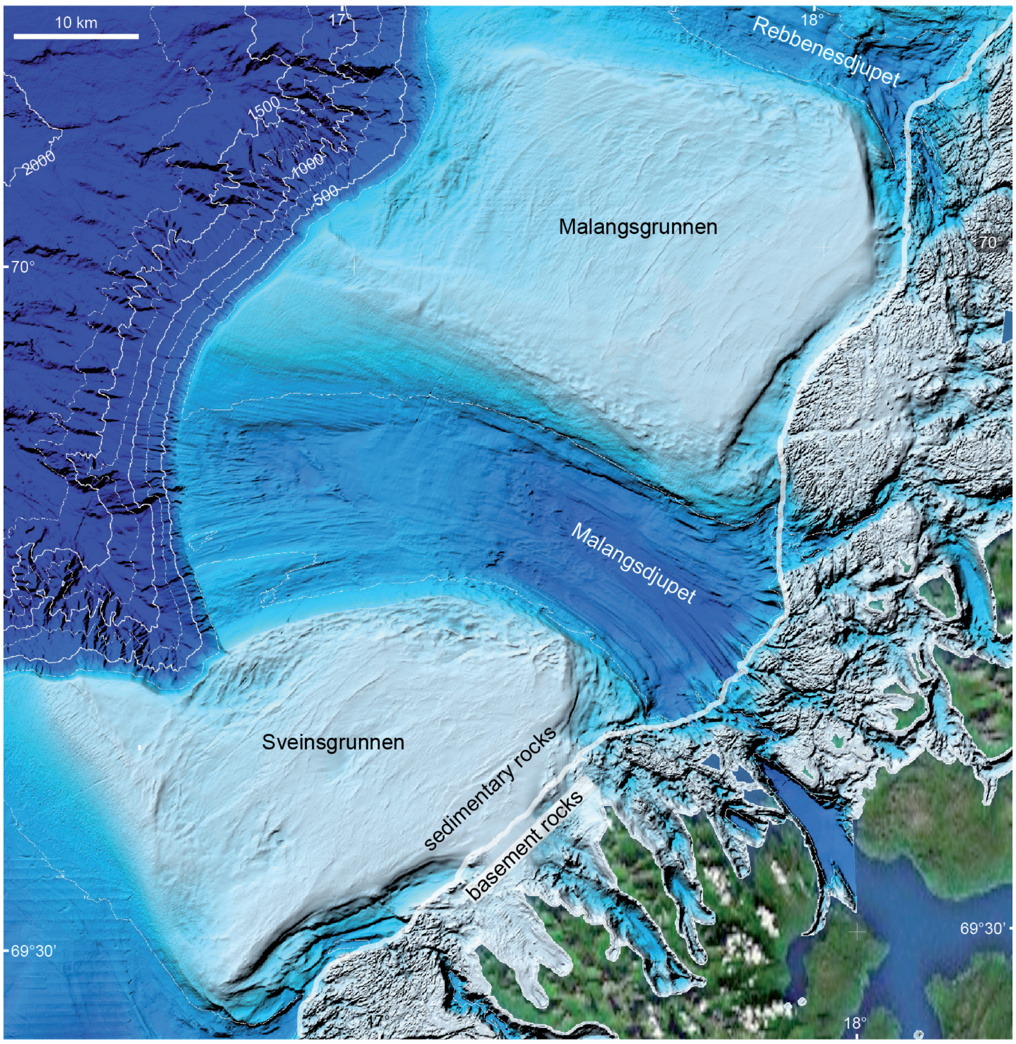


Figure 5. The fishing banks Sveinsgrunnen and Malangsgrunnen, are relatively flat topped and shallow with transecting moraine ridges. The Malangsdjupet trough separates the banks and has elongated ridges parallel to the direction of the ice flow.

The Vestfjorden-Trænadjupet is the longest glacial trough in the area (figure 1, 2). The distance from the inner parts of Vestfjorden to the shelf edge at the outer part of Trænadjupet is approximately 360 km. This was a major transport pathway from inland to the shelf edge for material eroded by the glaciers (ice-streams, which are fast-flowing parts of the ice sheet) during many glaciations. In fact, Vestfjorden is not a classical fjord in a geomorphological sense because it lacks a bedrock threshold in its outer parts (the threshold is found in the inner parts, where it narrows to a width of 10 km or less). Instead, it can be considered as an extension of the Trænadjupet cross-shelf trough (marine valley).

The fishing banks, such as Sveinsgrunnen and Malangsgrunnen, lie between the troughs dug out by the ice (figure 5). They are mostly formed by till (accumulations of boulders, stones and other material) carried and deposited by the glaciers on their course towards the shelf edge. In many places, there are ridges – either straight or curved and uneven – running in a southwest-northeast direction. These are moraines formed by retreating glaciers at the end of the last Ice Age. Where the fishing banks end towards land, there is a clear shift from flat banks and troughs to a shallow, rougher terrain (figure 5). This is the same transition that we see in Andfjorden, i.e. a transition from old crystalline bedrock towards land to sedimentary rocks covered by ice-deposited sediments further offshore (figure 4B). The same kinds of transition are found, with slight variations, all the way along the Norwegian coast, from Finnmark in the north to the Skagerrak coast in the south.

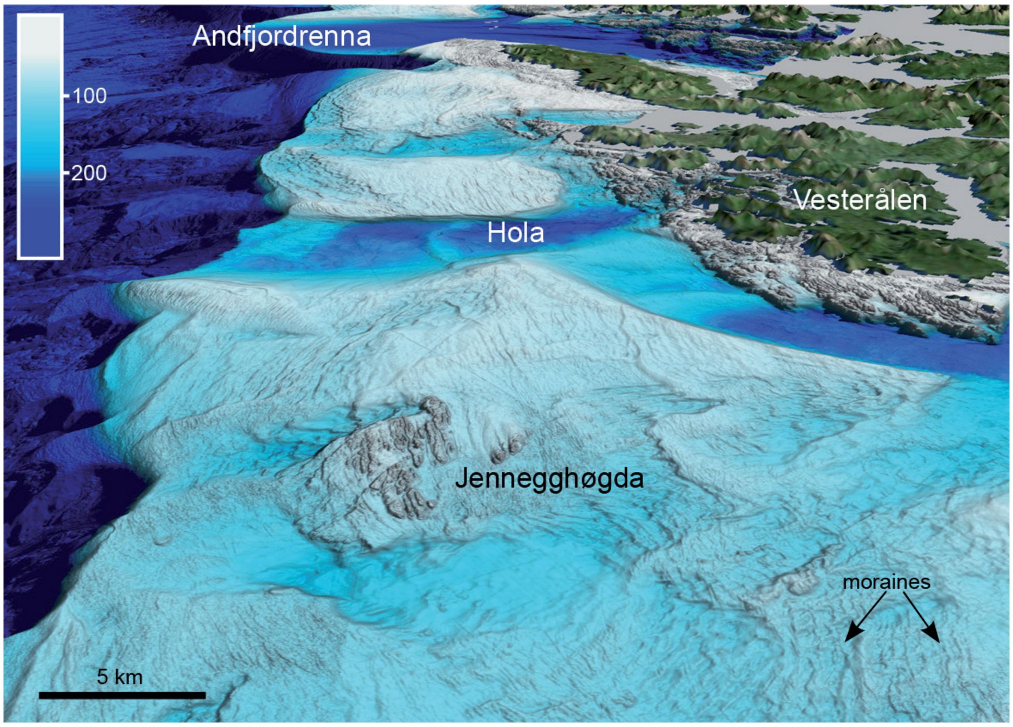


Figure 6. The Ribban area seen towards the northeast. Jennegghøgda is a protruding bedrock ridge in an otherwise relatively flat landscape. The banks Eggagrunnen and Nordgrunnen occur in the background. Large areas are dominated by moraine ridges. The depressions (darker blue) are up to 300 m deep while some of the ridges are less than 100 m below sea level.

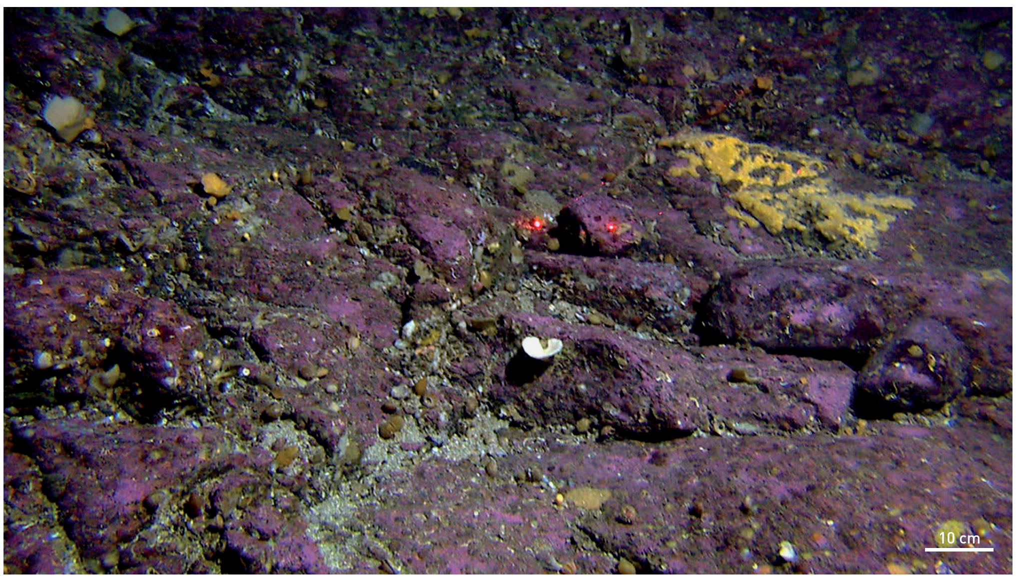


Figure 7. Hard bedrock protrudes from the seabed at Jennegghøgda, and organisms favouring hard ground thrive.

Bedrock ridges far out at sea

The Ribban area with its remarkable landscape formed by ridges and depressions running in various directions lies around 40 km west of Vesterålen (figure 6). Off Lofoten and Vesterålen we normally find a 50–200 m thick layer of sediments on top of sedimentary rocks deposited millions of years ago. An exception is at Jennegghøgda – where old crystalline bedrock protrudes through the layers of sedimentary rocks (figure 7). Jennegghøgda is the exposed part of the so called Utrøst Ridge – a large fault controlled basement ridge. The bedrock forms more than 50 m high NE-SW trending ridges, rising from a seafloor which is around 100 m deep. This can be considered as an offshore equivalent of the strandflat which fringes Lofoten and Vesterålen. It provides a very different environment for benthic organisms; with a seabed composed of hard rock, sand, gravel, cobbles and boulders instead of loose sediments.

Moraines, which are common in this area, are formed by mud, sand, gravel and boulders pushed into ridges by glaciers. These ridges can be over 10 m high and provide a distinct and often rich habitat for benthic organisms preferring a hard substrate, including colourful sponges and many other organisms (figure 8). Between the ridges, the seabed is covered by sandy sediments, with few organisms visible at the seabed.

