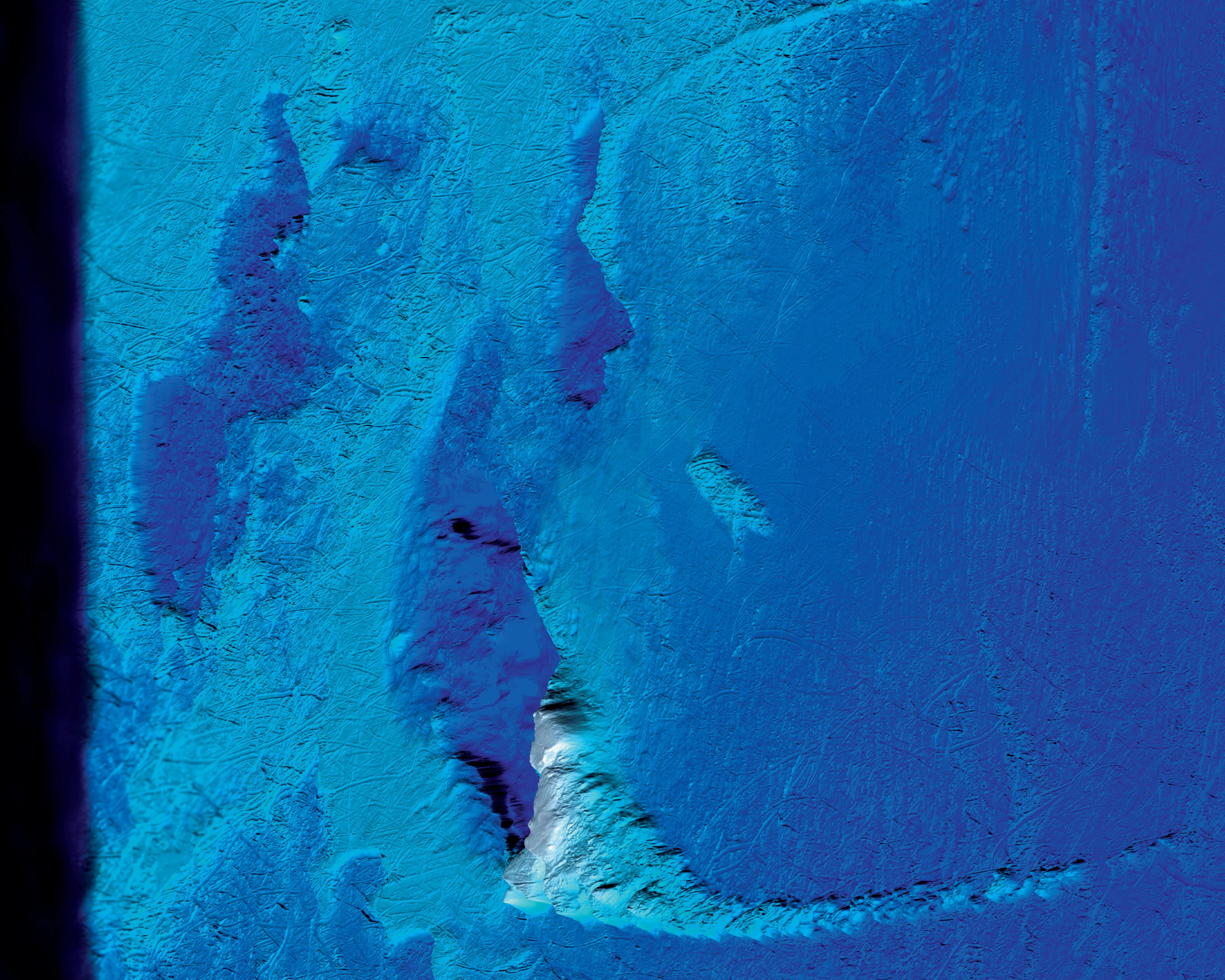

TROMSØFLAKET, EGGAKANTEN AND THE AREAS OFF FINNMARK

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The Tromsøflaket bank area was formed by large glaciers that transported boulders and finer sediments westwards. The Eggakanten marks the border between the shallow parts of the Barents Sea and the slope leading down to the deep sea. A rich benthic fauna including large sponges and squat lobsters are common on the Tromsøflaket. At the Eggakanten additional habitats are present which includes the Basketstar and the Pigtail coral.

3.1 THE SEABED – MARINE LANDSCAPES, GEOLOGY AND PROCESSES

3.1.1 – Large Landslides and Shallow Banks

"Tromsøflaket – strong wind from the northwest, decreasing in the afternoon. Waves 4 to 8 metres." Tromsøflaket and several other areas studied by MAREANO (figure 1) make regular appearances on the radio's shipping forecasts. These areas have played, and still play, an important role in providing food and income for the coastal population in Northern Norway, and ultimately for the whole country. Moreover, they are home to benthic fauna crucial to the ecosystem, such as the large areas covered in colourful sponges.

Ingøydjupet – *the Ingøy Deep* – is situated just east of Tromsøflaket and is filled with mud and peculiar round depressions on the seabed. If we move a few hundred kilometres west, we find the continental shelf edge – the so-called Eggakanten. The area designated as Eggakanten in the Management Plan lies west of Tromsøflaket and is about 60 kilometres wide. However, it is important to remember that the shelf edge is everywhere where the continental shelf plain meets the continental slope. This is where the rather flat marine landscape of the Barents Sea ends and the continental slope starts, running down towards the deep sea – in the Norwegian Sea down to several thousand metres. In the upper part of the slope, just off the shelf edge, there are concentrations of Greenland halibut that thrive in these conditions. Bjørnøyrenna – a wide

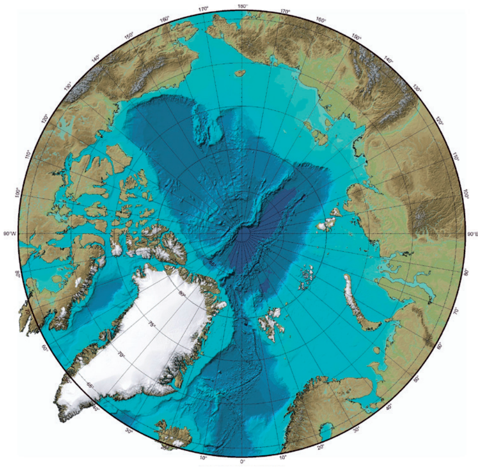


Figure 2. Map of the Norwegian Sea and the Barents Sea with the Polar Sea in the north (IBCAO).

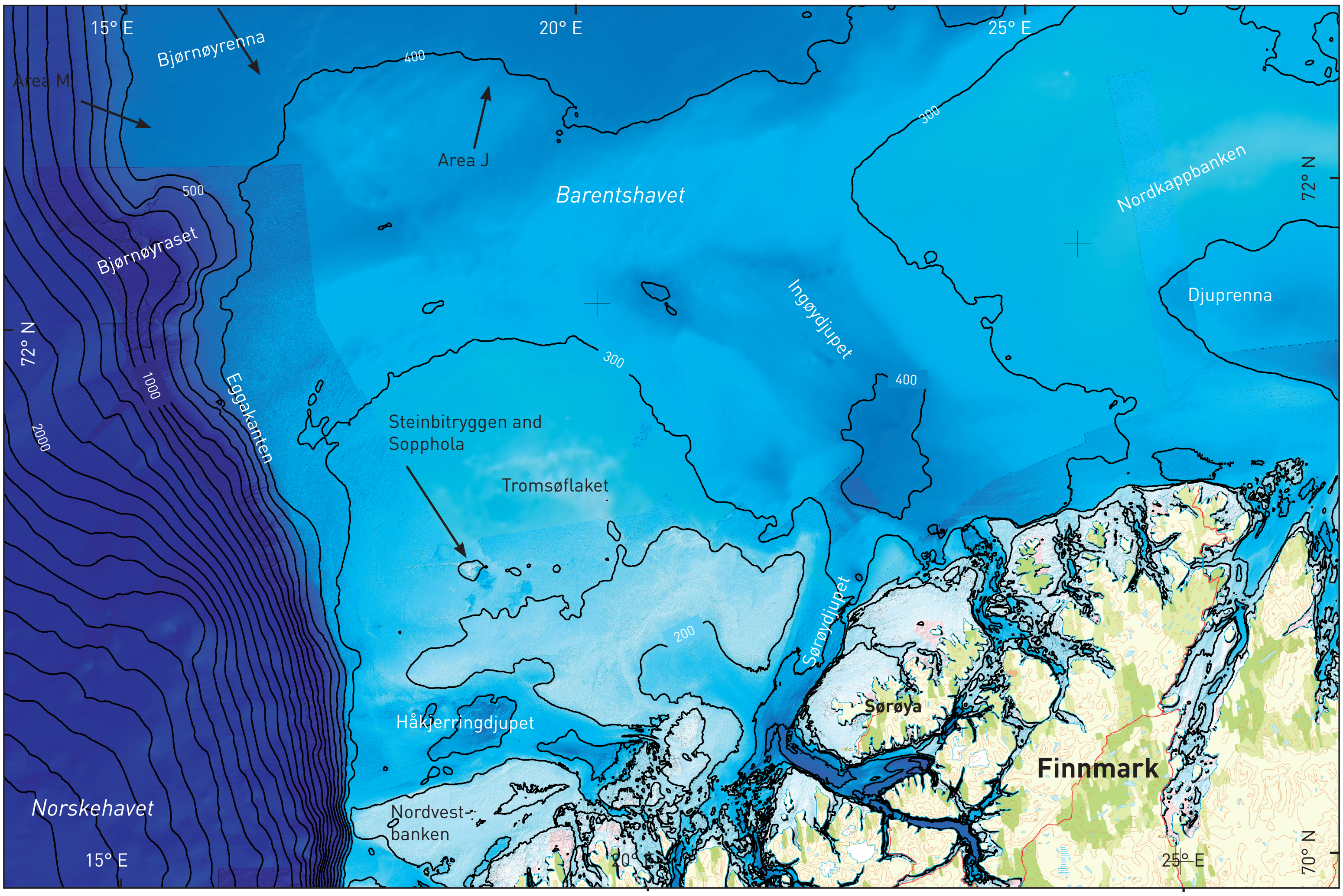


Figure 1. Map of Tromsøflaket, Eggakanten and the areas off Finnmark.

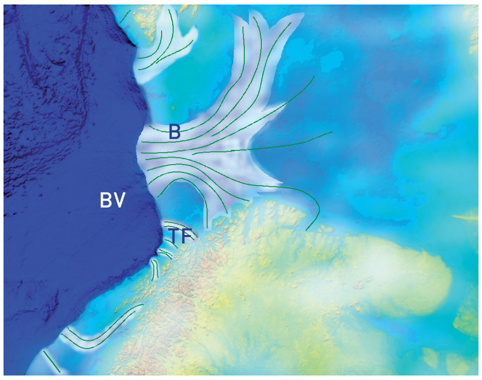


Figure 3. Towards the end of the last ice age, Bjørnøyrenna (BR) between Tromsøflaket (TF) and Bjørnøya (B) received its final shape. Large amouns of sediments were deposited on the continental slope, forming Bjørnøyvifta (BV - the Bear Island Fan).

Ice Cold Northern Wind

About 3 million years ago, cold winds started sweeping over the northern hemisphere. The climate turned considerably colder and the glaciers started to grow. With time, the ice masses covered the whole of Scandinavia and, for periods, filled the Barents Sea (figure 3). Over several periods, the ice moved west in the Barents Sea, towards the shelf edge. On its way, it picked up boulders and finer sediments from the seabed and pushed it forward like a bulldozer. In areas where the ice moved rapidly, it dug out marine valleys such as Bjørnøyrenna and Ingøydjupet. Shallow banks such as Tromsøflaket and the areas around Bear Island exist because the ice left some areas intact. But here too, there could be local ice domes for periods of time while at other times sediments were deposited here. At the shelf edge where the continental slope starts and the water becomes deeper, the ice lost contact with the seabed. It started to float and break up into large icebergs, and then dumped the sediments that had been transported from the Barents Sea and the surrounding areas.

Tromsøflaket, Fugløybanken and Nordvestbanken

Tromsøflaket is an area of about 25,000 km^2 northwest of Sørøya off Finnmark (figure 1). The name contains the word ”flak”

marine valley – lies north of Tromsøflaket and stretches several hundred kilometres northeast.

But... why is this? Why is the Barents Sea so flat, why do we find banks and deep channels, and why does the flat Barents Sea stop at the shelf edge? The answer lies partly in volcanic activity and cracks in the Earth's crust that started 60 million years ago, and partly in a dramatic climate change that started three million years ago.

Volcanoes in the Norwegian Sea

Imagine if a ferry trip from Norway to Greenland only lasted for a few hours. 60 million years ago, that would have been the case as the deep sea between the two countries did not exist. Instead, there was a relatively shallow sea, warm enough to go for a swim. Thick deposits of sand and clay had been transformed into sandstone and shale and, where the conditions were right, organic matter was transformed into oil and gas. But 55–60 million years ago, something quite dramatic started to happen. The Earth's crust cracked along a zone now stretching through the whole of the North Atlantic, passing under Iceland and between Greenland and Svalbard. The tectonic plates on each side of the crack started to drift apart as volcanic material from the centre of the Earth forced its way up. A spreading zone appeared and, with time, a deep sea was formed – the deep sea that we call the Norwegian Sea.

