Master Thesis

Degree Project in
Marine Geology 60 hp

Acoustic geohabitat mapping: A case study

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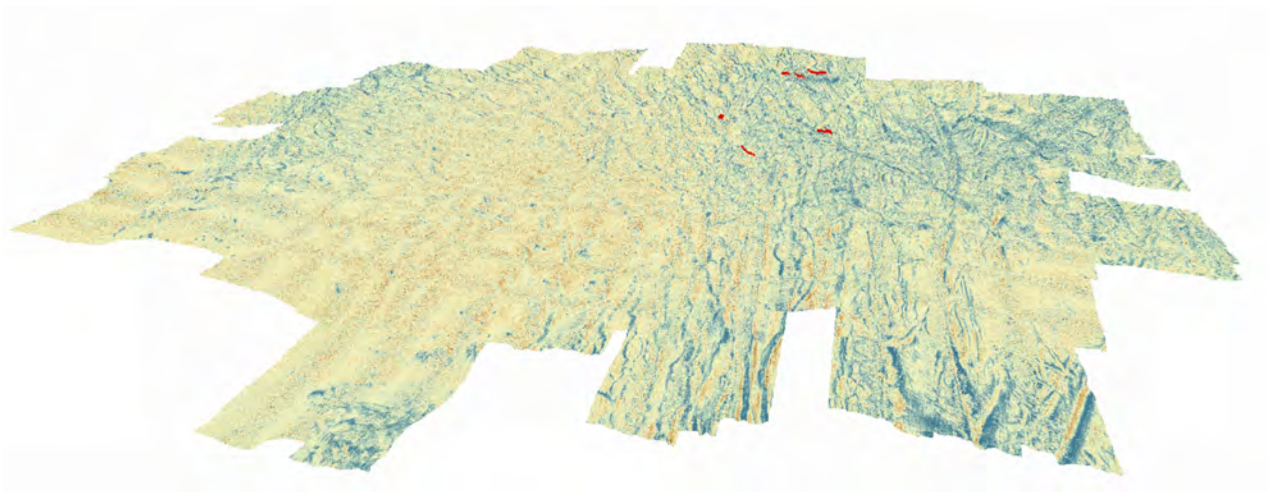

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Sammanfattning

Detta examensarbete (60 HP) behandlar möjligheten att med hjälp av multistråligt ekolod hitta och kartera olika geohabitat. Studien baseras på multistråle data och direkta observationer från RWE Dea Norge AS och Lundin Norway AS.

Under 1900-talet har en massiv exploatering av kontinentalsocklarna ägt rum. Det industriella fisket, som exempelvis havsbottentrålning har utökats och oljeriggar och pipelines har installerats på havsbotten. På grund av denna utökade verksamhet är det viktigt att ha en ingående kännedom om kontinentalsocklarna. Detta innebär att vi behöver känna till havsbottnens batymetri, sediment och förekomst av gas i de övre sedimentlagren, samt förekomst av marin bottenfauna och flora. Att använda styrkan i ekot (”backscatter”) från multistråligt ekolod för att bestämma sedimenttyp och strukturer på havsbottnen är en metod som nu utvärderas och utvecklas inom den maringeofysiska forskningen och offshoreindustrin.

Detta projekt fokuserar på just backscatter data och innefattar analys av data från två områden på den norska kontinentalsockeln. Syftet är att utvärdera möjligheten att kartlägga rev och marina svampar med multistråligt ekolod. Förekomsten av korallrev och marina svampar i de undersökta områdena har påvisats med fotografier och/eller videokamera vilka kan likställas med direkta observationer. I denna studie används data från multistråligt ekolod för att a) skapa en batymetrisk bild av havsbottnen och b) drapera denna med backscatter för att på så vis få en uppfattning om vad olika objekt har för ytegenskaper. Detta skulle i förlängningen kunna användas för att hitta och kartera exempelvis rev, havsbotten svampar eller pockmarks.

”Pockmarks” är på den norska kontinentalsockeln vanligt förekommande större gropar i havsbottnen som antas bildas via gasläckage från underliggande sediment. Pockmarks innehåller ibland hårda skorpor av cementerade karbonater vilka tros komma från utfällning av metan (”methane derived authigenic carbonates”- MDAC), vilka kan innehålla en speciell flora och fauna. I denna studie ingår också en utvärdering av att automatiskt kartera ”pockmarks” med hjälp av backscatter från multistråligt ekolod. En metod för att identifiera pockmarks där batymetri och backscatter används skulle förenkla sökandet efter pockmarks och analysen av dessa.

Den huvudsakliga slutsatsen av denna studie är att de undersökta områdena hade behövt bättre direkta observationer för att en säker klassificering av marin fauna och flora skulle kunna utföras. Backscattermosaiker draperade över batymetrin kan indikera var det finns korallrev om reven bildar ryggar på botten och har ett eko som skiljer sig markant från den omgivande havsbottnen.

Abstract

This master thesis (60 HP) evaluates the possibility to find and map different geohabitats with multibeam echo sounder. The study is based on multibeam echo sounder data and groundtruthing from RWE Dea Norge AS and Lundin Norway AS.

The 20th century has seen a massive exploitation of the continental shelves. The industrial fishing industry, for example bottom trawling has expanded and oil rigs and pipelines have been installed on the seafloor. Because of this expanded activity increasing knowledge of the continental shelves are crucial. This means that we have to recognize not only the seafloor bathymetry, sediment and presence of shallow gas but also marine fauna and flora, especially bottom dwelling species. To use the strength in the echo (the backscatter) from a multibeam echo sounder to determine sediment types and structures on the seafloor is a method currently being evaluated and developed in the marine geophysical research and the offshore industry. This project is focusing on backscatter data and comprises analysis of data from two geographical locations on the Norwegian continental shelf. The purpose is to evaluate the possibility to map reef structures and marine sponges with multibeam echo sounder. The presence of coral reefs and marine sponges in the surveyed areas has been shown with photography's and/or video footage which can be equated with direct observations. In this study data from a multibeam echo sounder is used to a) create a bathymetry of the seafloor and b) drape this with backscatter to achieve an estimation about the surface properties of different objects. This could then be used to find and map for example reefs, marine sponges or pockmarks.

Pockmarks are on the Norwegian continental shelf frequently occurring larger depressions in the seafloor, presumed to be formed by gas leakage from underlying sediments. Pockmarks sometimes contain hard crusts of cemented carbonates, assumed to be derived from deposition of methane ("methane derived authigenic carbonates"- MDAC) which can contain a specific flora and fauna. This study contains an evaluation of a tool to automatically map pockmarks in multibeam echo sounder backscatter maps. A method to identify pockmarks using bathymetry and backscatter would facilitate the mapping and analysis of these features.

The main conclusion from this study is that the surveyed areas would have needed better groundtruthing to make a safe classification of marine fauna and flora. Backscatter mosaics draped over bathymetry might indicate where there are coral reefs if the reefs are forming ridges on the seafloor and if they have an echo, clearly distinguishing them from the surrounding seafloor.

Acknowledgments

This thesis could not have been written without the invaluable contributions of my supervisors, Emma Sellén and Martin Jakobsson, I am so grateful for your time and effort.

I also want to take this opportunity to thank RWE Dea Norge AS and Lundin Norway AS for providing me with the data used in the project. Thank you also to Fugro Survey AS and Norges Geologiska Undersøkelse and the people on the MAREANO project for support, information and supervision.

Many other people have been of great help to me throughout the project, sharing their knowledge, providing me with literature, answering my questions, taking me out on energizing walks and discussing results, techniques, equipment and lunch boxes. To all of you at Stockholm University and all my friends and family – Thank You!

Contents

1. Introduction

There is an increased interest in exploration of the northern, Norwegian and Barents Seas, mainly due to the exploitation of oil and gas reservoirs, but also for the increasing intensity of fishing. The protection of endangered marine species and their habitats is therefore an increasing concern. Great efforts have been made by the Norwegian Institute of Marine Research (Havsforskningsinstituttet),as well as their collaborators and partners, to map the Norwegian shelf areas, including investigating fauna through the MAREANO project (www.mareano.no, from now on referred to as MAREANO). The mapping of the seafloor not only helps us to describe the abundance of seafloor features, but also to protect sensitive areas and to understand the different kinds of geohabitats existing under different marine conditions.

Recent advances in seafloor mapping techniques and survey instruments have led to new possibilities of detecting geohabitats and other distinct seafloor features, such as coral reefs and sponges. In addition to this, exploration companies are required by the authorities to carry out thorough investigations of the seafloor before they are allowed to install drilling rigs, pipelines and cables. These surveys are mainly carried out by mapping the seabed using seismic profiling and various echo sounding methods, such as side scan sonar, multibeam echo sounder and sub bottom profiling (Kenny et al., 2003). If geohabitats, such as coral reefs, pockmarks or sponge aggregations such as sponge reefs, are expected in the area then a more thorough environmental survey is required using groundtruthing methods such as video footage. The acknowledgement of cold water coral reefs and marine sponges as sensitive habitats has increased the demand for their protection and the need for effective and precise mapping tools. Recently the presences of sponges and "bubbling reefs", associated with methane outlets, have been considered geohabitats that need to be protected from exploitation of the continental shelf (Report EUR 27; Norsk rødliste for arter, 2010).

Today, the most widely used method for finding possible habitats is based on side scan sonar mapping. The side scan sonar mosaic provides an image of the seabed from which different seabed features can be interpreted. A reef seen on side scan sonar data can, for example, be recognized by its high reflectivity and the shadow indicating its height. In order to verify the geological interpretation and positively identify the geohabitats, further groundtruthing is essential. Standard groundtruthing methods when expecting geohabitats are high resolution video camera and/or still photos. Sediment sampling and photography can be carried out from the survey vessel's deck and video footage is typically collected using a remotely operated vehicle (ROV) or an autonomous underwater vehicle (AUV).

Multibeam echo sounders are presently among the tools suggested to improve the efficiency for geohabitat mapping (Roberts et al., 2005). The main advantage of using multibeam data is that backscatter is acquired simultaneously with bathymetric data during multibeam mapping. This means that correlating depth/height data and reflectivity data is simpler in the software provided, which is of great advantage when analyzing features with depth or height. The datasets will also have the exact same geographical reference and the same software can be used to process and interpret the data, which makes processing comparatively fast and cost effective. Earlier attempts to map reefs with backscatter have given results ambiguous to those expected (Fosså et al., 2005; Roberts et al., 2005; Conway et al., 2005).

1.1 Hypothesis

The hypothesis is that coral or sponge reefs should show a distinct backscatter pattern that is different from the surrounding seafloor. The literature suggests both high and low backscatter for reefs, depending on the surrounding seafloor substrates and on the reef characteristics. Seafloor sponges occurring in larger aggregates, acting as reefs, are expected to absorb an acoustic signal, resulting in a relatively low backscatter pattern. Pockmarks are shallow depressions that typically have a harder substrate than the surrounding seafloor and should also be possible to distinguish with multibeam bathymetry and backscatter data. If the resolution of the data permits, we would be able to map geohabitats and seabed features such as coral reefs, sponge reefs and pockmarks with multibeam bathymetry and backscatter.

1.2 Thesis objectives

The primary aim of this master thesis is to investigate the best method to map specific seafloor geohabitats and pockmarks found in three different areas in the Norwegian Sea, using multibeam backscatter, bathymetry data and groundtruthing data. A number of geohabitats have been investigated and the purpose of the thesis can be divided into the following partial objectives:

- Mapping coral reefs

  Cold water coral reefs are fragile geohabitats and home to a wide variety of species. Mapping their distribution is essential to protect them from offshore operations.

- Mapping seafloor sponges

  A wide variety of species of deep sea sponges are present in the Norwegian Sea. Many of them are currently on the International Union for Conservation of Nature (IUCN) “Red List Species”, implying that the areas where they occur are protected from exploitation.

- Mapping pockmarks and MDAC locations

  In the study areas of this thesis there is a frequent occurrence of pockmarks that may contain MDAC. MDAC sometimes contains a unique micro fauna and has a complex local chemistry, forming hard crusts inside the pockmarks. If the MDAC surface is harder than surrounding sediments, then the backscatter response can be used to map them.

A fast and simple method to map pockmarks using bathymetry data is tested in ArcGIS where the correlation between pockmark depth contours and backscatter response is evaluated. The possibility to use multibeam and backscatter to map the three features mentioned in the objectives would provide us with an additional tool for interpreting them. Extensive areas could be "scanned" and the information synthesized and interpreted in easily accessible software. To achieve the main aim of this thesis, the following questions need to be answered:

- Can backscatter be used to map some specific geohabitats and pockmarks on the seafloor in the surveyed areas?
- What are the limitations of using backscatter for detecting and mapping geohabitats?
- What other methods could be used to detect geohabitats, either independently or through combined multibeam bathymetry and backscatter techniques?

2. Background

2.1 Survey areas – general descriptions

All survey areas are located on the continental shelf in the Norwegian Sea. Survey Area A is located approximately 205 km west of Rørvik in the Vøring Basin (Figure 2.1), an area where the bottom sediment has not been mapped by the MAREANO project. Survey areas B and C are located approximately 200 km northwest of Hammerfest between the Loppa High, Bear Island Trough, Tromsøflaket and Ingøydjupet. Survey areas B and C are located just outside the areas where the MAREANO project has gathered sedimentary and biotope data (Figure 2.1).

2.2 Bottom morphology and geology of the survey areas

2.2.1 Area A

The Norwegian shelf area is characterized by its sedimentary rocks and, close to Area A, cretaceous deep water sandstone, which has been encountered during well drilling (NGU, 2003; Aram, 1999). Survey Area A is stretching approximately 11 km in an east-west direction and 9 km in a north-south direction. The sediment at Area A is mainly clay, from soft, to very soft, to stiff and hard clay/silt, sometimes containing sand or sand layers (FSLTD Report No. 9999). Processes in the area have affected the seabed substrate heavily, including formation of iceberg plow marks and the associated ridges of mainly coarser sediment, after the deglaciation mainly currents and waves affect the sediments in less dramatic ways (MAREANO). Iceberg plow mark ridges usually consist of coarser material, and in this area it is also mainly in the ridges that we find boulders, cobbles, pebbles and gravel (Lien et al., 1989).These types of coarser material are often preferred by bottom dwelling species such as *Lophelia pertusa* and *Paragorgia arborea*, as they are epilithic, i.e. require a hard substrate (Rapp, 2012).

2.2.2 Area B and Area C

The bedrock at the location of survey areas B and C is classified as sandstone, mudstone and/or limestone (NGU, 2003). It is possible that the same cretaceous sandstone that underlay Area A also underlay areas B and C. Large amount of sediment was removed in survey areas B and C by large scale glacial erosion, however, Tromsøflaket has sediment deposits with up to 150 m thickness (MAREANO). According to studies, based on the same data as presented in this thesis, the sediment properties vary highly, ranging from muddy to gravelly sediments, with sand, cobbles and boulders (Chand et al., 2009; Chand et al., 2012; MAREANO). Examples of the coarser grain sizes and cemented seabed substrate in and nearby survey areas B and C are shown in Appendix A. Both study areas B and C are subjected to heavy plow mark scouring.

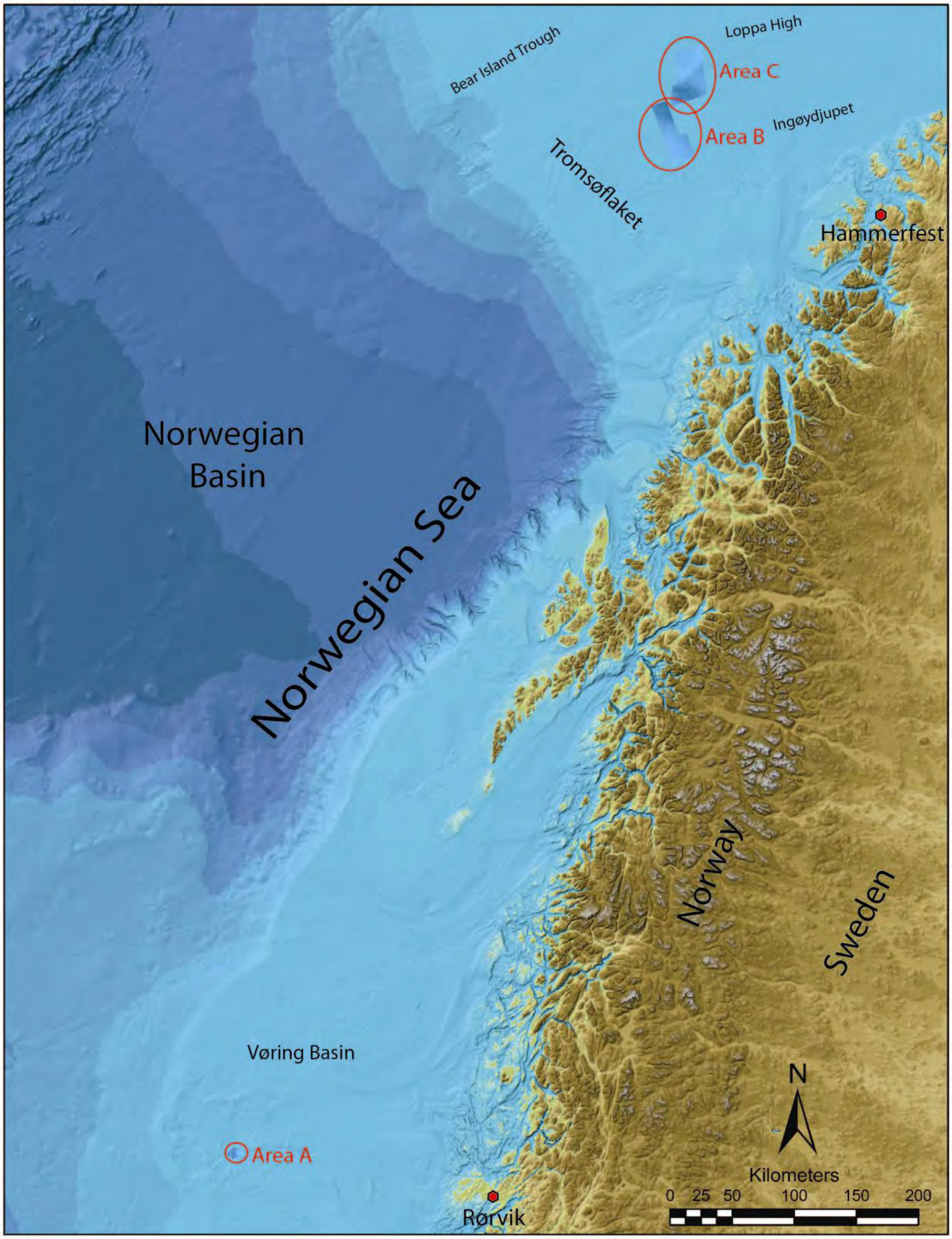


Figure 2.1 Overview map of the study areas. The bathymetry is from the International Bathymetric Chart of the Arctic Ocean (IBCAO), Version 3.0 (Jakobsson et al., 2012).

2.3 Habitats and biology in the survey areas

2.3.1 Area A

Smaller coral reefs have been found in the vicinity of the study area (MAREANO). These mainly colonize on coarser materials on the flanks of glacial iceberg plow marks. The Norwegian red list species present in Area A are *Lophelia pertusa* and *Paragorgia arborea*. There are no healthy *L. pertusa* found in the study area, only corals in poorer conditions were observed (Figure 2.2).

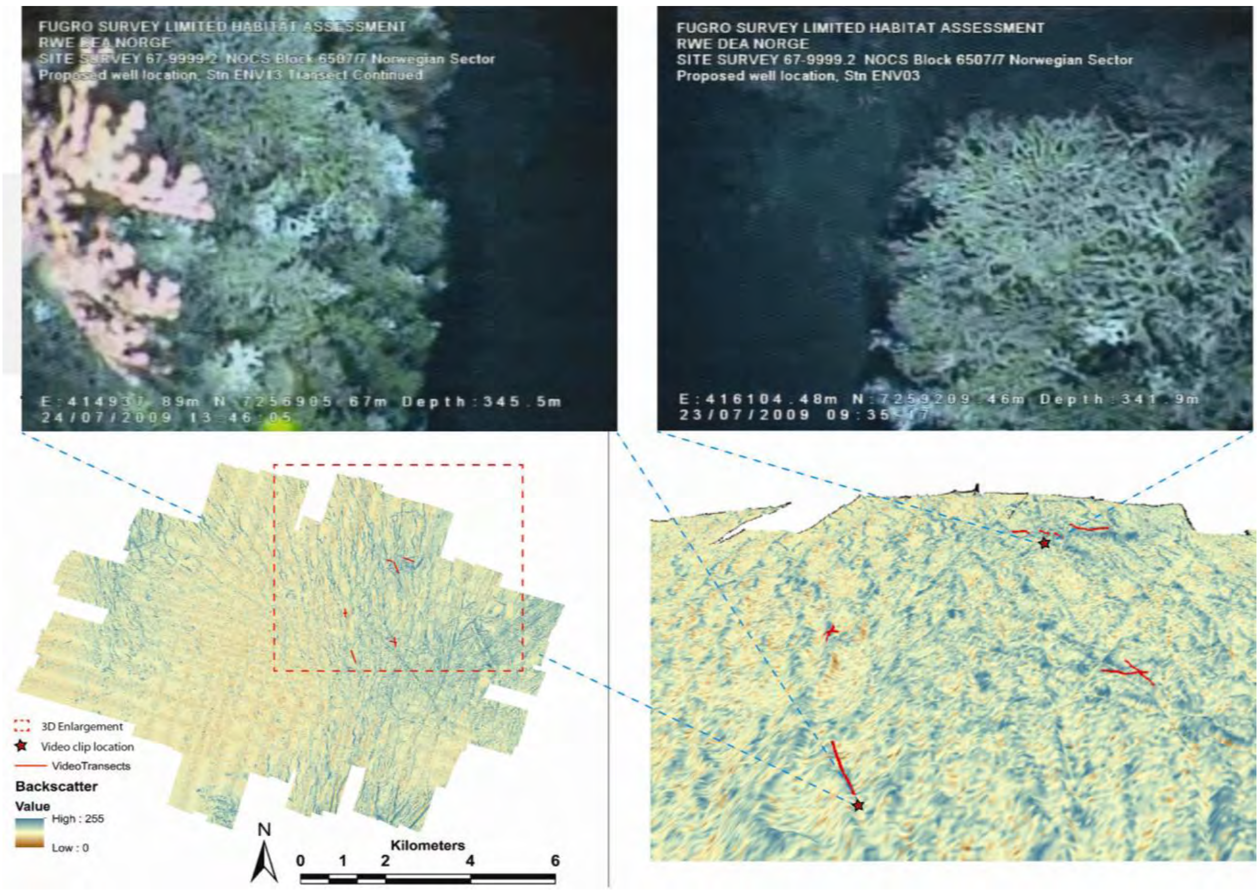


Figure 2.2 Still photos from groundtruthing videos from Area A showing *Lophelia pertusa*. The approximate locations of the video transects are marked with red lines and positions of the shown photographs are marked with red stars on the backscatter mosaic draped on bathymetry. The map on the right is an enlargement of the area within the red rectangle.

2.3.2 Area B and Area C

Close to survey areas B and C deep-sea sponge aggregations, coral gardens, polyps and burrowing megafauna were observed during the MAREANO survey. When there is a large occurrence within the area it is characterized as vulnerable. The organisms in these areas are generally fragile and easily crushed by physical impact on the seafloor (MAREANO).Appendix A has examples of fauna in and nearby survey areas B and C, as well as of anthropogenic debris, indicating human activity in the area.

A biotope description from Tromsøflaket has been carried out by the MAREANO project, defining the fauna in different sedimentary environments. They found that muddy sediments on the flat and smooth seabed with pockmarks have a fauna typically consisting of foraminifera, shrimps and glass sponges. The sediment within depressions on flat, smooth seabed is characterized as muddy with sand and gravel. Chand et al. (2012), working on the same dataset as presented in this study, commented on the high backscatter values in the pockmarks.

Typical fauna in these depressions consists of demosponges and calcareous foraminifera. Where the seabed is moderately rough or flat with iceberg plow marks, the bottom fauna instead typically comprise of glass sponges and echinoderms, such as sea cucumbers or sea stars. Ridges with moderate slopes and gravelly sediments with sand, cobbles and boulders typically have a fauna consisting of demosponges or marine worms (MAREANO). Similar biotopes can be expected in the survey areas B and C due to the proximity of this part of the MAREANO survey and the similar depths and morphology described.

2.4 Seafloor features and geohabitats investigated in this survey

2.4.1 Pockmarks

Features commonly referred to as pockmarks have been mapped in a broad range of marine and lacustrine settings. They can be found in different geological settings, such as in shallow bays, on continental shelves, continental rises and slopes, on submarine ridges, hydrocarbon provinces and lakes (Ussler III et al., 2003). The pockmarks found in the researched areas in the article by Hovland et al. (2005) are located at depths of about 100 m, mainly in softer sediments. Pockmarks are often circular depressions, wide and shallow with relatively steep sides and flat floor (Chand et al., 2012).

Figure 2.3 Nyegga pockmark area close to survey Area A.

Whether or not the different morphology of pockmarks is a response to difference in origin is not fully understood. Several explanations have been offered for the formation of pockmarks. In a study by Ussler III et al. (2003) one or a combination of the following factors are mentioned: venting of gas, pore water escape, seepage of freshwater, migrating of gas hydrates and rafting of water ice. Ussler III et al. (2003) suggests that differences in pockmark characteristics, occurrence, morphology and size is a direct consequence of the variety in pockmark formation processes.

Another possible formation process is suggested by Reiche et al. (2011) in a study of the Nyegga pockmark field (Figure 2.3), offshore of the coast of mid-Norway, where the pockmarks can reach a size of 300 m in width (Hovland and Svensen, 2006). They used high resolution seismic methods to understand the sedimentation history of the area, and the authors conclude that a rapid deposition of sediments triggered fluid expulsions causing the pockmarks (Reiche et al., 2011).

High quality seabed maps increase the possibility for scientists to chart all conceivable explanations for the formation of seabed pockmarks. The use of backscatter mapping could be of help when charting pockmarks since it gives information about the top layer substrates, including the substrate covering and surrounding the pockmarks. Chand et al. (2012), working on the same dataset as presented in this study (Areas B and C), suggest that higher backscatter within pockmarks is due to glaciomarine sediments. The pockmarks cut through the soft postglacial sediments and the upper parts of the glaciomarine sediments, leaving the coarse material exposed (Chand et al., 2012). A difference in sediment in pockmarks would probably give us a different backscatter response for these seabed features, thus making them possible to detect with backscatter mosaicking. Mapping pockmarks does not only give us the possibility to protect the specific fauna associated within these but could also help us to determine the genesis of sediments and the potential presence of hydrocarbons. Determining whether the pockmarks are active or inactive is also possible with so called “sniffers”, detectors measuring methane seepage from the seabed. The study carried out by Chand et al. (2012) uses hydro acoustic water column data to detect gas flares. The data shows methane seepage both in pockmark areas but mainly outside these (Chand et al., 2012). Chand concludes that the presence of active gas flares and inactive pockmarks suggests a two stage development. In the first stage pockmarks are formed due to dissociation of gas hydrates related to glacier retreating and deposition of glaciomarine sediments whilst in the second stage active acoustic gas flares along regional faults occurs due to fluid flow associated with isostatic uplift and opening up of faults (Chand et al., 2012).

2.4.2 Methane-Derived Authigenic Carbonates

Numerous continental shelf locations host structures formed by hydrocarbon gases such as methane, ethane, propane or butane (Hovland and Svensen, 2006). They are most commonly mentioned in the literature as methane derived authigenic carbonates (MDAC). Formed by carbonate minerals cementing the normal seabed sediment to form a hard rock, they are closely associated to seabed gas seeps (Judd et al., 2007). The carbonate cement is formed as a by-product of anaerobic oxidation of methane just below the seabed (Judd et al., 2007). The European Commission's Habitats Directive annotates the MDAC environments as "submarine structures made by leaking gases", which are considered to be a marine habitat worth protecting (Report EUR 27).The large areas of the Norwegian Sea seafloor that have recently been mapped have contained vast areas of MDAC (Hovland et al., 2005). MDAC are often found in pockmark areas, situated inside the pockmarks. Possibly, it is the MDAC Chand et al. (2012) described as exposed glaciomarine sediment. However there are also occurrences of MDAC that are not associated with pockmarks at all (Judd et al., 2007; Report EUR 27).

In the Nyegga area (Figure 2.3), pockmarks containing abundant MDACs have been mapped with bathymetric data, sampling and video footage (Hovland and Svensen, 2006). The hydrate structures studied in pockmarks in the Nyegga area display four distinct characteristics: rounded mounds and cones, bacterial mats as partial cover as well as tubeworms and distinct corrosion pits, which are probably a product of the sub-surface hydrate dissociation (Hovland and Svensen, 2006). They suggest that the pockmarks are formed during a dynamic process of gas hydrate sub-surface build-up at specific focused fluid flow locations (Hovland and Svensen, 2006).

The MDACs can usually be identified on multibeam echo sounder data because they form mounds on the seabed up to 10 m in height over the seafloor (Hovland et al., 2005; Hovland and Svensen 2006; Judd et al., 2007). Samples from the study by Judd et al. (2007) have shown that the mounds consist of a crust made of the normal seabed sediment, for example quartz grains locked together by carbonate cement. The carbonate cement is associated with the occurrence of shallow gas seeps and is a by-product of anaerobic oxidation of methane (Hovland and Svensen 2006; Judd et al., 2007). Carbonate minerals mentioned are, for example, high-Mg calcite, dolomite and aragonite (Judd et al., 2007).

The European Commission's Habitats Directive divides the submarine structures made by leaking gases into two different habitat types: bubbling reefs and pockmarks. Bubbling reefs are characterized by special topographic features, such as overhangs, vertical pillars and stratified structures (Report EUR 27). The morphology of bubbling reefs is expected to resemble coral and sponge reefs in the multibeam echo sounder data. The origin, which separate bubbling reefs from coral reefs or sponge reefs, cannot be decided without a thorough environmental investigation. Pockmarks are instead depressions in often muddy seabed, up to several hundred meters wide and 45 m deep (Report EUR 27).

The MDACs are often colonized by a diverse fauna of benthic and seabed living organisms, mainly specialists on hard marine substrates (Report EUR 27; Hovland and Svensen 2006; Chand et al., 2009; Johansson M., 2009). Plants, such as macroalgae, are only found in MDAC environments if they are situated in the photic zone. Animals, particularly invertebrates, can be found in both bubbling reef and pockmark environments. The main species belongs to *Porifera*, *Anthozoa*, *Polychaeta*, *Gastropoda*, *Decapoda*, and Echinodermata in the bubbling reefs. In the pockmarks we find species belonging to the *Hydrozoa*, *Anthozoa*, *Ophiuroidea* and *Gastropoda* groups, and in the softer sediment around the hard substrate mainly *Nematodae*, *Polychaeta* and *Crustacea* (Report EUR 27).