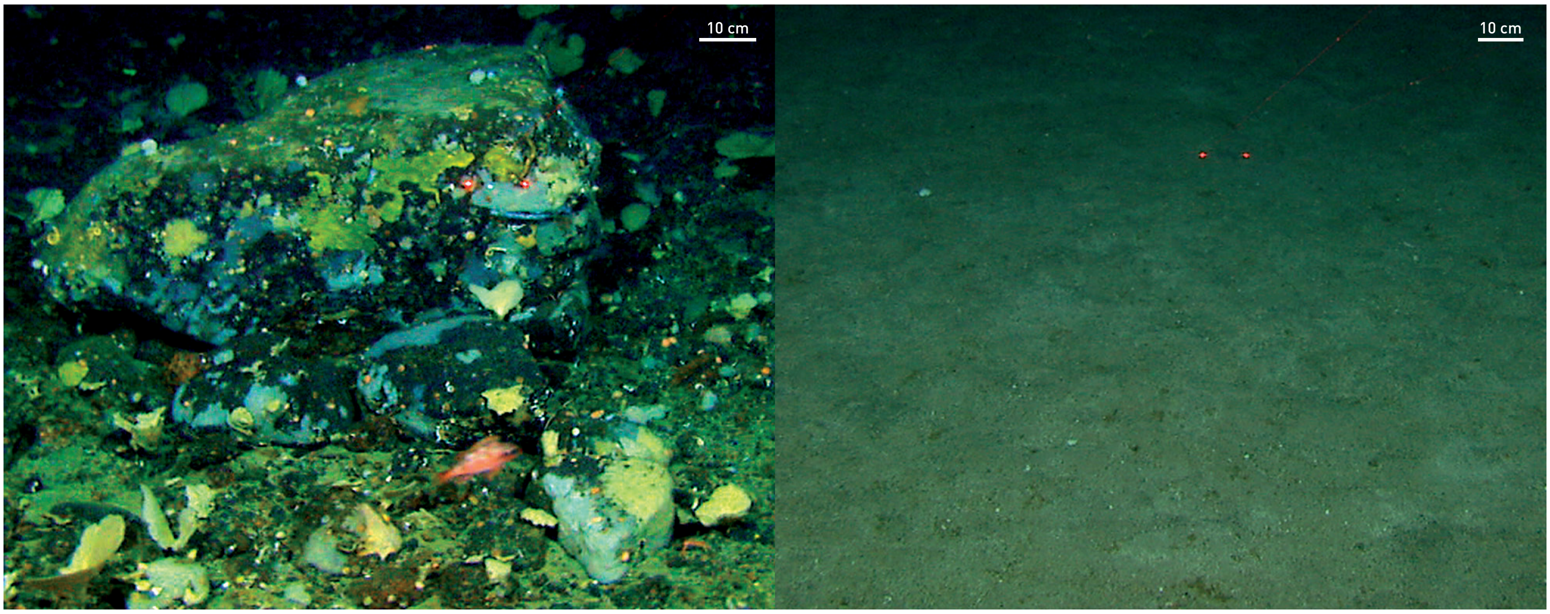


Figure 8. In the Ribban area, the seabed varies between moraine ridges (left) and sandy plains (right). Boulder covered moraine ridges often have a colourful fauna, while the sandy plains appear barren at the surface.

Marine landscapes

The seabed off Lofoten-Vesterålen-Troms can be divided into a range of marine landscapes (figure 9) based on the classification tool *Naturtyper i Norge* (i.e. *Norwegian Nature Types*, see box chapter 3). In the coastal zone, we find fjords and the strandflat. Between the coast and the shelf edge, the marine landscape is dominated by continental shelf plains such as Røstbanken and Sveinsgrunnen (banks), intersected by shallow marine valleys (troughs) such as Trænadjupet, Hola, Andfjordrenna, Malangsdjupet and Rebbenesdjupet. The principal landforms found on the shelf are moraines, sand waves, pockmarks, glacial ridges, iceberg plough marks, glacial erosional escarpments and glaciotectonic hill-hole structures.

4.1.2 Sediments

The Bank Areas – Nordvestbanken, Malangsgrunnen, Sveinsgrunnen, Vesterålsbankene (Langenesgrunnen, Nordgrunnen, Eggagrunnen), Ribban and Røstbanken

The banks off Lofoten, Vesterålen and Troms are covered in coarse-grained sediments. Gravel, cobble and boulders prevail in shallow areas and on moraines elevated from the surrounding seabed (figure 10). Otherwise, the seabed on the banks generally consists of sandy gravel

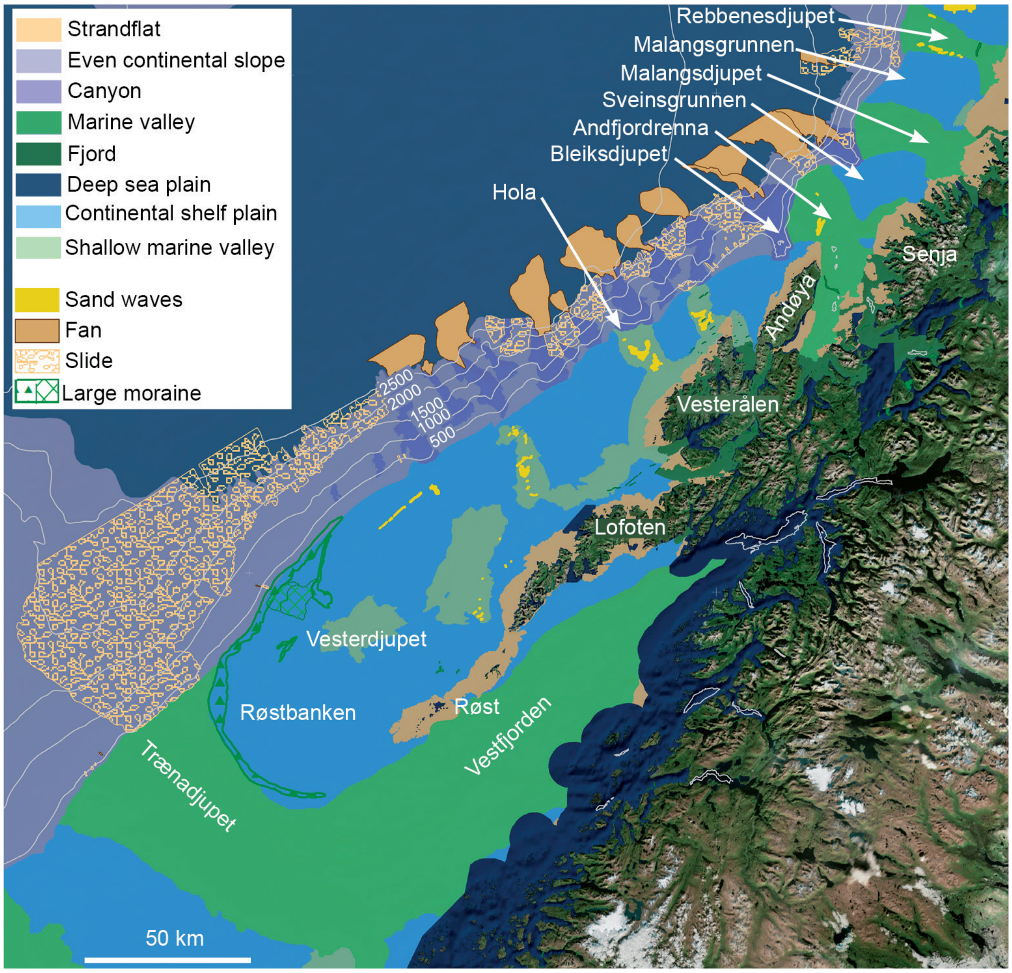


Figure 9. The shelf and the deep sea off Lofoten, Vesterålen and Troms display a wide range of marine landscapes.

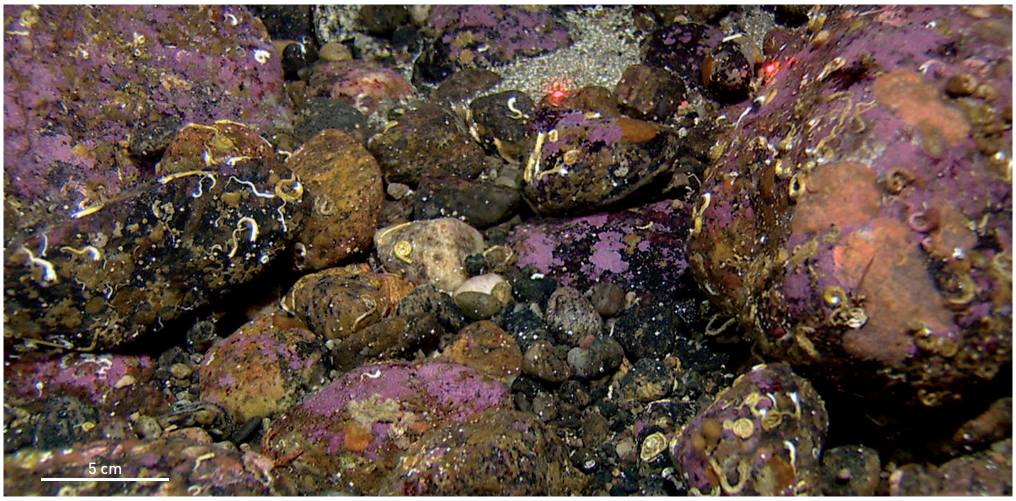


Figure 10. Gravel, cobbles and boulders at Sveinsgrunnen. The boulders were probably rounded by back and forth movement and by breaking waves on a beach when the sea level was lower shortly after the last ice age.

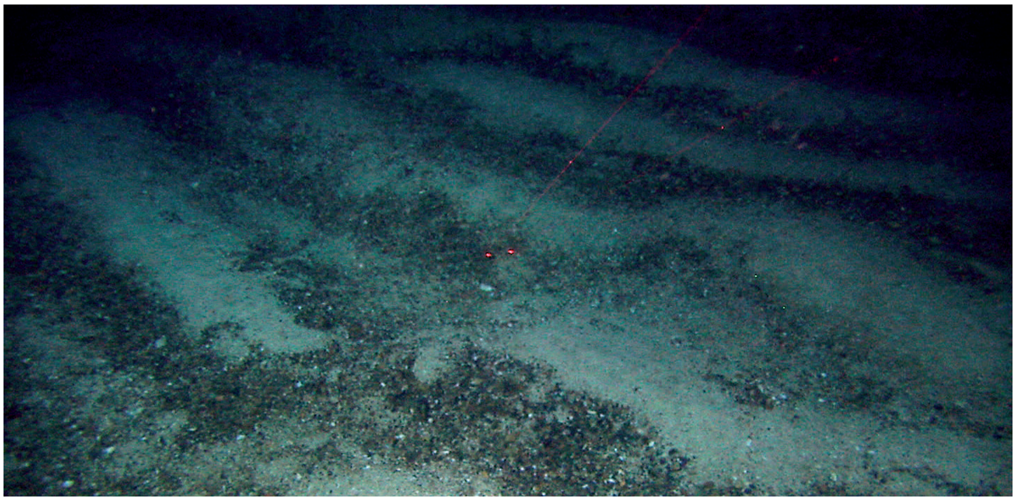


Figure 11. Sandy current ripples on a gravel bed on the southeastern part of Malangsgrunnen.

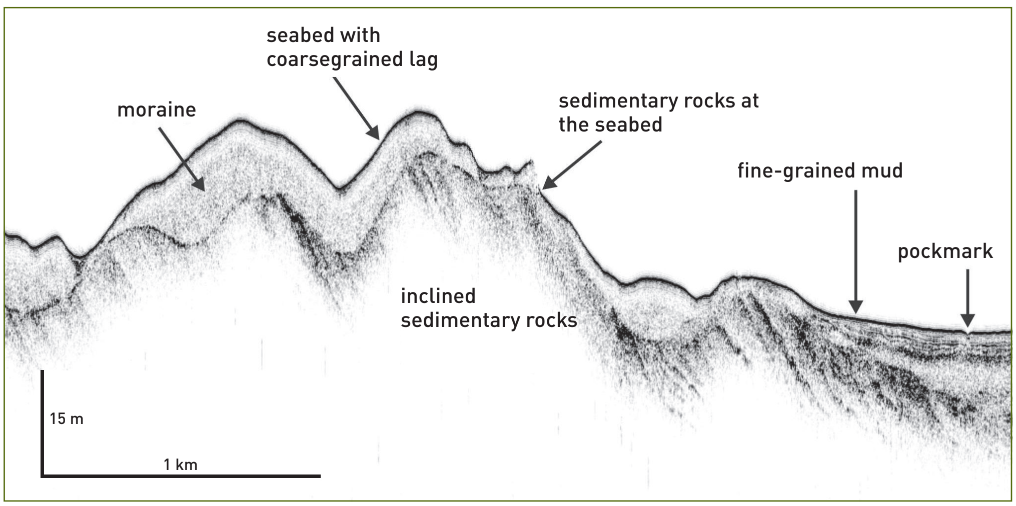


Figure 12. Seismic line (TOPAS parametric sonar) from the Vesterdjupet basin at Røstbanken. The figure shows how sedimentary rocks protrude from below the seabed. Till, deposited by ice and containing a mixture of grain sizes, covers the seabed in the shallowest bank areas. Fine-grained mud was deposited in the trough east of Røstbanken after the icecap melted 13,000–15,000 years ago.

(figure 11). The coarse top layer is often only a few centimetres or decimetres thick. The same sediment composition is often found on the sloping margins of banks, with some occurrences of gravelly sand. In some places, old crystalline bedrock protrudes (figure 12).

