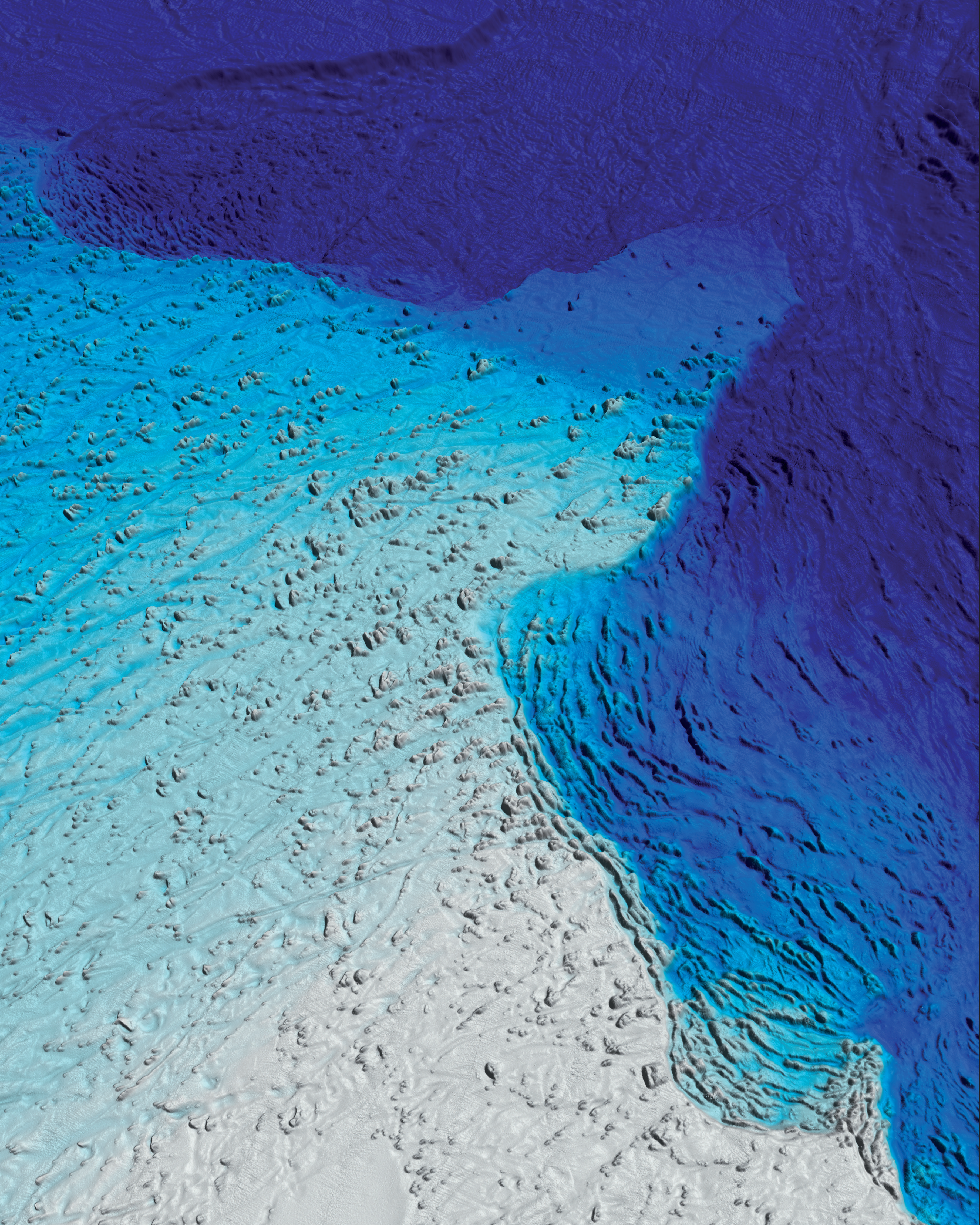

MID-NORWEGIAN CONTINENTAL SHELF AND SLOPE

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Tubularid hydroids are a local biodiversity hotspot. This hydroid is colonized by other hydroids, scalpellid barnacles and ophiuroids. This picture is from a location with sponges and gorgonians at the Storegga shelf break.

The mid-Norwegian shelf and slope forms the southeastern part of the Norwegian Sea management plan area. A number of particularly valuable and vulnerable areas (SVOs) occur within the region. Mørebankene is one of the world's most important herring spawning areas, and cold water coral reefs are abundant in several places. At the same time, the region hosts many petroleum installations, and fisheries activity is widespread. The region has been surveyed by MAREANO since 2012, and this chapter gives an overview of the results obtained so far.

7.1 THE SEABED – MARINE LANDSCAPES, GEOLOGY AND PROCESSES

7.1.1 Marine Landscapes – Main Features of the Mid-Norwegian Shelf

The term mid-Norwegian shelf is used, in this chapter, for the region between Mørebankene in the southwest, and Trænadjupet in the northeast (figure 1). MAREANO has surveyed the mid-Norwegian shelf and upper part of the slope, focusing on the SVOs. Descriptions of the geology and processes will be given for each area, rather than as a whole, in keeping with the level of detailed knowledge currently available.

The mid-Norwegian shelf covers an area of around 100 000 square kilometres. It is only 45 kilometres wide at Mørebankene, while it is 230 kilometres wide WNW of Vikna. The depth varies from around 500 metres in deep troughs, to less than 100 metres at the banks. The marine landscapes of the mid-Norwegian shelf (figure 2) are dominated by continental shelf plains (banks) and marine valleys (troughs). The banks are generally less than 200 metres deep, and locally less than 100 metres. The troughs commonly exceed 400 metres. The shelf edge - "eggakanten" in Norwegian is the boundary between the continental shelf plains and marine valleys, and the continental slope, including a continental slope plain (the Vøring Platform).

The construction of the mid-Norwegian continental shelf and slope is the result of geological processes occurring over many million years. Shaping of the seabed offshore mid-Norway started in the Late Cretaceous and Early Cretaceous with large scale faulting, rifting and deposition of sediments related to the opening of the North Atlantic Ocean. Glaciations during the Pleistocene 2.6 million years - 11.500 years ago), and major slides on the continental slope during the Holocene (11.500 years - present) have made their final imprints on the marine landscapes and the seabed. The seabed is, however, not static, and is constantly changing. Ocean currents sweeping over the seabed move sand, and new sand dunes and ripples are formed. Corals growing on bioclastic mounds die, and form new bioclastic sediments. On the continental slope, unstable sediments start moving and form small slides. Active gas seepages influence the chemical state in the sediments.

Major ice streams active during the glacial periods of the Pleistocene - the Ice Age - have shaped the mid-Norwegian shelf into what we see today. During the Ice Ages, Norway and the rest of Scandinavia were covered by ice sheets which may have been up to several kilometres thick. Glaciers coming from mainland Norway transported and deposited vast amounts of sediments. At the shelf edge off Vikna - at Skjoldryggen - the succession of sediments "bulldozed" towards the sea is more than 1500 metres thick.

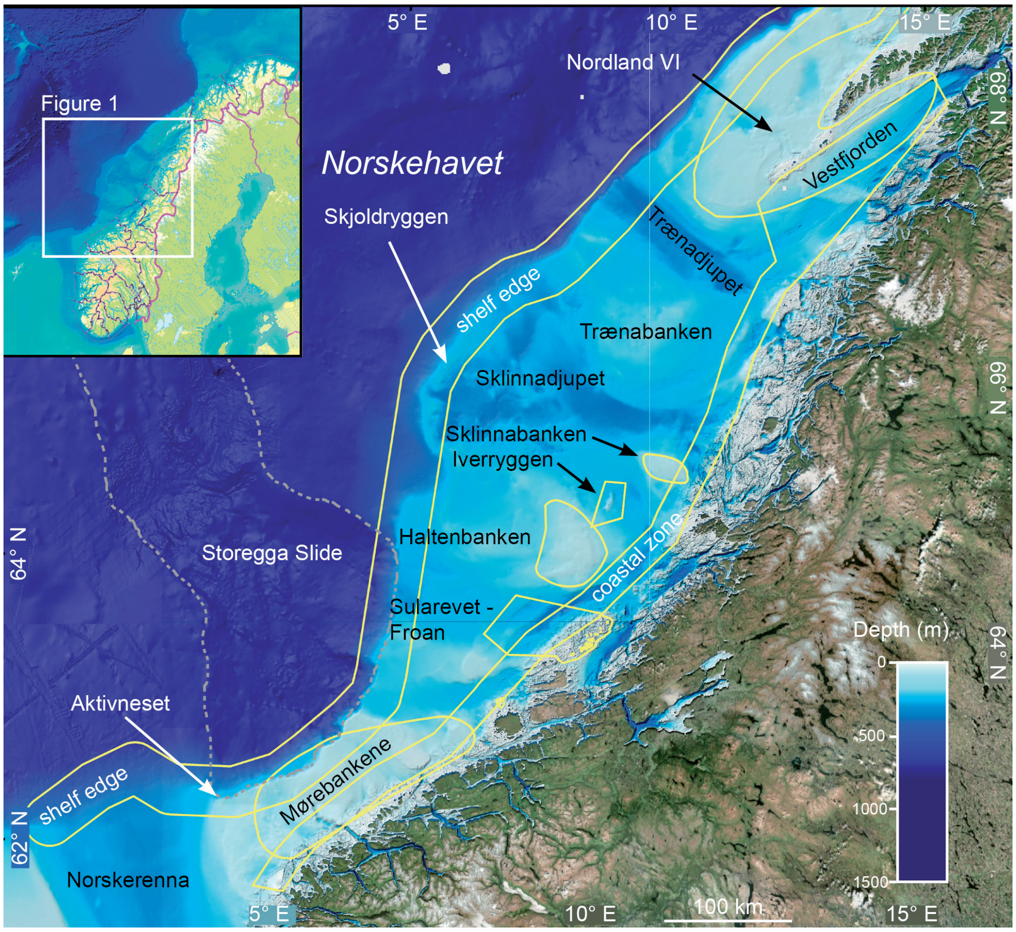


Figure 1. The mid-Norwegian shelf is located between Norskerenna in the southwest and Trænadjupet in the northeast. SVOs are marked in yellow.

7.1.2 Mørebankene, Storegga and the shelf edge south of Skjoldryggen – geology and processes

Mørebankene is around 10.000 square kilometres, and is a crescent-shaped shallow area, with water depths of less than 200 metres, except in the troughs where the water depth may exceed 300 metres (figure 3). The main part of Mørebankene, outside the strandflat (figure 3), is built up by moraines and other sediments deposited by the glaciers during the last 2.6 million years. The total thickness of these sediments is locally up to 250 metres, according to investigations performed by the former Continental Shelf Institute (IKU). Mørebankene is delimited westwards by the shelf edge - a steep escarpment (up to 35°) formed by the 300 kilometres long upper headwall of the Storegga Slide (see Storegga Slide box).

The boundary zone between the banks and the coastal zone is sharp, and marks the transition from hard and tough crystalline bedrock in the coastal zone, towards softer sedimentary rocks overlain by Quaternary and recent sediments towards the shelf. In some places, such as between Buagrunna and the coastal bedrock zone, troughs nearly 100 metres deep have been formed. These troughs are filled with sandy sediments, and in some areas spectacular sand wave fields occur (figure 4). Bioclastic mounds occur locally, in a similar way as in Breisunddjupet (see below). Small gullies formed at the landward edge of the banks are present. These were probably formed

The Storegga Slide

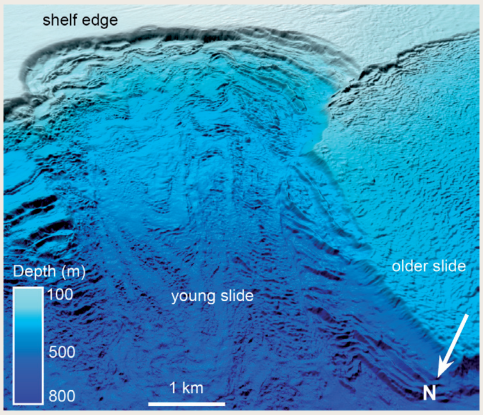


Figure 1 . 3D close up from the shelf edge, showing cross-cutting relationships between an older and a younger slide event.

The Storegga Slide is a gigantic submarine slide complex involving up to 3500 cubic kilometres of sediments and influencing an area of 90 000 square kilometres. The upper headwall of the slide scar is around 300 kilometres long and extends along the shelf edge between Ålesund and Vikna. The vertical height of the upper headwall is up to 250 metres, and the headwall is commonly very steep with slope angles up to 35°. The slide extends 800 kilometres into the Norwegian Sea and the slope in the slide scar is less than one degree. The slide which occurred approximately 8.100 years ago created a major tsunami, which hit large areas along the Norwegian coast, but also Shetland, Scotland and other surrounding areas.

Geological investigations show that several older 'Storegga slides' have occurred in the area, generally one between each major glaciation. Clear evidences for multi-phase sliding activity can be seen many places (figure 1). Repeated glaciations depositing large sediment volumes along the shelf edge, alternating with deposition of fine grained material in the intervening periods is the main basis for sliding. Loading of the fine grained sediments may have caused pore overpressure and thereby a weakening of the fine grained layers. When earthquakes occurred, these weak layers would have been susceptible to fail, causing the slide to start moving. The risk of a new, large submarine slide at Storegga is considered to be minimal.

The Storegga Slide scar contains blocks, debris slides, debris-flow deposits and compression ridges on scales from metres to many kilometres (figure 2). This diversity of size and elements indicates that sliding has occurred as a series of consecutive failures, and the morphology indicates retrogressive slide development from the lower- or mid-slope. The slides make up a major depression, with a rugged seabed terrain. This depression forms a sediment trap for fine grained material being transported with ocean currents from the North Sea. Slide blocks form a very irregular seabed, giving rise to a hard bottom substrate for organisms (figure 3). Several coral reefs are documented with video footage from the uppermost part of the slide, and mounds with bioclastic sediments are found in many places.

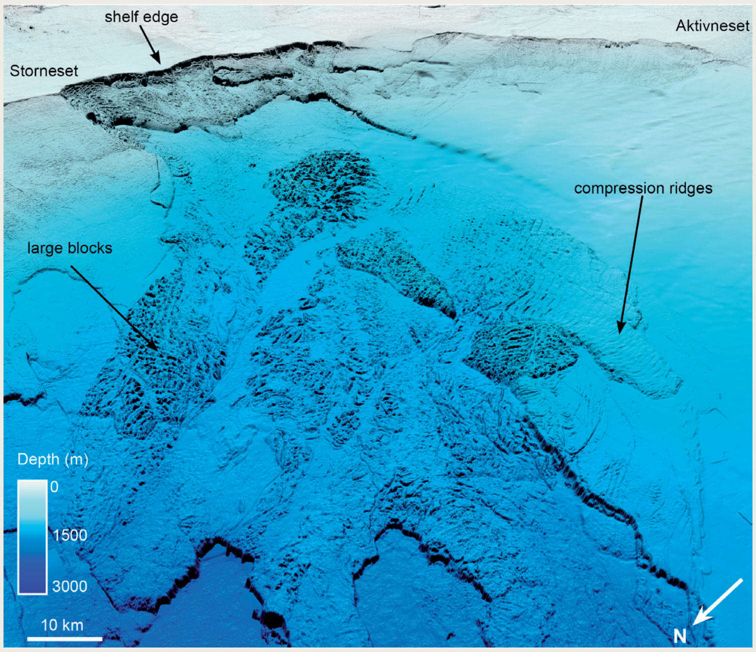


Figure 2. 3D overview of the Storegga slide, displaying some of the complex structures associated with the mass movement.

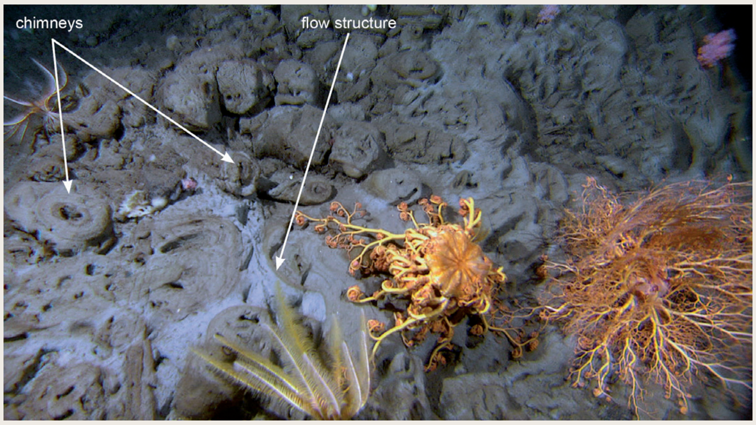


Figure 3. Compacted sediments block in the Storegga Slide at c. 750 metres depth. Note the strange features on the block looking like chimneys - these are probably related to degassing or draining of the sediments. A flow structure can be seen in the central part of the photo. The basket stars (*Gorgonocephalus*) use the hard bottom to settle.

as a result of localized currents draining down from the bank although some may be related to small slides.

Mørebankene has been designated as an SVO because it is one of the main spawning grounds for Norwegian spring-spawning herring and saithe. The Norwegian spring-spawning herring is the world's largest herring stock, and both ecologically and economically the most important fish stock in the Norwegian Sea. This is also an area of very rich fisheries in general. But why is it so important for the herring spawning? The reason is that the shallow banks are covered with coarse sediments – sand, gravel, cobbles and boulders – precisely the gravelly seabed the herring prefer for spawning. The herring deposit layers of eggs which may be up to several centimetres thick.

Fishery surveys conducted in the past by the Fishery Directorate and Institute of Marine Research have outlined broad areas as herring spawning grounds. The new MAREANO sediment maps delimit areas of high potential of herring spawning at a much higher resolution (figure 5). It is noteworthy that the broadly outlined areas include fairly large areas of sandy sediments, which probably have a limited potential for herring spawning. However - these sandy areas may be important for sand eels. On the other side – fairly large areas covered by gravel in the western parts of Mørebankene have not been included in the outlined areas. It is not yet known whether this is because they are actually not used for spawning, or whether they have been missed by the fishery surveys.