2.4.3 Cold water corals

During reconnaissance surveys of the Norwegian shelf areas, between 1982 and 2000, extensive seabed areas were mapped and a wide variety of different species, including cold water corals, were registered (MAREANO; Hovland et al., 2002; Norsk rødliste for arter, 2010). Since 1997 the Norwegian Institute of Marine Research has had a program for mapping potential areas of reefs through analyses of topography maps in the MAREANO project. There are approximately 115 different species of corals in Norwegian waters (Norsk rødliste for arter, 2010). The most important reef building coral in northern waters, including the Norwegian Sea, is the eye coral *Lophelia pertusa* (Figure 2.4). However, larger occurrences of Octocorallia have also been mapped in northern waters of the Norwegian continental shelf. *Lophelia pertusa* are capable of building up to 1000 m long and 30 m high reef structures, and the oldest parts of the reefs may be up to 8000 years old (Norsk rødliste for arter, 2010). In a study by Hovland et al. (2002), all reefs occur in clusters with up to 10 reefs per km^2. *Lophelia* reefs in the study area occur in specific geographical regions at depths of approximately 300 m and prefer to grow on so called “flat-iron” structures which are eroded rocks (Hovland et al., 2002). Fosså et al. (2002) states that the distribution of *Lophelia* reefs is concentrated between 200 m and 400 m depth and along the continental shelf break on moraine ridges. Even larger coral colonies can be built by the coral *Paragorgia arborea*, which is not a reef building coral itself but grows supported by dead coral material (Norsk rødliste for arter, 2010). The stony coral *Madreporaoculata* and the octocorallia *Anthelia borealis* are also dependent on larger reef builders to grow and survive (Norsk rødliste for arter, 2010).

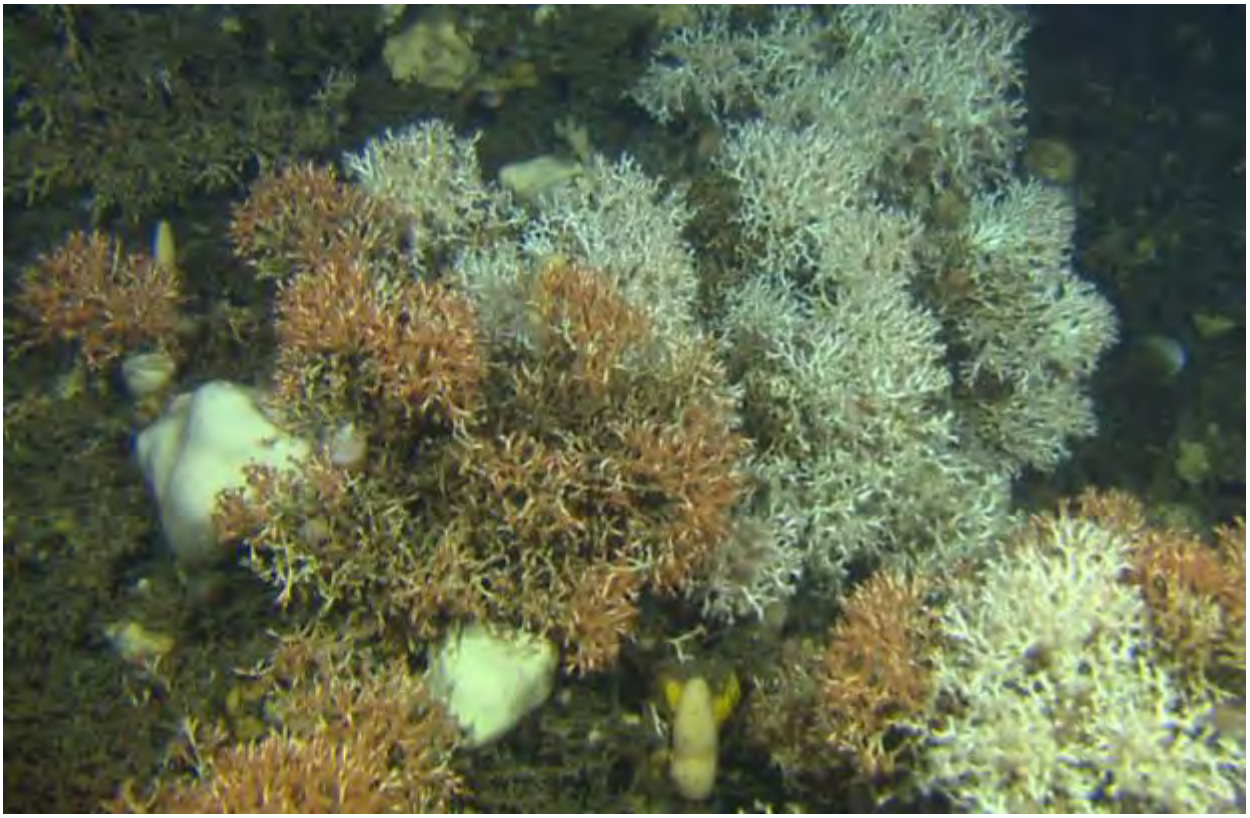


Figure 2.4 Lophelia pertusa (MAREANO)

In a study from Brazil, deep water corals were observed near giant pockmarks (Sumida et al., 2007). The authors suggest that the corals here may be related to oxygen rich Antarctic Intermediate Water (AIW) or sediment micro seepage of hydrocarbons that fertilize the water. However, the study does not give any evidence of gas venting, although the presence of certain organisms suggests a reducing bottom environment such as cold seeps or hydrothermal vents. The presence of the deep water corals in the studied area offshore Brazil was suggested to be related mainly to AIW flow, bringing oxygen and nutrients to the seafloor rather than the proximity to the pockmarks (Sumida et al., 2007).

The largest threats to the cold water corals within the Norwegian Exclusive Economic Zone (EEZ) and Norwegian territorial waters are bottom trawling and infrastructure installations on the seabed (Norsk rødliste for arter, 2010; Fosså et al., 2002). One report claims that between 30-50% of the reefs are affected or damaged by fishing, since the reef areas are traditionally rich fishing grounds (Fosså et al., 2002). Among the common reef builders, *Lophelia pertusa* and *Paragorgia arborea* currently have status as near threatened, most likely due to the damage caused by trawling. *Anthelia borealis* is classified as near threatened, and *Madrepora oculata* is characterized as data deficient because of the lack in knowledge about damage.

The recovery of these organisms is uncertain, but of great concern since they are slow growing species. The Norwegian fisheries authorities have declared that “intentional and negligent destruction” of coral reefs is prohibited, and precaution must be taken when fishing in the vicinity of known reefs (Norwegian Ministry of Fisheries and Coastal Affairs, www.fisheries.no).

2.4.4 Deep sea sponges

Between 93 and 270 sponges are currently recognized in Norwegian marine environments (http://www.marinespecies.org/porifera/distribution.php; Norsk rødliste for arter, 2010; Rapp, 2012). The sponge fauna in Norwegian and Nordic waters is very heterogenic; resulting in a large variety in shape and size of the sponges (Figure 2.5). Highly variable substrate, deep fjords, mixtures of southern and northern fauna, and varying habitats such as coral reefs, sponge grounds, cold seeps, hydrothermal vents, seamounts and abyssal plains are suggested to cause this diversity (Rapp, 2012). The sponges' main nutrition is filtrating particles from the seawater (Norsk rødliste for arter, 2010).

Deep sea sponges are divided into three subgroups based on their skeletal material: calcareous sponges (*Calcarea*), glass sponges (*Hexactinellida*) and demosponges (*Demospongiae*).

The demosponges includes more than 90 % of all known species of sponges and are characterized by skeletons of spicules, consisting of the protein *spongin*, silica or both (http://www.seawater.no/fauna/porifera/Demospongiae.html). Demosponges are most frequently growing on hard seabed in deeper waters (Norsk rødliste for arter, 2010). Demosponges accounts for the largest amount of known species in Norwegian waters and one of the most common species of this group is *Geodia barretti* (Christiansen, 2010). Six species of the genus *Geodia* are present in Norwegian waters; G. barretti, *G. hentscheli*, *G. macandrewi*, *G. atlantica*, *G. arctica* and *G. phlegraei* (Rapp, 2012).

From the middle of the 1980s the presence of reefs made of glass sponges has been known. Glass sponges are characterized by their skeleton made of siliceous spicules. Glass sponge reefs or sponge areas have been discovered in the North Atlantic Ocean off northern Norway, in the Barents Sea and off Svalbard (http://www.ices.dk/marineworld/sponge.asp). In the marine environments of Norway there are twelve glass sponge species, two in coastal waters and fjords, and ten in deep basins (Norsk rødliste for arter, 2010).

Calcareous sponges have a skeleton constructed of calcium carbonate spicules. It is a marine group of which approximately 40 species are found in Norwegian waters, in habitats varying from hard seabed, to soft substrates, and from the tidal zone to depths of more than 2000 m (Norsk rødliste for arter, 2010; Rapp, 2012).

The greatest threats for the deep sea sponges in Norwegian marine zones are suggested to be bottom trawling and global warming (Christiansen, 2010). Other threats include, for example, re-suspension of sediments, release of particulate and chemical wastes, physiological and ecological effects from oil drilling and mining pressure (Bannister, 2012). The sponges growing on fish banks and on the continental shelf are particularly vulnerable. One reason for the sponges' sensitivity is their highly limited ability to move (Norsk rødliste for arter, 2010). The glass sponge reefs are suggested to be added to the UNESCO list of world heritage sites since they are threatened from trawling in three ways: removal, damage and clogging (http://www.ices.dk/marineworld/sponge.asp).

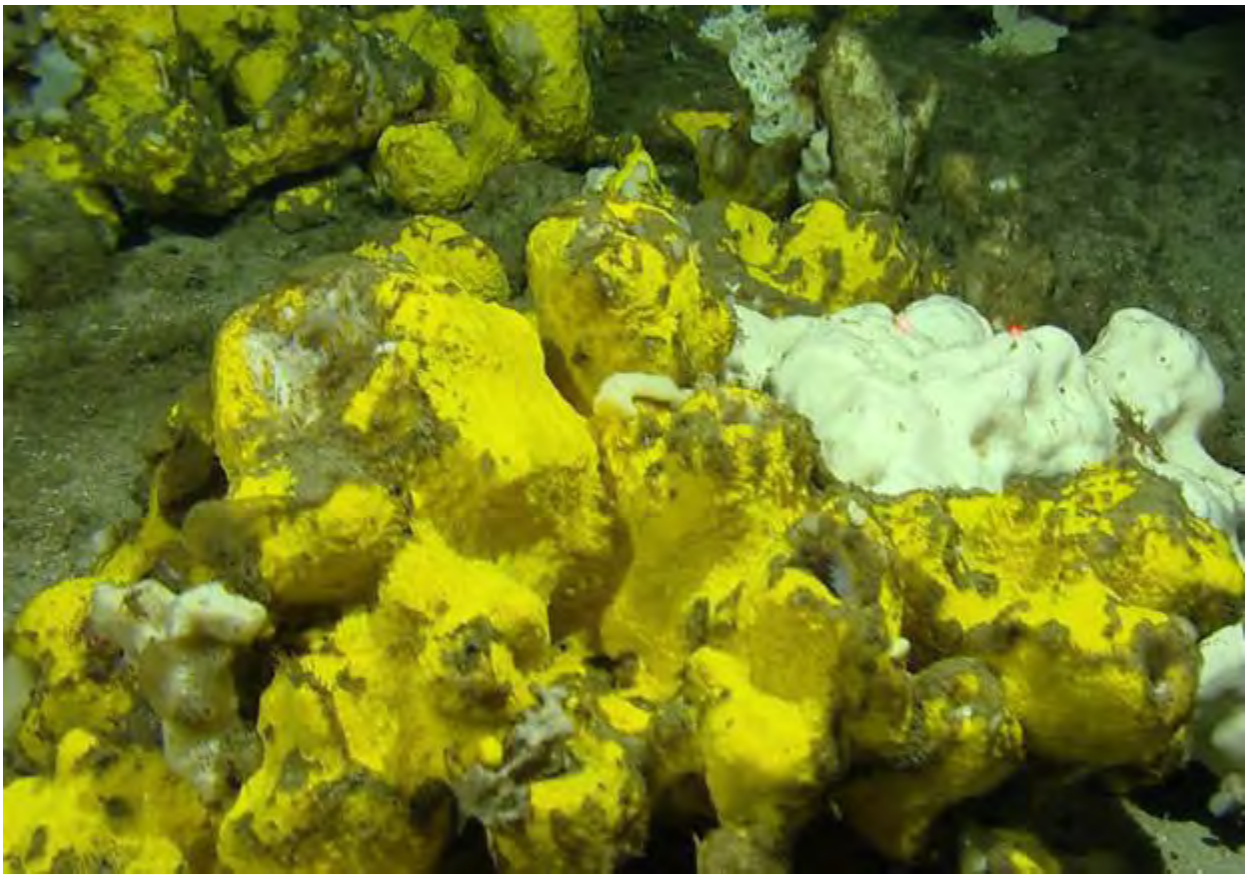


Figure 2.5 Sponges (MAREANO)

2.5 Backscatter

A multibeam echo sounder provides a wider coverage of the seafloor than a conventional single beam echo sounder as it sends out a broader acoustic pulse from which several beams are derived. Along with the data used for the bathymetry, the receiver on the multibeam echo sounder also collects backscatter. Multibeam backscatter is the strength of an acoustic signal after it has interacted with the seafloor and been echoed back. The signal is affected by the seafloor acoustic reflectivity, the absorption and scattering of the acoustic signal, and is measured in decibels (dB). The backscatter signal depends on seafloor reflectivity and can therefore provide information about the seafloor physical properties, specifically small scale topography and sediment types (Roberts et al., 2005; Jaramillo and Pawlak, 2011).

The acquired backscatter values in dB must be seen as relative values when comparing different sites since they depend on site specific factors such as water depth and seabed substrate. The three main factors controlling the reflectivity of a seabed substrate are seafloor roughness, acoustic impedance and sediment volume heterogeneities (Mayer et al., 2007; Fonseca et al., 2009).

We may use the backscatter to extract information about vast areas by extrapolating information from groundtruthing, such as cores or probes taken in the area with the same backscatter response. A large factor controlling the seabed substrate is the grain size of the sediment. Possibilities to map grain size changes of the seafloor sediment using backscatter is currently investigated, and several software already contains built-in grain size analyzers (Fonseca and Mayer, 2007; Mayer et al., 2008).

2.6 Mapping geohabitats with multibeam echo sounder

Multibeam echo sounding systems or side scan sonars are commonly used for geohabitat mapping in deep ocean settings. Side scan sonars provide information about sediment texture- and bed forms but no depth information. Bathymetric data are provided by multibeam echo sounding systems. Both of these devices produce backscatter information, in side scan data often referred to as “reflectivity”. The main difference is that for each backscatter value provided by the multibeam echo sounders, a depth value is precisely georegistered, providing the exact height or depth for all features. In side scan sonar data the height or depth of a feature is instead approximated based on the “shadow” that the feature causes on the record. In multibeam echo sounder data these shadows are not produced. A combination of shaded-relief bathymetry, slope and backscatter maps will provide good base data for seafloor habitat characterization (Kenny et al., 2003). Conway et al. (2005) and Brown and Blondel (2009) suggest that backscatter information combined with bathymetry is the ideal data to use for mapping coral reefs and other benthic communities, since there is a link between benthic community structure and substrate type. The kind of multibeam echo sounder and/or side scan sonar instrument to use for detecting seabed features can be determined from three different factors: 1) the size of the survey area, 2) the water depth in the survey area and 3) the object detectability required, i.e. the resolution needed for the specific habitat (Kenny et al., 2003).

Elevated seafloor areas are typically highly reflective, with high backscatter values characterizing bedrock or ridge crests. Estimating what the backscatter response for reefs would be is a complicated matter. Research concerning habitat mapping is ambiguous as to what a typical coral or sponge reef would look like on the backscatter mosaic (Conway et al., 2005, Roberts et al., 2005 and Fosså et al., 2005). A hard surface of the reef would typically give a strong echo, but the scattering factor from an uneven surface needs to be taken into account as well. Flora and fauna growing on the reefs could absorb the signal, thus decreasing it, and since cold water coral reefs often grow in symbiosis with sponges it is not always possible to determine if it is the corals or sponges that will dominate the echo signal strength. Most importantly, backscatter is also interpreted relatively to the surrounding seafloor and reefs growing on, for example, solid rock seafloor will appear like areas with relatively low backscatter.

An example is given by Conway et al. (2005) that suggest that the relatively low backscatter they see in sponge reefs on the Canadian shelf are not only caused by skeleton sponges trapping clay-rich sediments. The observed difference in backscatter for the reef and the surrounding seafloor is due to the highly reflective character of boulder and gravel rich glaciomarine sediments compared to the acoustic energy absorptive character of the sponge-rich clay sediments and the thin-walled siliceous skeletons of the sponges in the reef. These characteristics make the sponge reefs clearly identifiable with their low backscatter compared with other geological units such as bedrock (Conway et al., 2005).

This might also be the case for the Mingulay reef, offshore northern Scotland, studied by Roberts et al. (2005). It is a *Lophelia pertusa* coral reef, with a particularly “bubbly” bathymetric pattern, compared to the surrounding mounds comprised of fine to coarse sediment. The reef displays a distinct lower backscatter pattern compared to the surrounding seafloor, which is comprised by homogenous coarse, gravelly, shelly, muddy sand (Roberts et al., 2005). The author speculates that the decrease in reflected sound energy is caused by a change in seafloor substrate, or that sponges or other suspension feeders accumulate in the environment, absorbing the signal (Roberts et al., 2005).

In addition to these results, the paper by Fosså et al. (2005) shows a highly varying reflectivity in the side scan sonar records on mounds identified as coral reefs. According to the author, this is an effect of the hemispheroidal shape of the individual colonies which results in a “bubbly” appearance on the side scan mosaic. In the multibeam backscatter, high values at the coral reef locations are instead characteristic. The author concludes that this is likely due to the coral mounds roughness and hardness (Fosså et al., 2005). The multibeam data would instead give a more homogenous backscatter for the reef, whether this is high or low is depending on the surrounding seabed substrate.

3. Method

Visual analyses of created backscatter mosaics and Digital Bathymetric Models (DBMs) comprise one of the main methods used in this work. This is complemented with statistical analyses of the mapped seabed features carried out both in the GIS software, ArcGIS by ESRI, and the data processing and visualization software Fledermaus by QPS.

The analyzed dataset for Area A consisted of 36 multibeam survey lines, 17 running east-west and 19 running north-south. The groundtruthing is video footage from 10 different transects in the survey area. The data from Area A was provided by RWE Dea Norge AS and was acquired by Fugro Survey AS. The data from Area B consisted of 251 files with multibeam data, comprising 36 lines, and one side scan sonar survey line with an approximate length of 7.7 km and a range of 70 m. Area C was the largest survey area with 302 files, constituting 50 survey lines and 17978 black and white still photos. All data from Area B and C is provided by Lundin Norway AS and was acquired by Lundin Norway AS in collaboration with NGU.

3.1 Data acquisition

For Area A the mapping was carried out with a Kongsberg Simrad EM 1002 multibeam echo sounder, operating frequency 95 kHz. No acquisition information is available for the side scan sonar data. No processing or mosaicking of the raw side scan sonar data was done during the work on this thesis. The final mosaic GeoTiff was delivered from RWE and imported to ArcMap for analysis. The groundtruthing data for Area A consist of video camera footage that were acquired along transects at 26 locations using a Simrad Kongsberg OE14-366 camera system controlled by a Seatronics DTS6000 topside control unit. An example of this groundtruthing data is shown in Figure 5. The data were analyzed by applying the camera transects on top of bathymetric maps with draped backscatter (Figure 3.1). The data from Area A were collected in WGS 84 and later converted to ED50 UTM zone 32 N.

For Areas B and C the multibeam data were collected with a hull mounted Kongsberg Maritime EM710, operating at frequencies between 70-100 kHz. The spatial resolution is 1-2 m, at survey depths of about 350 m. The data for survey areas B and C were collected in WGS 84 but later converted to ED50 UTM zone 34 N. All bathymetry and associated backscatter data were provided in Kongsberg .all format.

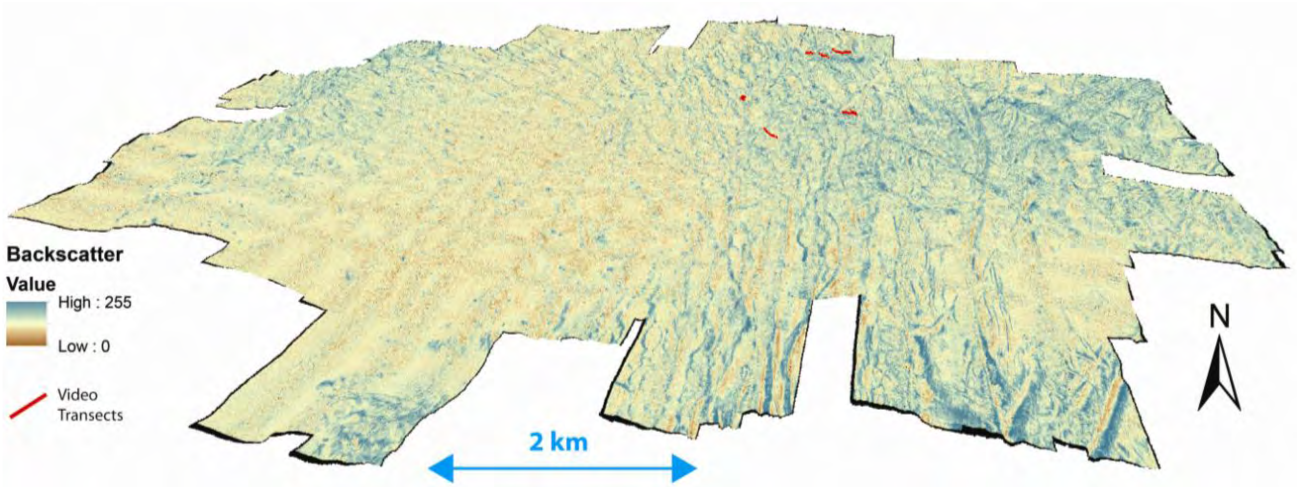


Figure 3.1 Survey Area A with draped backscatter and draped groundtruthing video transects shown with red lines.

A side scan sonar line covers a small part of Area B and was used as groundtruthing. The side scan sonar data was used for detecting features and comparing the possibility to find them on the backscatter mosaic. The resolution of the side scan sonar data is in general higher than the multibeam data. The reason for this is that multibeam data in general is collected from hull mounted instruments while side scan sonars are towed. The equipment used was an AUV mounted side scan sonar which recorded data at an altitude of 7 m above the seafloor. The side scan sonar range was set to 70 m.

The groundtruthing for Area C consists of black/white high resolution still photographs taken with an optical camera with LED lighting (Figure 3.2 and Appendix A). A selection of photos from interesting areas identified in the backscatter were here visually examined and interpreted and subsequently compared with the backscatter and bathymetric data. The photos were used for some further analysis of the backscatter pattern on the seafloor as well as an averaged view of the seafloor substrate. The still photos were, only partly mosaicked since they had to be cut and pasted manually in order to preserve the georeferencing information. There are also groundtruthing photos from a location approximately 3.6 km outside the survey area. These were not used for the main analysis but only as additional background information about the survey area. Examples from these can be found in Appendix A and coordinates for them can be found in Appendix B.

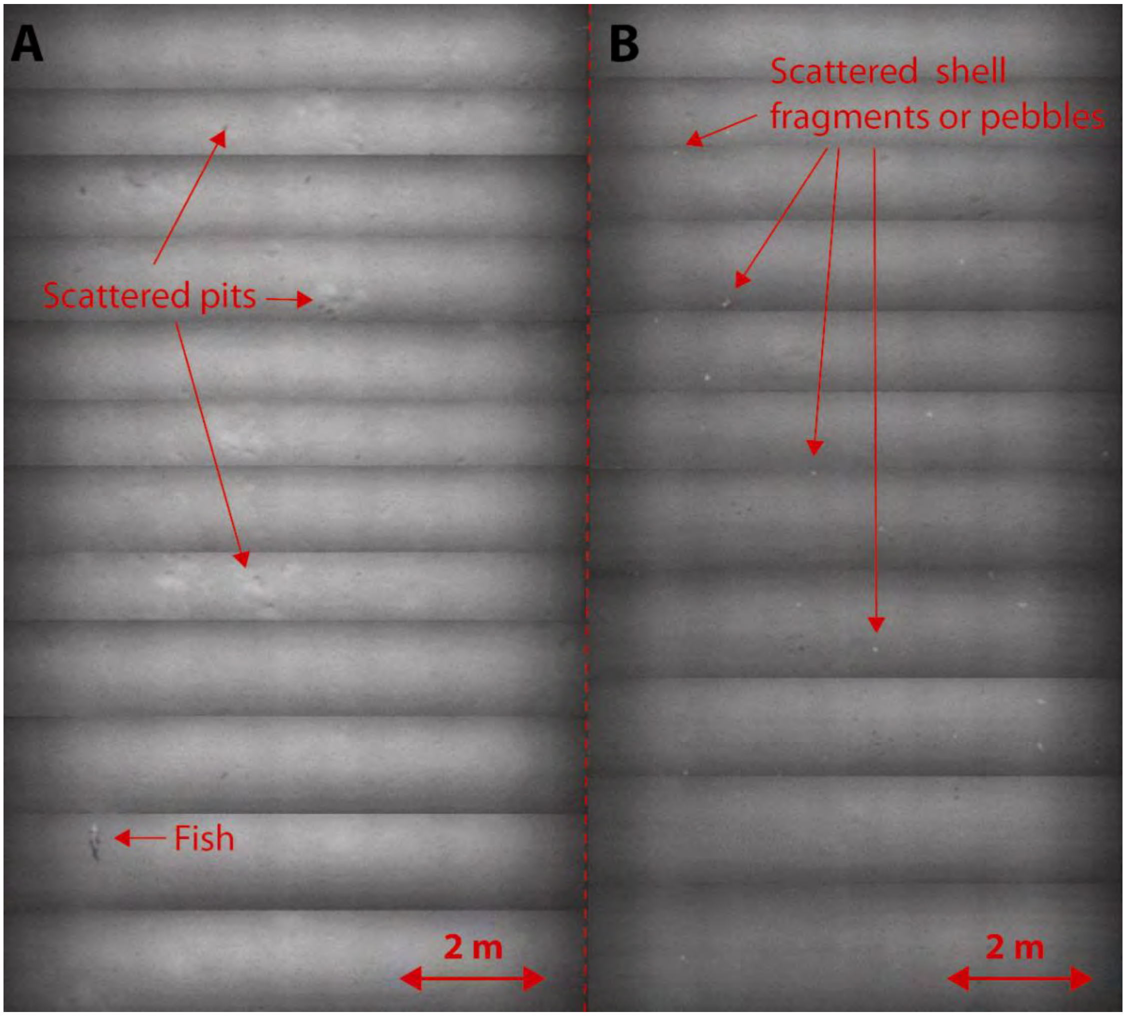


Figure 3.2 Manual mosaicking of Groundtruthing photos from survey Area C; A) Example of seafloor with pits; B) Type of seafloor with scattered coarser material.

3.2 Data processing

3.2.1 Bathymetry

All bathymetric data were gridded with a Weighted Moving Average algorithm. The bathymetry in all areas was gridded with a weight diameter of 3 and a cell size of 5 m. An example of the resolution is presented in Figures 3.3 and 3.4. The gridded data were imported into DMagic with a bin size of 5 m and a vertical resolution of 0.01 m. CUBE editing, see reference for details, was used when removing outliers with a vertical error of 0.25 m and a horizontal error of 2 m (Calder 2007). The bathymetry was exported from Fledermaus as a GeoTiff and imported in ArcMap for analysis but the color scale from Fledermaus was kept. The bathymetry was also exported from Fledermaus as an Ascii .xyz file, enabling analysis of the dataset as a grid.

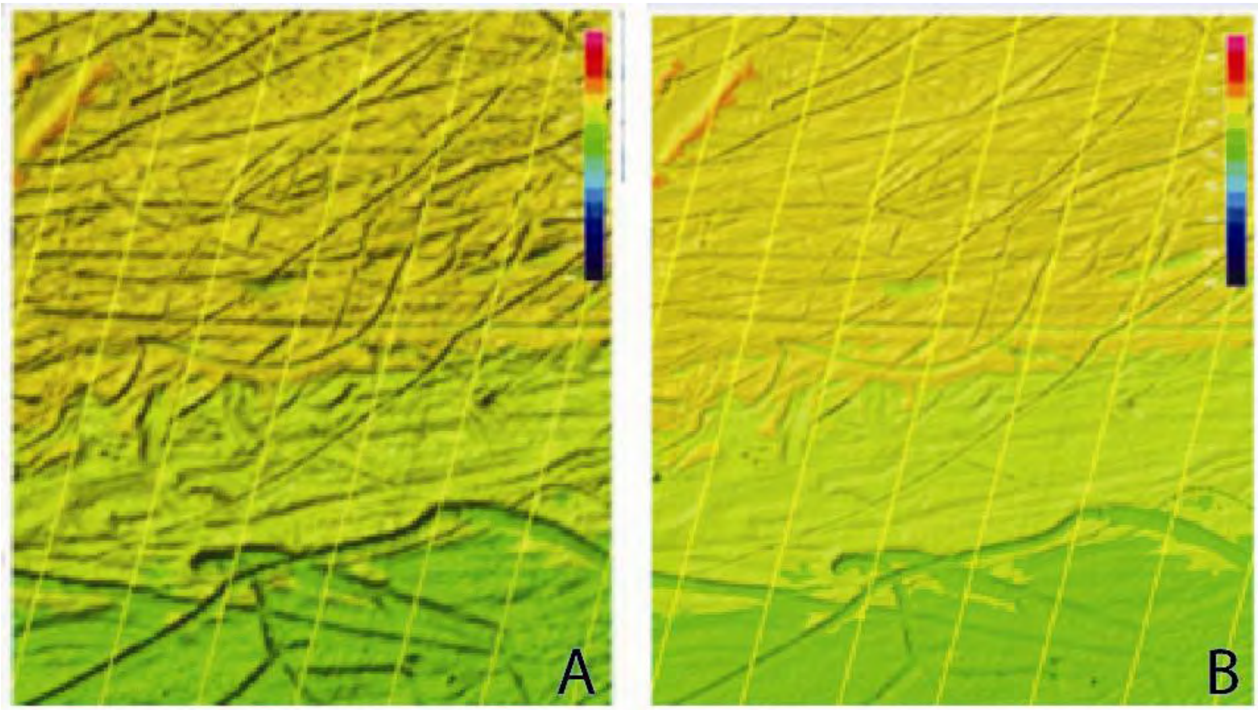


Figure 3.3 Multibeam bathymetry from Area C with a grid cell size 25 (A) and 5 (B). The yellow lines represent the survey lines positions.