Troughs – Rebbenesdjupet, Malangsdjupet, Andfjordrenna, Sanden, Hola, Djuphola, Trænadjupet

In the troughs between the banks, we find finer-grained sediments than on the banks. Here, the most common sediment types are sand and gravelly sand. In Rebbenesdjupet, Malangsdjupet, the trough to the east of Røstbanken and in local depressions in the Ribban area, gravelly sandy mud is common (figure 13). Sandy mud occurs in the deepest parts of Rebbenesdjupet and in the trough east of Røstbanken. Vesterdjupet has gravelly sandy mud in the shallowest parts, and sandy mud in the deepest parts. A seismic profile (figure 12) shows that fine-grained mud has been deposited in this basin after the area became ice-free.

Trænadjupet is dominated by gravelly sand, with smaller areas covered by sandy gravel, sand, and sandy mud. Along the northern flank of Trænadjupet, in the transition zone towards the southern part of Røstbanken, we find extensive deposits of bioclastic sediments (figure 14). Bioclastic sediments is a term commonly used to describe material originating from marine organisms such as coral and shells, and includes a range of grain sizes and compositions. Sediment grain size may range from silt to gravel clasts, and empty shells, calcareous algae, coral rubble and dead coral blocks are all included in this category. Bioclastic sediments normally have a minerogenic component, coming from either in situ deposits, traction currents along the seabed or deposition from suspension.

Bioclastic sediments are commonly found in biogenic mounds which may be wholly or partly covered by living corals and other organisms. The living corals and other organisms are not considered part of the bioclastic sediment. The biogenic mounds are defined based on morphology; i.e. they are structures which can be mapped from bathymetric data. If living corals are found on top of the mounds, they are characterised as a "coral reef". The morphologic interpretation of bioclastic sediments mapped by MAREANO is verified by video observations if possible (figure 15). Backscatter data from multibeam echosounder (which gives an acoustic proxy to the nature of the sediments) has locally proved to offer a good guide to the distribution of bioclastic sediments, but is used with care.

In Hola, the sediments are dominated by sand, but gravelly sand, sandy gravel and coarser sediments also occur. The sand in this area is composed of almost 100% shell material, and can thus also be classified as bioclastic sediments. Bioclastic sediments also occur associated with mounds and coral reefs.

The Shelf Edge

Off Troms, the shelf edge is clearly defined where the seabed suddenly drops off towards the deep. In these areas, we find gravelly sand at the shelf edge. Off Lofoten and Vesterålen, there are several terraced levels between the continental shelf and the continental slope. The uppermost part of the slope is characterised by a transition from gravel, cobbles and boulders to sandy gravel. The next level typically displays a transition from sandy gravel to gravelly sand.

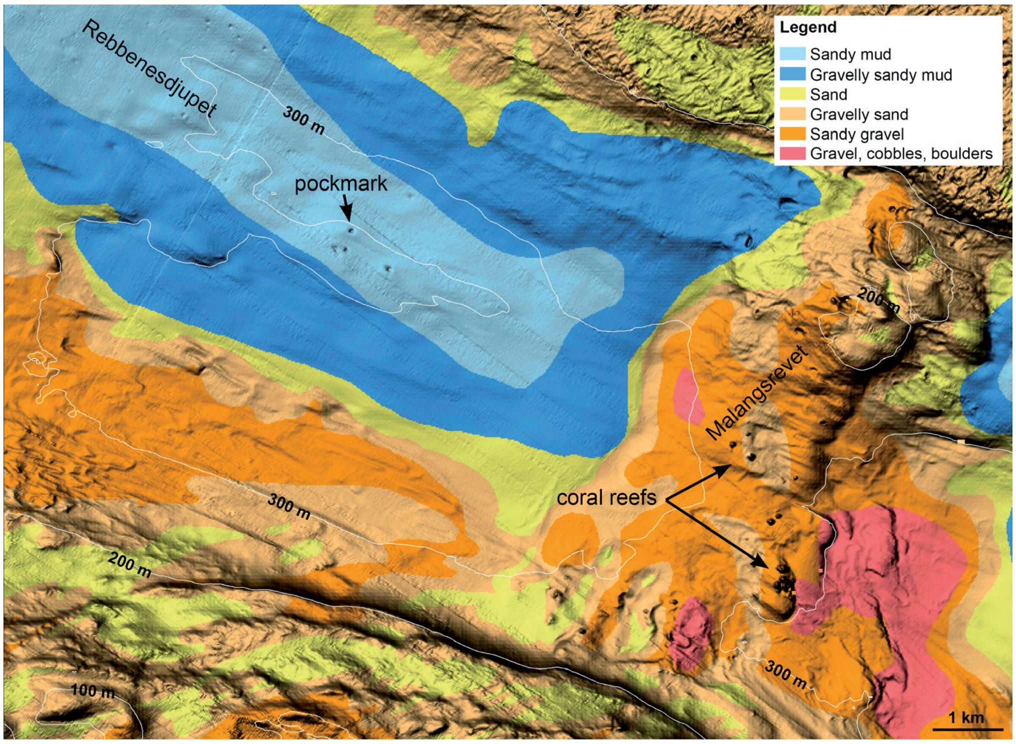


Figure 13. Seabed sediments in Rebbenesdjupet and on Malangsrevet. The corals on Malangsrevet grow on a northeast-southwest trending ridge of sedimentary rocks that is covered by a thin layer of till. There are numerous pockmarks in the deeper sandy mud area.

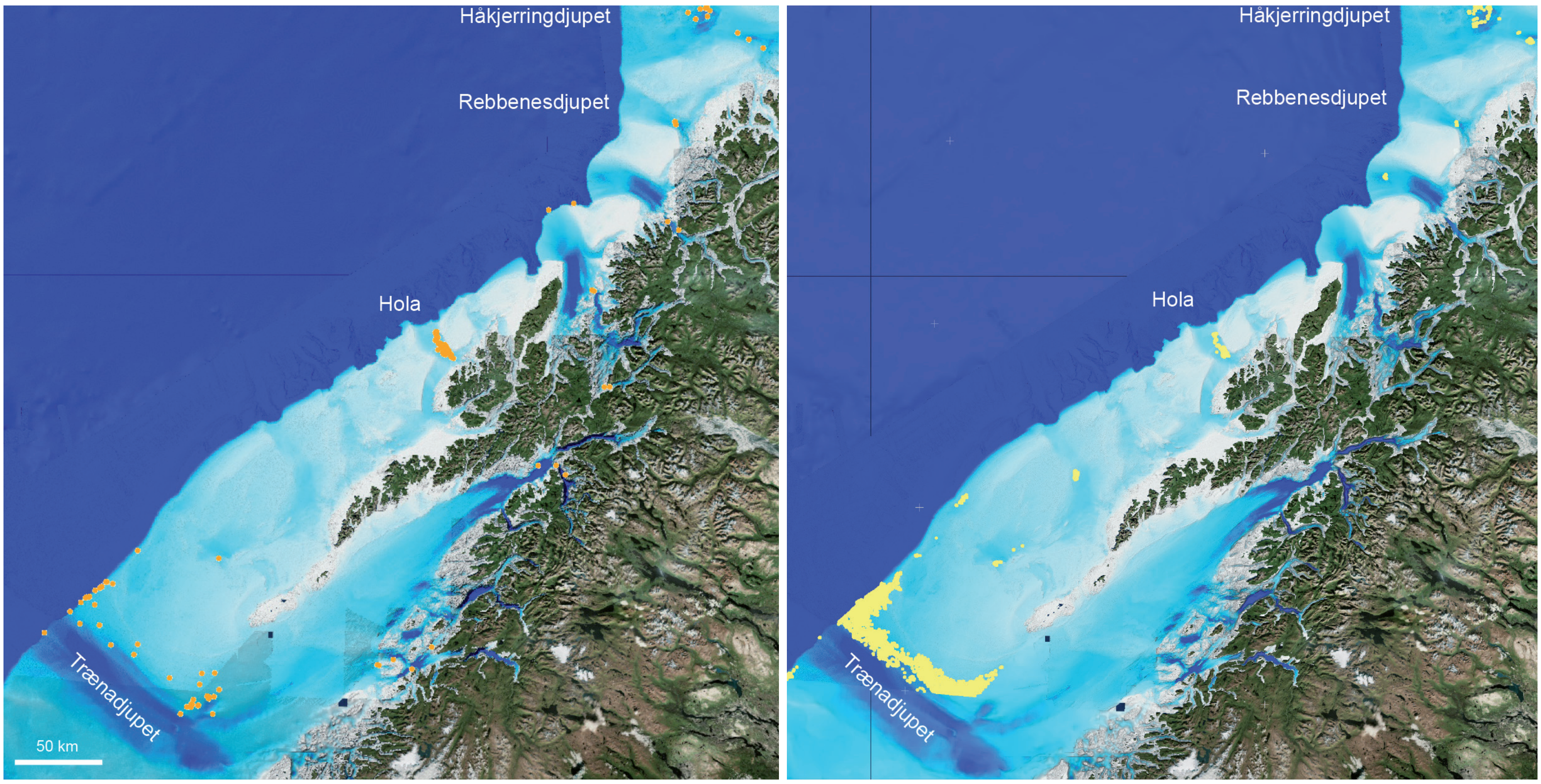


Figure 14. Left - distribution of coral mounds verified by video observations (orange colours). Right - distribution of bioclastic sediments and biogenic mounds based on interpretation of multibeam bathymetry and video observations (yellow colours).

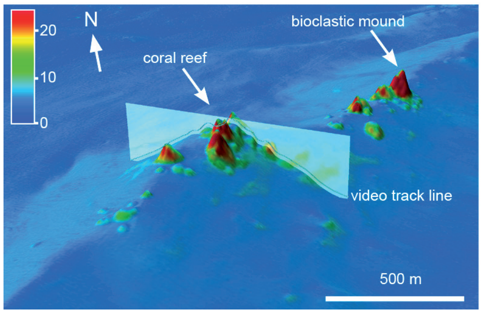


Figure 15. 3D view of a coral reef (verified by video) and a bioclastic mound on a glaciotectonic ridge in the southeastern part of the Vesterdjupet basin. The draped colours show angle of slope, locally exceeding 20°.

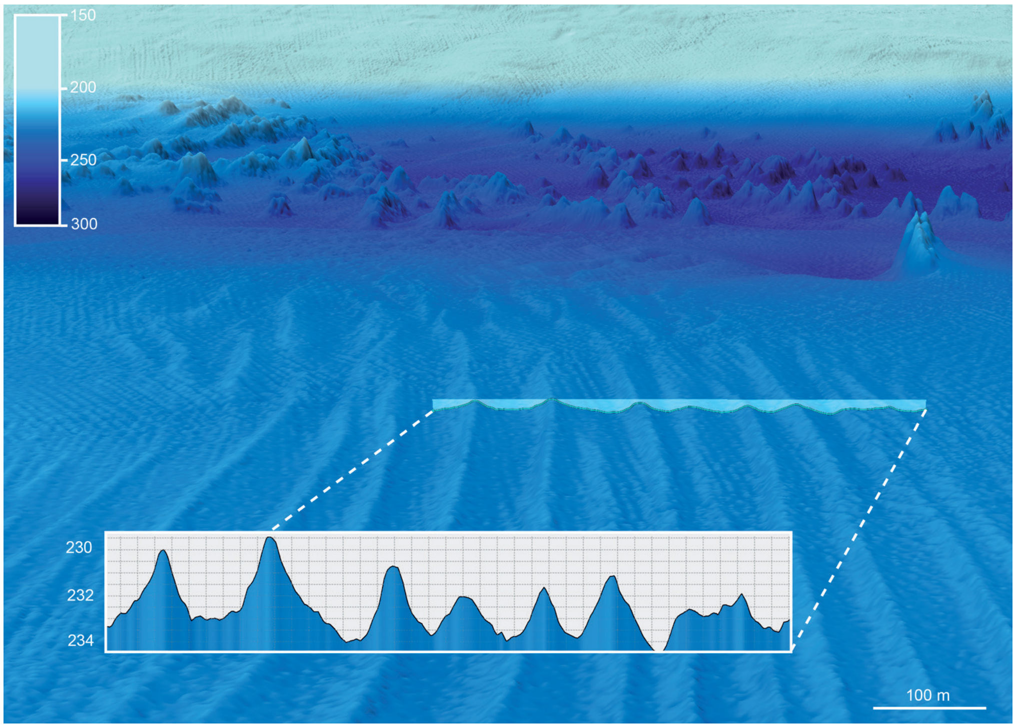


Figure 16. In the Hola trough off Vesterålen there are four sand fields with large sand waves. These waves are up to 3 km long and 7 m high and are formed by strong bottom currents. This 3D illustrations shows the sand waves, with the Hola coral reefs and the bank Nordgrunnen in the background.