Where the Barents Sea is today, there was dry land for long periods. Large rivers must have run across flat plains, and in the western areas, these rivers transported sand and gravel out to the coast where it was deposited in large fans. Up to 1000 metres thick layers of clay, sand and gravel were deposited on the continental slope and along what we call the shelf edge today.

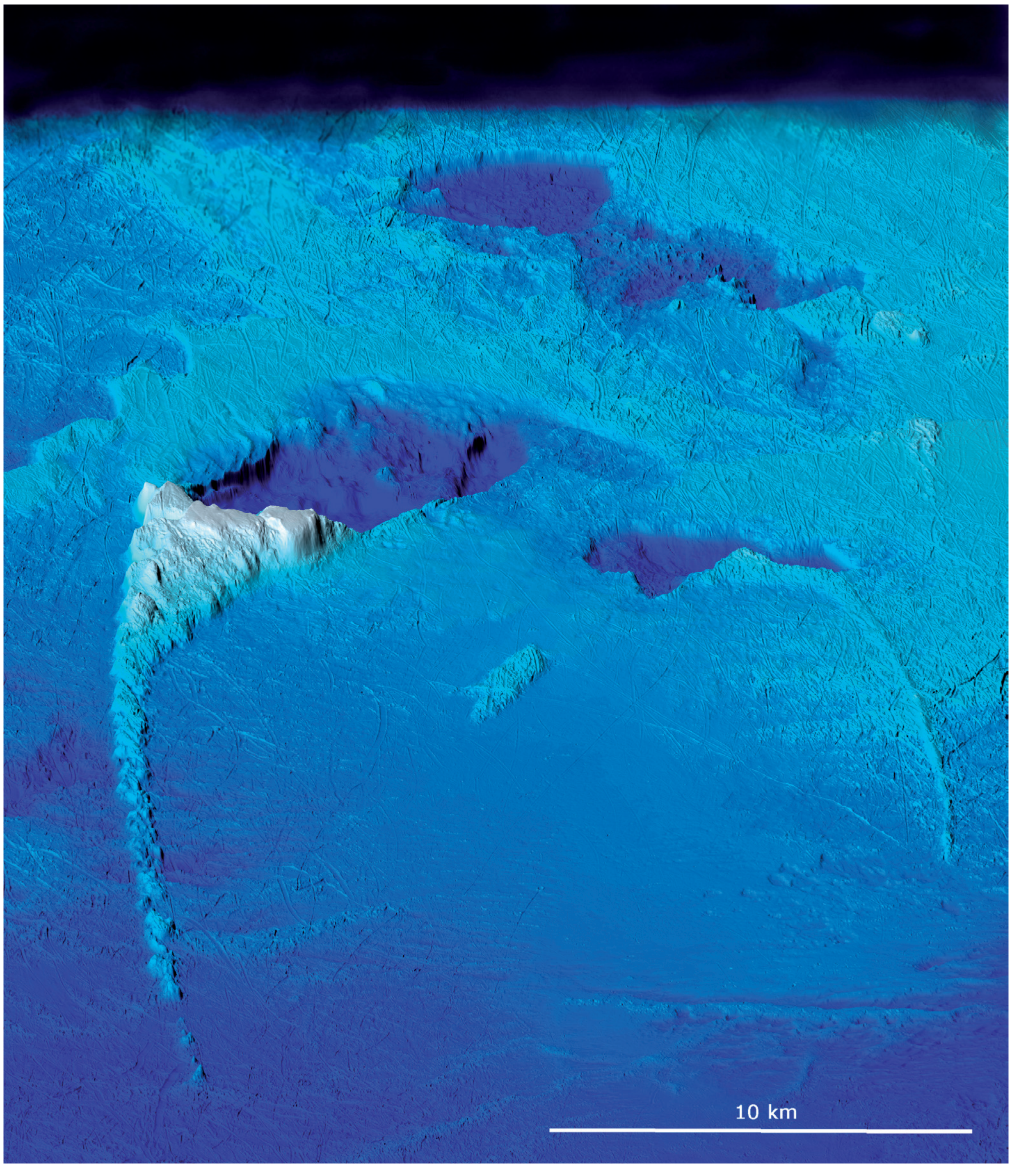


Figure 4. The almost 100 metres high Steinbitryggen on Tromsøflaket was built by the ice around 15,000 years ago. The sediments came from the depression Sopphola.

Marine landscapes

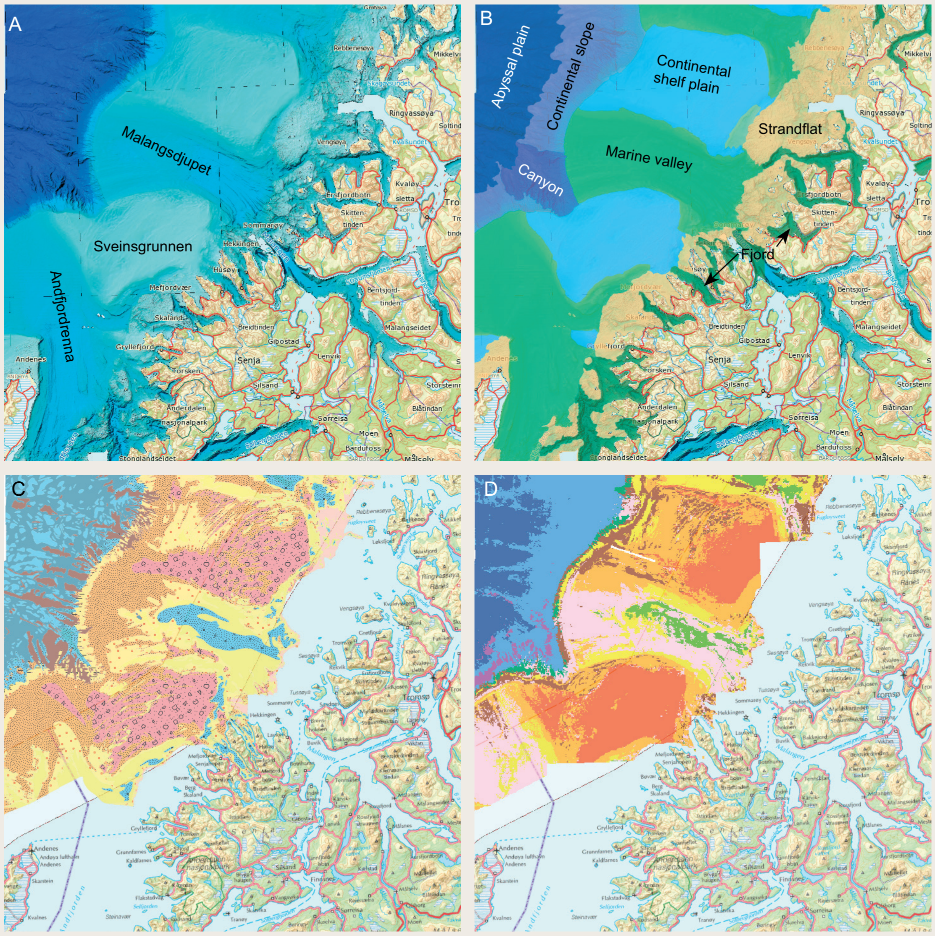
Varied landscapes of mountains and valleys are concealed deep beneath the water surface. Thanks to modern technology, it is possible to delineate these underwater landscapes with great precision. Marine landscape mapping is concerned with describing the main features in the seabed topography. The classification performed here is based on "Naturtyper i Norge - NiN".

For more information on this, see
http://www.artsdatabanken.no/temanaturtyper

Bathymetric data enable us to determine which areas should be classified as plains, continental slopes etc. We use a low-resolution bathymetry data and parameters that can be computed from these data. We have developed a GIS-based method that enables us to define the boundaries of features in a manner that is objective and reproducible.

In MAREANO mapping, landscape is defined as "large geographical areas with a visually homogeneous character". The mapping has so far covered the following types of landscapes:

- Strandflat. The low lying crystalline platform which characterises large parts of the Norwegian coast and which contrasts sharply with the sedimentary continental shelf and the more hilly/mountainous areas in the landward direction.
- Marine valleys. Eroded into the continental shelf and the strandflat, and a result of concentrated glacial erosion during the ice ages.
- Fjords. Over-deepened erosion forms which cut into the land and terminate at a threshold.
- Continental shelf plain. The residual landscape on the continental shelf, where the relief is predominantly low, but with areas that are morphologically similar to other types of landscape (particularly shallow marine valleys).
- Continental slope. The transition zone between the continental shelf and the deep ocean. In several places it is transected by large and small submarine canyons.
- Canyons. Submarine ravines formed by erosion on the continental slope.
- Deep sea plain. Starts at the foot of the continental slope and comprises all deep sea areas with low relief, including the continental rise.



The link between bathymetry (A), landscapes (B), and distribution of sediments (C) and biotopes (D) is evident. Marine landscapes have a significant influence on where different types of sediments and biotopes occur.

basic facts

– *flake* – indicating something flat and torn loose, which describes its shape well. The area is bordered by Lopphavet and Sørøydjupet towards the coast, by Ingøydjupet in the northeast, by Bjørnøyrenna in the north, by the continental shelf in the west and by Håkjerringsdjupet in the southwest. The water depth goes from 114 metres at Fugløybanken, which is the southwestern and shallowest part of Tromsøflaket, to about 350 metres in the north.

The ice deposited thick sediments on Tromsøflaket on its way west towards the shelf edge. The whole bank is dominated by this moraine, a mix of everything the ice tore loose and transported west – from clay to large boulders. There are numerous indications of how the last ice cover formed Tromsøflaket. In the shallowest areas by the shelf edge, we find moraine ridges – up to 40 metres high, 2 kilometres wide and 40 kilometres long - formed during periods where the ice front was stable. In the northern part of Fugløybanken, we find some distinctive elongated ridges up to 90 metres high, 5 kilometres wide and tens of kilometres long. At their starting point, we find large, deep depressions – often up to 5 x 5 kilometres and almost 100 metres deep (figure 4). These were formed when the ice dug up sediments from places where the depressions are today and deposited them at the ridges. These bottom features are good examples of how the fishermen have given geological structures names that reflect the ecosystems: "Steinbitryggen" – *Catfish Ridge* – and "Sopphola" – *Sponge Hollow*.

Nordvestbanken – *the Northwest Bank* – situated off the islands of Ringvassøya and

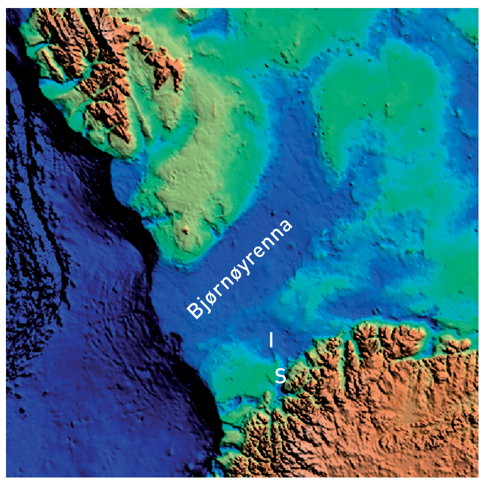


Figure 5. Bjørnøyrenna is a very large marine valley dug out by the glaciers which have covered the Barents Sea several times (I - Ingøydjupet; S - Sørøydjupet).