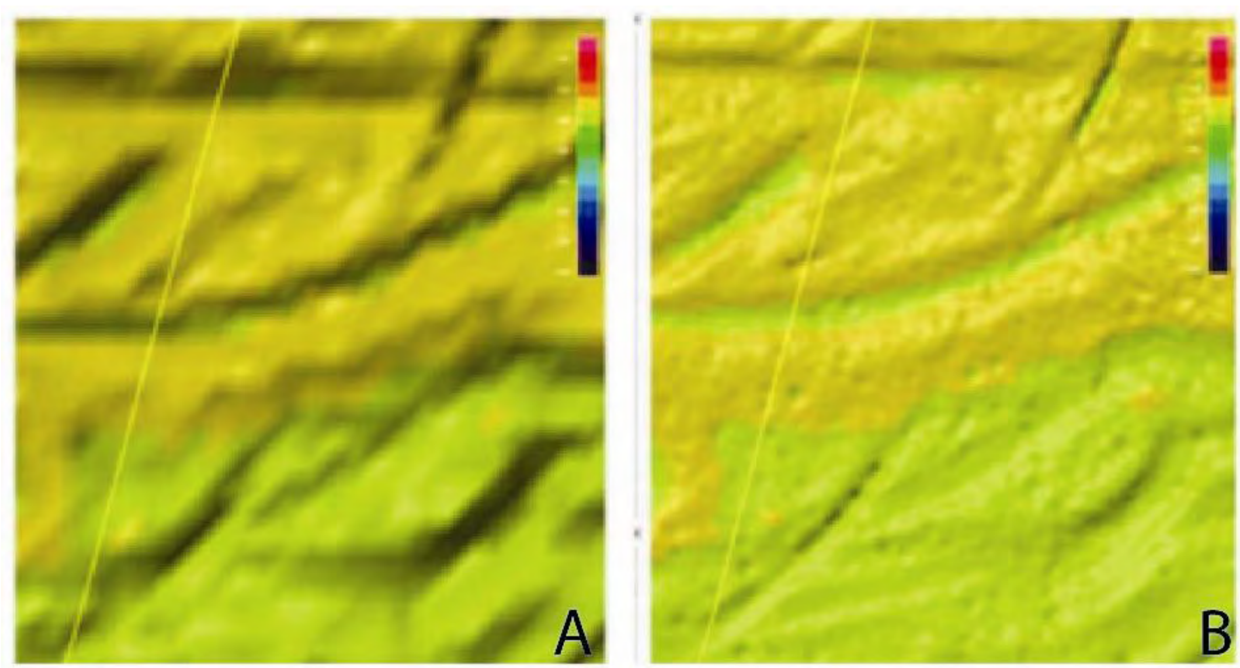


Figure 3.4 Multibeam bathymetry from Area C with a grid cell size 25 (A) and 5 (B). The yellow lines represent the survey lines positions.

3.2.2 Backscatter mosaicking

The backscatter data were mosaicked in Fledermaus Geocoder Toolbox, Version 7.2.1a, 64 bit. Depending on the size of the mosaics they were mosaicked with different resolutions. The mosaic from

Area B was mosaicked with a resolution of 1.3 m/pixel and Area C with a resolution of 1.2 m/pixel. The smaller mosaic, Area A, was instead mosaicked with a resolution of 0.35 m/pixel. This was not possible to do with the larger areas due to memory limitations of the software.

A mosaic was made with the highest backscatter resolution possible in order to compare the result with the mosaic presented in this study. The individual survey lines were mosaicked separately with a maximum resolution of 0.03 m/pixel and a minimum of 1.4 m/pixel (Figures 3.5 and 3.6). The resulting mosaics only differed slightly and the mosaic made from individually mosaicked survey lines was not draped or used in any other way. The backscatter mosaics from Area A, Area B and Area C were imported into ArcMap where the color scale was changed into a blue-green-brown gradational scale for improved visual analysis.

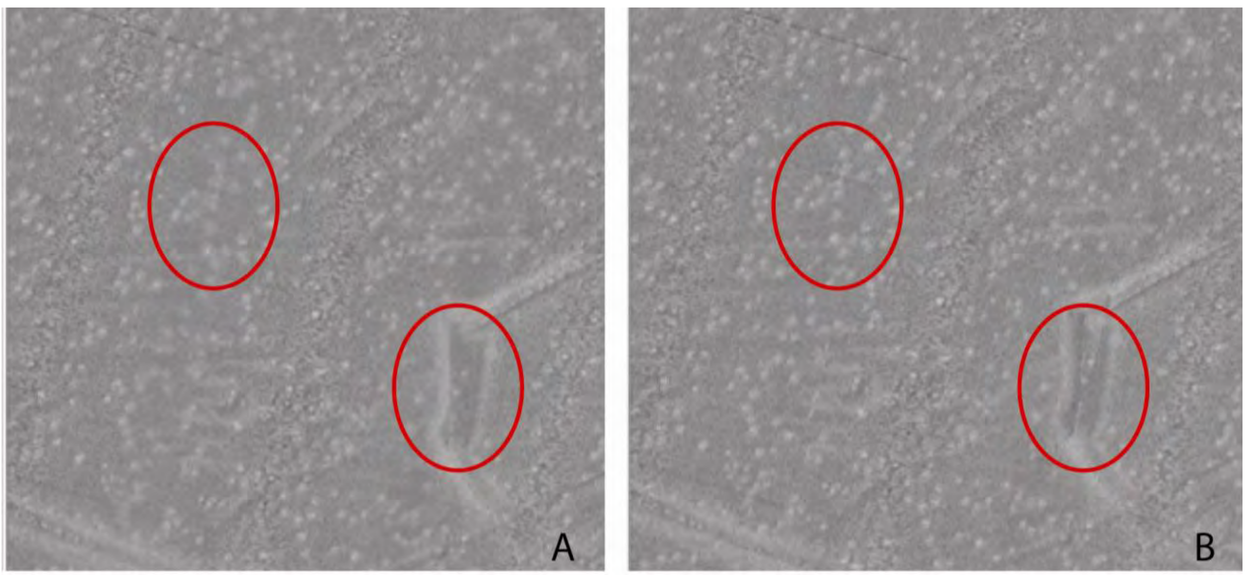


Figure 3.5 Example of different resolution in backscatter mosaic from survey Area C: A) Backscatter resolution 1.3 m/pixel; B) Backscatter resolution 0.03 m/pixel. Left circle shows pockmarks which has a slightly more “blurred” appearance in the lower resolution example. Right circle shows a smaller plow mark where the details are a bit more prominent in the higher resolution mosaic.

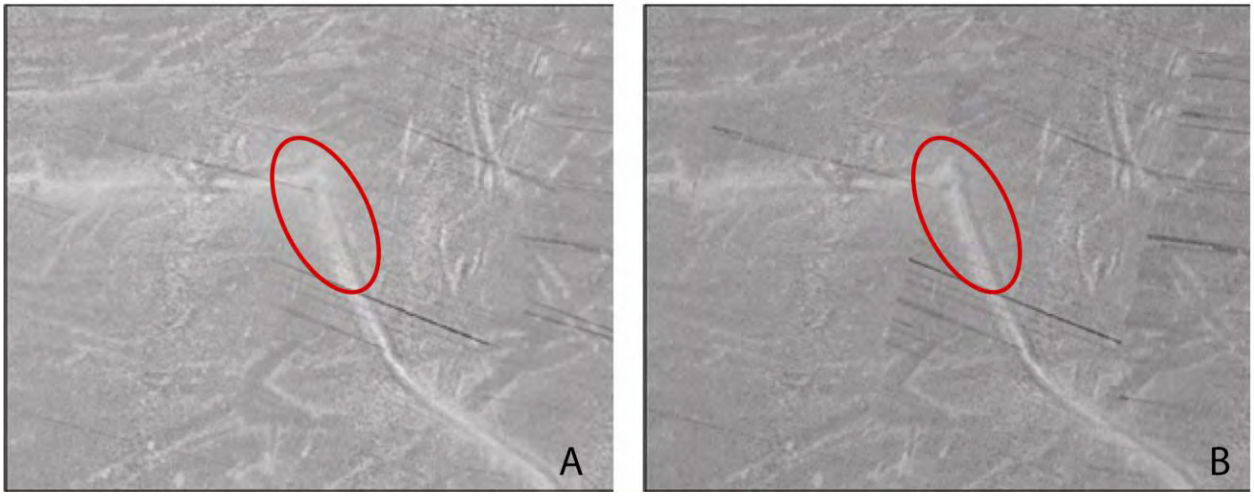


Figure 3.6 Example of different resolution in backscatter mosaic from survey Area C: A) All lines mosaicked together; B) Lines mosaicked separately. Circled part of plow mark has a bit more detailed appearance and the edges are sharper in the mosaic where the lines were mosaicked separately.

3.3 Built in analyzing tools

3.3.1 ARA-analysis

ARA is an abbreviation for Angle vs. Range Analysis or Angular Range Analysis. It is an automatic seabed characterization tool developed by the University of New Hampshire and the University of Delaware (Fonseca et al., 2005; Fonseca et al., 2007; Mayer et al., 2007).

The ARA tool is incorporated for example in the Fledermaus software and gives an estimation of the grain size based on the backscatter response (Fledermaus Reference Manual). The technique involves comparing the real angular response received from the multibeam echo sounder to the acoustic response curve from a mathematical model (Mayer et al., 2007). ARA adds together several backscatter values along a line and the resulting ARA value is an average estimation of the backscatter. This gives a lower resolution of grain size analysis data than if the backscatter values are independently evaluated but for larger areas ARA might be more suitable for an overall grain size analysis. The ARA resolution is 6 by 6 m in survey area A and 25 by 25 m in survey areas B and C.

Fosså et al. (2005) recognize that the main drawback in using backscatter is the variation in incident angle that the multibeam swath gives, causing higher signal echo close to the nadir line. This problem still exists in the last versions of the Geocoder software but the algorithm compensates for different beam angles when determining the final backscatter value. The built-in ARA analyzer in Fledermaus was used for all three data sets. The result is presented as a map for each data set.

3.3.2 Rugosity calculation

$$F_r = A_r / A_g$$

Equation 1 Rugosity calculation. A_r is true surface area, A_g is geometric surface and F_r is rugosity

Another seafloor analysis tool available in Fledermaus is the "rugosity" calculation, which provides an estimate of surface roughness (Equation 1). This is a measurement of small scale depth/height variations in a surface. The rugosity estimation is highly dependent on the scale and on the resolution of the data. This means that a comparison of two datasets collected with different instruments or gridded with different parameters has to be carried out with caution. In general, large features will create a clearly visible, relatively large variation on the rugosity map.

For mapping geohabitats rugosity may be a useful parameter since the result gives an approximation of the flatness of the seafloor and may help us to detect ecology and geology of the seafloor. For example, high rugosity may indicate the presence of corals and help us detect iceberg plow marks (Gleason 2003). The rugosity calculator in Fledermaus was used on all data sets. The result is presented as a map for each data set.

3.4 Data projection

There was a problem with the projection of the data which led to the solution that all data was to be presented in WGS84 UTM zone 31N in ArcMap. The re-projection enabled the mapping of all data in the same project folder, but also to use the coordinates provided for video transects in Area A. For presentation on the IBCAO map the data were projected in North Pole stereographic (Figure 2.1).

3.5 Automatic pockmark detection

In addition to the main objectives of the thesis an analysis of using the contouring tool for automatic pockmark detection in ArcGIS was canned out. This tool has the potential to provide us with a way to determine geological and biological properties of extensive areas in a fast and easy way. Several methods automating seafloor analysis have been previously developed and evaluated, for example by Andrews et al. (2010) and Gafeira et al. (2012). They use a more elaborate method; that combine the contouring of the rim with the "sink value", i.e. deepest point of the pockmark which allows them to extract information about depth, total volume etc. of the pockmark. The method tested in this thesis extracts the circumference of the pockmarks, assuming a circular shape. This can then be used to calculate an approximate diameter or radius of the pockmark. Also, larger areas can be analyzed to get for example average number of pockmarks/km^2.

A slope raster is created based on the seabed gradient and is displayed in black and white, with nine different intervals (Figure 3.7). This slope raster was then contoured and a vector file was generated. This file was saved in two versions, one untreated, raw file and one where all contours were deleted, except from the ones fitting the pockmark rims. The manually interpreted or "cleaned" file will henceforth be used as a 'key' for further analyses, providing us with a close estimate of pockmark rims. This key was used to pick the values that had the closest fit to the pockmark rims, to find the average circumference of the rims and to compare the automatic contouring made by the software with the manually interpreted rims.

Contours with seabed gradient values 3 and 4 were the most frequently occurring contour values in the key dataset; 464 respectively 474 of the total 1377 posts (Figure 3.8). All posts with these values were then exported from the raw dataset to see how well they were matching the key in regard to circumference distribution. The raw dataset had 2890 posts with the seabed gradient value 4, respectively 2624 posts with a seabed gradient value of 3. The area used as key had pockmark circumferences between 64 m and 385 m, values used for filtering out too large or too small contours. The resulting data set comprise posts with seabed gradient values 3 and 4 and pockmark circumferences between 64 and 385 m. The total amount or posts are 1037 posts with the seabed gradient value 4 and 849 posts with the seabed gradient value of 3.

The filtered data from Contour 3 and Contour 4 is presented graphically and compared with the key (Figure 3.9). Statistical analysis was also done on the mean circumference from the three datasets; the key, Contour 3 and Contour 4. An average pockmark circumference was calculated from the three data sets. All results are presented in chapter 4.4.

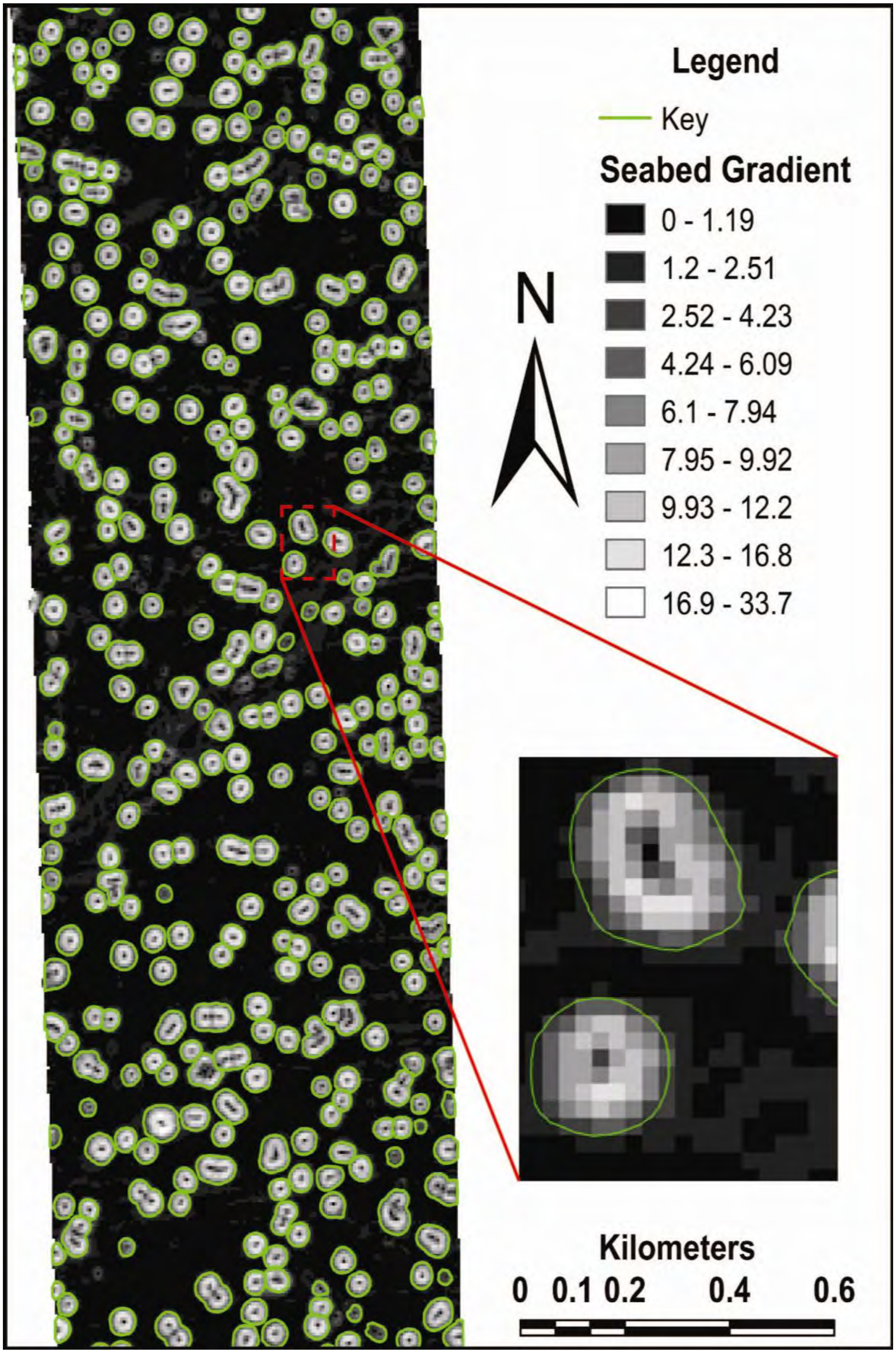


Figure 3.7 Example of part of the analyzed area showing the data that was extracted for automatic pockmark analysis. The background, black to white, is a seabed gradient map, and the green contours are the manually cleaned "Key" pockmarks.

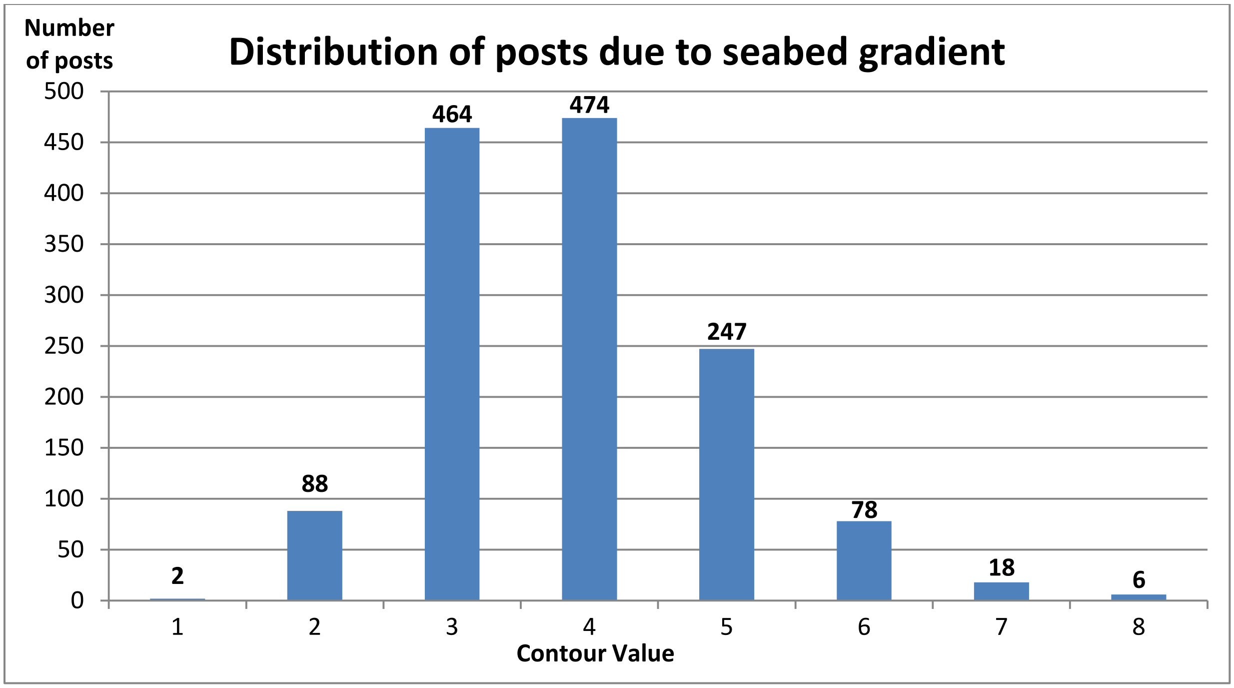


Figure 3.8 Distribution of contour values from pockmark rims in key.

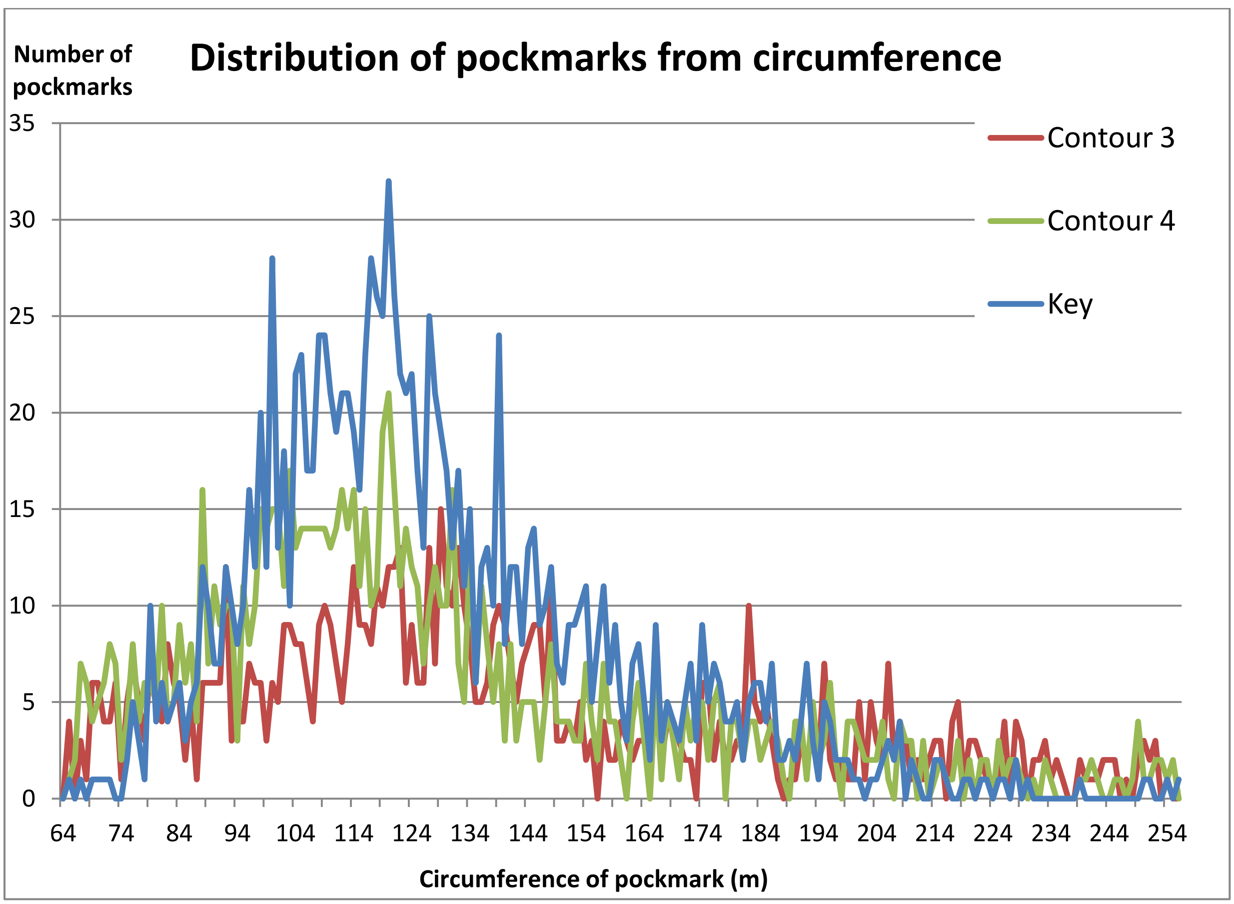


Figure 3.9 Distribution pockmark circumferences; y-axis showing amount, x-axis showing circumference.

4. Results

The results are presented by survey area.

4.1 Area A

This survey area has a minimum water depth of 324 m and a maximum water depth of 433 m and is sloping to the west (Figure 4.1). The central and deepest part of Area A, depths between approximately 370 m and 440 m, shows features that may be pockmarks. The most prominent features in the survey area are the iceberg plow marks in the eastern part. This part is a bit shallower with depths averaging between 330 m and 370 m. The iceberg plow marks are approximately 1 km to 5 km long, up to 100 m wide from crest to crest, and approximately 10 m deep. The ridges of the iceberg plow marks are on average 1 m to 3 m higher than the surrounding seafloor and differ in width between 35 m and 150 m, but variances occur. A general trend of north-south orientation is observed in the iceberg plow marks, but again variation occur and some shorter plow marks are completely perpendicular to the main orientation.

The northern and western parts of the area display almost linear high backscatter features fanning northwest (Figure 4.2). The water depth in this part is approximately 370 m. These features are also visible in the bathymetry where they appear as ridges measuring approximately 2 m to 6 m in height and occasionally are more than 100 m in width. The dimensions give them a slightly “eroded” appearance. There are differences in length but typically the features span across the whole survey area, displaying lengths of more than 6 km. The average sediment grain size in Area A is estimated to be sandy to medium silt from the ARA. This differs from previous estimation of the grain size, where the sediment was estimated to be soft to very soft clay (FSLTD Report 9999).

The deeper seafloor at approximately 400 m, comprising the southwestern part of the survey area, is estimated to be covered by silty sand to clay. In comparison, the average grain size of the ridges chosen as locations for the video transects is coarse silt to silty sand. However, in areas heavily affected by iceberg scouring, coarser material is typical. Possibly this is due to the varying bathymetry causing finer sediment to become sieved out and settles between ridges, leaving gravel and larger grains on the ridges. Cone penetrometer testing from one of the smaller ridges in the northwestern part of the survey area indicate that the top 2 m of the sample location is characterized by very soft to soft clay/silt (FSLTD Report 9999).

The backscatter strength from the eastern part of Area A is relatively higher than the western side, most likely due to the presence of iceberg plow marks and ridges (Figure 4.2). The variance in absolute backscatter values for survey Area A is between approximately -37.5 dB and -16.5 dB. The average ridge has a value of approximately -20 dB and flat seafloor typically approximates -30 dB. The lowest values are in the trough of the iceberg plow marks where values are typically between -30 and -37.5 dB.

As can be seen in Figure 4.2, most locations with video transects are from the northeastern corner of the area. The locations for transects were chosen from their probability of coral presence, with the exception of one location, Station 19A, where reef structures in poor to moderate conditions were found at all camera transects (Figure 4.3). The location of transect 19A was chosen due to its proximity to a ridge with coral presence and only cover a high backscatter.

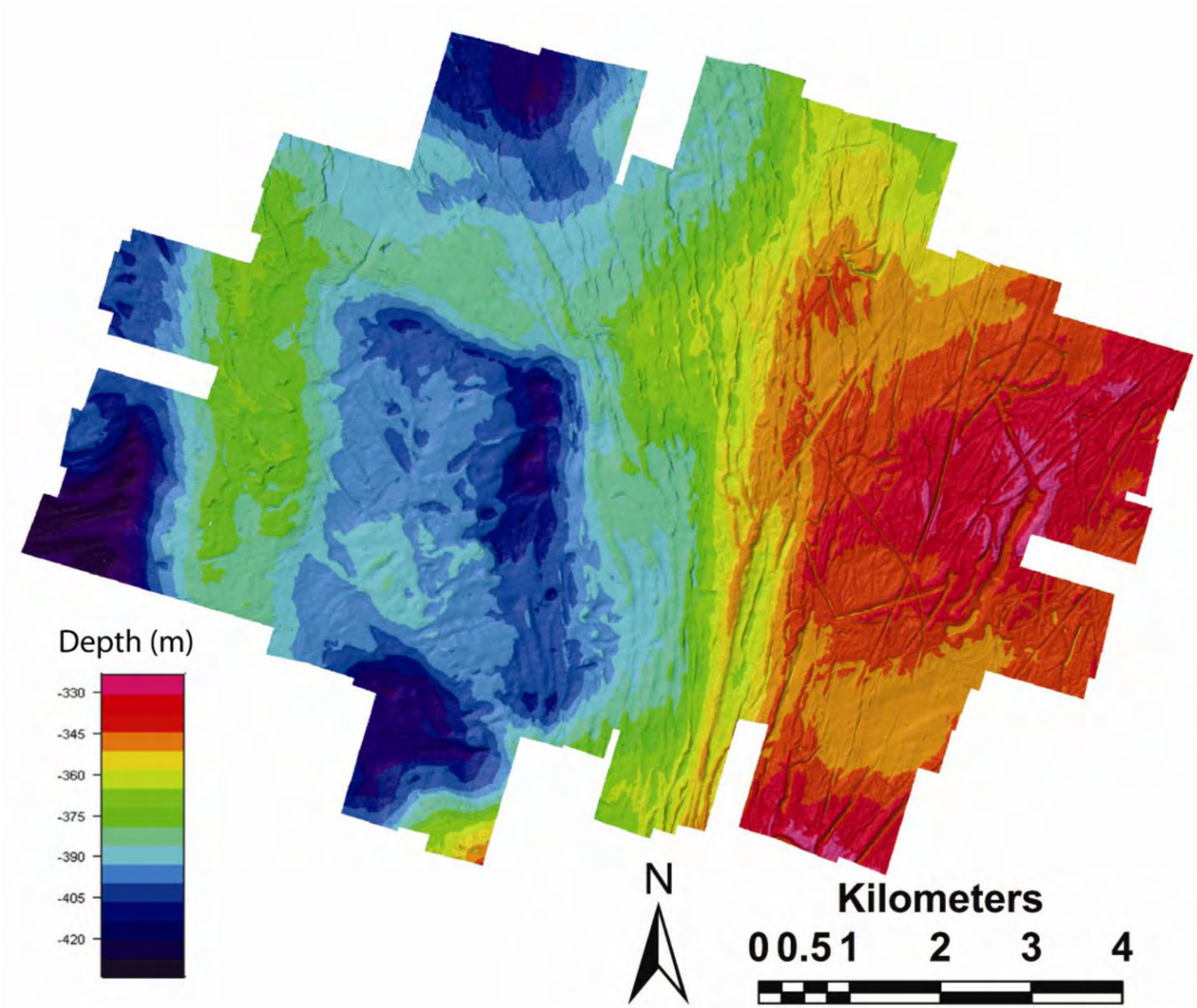


Figure 4.1 Bathymetry map of Area A. Large scale features such as iceberg plow marks are visible in the shallower eastern part of the survey area while the "fanning" smaller ridges are seen in the central part with depths approximating 375 m. The western part of the area is deeper and generally less affected by iceberg movement.