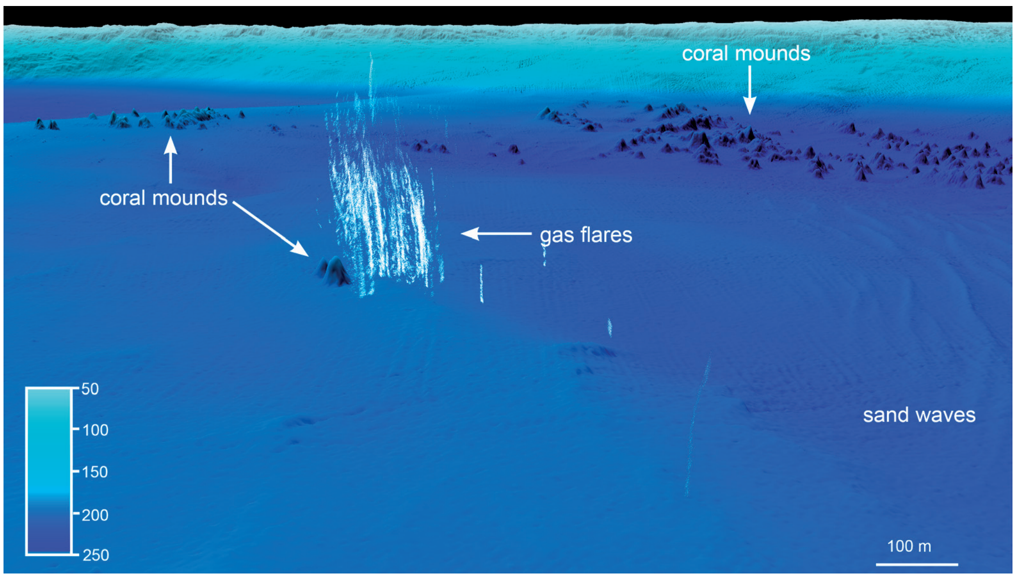


Figure 17. 3D view of gas flares and coral mounds in Hola. Nordgrunnen in the background. 5x vertical exaggeration.

4.1.3 A Changing Seabed – Sand Waves and Gas Seeps

Sand Waves

Sand waves occur at various locations on the shelf off Lofoten, Vesterålen and Troms. The largest sand wave areas are found in troughs between the banks, mostly in Hola, Sanden and west of Ribban (figure 9).

The sand waves in Hola trough have been studied closely to understand how they form and how sand is transported on the seabed. Approximately 50 km^2 of the seabed in Hola is covered by sand waves. The waves are up to 7 m high and 3 km long, while the distance between the wave crests are up to 300 m (figure 16). Most of the sand comes from the surrounding areas. Waves, tide and currents have eroded and transported sediments from the shallow banks into the trough, and over thousands of years, a layer of sand up to 10 m thick has formed. The top layer is rich in shells and shell fragments, mainly from mussels, sea urchins and snails. Transport and deposition of shell sand is an ongoing process in the Hola trough. This is of great significance for the benthic fauna. A good understanding of the processes on the seabed helps understanding future development – of both biological and physical conditions. Most likely, there is also shell sand in the other sand wave areas on the shelf.

The sand waves at Hola vary considerably over short distances. This is due to a complex pattern of currents, where strong ocean currents (the Atlantic Current and the Norwegian Coastal Current) and tidal currents both influence the circulation in a relatively narrow trough. Locally, the bottom current can reach speeds of up to 1 m/s. The tidal currents change directions four times a day. This is reflected both in the shape of the sand waves and in the fact that they move back and forth on the seabed.

Carbonate Crusts and Gas Seeps in Hola

Multibeam echosounder data are primarily used to produce terrain models of the seabed, but modern echosounders also have the possibility to acquire data in the water column between the seabed and the ship, which can indicate the presence of features such as gas bubbles. Multibeam water column data show that extensive gas seeps are present in Hola, coming from an area close to two coral mounds (figure 17). Video records show areas of carbonate crusts and bacterial mats on the seabed (figure 18) close to the base of the gas flares. The carbonate crusts and the bacterial mats are signs of methane and dissolved chemical compounds seeping out of the seabed.

The carbonate crusts were formed as a result of chemical reactions related to seepage from the subsurface to the seabed, where anaerobic microbial oxidation of methane-rich fluids has caused precipitation of carbonate in the sediment. This process took place in the past, a few tens of centimetres below the seabed. Later erosion has exposed the crusts at the seabed.

The bacterial mats, perhaps better known from stagnating water, form where chemical processes related to gas seeps favour bacterial growth. Similar bacterial mats have been observed on the Håkon Mosby mud volcano on the Barents Sea continental slope. The fact that gas flares are recorded in recent multibeam water column data indicates that the bacterial mats are likely related to present-day gas seepage. Shallow gas can originate by decomposition of organic material in the upper seabed or the Quaternary deposits. Gas formed under these circumstances will be called biogenic. Shallow gas can also come from deeper layers – sedimentary rocks – , e.g. from slate or mudstone which contain hydrocarbons, or from leaking oil and gas fields. Hydrocarbons from deeper layers have a “petrogenic” or “thermogenic” origin.

The exact origin of the gas seeping from the seabed in the Hola trough is not yet known, but geological maps show that the bedrock primarily consists of mudstone and sandstone from the Cretaceous period, i.e. rock that is 65–145 million years old. These may contain oil and gas. The sediments on the seabed and in the shallow sub-surface mostly consist of till from the last Ice Age and probably do not contain enough organic material to generate gas.

Scour Tracks and Comet Marks

Strong bottom currents on the continental shelf create a wide range of bedforms. Some of the most unique are found around the coral reefs in Hola. Here, the bottom currents have heavily eroded the seabed on the lee side of the coral reefs. The reefs act as obstacles that cause turbulence in the water, in a similar way to rocks in a fast flowing river. The turbulence results in the formation of scour depressions up to 12 m deep and 1.5 km long (figure 19). The bottom of the troughs is predominantly composed of gravel as fine sediments have been washed away. Other places, we find sand deposits in the shape of a comet tail (comet marks or sand shadows) in the lee of protruding structures on the seabed. These structures can either be small coral reefs or rocks and the comet marks can be up to 100 m long.

Figure 18. Carbonate crust and white bacterial mat on the seabed in Hola. Holes in the carbonate crust indicate where gas or fluids have been seeping during the formation of the crust. The seabed around the crust consists of gravelly sand with high content of shell material.

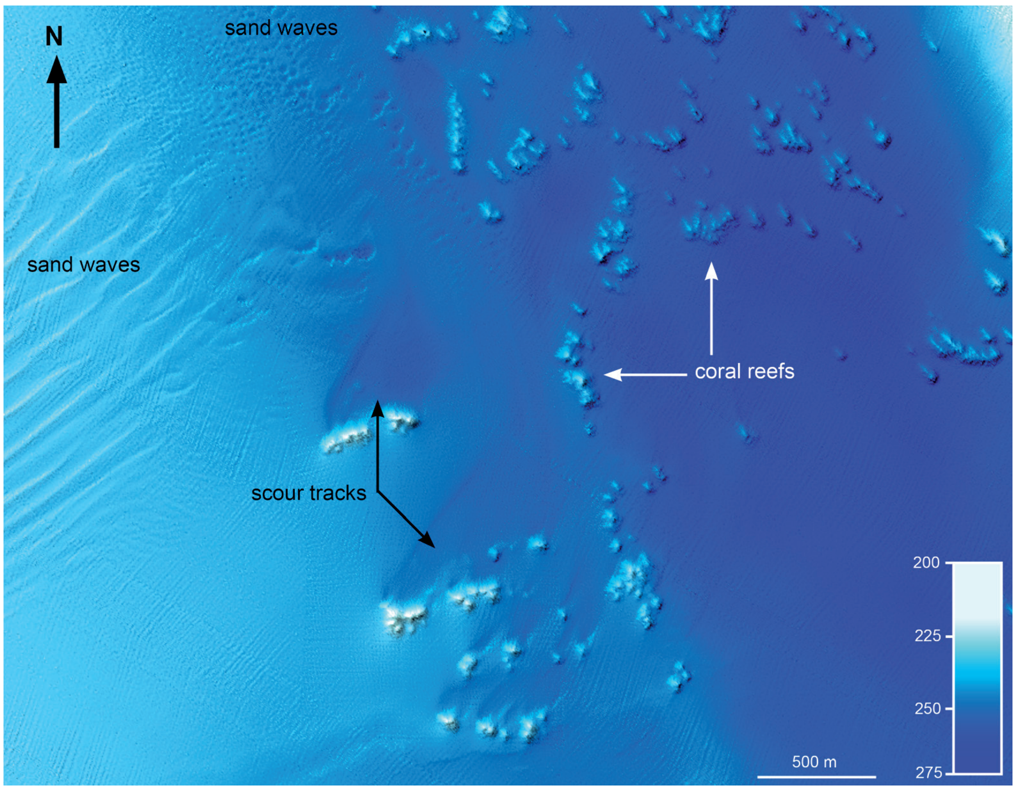
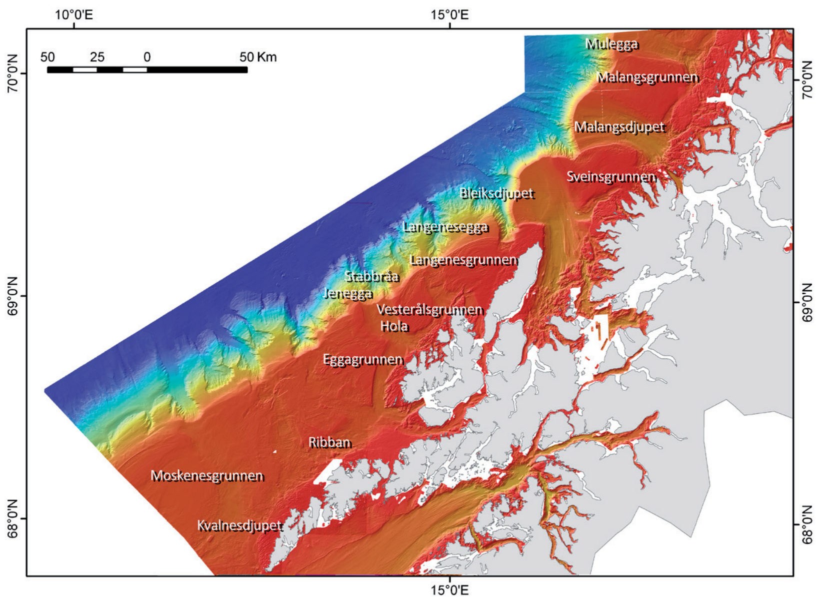


Figure 19. 3D Strong bottom currents create scour depressions on the lee side of the coral reefs in Hola. The direction of the troughs reflects the direction of the bottom currents. Various kinds of sand waves can be seen in the top left.

Figure 20. Seabed topography and overview of place names of the seabed off Lofoten, Vesterålen and Troms.