Breisunddjupet is a 50 kilometres long depression crossing the strandflat, nearly at right angles to the coast and extending to the shelf

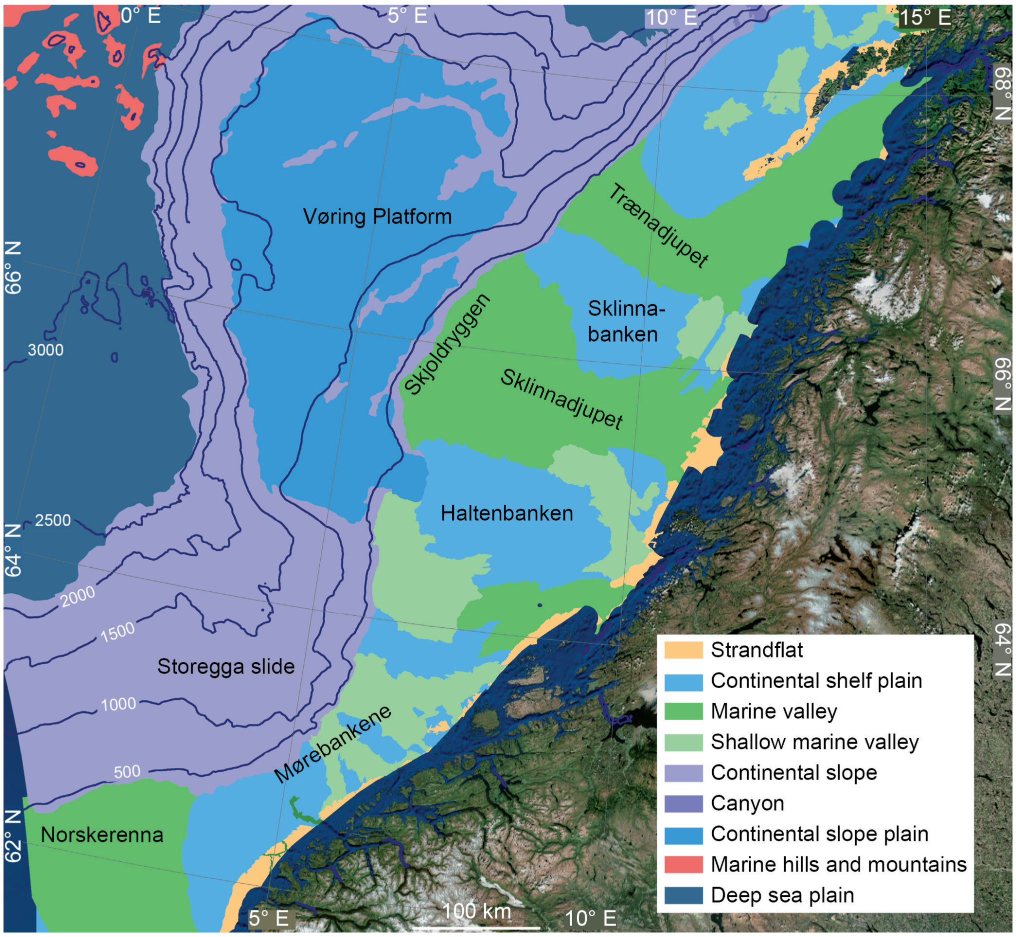


Figure 2. Marine landscapes on the mid-Norwegian shelf.

from Sulafjorden, forming the outer part of Storfjorden. Breisunddjupet is a glacial erosion feature occurring in the direct continuation offshore of these fjords. It may have been formed by an ice-stream following a paleo-valley supported by sediments (or stagnant ice) on either side, which were later removed by broad scale glacial erosion. Breisunddjupet is more than 200 metres deep, and hosts at least 10 coral reefs (verified with video) and several hundred mounds with bioclastic sediments (figure 6). It is quite possible that many of the bioclastic mounds may also have live coral growth, however, this has not been verified by video investigations. Sand and gravelly sand dominates in Breisunddjupet, with minor patches of sandy gravel, and gravel, cobbles and boulders. Spectacular current related features are found over large areas - particularly in the outermost part (figure 7). Sand waves with complex geometries and heights up to 10 metres have been observed. The Langeled pipeline transporting natural gas from the Ormen Lange gas field, via the Nyhamna terminal, to England is visible as a thin line on the seabed in some places. In other places, the pipeline appears to be covered by drifting sand.

Aktivneset forms the southernmost part of the shelf edge, and is situated at the ”triple junction” between Norskerenna (the glacial trough running coast-parallel from Skagerrak), Mørebankene and the Storegga Slide (figure 8).

Sandy to gravelly sediments dominate in the northern part of Norskerenna, and at Mørebankene. Gravel, cobbles and boulders associated with ridges and blocks of compacted sediments dominate in the upper part of the Storegga Slide. Sand and mud become increasingly abundant below 500 metres water depth. Bioclastic mounds are very abundant at Aktivneset (figure 9).

The mounds can be solitary or form complexes. The solitary mounds are often elongated in a NE-SW direction, but are also semi-circular. These mounds are normally up to 100 metres long, and 10-15 metres high. There is a gradual transition to mound complexes, which may exceed a length of 500 metres and a height of more than 20 metres. These complexes have a more irregular shape, but the main orientation is in a NE-SW direction. The location of the bioclastic mounds are in many places controlled by the glacial geomorphology – i.e. the iceberg ploughmarks (figure 10).

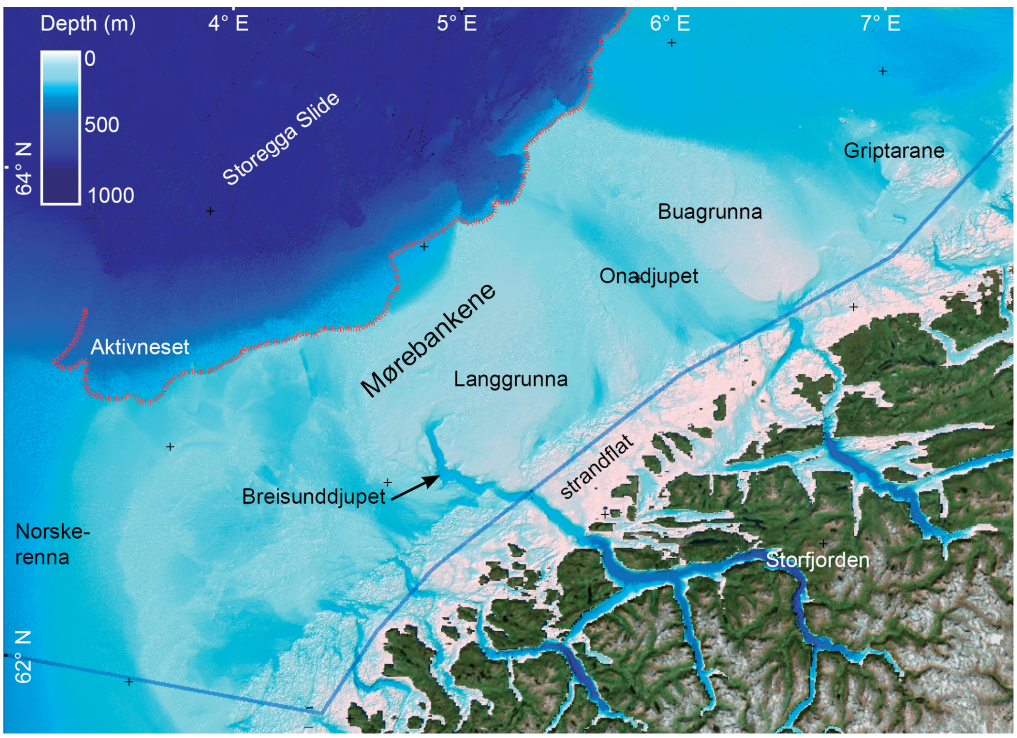


Figure 3. Mørebankene and the Storegga Slide(headwall marked by hashed red line). Note that Breisund-djupet is a continuation of Storfjorden in Sunnmøre.

The majority of the solitary mounds are positioned on the raised berms of the iceberg ploughmarks. The orientations of the iceberg ploughmarks are dominantly NE-SW, probably reflecting the general ocean current direction at the end of the last glaciation, when the icebergs broke off the ice sheet and starting floating around. In some places we find iceberg ploughmarks which have other orientations, with bioclastic mounds on their berms. But, even though the mounds are aligned along the iceberg ploughmark, we may find that the orientation of the individual mounds are in NE-SW direction, reflecting the general ocean current direction in this area when the mounds were formed.

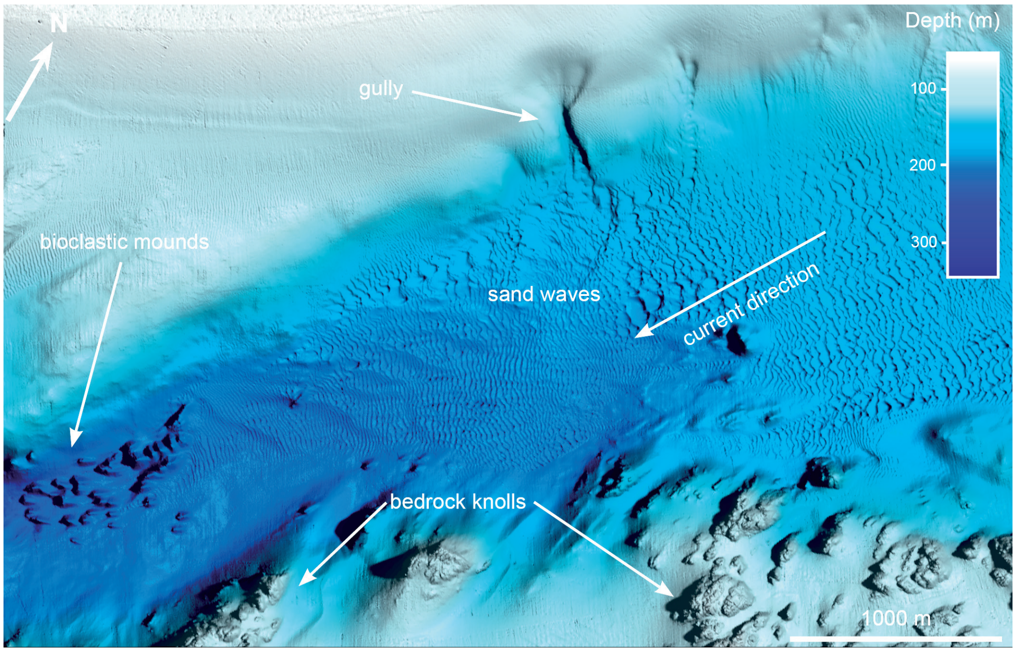


Figure 4. Sandwaves in the trough between Buagrunna and the crystalline bedrock in the coastal zone. Note also bioclastic mounds and small gullies.

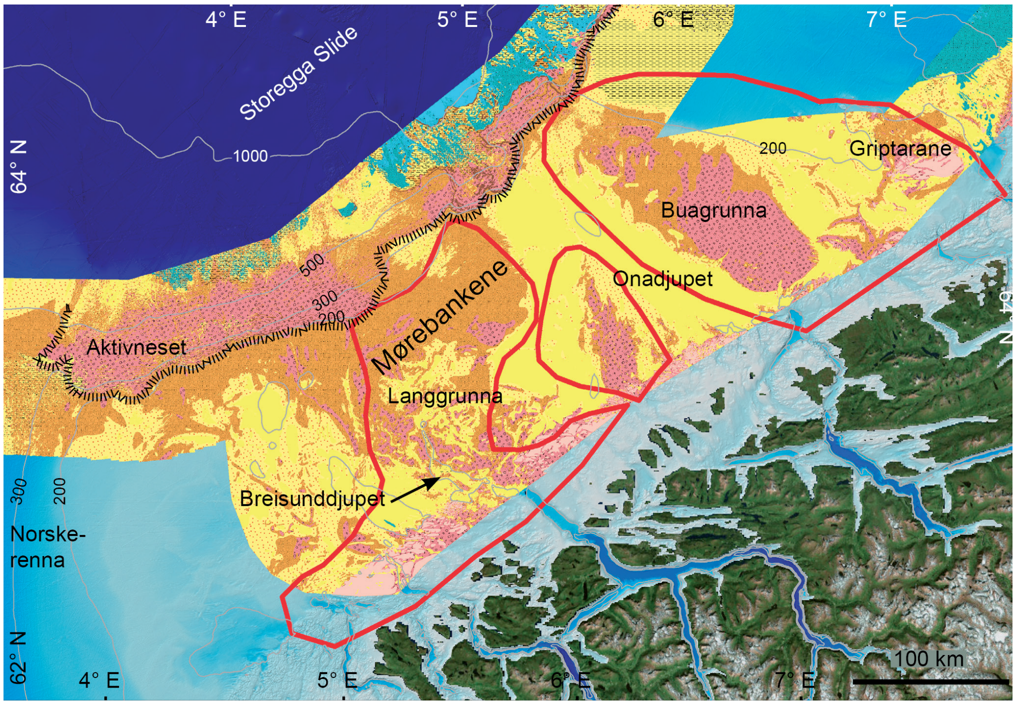


Figure 5. Sediment map (grain size) over Mørebankene and the southern part of the shelf edge. Red outlines indicate herring spawning areas identified prior to MAREANO. Colours indicate different sediment types. Orange: gravelly sediments; pink: gravel with cobbles and boulders; yellow: sandy sediments. The headwall of the Storegga Slide is marked by the black hashed line.

7.1.3 Skjoldryggen and the northern part of the shelf edge – geology and processes

The shelf edge between the Storegga Slide to the southern margin of Trænadjupet is located at 270-370 metres water depths over a 300 kilometres long distance (figure 11a). The dominant topographic feature in this area is the 110 kilometres long, 10-20 kilometres wide and up to 200 metres high Skjoldryggen moraine, situated east of the shelf edge (figure 11b).

Skjoldryggen is an up to 150 metres thick terminal moraine, created by an ice stream which crossed the mid-Norwegian shelf along Sklinnadjupet and reached the shelf edge during the last glaciation. The ice margin position is sharply depicted by the Skjoldryggen terminal moraine in figure 12, showing how far west the ice stream reached before breaking up at the shelf edge.

Glacigenic debris flows on the continental slope are a result of "bulldozing" by glaciers, bringing sediments to the shelf edge (figure 13). Mass movements are also evident in front of the ridge (figure 11b).

Extensive iceberg ploughmarks occur on top of the ridge (figure 12), and tell a story of numerous icebergs breaking off the ice sheet edge towards the end of the last glaciation. Many of the ploughmarks show complicated patterns, witnessing of drift influenced by ocean currents and changing wind directions. Some of the iceberg ploughmarks are up to 20 kilometres long, 500 metres wide and more than 10 metres deep. The majority of the ploughmarks are smaller – less than 100 metres wide, and a few metres deep. The ploughmarks are normally linear to curvilinear, but in some places irregular ploughmarks can be seen (figure 13). This can be due to deep icebergs which were pushed by currents and winds towards the shallowing slope.

The shallowest parts of Skjoldryggen are dominated by sandy gravel, with local boulder fields. Gravelly sand and muddy sand fringe

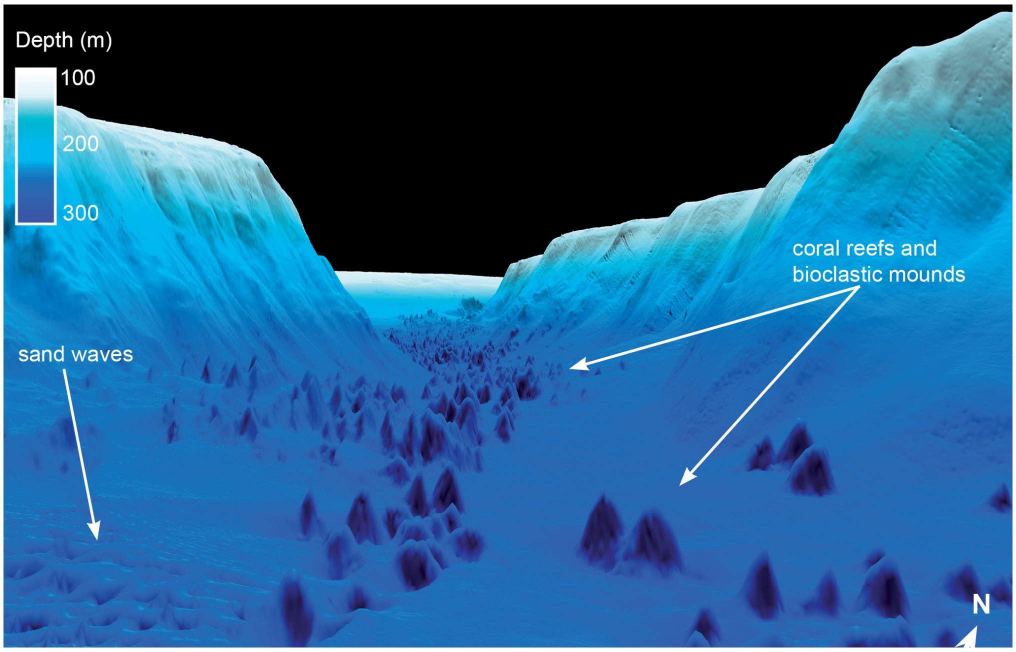
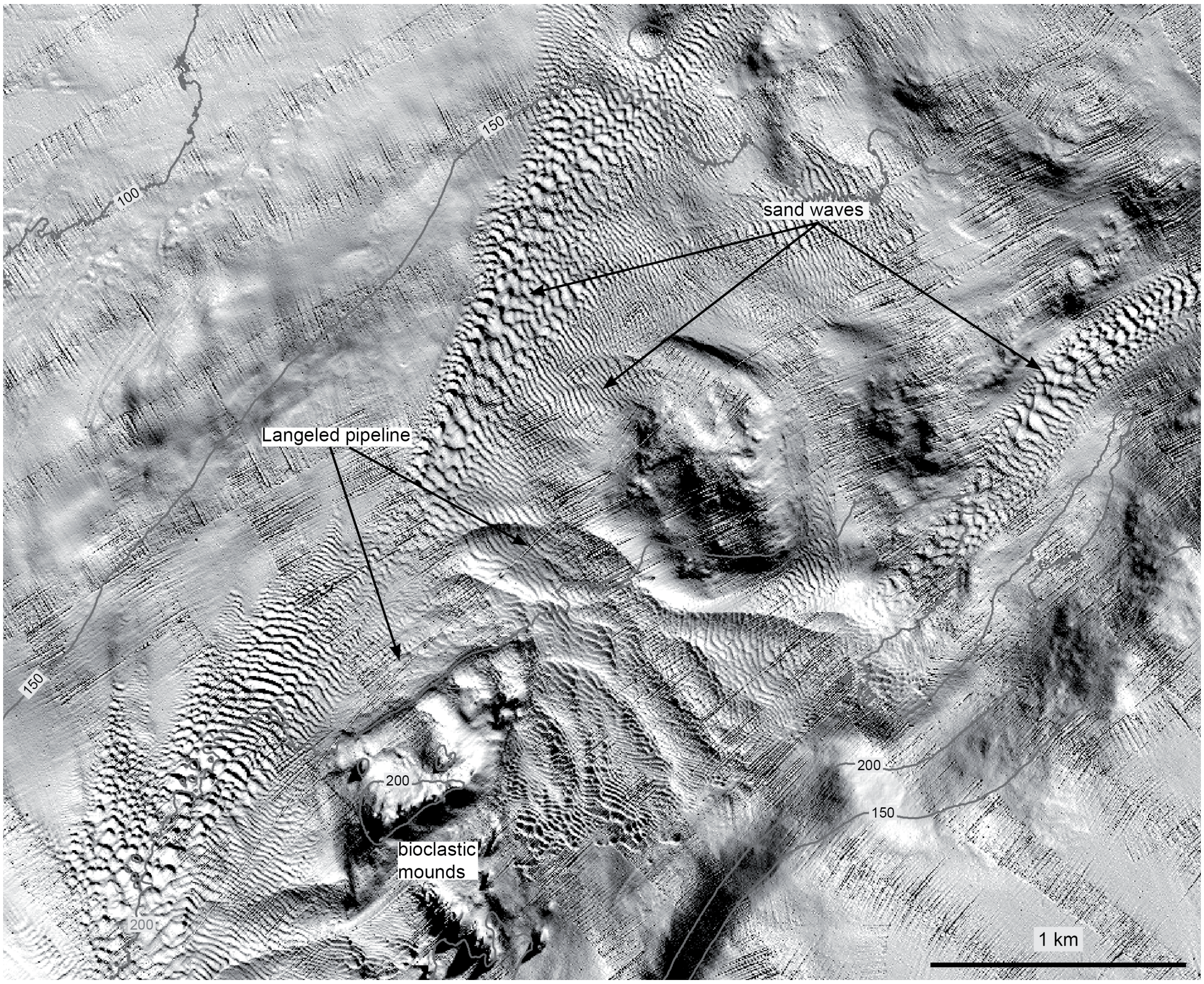


Figure 6. 3D view of the Breisunddjupet depression, looking towards NW. The elevation difference between the deepest part and the surrounding plateau is in excess of 200 metres. Numerous coral reefs and mounds of bioclastic sediments occupy the central part. Sand wave fields occur many places. Vertical exaggeration - 5x.