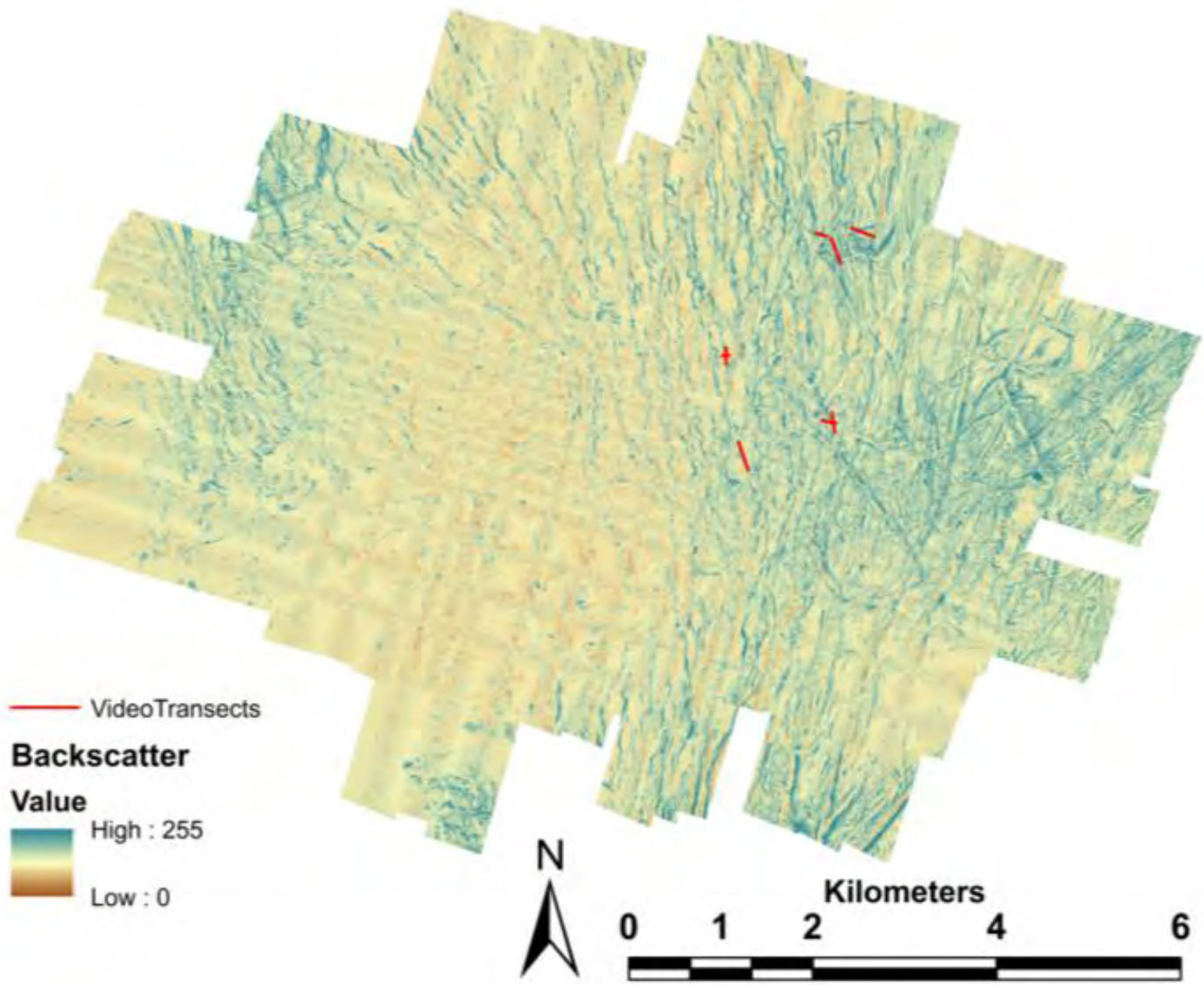


Figure 4.2 Backscatter map of Area A with video transects. Higher backscatter values in the eastern part where iceberg motion has created plow marks. Fanning smaller ridges located in the central north and north western parts of the survey area. Checked pattern in areas with low backscatter is an artifact from the mosaicking.

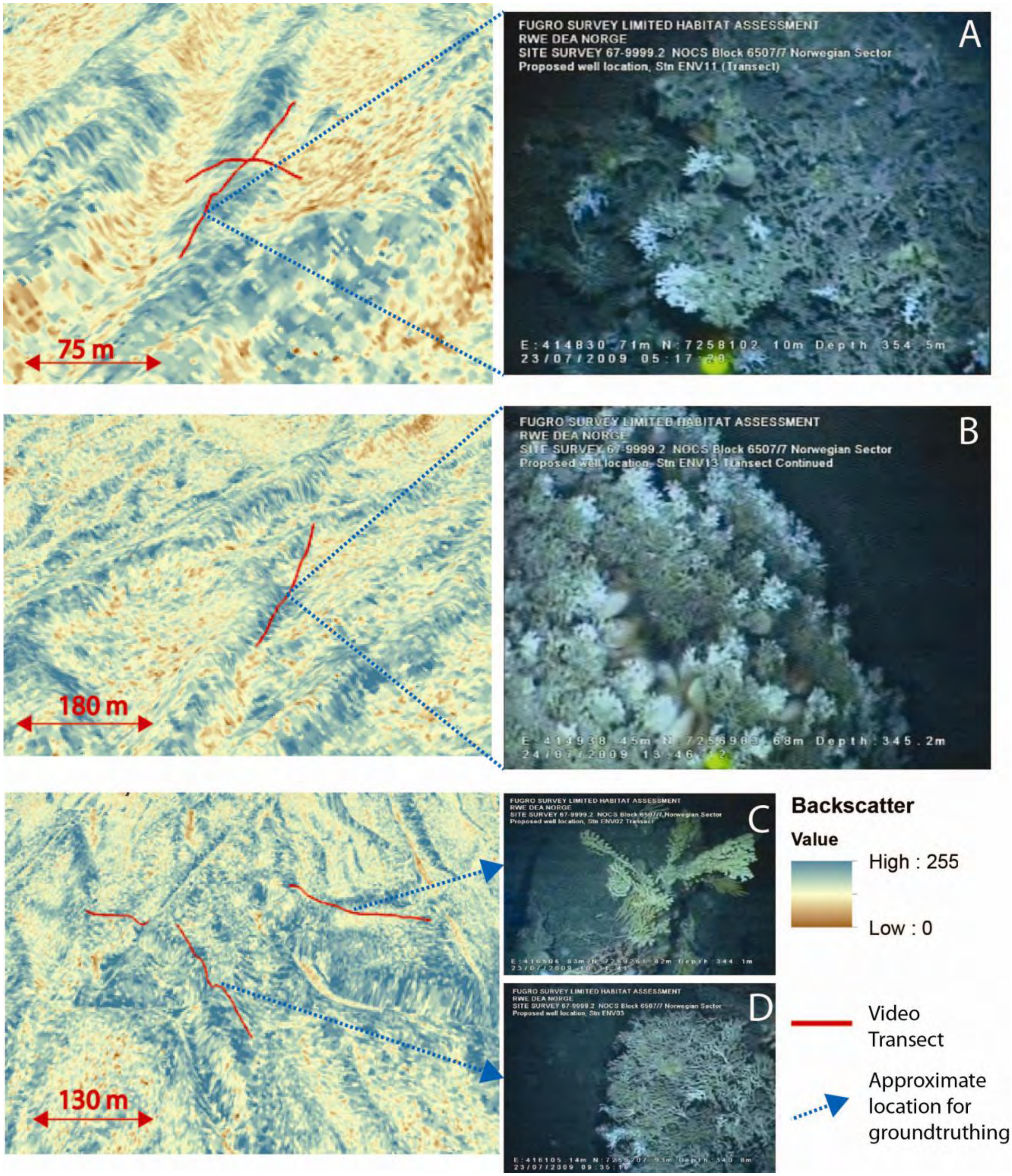


Figure 4.3 Backscatter draped on bathymetry. A-B) Moderate *Lophelia pertusa*; C) Other coral; D) Moderate *Lophelia pertusa.* The relatively high backscatter on the ridges is visible on the mosaic.

The side scan sonar mosaic from Area A shows the reflectivity at the ridges. The approximate height of objects and features can sometimes be estimated based on the shadows created (Figure 4.4). However, since the side scan data was analyzed only as a mosaic, no estimations of individual objects were carried out. The same large-scale objects that are visible and interpreted in the bathymetry and in the backscatter mosaic are also visible in the side scan sonar mosaic. A more thorough analysis of the side scan data through interpretation of the individual lines should have been carried out, but this data was not available in this study.

The survey area has predicted sediments between clay and medium sand according to the ARA. The ARA response is lower in the iceberg scoured area implying coarser sediments, potentially gravel, pebbles or boulders and possibly also shell fragments. However, the resolution of the ARA is not high enough to draw any systematic conclusions from the ridges (Figure 4.5).

The rugosity analysis of Area A (Figure 4.6) is more likely to provide us with useful results since it is a smaller area than Area B and C. The smaller size of the area makes small-scale variations in height or depth of the seafloor more visible. The general result from the rugosity analysis is that the largest variations in bathymetry can be seen in the eastern parts of Area A where the iceberg plow marks are present. When doing 2D analysis, comparing the rugosity map and the backscatter helps separating the features due to their variations in scale. For example, the rugosity clearly shows that the iceberg plow marks differ more in depth than the smaller ridge like features in the northern and western parts. This means that a combined analysis of rugosity and backscatter might provide us with more information compared to only backscatter.

The slope map from Area A can be used to visualize both the large-scale iceberg plow marks and the smaller pockmarks (Figure 4.7). When comparing the results of the slope map and the rugosity map it is clear that, apart from the color scales, they show the same features. The maximum gradient of the plow marks is approximately 35° to 38°.

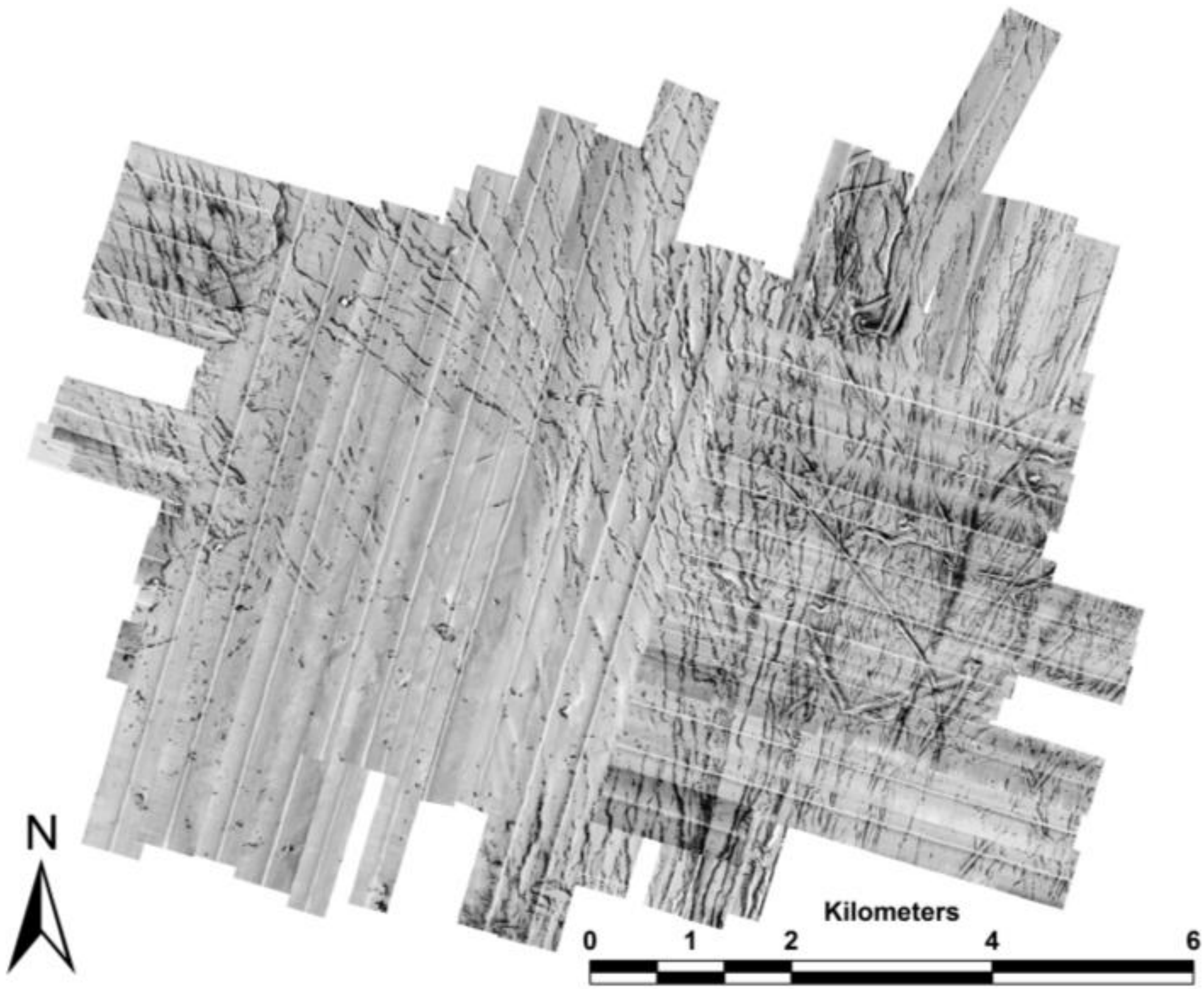


Figure 4.4 Side scan mosaic from Area A. Dark and white areas are high reflectivity or shadows.

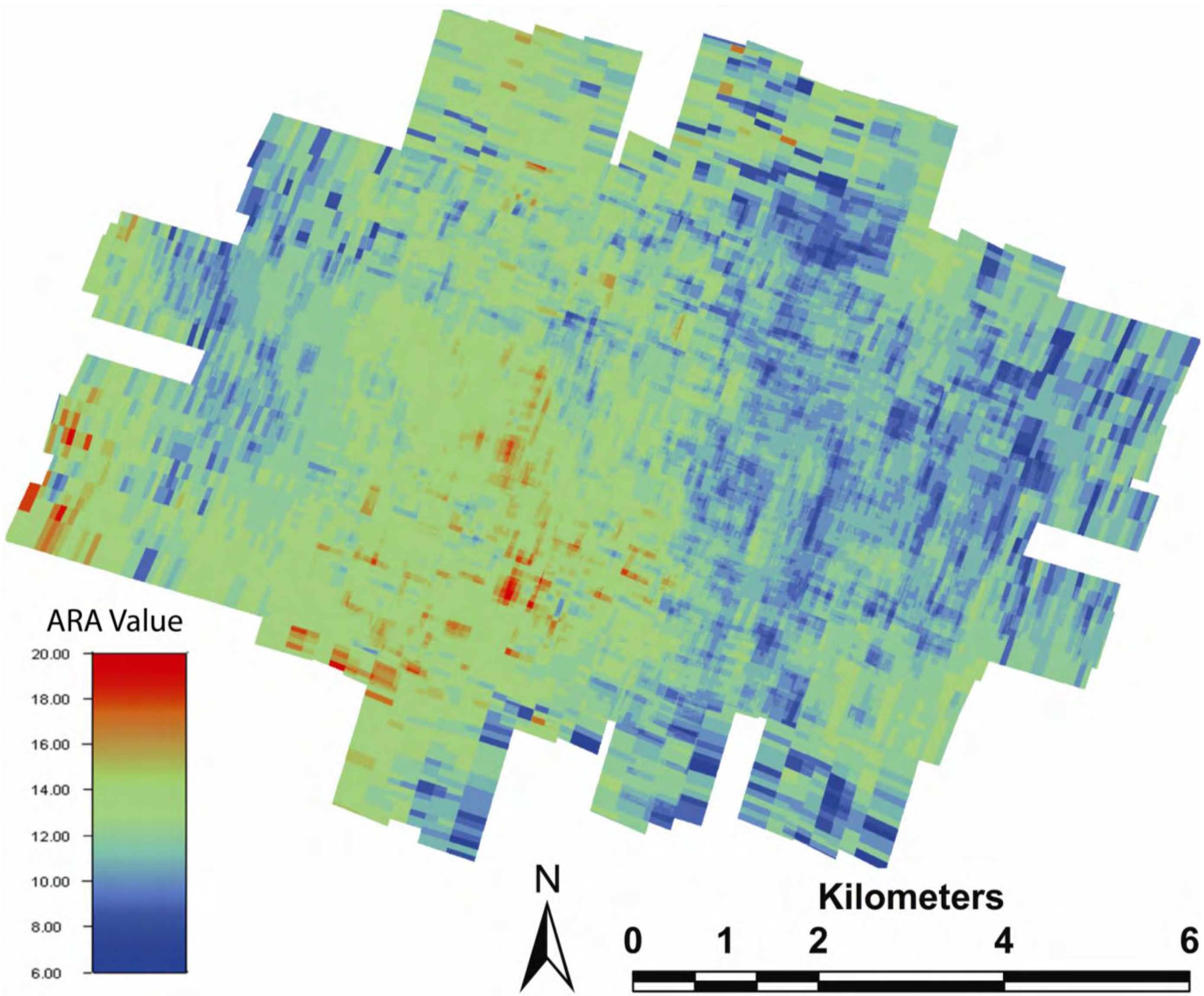


Figure 4.5 Angular Range Analysis map of Area A, areas in the eastern part of the area have a relatively lower ARA value corresponding to relatively higher backscatter values.

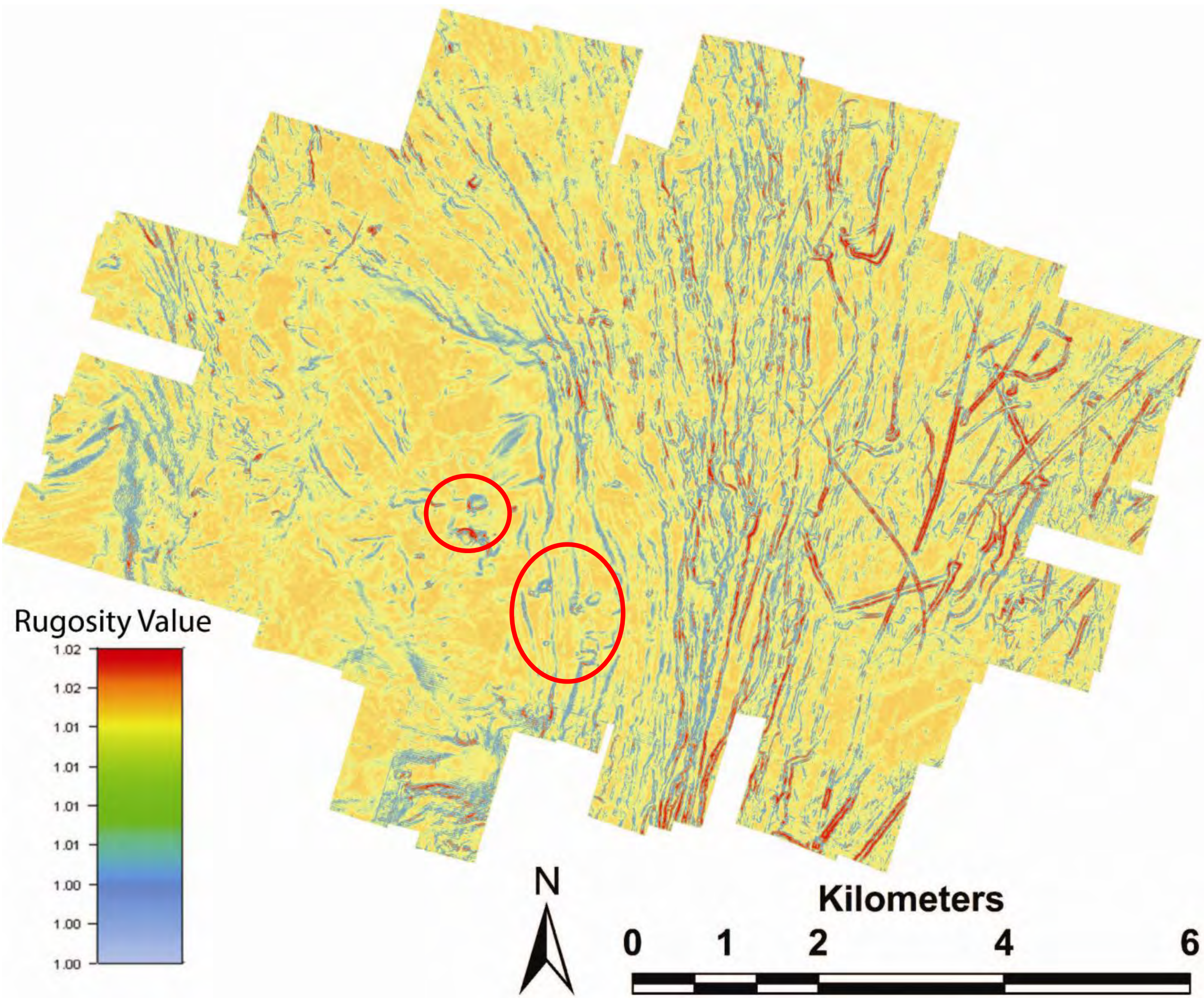


Figure 4.6 Rugosity map of Area A, showing iceberg plow marks and ridges with high rugosity. Central in the survey area are also some circular features, see encircled areas, these depressions might be interpreted as pockmarks.

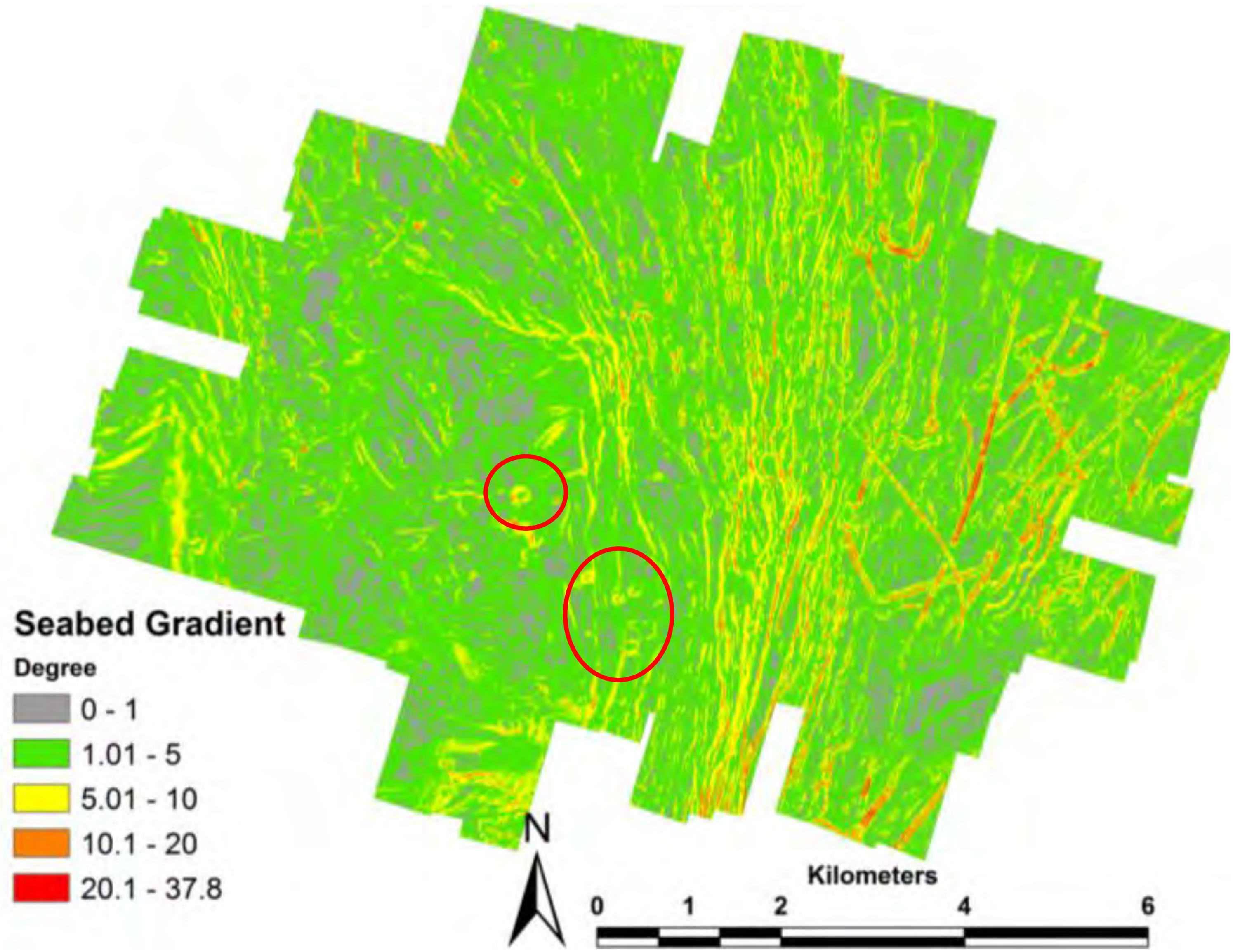


Figure 4.7 Seabed gradient map from Area A. Slope degrees visible in the legend. Central in the survey area are also some circular features, see encircled areas, these depressions might be interpreted as pockmarks.

4.2 Area B

Survey Area B extends almost 49 km north-south and 12.5-18 km east-west. Area B is gradually sloping from south to north between a maximum depth of 355 m and a minimum depth of 237 m. Area B is a fairly homogenous area, and distinguishable seabed features are mainly the numerous iceberg plow marks throughout the whole survey area, orientating predominately west southwest – east northeast (Figure 4.8 and 4.9).

In general, survey area B can be divided in two parts based on the backscatter map and the ARA map. The northern part clearly has a much higher signal response, compared to the southern part. The seabed throughout the survey area has been subjected to iceberg scouring but seems to differ between a substrate with higher backscatter and patches with lower backscatter (Figure 4.9). Large-scale plow marks, approximately 3 km length or more, are visible on the ARA map. Both the backscatter mosaic and ARA map of Area B provide a coherent estimation of the iceberg plow marks (Figures 4.9 and 4.10). For this survey area the finest grain sizes are fine silt or sandy mud, and the coarsest material consist of gravelly sand or gravel, according to the ARA. When comparing these two charts it is obvious that they consistently suggest coarse material and/or hard substrate in the iceberg plow marks as opposed to on the plow mark ridges (Figure 4.10). There are no signs of extensive pockmark formation in survey Area B. Survey Area B has absolute backscatter values between -33 dB and -11.5 dB.

A small part of the south-eastern part Area B is covered with side scan sonar data (Figure 4.9). On the small side scan mosaic area we can see at least two depressions with an approximate size of 50 by 30 m (Figure 4.11). These depressions are not as circular in shape as the pockmarks from survey areas A and C. The depressions are not visible in the backscatter mosaic possibly because the surrounding sediment has fairly high reflectivity they not visible in the bathymetry either. The presence of large-scale icebergs in the survey area may cause the automatic pockmark analysis to be less successful. There are no signs of extensive pockmark fields in Area B, although scattered pockmarks may occur. These are expected to be smaller than what is possible to detect with the available multibeam bathymetry.

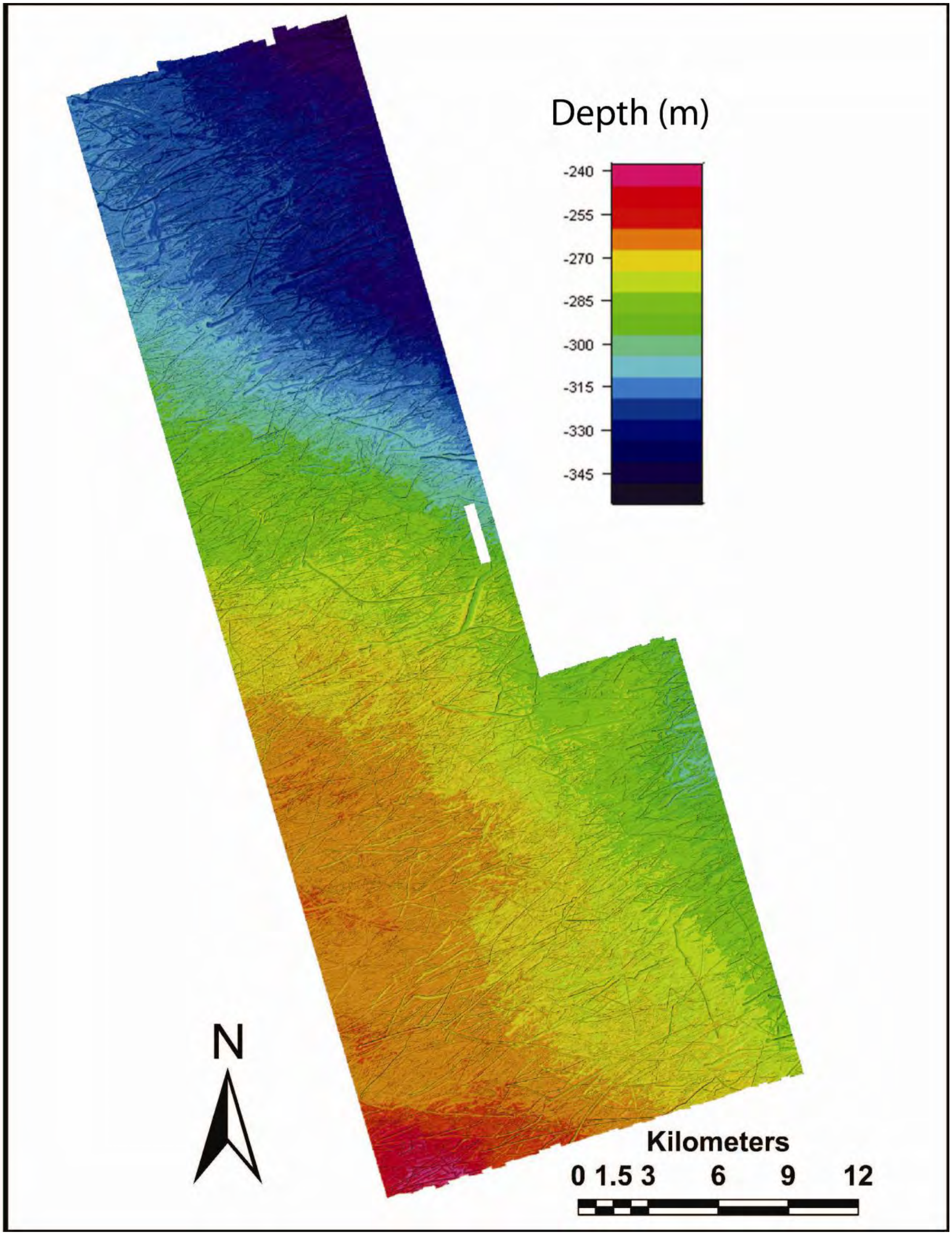


Figure 4.8 Bathymetry map of Area B, larger features such as iceberg plow marks visible throughout the survey area.