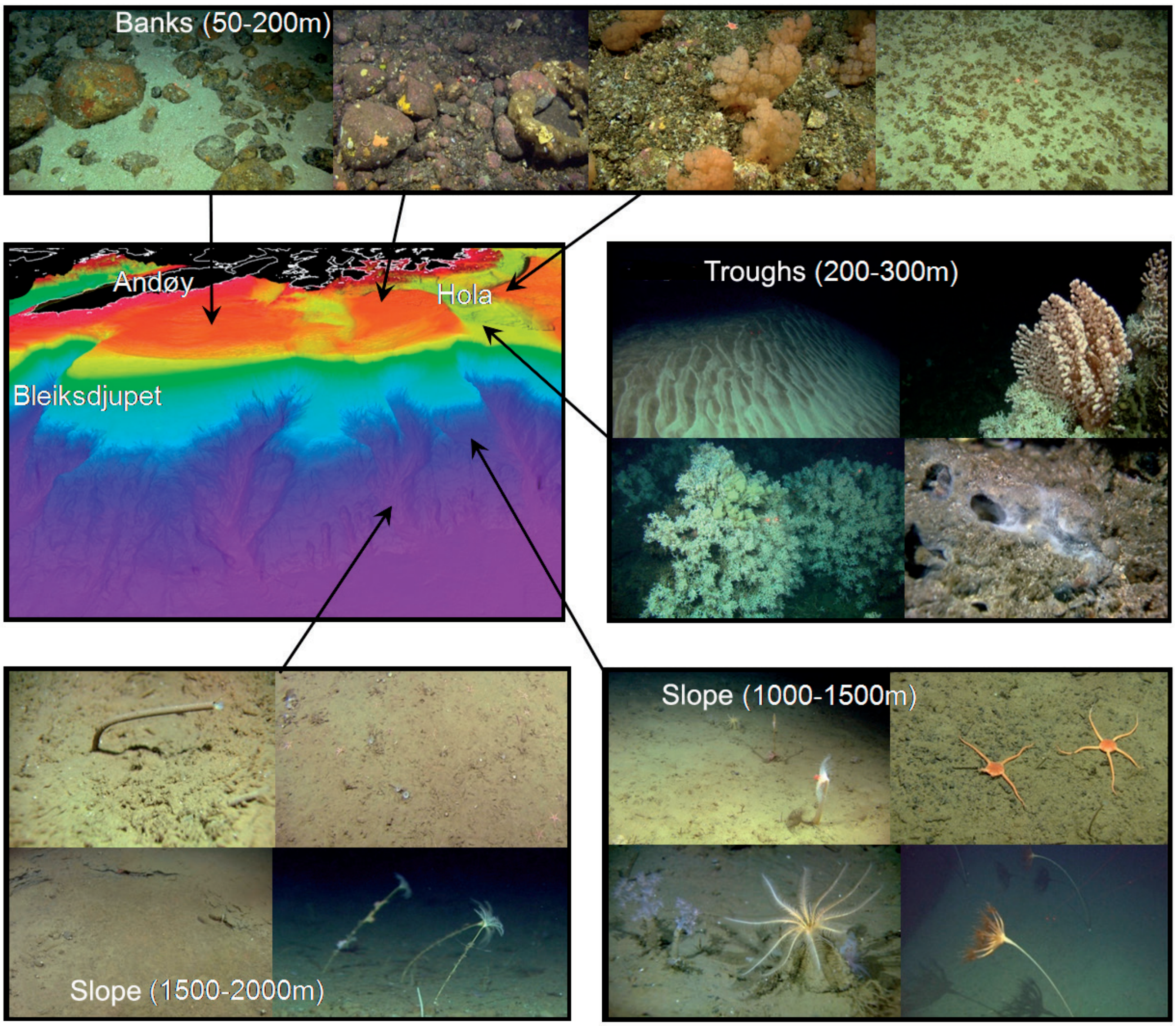
4.2 BENTHIC FAUNA – THE SHELF OFF LOFOTEN-VESTERÅLEN-TROMS

4.2.1. Habitat distribution

The Norwegian shelf is long and covers several climatic regions. In general, it is wide, but its northern part of Troms and Nordland counties it is at its narrowest. Here the distance between the coast line and the deep Norwegian Sea is very short (figure 20).

The shelf off Lofoten, Vesterålen and Troms has a varied seascape with a high associated biodiversity (figure 21 and 22). In this area, the shelf is separated by deep troughs and and

Figure 21. The shelf off Lofoten, Vesterålen and Troms has a varied seascape with a high associated biodiversity. The photographs show examples of some of the typical habitats.



incisions in the form of canyons. Some of the shelf troughs are connected to the fjords. The area is rich in nutrients for organisms at all levels in the food chain – from plankton and coral reefs to cod and whale.

Figure 22 is a schematic representation of a typical depth profile of the shelf off Vesterålen. The information on the composition of bottom substrates and biodiversity has been collected by video. This diagram indicates that the highest biodiversity is found in the areas closest to the coast and at the shelf edge.

Banks

The banks largely consist of moraine with cobbles of various sizes. The solid substrate and the strong current often found on the banks favour filtrating organisms such as sponges. Above the banks, eddies created by the current increase the concentration of plankton and other particles. It is also where the distance is the shortest between the bottom and the productive upper layers of the water column. Many places on the shallow banks of 50–100m depth, we find rounded cobbles covered in colourful flora and fauna (figures 23–25). In Northern Norway, the water is so clear that even at 80m depth, we find flora covering the cobbles with a delicate layer of pink. The gaps between the cobbles are good hiding places for crabs and fish such as redfish (figure 23).

Malangsgrunnen and Sveinsgrunnen have areas rich in biodiversity with boulders covered in calcareous algae, sponges and sessile fauna (figure 24 and 25) but also species-poor areas characterised by large sand waves.

The Deep Shelf Troughs

The banks on the continental shelf are separated by troughs, or under-water valleys, that often are prolongations of the fjords. Sea pens, sea cucumbers and shrimp dominate on the 200–500m deep muddy seabed between the banks (figure 26).

The seabed at Hola (the trough running across the continental shelf northeast of Eggagrunnen) is unique. It consists mainly of sand and gravel (a difficult bottom to sample with grabs and corers). The area is highly interesting in many ways and different from deep basins and fjords due to more water movement. The strong current has put its mark on the seabed. On the southern side of the trough, where the current mainly moves towards land, we find distinct sand waves. On the northern side, the current mainly moves from land. The demarcation between habitats is sharp and clear. In addition to

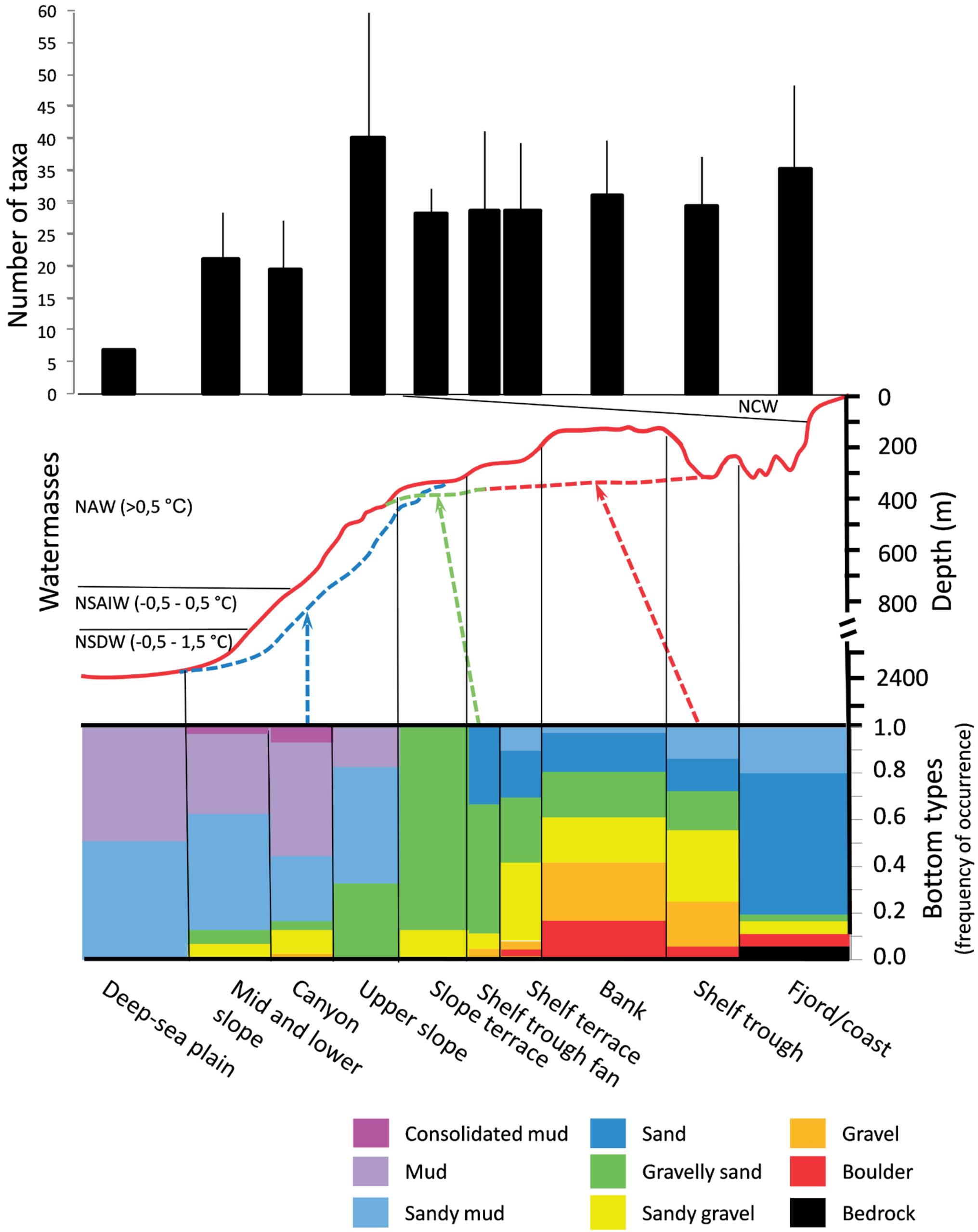


Figure 22. Relative amount (occurrence frequency) of bottom types along a general depth profile and through various seascapes. The biodiversity is indicated by columns representing an average number of observed species per video transect.

sand waves and coral reefs, we find gravel and fields of rounded cobbles and gas seeps.

At the deeper stations of Vesterålsbanken, we found areas of muddy bottom where we observed large sea pens (*Funiculina quadrangularis*), which frequently were hosts for brittle stars (*Asteronyx loveni*) (figure 27). Many organisms need a firm substrate as well as the opportunity to reach up into current to feed. *Asteronyx* live in symbiosis with *Funiculina*. In addition to particles in the water, the brittle stars probably also find some extra feed in the sea pen's polyps.

Figure 23. In addition to redfish and sponges that thrive on and between cobbles, there are Nephrops and crabs in the gaps. At Sveinsgrunnen, we found this colourful "gladiator", the king crab *Lithodes*.

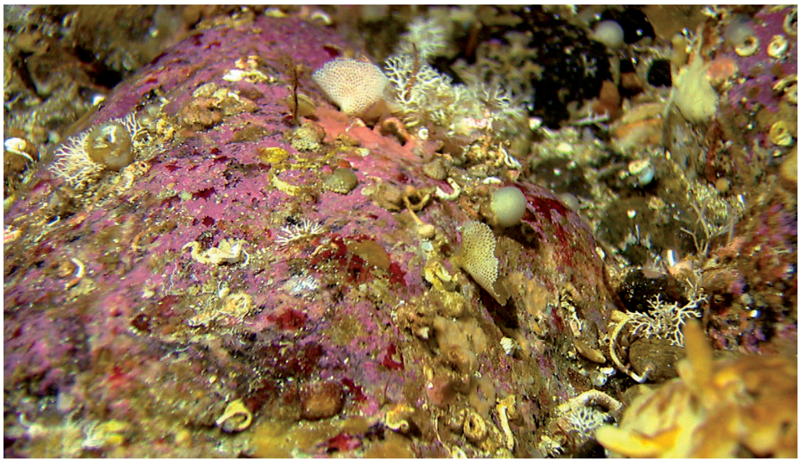


Figure 24. The moraine on the shallow banks are biodiverse areas with boulders covered in calcareous algae, sponges and sessile fauna

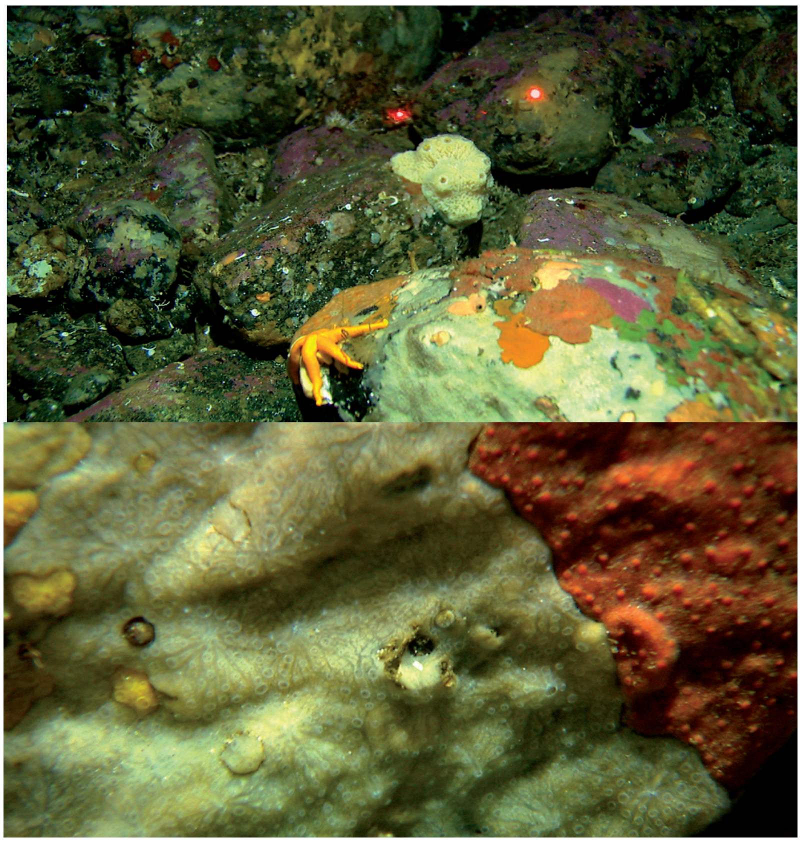


Figure 25. The bright colours of the cobbles on and around the banks make them look like they belong in tropical waters rather than at 80m depth on the Norwegian continental shelf. There is a clear lack of space and battles are fought on the cobbles. These photographs show the clear-cut border between sponges and tunicates. The red dots are laser beams used to measure scale. The dots are 10cm apart.