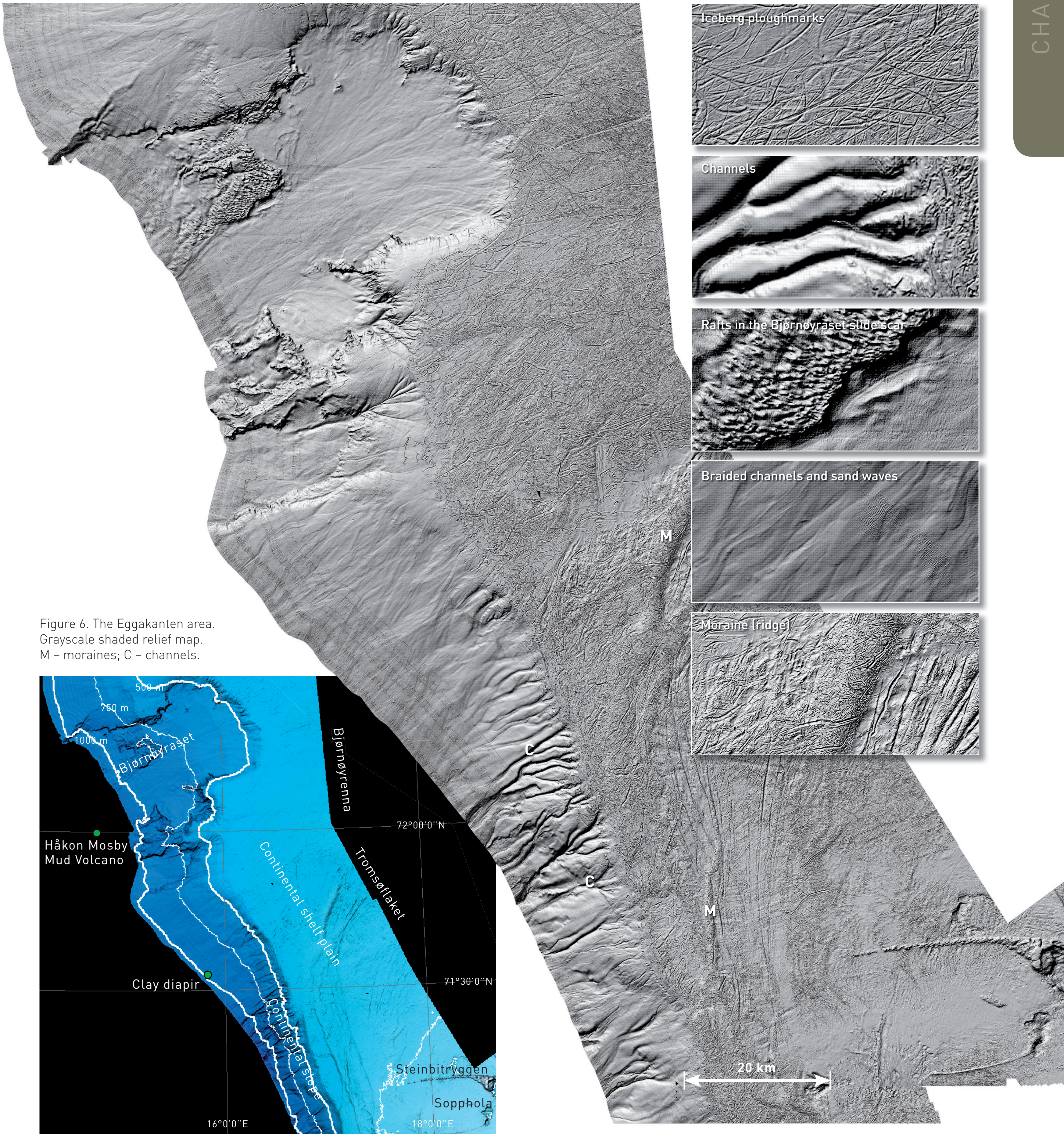


Figure 6. The Eggakanten area. Grayscale shaded relief map. M – moraines; C – channels.

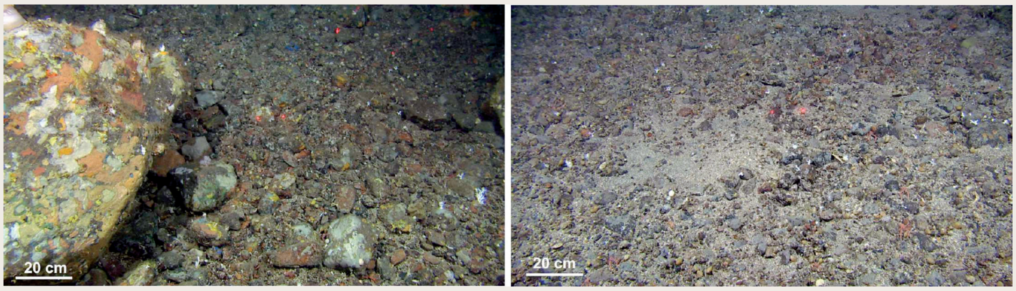
General about erosion, transport and deposition of sediments

The large scale landscapes of the seabed are created by geological processes that have occurred over millions of years. After the ice sheet melted away from the shelf around 15 000 years ago, the seabed has been shaped mainly by waves and currents.

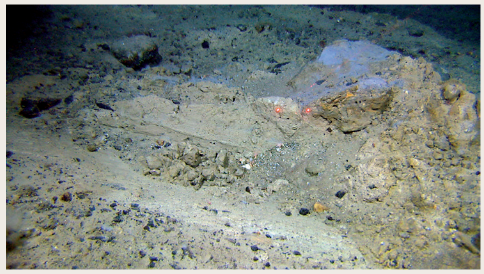
Around 15 000 years ago, the sea level was around 100 metres lower than it is today, and many of the banks, or continental shelf plains, were in shallow water. It was shallow enough for storms and large waves to erode and move large blocks. As the sea level rose, the waves had less impact on the seabed.

Erosion of the seabed and movement of bottom sediments is nowadays caused by strong bottom currents. This can be tidal currents, or more stable ocean currents such as the Norwegian Coastal Current and the Atlantic Current (see chapter 9). The ocean currents are often, but not always strongest close to the sea surface and in shallow areas. The strength and direction are influenced by wind conditions, tides and the topography of the seabed. Bottom currents have caused strong erosion of shallow banks consisting of till deposited by glaciers. This material normally contains a mixture of many different grain sizes. Fine grained sediments such as clay, silt and sand are eroded by the currents, and transported to places with weaker currents. A lag deposit is left behind, usually consisting of gravel, cobbles and boulders. The thickness if this lag ranges from a few centimetres to a few decimetres. The lag deposit will often act as a protecting layer, preventing further erosion of the seabed.

Human impact, for example bottom trawling may puncture or remove the lag deposit, and the underlying sediments are exposed. This may lead to further erosion and transport of sediments by bottom currents. High rates of mud deposition in Ingøydjupet is possibly caused by an increase in supply of fine grained sediments due to bottom trawling.



Lag deposit on the seabed, consisting of gravel left behind after removal of the more fine grained sediments by bottom currents. Lag deposits are very common on most of the banks, such as here on Nordgrunnen offshore Vesterålen.



Trawl marks on the seabed. Bottom trawling may lead to the seabed being plowed like a field onshore. In this case, the lag deposit has been destroyed, leading to renewed erosion of the seabed.

basic facts

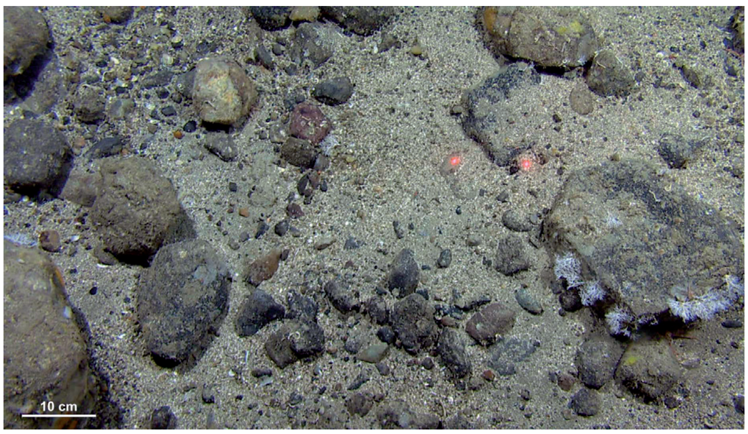


Figure 7. Sandy gravel and gravel, cobbles and boulders are typical bottom types on shallow bank areas and moraines. Bottom currents prevent deposition of fine-grained sediments. The picture is from a moraine near Sopphola on Tromsøflaket.

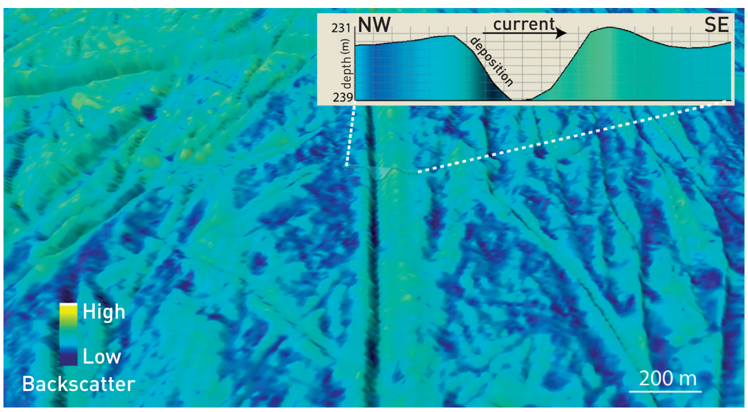


Figure 8. Iceberg ploughmarks at Tromsøflaket. The figure shows bottom reflectivity in colours draped over a shaded relief map created by illuminating the terrain with a low, artificial sun in order to create shadows in depressions and behind elevations. In this area, the finer sediments (blue colours) are deposited on the north and west facing slopes of ploughmarks, indicating that the bottom currents in the area mostly run northwest.

Vannøya in northern Troms, is a 400 km^2 large bank area bordered by Håkjerringdjupet in the north, Rebbenesdjupet in the southwest and the coastal zone in the southeast. Just like Tromsøflaket, Nordvestbanken also consists of moraine. Moraine ridges occur particularly in the east. Sand waves occur in several places on the western part of the bank area, while elongated ridges and depressions indicate how the ice once slid along the seabed on its way towards the shelf edge in the west.

Håkjerringsdjupet, Sørøydjupet, Ingøydjupet and Bjørnøyrenna

Tromsøflaket is surrounded by the marine valleys, Håkjerringsdjupet – *the Greenland Shark Deep* – (between Fugløybanken and Nordvestbanken), Sørøydjupet – *the South Island Deep* – Ingøydjupet – *the Ingøy Deep* – and Bjørnøyrenna – *the Bear Island Trench* – the last being the biggest (figure 5). Over 500 kilometres long, almost 200 kilometres wide and in places deeper than 400 metres, Bjørnøyrenna is by far the largest erosion depression in the Barents Sea. In some places inside the depression, there are parallel ridges and trenches formed below the ice in the direction of the ice movement. Just east of

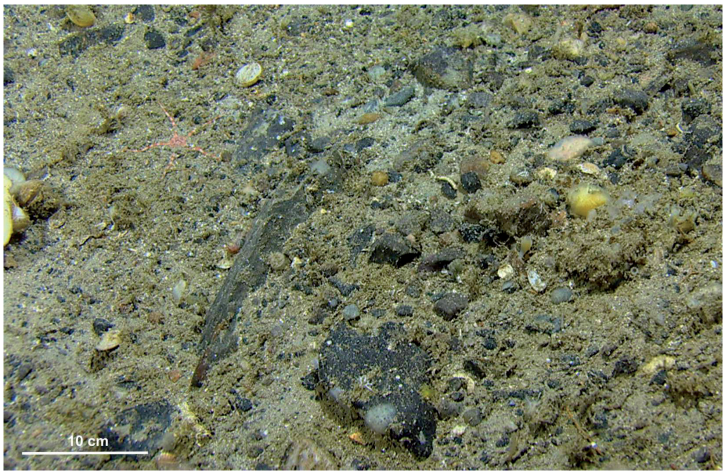


Figure 9. In Sørøydjupet, the seabed consists of a thin layer of gravel, between cobbles and boulders, due to the removal of finer sediments by strong bottom currents.

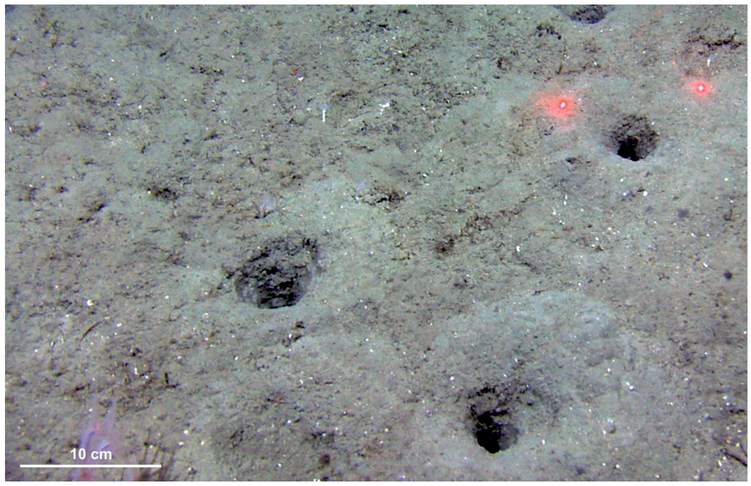


Figure 10. Ingøydjupet is covered in mud with numerous holes dug out by animals.

Håkjerringsdjupet, the ice has left a particularly noticeable mark: ridges up to 20 metres high with channels in between. In Håkjerringsdjupet and Ingøydjupet we also find pockmarks, i.e. pits in the seabed formed by seeping gas or fluid. They are generally 20–50 metres in diameter, 2–4 metres deep and occur in places where soft clay is deposited in troughs and depressions.

Eggakanten Area

The continental slope – the area between the shallow Barents Sea and the deep parts of the Norwegian Sea – lies far west in the Eggakanten Area mapped by MAREANO (figure 6). The border between the continental slope and the continental shelf plains/banks in the Barents Sea runs along the shelf edge at around 400 metres depth. The "shelf edge" terrain can be found all the way from the North Sea to north of Svalbard, while the area called Eggakanten – *The Shelf Edge* – in the Management Plan is situated west of Tromsøflaket.

