Submarine landscapes along the Lofoten-Vesterålen-Senja margin, northern Norway

Terje Thorsnes, Lars Erikstad, Margaret F.J. Dolan, Valérie K. Bellec


Eight landscape types have been defined and spatially documented from a 40 000 km² large area off Lofoten, Vesterålen and Senja in northern Norway. The area represents some of the most geologically diverse coast and offshore margin areas in Norway. The basis for the classification is an integrated, hierarchical system for terrestrial, coastal and marine nature types, presently being developed in Norway. This is the first broad-scale attempt to apply the new system in the marine domain. Detailed multibeam bathymetric data form the basis for 3D models of the seafloor, which have also been analysed using modelling and GIS tools.

Keywords: landscape, multibeam, terrain analysis, classification.

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Introduction

Knowledge of the submarine environment is still limited. However, advances in offshore technology now make it possible to acquire information about seabed structures in great detail. Interpretation of such information, with integrated analysis of geomorphology and sediments, mean these data can contribute to a better understanding of ecological conditions on the seabed. Abiotic conditions make a significant contribution to habitat structure and benthic communities, and the link between geological and geomorphological mapping and ecological understanding is therefore of great importance.

The continental margin off Lofoten, Vesterålen and Senja in northern Norway has been mapped as part of the MAREANO (MARine arEal database for NORwegian waters) programme (see Thorsnes 2009, this volume). The work involves identification and spatial documentation of the benthic environment which is relevant for ecosystem-based management, and is a key goal for MAREANO. At the same time, a new system for hierarchical classification of nature types (“Naturtyper i Norge (NiN)”), across both terrestrial and marine environments has been developed (Halvorsen et al. 2008). The purpose of this system is to provide a tool for the management of Norway’s land, coast and ocean areas, both for preservation of environmental values, and for effective use of natural resources. The approach of the classification system is basically ecological, rather than geological or geomorphological. This means that the classification should be based on ecological knowledge. Ecosystems may occur in several well established geological and/or geomorphological types/classes, and the boundary for these ecosystems may cross geological/geomorphological boundaries. In such cases, the NiN classification will give priority to the need to delimit the ecosystems. It has therefore been necessary to modify some of the standard geological and geomorphological terms, and introduce some new terms in order to comply with the ecological requirements. Important geological and geomorphological features are used as descriptors in the NiN classifications scheme. A study on the associations between megafaunal diversity and landscapes is presented by Buhl-Mortensen et al. (this volume).

The system comprises five levels of nature types – regions, landscapes, landscape elements, nature systems, and life media. In addition, a descriptive system has been developed using six sources of nature variation in which landform variation is one. Landform variation in this context is split into a gradual variation of terrain characteristics combined with a traditional geomorphological description. In order to test the proposed system at the landscape level, we have analysed swath bathymetry terrain data, combined with current knowledge of geological structures, features and processes, to produce a first order landscape map for the study area. Besides offering the first landscape classification for the region, this initial map will help to provide guidance for further development of the nature type classification, and integration with related work (Dolan et al., this volume).
Study area

The study area is situated at the continental margin off the Lofoten, Vesterålen and Senja islands, of northern Norway (Fig. 1). The area has been mapped and studied as part of the MAREANO programme between 2005 and 2008. The area of interest was selected because it is topographically diverse and provides a good area for testing and development of a submarine landscape classification system.