Areas with Strong Currents and Coral Habitats

Coral reefs and tree corals are often found in areas with strong currents on the continental shelf or on ridges between the banks. Although corals also occur in shallow waters in many Norwegian fjords, these are in minority compared to the vast amount of coral on the shelf, at depths between 200 and 300 metres.

The reefs are formed by the Spider Hazards, *Lophelia pertusa*, which builds reefs up to 35m high and several kilometres long (figure 29). The coral has gender specific colonies, but it is unclear whether this is connected to its two colour variations, white and pink. In connection with the reefs, we often find so-called bubblegum corals (figure 30). These gorgonian corals can reach 2–3m in height and width and stretch out like paraboles, filtering food particles from the water. The tree-like coral, which carries the Latin name *Paragorgia arborea*, also exists in a variety of colours, ranging from dark red to white, and scientists do not know what makes the colour vary. Coral trees do not get as old as the reefs but some colonies can be several hundred years old. A rich fauna of small animals lives in connection to the corals and fish use them to hide. Gorgon's Head (*Gorgonocephalus caputmedusa*) is a basket star that captures small animals and particles in the water with its long arms and is often found on tree corals (figure 31) and coral reefs.

The Malang Reef in Troms II

In April 2007, during a cruise with the research vessel "G.O. Sars", a healthy and well-developed coral reef was discovered on the ridge between Malangsgrunnen and Fugløybanken, the so-called Malang Reef (figure 32–34). The reef, which is 30m high and more than 1km long, was known by fishermen but had not yet been mapped. On both sides of the coral-covered ridge there are deeper basins with a soft seabed where sea cucumbers, sea pens and feather stars are common.

Inside the shelf edge southwest of Malangsgrunnen, we found three coral reefs not previously recorded. They were found based on analyses of topographic maps provided by the Norwegian Mapping Authority Hydrographic Service.

The Reefs in the Hola Trough

In the trough south of Vesterålsgrunnen, Hola, there are more than 330 coral reefs (figure 35–37). These are elongated structures facing the

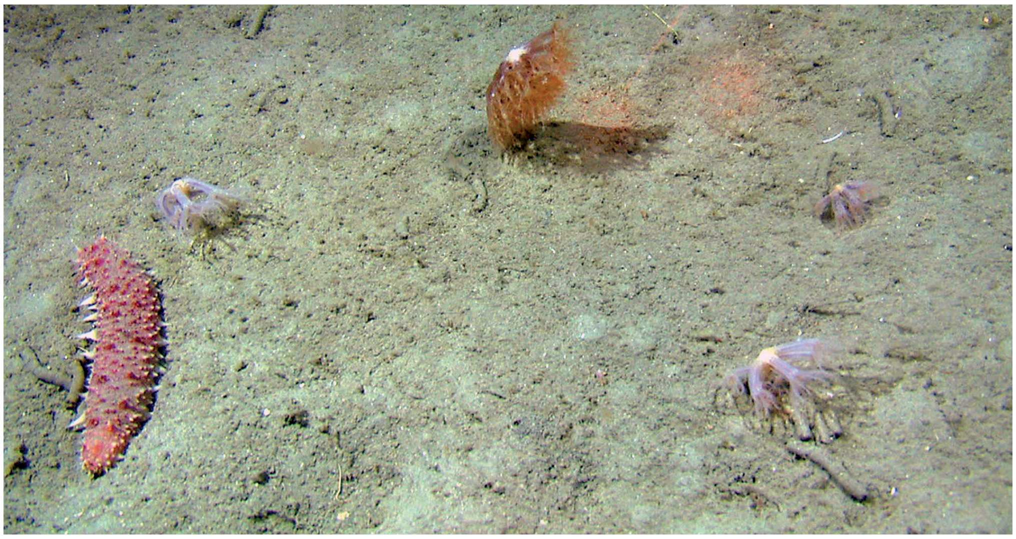


Figure 26. Sea pen (*Kophobelemnon stelliferum*) and sea cucumber (Stichopus tremulus) are common species on the soft bottom in the shelf troughs.

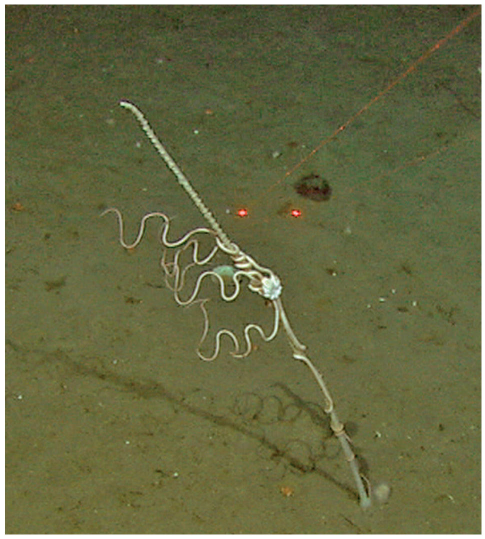


Figure 27. The brittle star, *Asteronyx loveni*, lives in symbiosis with sea pens. Here, it sits on a large sea pen (*Funiculina quadrangularis*) in a trough south of Vesterålsgrunnen.

current. In shape, they resemble reefs previously found in Trænadypet, with a living front facing the main current and a tail of dead coral stretching a couple of hundred metres westward in the direction of the current.

The reefs are surrounded by sand and appear as oases in the desert. Coral reefs need a solid substrate to develop. The scattered cobbles in the area may provide this substrate but carbonate crusts from gas seeps may also have been an important substrate for the first coral larvae settling at Hola about 9000 years ago. The dense population and the general uni-directional growth of the reefs in the area are probably due to its unusual currents. The current arrives over the shelf south of Hola and forms large sand dunes with a relatively poor fauna. In the coral area, the current enters from near the coast, carrying nutrients. Whether these nutrients come from biological production closer to the coast or whether they are also present in the water flowing in over the shelf is unknown. Allegedly, there is no trawling in the area, but based on numerous observations of lost lines, it is evident that it has been frequently used by long-liners. So far, after having passed over about 20 of these mounts scattered around the area, we can conclude that they are probably all living coral reefs. Measurements on the detailed multi-beam maps of the area reveal

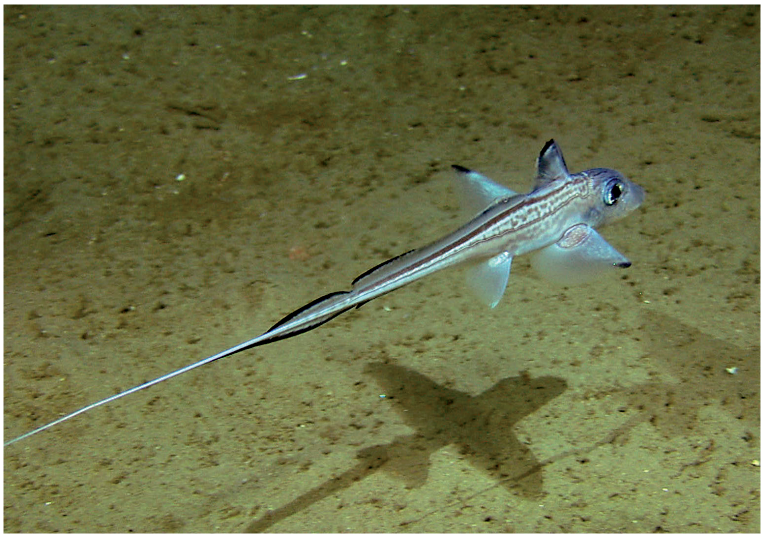


Figure 28. The rabbit fish is common on the soft bottom in the toughs between the banks. It is always an eye-catcher with its shimmering pectoral fins and graceful movements through the water.

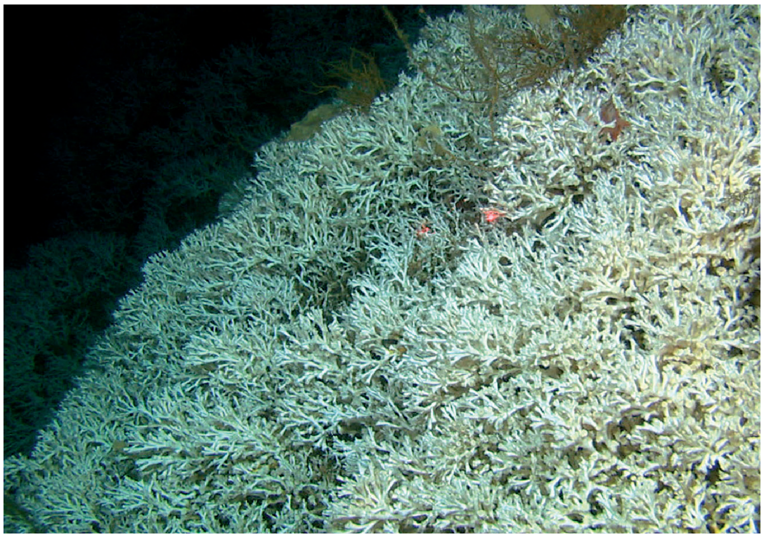


Figure 29. A *Lophelia* reef is built of generation after generation of polyps. In the centre, the coral colony is dead and only the outer parts consist of live polyps that use their tentacles to capture particles in the water. The red laser dots are 10cm apart.

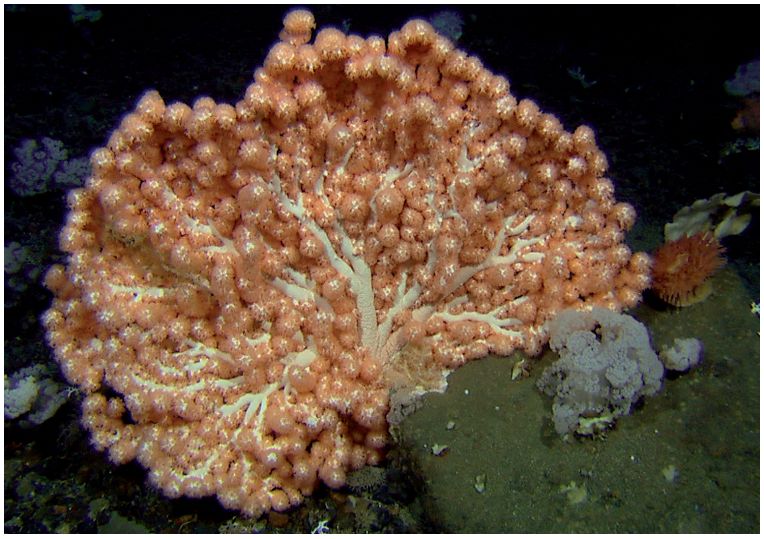


Figure 30. Bubblegum coral, *Paragoria arborea*, surrounded by white broccoli coral. In the photograph, we also see sea anemones and some sponges in the far right.