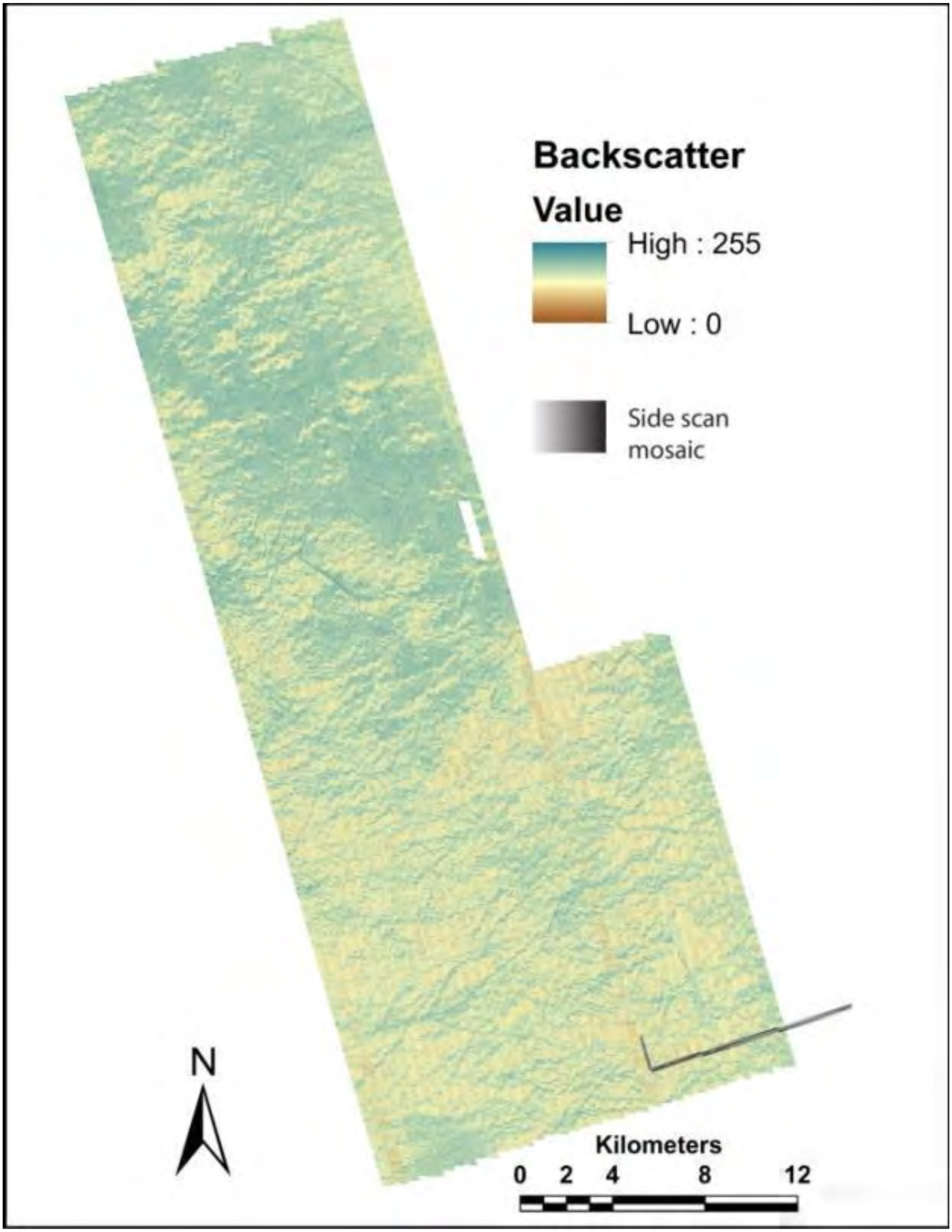


Figure 4.9 Backscatter map of Area B, larger features such as iceberg plow mark visible throughout the survey area. Striped pattern on backscatter mosaic is a beam angle effect. The side scan mosaic shown in the southeastern corner of the survey area.

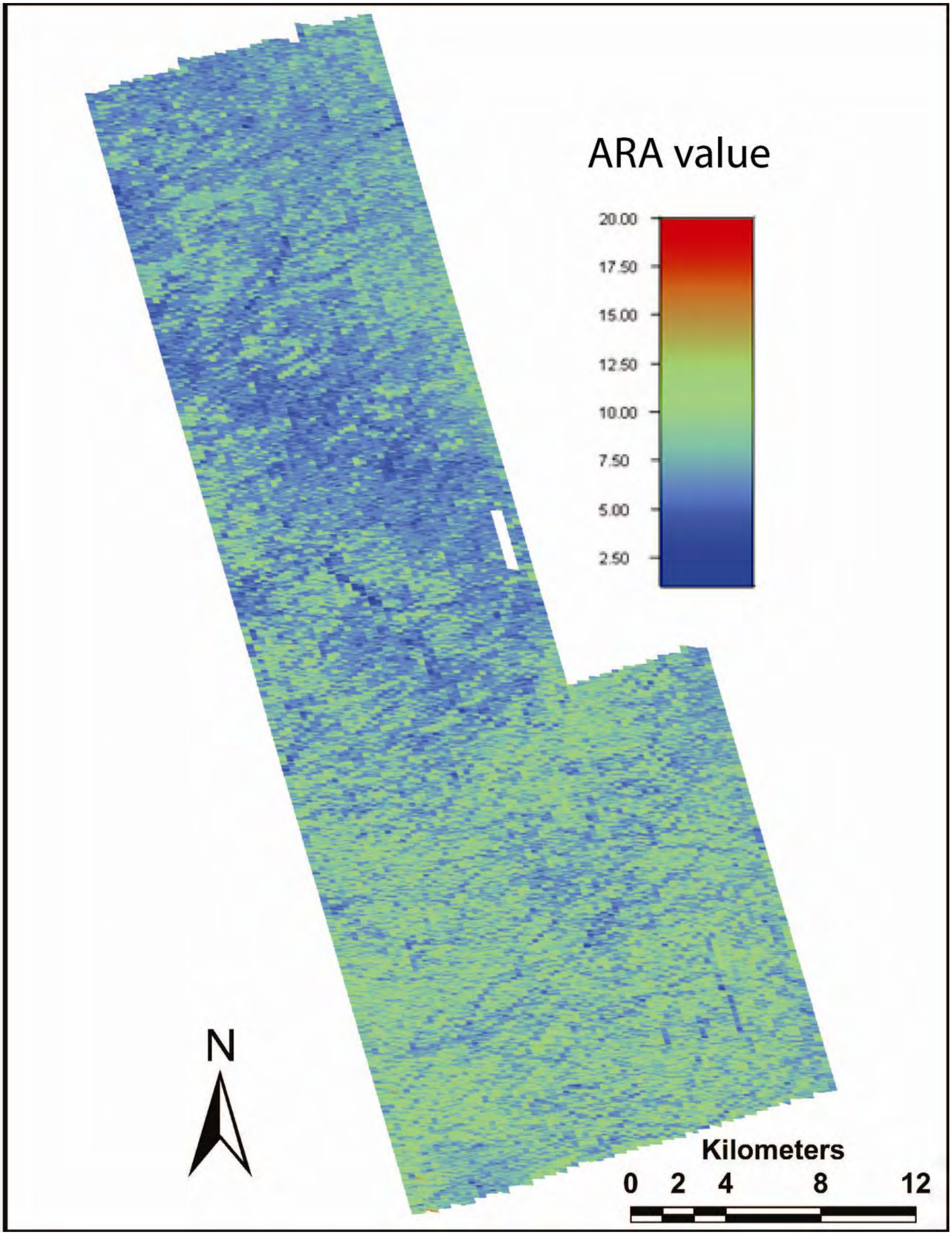


Figure 4.10 Angular Range Analysis map from Area B showing larger iceberg plow marks throughout the survey area.

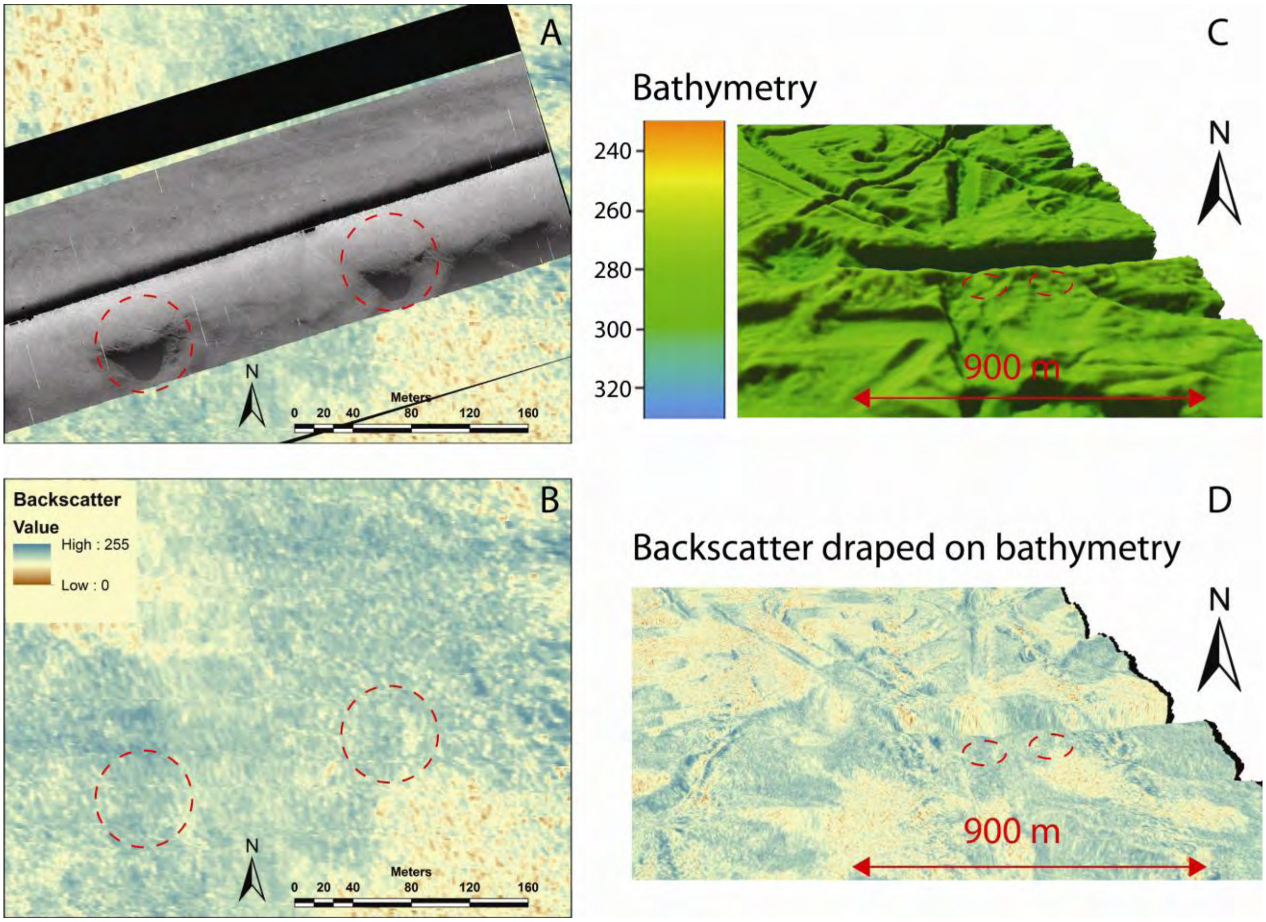
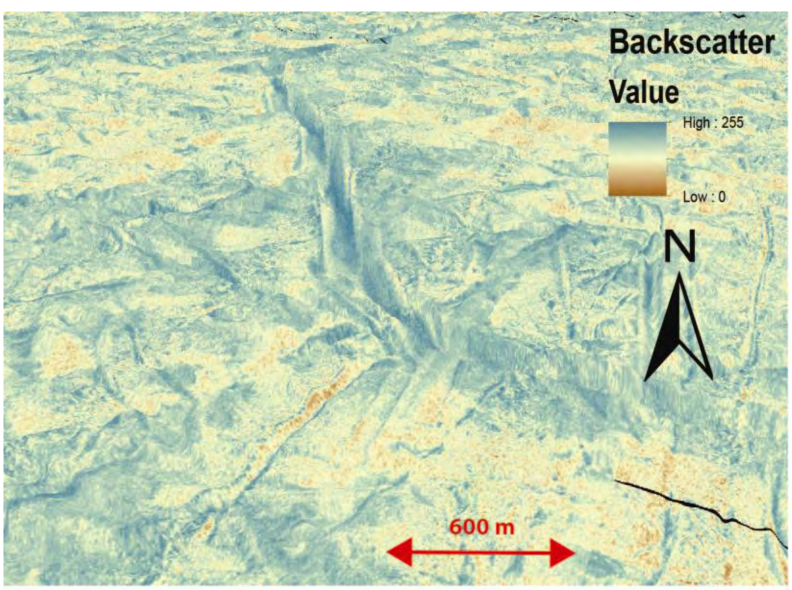


Figure 4.11 A) Detail of side scan sonar mosaic. Red circles show potential pockmarks. B) The same area with backscatter mosaic. Red circles show potential pockmarks. C) Bathymetry showing area with potential pockmarks encircled. D) Backscatter draped on bathymetry showing area with potential pockmarks encircled.



4.12 Example of plow mark seen in backscatter from Area B. Notice how the high backscatter is localized in the trough of the plow mark and not on the ridges.

The distribution of the large scale features of survey area B is most visible in the rugosity result from the area (Figure 4.13 and 4.14). The rugosity analysis from Area B also shows some large scale features, such as iceberg plow marks that are not visible on the backscatter map (Figure 4.13).

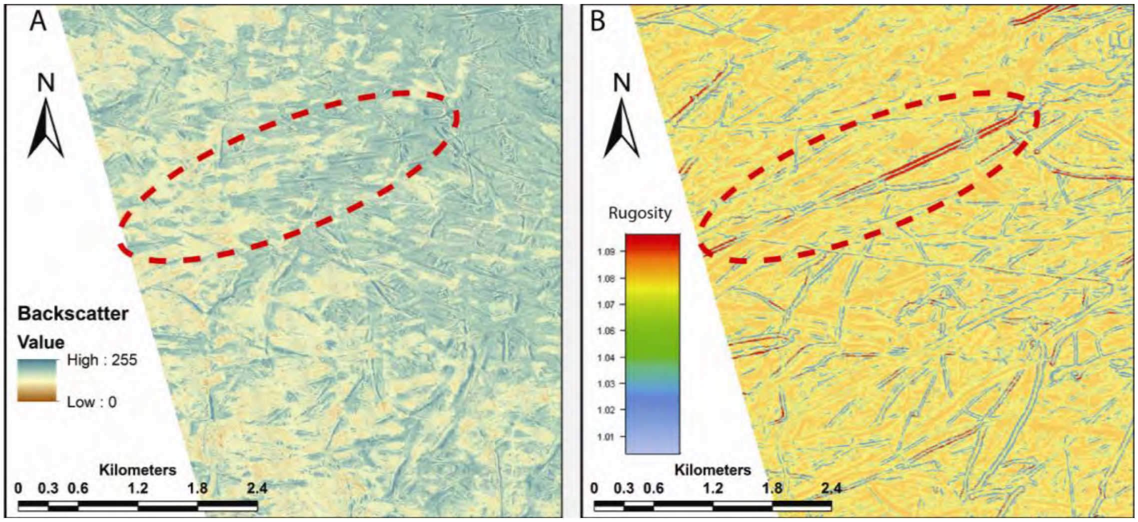


Figure 4.13 Comparison of rugosity and backscatter maps. Some features interpreted as iceberg plow marks visible in the rugosity map (circled areas) are not visible in the backscatter map.

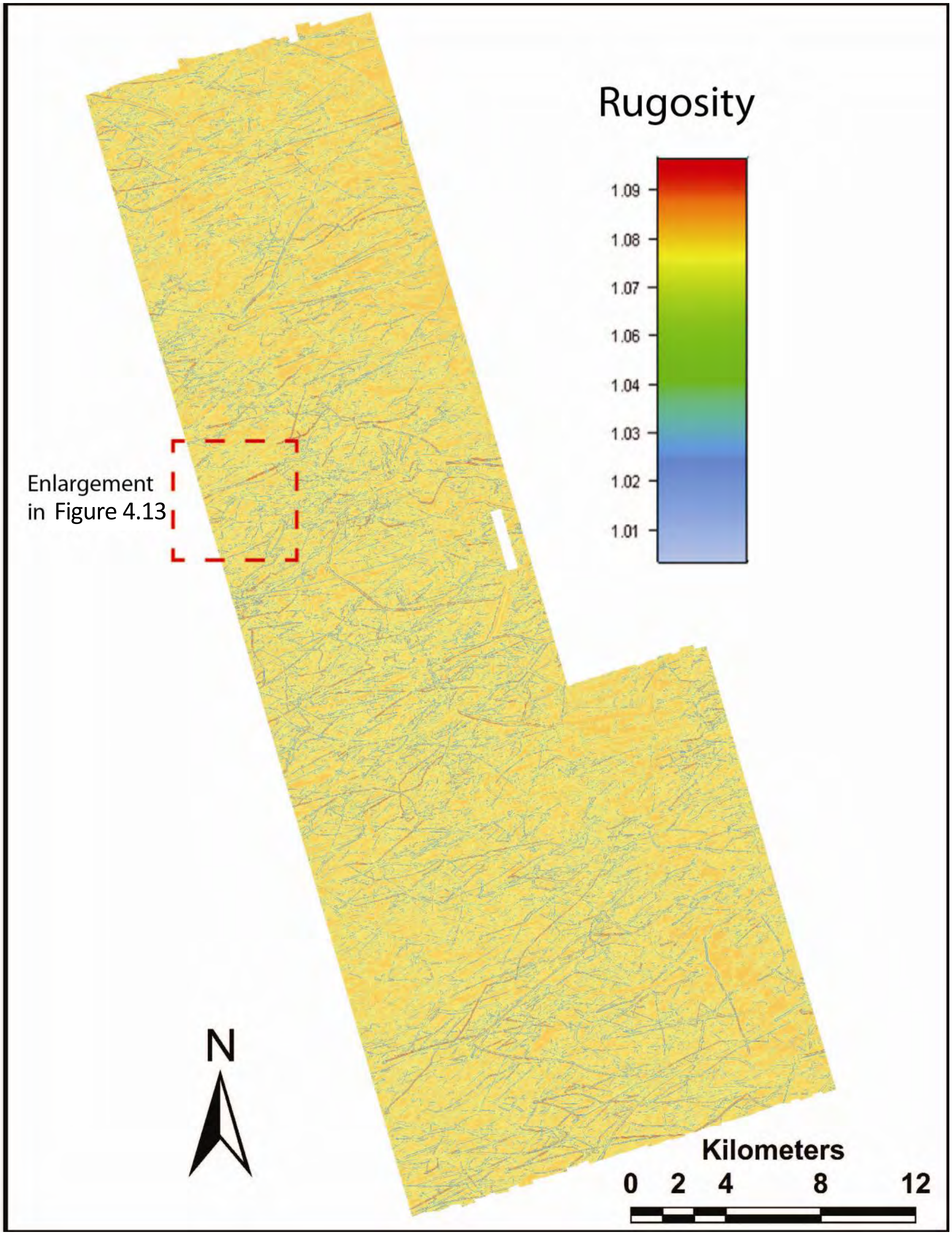


Figure 4.14 Rugosity analysis of Area B, large scale features such as iceberg plow marks visible throughout the survey area.

One iceberg plow mark in Area B has a crest to crest width of almost 400 m (Figure 4.15). This is however an exception since the iceberg plow marks has a typical crest to crest width of approximately 100 m. In survey area B, the longest iceberg plow mark reaches a length of more than 13 km. The slope map shows some iceberg plow marks with sloping parts up to almost 60 degrees (Figure 4.16). There is a general direction for the iceberg plow marks, west southwest – east northeast, however variations occur with plow marks almost perpendicular to this. Some of the iceberg plow marks are straight but most seem to be created under, for example, changing weather conditions or with shifting currents causing the iceberg to change direction. The resulting plow mark may be kinked or curved. The groundtruthing in Area B consisted of a smaller side scan sonar mosaic that did not cover the iceberg plow marks, which made a more comprehensive analysis of them impossible.

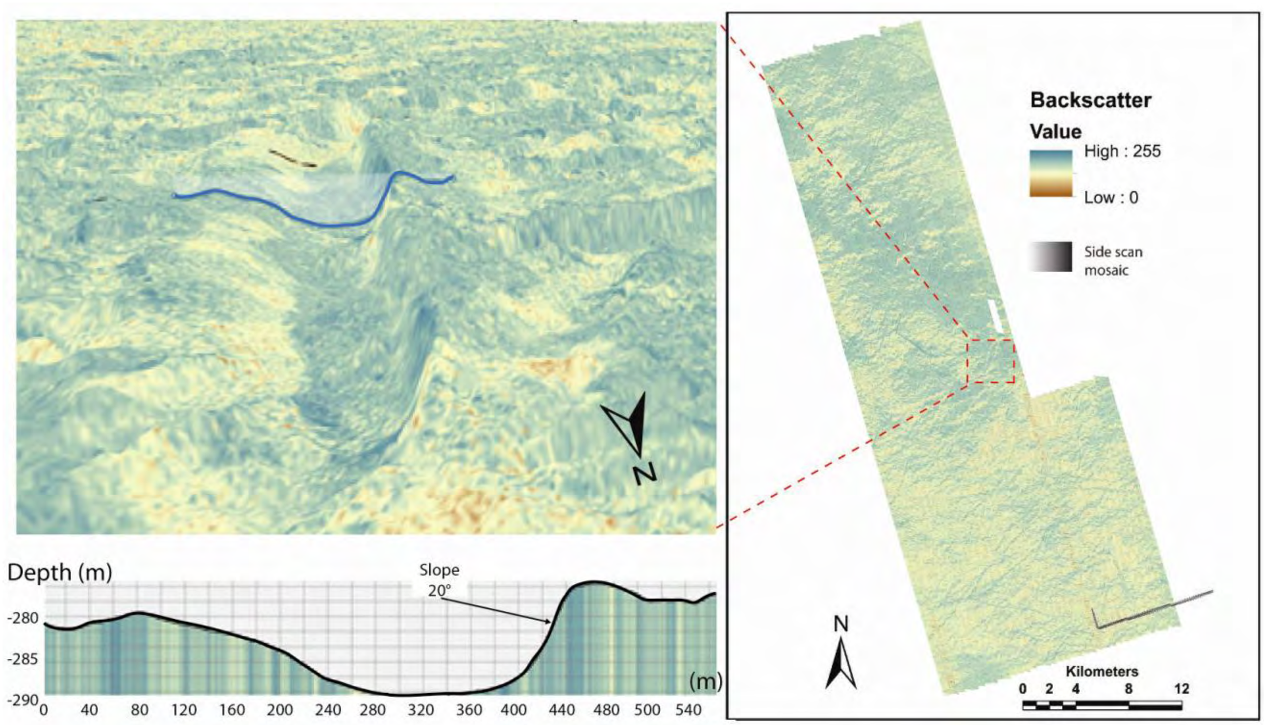


Figure 4.15 Crossection from plowmark in Area B. Backscatter draped on bathymetry.

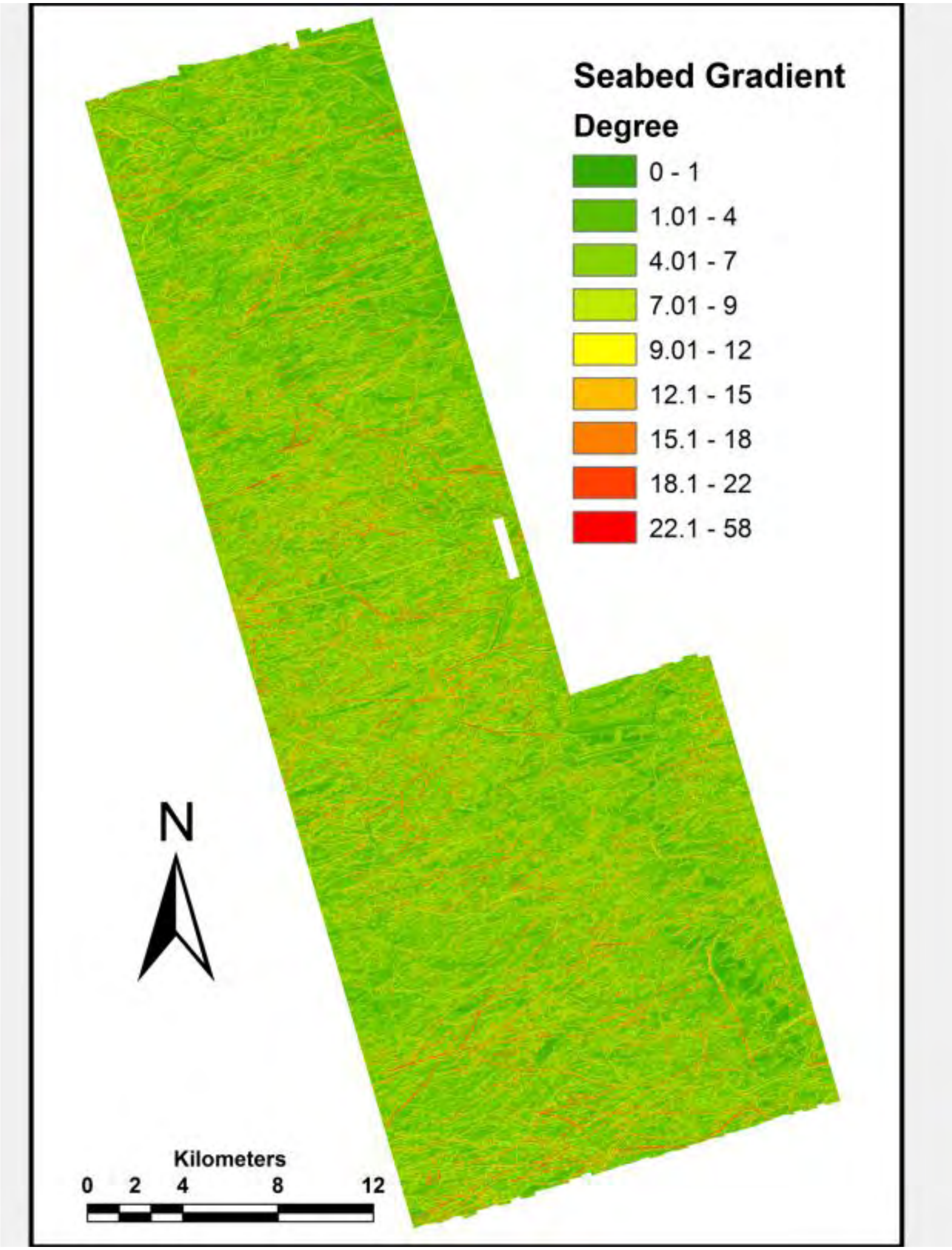


Figure 4.16 Slope map for Area B, larger features like iceberg plow marks are visible as red lines indicating seabed gradients up to 58 degrees.

4.3 Area C

Survey Area C is approximately 40 km north-south and 21-29 km east-west, reaching a maximum depth of 415 m and a minimum depth of 315 m.

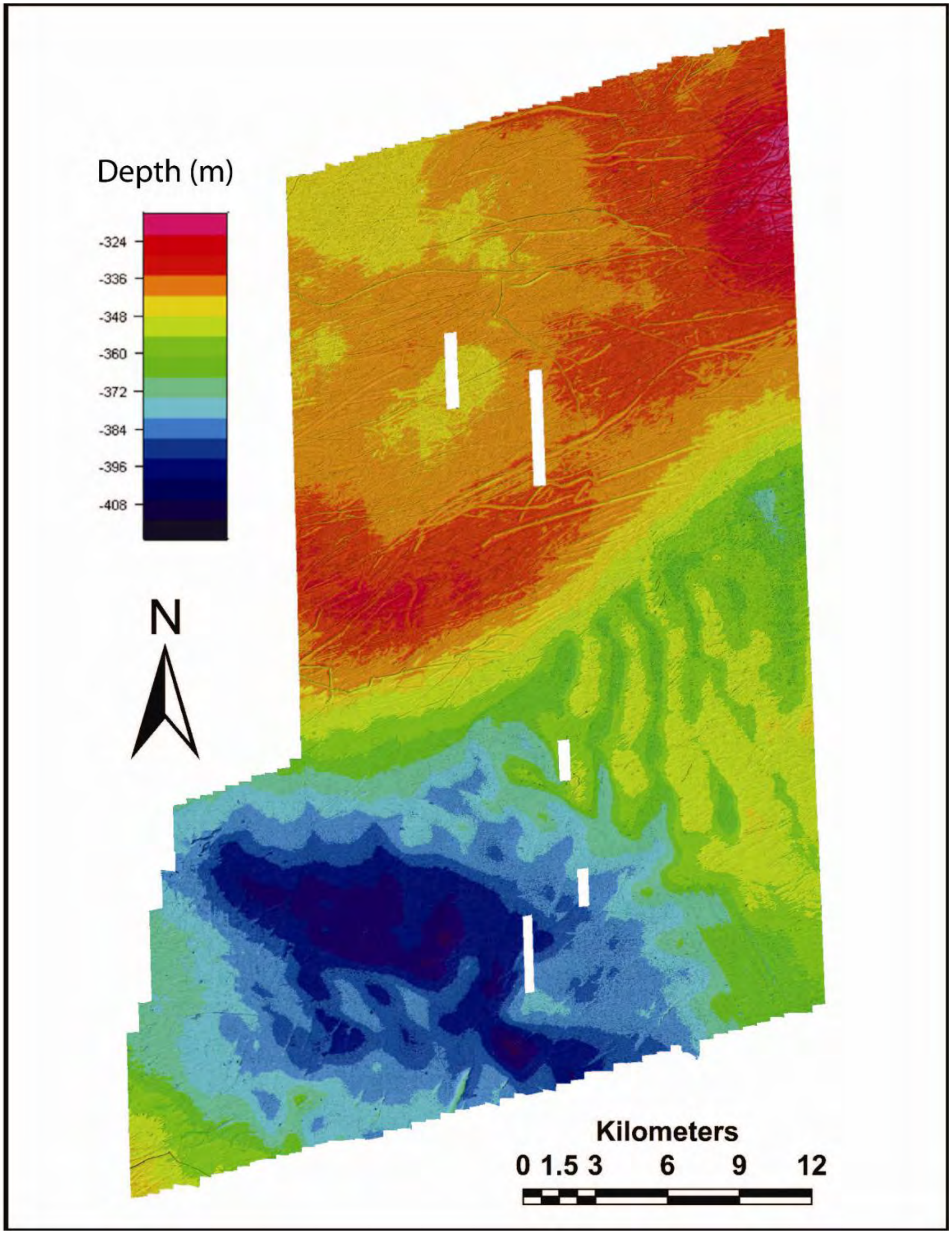


Figure 4.17 Bathymetry map from Area C. The northern part is characterized by large scale iceberg plow marks. The eastern area is characterized by large scale ridges and the southwestern part is characterized by a deeper area with extensive pockmark formation.