In the southern part of the area, the shelf edge runs north-northwest–south-southeast with noticeable channels starting at the shelf edge and running down into the deep. These

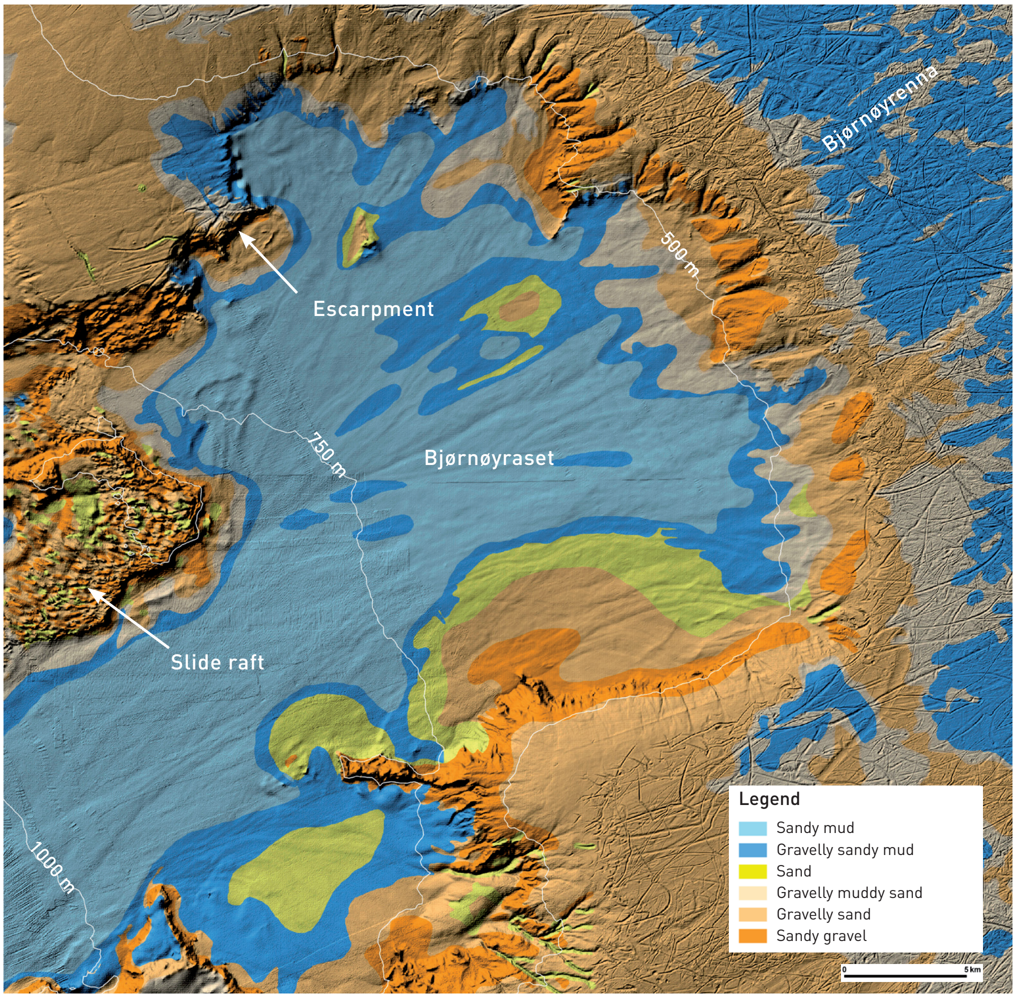


Figure 11. Bottom sediments at Bjørnøyraset – the Bear Island Slide. The landslide occurred around 200,000 years ago but the depression is still easily detectable on the seabed. The figure was made by superimposing analysed bottom types in colour on a shaded relief map, where the bottom topography is illuminated from the northwest by "a low sun".

channels were formed during the last Ice Age when the ice was resting on the seabed at Tromsøflaket. In the north, the shelf edge is different and the seascape is dominated by a large pit-shaped circue-like depression. Inside this pit big, uneven "rafts" with an irregular surface stand up to 100 metres taller than the surroundings. The clear-cut channels found in the south are non-existent here. Instead, the seabed is quite smooth, with a network of indistinct channels, low ridges and shallow depressions. The large pit was formed by a gigantic submarine landslide (Bjørnøyraset – *the Bear Island Landslide*) about 200,000 years ago, according to scientific investigations performed by the University of Tromsø. The ice masses that dug out Bjørnøyrenna dumped large amounts of sediments on the continental slope, which with time created the large Bjørnøyvifta – the Bear Island Fan. In total, the shelf edge was moved about 100 kilometres west by these deposits. Due to their high water content, the dumped sediments were unstable. Maybe an earthquake caused the landslide – we do not know. But the result was a landslide that influenced about 1000 km^2 of the continental shelf and even larger areas of the slope. The rafts we see today are sections of seabed broken off and moved by the landslide. The network of diffuse channels and structures were caused by smaller landslides from the shelf edge running down the continental slope.

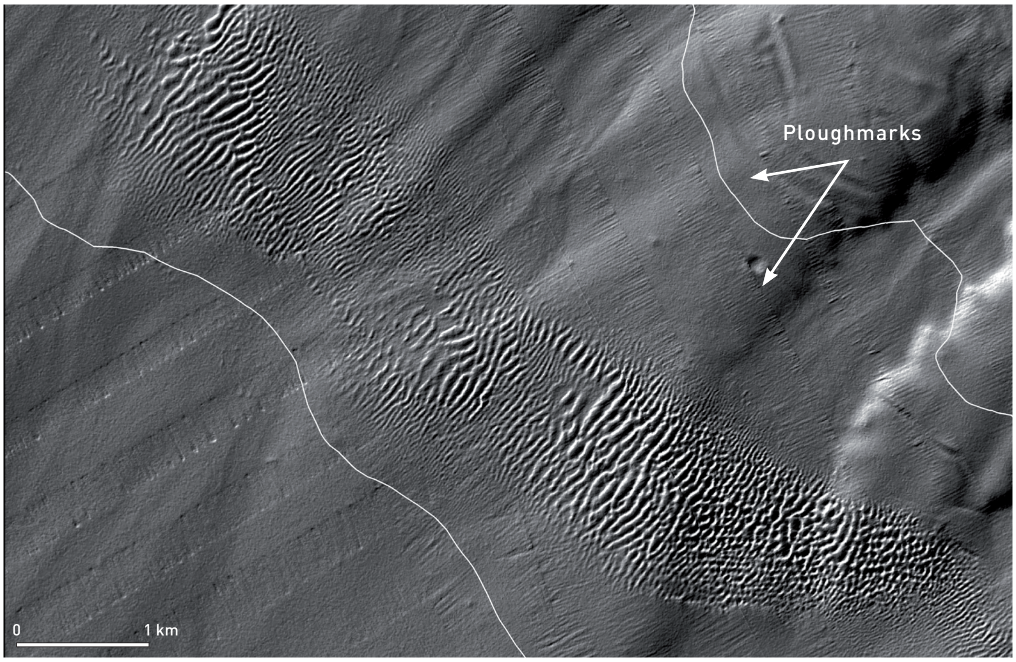


Figure 12. One of several sand wave fields on the continental slope in the Eggakanten area. The sand waves move northwest, with the Atlantic Current, and back and forth on the seabed with tidal currents.

Areas off Northern Troms and Finnmark

So far, MAREANO has mapped three areas off Northern Troms and Finnmark situated north of Sørøya, north of Porsangerhalvøya-Magerøya and northwest of Nordkinnhalvøya (Figure 1). Off Magerøya, a transect goes north to Nordkappbanken. Off Sørøya, the mapping area stretches far into the strandflat, which can be described as the underwater part of the skjaergard (skjærgard – *skerry zone*). The strandflat off Sørøya stretches far into the sea and is generally less than 100 metres deep. Typically, the strandflat is irregular, with numerous peaks, depressions and channels, which are due to the thin or non-existent layer of sediments resting on old bedrock, just like in the skerries. The

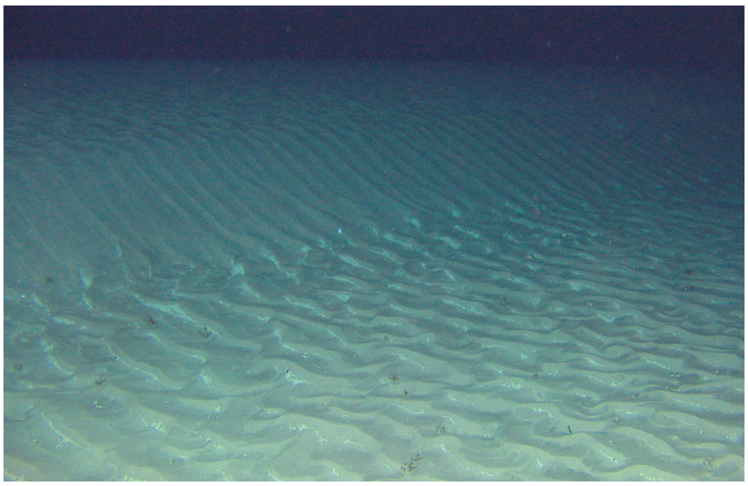


Figure 13. A one-meter high sand wave on the continental slope in the Eggakanten area. The sand wave moves towards the bottom right corner of the image and is covered in smaller ripples indicating currents in other directions.

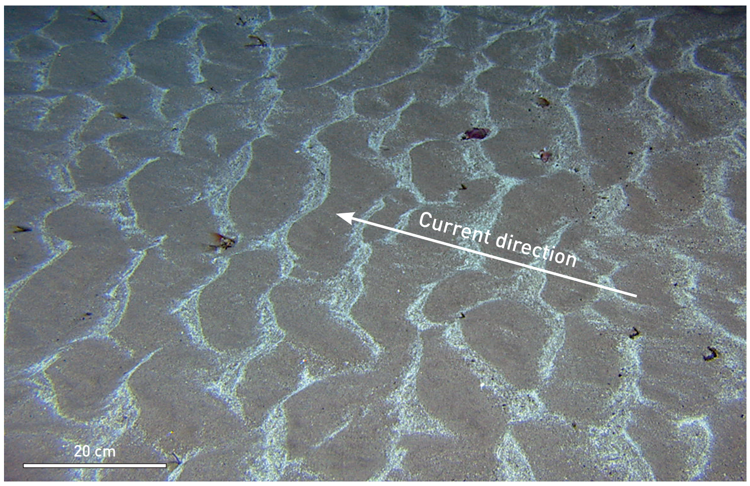


Figure 14. Sand ripples in the Eggakanten area. The direction of the arrow indicates that the bottom current runs towards the upper left corner. On the lee side (the steepest side) of each ripple, there is coarse, white shell sand, which is easily transported on the bottom due to the large surface area and lightness of each shell particle.

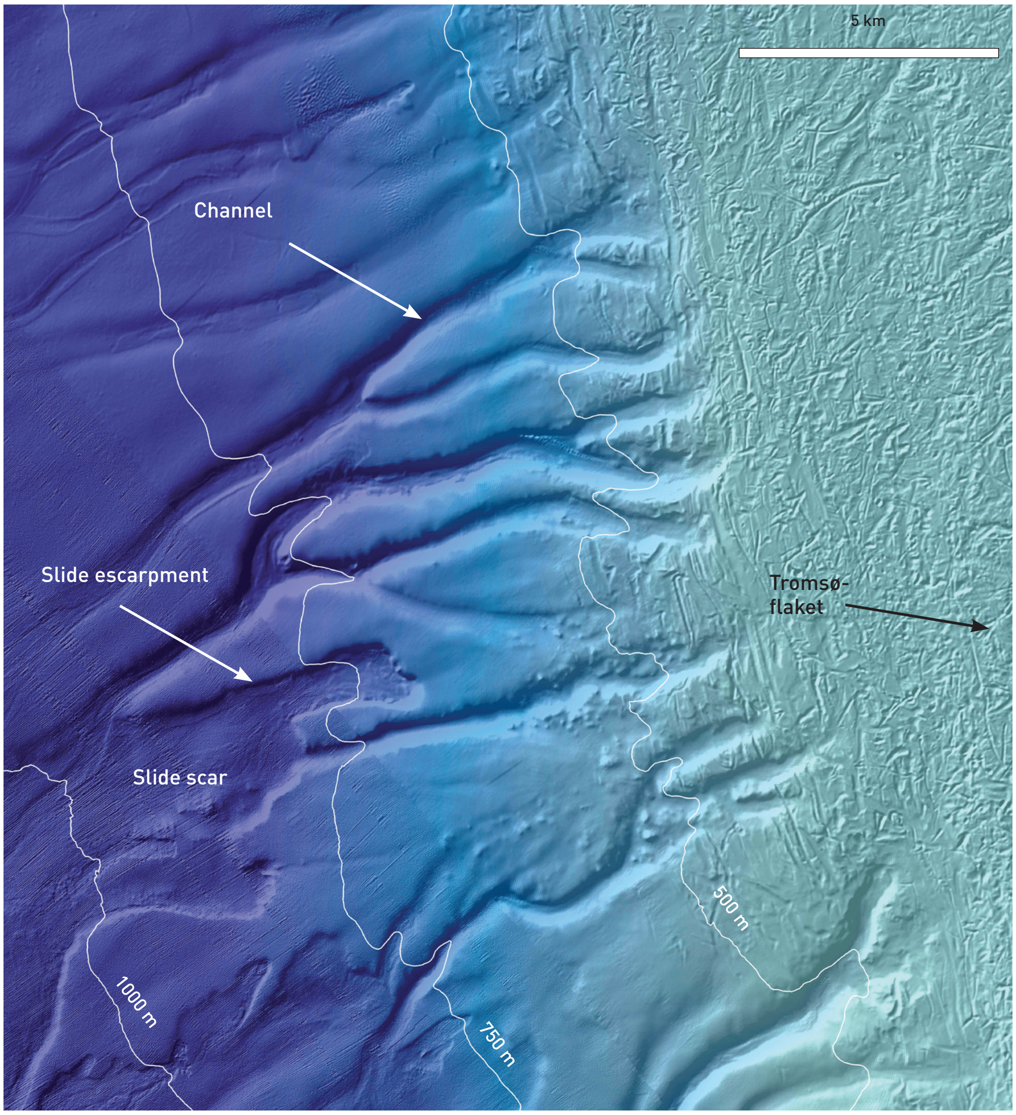


Figure 15. Channels and slide scars on the continental slope west of Tromsøflaket.

mapping area off Porsangerhalvøya-Magerøya and Nordkinnhalvøya stretches only just into the strandflat. Further out, there is an area where the seabed is scattered with iceberg ploughmarks. In Djuprenna – the Deep Trench – the seabed is even, but large areas are covered in pockmarks.