Figure 31. Two Gorgon's Head basket stars on a bubblegum coral in Stjernsund.

that the reefs are 31–334m long, 27–114m wide and 4–17m high.

Sand Waves

The strong current close to the seabed in the trough off Vesterålen has formed sand waves of three different sizes. The largest can be compared to 200m long swells. On these "swells" there are smaller waves 10–50m long and about 1m high. The smallest waves are called sand ripples and are no higher than 10cm (figure 38). The fauna is scarce in this area of strong currents and moving sand.

Gas Seeps off Vesterålen

In the outskirts of the coral area off Vesterålen, MAREANO discovered an area of bacterial mats and carbonate crusts (figure 39), which are indications of gas seeps. We observed no bubbles in the water so the gas probably reaches the surface of the seabed dissolved in the pore-water (water in the bottom substrate). Seeps of natural gas, or light hydrocarbons, are known from a number of locations in the North Sea, the Norwegian Sea and the Barents Sea. What significance they have for the ecosystem is uncertain. The fauna on the carbonate crusts was similar to what is frequently found on other hard substrates, e.g. sponges, hydroids, anemones etc.

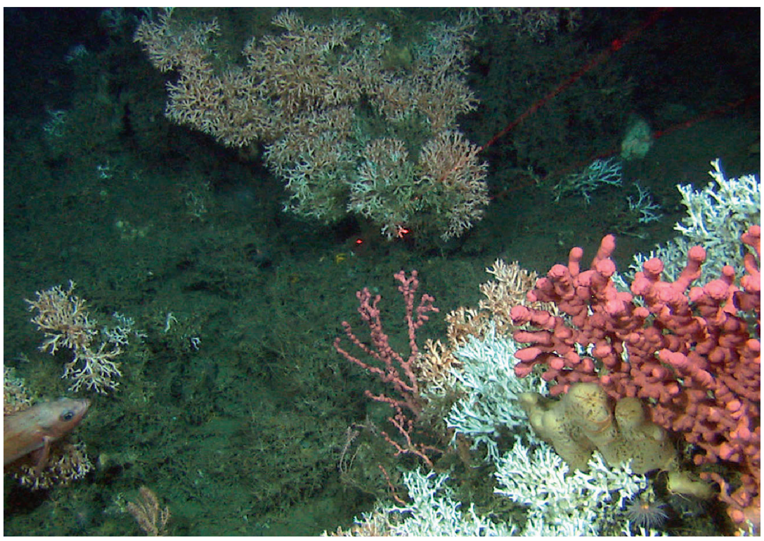


Figure 32. Image from the lower part of the Malang Reef. In the foreground, a red bubblegum coral (*Paragorgia*) with the white *Lophelia* coral and a redfish. In the background, a collection of salmon coloured *Lophelia* colonies.

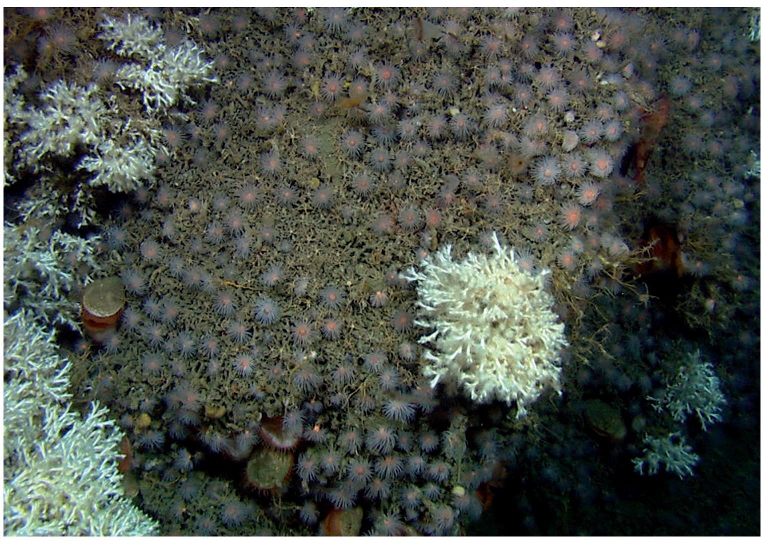


Figure 33. In addition to corals, there is a dense population of anemones on the old coral rubble. The species in this photograph is a sealoch anemone (*Protanthea simplex*), commonly found on *Lophelia* reefs.

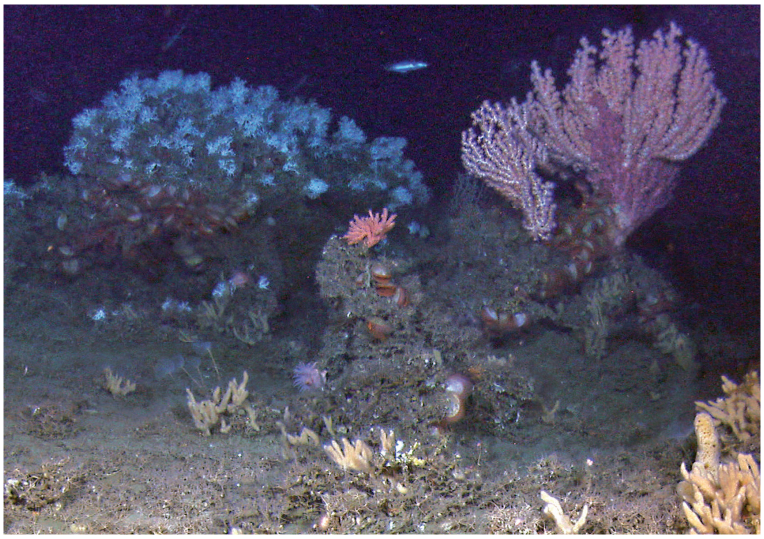


Figure 34. Coral reef south of Malangsgrunnen. The reefs provide a habitat for numerous species and fish is often found in these locations. This photograph shows live *Lophelia* coral in the background with a bubblegum coral to the right. Excavated fileclams agglomerate on dead coral.

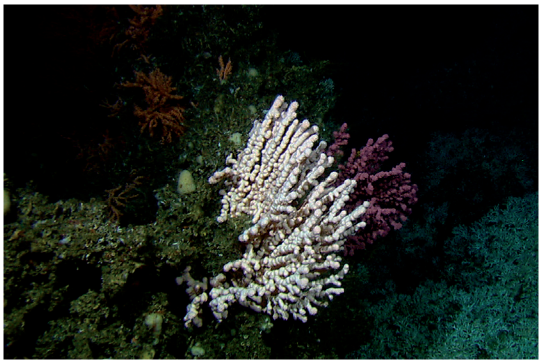


Figure 35. The coral reefs at Hola are elongated with only a small area of live, reef-building coral (*Lophelia pertusa*) facing the current.

basic facts

Coral Reefs

The coral reefs in Norway are formed by the stony coral, *Lophelia pertusa*. This species lives at 40–2000m depth in most oceans, with the exception of polar areas. In Norwegian waters, the species is found from 40m depth in Trondheimsfjorden to approximately 450m depth in the upper parts of the continental slope. The reefs generally occur in water with salinities higher than 34 ‰ and temperatures between 4 and 8 °C. Age measurements at some of the large reefs suggest that they established just after the end of the last Ice Age, 8000–9000 years ago. The largest *Lophelia* reef complex observed is the Røst Reef at 300–400m depth. It is 35km long and 2.8km wide. The northernmost *Lophelia* reef recorded lies north of the island of Sørøya. *Madrepora oculata* is another stony coral often found alongside *Lophelia*, but this species does not form reefs alone. *Lophelia* reefs are home to a number of other corals, such as bubblegum coral, rice coral, sea fan, broccoli coral and other, rare species. They all contribute to the biodiversity and colourfulness of the reef.

Coral reefs can be up to 35m high and the large coral structures form numerous micro habitats that are important to many species. The biodiversity is great but not well studied. In four fauna studies on coral reefs in the Northeast Atlantic, a total of 775 species were observed, of which only 14 were common to all four studies. This suggests an actual number of species far greater than what has been described to date. It has also been demonstrated that fish such as tusk, ling and redfish live in association with reefs, and trawling has contributed to the destruction of coral reefs along the Norwegian coast. Corals are vulnerable organisms. In relation to oil activity, there are a number of threats to coral reefs, such as deposition of suspended sediments or mud from drilling; crushing as a result of mechanical effects of installations and building of pipelines; and poisoning by emissions of drilling chemicals and oil.

Lophelia is efficient cleaning its surface from occasional deposition of moderate sediment amounts, but we know little about the effects of long term exposure to enhanced particle concentrations or chemical pollutants.

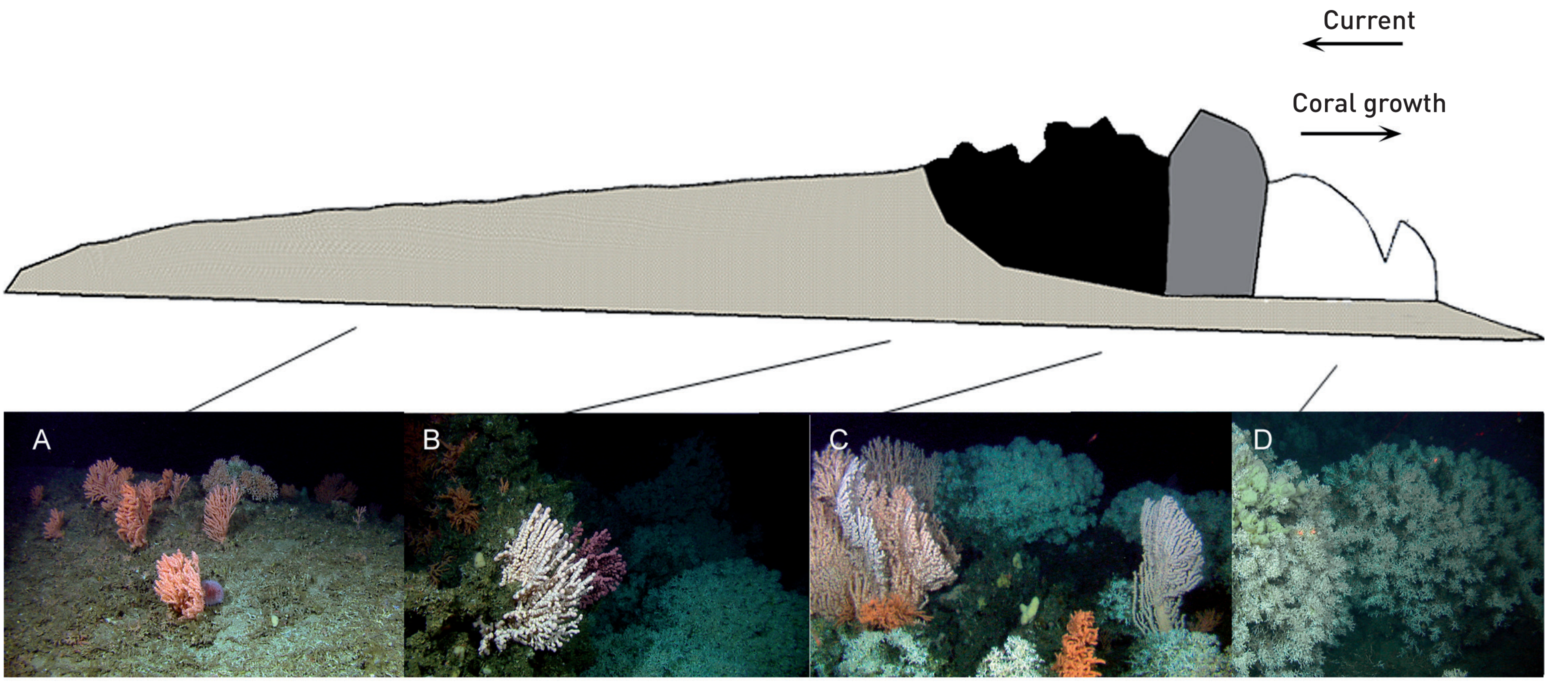


Figure 36. Schematic representation of an elongated coral reef at Hola. A: The growth started several thousand years ago at the tip of the reef "tail" in the left. In this zone, the seabed consists of small, old pieces of coral skeleton (coral rubble). B: Blocks of dead coral. This part of the elongated reefs has the highest biodiversity. C: Dying and recently dead coral colonies. D: Live coral colonies where the biodiversity is relatively low compared to the other reef zones.