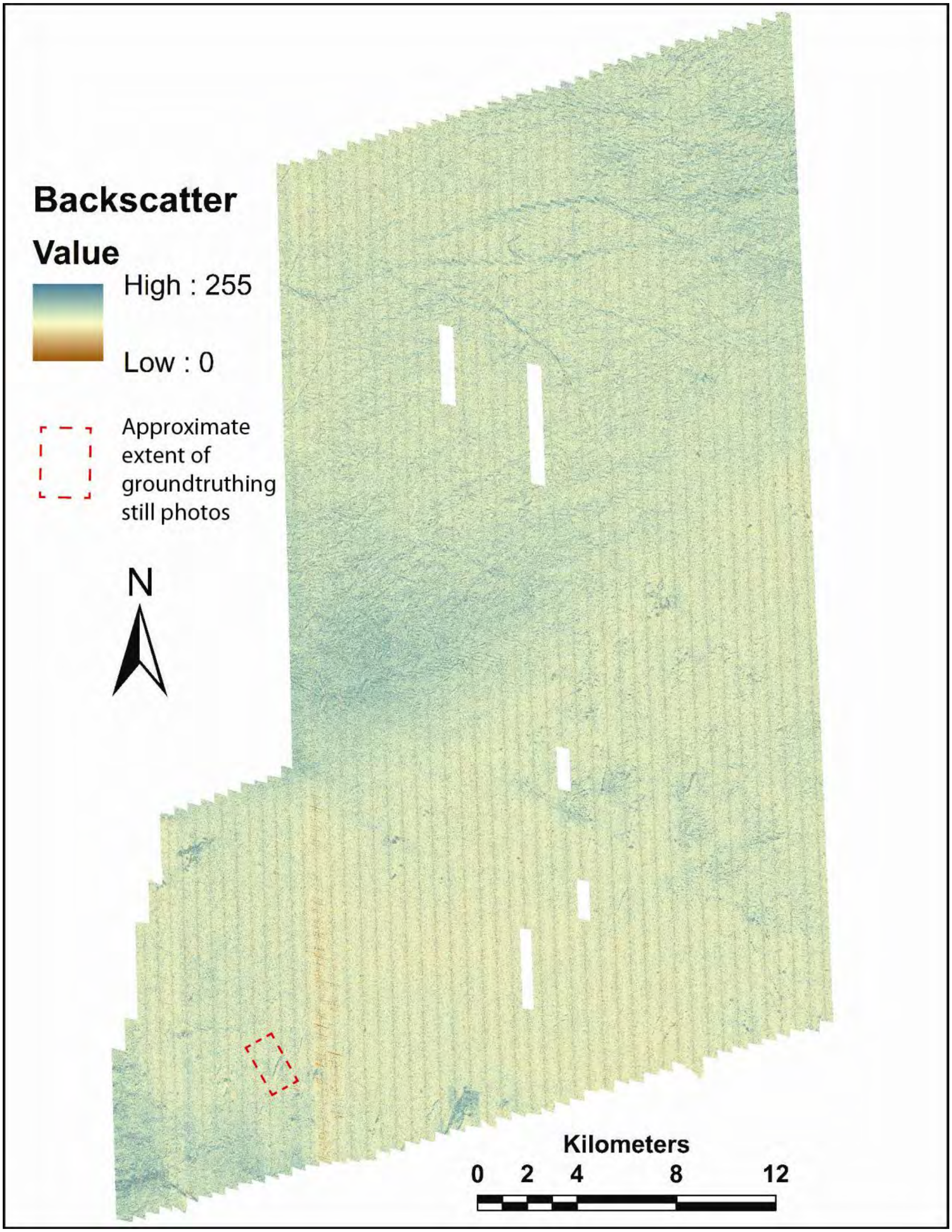


Figure 4.18 Backscatter map of Area C. Areas appearing darker are characterized by more large scale features such as iceberg plow marks. The southwestern area appearing more yellow is characterized by extensive pockmark formation. The groundtruthing photos only cover an area with low backscatter. The striped pattern conforms with the survey tracks and is a beam angle effect.

The survey Area C can be separated into three parts based on the bathymetry. The southwestern part is characterized by depths greater than 370 m and contains numerous pockmarks (Figure 4.17). This part displays low backscatter and high ARA (Figures 4.18-4.20).The pockmarks in survey Area C have higher backscatter response, compared to the surrounding seafloor sediments (Figure 4.18 and 4.19). The pockmarks are generally circular depressions, approximately 35 m in diameter and 2 to 3 m deep, which is coherent with the study by Chand et al. (2012). The northern part of Area C is characterized by relatively shallow depths, ranging from approximately 270 m to 330 m, dense iceberg scouring and pockmark formation. This part has consistently higher backscatter and lower ARA than the southwestern part. The eastern part of Area C is dominated by large ridge like features, 1.5-2 km wide, >7 km long, with a height averaging 30 m over the seafloor and running in a north-south direction. The average depth is varying between 330 m at the top of the ridges to 370 m in the basins between them. These features are visible on the bathymetry map (Figure 4.17). The different parts of Area C are also easily distinguishable on the rugosity map (Figure 4.21).

The grain size differs between very fine silt and very fine sand in the deepest part and between coarse silt and medium sand in the shallower parts in survey Area C according to the ARA. The typical sediment along the ridges is fine to coarse sand. The absolute backscatter values for survey Area C range between -33.5 dB to -16 dB. The pockmarks at survey Area C have an approximate backscatter value of -20 dB.

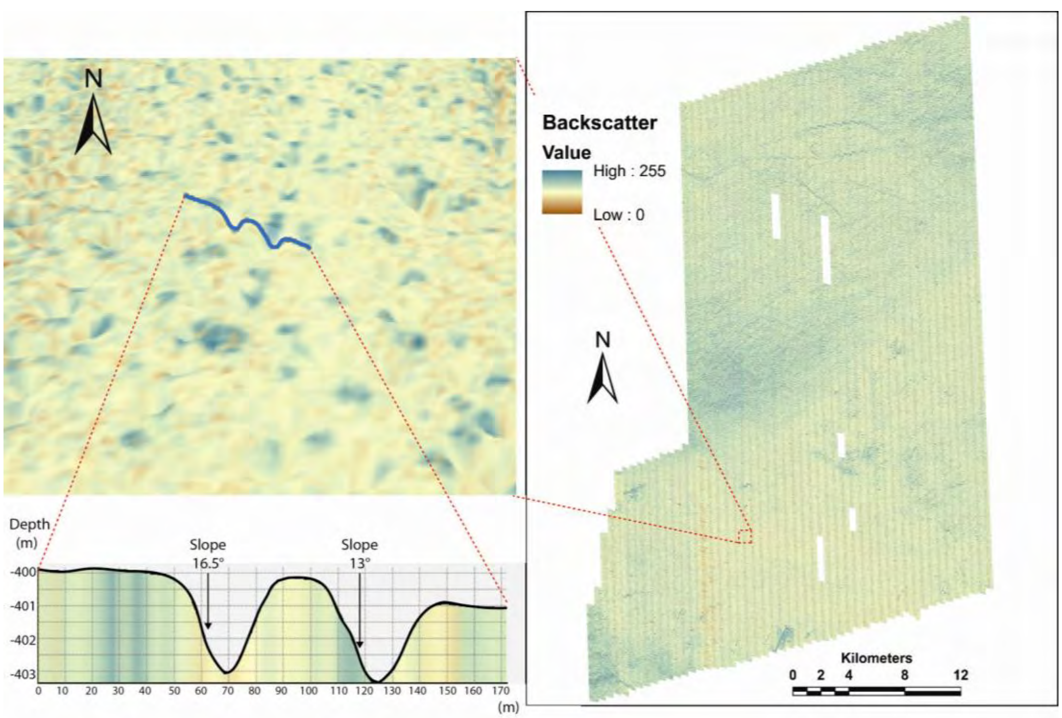


Figure 4.19 Profile from typical pockmark in Area C. Backscatter draped on bathymetry. The profile shows the higher backscatter values on the bottom of the pockmarks as a blue shade.

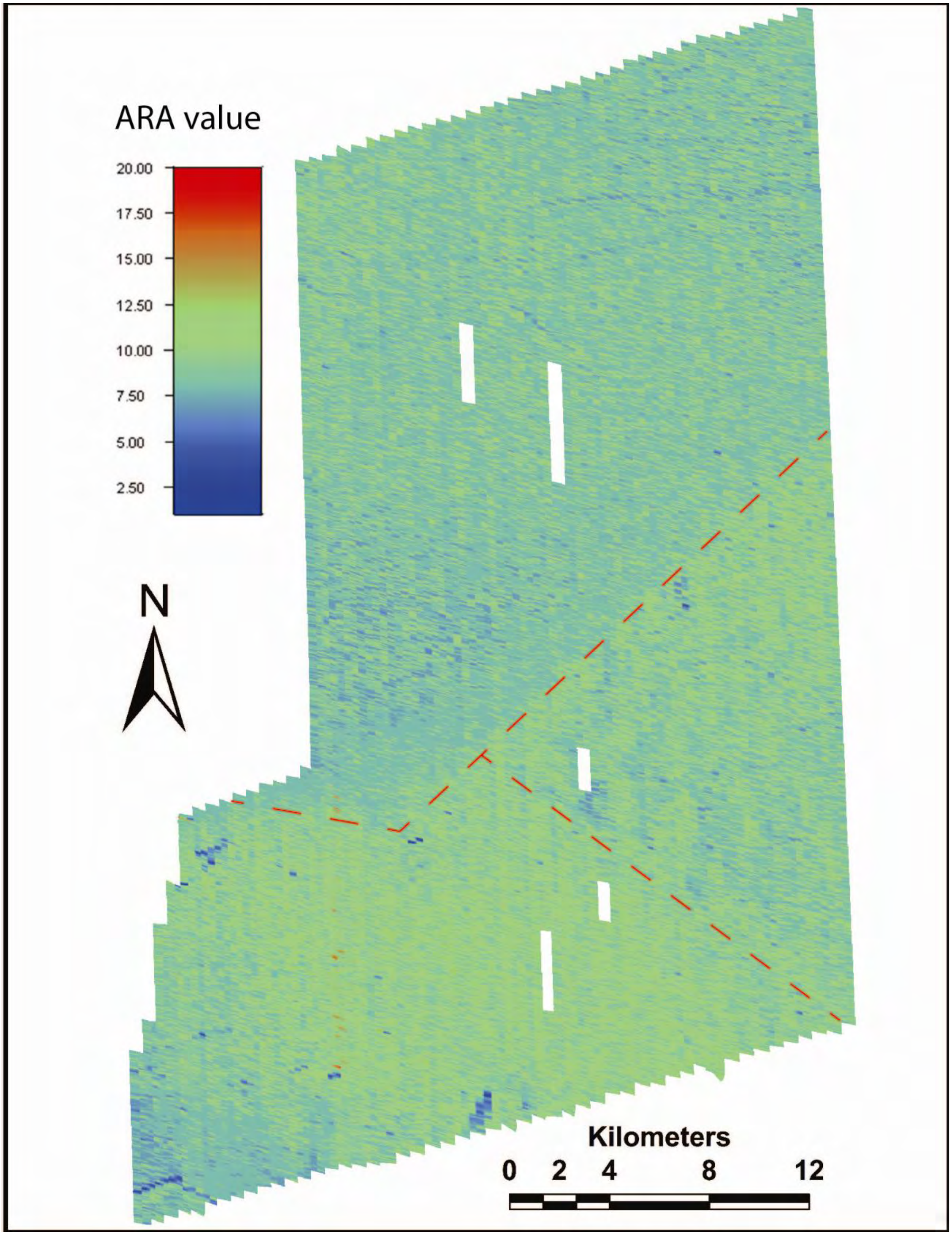


Figure 4.20 Angular Range Analysis of Area C. The three different parts can be distinguished due to their large scale differences in backscatter values. The striped pattern conforms with the survey tracks and is a beam angle effect.

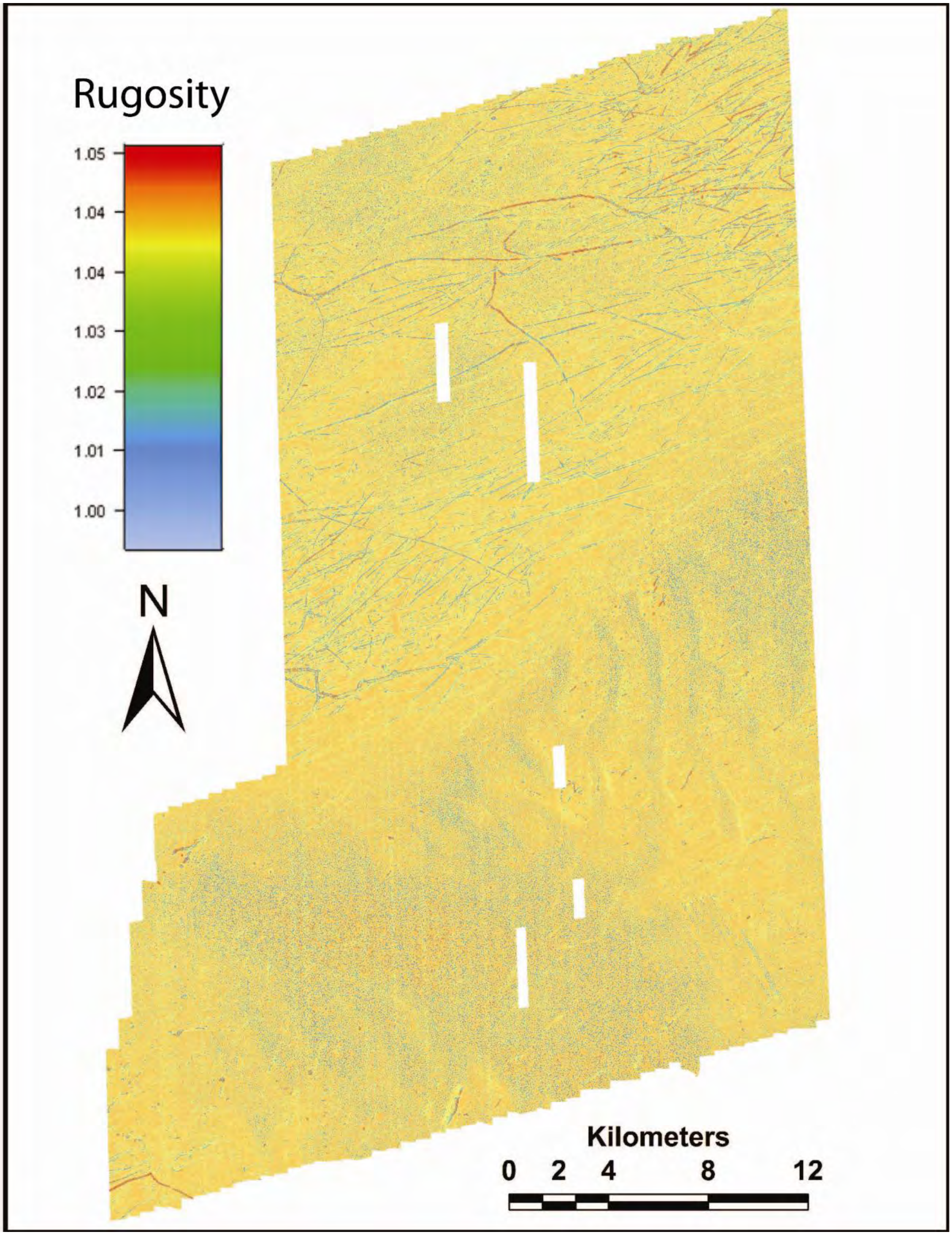


Figure 4.21 Rugosity analysis of Area C, iceberg plow marks are visible throughout the northern part, a pockmark area is observed in the southwestern corner and large ridges are present in the eastern part.

The groundtruthing data for Area C consist of high resolution black and white still photos, covering parts of the southern area (Figure 4.18). Areas covered by groundtruthing photos showing significantly higher or lower backscatter than the surrounding areas were visually examined and analyzed. The locations chosen for further analysis are shown in Figure 4.22. The coverage of the groundtruthing was moderate and no larger structures were visible on the seafloor photos. The smaller features visible were crusts or boulders, solitary sponges and small pits.

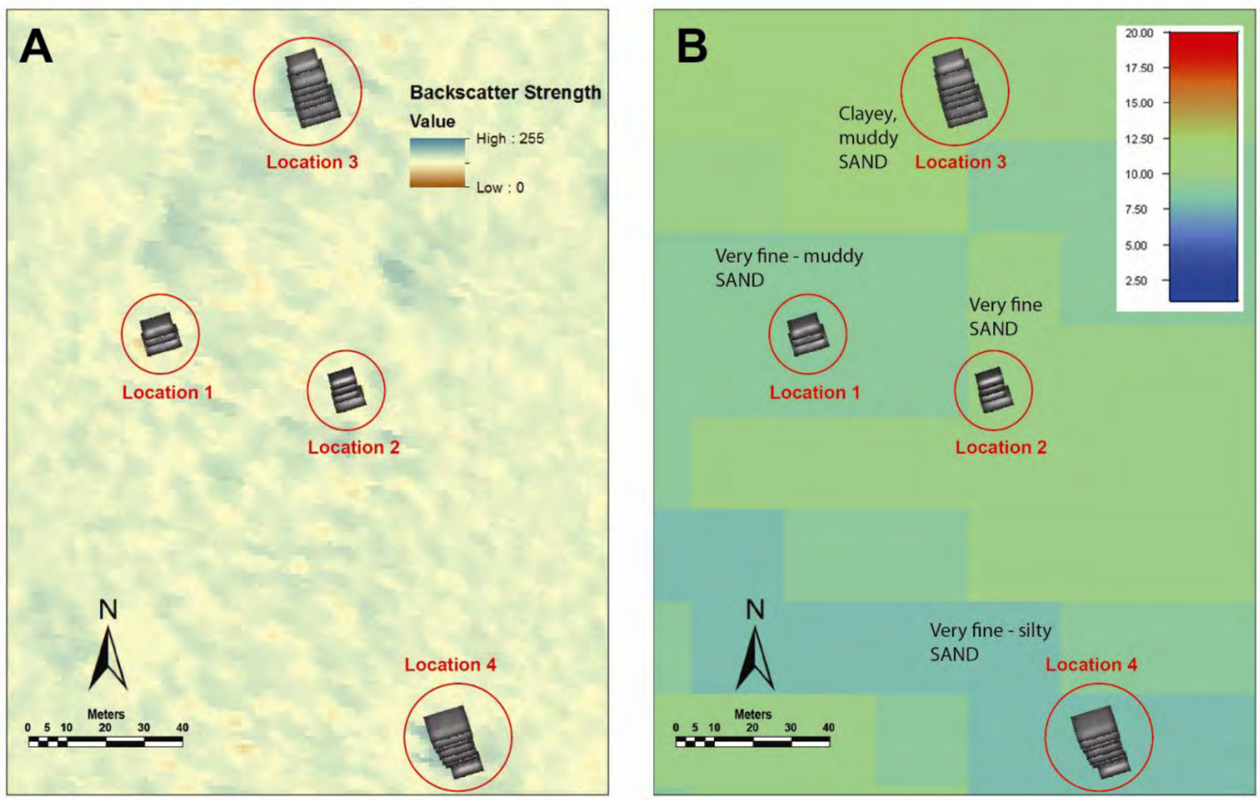


Figure 4.22 A) Backscatter mosaic with groundtruthing locations selected for further analysis. B) Angular Range Analysis with locations chosen for groundtruthing analysis.

Two areas with low backscatter are visually examined (Figures 4.23 and 4.24). Backscatter data from Location 1 show a low response, which suggests finer grain size. However, the ARA has a low value, which would be more coherent with a coarser gain size. Location 2 has a low backscatter pattern that implies that the area here is dominated by finer grain sizes, and the ARA response from the area is slightly higher than for Location 1, which is more coherent with the low backscatter value. The groundtruthing photos are centered over a pockmark rim, with the pockmark itself measuring approximately 45 by 40 m. The groundtruthing photos for locations 1 and 2 shows that the seabed substrate probably constitutes of finer grain sizes with no gravel, pebbles or shell fragments visible in the groundtruthing photos. The small features in Figure 4.24, trails and pits on the seafloor, also suggest that the sediment is fine enough for such small scale features. In coarser sediment, such as gravel or sand, it is less likely that such small features would be visible.

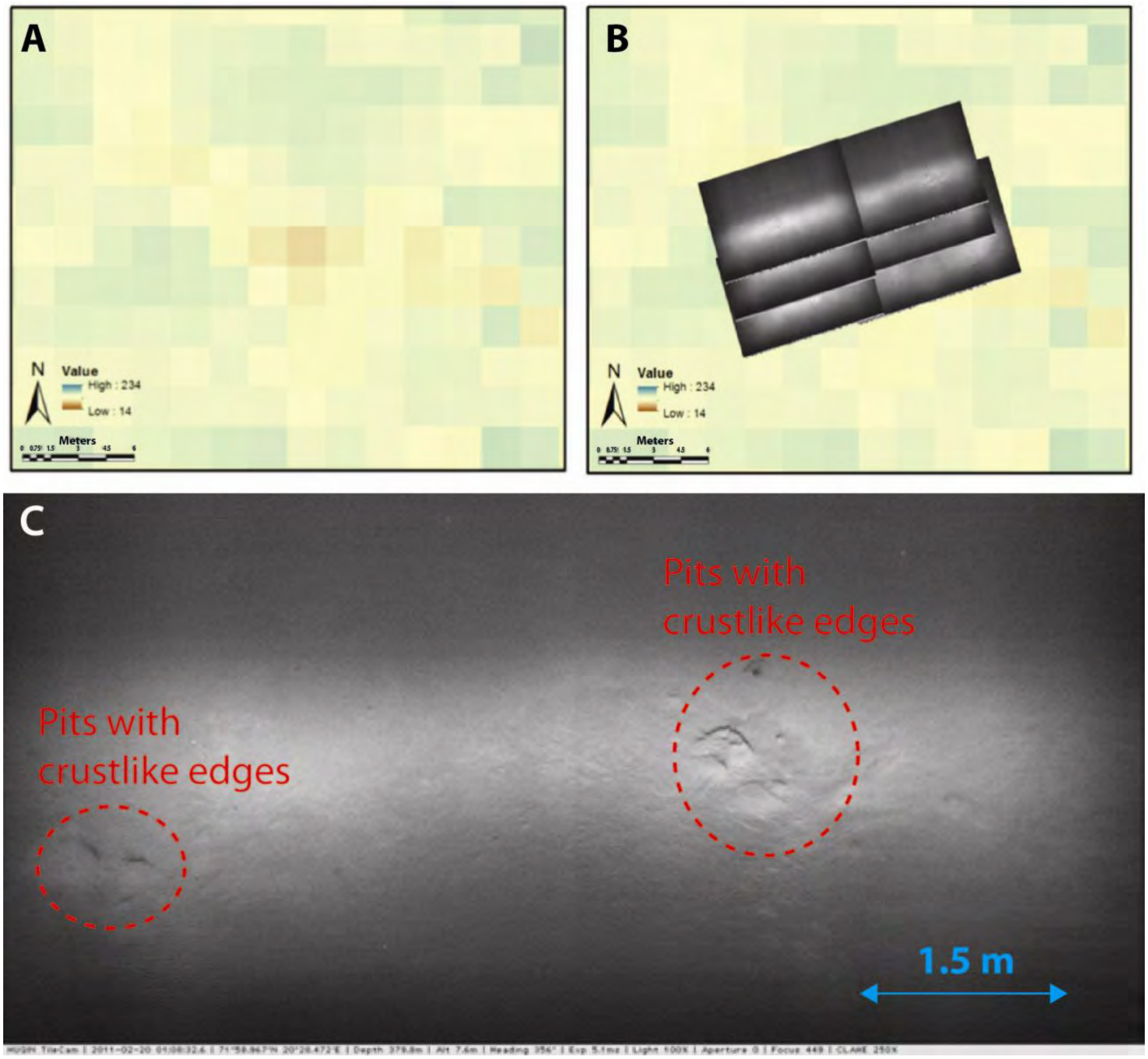


Figure 4.23 A) Location 1, backscatter mosaic with low backscatter. B) Groundtruthing photos on Location 1. C) Groundtruthing photo at Location 1 showing pits with crust-like edges that might indicate a harder seabed substrate.

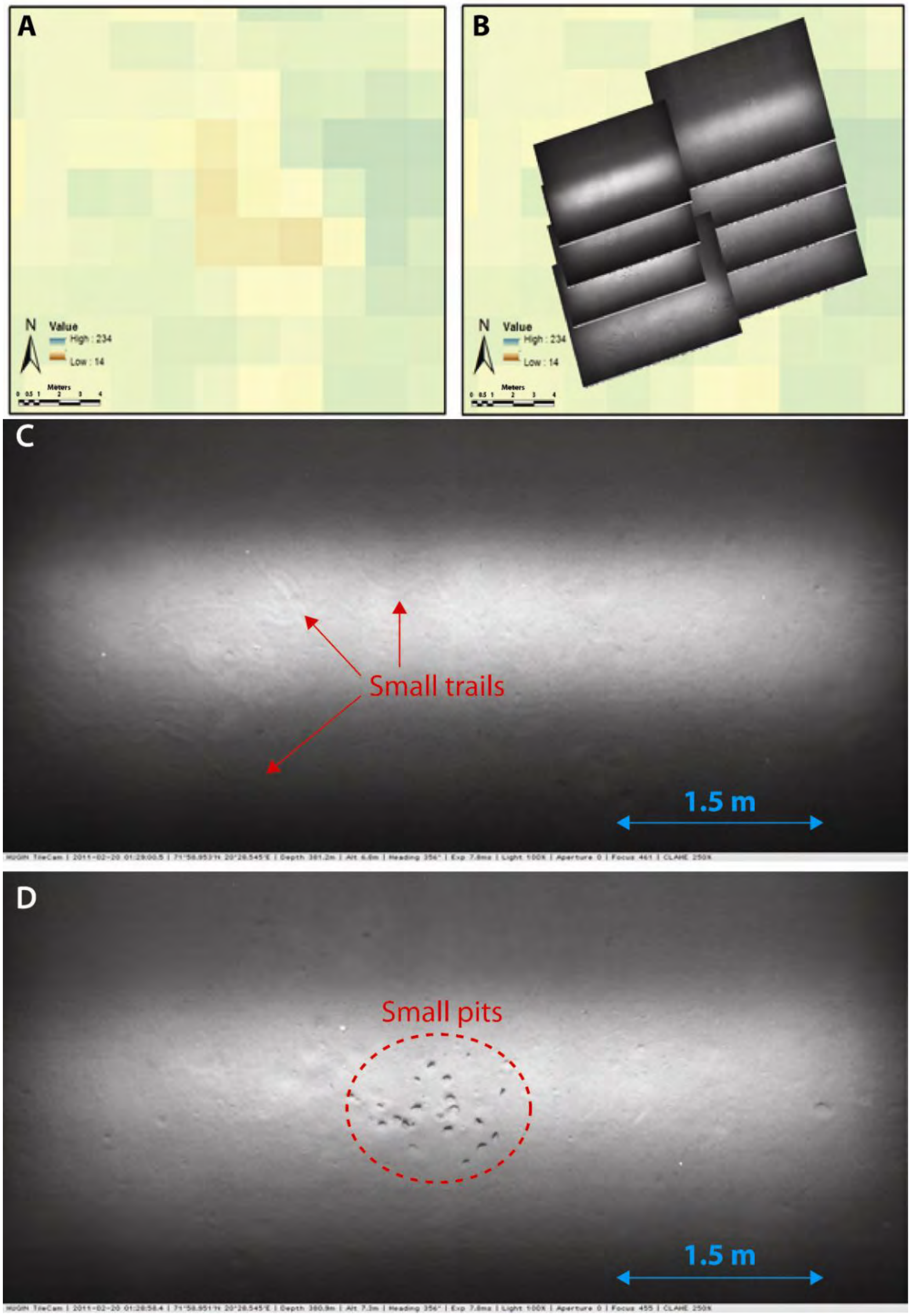


Figure 4.24 A) Location 2, backscatter mosaic with low backscatter. B) Groundtruthing photos on Location 2. C) Groundtruthing photo at Location 3 showing small trails that might indicate finer sediments. D) Groundtruthing photo showing pits without the crust-like edges seen in Figure 32 C.

Locations for the two chosen high backscatter areas can be seen in Figure 4.22. Both groundtruthing Location 3 and Location 4 are situated in pockmarks of approximately 35 m in diameter. Location 3 is the groundtruthing place situated on the highest value ARA of all the four locations (Figure 4.25). High ARA values are usually what may be expected from a low backscatter seafloor. In Figure 38 some boulders or MDAC are visible inside a smaller pit. The boulder or the crust may partly cause the high backscatter at groundtruthing location 3. However, the groundtruthing photos are too up-close in order to get a good overview of the whole pockmark.

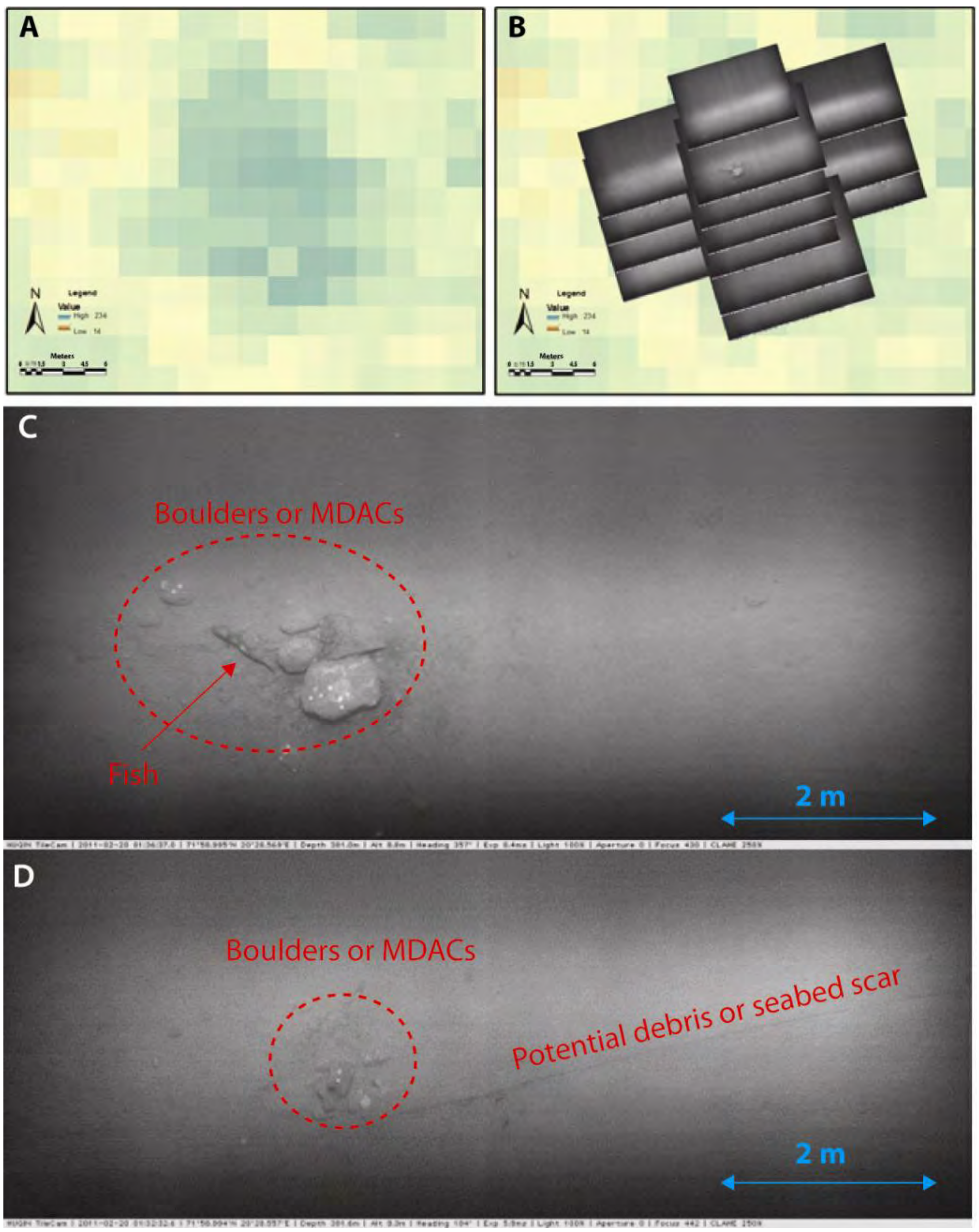


Figure 4.25 A) Location 3, backscatter mosaic with high backscatter. B) Groundtruthing photos on Location 3. C) Groundtruthing photo at Location 3 showing boulders or MDACs that might give rise to the high backscatter. D) Groundtruthing photo showing a linear feature and boulders or MDACs that might give rise to the high backscatter.

Location 4 has a high backscatter and might be interpreted as a hard substrate or a coarse material (Figure 4.26). This is the groundtruthing location with lowest ARA result, which is consistent with the backscatter, compared to the ARA and backscatter results at Location 3. Based on the groundtruthing pictures, the seabed substrate looks more solid at Location 4, containing pits with a crust like edge, similar to the one at Location 1. A direct analysis as to what gives rise to the high backscatter value at Location 4 is not possible from the data given.