Figure 7. Shaded relief image in greyscale from the outer part of Breisunddjupet. Sand waves with different sizes and geometries reflect a complex current environment. The Langeled pipeline can be seen several places.



the central, gravelly parts, and sandy mud are found in the outer parts of the ridge (figure 11c). Mounds with bioclastic sediments are found in the central and southern parts. Similar sediments are found in changing proportions along the entire shelf edge.

Pockmarks occur in water depths between 550 and 600 metres, in areas with sandy mud (figure 14). Most of the pockmarks are found in the southern part, where several types can be recognised. Small pockmarks are relatively shallow (up to 40 metres in diameter and less than 1 metre deep), slightly elongated in the NE-SW direction, and regularly distributed. Large pockmarks are deeper, with diameters up to 100 metres and depths up to 5 metres. These pockmarks tend occur in clusters, irregularly distributed (figure 14a). Further out, elongated and asymmetric pockmarks are found (figure 14b, 14c). Their shape is likely to be strongly influenced by currents close to the seabed. Pockmarks in the middle and

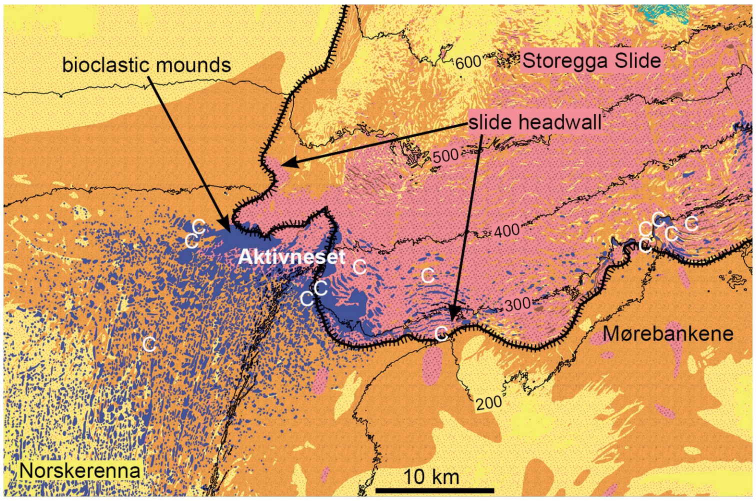


Figure 8. Aktivneset is situated where Norske-renna, Mørebankene and the Storegga Slide meets. Bioclastic mounds (dark blue) occur in high density. Coral reefs verified by video observations are marked with "C". Colours indicate different sediment types. Orange: gravelly sediments; pink: gravel with cobbles and boulders; yellow: sandy sediments. The Storegga Slide headwall is marked by the black hashed line.

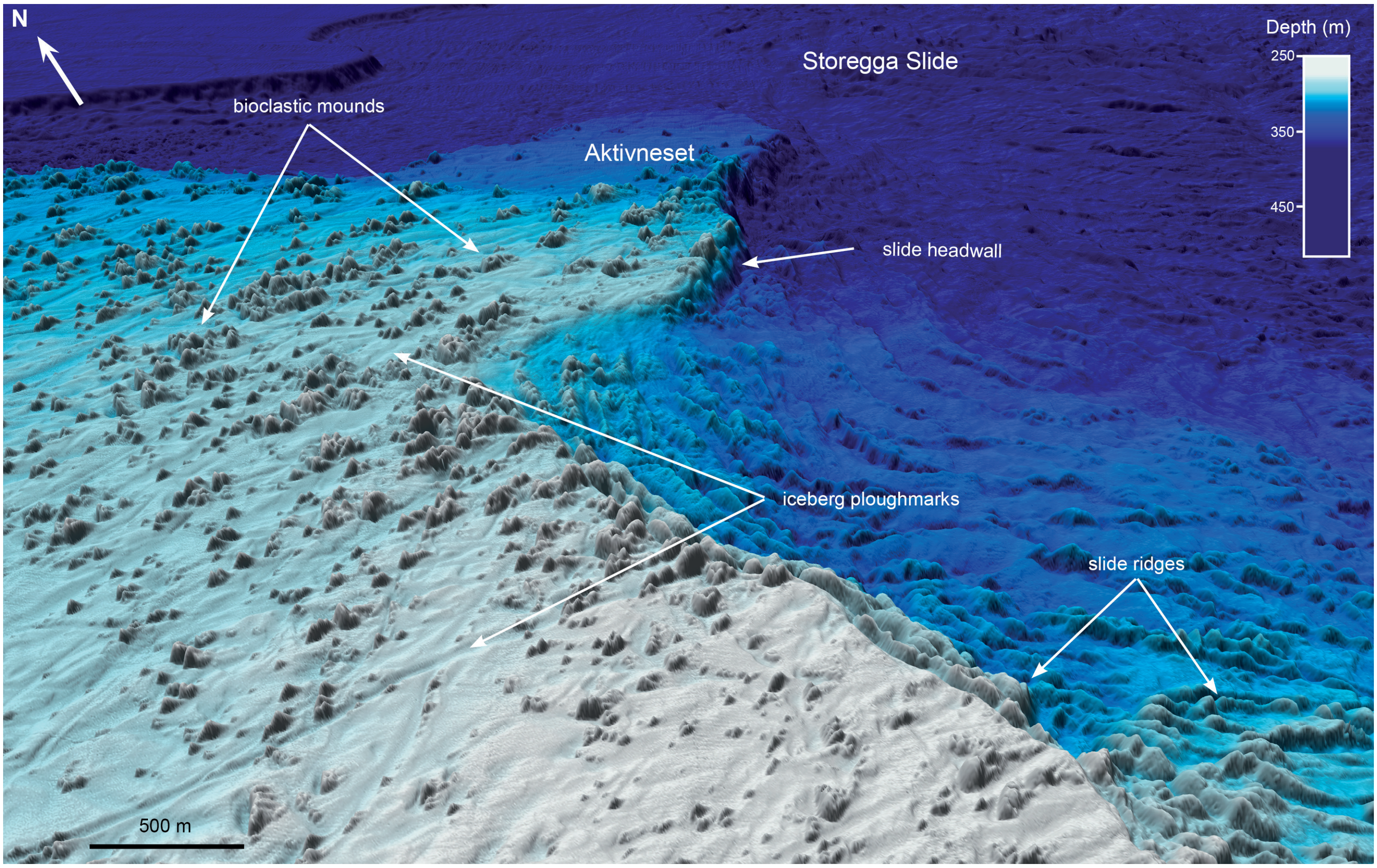


Figure 9. 3D view of Aktivneset and the Storegga Slide, looking towards north from the outlet of the Norskerenna trough. Note abundant bioclastic mounds, iceberg ploughmarks, the Storegga Slide headwall and well developed slide compression ridges.

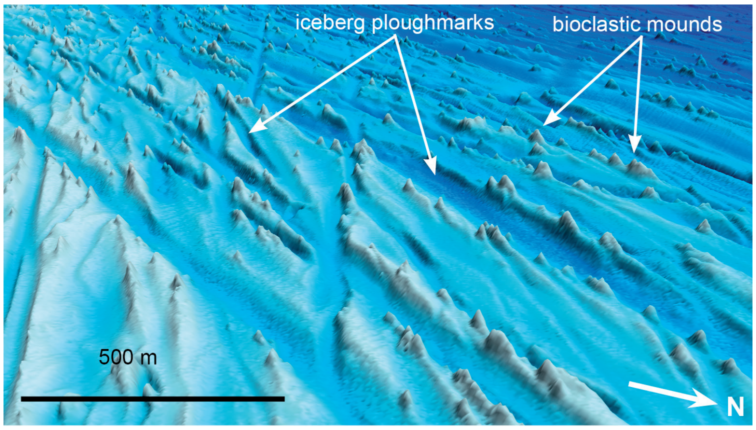
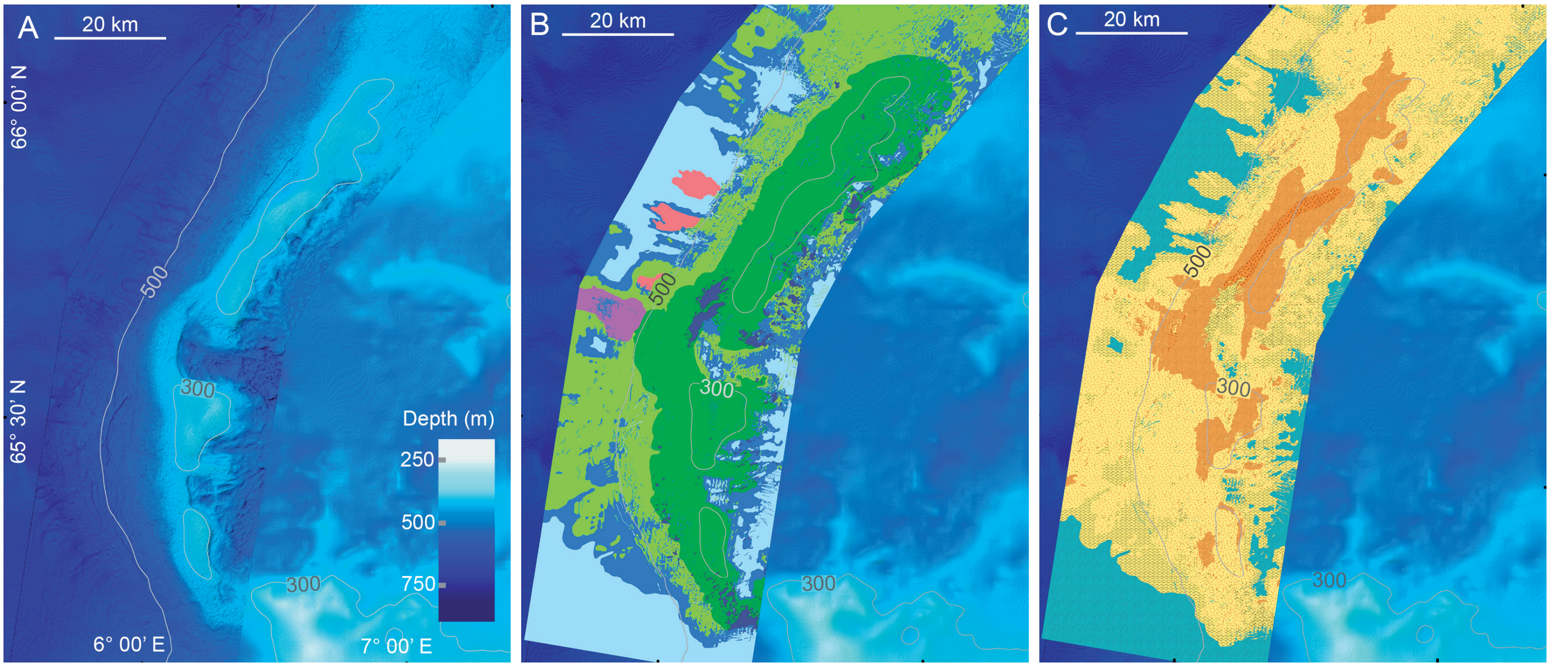


Figure 10. 3D view from Norskerenna, (c. 20 kilometres SSW from Aktivneset) with bioclastic mounds on the berms of iceberg ploughmarks.

Figure 11. Bathymetry, genesis and sediment grain size maps from Skjoldryggen.
A - shaded relief image, with multibeam bathymetry in central parts, and regional bathymetry in the remaining part.
B - genesis map. Dark green - terminal moraine. Light green - unspecified till. Medium blue - glaciomarine deposits. Light blue - suspension deposits. Violet and pink - mass movement deposits. Dark blue - bioclastic sediments.
C - grain size map. Orange: gravelly deposits; yellow: sandy deposits; blue: fine grained deposits.



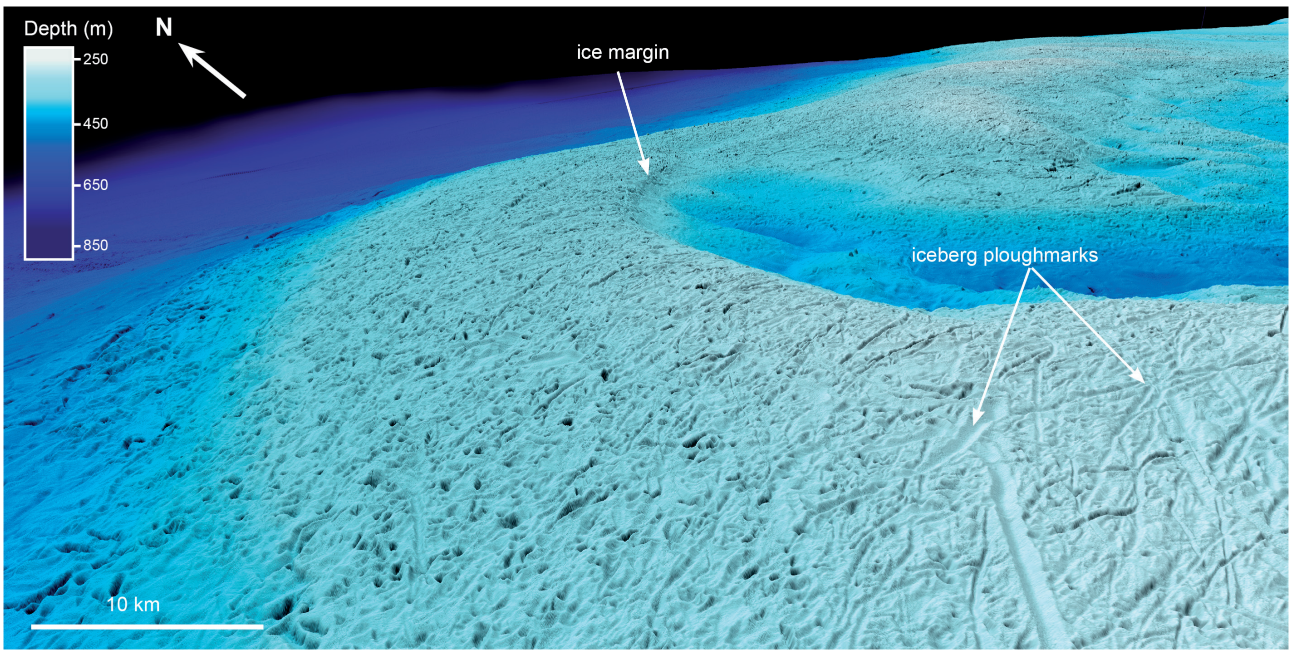


Figure 12. 3D view of the Skjoldryggen terminal moraine, forming an up to 150 metres high ridge. Note abundant iceberg ploughmarks.

northern parts of Skjoldryggen are of variable size, up to 100 metres in diameter. The highest concentration is found between 500 and 600 metres water depth.

In the very SW part of the Skjoldryggen several hundred cigar shaped ridges, all oriented roughly N-S to NNE-SSW are found on the seabed at water depths greater than 550 metres (figure 15). The ridges, which probably represent sand ribbons and longitudinal furrows in areas of strong bottom currents, are up to 250 metres long, 50 metres wide and a few metres high. They are spatially associated with areas with irregular depressions having the same orientation. These depressions can be erosion features in areas where sediments have covered the ridges.

7.1.4 Sularevet and the coastal zone

Sularevet - the Sula Reef - has a special position in the MAREANO programme. This was the first site mapped with multibeam bathymetry with regard to coral reefs, following earlier reports on coral reefs from Statoil. A small area was mapped in 1999 by the Hydrographic Service, the Geological Survey of Norway and the Institute of Marine Research, and gave important input to the design of the MAREANO programme which became fully funded from 2006. Sularevet (1.430 square kilometres) and the adjacent coastal zone (3.000 square kilometres) are particularly valuable and vulnerable areas (SVOs), located off the coast of Trøndelag (figure 16).

The coastal zone from Mørebankene and northeastwards (figure 16) is varied, and a clear zonation is evident. In the innermost parts, bedrock and gravel with cobbles and boulders dominate. Sand, gravelly sand and sandy gravel are the most common sediments in the

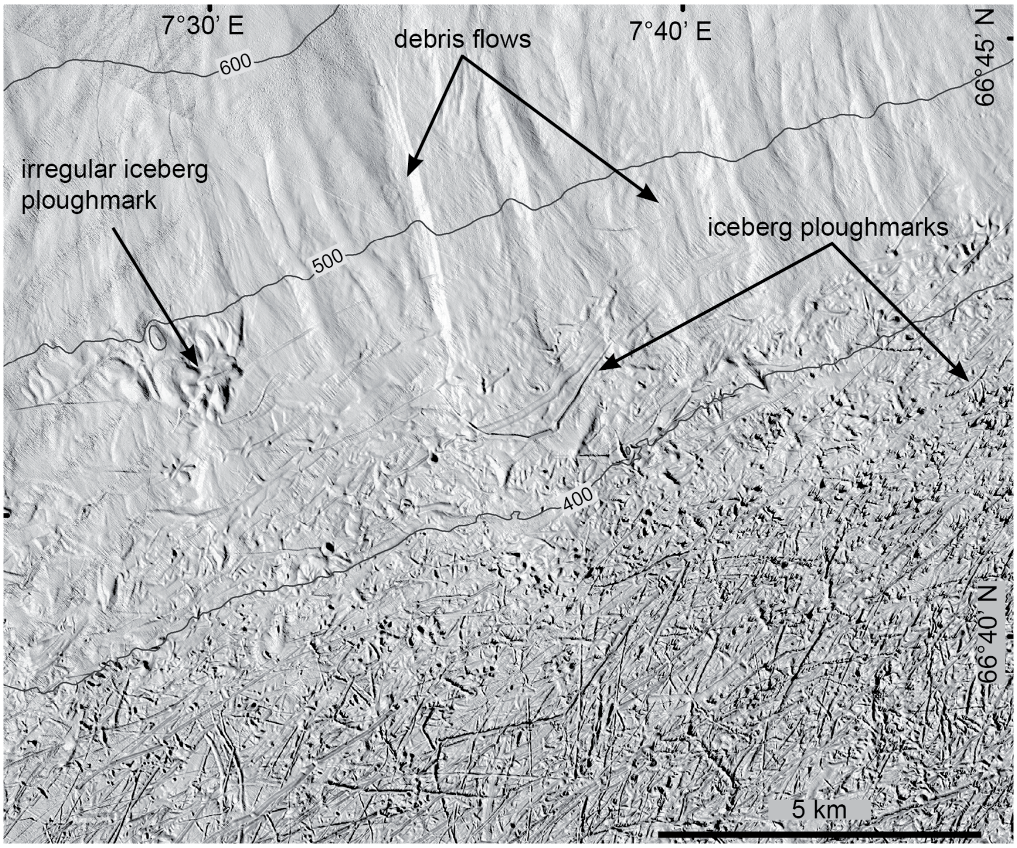


Figure 13. Grey scale shaded relief image showing debris flows and iceberg ploughmarks at the shelf edge north of Skjoldryggen. Note the irregular iceberg ploughmarks at 490 metres water depth.