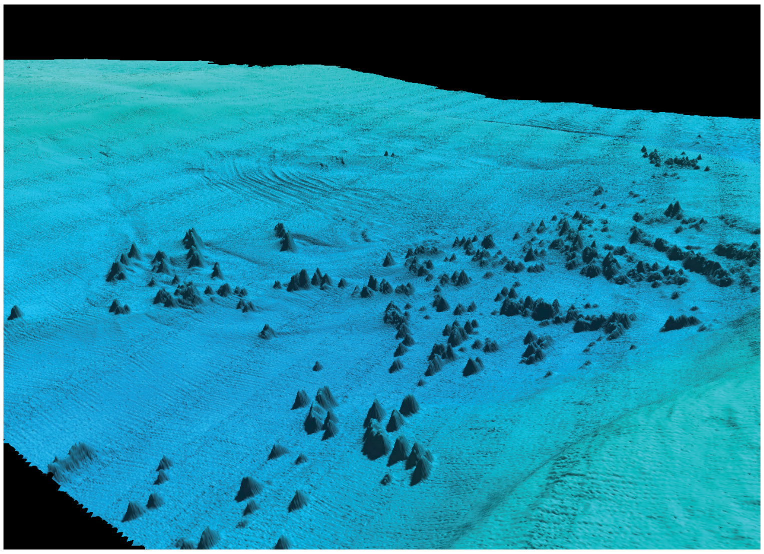


Figure 37. In the Hola trough south of Vesterålsgrunnen, there are hundreds of elongated reefs facing the current.

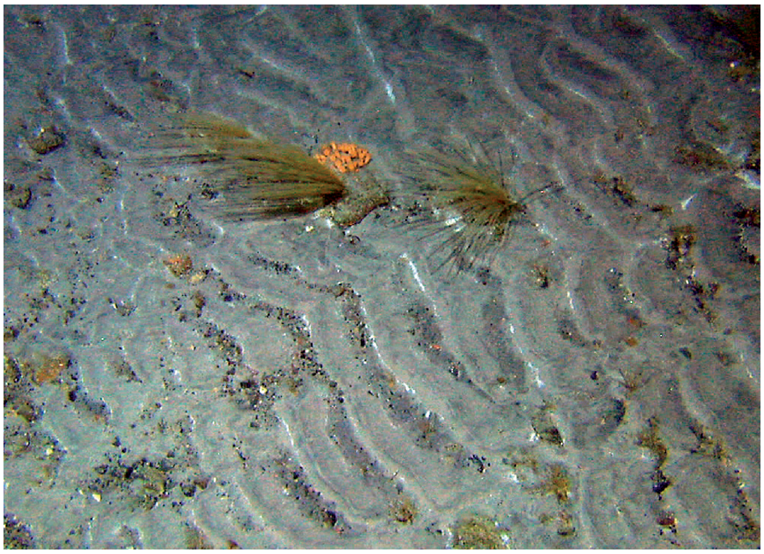


Figure 38. In the areas between the sand waves, where cobbles and gravel are apparent on the surface, there is a distinctive fauna, including the hydroid *Nemertesia*, Zooanthida anemones and large snails.

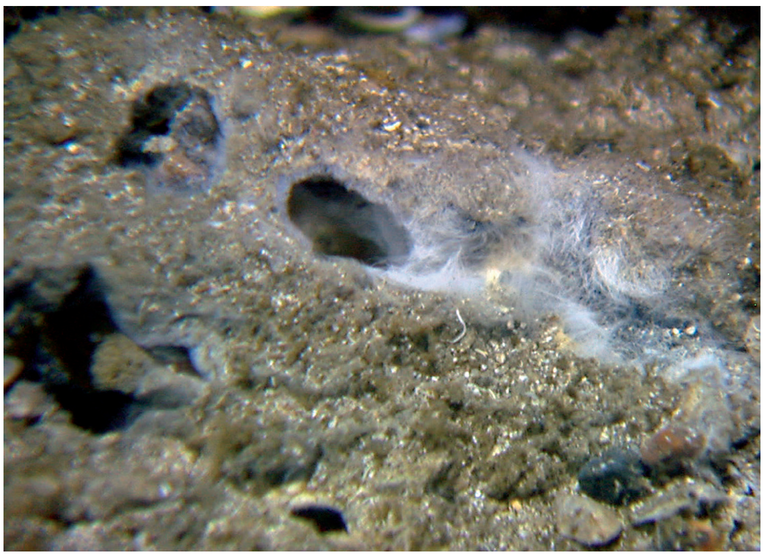


Figure 39. In gas seep areas, threads of white bacteria form mats on the seabed.

4.2.2. Biotope distribution

Biotope maps have been made separately for two areas (Nordland VII/Troms II, and Nordland VI) using fauna distribution patterns from video and predictors derived from multibeam data and interpreted sediment distribution. The patterns of biotope distribution for the two areas show great similarities (figure 40), but also differences which are difficult to explain without a collective analysis of the two areas together. Such analysis will include oceanography (values for bottom temperature, salinity and currents, including their variability). We will in this chapter only focus on presenting the modelled biotopes for the Nordland VII/Troms II.

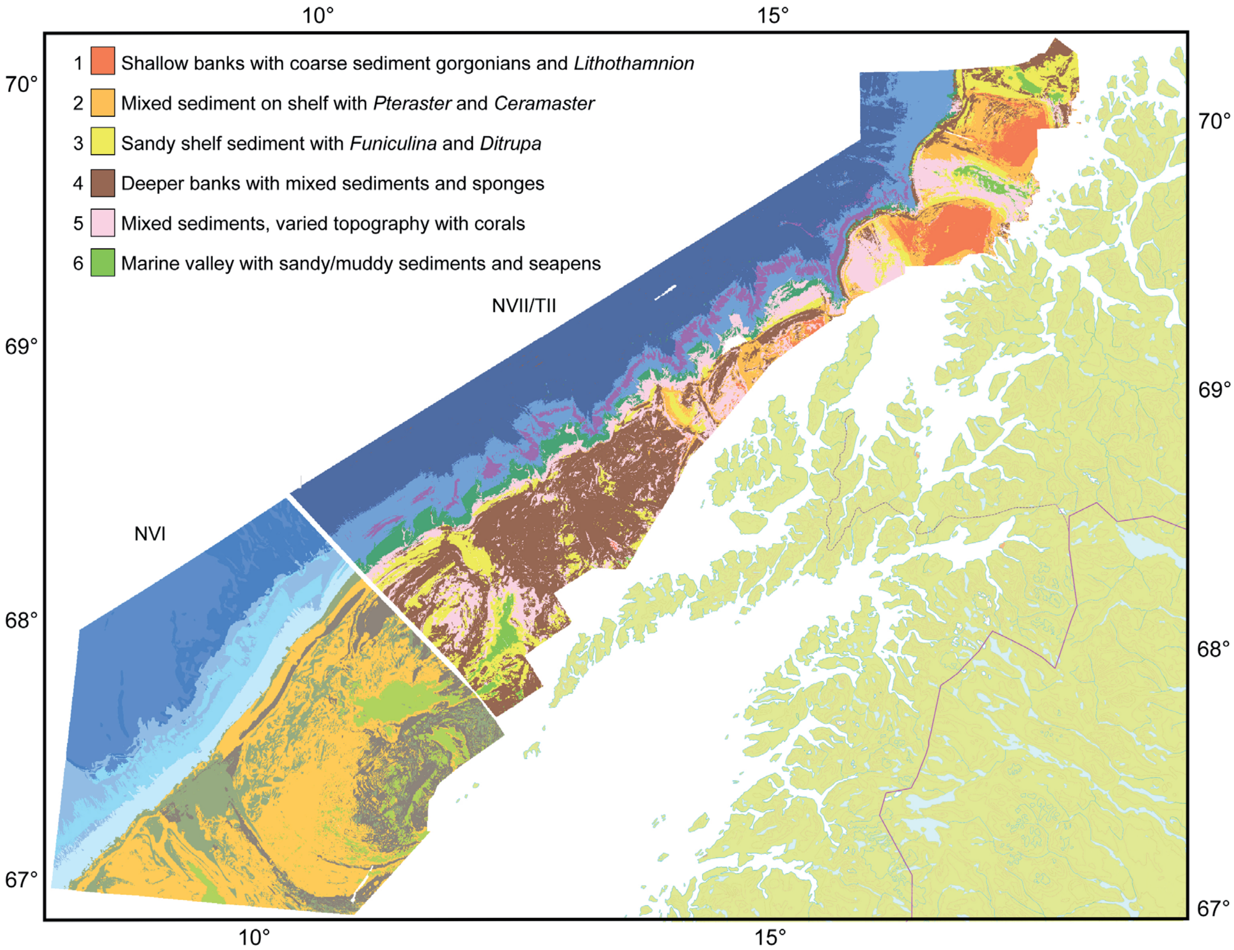
Biotopes in Nordland VII and Troms II:
Six biotopes were predicted for the shelf areas off Nordland VII and Troms II (figure 40):

1 Shallow banks with coarse sediment gorgonians and *Lithothamnion*
2 Mixed sediment on shelf with *Pteraster* and *Ceramaster*
3 Sandy shelf sediment with *Funiculina* and *Ditrupa*
4 Deeper banks with mixed sediments and sponges
5 Mixed sediments, varied topography with corals
6 Marine valley with sandy/muddy sediments and seapens

1) Shallow banks with coarse sediment gorgonians and Lithothamnion
This biotope only occur at the relatively flat, shallow banks Malangsgrunnen and Sveinsgrunnen. The bottom is characterized by gravel, cobbles and boulders. Characterising taxa are calcareous red algae (*Lithothamnion* sp.), unidentified smaller gorgonians, *Filograna implexa* tube worms, white colonial tunicates and different serpulid tubeworms in addition to *Filograna*.

2) Mixed sediment on shelf with Pteraster *and* Ceramaster
This biotope occurs at the slopes around banks, and other areas of banks with variable sediment composition (sand to coarser). Typical taxa are the sea stars *Pteraster* sp., cushion star (*Ceramaster granularis*) and *Hippasteria phrygiana*. Redfish *Sebastes* spp. and purple heart urchin (*Spatangus purpureus*) are also anbundant.

Figur 40. Predicted spatial distribution of modelled biotopes off Lofoten, Vesterålen and Troms. Legends are indicated for biotopes on the shelf in Nordland VII (NVII) and Troms II (TII).



3) Sandy shelf sediment with Funiculina *and* Ditrupa
The biotope is found both in shallow marine valleys and along the shelf break. The sediment is mainly composed of sand, with occational contribution of gravel. The areas are typically flat and house the seapen *Funiculina* quadrangularis (occationally with the associated brittle star *Asteronyx loveni*), and solitary cup corals (*Flabellum macandrewi*).

4) Deeper banks with mixed sediments and sponges
The deeper banks off Vesterålen and Lofoten have a variable but generally coarse sediment composition (gravelly sand to coarser). This biotope is characterized by different sponges (*Phakellia* spp., *Craniella zetlandica*, *Geodia* spp., *Stryphnus ponderosus* and *Mycale lingua*). This is not the same sponge biotope as found at Tromsøflaket where *Geodia* and *Stryphnus* occur on softer sediments.

5) Mixed sediments, varied topography with corals
Similar to biotope 3, this biotope occurs in marine valleys and along the shelf break. However this biotope has a more varied sediment composition and topography, and has a different fauna. In this biotope we may find Lophelia pertusa (the reef building coral), sea corn coral (*Primnoa resedaeformis*) the large bivalve *Acesta excavata*, the sponge *Axinella infundibuliformis* and the anemone *Protanthea simplex*.

6) Marine valley with sandy/muddy sediments and seapens
This biotope is found in two marine valleys between banks in the northern and southern part of NVII/TII. These areas are characterized by soft sediments (muddy and/or sandy) in a flat terrain. Two species of sea pen (*Kophobelemnon stelliferum* and *Virgularia mirabilis*), the red seacucumber (*Parastichopus tremulus*) and shrimps are characteristic. Areas within this biotope may also be characterized as seapen and burrowing megafauna communites.