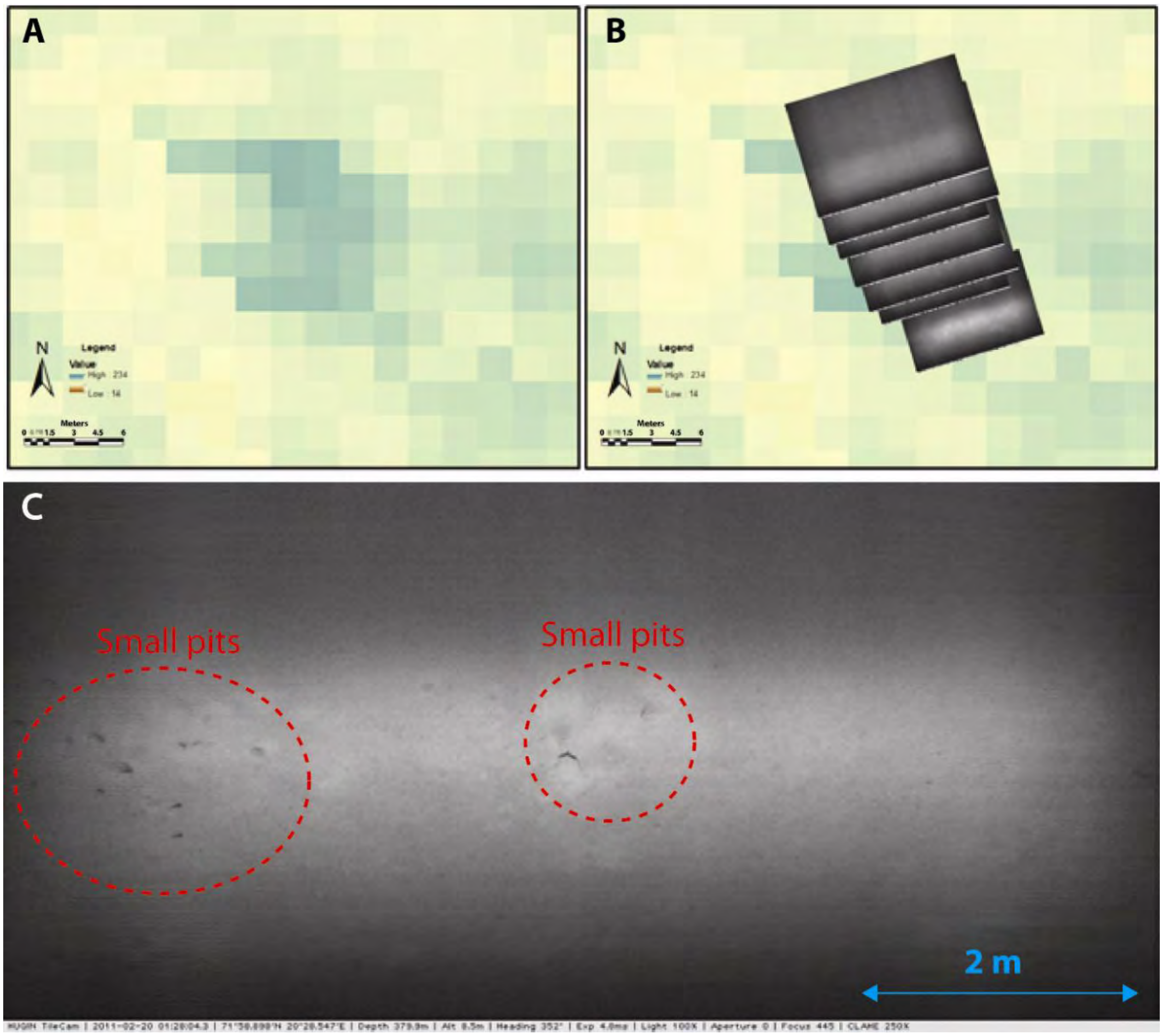


Figure 4.26 A) Location 4, backscatter mosaic with high backscatter. B) Groundtruthing photos on Location 4. C) Groundtruthing photo at Location 4, showing pits that have the same crust-like edges that are seen in Figure 32 that might indicate a cemented seafloor substrate.

4.4 Evaluation of automatic pockmark detection using ArcGIS

Figure 3.9 reveals a trend with peaking values at circumferences between 100-140 m. This is particularly true for the Key dataset (the manually cleaned values) and Contour 4. Contour 3 seems to have slightly more evenly distributed values, although its peaks coincide with the two other data sets. The distribution of pockmark circumferences peaks at approximately 120 m for all the data in the Key and for Contour 4. Thirty-two pockmarks in the Key have a circumference of exactly 120 m, and for Contour 4 the amount of pockmarks with 120 m circumference is 21 compared to 12 in the Contour 3 dataset. In comparison, the most common pockmark circumference in the Contour 3 dataset is 129 m. The percentage of circumference 129 m is 2.3% for the Key, 2.0% for Contour 4 and 1.4% for Contour 3.

The mean values of pockmark circumferences as presented in Figure 3.9 are estimated to be between 127.3 m and 137.4 m in the different datasets, with an average value of approximately 131 m (Table 1). This can be compared with the most common value 120 m and 129 m as presented in Figure 3.9.

Table 1 Mean values pockmark circumferences

Key	128.2396
Contour 3	137.3548
Contour 4	127.3472
Mean	*130.9805*

A visual comparison between Contouring values 3 and 4 and the Key was done as evaluation of the data (Figure 4.27). This gives us a rough estimation of the actual fit between the automatically generated Contour 3 and Contour 4 pockmark rims and the actual pockmarks, as decided in the key. In the figure no filtering based on pockmark circumference has been done. Best fits of the automatically generated contours are the ones with seabed gradient differing ± 2 degrees from the manually interpreted rim.

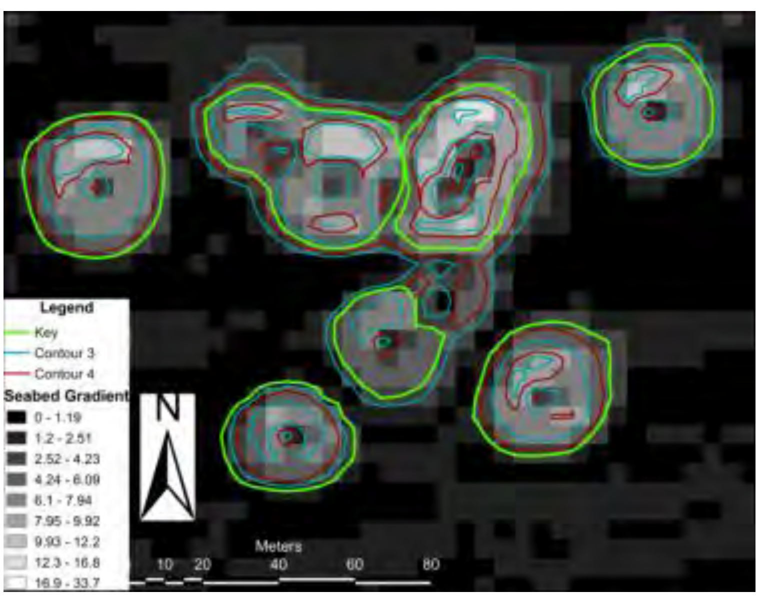


Figure 4.27 Comparison of the automatically generated Contour 3 and Contour 4 rims with the manually estimated pockmarks.

5. Discussion

The objectives of this thesis were to investigate the possibility of mapping different kinds of habitats; coral reefs, seafloor sponges and pockmarks and MDAC locations, with multibeam backscatter. The data used is from three different survey areas on the Norwegian continental shelf. The multibeam backscatter was analyzed mainly at locations covered by groundtruthing, such as video footage, still photos and a high resolution side scan mosaics. The aim was to answer three questions:

- Can backscatter be used to map some specific geohabitats and pockmarks on the seafloor in the surveyed areas?
- What are the limitations of using backscatter for detecting and mapping geohabitats?
- What other methods could be used to detect geohabitats, either independently or through combined multibeam bathymetry and backscatter techniques?

5.1 Survey area characteristics

Two main types of seafloor can be distinguished from the multibeam bathymetry and backscatter in all three survey areas. It is not only the depth that separates the two main types but also the seafloor characteristics. Shallower seabed, less than approximately 370 m water depth, is in all three survey areas affected by heavy iceberg scouring and displays features related to this such as iceberg plow marks and larger ridges. In the backscatter map this type is easily recognized with generally higher backscatter, especially on the plow mark ridges in survey areas A and C and inside the troughs of plow marks in survey area B. The high backscatter is coherently corresponding to low ARA values. Grain size analysis from the ARA at the shallower seafloor areas shows a heterogeneous substrate with coarse material, gravel, pebbles and boulders constituting the ridges and finer sediments settling in between the ridges or in patches between the ridges or plow marks. Previous investigations have revealed that local dips or hollows in the seafloor generally contain finer sediments (MAREANO). This implies that the analysis made here fit the hypothesis that pockmarks can be found with multibeam backscatter.

The second type of seafloor is at depths greater than 370 m and is not subject to iceberg scouring. This type is present at survey areas A and C. The seafloor type can be distinguished on the backscatter maps with a generally lower and more homogenous backscatter. In survey area C, the most prominent features of this second type of seafloor are the numerous pockmarks. Some depressions that might be interpreted as pockmarks are present in this type of seafloor at survey Area A but in general the seafloor here is smooth with infrequent small to medium scale ridges. From the ARA maps of the three different survey areas we can clearly see a difference in the predicted sediment size between this seafloor type and the areas characterized by the iceberg plow marks.

Area C, the only survey area with obvious and extensive pockmark formation, has pockmarks at depths greater than 325 m throughout the whole area with the exception of the southwest corner. This part of Area C has the same characteristics as survey Area B, in that it is heavily affected by iceberg scouring and there is no pockmark formation at seabed shallower than approximately 350 m.

The ARA gives a grain size that is coherent with the groundtruthing result provided by other investigations of the survey areas (Chand et al., 2012; FSLTD Report 9999). Smaller discrepancies between the ARA results and the groundtruthing are shown, for example at groundtruthing locations in Area C, but this might be explained by the resolution of the ARA. Since the ARA is an average of backscatter values from a larger area, the automatically calculated grain size for a specific location will be different from the true grain size at this location if there is significant variation in grain size within the range of the ARA sample area. A good example of this is shown when looking at pockmarks in the backscatter; the backscatter clearly shows where the pockmarks are but there are no signs of specific pockmarks in the ARA. It is only in an overview of the full survey area that general changes and patterns in the ARA are discernable. The resolution of the ARA in the data is too low to conclusively identify small changes in the seafloor.

The general variance in absolute backscatter values is not that big for survey areas B and C. According to the study by Chand et al. (2012), the small variance in backscatter suggests that there is a relatively small change in sediments throughout these survey areas.

Area A display an intermediate between the two different types of seafloor, i.e. a smoother seafloor with elongated ridges with the same high backscatter but with a more eroded appearance than the iceberg plows mark ridges. The water depth at the base of the more eroded ridges varies between 360 m and 390 m and this type is most obvious in the north and western parts of the survey area.

The large scale ridges in the eastern part of survey Area C have the morphology and approximate dimensions of typical ribbed moraines or Rogen moraines (Möller 2005; MAREANO).

5.2 Results from the groundtruthing data

The groundtruthing that with certainty reveals coral reef formations all come from the shallower parts of Area A, where iceberg scouring is a distinctive feature of the seafloor. In general, the groundtruthing locations from the reef structures and iceberg plow mark ridges in Area A have slightly higher backscatter values than the surrounding seafloor. Research about the backscatter response for reefs indicates that results vary depending on the surrounding seafloor (Fosså et al., 2005; Conway et al., 2005; Roberts et al., 2005). Both high and low backscatter has been proven to indicate reefs, though in different geographical locations. The difference in backscatter response is suggested to be caused by the varying surrounding seabed substrate. Another explanation is that a different fauna dominating the reef give a different backscatter response. For survey Area A, the only survey area where it is certain that coral reefs exist, the reefs has a high backscatter compared to the surrounding seafloor. However, due to the sporadic occurrence of reef structures in this study this is merely a suggestion that requires further investigation. The seafloor areas with reefs in this study were also not “clean enough” to identify them in the backscatter mosaic, i.e. bathymetry and seabed substrate complicates the analysis.

It is harder to answer the question about what detectability is needed to identify coral reef structures in multibeam backscatter data. The higher backscatter at ridges chosen for video transects might be due to increasing reflectivity from the hard surfaces on the reef. However, it might be the hard substrate of the ridge itself giving rise to high backscatter values. Since the groundtruthing is sparse there is no certain knowledge of which ridges have corals and which ridges do not and so it is impossible to tell if there is a difference in backscatter between the coral and the underlying ridge. Therefore, we cannot be certain that it is the coral reefs that provide high reflectivity patterns or if it is the ridge they prefer to grow on. The conclusion being that not even the very highest resolution backscatter from a hull mounted multibeam could with 100 % certainty say that it is a reef that we find on the seafloor in the surveyed areas.

The groundtruthing photos have captured sponges, mainly located outside survey Area C, thus not covered by multibeam data, making it impossible to do an interpretation of their effect on the backscatter. What we can see in these groundtruthing pictures is that the dimensions of these organisms are approximately 0.3 x 0.3 m which would make them too small to detect on the 0.35 - 1.3 m/pixel resolution mosaic anyway. Questions about the backscatter response of sponges are for these two reasons left unanswered.

The reason for the higher backscatter in the pockmarks compared to the surrounding seafloor, could be due to interference from MDACs on the signal or, more probably, that the underlying coarse sediments are exposed in pockmarks. However, no certain results can be done since the groundtruthing from pockmark areas does not show any conclusive evidence of either concreted substrate or coarser sediments in the pockmarks.

The high backscatter was expected on ridges but high backscatter is also present within the trough of iceberg plow marks in survey Area B. This could be due to winnowing of finer sediments in the plow marks which is an effect of the plow mark orientation but could also be a result of the sediments being “concreted” together inside the plow marks, which would give rise to a higher backscatter.

The successful mapping of geohabitats with multibeam backscatter appears to be highly dependent on the resolution of the data. It must be taken into consideration that with bad resolution of the data it is hard to detect the small scale variations in the backscatter or in the multibeam bathymetry that often constitutes coral reefs or sponges. The gridding values of the 3D representation and/or the resolution of the backscatter mosaic must be smaller. For positive identification a resolution of decimeter or even higher could be required if the seabed is very complex. Multibeam backscatter with the resolution available for this study is more suitable for an initial “scan” of the seafloor and for the selection of sites for groundtruthing.

5.3 Results from rugosity and seabed gradient maps

Other analyses were done on the dataset, involving built in analyzing tools such as the rugosity calculator in Fledermaus and the seabed gradient analyzer in ArcGIS. These two methods gave a similar result with features of approximately the same size detectable in the maps. The result from the rugosity calculation displayed variations in rugosity mainly in areas where larger seabed structures, such as iceberg plow marks exist. Iceberg plow marks were characterized by increased rugosity values i.e. a rougher surface than the surrounding seafloor.

For Area C we could also see rugosity variations where the pockmarks were abundant. In general, the bathymetry and rugosity are equally suitable for finding large scale features.

When comparing rugosity and seabed gradient maps with the backscatter mosaic some larger iceberg plow marks that were anticipated to be visible, if all ridges and/or troughs had a higher or lower backscatter, are hardly visible at all in the backscatter (Figure 4.13). A possible explanation could be that this is a result of a uniform reflectivity in the sediments of the iceberg plow marks and the seabed substrate from the surrounding seafloor. Another reason for this might be that the backscatter gets gradually higher on these specific features and does not have a distinct boundary as observed on the plow marks, which makes it a bit less obvious than plow marks in other locations.

5.4 Evaluation of automatic pockmark detection

The area this method was tested on was a flat area with an equal distribution of pockmarks. By creating a key, where the pockmark rims were manually defined, a comparison of using the contouring tool in ArcGIS for automatic pockmark detection was carried out. The key was compared to the data extracted from ArcGIS where two seabed gradient values were picked out based on the most common contouring values in the key. These two datasets were also filtered using pockmark circumference, with values in the same range as the pockmark circumferences, 6 m to 385 m, present in the key.

After filtering the two contour files, the match with the key is fairly good, considering the spread of circumferences (Figure 4.27).

The conclusion is that this is a fast and easy but time consuming method for detecting pockmarks. One would need to create a key to extract parameters, such as typical circumference and gradient values, for filtering the data. Creating a key is also a source of error since it is a manual task subject to individual interpretation and therefore subject to partial opinion.

One complication is that pockmarks are presumed to be hard to distinguish if they are located in areas with sudden changes of the seafloor gradient, such as areas heavily affected by iceberg movement (Andrews et al., 2010). Since the area where this method was tried is from a part of the survey area where no iceberg plow marks were present, no conclusions on how the method would work in a varying bathymetry could be made. Another possible complication to the method is that some of the pockmarks were "double" i.e. they were overlapping and the contouring value would therefore be normal, but the circumference would be almost double that of an average pockmark circumference.

5.5 Limitations to the data set

The most limitating factor of the data set is the resolution of the data, as has been mentioned already. Also software limitations, such as the possibility to create mosaic with higher resolution in Fledermaus would improve the analysis.

The beam angle effects characteristic striped response is visible in the low backscatter parts in all three survey areas, the checked appearance of survey Area A is due to survey lines oriented perpendicular.

Evaluating photos as a means for groundtruthing leads to the conclusion that to analyze almost 18000 photos is a very time consuming method. A way to automatically mosaic these in GIS software would be very helpful. An example of automatic mosaicking would for example be a tool that cut out the part of the photo where the seafloor is visible without losing the georeferencing. A more efficient way to detect seafloor sponges than the still photos provided would be video groundtruthing.

5.6 Suggestions for further analysis

To improve the analysis further groundtruthing from areas with very high or very low backscatter are required. In this study, there was not enough groundtruthing in the areas of multibeam data. This resulted in limited analysis of seafloor features such as the iceberg plow marks and ridges in Area C or the iceberg plow marks in Area B. Area A would also have benefited from a more thorough groundtruthing investigation, especially concerning the linear, fanning features in the northern and western parts. Also groundtruthing from features with distinct bathymetry, such as ridges or mounds, could be valuable to analyze, especially if they have a distinct backscatter pattern. However, it was not possible to distinguish smaller features of this type with the current resolution of the data.

A safe, fast and relatively cheap way to detect geohabitats on the seafloor would be to conduct a multibeam survey, making sure that the data were of high enough resolution to grid with a decimeter scale pixel size, small enough to identify individual corals. Ideally the multibeam survey would cover a survey area of an even seabed with homogenous sediments containing well defined geohabitats, such as coral reefs and sponge accumulations. The multibeam backscatter can then be draped on the bathymetry and areas with shapes such as mounds, ridges or anomalies in the backscatter, i.e. unusually high or low values would be further investigated with groundtruthing. Preferred groundtruthing is color video footage. A homogenous seafloor of softer sediments with a larger coral reefs structure would probably reveal itself in a backscatter mosaic as a low backscatter area with a ridge, i.e. the reef, with distinctively higher backscatter. If sponge reefs were to be found in the data they would probably be seen as a ridge with lower backscatter than the surrounding sediments (Conway et al., 2005).

If the anomaly did not have any specific height, seabed sampling, for example grab sampling or box sampling could be carried out instead. With the drawback of disturbing a smaller part of potential fauna this is usually a more cost efficient method then for example AUV or ROV operations.

Side scan sonar data is a good, but not necessary, complement to multibeam and groundtruthing data. Data from towed side scan sonar has higher resolution than hull mounted multibeam in deeper water. Side scan sonar also shows variances in reflectivity of the seafloor but it does not give depth values and the height of features has to be inferred from potential shadows of the feature. The positioning of side scan sonar data is also less exact than multibeam data as well as dependent on incident angle rendering high reflectivity values due to angle and not due to seafloor characteristics.

6. Conclusions

- The data set provided in this study was not suitable for using multibeam backscatter as the only means to detect reefs, solitary sponges or MDACs.
- The effectiveness of multibeam backscatter as a means to find and map geohabitats is primarily constrained by the resolution of the data, especially when mapping smaller features such as sponges.
- Using multibeam backscatter is a good method when mapping pockmarks, due to the high backscatter these have compared to the surrounding seafloor.
- The characteristics of the habitats and/or seabed features are also limiting the effectiveness in detecting them.
- Mapping smaller geohabitats with a very high or very low backscatter compared to the surrounding seabed may be possible, depending on the backscatter characteristics of the surrounding seabed.
- More multibeam echo sounder and groundtruthing data is required from several areas with different conditions before it will be possible to establish how to best detect reefs with acoustic mapping methods and what factors need to be considered when conducting such surveys.

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7.2.1 Websites

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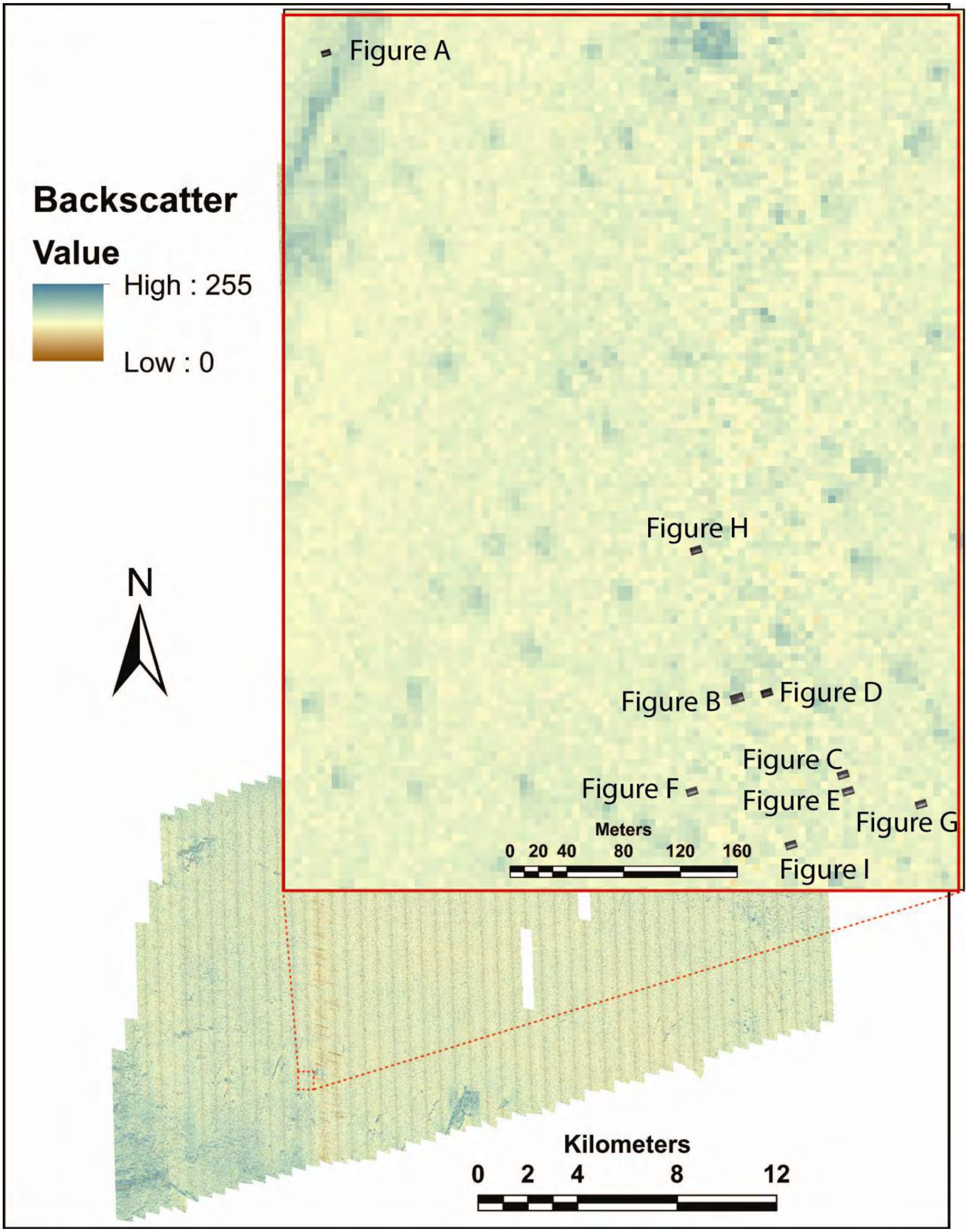
8. Appendices

A. Example groundtruthing photos from survey Area C



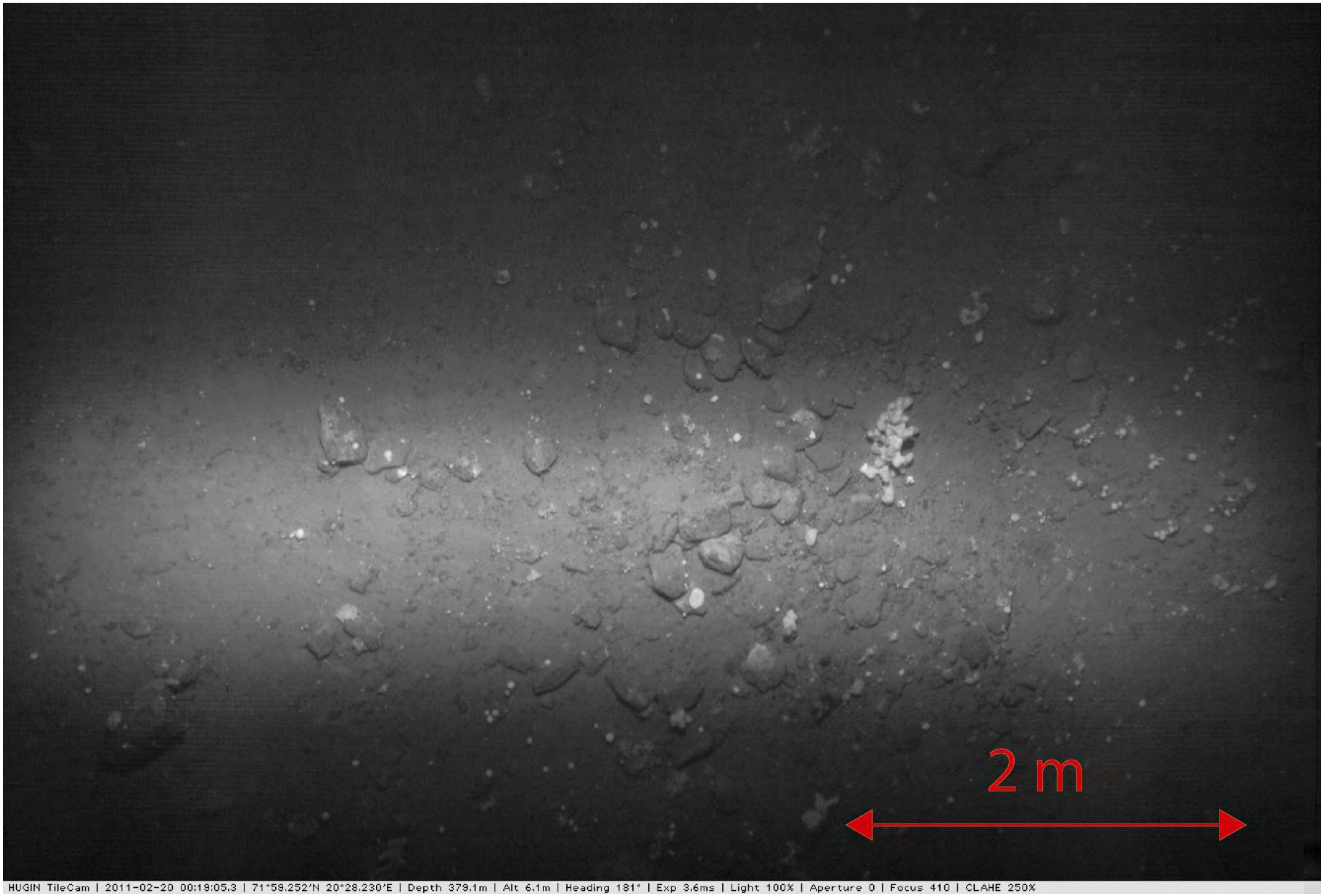


Figure 8.1 Example of coarse sediments, gravel, pebbles and boulders.

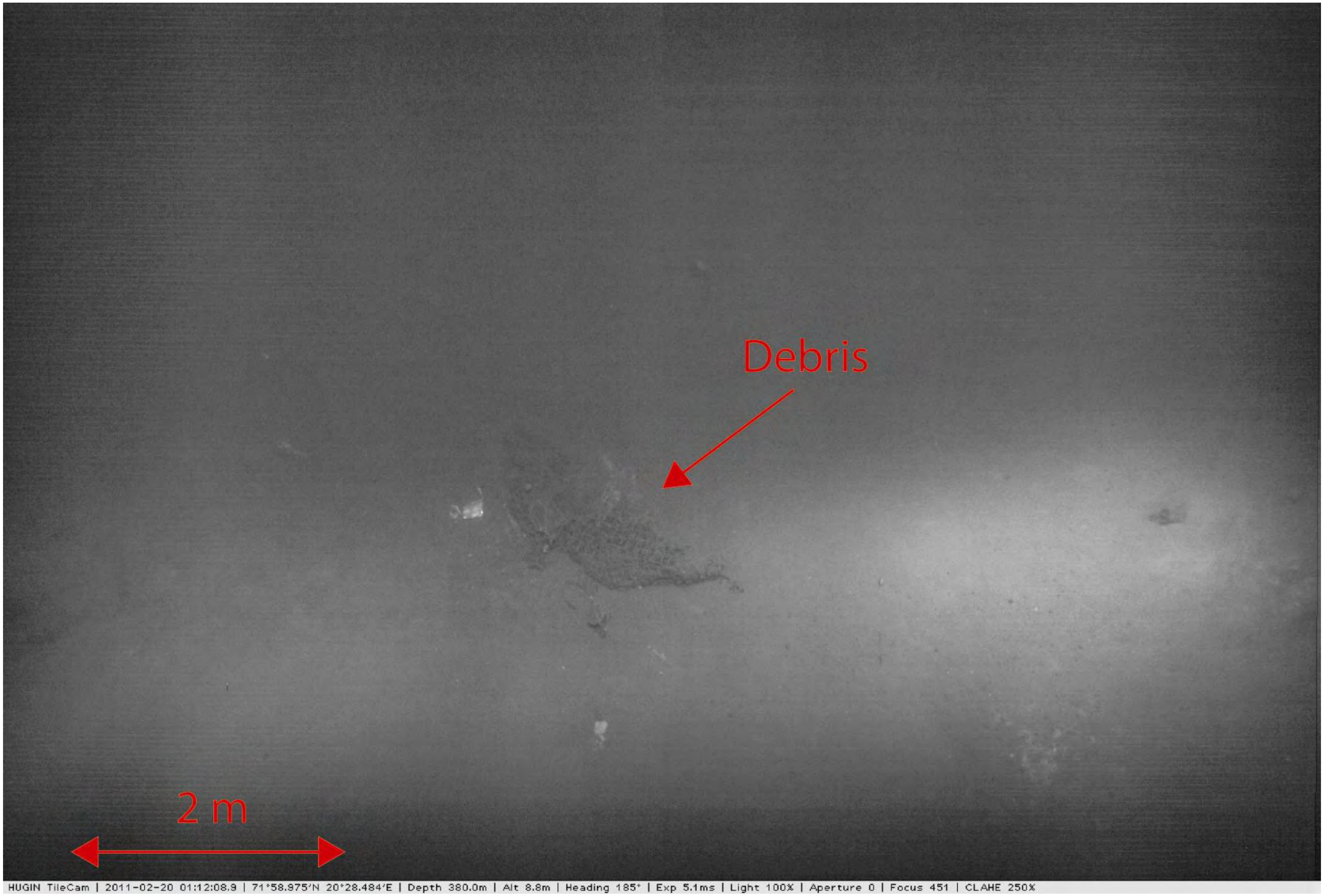


Figure 8.2 Example of debris, potentially a discarded fishing net.