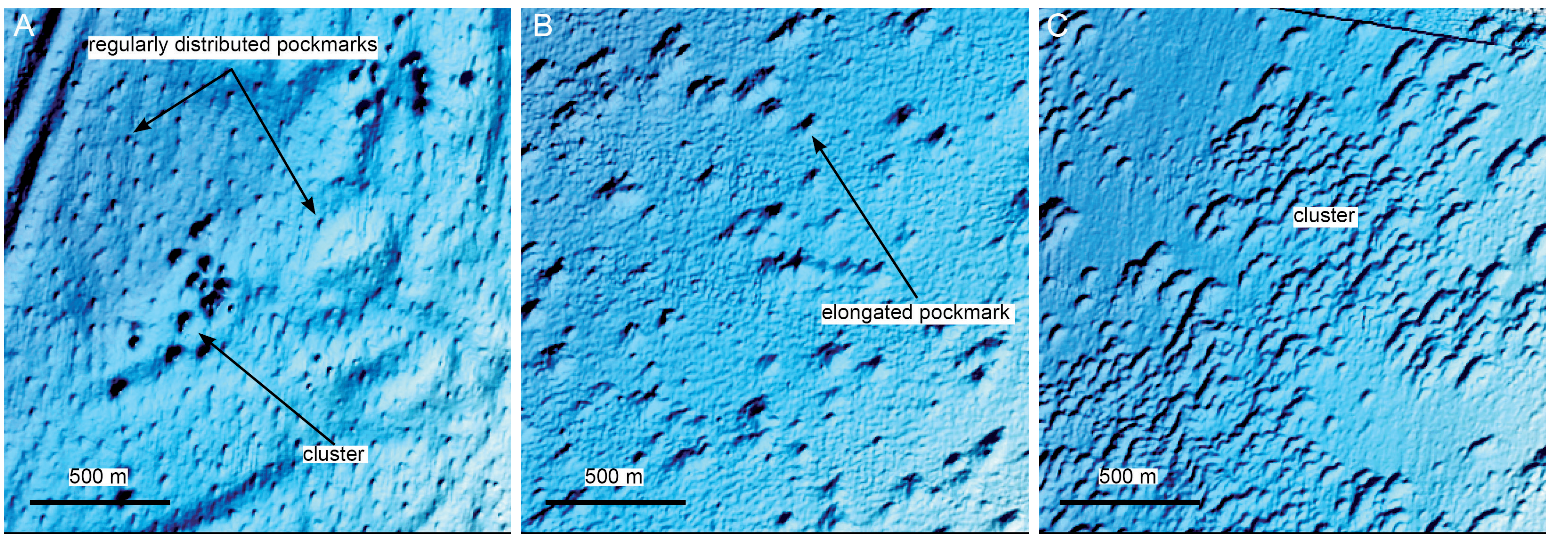


Figure 14. Different types of pockmarks from the southern part of the Skjoldryggen area. Shaded relief image, with sun from the NW. A - Small, regularly distributed pockmarks, clusters of larger pockmarks and iceberg ploughmarks. Water depth around 450 metres. B - Elongated, asymmetric pockmarks. Water depth around 550 metres. C - Cluster of elongated, asymmetric pockmarks. Water depth around 600 metres.

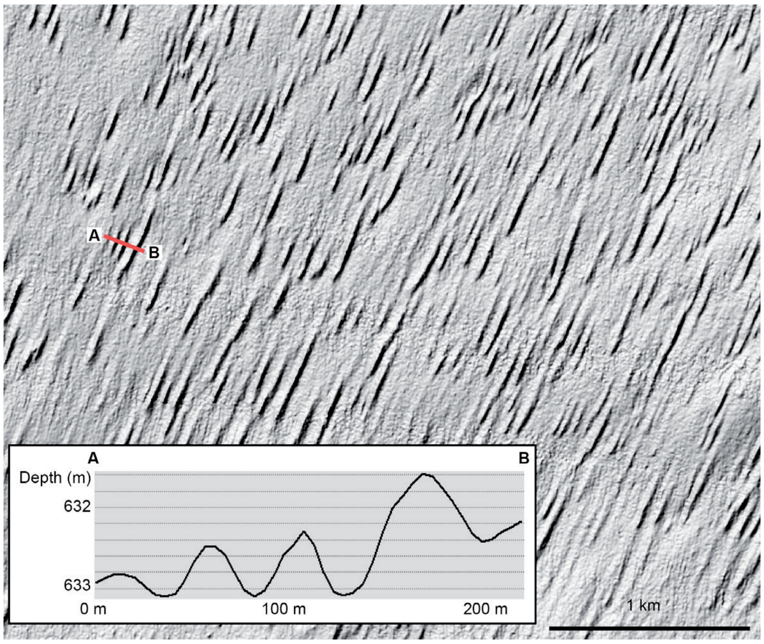


Figure 15. Up to 250 metres long and 2 metres high cigar shaped ridges dominate the seabed morphology on the continental slope in the southern part of Skjoldryggen and southwards. Inset image - depth profile along line A - B.

intermediate part of the coastal zone, in water depths between around 100 and 400 metres, Numerous bioclastic mounds are found (figure 17), usually on top of ridges related to mega scale glacial lineations (MSGLs) formed beneath the ice-streams crossing the mid-Norwegian shelf during the Late Weichselian glaciation of the Norwegian shelf.

The MSGLs extend more than 50 kilometres towards the shelf, and cross the Sula Ridge (see below). Few bioclastic mounds have been identified in the innermost part of the coastal zone which is dominated by bedrock and gravel with cobbles and boulders. It is difficult to separate bioclastic mounds from bedrock mounds and knolls from the bathymetry data, and the occurrence of bioclastic mounds may be underreported from this zone.

In the outermost part of the coastal zone, sandy mud dominates. This is also the case in

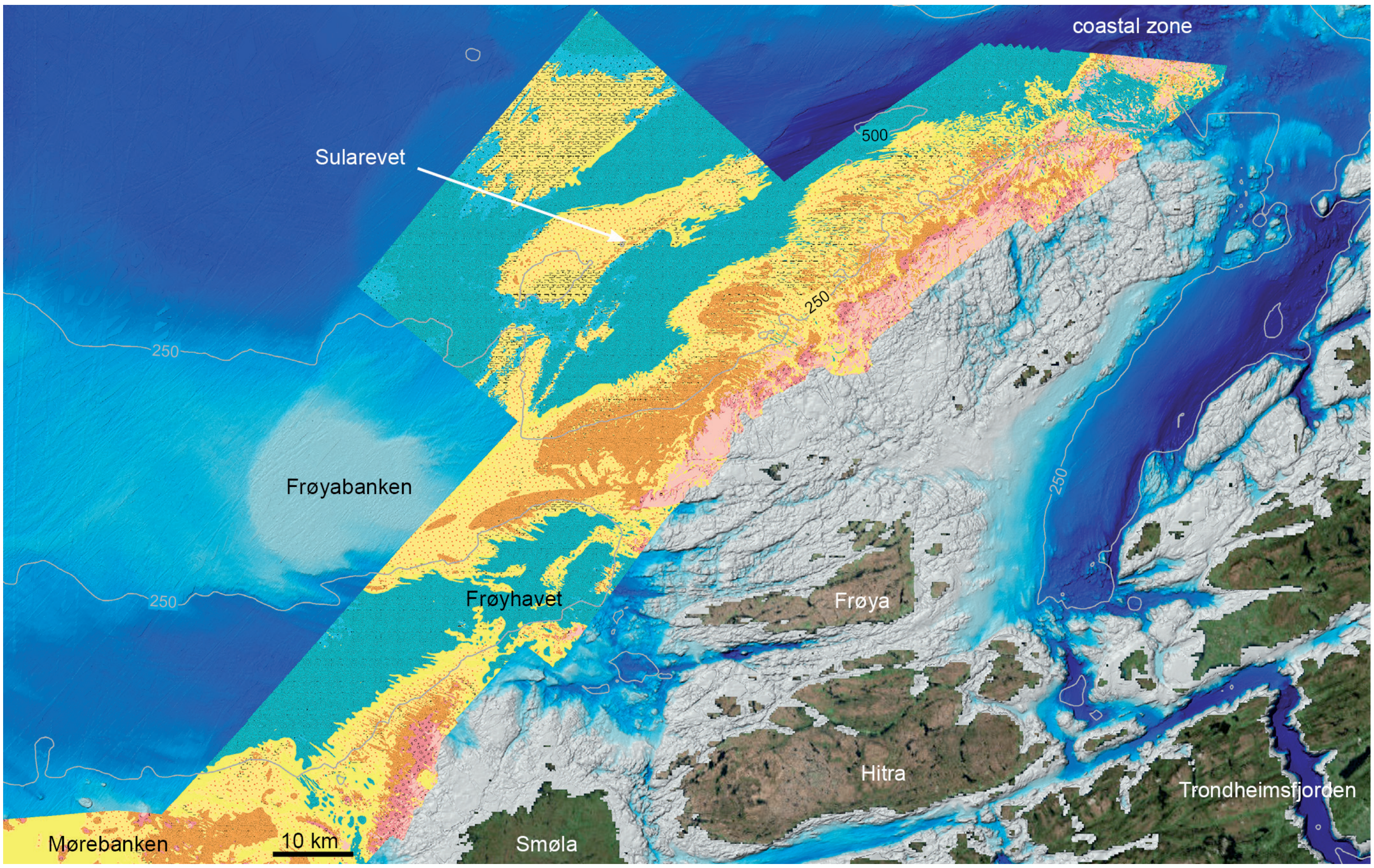


Figure 16. Overview of the coastal zone off Trøndelag, including the Sularevet SVO. Colours indicate different sediment types. Orange: gravelly sediments; pink: gravel with cobbles and boulders, or bedrock; yellow: sandy sediments; blue: fine grained deposits.

Frøyhavet trough extending WSW across the entire coastal zone from Frøya. Pockmarks are found in Frøyhavet, where a thin layer of sandy mud is draped on mega scale glacial lineations. Pockmarks are mostly elongated in the NE-SW direction, with maximum length less than 100 metres and depths usually less than 10 metres. The pockmarks are often found in arrays, in the depressions between mega scale glacial lineations, or in iceberg ploughmarks covered by sandy mud.

An unidentified structure which may be a ship wreck is also found in Frøyhavet (figure 18). The object is 110 metres long, 85 metres wide and more than 20 metres high. It is asymmetric, with slopes exceeding 60° on the SE side, and around 20° on the NW side. It does not look like a bioclastic mound, and similar structures have not been observed elsewhere, perhaps except the ”Vest-Brona volcano” in the NE part of Mørebankene.

Sularevet is located on the ENE-WSW trending Sularyggen ridge on the mid-Norwegian continental shelf (figure 19). The ridge is about 20 kilometres long, and up to 50 metres high; ridge height decreases towards the northeast. Sularyggen is made up of layered,

basic facts

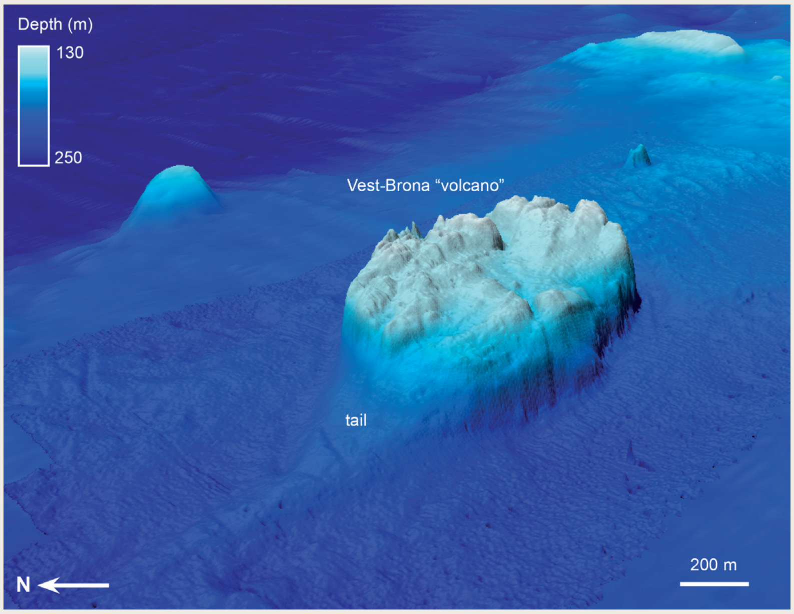
The Vest-Brona ”volcano”

Around 55 million years ago there was volcanic activity in the northeastern part of Mørebankene, offshore mid-Norway. Today we can find remains of this volcanism in the form of a steep sided column-like volcanic plug rising from an otherwise fairly flat seabed. The volcanic plug provides a home for a variety of fish and other bottom dwelling animals.

Around 60 million years ago, Northern Europe started to break up and Greenland started to move away from Norway. The Norwegian Sea opened and volcanoes spurted out lava and ash. The steep sided volcanic plug we find rising from the surrounding sea floor today offshore Griptarane is the remain of a volcano that was active around 55 million years ago. It is a volcanic pipe with solidified magmatic rocks, through which magma was brought up to what, at that time, was the earth's surface. The plug consists of solidified magmatic rocks in a volcanic pipe. Over the millions of years since its formation, the area has been eroded, particularly by glaciers during the ice ages. These huge glaciers had sufficient power to erode everything but the hard rocks which solidified within the volcanic pipe itself. The surrounding sedimentary rocks were no match for the power of the glaciers and have been eroded away leaving only the hardest rock we see today at the Vest-Brona volcano. Studies published in the 1980's indicated that the rock is of a type called porphyritic olivine nefelith and dating by the K-Ar method gave an age of 55.7 +/- 0.9 million years (Bugge et al., 1980, Marine Geology 35, 277-286).

The Vest-Brona volcanic plug measures around 1100 x 1450 metres, slightly elongated in WNW-ESE direction. It rises up to 90 metres above the surrounding seabed, with slopes between 25 and 50 degrees, but locally up to 70 degrees. The rock is brownish, with a rugged surface, with many colourful organisms utilising this hard-bottom substrate. On the top of the plug, in a central depression, rounded blocks form an irregular landscape. Rounded cavities reflect the magmatic origin of these rocks.

The "Vest-Brona volcano" is a volcanic plug which rises up to 90 metres above the surrounding seabed. The 'tail' of the plug to the left of the image is probably sediments left behind during glacial erosion. The highs in the background are also possible volcanic plugs.



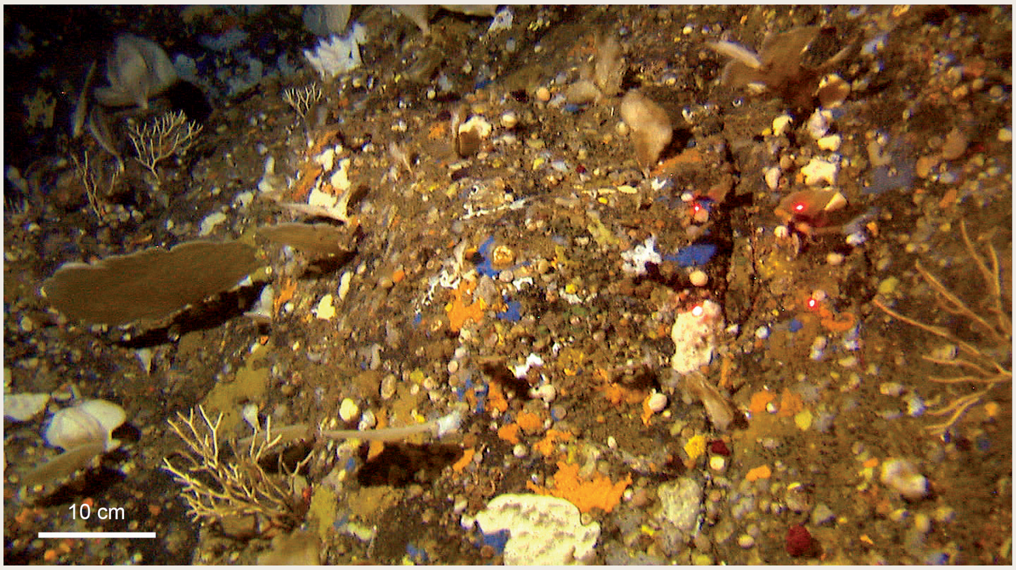


Photo from the wall of the volcanic plug: Colourful organisms covered the lower part of the wall, further up various sponges dominated.

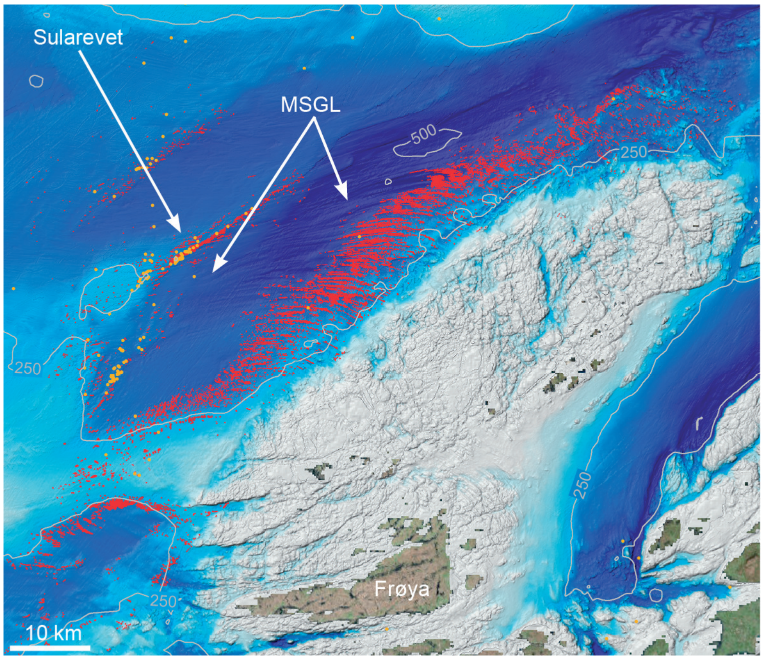


Figure 17. Shaded relief map of the Sula-Froan region with verified coral reefs (orange dots) and bioclastic mounds (red dots and polygons). MSGL - mega scale glacial lineations.

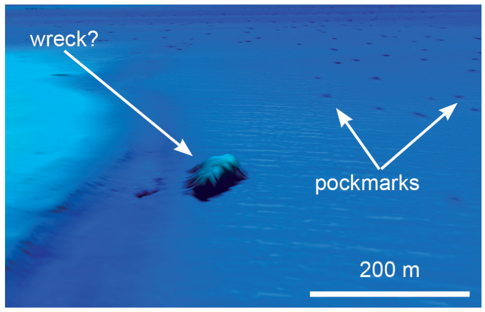


Figure 18. 3D view of a possible ship wreck in Frøyhavet.