The area investigated is elongated in a SW-NE direction, 350 km long and 80-180 km wide. It extends offshore from the coastal domain dominated by strandflats and fjords, and includes the continental shelf, continental slope, and deep sea plains to where water depths approach nearly 3000 m (Fig. 2). The coastal region, with strandflats and fjords, is underlain by Archean and Palaeoproterozoic metamorphic crystalline complexes of the Fennoscandian shield, and Neoproterozoic to early Palaeozoic metamorphic rocks of the Caledonides (Sigmond 1992). These metamorphic rocks extend several kilometres offshore (Bugge et al. 1995). West of the metamorphic bedrock, seaward-dipping sedimentary rocks of Late Palaeozoic and younger age occur (Bugge et al. 1995, Sigmond 2002). The seaward-dipping strata are a result of tilting through repeated periods of uplift of the Norwegian mainland (Gabrielsen et al. 1990, Sættem et al. 1994, Riis 1996, Smelror et al. 2007), with the last uplift phase probably associated with extensive glacial erosion of the Barents Sea floor (Eidvin et al. 1993). Uplift during the Neogene affected the Norwegian mainland and adjacent shelf areas, and subjected the uplifted areas to erosion (Henriksen & Vorren 1996). The shelf is covered with Quaternary sediments, with a few exceptions, and here sedimentary or crystalline rocks crop out on the seabed. The thickness of these Quaternary sediments is less than 100 m. The shelf is characterized by large banks, separated by cross-shelf troughs (Ottesen et al. 2008). The sediments on the shelf range from mud to cobbles (Bellec et al., this volume). The deepest troughs are continuations of the fjords, and were formed by palaeo-ice streams (Ottesen et al. 2008). The continental slope has an overall dip of between 2 and 10°, and is heavily incised by submarine canyons which are up to 1100 m deep. Submarine canyons in this area form part of a high-latitude, glacially influenced sedimentary system with 10 canyons along the Lofoten-Vesterålen margin (Taylor et al. 2000). The northernmost canyon, the Andøya Canyon (Laberg et al. 2000), is located immediately south of the Andøya Slide (Dowdeswell 1996), and represents the upper part of the Lofoten Basin Channel (Haflidason et al. 2007). The Andøya Slide and fans associated with the submarine canyons run out onto the abyssal plain (Taylor et al. 2000). A study addressing sedimentary processes involving the formation of plough marks by icebergs has recently been undertaken by Bellec et al. (2008).

Methods

Data sources

Data used in this study comprise extensive multibeam echosounder images. Multibeam data outside the 12 nautical mile (Fig. 2) territorial limit (bathymetry and backscatter) were acquired by Fugro OSAE (Offshore Survey and Engineering) in the period 2007-2008 for MAREANO. In areas shallower than 1000 m, data were acquired using a Kongsberg Simrad EM710 (70-100 kHz) and Reson Seabat 7125 (200/400 kHz) multibeam system also from 2007 to 2008. In areas deeper than 1000 m, a Kongsberg Simrad EM300 (30 kHz) multibeam system was used in 2007 and 2008. Data inside the 12 nautical mile boundary were collected by the Norwegian Defence Research Institute and the Norwegian Hydrographic Service during a series of surveys undertaken since the mid-1990s, using Kongsberg Simrad EM1002 (95kHz) and other systems.

Analysis

The bathymetry data were gridded at 5 m, 50 m and 500 m. The data were then analysed using the geographical software ErMapper, ArcGIS and ArcView. For visual interpretation we have used hillshade representations and profiles using the ErMapper algorithms. For calculations of landscape indices we have used the (ArcView)/ArcGIS
Spatial Analyst extension. The main bathymetric derivatives used in the classification have been slope (standard Spatial Analyst algorithm) and Relative Relief (Rudberg 1960), calculated as the bathymetric range within running 1 km² squares using the "Range" algorithm in Spatial Analyst's Neighbourhood Statistics option (Bekkby et al. 2002). An example of this is shown in Fig. 3.

Landscape classification system

The classification system is based on the classification scheme for landscapes produced by the Norwegian expert group on "nature types" in Norway (Naturtyper i Norge – NiN, Halvorsen et al. 2008). The term “nature type” can be defined as: "A nature type is an area with a relatively homogenous type of nature with characteristics making it different from other areas. Each nature type has normally a unique community. The composition of the community is determined by the environmental factors".

The nature type classification scheme has been divided into five levels (1 - Life medium, 2 - Nature system, 3 - Landscape element, 4 - Landscape and 5 – Region) and operates at scales ranging from very detailed (cm- to m-scale) to regional scale (extending over several hundred kilometres). The classification scheme covers both marine, terrestrial and limnic nature types in order to allow interrelationship. The main aim is to provide an ecologically relevant scheme, based on a systematic use of varying environmental factors.

In this paper, we focus on the Landscape level and combine the analysis with assessments concerning landform variation.

The term "landscape" is used for large areas with a common visual character resulting from a widespread occurrence of large landforms, and with a characteristic distribution of landforms, landscape elements and nature systems. The smallest area for a "landscape" is 1 km² and the units should be mappable at the 1:500,000 scale. The landscape classification provides a full areal coverage and units should not overlap. The term "landscape elements" is used for features which are generally smaller, and form parts of the "landscapes". The minimum size is 0.01 km², and they should be mappable at the 1:50,000 scale. This category does not provide full area coverage and units may overlap. They can be explained as complexes of nature systems and are ecologically defined. Up to now only one such element is defined in marine environments outside coastal waters (coral reef), and we do not focus on this level in this paper.