3.1.2 Sediments and Bottom Types

The Bank Areas – Tromsøflaket, Fugløybanken and Nordvestbanken
The shallowest parts of Tromsøflaket, Fugløybanken and Nordvestbanken are dominated by sandy gravel and gravel, cobbles and boulders (figure 7). Elsewhere, the seabed down to about 250 metres depth is largely covered by gravelly sand, muddy sand and gravelly muddy sand. In the northern part of the mapping area at Tromsøflaket and deeper areas off Lopphavet, there is sandy mud and, in some places, a higher content of sand and gravel. The large moraines in the western part of Tromsøflaket consist of gravelly sand.

Generally, there is a gradual transition between the bottom types. The bottom sediments tend to be finer grained in local depressions such as iceberg ploughmarks, which can be 10–15 metres deep and several kilometres long (figure 8). The sediments on the ridges are coarser. Sediments transported by bottom currents are generally deposited on the lee side of iceberg ploughmarks.

In the western part of Tromsøflaket, the bottom sediments have a high content of sponge spicules, i.e. residue of dead, disintegrated sponges. The large amounts of sponges on the seabed in this area is reflected in the name: Sopphola – *Sponge Hollow*. Here, and in a similar depression further west (see chapter 3.1.1), the bottom sediments consist of mud.

The Marine Valleys – Sørøydjupet, Ingøydjupet, Bjørnøyrenna and Håkjerringdjupet
In marine valleys, sediments tend to be fine-grained, but there are exceptions. In spite of being a marine valley (> 250m), Sørøydjupet has unusually coarse bottom sediments. Strong bottom currents remove finer sediments, and

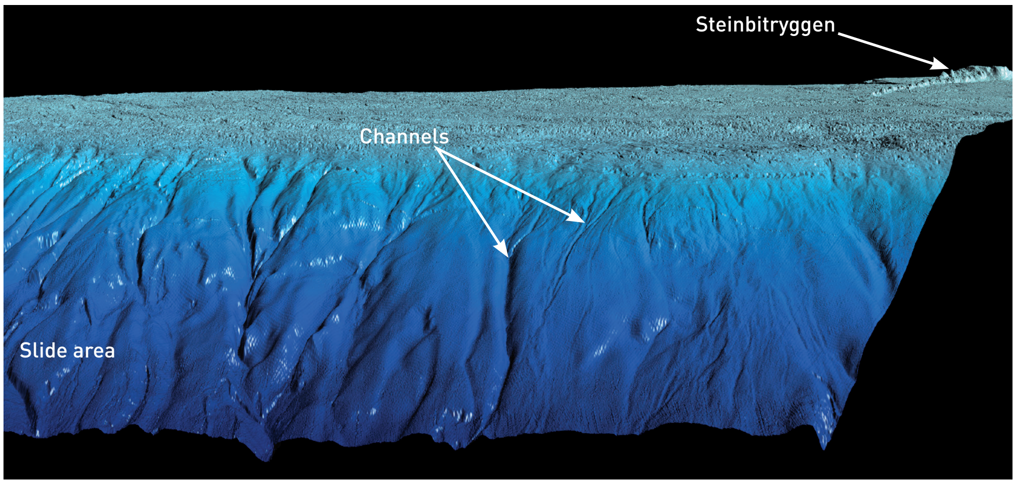


Figure 16. 3D representation of the continental slope in the Eggakanten area. Steinbitryggen – the Catfish Ridge – on Tromsøflaket is also shown.

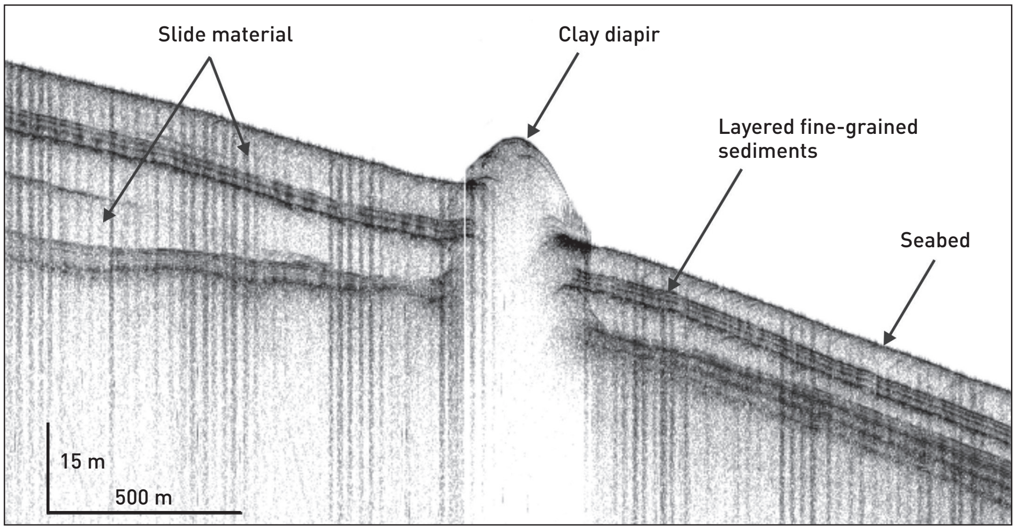


Figure 17. Clay diapir on the seabed. TOPAS transect from the continental slope west of Tromsøflaket.

the remaining sediments consist of sandy gravel as well as gravel, cobbles and boulders (figure 9). The slope up towards Tromsøflaket in the northeast is dominated by gravelly sand washed down from the bank.

Ingøydjupet is covered in a layer of mud up to 15 metres thick (figure 10). The layer becomes gradually thinner towards Tromsøflaket in the southwest and turns into sandy mud and then gravelly sandy mud.

In Bjørnøyrenna, north and northwest of Tromsøflaket, the bottom sediments vary between gravelly sandy mud, gravelly muddy sand and sandy mud (figure 11).

The bottom sediments in Håkjerringdjupet vary between areas. In central and eastern parts of the trench, the bottom is covered by sandy mud and gravelly sandy mud. In western parts, the moraines and shallower area are covered in sandy gravel and gravelly sand, while sediments in deeper areas consist of a range of grain sizes. Moreover, the sediment types shift rapidly over short distances. On the slope towards Nordvestbanken, there are large areas of sand. In the extreme west of Håkjerringdjupet, towards Eggakanten, the bottom sediments consist of sandy gravel and gravelly sand. Mounds with bioclastic sediments (see chapter 4.1.2) are frequent in the central and eastern parts of Håkjerringdjupet.

The Continental Slope at Eggakanten

The dominating sediment type on the continental slope west of Eggakanten is gravelly sand, but at the shelf edge in the south, at 400–500 metres depth, the seabed consists of sandy gravel. At depths of 500–800 metres, sand covers large areas but also occurs at greater depths, such as in the numerous channels in the southern part of the continental slope.

Sandy mud dominates in the depression left by Bjørnøyraset – the Bjørnøya Landslide – but there are also large areas of gravelly sandy mud (figure 11). Sand is also a common bottom type in the south-southeastern parts of the depression. The steep slopes demarcating the slide are mainly covered by sandy gravel. This is also the case for the slopes surrounding the bank in Bjørnøyraset. Hard, layered sediments and old till protrude in some places.

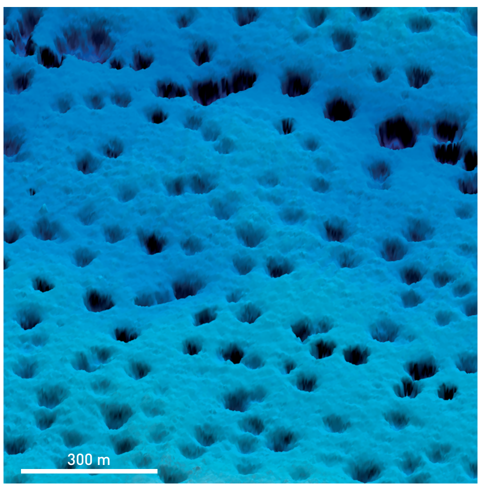


Figure 18. Pockmarks in Ingøydjupet. The pits are 40–60 metres in diameter and 2–10 metres deep and were formed by gas and fluids seeping out from the seabed. The depth in this area is about 430 metres.

Areas off Northern Troms and Finnmark

The sediment layer in the mapped areas of the submerged strandflat off Northern Troms and Finnmark is generally thin or discontinuous. Bare rock protrudes many places on the seabed, and there are also areas of gravel, cobbles and boulders. The slope down from the strandflat consists mostly of sandy gravel. Further north, there are areas dominated by gravelly sand while the sediments in Djuprenna consist of gravelly mud. In the somewhat shallower areas of the transect running north into the Barents Sea, gravelly sandy mud dominates.

3.1.3 A Changing Seabed – Sand Waves, Pockmarks and Clay Diapirs

Sand Waves on the Continental Slope

In the Eggakanten area, sand is deposited in large sand fields at 500–800 metres depth on the continental slope (figure 12). The sand moves in ripples and waves with bottom currents, and the sand waves can become several meters high (figure 13, figure 14). The sand comes from areas with strong currents and seabed erosion where only a thin layer of gravel remains – an erosional lag.

Sand waves and sand ripples are formed by bottom currents – either permanent ocean currents with a constant direction, or tidal currents that change in both direction and strength over the 12-hour tidal cycle. It has long been known that the Atlantic Current, which follows the continental slope north, is strong. A speed at the surface of up to one meter per second is not unusual.

Channels on the Slope

On the continental slope south of Bjørnøyraset there are numerous shallow channels. They start at the shelf edge and run almost perpendicular to the depth contours towards the deeper waters. West of Tromsøflaket, the channels are much deeper – up to 30-40 metres – and stand out more clearly (figure 15, figure 16). The channels were formed during the last Ice Age, when the ice was resting on Tromsøflaket (see chapter 3.1.1). Cold melt-water with a high sediment content flowed out from underneath the ice and down the continental slope, like underwater rivers on the seabed. This heavy sludge eroded the seabed.

Sediments are continually deposited in the channels, but this time by the Atlantic Current, which follows the depth contours north-northwest along the continental slope, as well as by tidal currents. In the channels, we have observed sand waves and sand ripples, indicating that sand is being moved by the currents.

Clay Diapirs

Detailed depth data from the continental slope west of Tromsøflaket (figure 6) show several distinct elevations on the seabed. We have passed over some of these with TOPAS – a powerful echo sounder that can look down into the seabed – and the data show that these elevations probably are clay diapirs (figure 17).

A clay diapir is a plug of clay protruding from geological layers deep below the seabed. Because clay has a relatively high water content, is soft and generally lighter than many shallower sediments, it can rise through weak zones such as cracks and faults. If the clay diapir reaches the surface, it will appear as an elevation on the seabed.

We have studied the seabed using video to try and observe active diapirism, such as seeping gas or soft clay, but so far we have not seen any signs of such activity. On the slope above the diapir, we see through about 30 metres of loose sediment. The sediments continue below the diapir but the layers of slide material are thinner, so the landslides have partly stopped against the diapir and partly moved around. This indicates that the clay diapir was there already when these sediments were deposited during the last Ice Age.

With the right conditions, clay diapirs may evolve into clay volcanoes where liquid clay flows out together with gas and fluid. In Norway, there is only one known active clay volcano – the Håkon Mosby Mud Volcano (figure 6) – on the continental slope in the western part of Bjørnøyraset.

Mud Plains and Pockmarks in Ingøydjupet

The seabed in Ingøydjupet, close to the Goliat oil and gas field, is littered with thousands of pockmarks (pits in the seabed). Pockmarks are formed where gas or fluid have been seeping out of a seabed consisting of fine-grained sediments. Gas seeps occur either as continuous seeps, where gas trickles out of the seabed, or as sudden explosive emissions. In Ingøydjupet, the pits are around 40–60 metres in diameter and 2–10 metres deep and thus appear clearly in terrain maps (figure 18).

We also see the pockmarks clearly on backscatter maps, where they appear as areas of higher reflectivity and thus harder seabed. Inside the pockmarks, the sediments tend to be coarser than in the surrounding areas, either because fine-grained material has been transported away or because of carbonate crusts formed by seeping gas and fluids. We assume that the pockmarks were mainly formed during the first few thousand years after the ice cover melted and that there is little activity today.