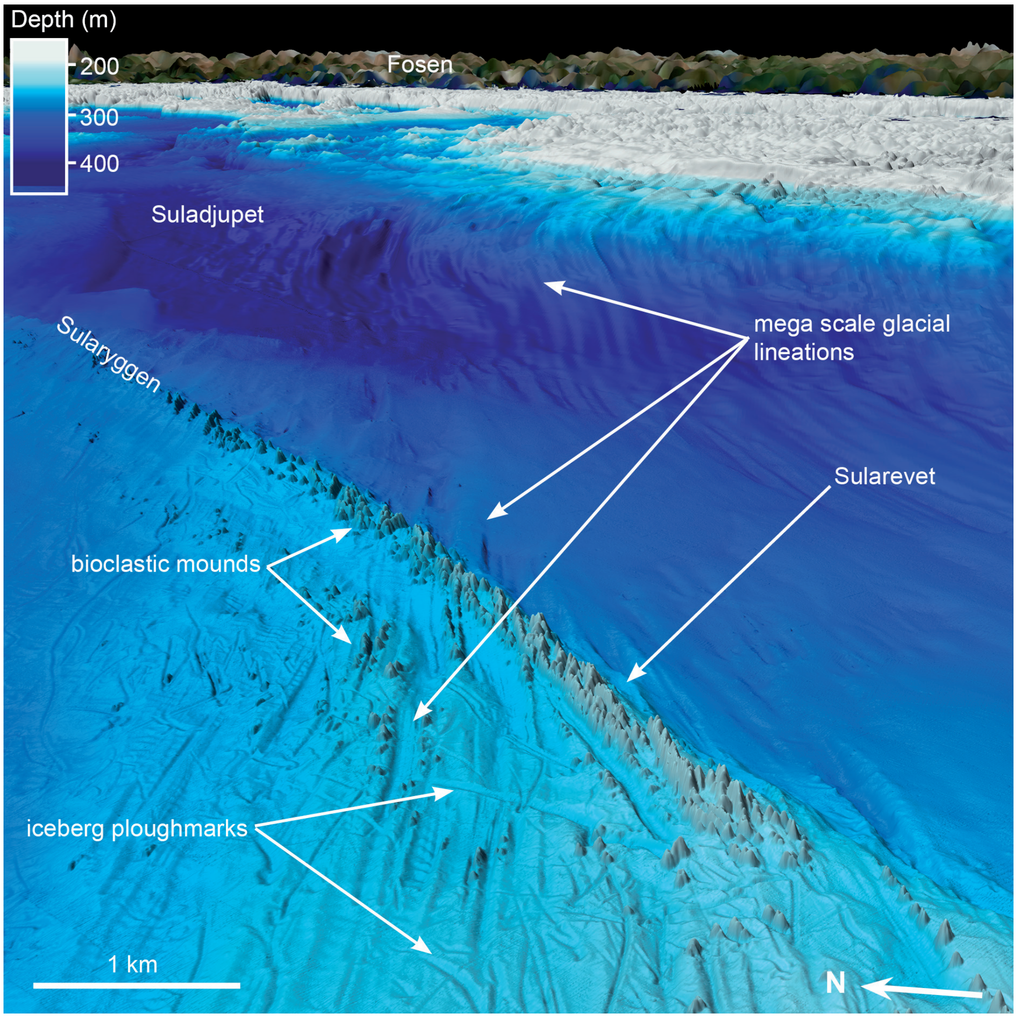


Figure 19. 3D view of Sularevet and Sularyggen, looking NE-wards towards the coast with the Fosen mountains in the background. Vertical exaggeration - 5x.

erosion resistant sedimentary rocks of Jurassic age. Quaternary and Holocene glacial and post glacial laminated sediments up to a few tens of metres thick drape these older rocks. Sandy gravel and gravelly sand dominates along the ridge. More fine grained sediments such as sandy mud (locally gravelly) are found in the Suladjupet between Sularyggen and the coast (figure 14). The ridge is asymmetric, with a fairly steep escarpment towards the Suladjupet basin on its southeast side. The escarpment slope locally exceeds 10° in the southwest part of the ridge, gradually decreasing to <5° to the northeast, except locally where glacial erosion has produced steeper slopes. Towards the southwest, the ridge broadens and is replaced by a wide arch forming the northeastern part of the Frøya Bank.

Roughly 1000 bioclastic mounds occur along Sularyggen, forming part of the Sularevet reef complex. Video investigations have shown that live corals occur on the surface of many of mounds. The mounds occur either in isolation, in linear arrays, or as complex mounds, formed by irregular mounds having grown together (figure 20). Solitary mounds are normally circular or sub-circular, with diameters of 50-100 metres and heights of up to 30 metres. There is no preferred orientation to the slopes on which corals are found. In some places, elongate mounds occur with the longest axis up to 150 metres, and slopes exceeding 25° in many places. These linear-mound arrays are found on MSGLs or on the flanks of ploughmarks. The MSGLs cross the Sularyggen ridge at an angle of 0-20° (figure 19). The MSGLs are up to 200 metres wide and 15 m high. In Suladjupet, MSGLs are found down to at least 460 metres water depth.

Complex mounds are also found on MSGLs, and may exceed 1000 metres in length in the southwest part of the Sula Ridge;

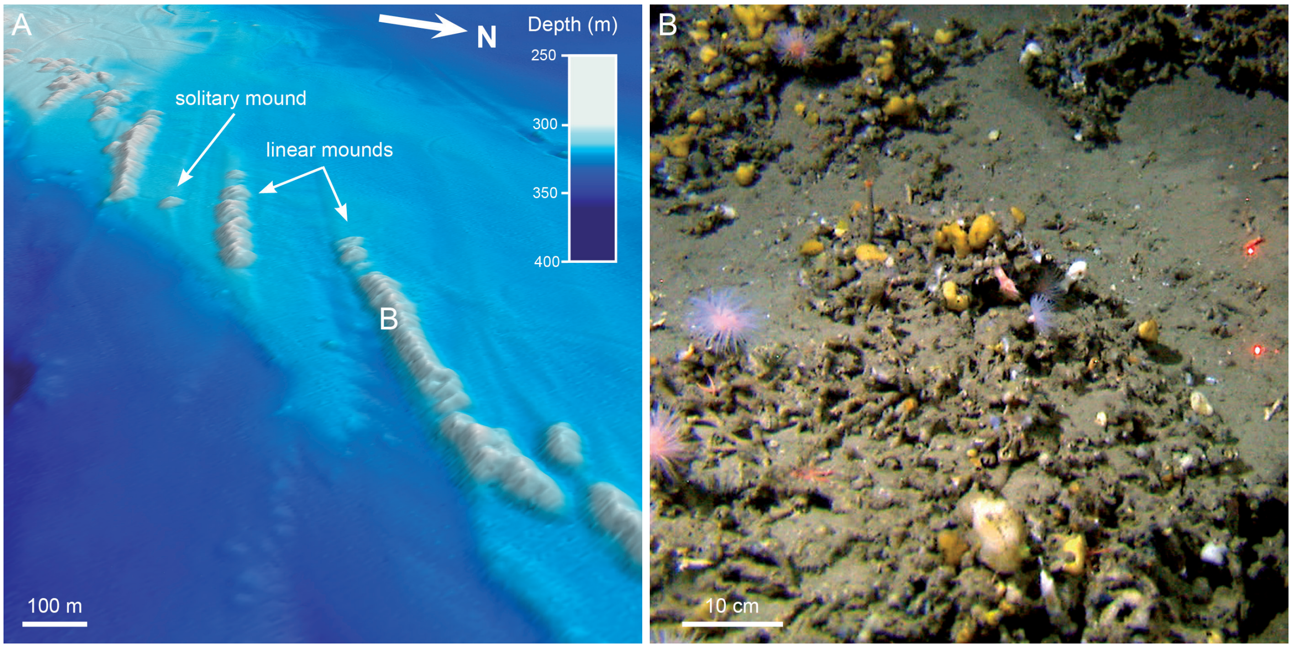


Figure 20. 3D view of linear and solitary bioclastic mounds on the Sularyggen ridge and photograph. A - colour coded bathymetry. No vertical exaggeration. B - photograph of bioclastic sediments (muddy sand, coral rubble) partly covered by living organisms.

they are between 500 and 1000 metres long in the northeast.

Several glacial landforms are present on the seafloor. Ploughmarks, produced when iceberg keels impinged on the sedimentary seafloor, criss-cross the northwest flank of the ridge down to about 330 metres (figure 19). The ploughmarks are up to 8 kilometres long, 100-300 metres wide and 10 metres deep. The side walls have slopes up to 20°. Many ploughmarks have raised berms up to 1 metre high.

7.1.5 Iverryggen and Haltenbanken

Iverryggen and Haltenbanken are both SVOs, but for different reasons. Iverryggen is an SVO because of important occurrences of Lophelia coral reefs. Haltenbanken is an important spawning field for Norwegian spring-spawning herring, and an important retention area for larvae and juveniles. Haltenbanken is one of the large, shallow banks on the mid-Norwegian shelf, created by large ice sheets shaping the shelf during the last glaciations (figure 2, figure 21). Iverryggen is located on the NE flank of Haltenbanken, and was formed by glacial processes acting on a smaller scale.

Iverryggen is a N-S-trending ridge, around 20 kilometres long, 7 kilometres wide, and up to 120 metres high (figure 22a). Extending from the southwestern part, two smaller ridges are

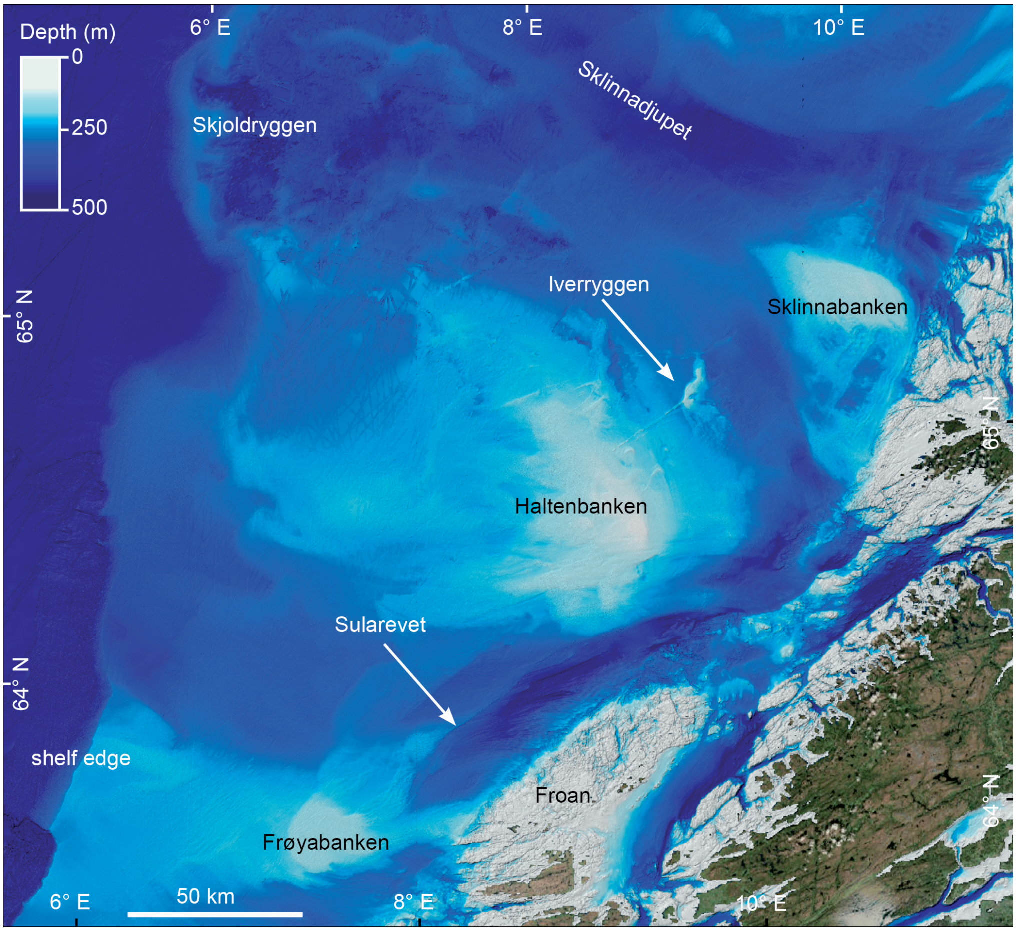


Figure 21. Haltenbanken is one of the large, shallow banks on the mid-Norwegian shelf. Iverryggen is located on the NE flank of Haltenbanken.

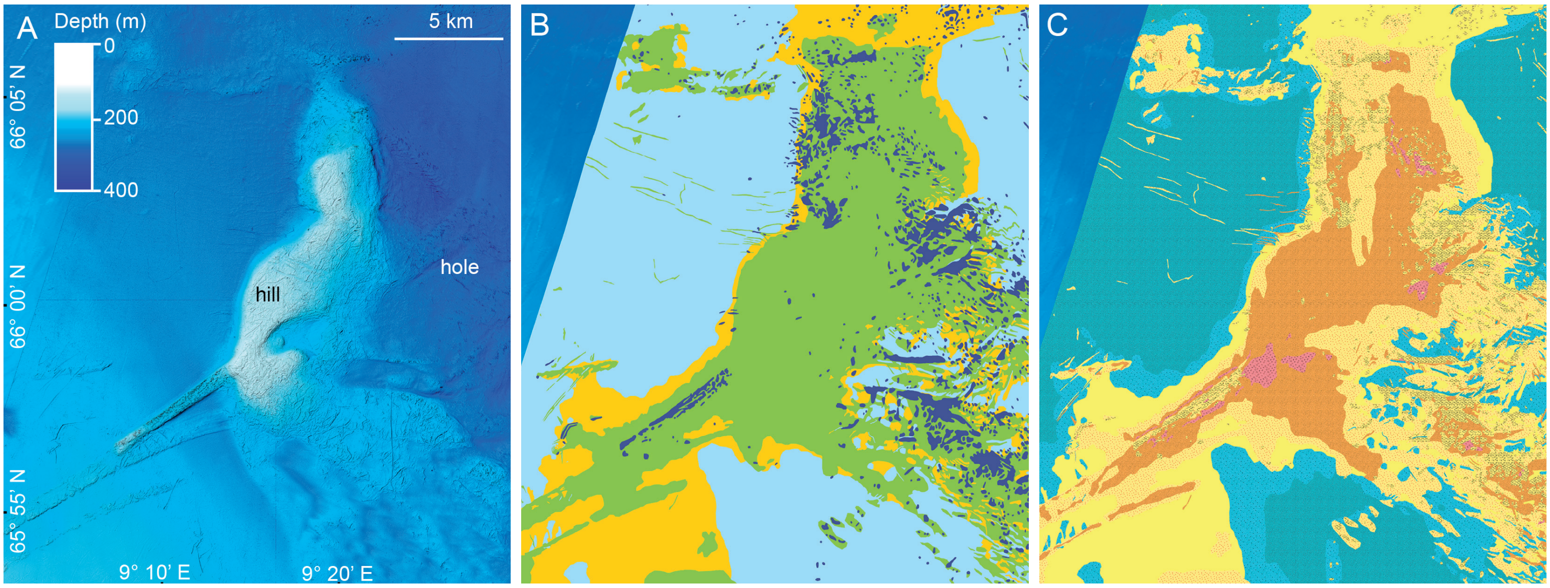


Figure 22. Bathymetry, genesis and sediment grain size maps from Iverryggen. A - shaded relief image, with multibeam bathymetry. Note "hill-hole" relationship. B - genesis map. Light green - unspecified till. Light blue - suspension deposits. Orange - bedload deposits. Dark blue - bioclastic sediment mounds. C- grain size map. Pink: Gravel, cobbles and boulders. Orange: gravelly deposits; yellow: sandy deposits; blue: fine grained deposits.

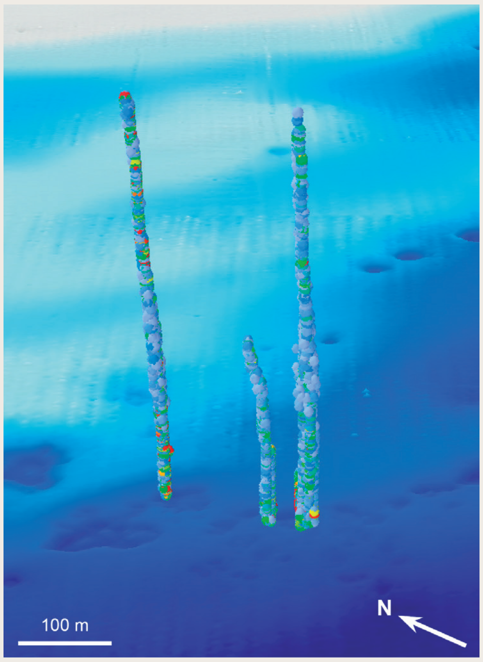
found. One ridge is about 6 kilometres long, up to 1 kilometre wide, and 60 metres high. The other ridge is nearly 25 kilometres long, up to 1 kilometre wide and generally less than 20 metres high. The water depth of the surrounding seabed is up to 290 metres west of the Iverryggen ridge, while the basin east of Iverryggen is up to 380 metres deep.

The structures found on the seabed indicate that Iverryggen is a glacitectonic ridge, with a classic "hill-hole" geometry (figure 22a) formed by moving ice, probably during the last ice age. In periods with limited ice movement, the ice froze to the seabed. When it started moving again, the ice transported huge rafts of sediments westwards which were dumped, in what we now see as Iverryggen.

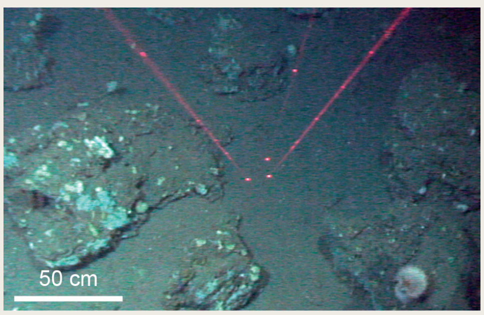
The main ridge extending SW from Iverryggen is covered by more than 200 bioclastic mounds (figure 23). The mounds are generally elongated, up to 150 metres long, 50 metres wide and 20 metres high. The longest axis is NW-SE, i.e. normal to the ridge. This is likely to reflect the dominant local current direction.

Iverryggen consists mainly of unspecified till, with a marginal zone of bedload deposits (figure 22b). Suspension deposits dominate the seabed around Iverryggen. Gravelly sediments,

A leaking seabed - gas flares and carbonate crusts



3D view of gas flares detected by multibeam data and seabed with pockmarks, from Onadjupet, Mørebankene. Vertical exaggeration - 5x.



Carbonate crusts in pockmark from Skjoldryggen.

Cold seeps releasing methane and supporting microbial communities are widespread on the continental margins worldwide. They are thought to bring large quantities of greenhouse gases from the deeper geo-sphere into the water column and upwards to the atmosphere. The influence of these gasses is enough to have a global scale effect and may be linked to climate change. Active seepage on the continental shelf is commonly associated with underlying oil and gas reservoirs, trapped gas under gas hydrates, and also dissociation of gas hydrate itself.