In addition to the "landscape", we use the terms "landform" and "landform complexes" for important geological features (Table 1) which are incorporated in the NiN classification and descriptive system as a specified source of natural variation together with regional variation, species domination, content of nature systems, state, and local variation in environmental conditions on a very detailed scale. This includes, for example, linear features such as individual moraine ridges. Individual landforms may form complexes where the landform dominates a larger area, such as a moraine ridge field. Areas such as
Shallow marine valleys, which have a clear valley shape, but with a relief less than 100 m are also included as landforms.

The term “landscape” is to a certain extent comparable to the terms “mega-habitat” and “macro-habitat” as defined by Greene et al. 1999, but differ from recent work in the UK (e.g. Golding et al. 2004), in giving more attention to the geological and geomorphological aspects, and less attention to other physical attributes, such as salinity and temperature, which have been used to define “seascapes” (for instance in the MESH and BALANCE projects – http://www.searchmesh.net/ and http://balance-eu.org/). The Norwegian system has a translation key to the EUNIS system (Davies et al. 2004).

**Results**

**GIS-based classification**

Using the various GIS tools, and manual delineation of the features using experience from terrestrial geomorphological classification and marine geological classification of structures, we produced a classification of landscape types (Fig. 4A and 4B). A list of relevant NiN landscape types, landforms and landform complexes is listed in Table 1.

<table>
<thead>
<tr>
<th>Landscape type (areas, NiN)</th>
<th>Landform complexes (areas)</th>
<th>Landforms (linear features, points or areas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strandflat</td>
<td>Sand wave field</td>
<td>Shallow marine valley</td>
</tr>
<tr>
<td>Plain (with two subdiv.)</td>
<td>Moraine ridge field</td>
<td>Glacial trough</td>
</tr>
<tr>
<td>Continental shelf plain</td>
<td>Pockmark field</td>
<td>Sand wave</td>
</tr>
<tr>
<td>Deep sea plain</td>
<td></td>
<td>Moraine ridge</td>
</tr>
<tr>
<td>Hill and mountain landscape (no subdivision)</td>
<td></td>
<td>Slide</td>
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<tr>
<td>Fjord and valley landscape (with two subdiv.)</td>
<td></td>
<td>Fan</td>
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<tr>
<td>Fjord landscape</td>
<td></td>
<td>Canyon</td>
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<tr>
<td>Marine valley</td>
<td></td>
<td>Small basin</td>
</tr>
<tr>
<td>Continental slope (with two subdiv.)</td>
<td></td>
<td>Iceberg ploughmark</td>
</tr>
<tr>
<td>Smooth continental slope</td>
<td></td>
<td>Pockmark</td>
</tr>
<tr>
<td>Marine canyon</td>
<td></td>
<td>Glacial lineation</td>
</tr>
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<td></td>
<td></td>
<td>Bank</td>
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<td></td>
<td></td>
<td>Continental rise</td>
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<td></td>
<td></td>
<td>Abyssal plain</td>
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</table>

**Strandflat**

Shallow waters outside the Lofoten Islands are parts of the strandflat (Fig. 5). The term “strandflat” was originally introduced by Reusch (1894). The origin of the strandflat has been a matter of intense discussion (e.g. Nansen 1922, Holtedahl 1929, Holtedahl 1959), but it is now commonly accepted that agents such as freezing and thawing, and marine and glacial erosion during repeated glacial and interglacial periods have been important (Klemsdal 1982, Sulebak 2007, Holtedahl 1993). It is particularly widespread between Stavanger and Lofoten, but also extends to Nordkapp.

The strandflat in the NiN classification comprises an area of irregular terrain stretching from 50 m below to 60-70 m above sea level. It forms a brim of variable width (up to 20-40 km) around large parts of Norway, and includes a multitude of islands and islets. A typical feature of the strandflat is the presence of islands each of which is composed of a flat brim encircling a monadnock hill or mountain, being the remains of a former, more elevated landscape. These hills are classified as a “hill and mountain landscape” if they are large enough to be mapped as separate landscape units (> 1 km²), but are incorporated in the strandflat classification if they are small. The geomorphological structure in the submarine parts of the strandflat, with small linear basins and ridges is in many places inherited from the tectonic structure and bedding of the crystalline bedrock. The strandflat includes occasional deeper depressions (channels) which run parallel to the coast or transverse to it, and follow fractures and fault zones, or zones of less resistant (eroded) bedrock.
**Plains**