In certain places, seismic data show shallow gas occurrences in sediment layers just under the seabed. The gas generally consists of methane, but ethane, propane and heavier hydrocarbon gases are also found. Gas in sediments can come from decomposing organic material in the upper layers of the seabed, or from deeper layers where it is either formed continually from sediment or rock layers with a high organic content or comes from leaking gas reservoirs.

The Submerged Strandflat off Finnmark

The strandflat along the Norwegian coast is the low-lying landscape in the skjaergard zone, both on land and in the sea, formed by erosion over million of years. After the last Ice Age, large parts of the strandflat were dry land that was gradually submerged as the sea level rose. The strandflat is dominated by bare rock with just a thin layer of sediments over old, irregular bedrock (figure 19). On shaded relief maps we can study the structures of the bedrock and see cracks, ravines and peaks. Channels in the bedrock surface may have been formed by meltwater streaming under the ice cover when the area was covered by glaciers.

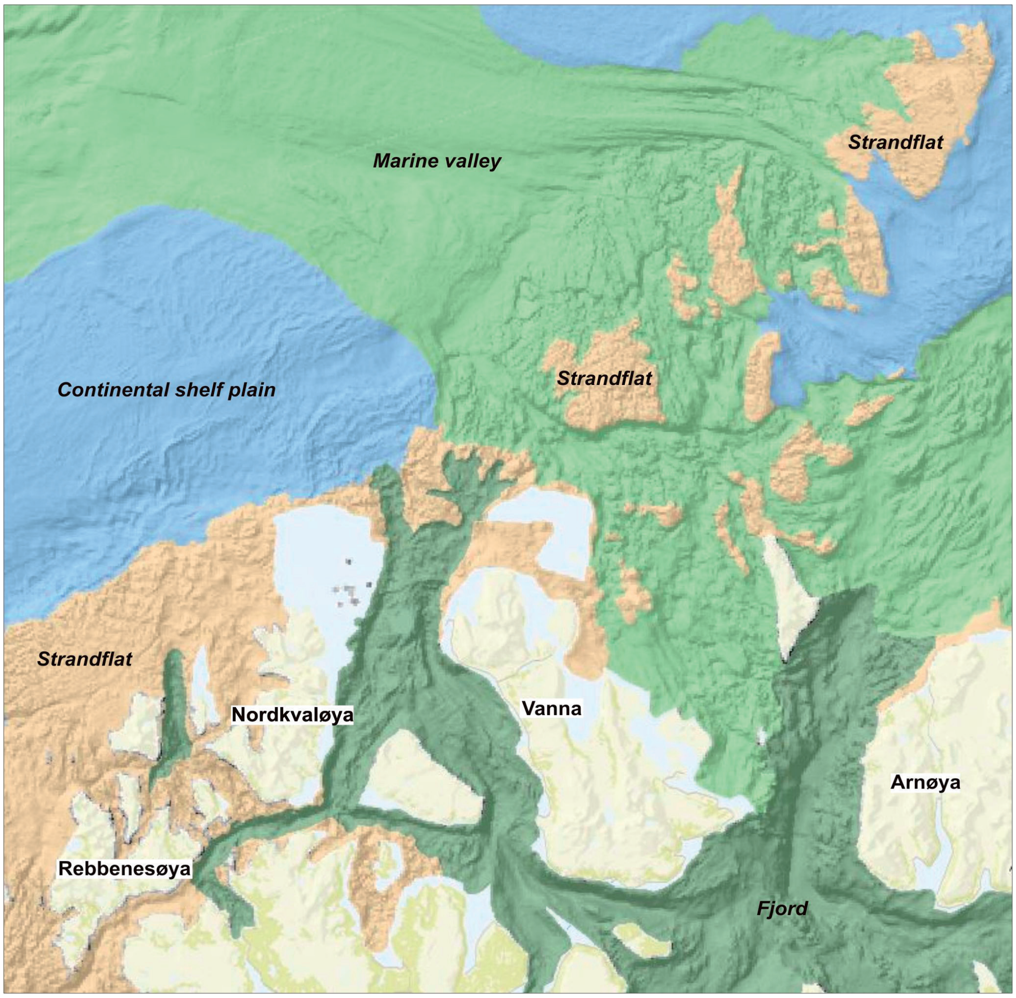


Figure 19. The strandflat extends around 40 kilometres from the coast in western Finnmark.

3.2 BENTHIC FAUNA – TROMSØFLAKET AND EGGAKANTEN

3.2.1 Tromsøflaket

Biotope distribution

Tromsøflaket is a large and relatively deep bank area in the western part of the Barents Sea. It is a biodiverse area with numerous species and biotopes. The shallowest plains on the bank are at depths of between 200 and 300 metres. The area is now recognised for its rich sponge community. Before MAREANO started mapping the seabed here in 2006, these sponge communities were relatively unknown and had only been documented as by-catch in trawls. Tromsøflaket is bordered to the north by Bjørnøyrenna (the Bear Island Trench) and to the west by the steep continental slope towards the depths of the Norwegian Sea. On the northern edge of the bank lies the Snøhvit oil and gas field. East of Tromsøflaket lies Ingøydjupet (the Ingøy Deep) with a high density of pockmarks, i.e. gas or water seeps. This area also hosts the Goliat oil and gas field.

Figure 19. Saithe shoals can be dense at Tromsøflaket.

The currents are largely influenced by the seabed topography. Due to an eddy over Tromsøflaket, the water remains in the area for a relatively long time, which in turn causes large concentrations of larval fish such as cod, herring and haddock. During the years when the capelin spawns in the west, Tromsøflaket can also be an important larvae area for this species. Above the bank, the concentration of plankton and other particles increases due to the eddies formed by the currents. Furthermore, the distance is short between the productive upper layers and the seabed. This is one reason why banks are generally favourable areas for fish. On shallow banks above 100 metres depth, many areas have rocks and boulders covered in colourful flora and fauna. On deeper banks such as Tromsøflaket, however, there is less hard substrate for animals to colonise, and the depths are too great for plants to grow. In the central parts of Tromsøflaket, large areas of the seabed consist of till, consisting of a mixture of many different grain sizes. This includes compact clay embedded gravel beneath sandy, gravelly surface sediments. This makes it difficult to take samples of sediments and benthic animals living in the seabed. The shallow, flat areas seem environmentally homogenous. The seascape seems barren, with few organisms present, and

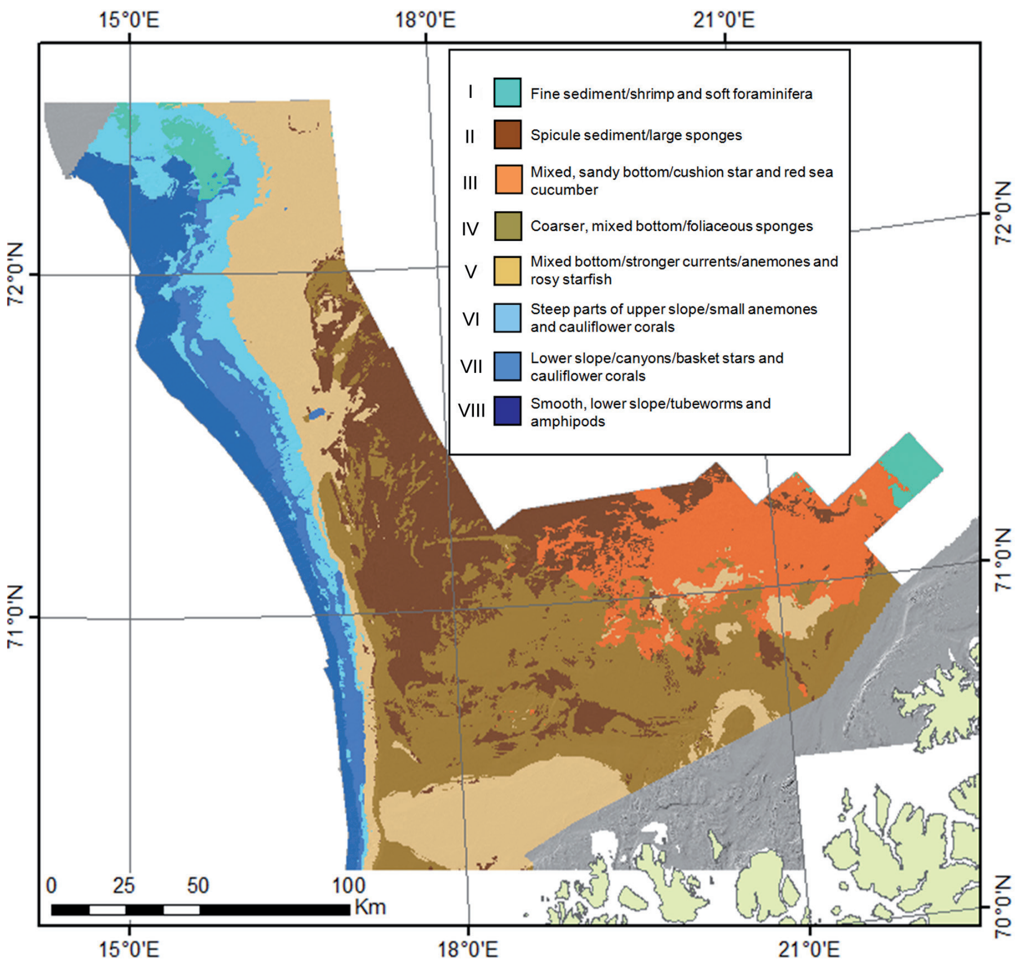


Figure 20. Biotope map for Tromsøflaket, Troms III and Eggakanten. The map shows the predicted distribution of biotopes based on classified observations from video data, together with full coverage data on seabed bathymetry, morphology, sediment distribution and oceanographic conditions

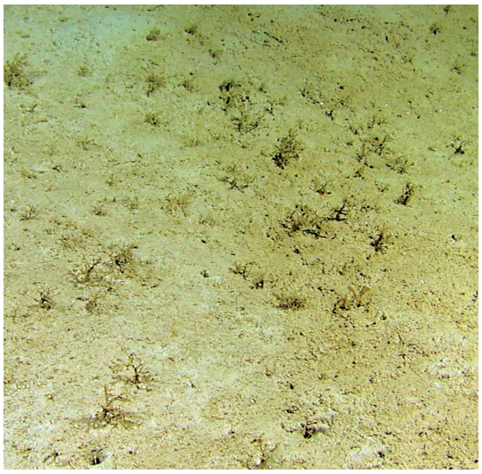


Figure 21. Muddy bottom at Ingøydjupet with small, tree-shaped bushes of the foraminifera *Pelosina*. Foraminifera are large single-celled organisms.

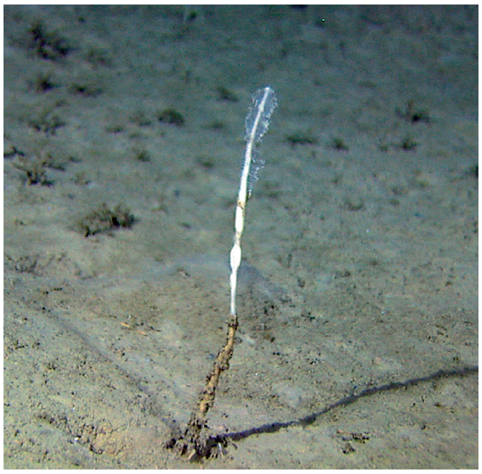


Figure 22. *Asbestopluma pennatula* occurs in several habitats, but at Tromsøflaket it was most commonly found in clay basins. This is a carnivorous sponge that captures small crustaceans from the water with its comb-like branches. When an animal is stuck, amoeba-like cells attack the animal and digest it.

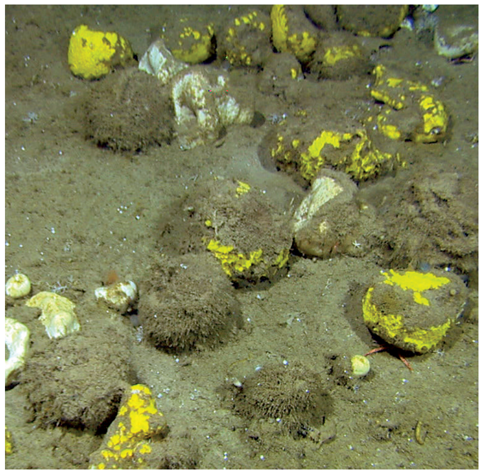


Figure 23. Sponges are the most characteristic animal group on sponge spicule bottom. They occur in large groups on sandy mud at Tromsøflaket. In this photograph, we see the hairy, dark sponge *Stelletta*, the sulphurous yellow *Aplysilla*, the yellow-white *Geodia baretti* and the white *Isop*.

is partly dominated by dense occurrences of trawl tracks and lost fishing gear. There is an extensive gadoid fishery in the area and large shoals of saithe tend to gather here (figure 19).

Generally, the finer sediments occur in the deeper parts, while gravel and cobbles dominate the shallower parts of the area (see chapter 4.1). At the edge of Tromsøflaket, both sediments and fauna are more varied.