Active seeps form acoustic flares in the water column and can be detected using data from single or multibeam echo sounders. Carbonate crusts typically form in sediments at cold seeps, as a result of microbial oxidation of methane-rich fluids. Anaerobic oxidation of methane results in increased alkalinity and dissolved sulphide contents in the pore waters. This favours precipitation of carbonate in the sediments, commonly associated with development of chemosynthetic communities at the seabed. The OSPAR Commission, whose goal is to protect and conserve the North-East Atlantic and its resources, have recently paid considerable attention towards cold seep ecosystems.

Multibeam water column data collected by MAREANO have revealed several hundred active gas seeps. The highest abundance is found off the coast of Troms, in Håkjerringdjupet. Other occurrences include Hola, west of Vesterålen, and Onadjupet in Mørebankene. Carbonate crusts associated with the gas seeps have been observed at all of these locations.

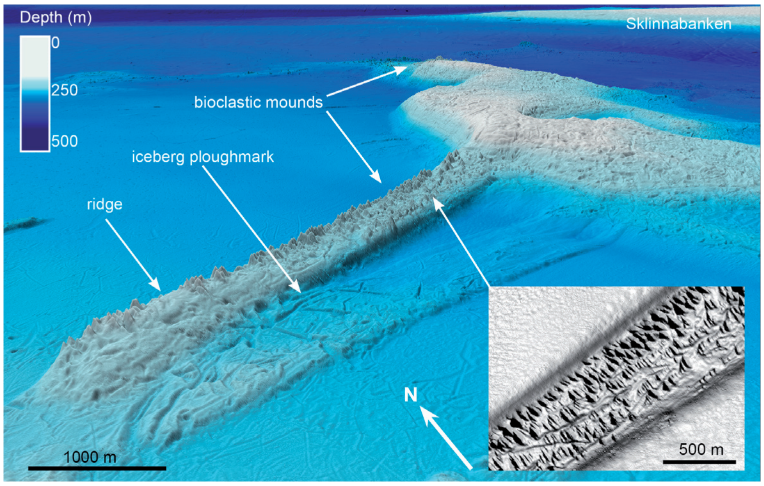


Figure 23. 3D view of Iverryggen, looking towards north. Note the two parallel ridges, with many bioclastic mounds on top of the main ridge. Inset image - 2D view, greyscale, of bioclastic mounds in the NE part of the main ridge.

locally with cobbles and boulders are found on the highest, central part of the ridge, while sand and gravelly sand sediments dominate in the fringe of the ridge (figure 22c). Sandy mud and gravelly sandy mud are the main sediment types around the ridge.

Haltenbanken is one of the areas where MAREANO mapping is still in progress. It has been mapped with multibeam bathymetry, but sampling or visual inspection has not yet been undertaken. This description is therefore based on the morphology only. Haltenbanken is a broad and smooth bank (figure 24), formed by the ice-streams depositing thick layers of moraine during the last glaciations. The area is 2 680 square kilometres, with water depths ranging from 260 to 90 metres. Indications for glacitectonic processes are found in the northern part of Haltenbanken, with hill-hole structures and ridges similar to the ones found at Iverryggen. No bioclastic mounds have been observed on top of the ridges, but a few are present in the southeastern part of Haltenbanken.

Mega scale glacial lineations (figure 25) oriented E-W beneath the upper moraine sheets show that an ice-stream at some stage moved in a direction similar as the ice-stream in the Sula-Froan region. The shallower parts of Haltenbanken are heavily indented by iceberg ploughmarks. Most of the ploughmarks are oriented WSW-ENE. The largest ploughmarks are more than 10 kilometres long, up to 100 metres wide and up to 10 metres deep. Small pockmarks, up to 100 metres wide are found in the depressions, most likely because of the presence of fine-grained sediments (figure 25). No video observations or physical samples have yet been collected by MAREANO.

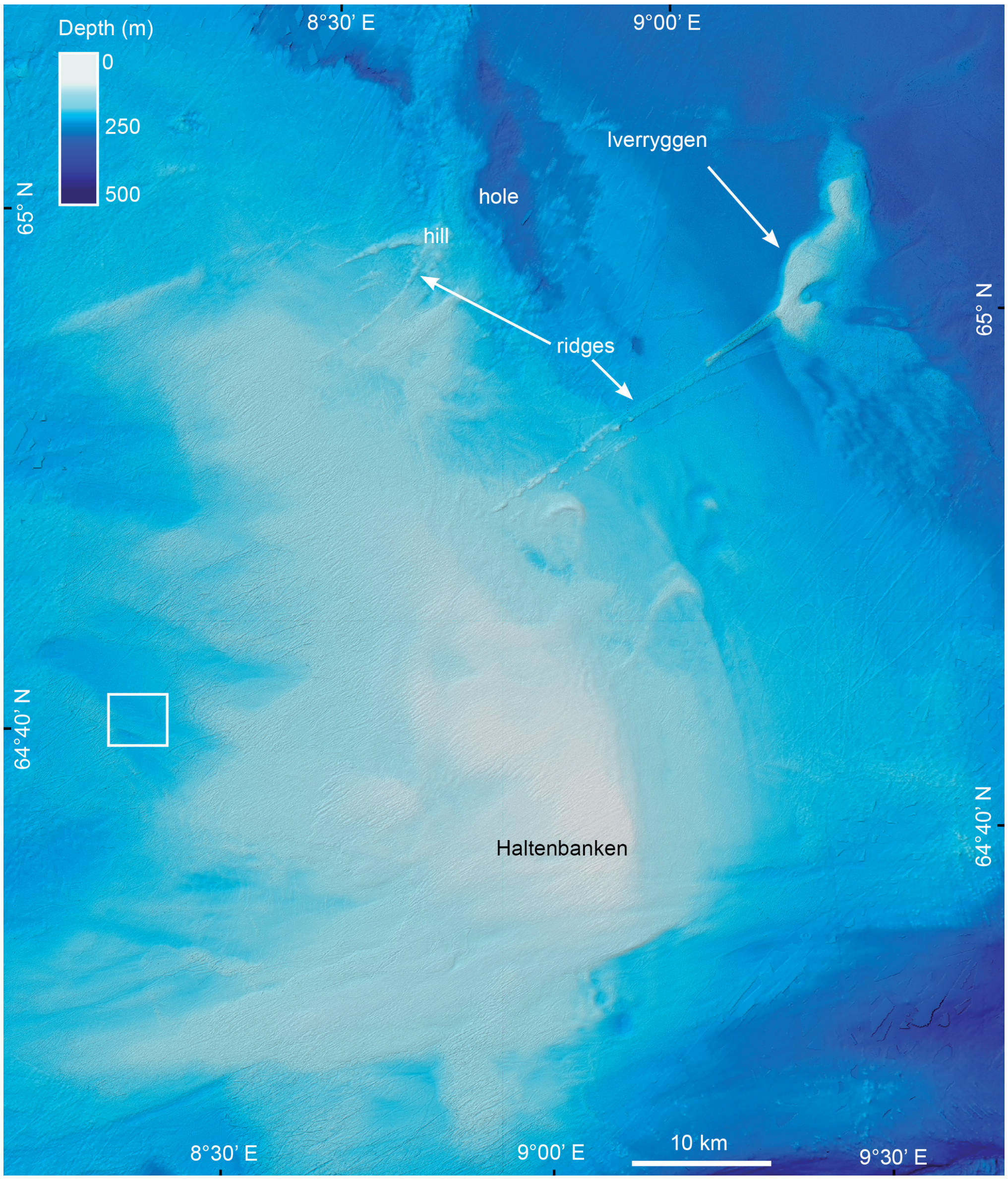


Figure 24. Shaded relief map of Haltenbanken and Iverryggen. Note ridges and hill-hole structures in the upper central part. White square shows the outline of figure 25.

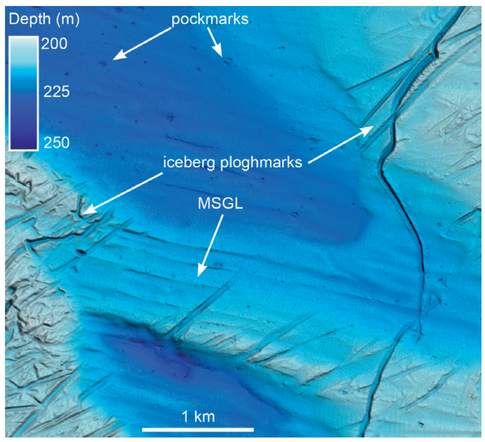


Figure 25. Shaded relief map from Haltenbanken (for location, see figure 24), showing iceberg ploughmarks, pockmarks and mega scale glacial lineations (MSGL).

7.2 BOTTOM HABITATS AND FAUNA

7.2.1 Introduction

The Norwegian Sea is a productive area and zooplankton (mainly small crustaceans) is key to the functioning of the whole ecosystem on the mid-Norwegian shelf and slope. The deep layer of zooplankton, at around 400 – 800 m water depth, is particularly important for supporting commercial fish stocks. For example, herring larvae drifting northwards from the spawning areas on the banks of the mid-Norwegian shelf during spring and summer feed on the planktonic copepod *Calanus* which is most abundant at these times. The benthic species diversity is generally high in this area, and many species found here do not extend further north than the tip of Lofoten, the northern border of what we regard as mid-Norway.

MAREANO is the first initiative to systematically map the seabed and benthic fauna at a broad scale off mid-Norway. Previous biological investigations have focused on smaller areas or a limited number of taxonomic groups, not providing a comprehensive, unified presentation of habitats and communities. The results presented in this chapter come from six MAREANO biological-geological sampling cruises to areas in mid Norway and are based on full post-cruise analysis of video data from two cruises in 2012, and field results from three cruises in 2013 and one in 2014.

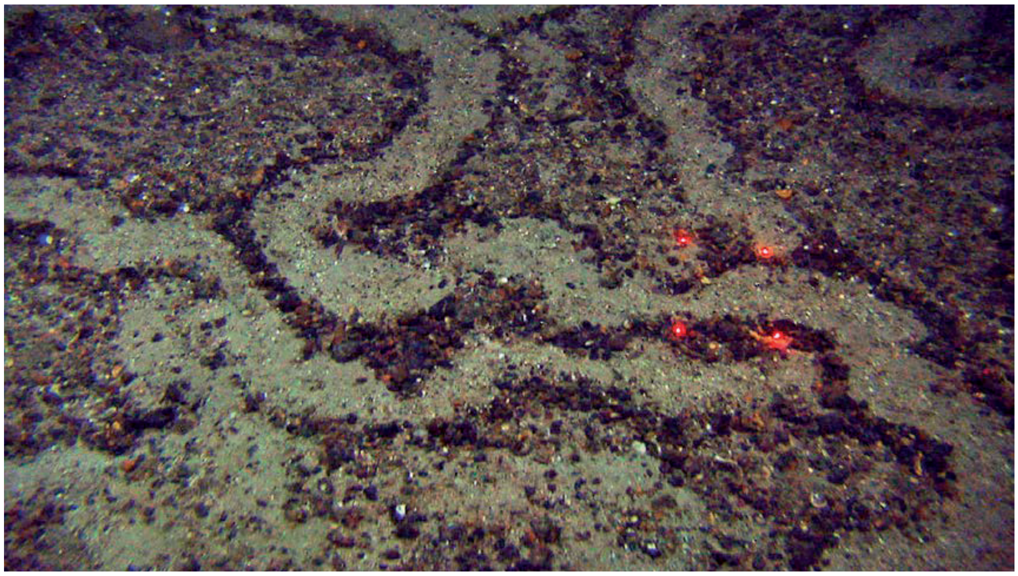


Figure 26. Labyrinths of tracks left by the sea urchin *Spatangus purpureus*, at around 200 m depth at Sunnmørsbankene.

7.2.2 Contrasting marine landscapes

The Banks

The banks on the mid-Norwegian shelf are ecologically important areas and represent major spawning and nursery areas for Norwegian spring-spawning herring. On the gravelly seabed the eggs are well oxygenated and survive much better than on finer-grained sediment. The banks generally exhibit high biodiversity, and at Mørebankene MAREANO has observed several vulnerable and species rich habitats including coral reefs, sponge gardens, coral gardens, and sea-pen communities. Mørebankene, Haltenbanken, and Sklinnabanken are all highly productive retention areas where drifting fish egg and larvae stays for an extended period of time.

In general, the surveyed localities on the shelf are dominated by sandy sediments, with muddy sediments in the troughs, and gravelly sediments, locally with cobbles and stones, on the banks (for further details, see chapter 7.1). In the shallowest areas on the banks, the bottom is dominated by cobbles and boulder. Here we observed hard-bottom sponge gardens including the chalice sponge, *Phakellia ventilabrum* and the funnel shaped sponge, *Axinella infundibuliformis*.

Tracks in the sediment left by benthic animals are called ”lebensspur”. Such tracks can be holes, mounds or traces that are a result of the animals' movement. High densities of tracks, forming complex patterns were observed at around 200 m depth at Sunnmørsbankene (figure 26). These were made by the sea urchin *Spatangus purpureus*. Just by observing these tracks, it is easy to infer that this species has a great influence on the environment, and could therefore be considered a key species in the areas where they occur.

Figure 27. Juvenile specimens of the sea urchin

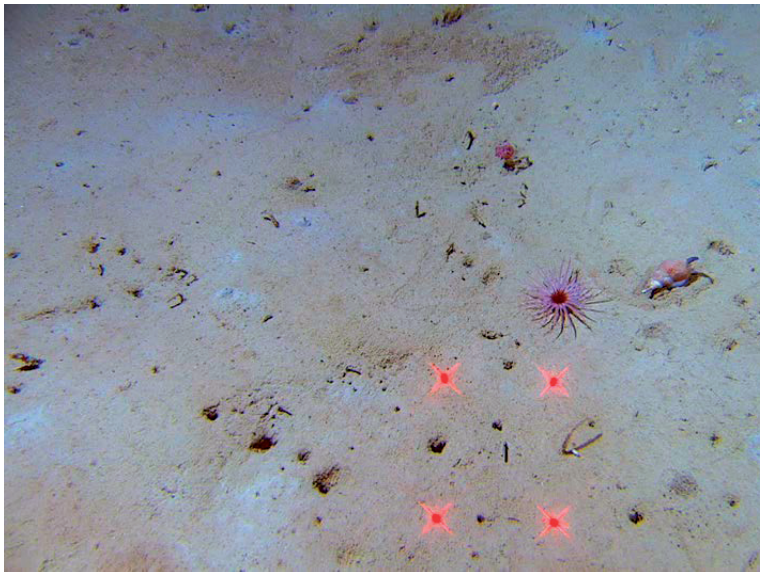


Figure 28. In some places the seabed is perforated by the amphipod Neohela. In the picture we can also see the anemone *Cerianthus vogti* and the whelk *Buccinum hydrophanum.*

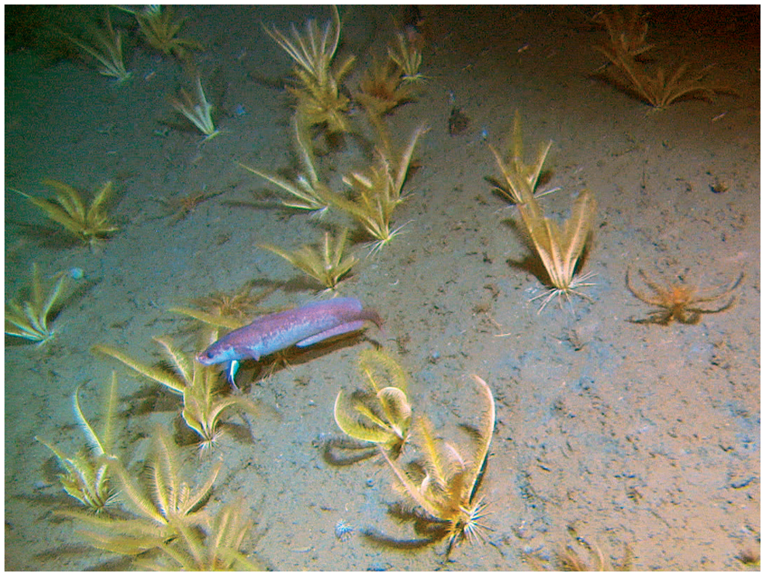


Figure 29. Greater fork-beard fish (*Phycis blennoides*) and feather stars at around 800 m depth at Storneset.

In 2012, we observed mass occurrences of juveniles of the sea urchins *Gracilechinus esculentus* (figure 27). In some areas there was as many as two hundred in one square metre, with each individual measuring approximately 1 cm. The unusual high density of this species is probably a result of successful recruitment earlier that year. Similar occurrences have not been observed during later MAREANO cruises.

The troughs

The troughs are wide, channel-like depressions crossing the shelf. Some of them have connections with the fjords. This marine landscape offer suitable habitat for sea-pen communities. At some sites the bamboo coral *Isidella lofotensis* has also been observed. This coral is one of the few gorgonian corals growing on soft bottoms, and is more common within the larger fjords (Hardangerfjorden, Trondheimsfjorden, and Andfjorden).

The shelf break

The area close to the shelf break is regarded as highly ecologically valuable. This is where the water masses are being vertically mixed and where a relatively high nutritional supplement leads to high plankton production. The area is also known for having many coral reefs, but prior to MAREANO most of these had not been accurately located, although often roughly indicated through by-catch in fishing gears. The shelf break marks the edge of the shelf where the seabed changes dramatically and turns into steeper sloping terrain leading down to the deep sea. The southern part of the shelf break is called Storegga, well known for gigantic prehistoric submarine slides, good fishing grounds and plenty of coral reefs.

The Continental Slope

MAREANO has investigated the seabed on the slope off mid-Norway down to 970 m depth. The sediments vary between gravelly and sandy sediments with local cobble and boulder fields in the upper part of the slope, to muddy sediments further down. Very compacted sediments are found locally in the Storegga Slide. The different sediments have different fauna, but the greatest differences in species composition is found between the three different water bodies with warm Atlantic water in the upper part and cold Norwegian Sea Deep Water in the lower part, and a thin mixed layer with Arctic intermediate Water in between. During the cruises the temperature in the Atlantic water was around 8 ºC while it was – 0.9 ºC at the deepest locations.

On the slope, below 500 m depth, the Greenland halibut is common. The active fisheries on this species are apparent from the frequent trawlmarks observed. The Storegga slide characterises the Storegga part of the slope. The slide area has a complicated rugged terrain with ridges, depressions and escarpments in various dimensions. (see chapter 7.1 – the Storegga Slide fact box).

At the slope below Storneset in the northern end of Storegga the boidiversity is high. Here we find several biotopes with characteristic megafauna. There are "meadows" with the feather star *Heliometra*, basket stars and broccoli coral meadows, stands with the sea-pen *Umbellula*, and coral and sponge gardens, coral reefs, and mud perforated by caves of the amphipod *Neohela* (figure 28, 29, and 30). Most common however, is seabed where it is difficult to recognise any characteristic or dominating species. To find differences and similarities between such undistinctive bottom communities the videos have to be analysed in more detail and followed up with statistical tests of the results.

7.2.3 Species richness

Species richness indicated from video is a good indicator of bio-diversity. A quick way of presenting species richness is by counting the number of observed taxa (identified and un-identified species) for each video transect (figure 31).