Plains are characterised by having a low relief (Rudberg 1960) of less than 50 m over 1 km$^2$. The plain types used in this study are *continental shelf plains*, and *deep sea plains*. All of these plains have internal variations of morphology and landforms, which provide the basis for further classification. We have proposed to use the term "continental shelf plain" rather than for example just "continental shelf", in order to separate between the really flat parts of the continental shelf (the plains), from more topographically diverse areas such as marine valleys or hills. Similarly, we propose the term *deep sea plains* as a common classification term for all plains seaward of the continental slope. The well established geological terms "continental rise" and "abyssal plains" are treated as landforms. This allows the NiN classification system to be ecologically based, and at the same time, allows the use of geological terms for descriptive purposes, making it easier to communicate with geological and geomorphological scientific communities.

*Continental shelf plains* are the dominating landscape types on the continental shelf (Fig. 4A). These plains are normally found seaward of the strandflat, at water depths between 50 m to 500 m. The plains in this study vary in size from 750 km$^2$ (Sveinsgrunnen) to 8000 km$^2$. Common landforms occurring on the *continental shelf plains* include banks, glacial troughs, sand waves, moraine ridges, small basins, iceberg ploughmarks, pockmarks and glacial lineations. The smaller plains such as Sveinsgrunnen and Malangsgrunnen are separated in North-South directions by large marine valleys (glacial cross-shelf troughs), and seawards by the inner limit of the
continental slope. We classify these features as continental shelf plains. In order to describe them, we use the landform term bank. The composite name for these features will therefore be: landscape type continental shelf plain, landform bank.

The largest plain in this study is found offshore Lofoten, with an area of 8000 km². Some plains have extremely low relief such as Malangsgrunnen, where 50-70% of the area has a relative relief lower than 5 m, and virtually all is below 10 m (Fig. 6). Other plains have a more pronounced relief, such as the large plain offshore Lofoten, where the dominant relative relief is in the order of 10-25 m. Important broad-scale geomorphological features (landforms) on this plain include moraine ridges, shallow marine valleys (Fig. 7A, 7B), iceberg ploughmarks and pockmarks (Fig. 7C, 7D). The moraine ridges and iceberg ploughmarks may occur over considerable areas as swarms, and may constitute landform complexes (Fig. 4B).

The deep sea plain has a relative relief of 10-25 m, with a general seaward slope of 0-2°. The term deep sea plain is, for the NiN classification scheme, proposed to include the landforms continental rise and abyssal plain. The break between the continental slope and the deep sea plain is well defined over large areas but occasionally interrupted locally where limited fan/slides occur (Fig. 8A), and more gradually where extensive slides occur (Fig. 8B).
8B). Fan deposits occur everywhere in the continental rise part of the deep sea plain of the study area, and a very large slide is found in the northern part of the area—the Andøya Slide. In the region where fan and slide deposits are most prominent, the relative relief exceeds the prevailing 10–25 m relative relief.

Hill and mountain landscape

Hill and mountain landscapes as defined in NiN have a relative relief larger than 50 m per 1 km². Three distinctly different possible hill landscapes occur in the study area. Only one of them is a clear cut hill landscape, and the two others have been included to illustrate the challenges associated with a classification based strictly on bathymetric derivatives.

The deepest part of this landscape type occurs in the proximal Andøya Slide (Fig. 4B), which forms part of the deep sea plain. It has an area of 35 km², and is made up of slide blocks (Fig. 9A). The largest block is approximately 200 m high, with an area of 3 km². This hill landscape satisfies the criteria set for the bathymetric derivatives.

A possible candidate for a hill landscape is found on the continental shelf plain (Fig. 9B). The visual appearance of the 45 km² area is clearly hilly, with hill ridges up to 30 m high striking SW-NE. However, with the present criteria a relative relief larger than 50 m within 1 km² is not a hill landscape. Instead we use the landform term rock ridge to describe it as a separate part of the continental shelf plain, but will consider adjusting the algorithms in the future to incorporate such structures in the hill landscape type.

In our study, we have suggested subdividing Andfjorden into a marine valley in its outer part, a hill landscape in its...
middle part, and as a fjord in the inner part (Fig. 4A, see section “Fjord and valley landscape” for the reasoning). The boundary between the hill landscape and the marine valley coincides with the boundary between crystalline bedrock and sedimentary rocks. This hill landscape satisfies the criteria set by the bathymetric derivatives, but it can be discussed whether it makes sense to classify parts of what is commonly considered to be a fjord as a hill landscape.