Based on analyses of video recordings from TromsøflaketEggakanten, and Troms III the seabed at Tromsøflaket was divided into five types, based on differences and similarities in species composition (figure 20):

- I Fine sediment bottom – Deeper shelf areas with moderate bottom temperatures and weak currents. Mixed, often fine-grained sediments. Typical taxa: *Pelosina* og *Asbestopluma*.
- II Sponge spicule bottom – Shallower flat areas with frequent sponge aggregations, moderate bottom temperatures and moderate currents. Mixed sediments, mostly sandy/gravely, including sponge spicules. Typical taxa: *Geodia* spp., *Aplysilla* and *Stryphnus*.
- III Mixed, sandy sediments – Shallower flat areas with higher bottom temperatures and lower bottom currents. Mixed, often sandy sediments. Typical taxa: *Stylocordyla* and *Parastichopus*.
- IV Mixed, coarser sediments – Shallower flat areas with higher bottom temperatures and moderate currents; mixed sediments, often coarse. Typical taxa: *Phakellia* and *Porania*.
- V Mixed bottom with stronger currents – Shallow flat areas with moderately low bottom temperatures and strong currents. Mixed sediments. Typical taxa: *Homathiidae*, *Gadus morhua*, *Sichastrella* rosea, *Echinus acutus*.

The names of these five biotopes are short descriptions of geology, terrain and oceanography. On land, habitats are generally described by vegetation, along with geology and elements of the landscape. Here, long natural history traditions and better background knowledge provide a solid foundation for establishing short habitat names. In shallow waters there are a number of habitats that are easy to recognise, for instance seagrass meadows and kelp beds. In deep waters, however, the same amount of background knowledge and experience does not exist in deep waters and therefore there are only few examples of established habitat

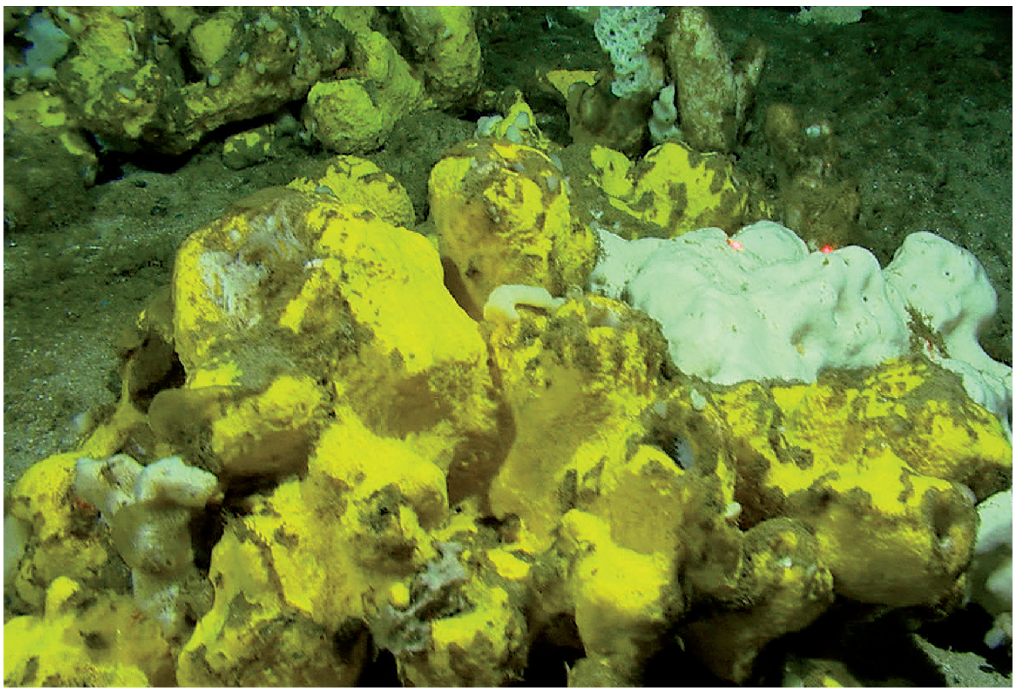


Figure 24. In some areas, there are large occurrences of the sulphurous yellow *Aplysilla sulfurea*, seen here covering the white *Stryphnus ponderosus*. The red points from the lazer lights indicate a 10cm scale.

Figure 25. The sea cucumber *Parastichopus tremulus* and the anemone *Bolocera tuedia* are typical species on the sandy plains of Tromsøflaket. The sea cucumber slowly crawls across the sediments eating mud, digesting what it finds among the particles and leaving behind a trail of muddy excrements.

names, such as cold-water coral reefs. Several of the terms used for deep water today (e.g. sponge aggregations) constitutes several sponge communities with different species composition. Which habitats the more common bottom environments could be defined as is still not completely clear, but MAREANO continue systematizing the information about the seabed fauna and environment to enable new and improved habitat descriptions for the Norwegian seafloor. For the present time maps describing the environment and typical fauna are the most suitable method for presenting our findings and these are most accurately termed biotope, rather than habitat maps.

I Fine sediment bottom with shrimp and soft foraminifera

This is not the most common biotope at Tromsøflaket, but occurs in the deep area in the northeastern part of the survey area (indicated in green on the map of predicted biotopes on Tromsøflaket). The area between 350 and 440

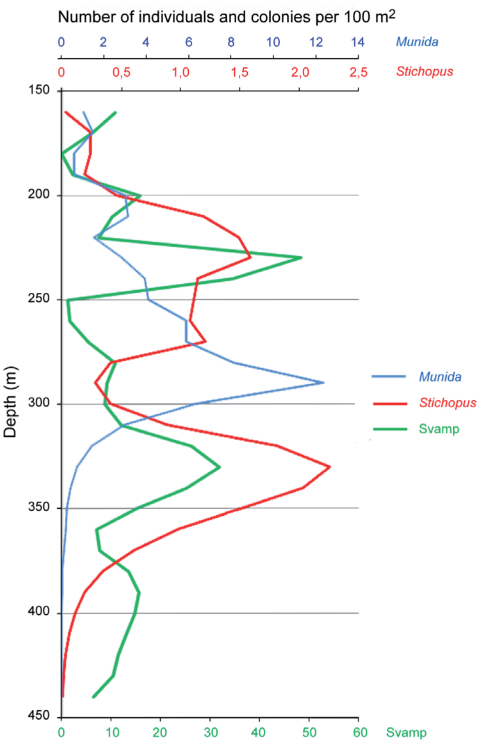


Figure 26. Depth distribution of three dominating organisms at Tromsøflaket: large sponges, sea cucumbers and *Munida.*

Figure 27. The stalked sponge *Stylocordyla borealis* and colonial tunicates (grey lumps).

Figure 28. Lamp shells (*Brachiopods*) on gravelly sand in the iceberg plough marks.

Figure 29. The fauna is rich on and around the rocks on the moraine ridges. In the photograph we see the bryozoan *Reteporella beaniana* and a small hermit crab.

metres depth is remarkable due to its pockmark density. The seabed consists of fine-grained sediments with few gravel or cobbles. Trawl tracks were observed quite frequently here, on average 3.6 tracks per 100 m video line. Shrimps were more abundant in this area than in any other biotope. The other most typical species are the feather shaped sponge Asbestopluma and the foraminifera Pelosina (figures 21 and 22). Biodiversity is poorest in this biotope, compared to the other biotopes at Tromsøflaket.

II Spicule sediment with large sponges

Large, habitat-forming sponges are typical for this area of sandy sediments, including mud and gravel, in local basins characterised by iceberg plough marks. Fishermen in Northern Norway often call these areas ”sponge holes”. Spicule bottom occurs between 200 and 400 metres depth at Tromsøflaket. In these areas, the seabed is covered by a mix of sponge spicules and muddy sand or sandy mud, sometimes with gravel. When collected samples of this bottom type are sieved, bucket loads of white sponge spicules are left in the sieves. These are fine glass needles that can easily puncture the skin, so wearing gloves while working on these samples is important.

The most common sponge species forming this spicule bottom are: *Geodia baretti*, *Stryphnus ponderosus*, *Steletta* sp. and *Aplysilla sulfurea*. In addition, there are many other sponge species living on these sponges, on scattered rocks or directly on the spicule/mud bottom (figure 23 and 24).

Many animal groups take advantage of the environment created by the sponges, e.g. squat lobster, shrimp, hydroids, feather stars, anemones and bryozoans, as well as redfish and saithe.

There are many unanswered questions when it comes to the biology and ecology of sponges. We do not know with certainty how old they get, how fast they grow, how well they cope with bottom trawling or what their importance is for the biodiversity in the area. The photographs (figure 23 and 24) illustrate the high biodiversity of the ”sponge holes” and show how colourful the sponges are on the seabed, in contrast to their rather sorry appearance after being accidentally caught in fishing trawls.

III Mixed, sandy bottom with cushion star and red sea cucumber

The most common biotope in the central parts of Tromsøflaket has a sediment surface dominated by sand. Beneath the layer of sand, the bottom often consists of till with compact clay and embedded gravel, which makes it difficult to take samples of the sediments and animals living buried in the seabed. The cushion star (*Ceramaster granularis*), red sea cucumber (*Parastichopus tremulus*), the stalked sponge *Stylocordyla borealis*, and deeplet sea anemone (*Bolocera tuediae*) are characteristic species in this biotope. The sandy

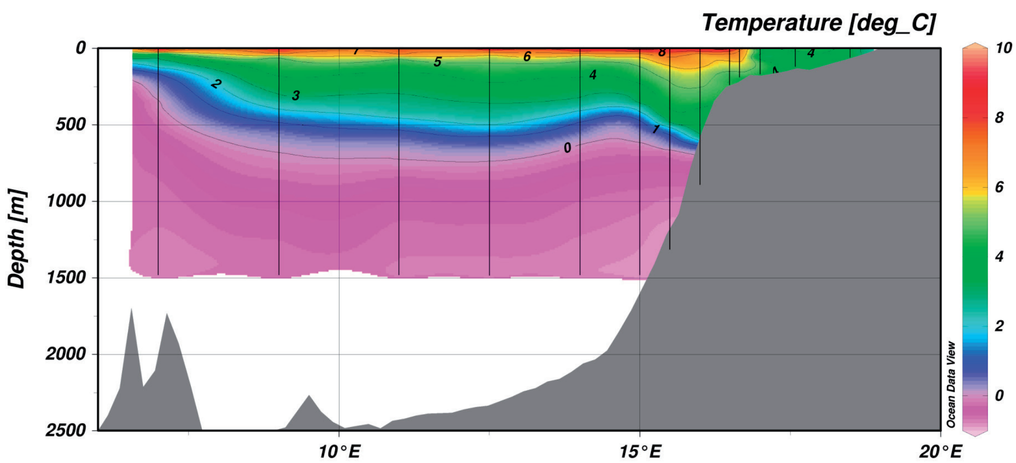


Figure 30. Temperature at various depths in a transects west of Bear Island. Below 700 metres the temperature is always below 0° Celsius.

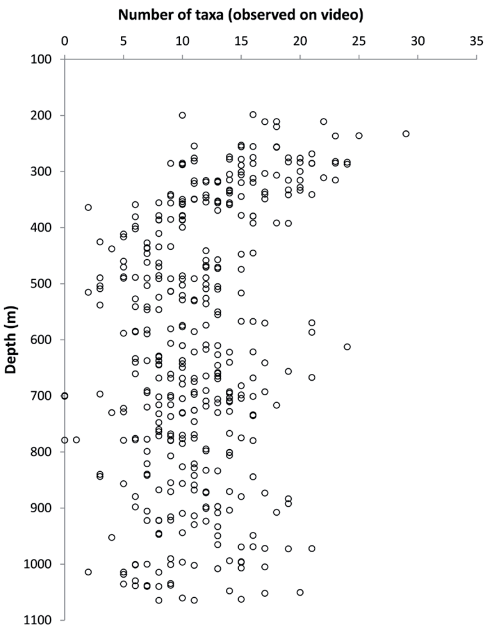


Figure 31. Number of taxa (identified and unidentified species) observed at various depths in the Eggakanten area.

bottom at Tromsøflaket is the bottom type that is most frequently trawled.

The sea cucumber feeds on organic material in the sediments. With the tentacles surrounding its mouth, it shuffles sediments into its mouth and slowly eats its way across the seabed. Its function in the ecosystem is unknown but can possibly be compared to the function of the worm on land. The highest densities can reach seven individuals per 100m^2, while the averaged over several bottom types the maximum for 10 metres depth intervals is a little over two individuals per 100 m^2.

IV Coarser, mixed bottom with foliaceous sponges
The mixed sediments include gravel and cobbles material left by glaciers and often forming moraine ridges. These coarser areas have a rich hard-bottom fauna (figure 29). The sponge *Polymastia* and the starfish *Poraniomorpha* are typical species in this biotope which is the most biodiverse at Tromsøflaket. Various small sponges, such as *Axinella infundibuliformis* and *Phakellia ventilabrum* are also typical for this biotope. Plough marks from icebergs are part of the seascape in several of the biotopes and, in this particular biotope, the plough marks host a distinctive fauna. Inside the plough marks, we commonly find large accumulations of lamp shells (figure 28), an invertebrate which is at its most numerous at Tromsøflaket.