By comparing the results from estimates of taxonomical richness observed in the field with results from later video analysis, we see that the main patterns are similar. Locations near the shelf edge and at the inner part of the shelf are the most diverse. This is the same patterns as also reflected in the video results from the other areas mapped by MAREANO. Not surprising, the analysis of videos performed in the lab, after the cruises

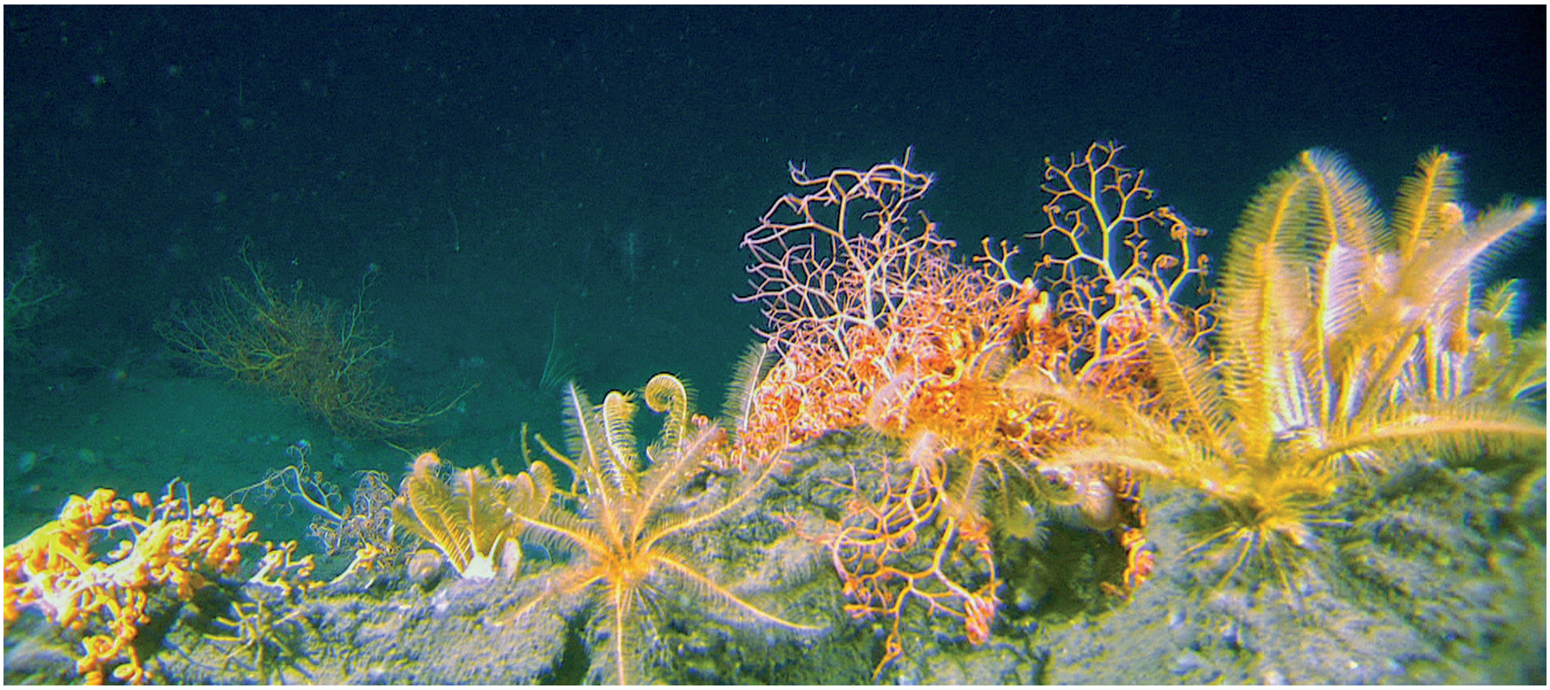


Figure 30. Basket stars (*Gorgonocephalus* sp.) and feather stars (*Heliometra* sp.) have colonised compacted sediments transported during underwater landslide activity. These organisms are mobile and can actively seek up exposed parts of the seabed to reach the best positions for filtering food particles from the currents passing by. In this picture we are crossing a ridge at a depth of 688 m

reveal much greater numbers of taxa. Up to more than 100 identified and unidentified species have been recorded along the 700 m long video transects.

7.2.4 Vulnerable and valuable habitats

Many of the habitats listed by the Oslo/Paris convention (OSPAR) as threatened and/or declining have been observed on the mid-Norwegian shelf and slope. After statistical classification of thousands of subsamples from the videos it is clear that some of the OSPAR habitats are defined to broad to reflect the variation in types of habitats defined

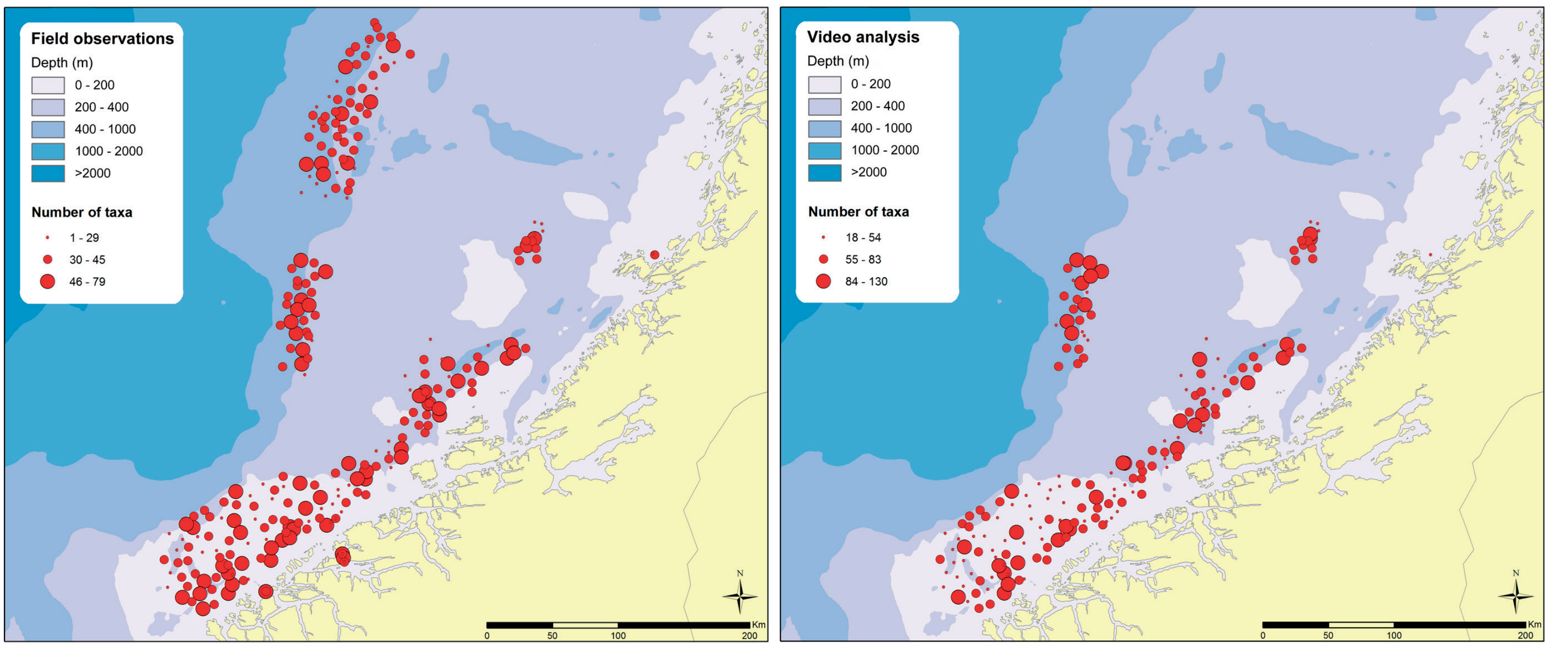


Figure 31. Biodiversity indicated by number of observed taxa during video recording in the field (to the left) and after full post-cruise video analysis (to the right). (post cruise analysis was not complete for the Skjoldryggen area in the north).

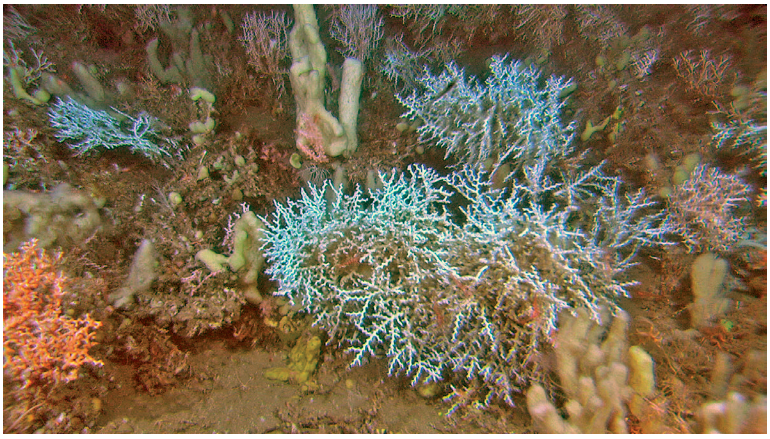



Figure 32. The deep coral reefs at Storneset are dominated by the stony coral *Madrepora oculata*. The upper picture shows both white and red varieties. Its Norwegian name "zig-zag coral" describes it shape very well. In the lower picture we have zoomed in so we can see the polyps with tentacles out to capture zooplankton.

by sea pens, coral and sponges. MAREANO has identified that sponge aggregations occur in Norwegian waters as three separate types: hard bottom sponge aggregations, soft bottom sponge¸ aggregations, and deep-sea glass sponge communities. The coral gardens can be divided into soft bottom coral garden and hard bottom coral garden. The *Umbellula* stands are not covered by the OSPAR habitat Seapen and burrowing megafauna communities but appear to be important vulnerable habitats in this region of Norway. On the mid-Norwegian shelf and slope all of these habitats were present except for soft bottom coral garden.

Coral reefs

Mid-Norway has become well known for its numerous cold-water coral reefs, which occur both coastal and offshore. The coral reefs are the habitat that is easiest to identify in the field. In Norwegian waters they are with only a couple exceptions, made of the stony coral *Lophelia pertusa* (see fact box in chap 4.2).

The coral reefs are probably the most species-rich habitat in Norwegian waters.

Important commercial fishes such as common redfish ling, tusk and saithe are often numerous on the reefs. The common redfish is listed as "endangered" on the Norwegian Redlist from 2010.

The MAREANO-records are valuable not only because of the precise location but also because they provide information about state of the reefs.

The deepest records of reefs made by MAREANO are from around 450 m depth at the northern part of Storegga. These deep reefs were unusual compared to all others observed since they were dominated by another stony coral *Madrepora oculata* (figure 32) and not *Lophelia pertusa*. Here *Lophelia* occurred as small scattered colonies – the opposite of what otherwise is regarded common in Norwegian waters. This could be related to the environment at this depth close to the border to the colder water masses.

Most of the reefs on the mid-Norwegian shelf and slope are alive, but to confirm this at new locations we have to survey larger parts of the reefs with video. The live parts of a cold-water coral reef can cover a very limited area. This is especially evident on the elongated reefs growing towards a more or less uni-directional current. The live corals here may cover less than the area of a living room, while the whole reef may be a couple of hundred meters long and around 50 metres wide.

Out on the shelf we can find coral reefs that appear to have been completely destroyed by bottom trawling. Several damaged reefs have been observed in mid-Norway, especially along the Storegga shelf break (figure 33). The reef structures take a long time to develop but not much bottom trawling effort is needed before

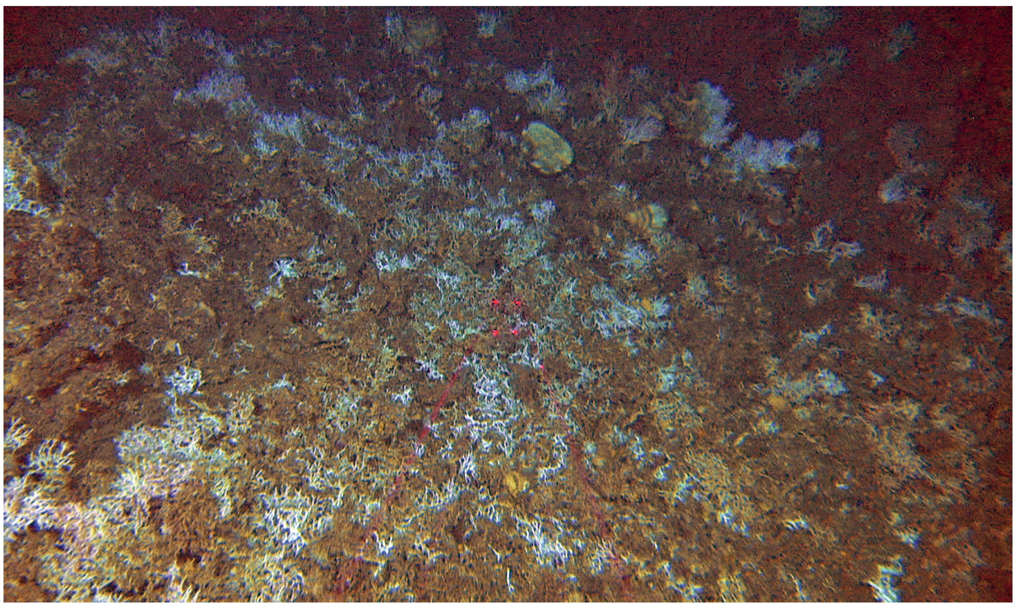


Figure 33. Crushed corals at Storegga. Bottom trawling is the major threat to the corals here, but also gill net and long-line may easily break the skeletons.

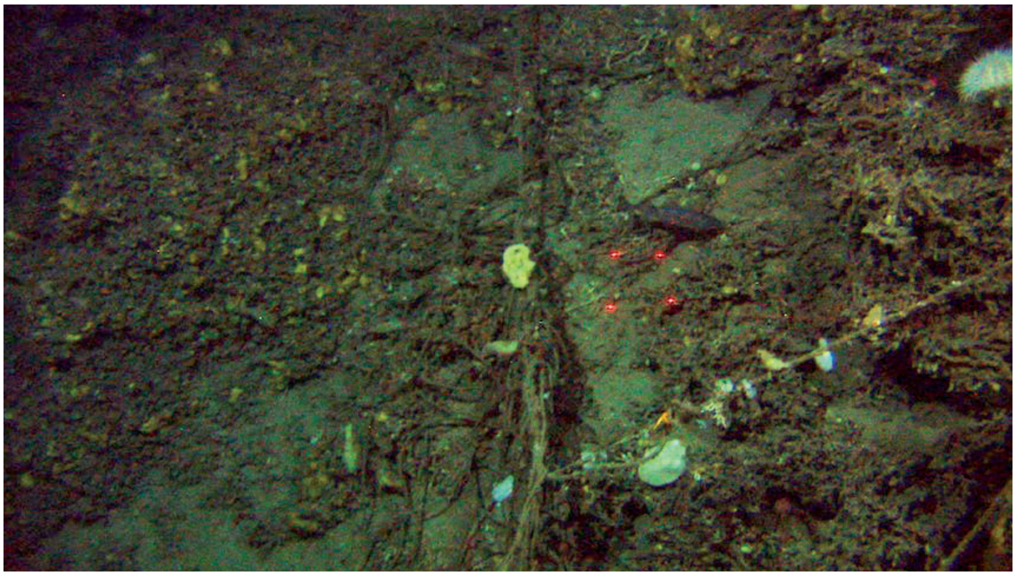


Figure 34. Lost fishing gear in the midst of dead corals on the seafloor at Iverryggen. It is not possible to determine how long this gear has been here.

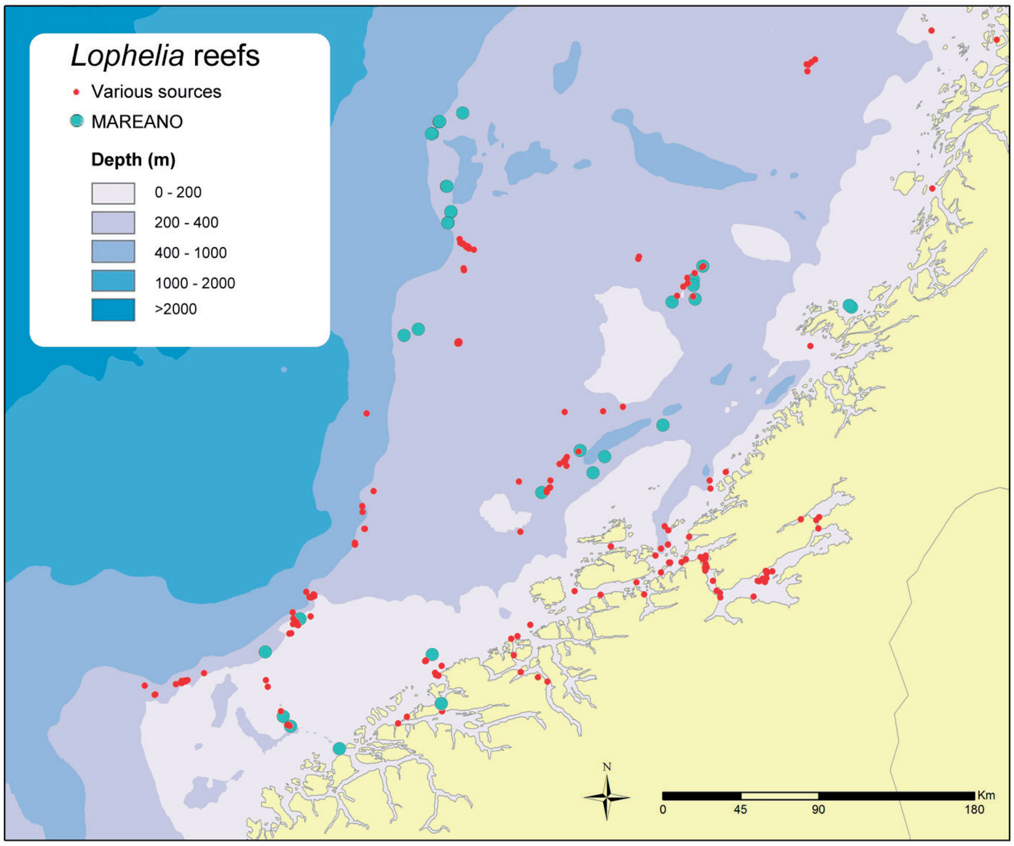


Figure 35. Verified occurrences of *Lophelia*-reefs off mid-Norway. Observations made during MAREANO-cruises are indicated with turquoise dots. Red dots marks earlier records from scientific reports, environmental reports from the petroleum industry and from fishers.

they are gone. This is the background for the implementation of the Norwegian fisheries acts from 1999 prohibiting intended damage on known reefs. Fishing with so called passive gear (nets and long lines) is still allowed within the protected area. Such gears can also cause damage to coral reefs (figure 34), but the extent of damage is considered much sless than that caused by bottom trawling.

Geographic distribution of coral reefs

The map (figure 35) shows an overview of all verified coral reefs in mid-Norway. Green dots indicate 20 new reefs discovered during MAREANO cruises, while the red dots indicate previously known reefs. Geological interpretation of multibeam data has indicated so-called "bioclastic sediments", a class of sediments that may contain living or dead corals, but also other fragments of biogenic origin such as shells (see e.g. chapter 7.1.4). These bioclastic sediments indicate likely coral reefs, but it remains to be confirmed how accurately the mapped occurrence of bioclastic sediments estimates the actual distribution of coral reefs with live coral cover. We focus here on coral reefs where the presence of live cold-water coral has been verified using video.