**Fjord and valley landscape**

We restrict ourselves to the marine parts of the fjord and valley landscapes. For NiN purposes, we use the definition that a fjord is an elongated, overdeepened, glacially excavated depression with a threshold (sill) limiting its outward extension. In many cases the seaward position of the threshold coincides with the inner boundary of the strandflat. According to the NiN proposal, fjords and valleys need to be deeper than 200 m along a cross-profile, and wider than 1 km to be classified as the landscape types "fjord" and "valley". However, for marine valleys we propose to use 100 m instead of 200 m.

The fjords are marine continuations of terrestrial, glacial valleys. Because the major "fjords" Vestfjorden and Andfjorden do not have a clear threshold in their outer parts, we have proposed classifying the outer parts as marine valleys, and restrict the term fjord for the inner part with overdeepening being limited seawards by a threshold (Fig. 4A).

Marine valleys have similar criteria as the terrestrial valleys and fjords, but for this study we have used a 100 m depth cut-off in order not to exclude major features such as Hola and Malangsdjupet. Cross-shelf troughs (Ottesen et al. 2008) are included in this landscape type. In the

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Fig. 10. Marine valley (glacial cross-shelf trough) (A-B) with glacial lineations (GL). Vert. ex. 4X.

Fig. 11. Basins (B) in a marine valley. Vert. ex. 4X.

Fig. 12 A. Shaded relief image. Fig. 12B. Interpretations overlain on the shaded relief image, showing the landforms moraines, glacial lineations, and sand waves. Vert. ex. 4X.
In the present study, we have identified 5 marine valleys, from Hola in the south, to the trough north of Malangsgrunnen (Fig. 2), which has no generally recognised name. In some places, the marine valleys are rooted in a complex of fjords (Fig. 10), and the fan-shaped pattern of the glacial lineations (longitudinal ridges) in the marine valley indicates that the latter acted as a confluent basin for cross-shelf ice flow. A cross-section of one of the fjords is shown in Fig. 10.

In some of the marine valleys, we find landform basins (Fig. 11). These are locally overdeepened structures, normally with a very smooth relief due to the accumulation of fine-grained sediments. In this study, they have been distinguished by visual classification from shaded relief imagery from multibeam bathymetry, without using supervised or unsupervised classification systems. The landform complex sand wave field occurs locally in the marine valleys (Fig. 12), the best examples being from Hola (Bøe, pers.comm.).

**Continental slope**

The continental slope is the zone between the shallow continental shelf, and the continental rise/abyssal plain (deep sea plain). The slope is on average approximately

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**Fig. 13** A. 3D view of the continental margin between Lofoten in the south (right) and Senja (left). Maximum depth (dark blue) is c. -2900 m. Frame shows the area covered by Fig. 13 B. B. Calculated slope from 50m grid, from 0 to 40 °, draped over 3D model. Vert. ex. 6X.
3° globally (Duxbury 1971). In the present study area, the overall slope is between 3 and 10°. The slope is heavily incised by canyons, and strongly affected by slides (Fig. 13A, 14). Canyons could be considered a special type of marine valley, as they satisfy the geometric conditions. Canyons are, however, confined to the continental slope, and are therefore treated as a separate division of this landscape type (Table 1). The canyons are up to 10 km wide, up to nearly 1100 m deep when measured from rim to rim, and may extend up to 500 km² in area. They have well developed fans with canyon-derived sediments (Taylor et al. 2000) at their mouths. The walls of the canyons have slopes up to 40°, particularly where they crown the heads of slide scarps and other mass movement features (Fig. 13B). They have a longitudinal (axial) dip greater than 2°. From the morphology, it is evident that canyons have developed and/or been modified by extensive mass movement. A detailed study by Laberg et al. (2007) from the Andøya Canyon concluded that the canyon excavation processes included sliding and slumping, axial incision and gullying. Proximal fans are well developed in the distal parts of the canyons (Fig. 14) with the distal parts extending into the deep sea plain. Some of the canyons are clearly spatially associated with slides. The fans extending from these slide-related canyons have a more irregular and blocky appearance (Fig. 15).

The huge Andøya Slide in the north extends over an area of c. 2500 km² in the study area (total area is 9700 km² - Laberg et al. 2000), and has a highly irregular topography, with extensive channelling and blocky surfaces. More or less the entire lower section of the continental slope is affected by sliding, evidenced by the presence of slide scars and the characteristic pattern of mass movement, with irregular down-slope ridges. This is in contrast to the upper part of the continental slope from the Andøya Canyon (Fig. 2) and southwards, where the slope is quite smooth.