V Mixed bottom with stronger currents, anemones and rosy starfish
Shallow flat areas with moderately low bottom temperatures and strong currents. Mixed sediments. Typical taxa: *Hormathiidae*, *Gadus morhua*, *Sichastrella rosea*, *Echinus acutus*. This biotope is more extensive in parts of Troms III and towards Eggakanten, but also occurs at Tromsøflaket where it seems to be linked to the seabed topography on or around more elevated areas.

3.2.2 Eggakanten

The edge of the continental shelf constitutes a clearly defined area starting at 200–500m depth. The seabed here slopes down towards the depths of the Norwegian Sea. The continuation of the Gulf Stream, which gives Norway its relatively mild climate despite its northerly position runs along the upper part of the slope. The southern part of Eggakanten starts west of Tromsøflaket including the area referred to as Troms III elsewhere in this book. Along the slope there are large canyons (submarine ravines) and traces of landslides. In this area, at 600–700m depth there is a transition between deep, cold water at constant freezing temperatures and warm water (figure 30, see also chapter 7).

Generally speaking, the biodiversity declines as one goes deeper (figure 31). Furthermore, the number of taxa observed by video seems to be somewhat lower in the Eggakanten area than in the more southerly MAREANO areas. Eggakanten has its distinctive features, such as rare corals and a rich fauna of small crustaceans.

Several biotopes extend north-westwards from Tromsøflaket into the adjacent Eggakanten area. Eggakanten was surveyed with G.O. Sars during a cruise in 2009 and Troms III in 2010. The analyses of video recordings, suggest a division of Eggakanten into seven biotopes (figure 20). On the continental shelf, shallower than 500 metres, four biotopes were identified.

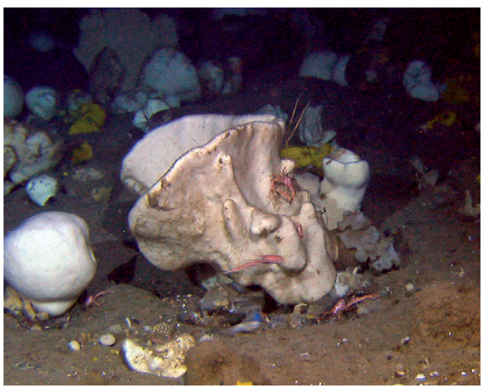


Figure 32. Sponge spicule bottom type, with scattered dense collections of sponge and *Munida* squat lobster.

Figure 33. Squat lobster (*Munida sarsi*) is common in the shallower parts of Eggakanten. They frequently fight with each other and like to hide under rocks and sponges.

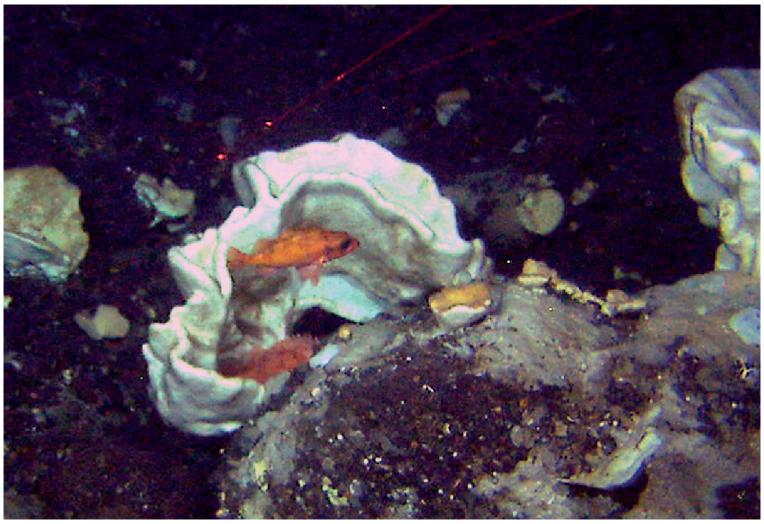


Figure 34. Judging by its behaviour, the redfish is a very calm and drowsy fish. It often stands perfectly still or lies on the seabed or inside sponges. Resting among rocks, corals or sponges assures protection against predators and strong currents.

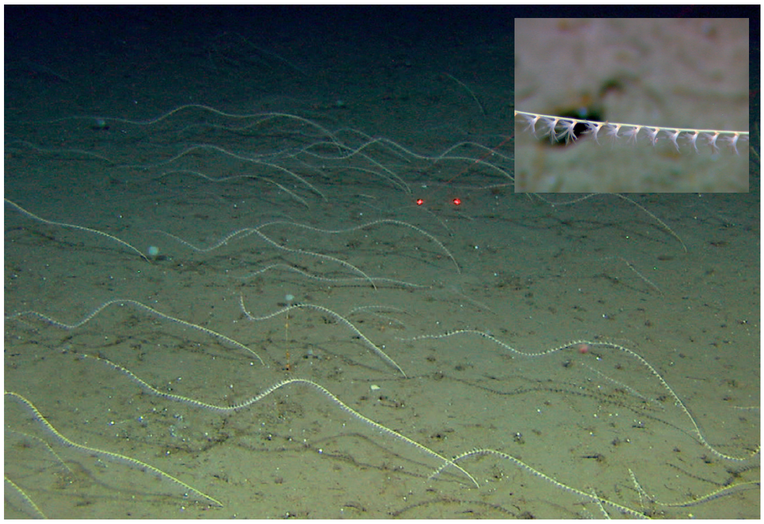


Figure 35. Gorgonian corals of the *Radicipes* genus have not been observed in Norwegian waters before. The spiral shape has earned it the name of "pigtail coral". The red dots indicate a 10cm scale.

I Fine sediments with shrimp and soft foraminifera
II Spicule sediment with large sponges
III Mixed, sandy bottom with cushion star and red sea cucumber
IV Coarser, mixed bottom with foliaceous sponges
V Mixed bottom with stronger currents, anemones and rosy starfish

V Mixed bottom with stronger currents, anemones and rosy starfish

In the deeper part of the shelf at Eggakanten (average depth 400m), there is a larger proportion of mud on the seabed compared to the shallower part. At the same time, a hard seabed in the form of gravel and cobbles is characteristic. In this biotope, anemones and various small sponges, such as *Tethya* and *Craniella*, are common.

The shallower areas (average depth 300m) have varied seabed conditions dominated by sponges and redfish, and share biotopes with Tromsøflaket. Common larger organisms includesponges (*Geodia*, *Aplysilla*, *Steletta*, *Hymedensmia* and *Phakellia*), the starfish *Henricia* and *Ceramaster*, sea cucumber (*Parastichopus*), squat lobster (*Munida*) and redfish (figures 25, 34 and 35).

Many animals take refuge in sponges. Inside a sponge, there are hollows and tunnels where small crustaceans can live. On the outside, we often see brittle stars and feather stars. Furthermore, the sponges increase the spatial structure providing protection against strong currents and predators. Squat lobsters often live under sponges, and redfish like to sleep between, and sometimes on top of, sponges.

Below the edge of the continental shelf, three biotopes were identified that do not occur on the shelf towards Eggakanten or at Tromsøflaket but are confined to the shelf-edge and slope:

VI Steep parts of upper slope with small anemones and broccoli corals
VII Lower slope with canyons with basket stars and broccoli corals
VII Smooth, lower slope

The fine sediment bottom biotope (1) seen in deeper parts of Tromsøflaket also occurs on parts of upper slope.

VI Steep parts of upper slope with small anemones and broccoli corals

This biotope lies in a deep area (average depth 630m) where we find the transition between relatively warm surface water and the colder, Arctic water masses that occur below approximately 700m depth. Here, the seabed is mixed but typically consists of gravelly muddy sand. The most characteristic animal groups were small zooanthide anemones and broccoli corals. Here, as well as below the transition between and cold water masses, glacial eelpout and Greenland halibut are common. In the southern parts of Eggakanten, there are also areas of strong currents and large sand waves in the upper slope.

VII Lower slope with canyons, basket stars and broccoli corals

The species found in this biotope with an average depth of 630m, belong to the typical Norwegian Sea fauna. Roughhead grenadier and glacial eelpout (figures 37 and 39) are typical fish species in this fauna. The sponge Chondrocladia gigantea (figure 39) and the basket star Gorgonocaphalus eucnemis (figure 40 and 41) are the most characteristic bottom-dwelling species in this biotope.

In some areas with gravel and cobbles, *Gorgoncephalus* stands with its arms stretched out like a net to capture drifting food in the water. There are hooks at the tips of the arms that give the animal a good grip on its prey. Studies have shown that *Gorgoncephalus* can reach out and capture plankton, which it then leads to its mouth on the underside of the central body disk, hence the importance of reaching as far out into the water masses as possible. Young *Gorgonocephalus* have been observed on the branches of broccoli corals where they are probably protected from predators and able to reach higher up into the current where more food is available.

Broccoli corals look like small trees and use polyps to collect food from the water masses. They can contract into small balls or bend over to pick up food from the seabed. There are several species in the area, but they are difficult to identify from video. The most common species belongs to the *Drifa* genus.

Figure 36. The amphipod *Cleippides quadricuspis* often sits on tubeworms in deep waters.

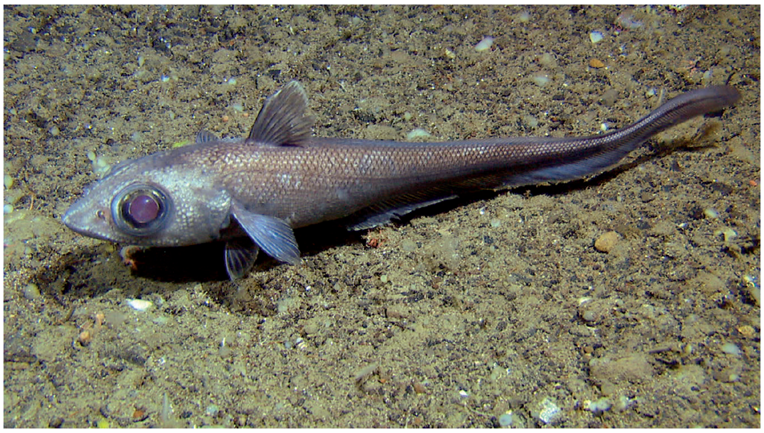


Figure 37. In the cold water at 700m depth and below, we find the roughhead grenadier. The large eyes indicate that it has adapted to a life in the dark.

Figure 38. Arctic eelpot at 1200 m depth.

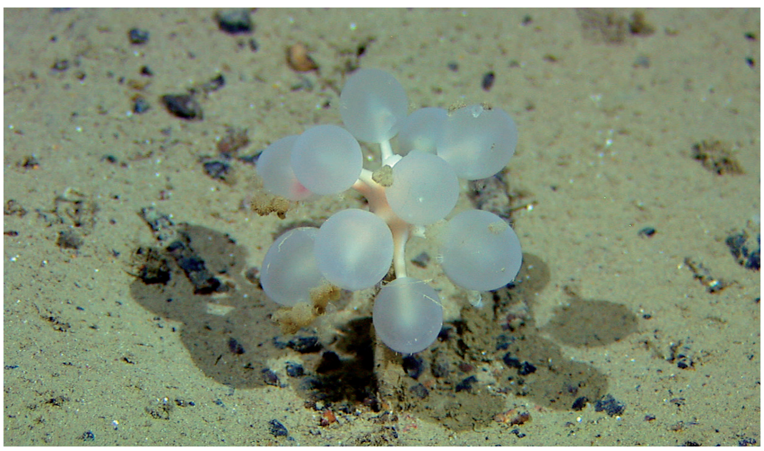


Figure 39. *Chondrocladia gigantea* is a carnivorous sponge typical for the deeper parts of the continental slope.

VIII Smooth, lower slope with tubeworms and amphipods

On the soft seabed at an average depth of 900m on the slope at Eggakanten, a rich fauna of small crustaceans (*Peracarida*) was observed. The most characteristic organisms were tubeworms (*Sabellidae*) and, often sitting on the tubes, the large amphipod *Cleippides* (figure 36).

Fine sediment bottom biotope also occurs on parts of upper slope at Eggakanten. In a landslide area (Bjørnøyaraset) in the northern part of Eggakanten, we observed large occurrences of the gorgonian coral *Radicipes gracilis* ("pigtail coral") within this biotope (figure 35)

It stands up from the seabed as long pigtails, hence the name "pigtail coral". *Radicipes* can reach a height of 70cm and only has polyps on one side of its stem.

Two species of *Radicipes* can live in northerly areas and both have already been observed in the Norwegian Sea outside Norwegian waters. *R. challengeri* has been observed at 1717m depth off Iceland and *R. gracilis* has been observed between 957 and 2702m depth south of Iceland and west of Greenland. *Radicipes* was only observed at a few stations and therefore not in sufficient numbers to characterise a distinct biotope. It is therefore grouped together with other soft bottom fauna with similar environmental requirements.

Figure 40. Broccoli coral, with basket star on top, at 900m depth. The broccoli coral belongs to a group of soft corals in the Nephtheidae family.

Figure 41. The basket star, *Gorgonacephalus eucnemis*, is a typical species on rocky bottom on the continental slope. It likes to position itself high up on a hard ground in order to stretch out its arms and capture food drifting in the current. It curls up around its prey to put it in its mouth.