The coral reefs occur mainly in three types of terrain: 1) along the shelf break, 2) on ridges and local elevations on the shelf, and 3) glacial troughs. In coastal areas coral reefs are found in other geomorphic settings, for example occurring on crystalline bedrock.

The Sula Reef and Iverryggen are major cold-water coral reef areas on the mid-Norwegian shelf. When the Norwegian oil company, Statoil, discovered lots of cold-water coral reefs on the Sula Ridge in the 1990's research on such reefs was boosted, not only in Norway but also internationally. Prior to the discovery of the Røst Reef by IMR in 2003, the Sula Reef was the largest known cold-water coral reef complex in the world. Based on interpretation of multibeam echosounder data Sula Reef comprises around 500 individual coral reefs. Many of these have already been verified to be living cold-water coral reefs and in 2012 MAREANO inspected two of the reefs here that were not verified earlier. The Sula Reef was designated a Marine Protected Area (MPA) protected in 1999, and the area inside the MPA was the focus of MAREANO mapping. Nevertheless, multibeam bathymetry data acquired from the research vessel G.O.Sars during MAREANO cruise during transit from Iverryggen to Sula indicate that coral reefs also extend outside the designated MPA border in the northern end of the reef complex (figure 36).

Iverryggen, justNorth of Haltenbanken, is a nearly 20 km long ridge created by moving ice (see chapter 7.1.5). Iverryggen rises more than 130 meters above the otherwise fairly flat topography of the surrounding seafloor. Many coral reefs are found on the slopes of Iverryggen. This area is protected against bottom trawling. Multi beam data indicate that it is especially a narrower ridge projecting southwest from the main ridge where the reefs are abundant. In 2012 four new live reefs were documented during a MAREANO cruise. Observations made during this survey confirm damage to coral reefs in the area. Most reefs are quite small, and appear to have limited amounts of live coral.

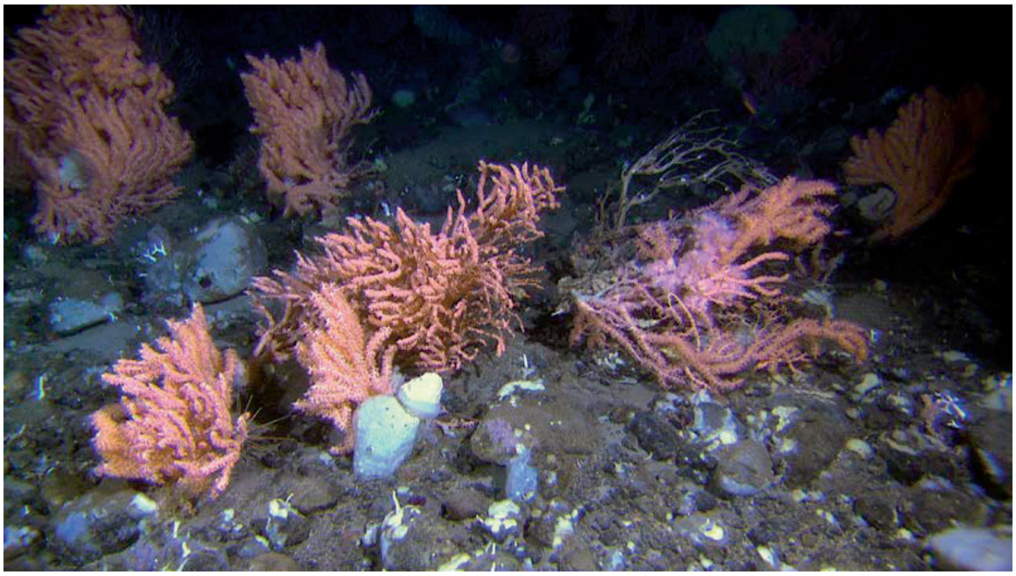


Figure 38. Hardbottom coral garden with *Primnoa resedaeformis* on rugged seabed with cobbles, gravel and sand at around 460 m depth.

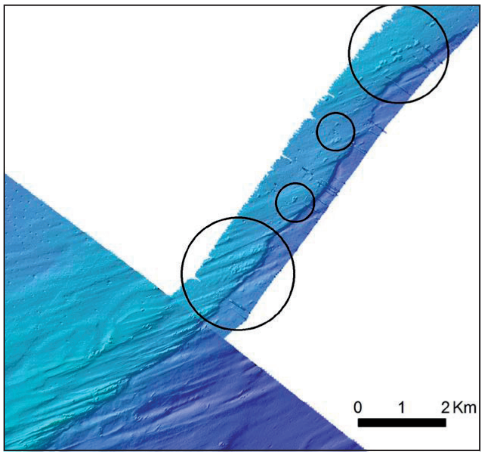


Figure 36. New likely coral reefs (encircled) at the NE extension of the Sula reef complex indicated from multibeam data.

Fishermen have known about the reefs on Iverryggen since bottom-trawl fishing started here in the 1990s. In 1999, IMR investigated the seafloor in five areas of Iverryggen, and extensive trawl damage to coral reefs was observed within all areas. Available information indicated that there were plenty of coral reefs on Iverryggen, and to prevent their destruction, the area was closed to bottom trawling in 2000.

Rich coral reef areas are also found in Breisunddjupet at Mørebankene, and several places just inside the shelf break, especially North of Skjoldryggen, and at Aktivneset, southern part of Storegga.

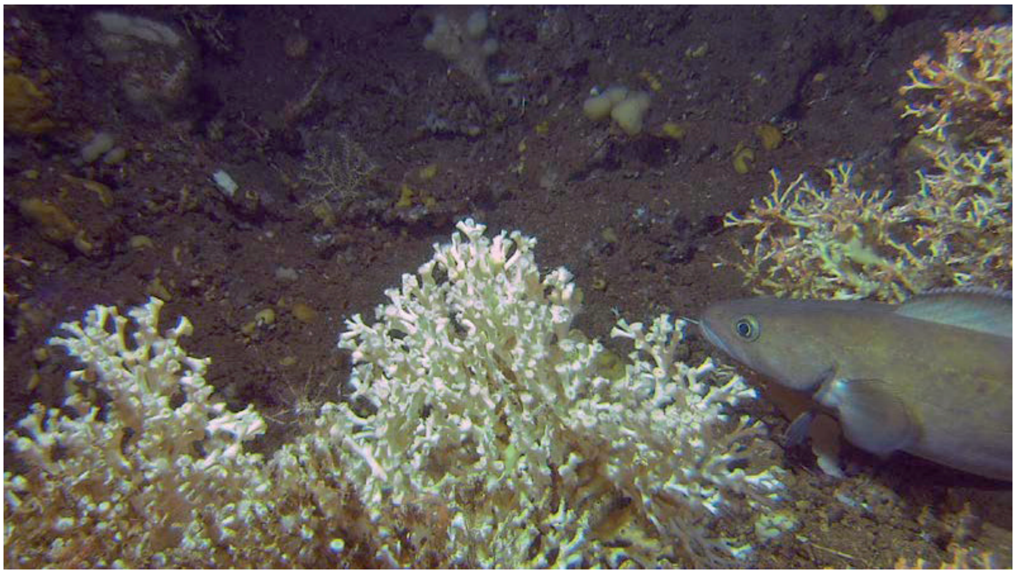


Figure 37. A tusk (*Brosme brosme*) moving slowly around on a *Lophelia* reef at 293 m depth at Storneset.

Hard Bottom Coral Gardens

Hard bottom coral garden may contain the gorgonian species *Paragorgia arborea*, *Primnoa resedaeformis* (figure 38), *Paramuricea placomus*, *Anthelia borealis*, and *Anthothela grandiflora* in various combinations. The last two of these species, however are most commonly found on coral reefs. MAREANO has recorded occurrence of gorgonians that can form coral gardens on hard bottom at 22 locations along the shelf break. Only at a few locations do they occur in sufficient densities that they could be called "coral garden". The general distribution of the hard bottom gorgonians seem to overlap with the regions where the coral reefs occur.

Sponge communities

Hard bottom sponge aggregations (figure 39) are quite common in the area, while soft bottom sponge aggregations are much less

Figure 39. Hard bottom sponge garden with foliaceous sponges (*Axinella* sp. and *Phakellia* sp.), various encrusting sponges, broccoli corals and anemones on mixed seabed at around 490 m depth.

common off mid-Norway than previously observed at Tromsøflaket and Eggakanten.

Sea-pen communities

Dense stands of sea-pens are most common in marine valleys with sandy mud or muddy sand on the shelf, but they may occasionally be found at greater depths at the slope (figure 40). The most common species in mid-Norway were *Kophobelemnon stelliferum*, *Virgularia mirabilis*, and *Funiculina quadrangularis*. *Pennatula fosforea* and species of the genus *Halipteris* have also been observed a few time.

7.2.5 Distribution of modeled biotopes

A map showing the predicted distribution of biotopes for parts of the mid-Norwegian shelf and slope (figure 16) has been produced based on video data from MAREANO 2012 and environmental predictors derived from bathymetry data together with interpreted sediment and landscape maps. Biotopes are regions with similar communities of animals living on the seabed, in a similar physical environment. The biotope maps provide a basis for the evaluation of vulnerability, species richness and uniqueness in a particular area of the seabed. This is important information when developing management plans and other advice related to the use of marine areas.

The biotope map (figure 41) shows where each biotope is predicted to be most likely to occur based on modeling results. Seven different biotopes were identified based on classification of video samples with similar species composition. Their characteristics, based on seabed video observations, are summarised in below The biotopes are quite broadly defined and biotope 1, 3 and 4 also contain vulnerable OSPAR habitats.

All the biotopes, with the exception of number 5 occur with the depth range of Atlantic water. Biotopes 7, 6 and 1 are closely linked to the different types of sediments occurring on the banks. Biotopes 2 and 4 typically occur in marine valleys which transect the continental shelf. Biotope 3 is characterised by coral reefs and coral forests on various bottom types, often with ridges of various geologic origin. Biotope 5 represents the deepest parts of the study area and is dominated by deep sea fauna in cold Norwegian Sea water.

Biotope 1 (dark brown) is typically found in rugged terrain, relatively shallow at an average depth of 150 m. It is characterised by hard bottom sponge aggregations, commonly represented by the foliaceous and arborescent *Phakellia* spp., *Axinella infundibuliformis* and *Antho dichotoma*. In addition a variety of other attached sponges may occur in high densities. The map shows that this biotope is most common in the inner part of the mapped area, where the outcropping, or thinly covered bedrock provides suitable substrate for many of the animals.

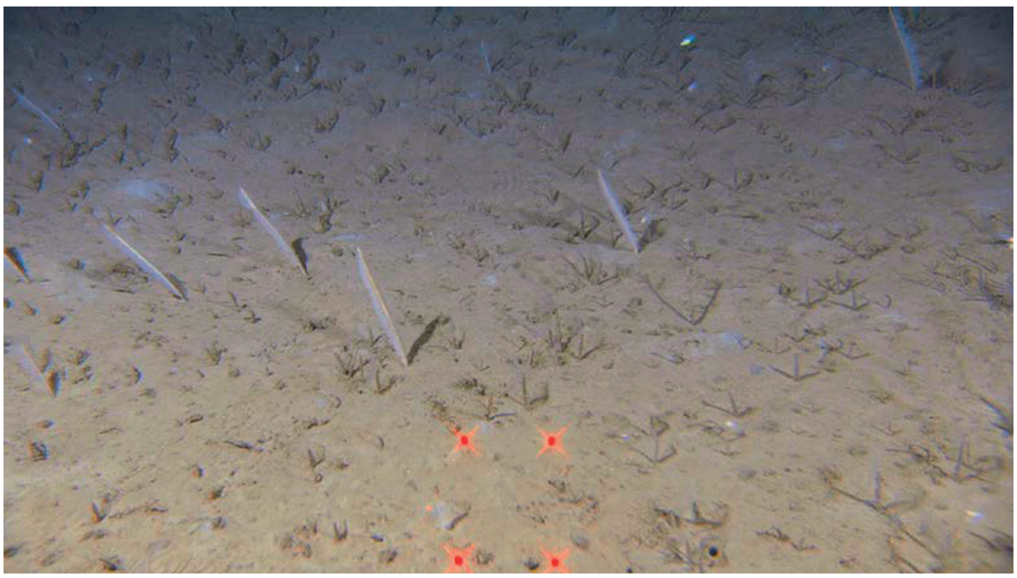


Figure 40. The seapen *Funiculina quadrangularis*,together with sabellid tube worms on soft bottom at around 760 m depth.

Biotope 2 (turquoise) occur mainly on sandy mud, and muddy sand in the marine valleys on the shelf. The solitary stone coral *Flabellum macandrewi*, and the tube anemone *Pachycerianthus multiplicatus* characterizes this biotope.

Biotope 3 (pink) contains almost all of the observed occurrences of cold-water corals, both gorgonians and coral reefs. It is the wider "coral biotope" yet extension of this biotope on the predicted map down into much deeper water on the slope than the known distribution of cold-water corals reflect the fact that it is much more broadlydefined and not just limited to the extent of the coral species. However, the limited number of video samples from the deeper parts of the shelf edge and slope on which this modeling is based may also have led to sub-optimal classification and prediction. The existing maps will be updated and extended to include new video data from surveys after 2012 using relevant predictor variables.

Biotope 4 (green) is dominated by sea-pens. It occurs on sandy mud in shallow wide marine valleys.

Biotope 5 (blue) represents the deepest parts (>700 m) of the mapped area. The sediment is commonly mud, and the fauna represents species thriving in cold water including broccoli coral and basket stars. Common species are: *Gersemia rubiformis*, *Gorgonocephalus* sp., *Bythocaris* sp., *Cerianthus vogti*, and *Drifa glomerata*.

Bioptope 6 (orange) covers the continental shelf plain and shallower regions of marine valleys, often slightly eastward facing. The sediment is typically sandy. Typical taxa are *Ditrupa arietina*, *Luidia* sp., *Molva molva*, *Trisopterus* sp.

Biotope 7 (red) is the Continental shelf plain (banks) mainly above 200 m with sandy and coarser sediments. The fauna is represented by various hard bottom dwelling animals and cod. *Gadus morhua*, *Phakellia* sp., *Psolus squamatus*, ubnidentified Zoanthidae, are common taxa in this biotope.

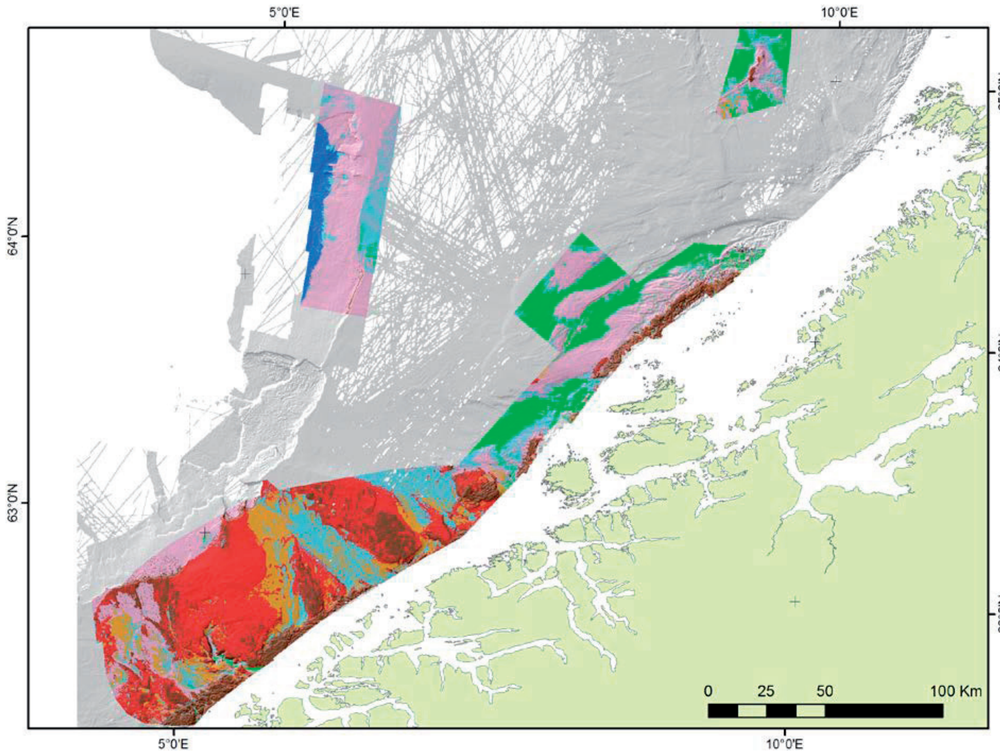


Figure 41. Predicted spatial distribution of biotopes from modelling in the studied area of the Norwegian Sea. The biotope map is shown as a semi-transparent layer over a shaded relief map of combined multibeam and Olex (single beam) bathymetry data which was the best available data in this area at the time of modelling. See text for colour legend and details on the physical and biological characteristics of each biotope.

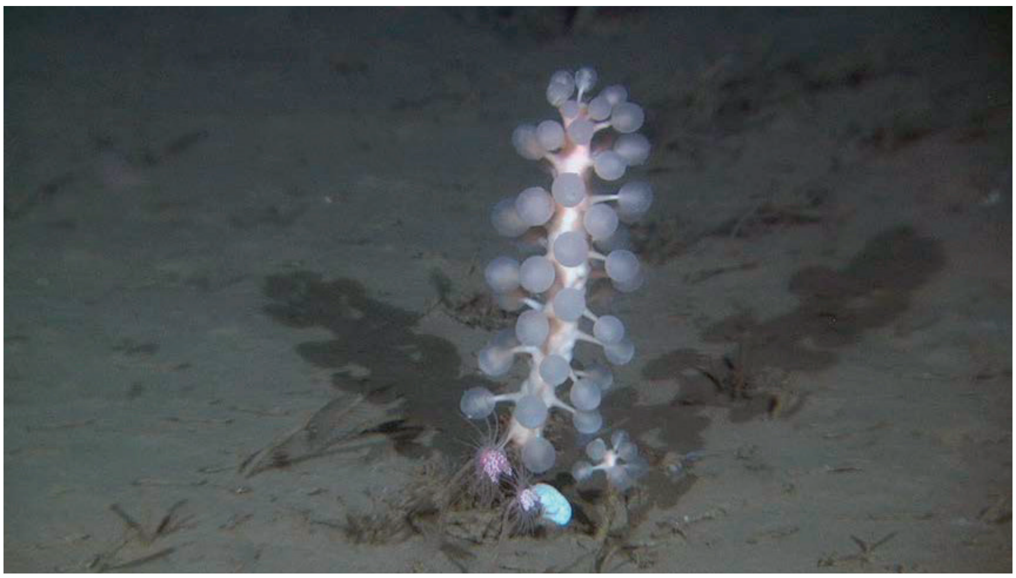


Figure 42. On the muddy bottoms in the deep Norwegian Sea the fascinating carnivorous sponge *Chodrocladia gigantea* can be found. This image is taken at 770 m depth.