Large trough mouth fans occur in the northern part of the study area, to the north of the Andøya Canyon. These extend from the shelf via the slope to the continental rise. Their distal part is heavily affected by the Andøya Slide, and the transition between continental slope and deep sea plain is gradual (Fig. 8B).

Discussion

This classification scheme represents the first step towards a unified system for classifying landscapes, as part of a comprehensive nature type classification in the Lofoten-Barents Sea area. It is based on a common terrestrial, coastal and marine approach. This ensures interrelationship between the individual domains, but also poses challenges, and the need for new terminology. An example of the latter is the term "marine valley", used by us for features previously termed glacial troughs, channels or cross-shelf troughs (e.g. Ottesen et al. 2008). Similarly, the use of the landscape type continental shelf plain rather than the common term "continental shelf" may seem unnecessary. However, the reasoning for this is that continental shelves include several landscape types which we want to differentiate. An example of this is the marine valley found in our study area. One possibility could be to upgrade the term "continental shelf" to include both continental shelf plains and marine valleys. We have chosen not to do this, in order to keep the number of levels as small as possible.
Whilst providing a good initial overview of the landscapes in the study area, the work has raised many questions. For example, should elongated, glacially excavated depressions such as Vestfjorden be classified as a fjord despite the lack of a clear threshold in its outer parts, or should it be classified as a marine valley? Clearly, a redefinition into a marine valley rather than a fjord contradicts the common usage of the term fjord, but we consider this as a valuable trigger for discussion.

Another issue is the classification of hill landscapes on the continental shelf plain, and in the middle part of Andfjorden. The irregular terrain with rocky hills on the continental shelf plain (see Fig. 9B) is too flat to qualify for classification as hill landscape, when using the criteria with a relative relief larger than 50 m. On the other hand, it gives the visual impression of a (low relief) hilly landscape, and probably has considerable ecological significance, as it represents an isolated outcrop of crystalline bedrock in an environment nearly entirely covered by Quaternary sediments. We will therefore evaluate the present algorithms and criteria used for this paper, and evaluate the usefulness of current limits and algorithms in further work. The NiN classification system will at the moment treat these small hills as landform variations within their descriptive context.

This study has employed visual classification of the submarine landscape, aided by several computed terrain parameters, to help delimit the boundaries. Further work will be needed, involving a more detailed determination of the limiting values for the different terrain parameters in relation to the landscape classes, and also multi-scale terrain analysis (e.g. Wilson et al. 2007). This will provide the basis for semi-automatic classification of landscape and will also aid in future work of linking species distribution and natural systems to landscape classification and landform variation. As nature type mapping on a more detailed scale (nature system level, using environmental factors such as grain size), becomes available, it will be necessary to evaluate this landscape division with regard to its possible ecological significance. We anticipate that modifications will need to be made, in order to ensure that the classification is able to reflect major ecological trends at a high level. New definitions of formal landscape elements may be one result of this increased knowledge.

Conclusions

The structure and large scale morphology of the continental margin off Lofoten, Vesterålen and Senja is the result of repeated periods of tectonics, the formation of sedimentary rocks, uplift, glacial erosion and sedimentation over a long period (Caledonian Orogeny to the present). The complex geological processes are reflected in an extremely diverse submarine landscape in water depths ranging from 0 to nearly 3000 m and over a 40 000 km² large area. New data giving detailed 3D terrain models of the seafloor have been used to classify the submarine landscapes into eight landscape types. These are, from shallow to deep: strandflat, fjord, marine valley, continental shelf plain, hill landscape, continental slope, and deep sea plain. Landforms and landform complexes such as sand wave field, moraine ridge field, slide, ploughmark field, glacial trough, bank and marine basin have been identified. The landscape types can be further described in the NiN by using a series of sources for environmental variation, one of which is landform variation.

The landscape types in the coastal region of the shelf are the result of dominantly glacial processes, but with strong control from the underlying crystalline basement rock. The shelf landscape types are mainly controlled by glacial processes (e.g., excavating the marine valleys, shaping the banks and creating a composite set of ridges off Lofoten). On the slope, glacial processes together with erosive forces have resulted in a complex of canyons and slides. On the deep sea plain, depositional processes involving material from the canyons and slides have been the most important features. Recent landscape-forming processes appear to be mainly bottom currents, giving rise to sand wave fields, such as those in Hola. The study has shown that the NiN classification scheme can be successfully applied to areas with a complex marine landscape, but that further refinement is required.

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