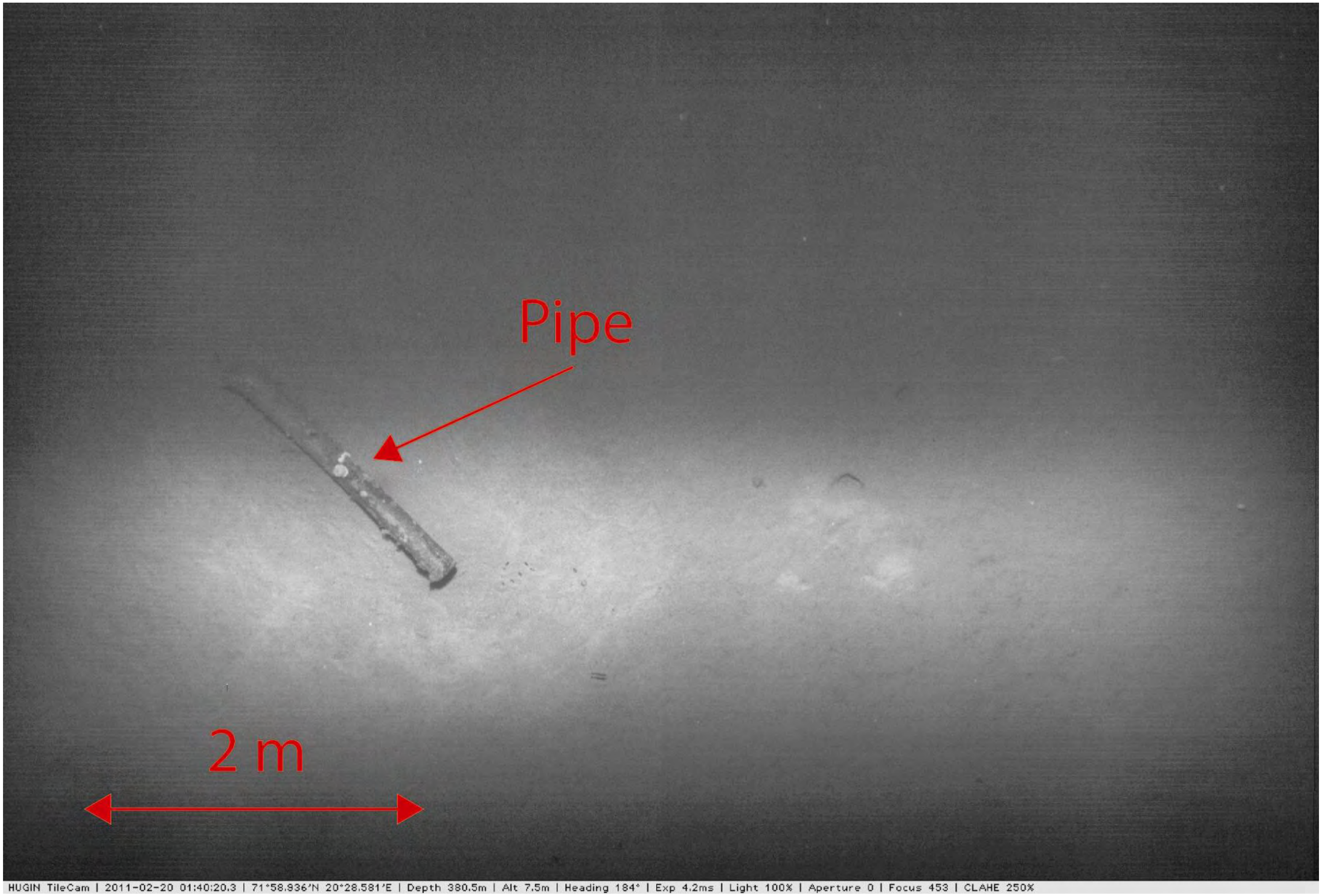


Figure 8.3 Example of debris, potentially a pipe.

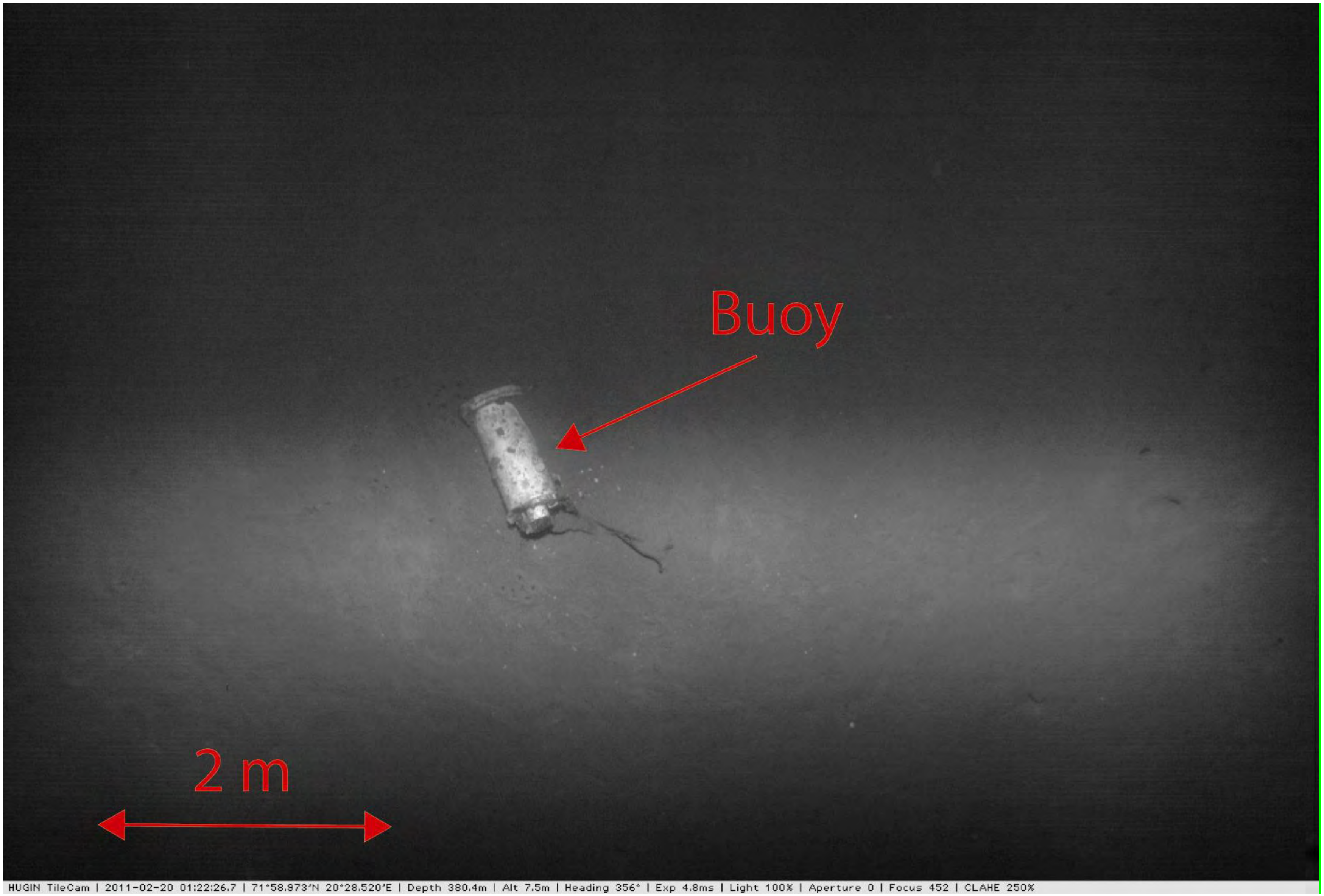


Figure 8.4 Example of debris, potentially a buoy.

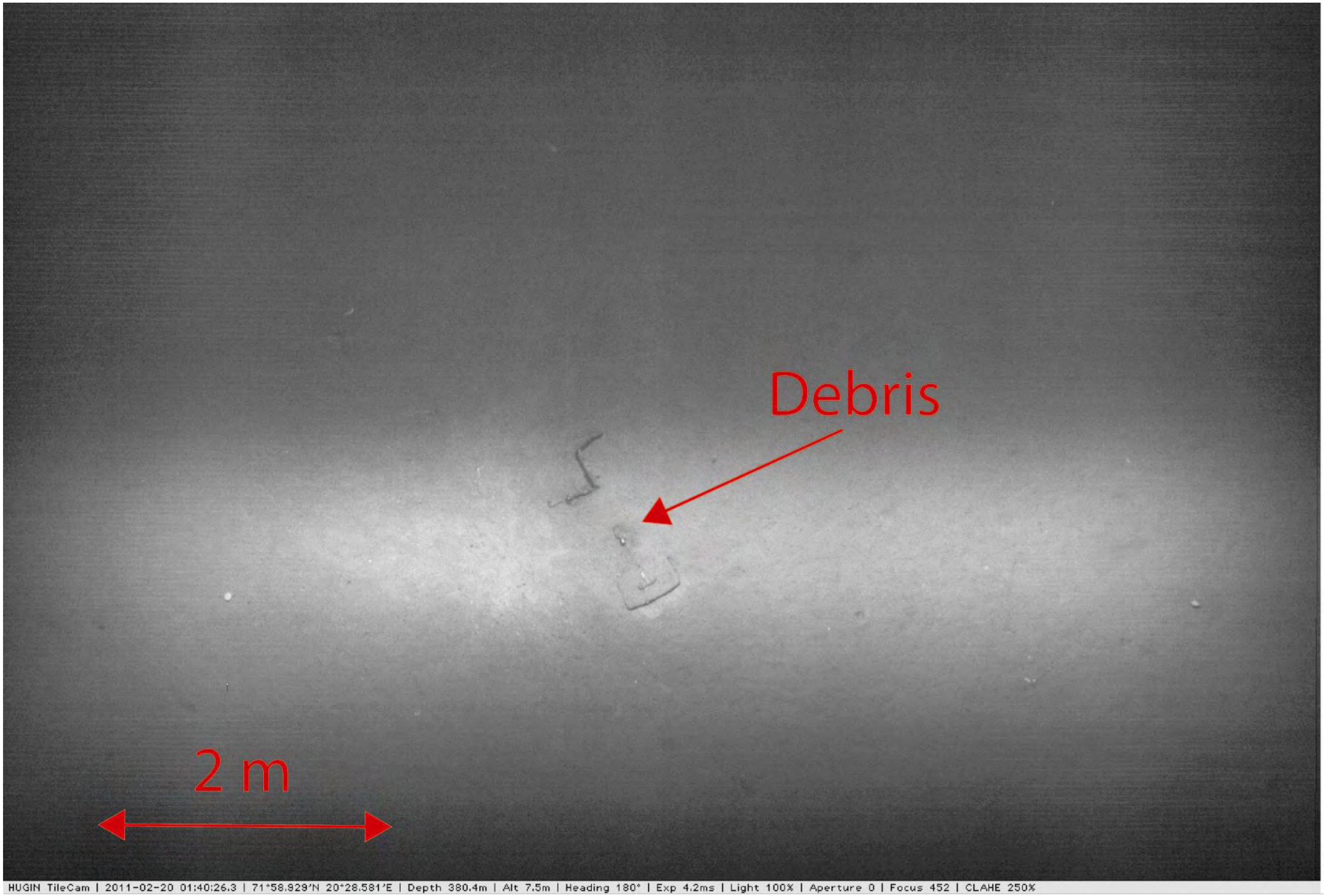


Figure 8.5 Example of debris, unidentified object.

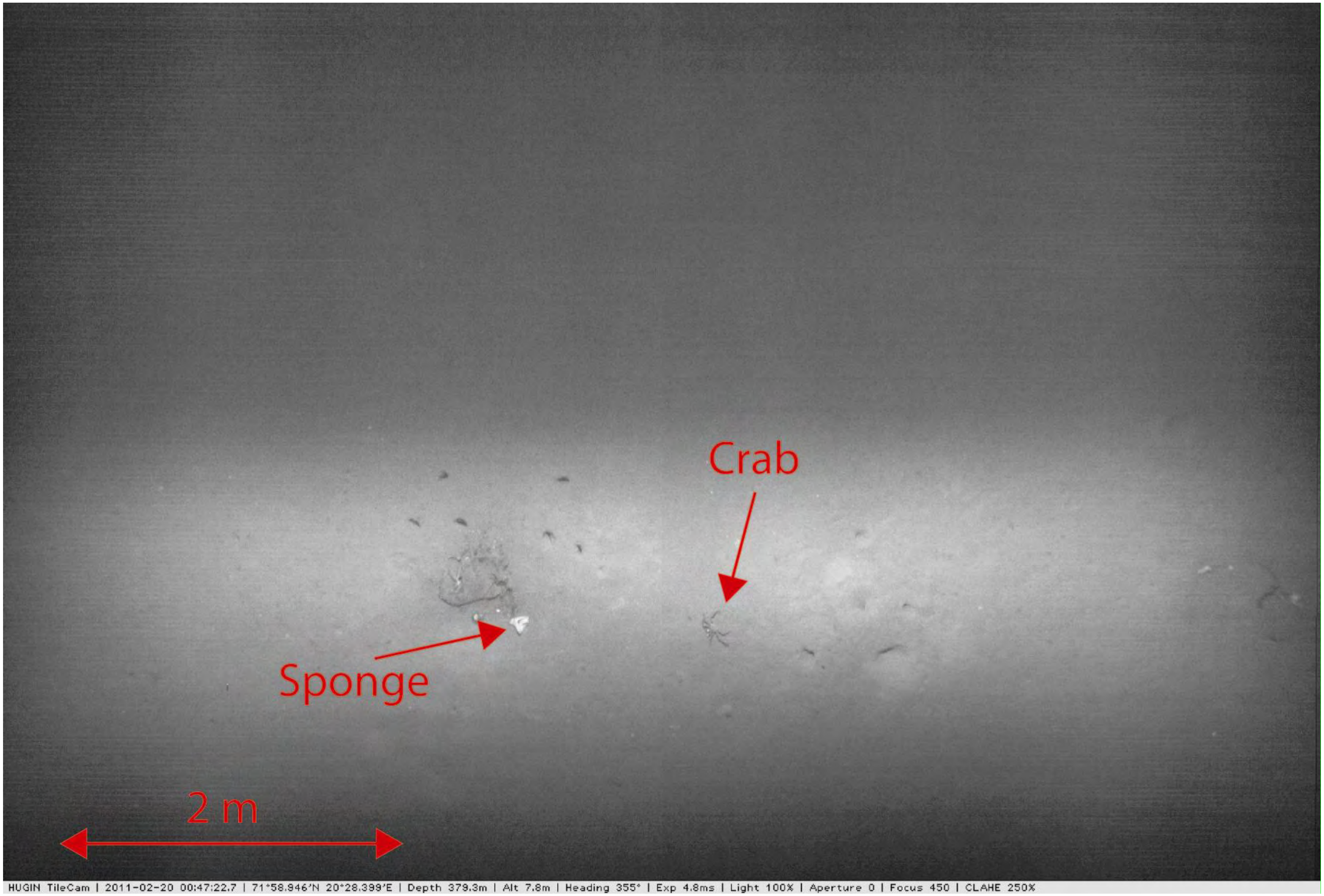


Figure 8.6 Example of bottom fauna in the survey area, seafloor sponge and crab.

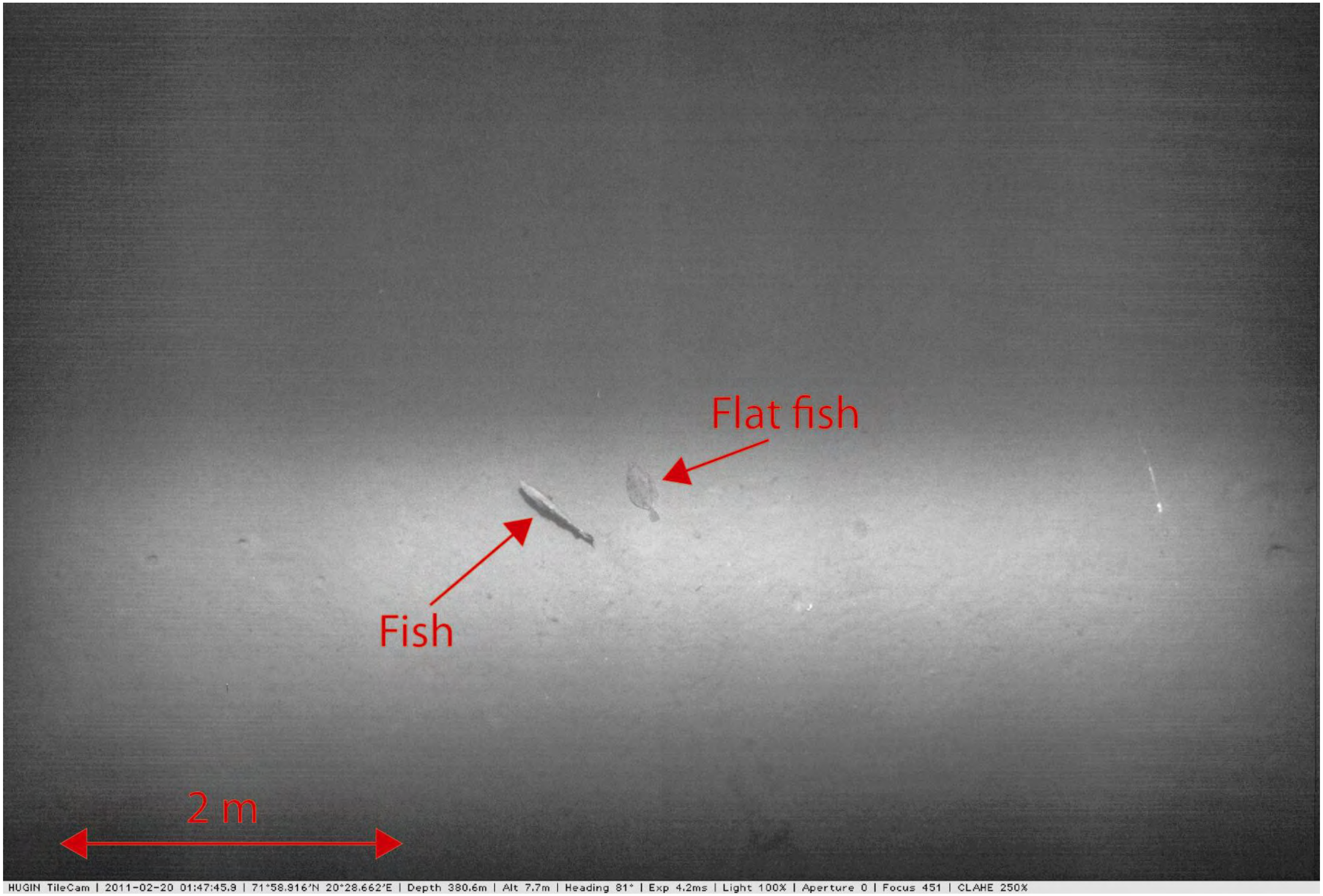


Figure 8.7 Example of fauna in the survey area, one flat fish (Pleuronectiform) and one unidentified fish.

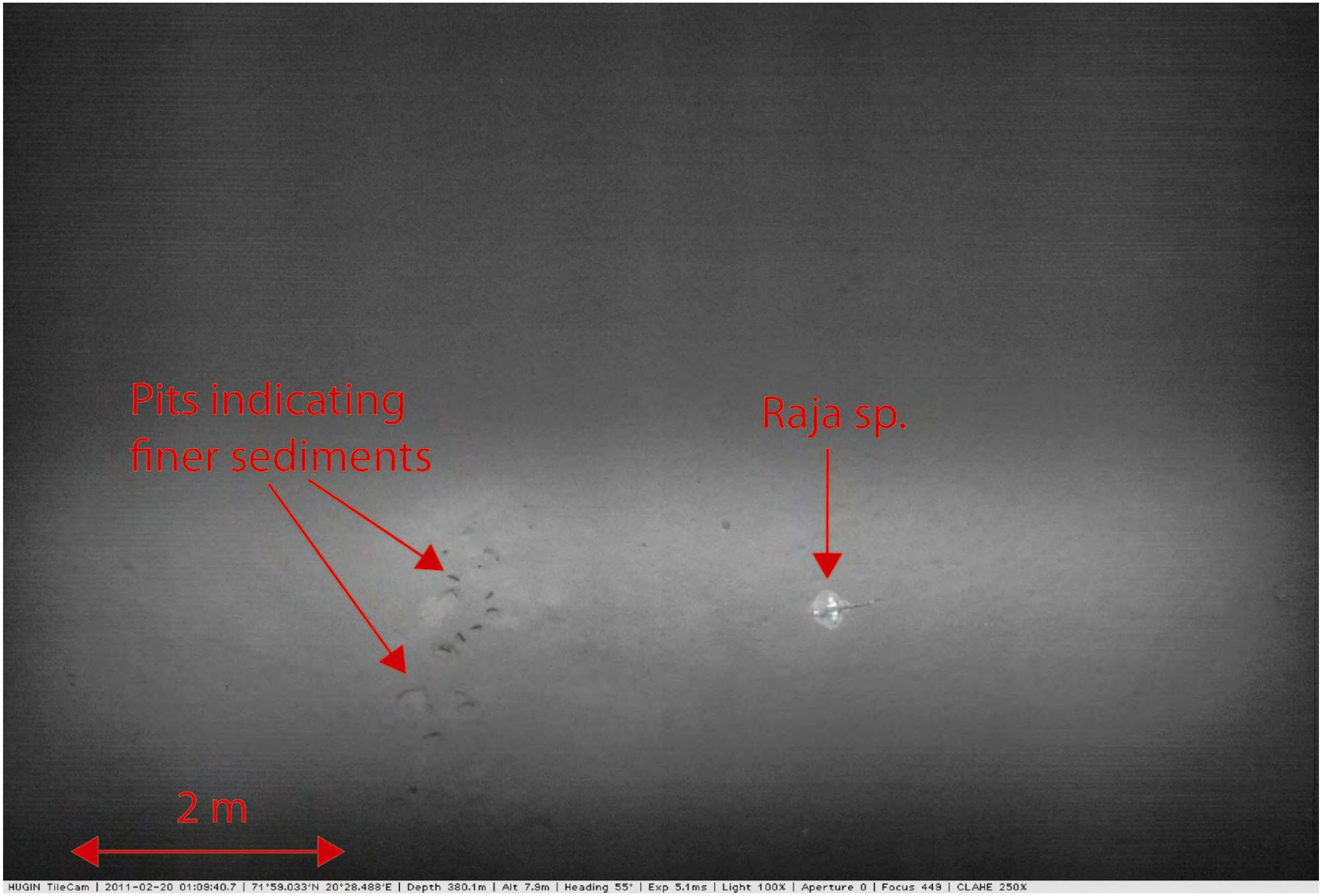


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Figure 8.8 *Raja* sp. in the survey area.

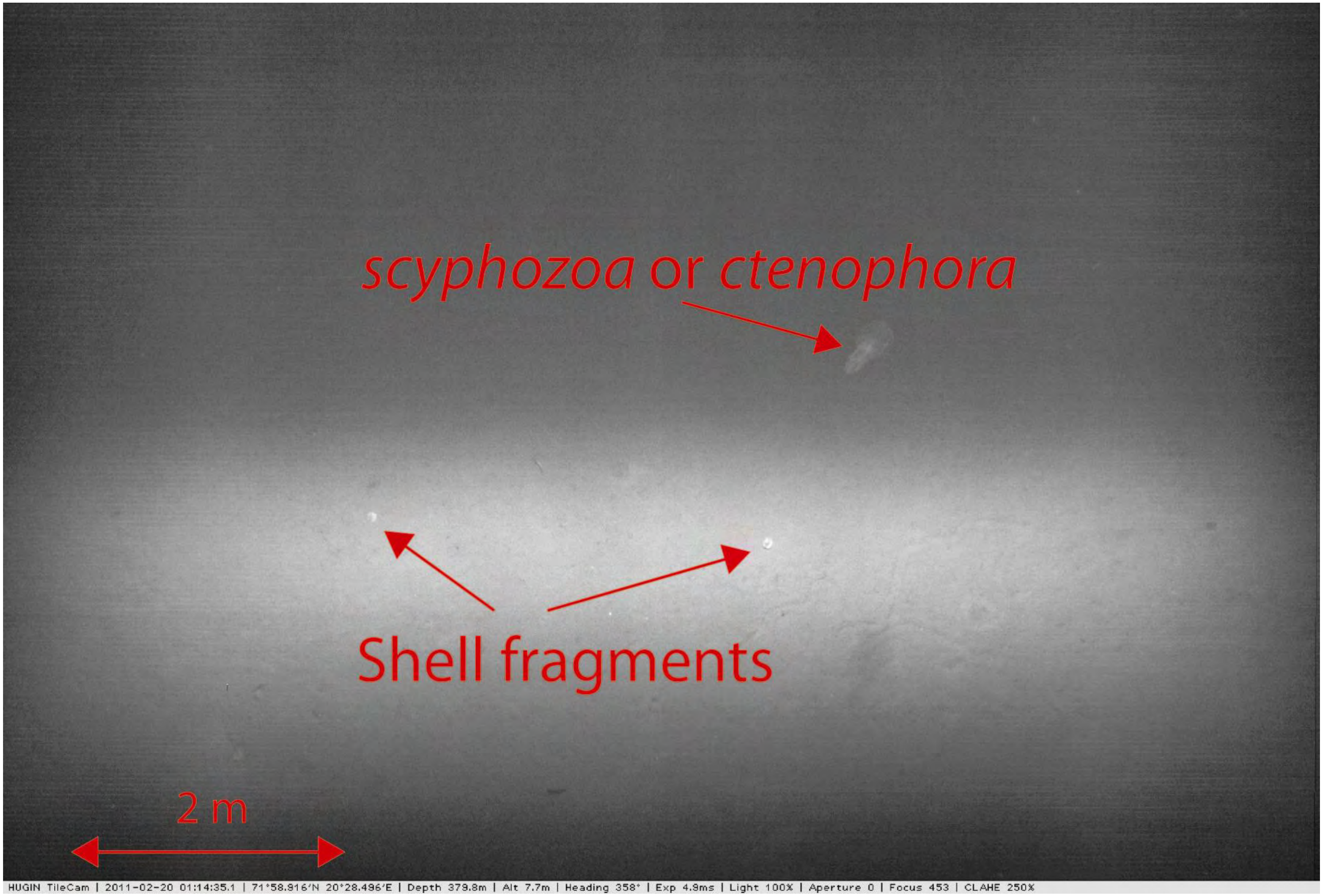


Figure 8.9 Examples of bottom and water column fauna in the survey area, possible *scyphozoa* or *ctenophora* and shell fragments.

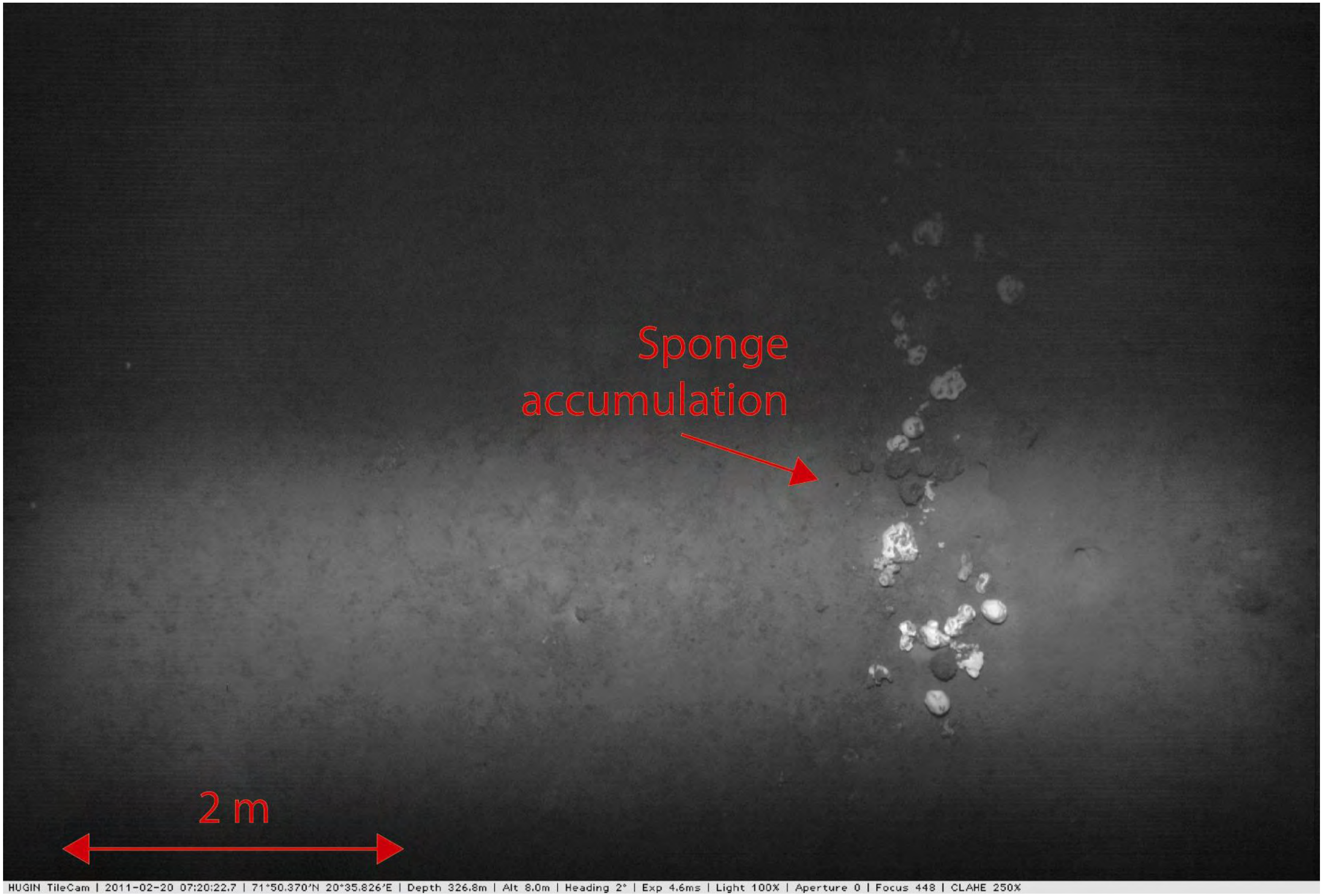


Figure 8.10 Example of sponge accumulation from the vicinity of the survey area.

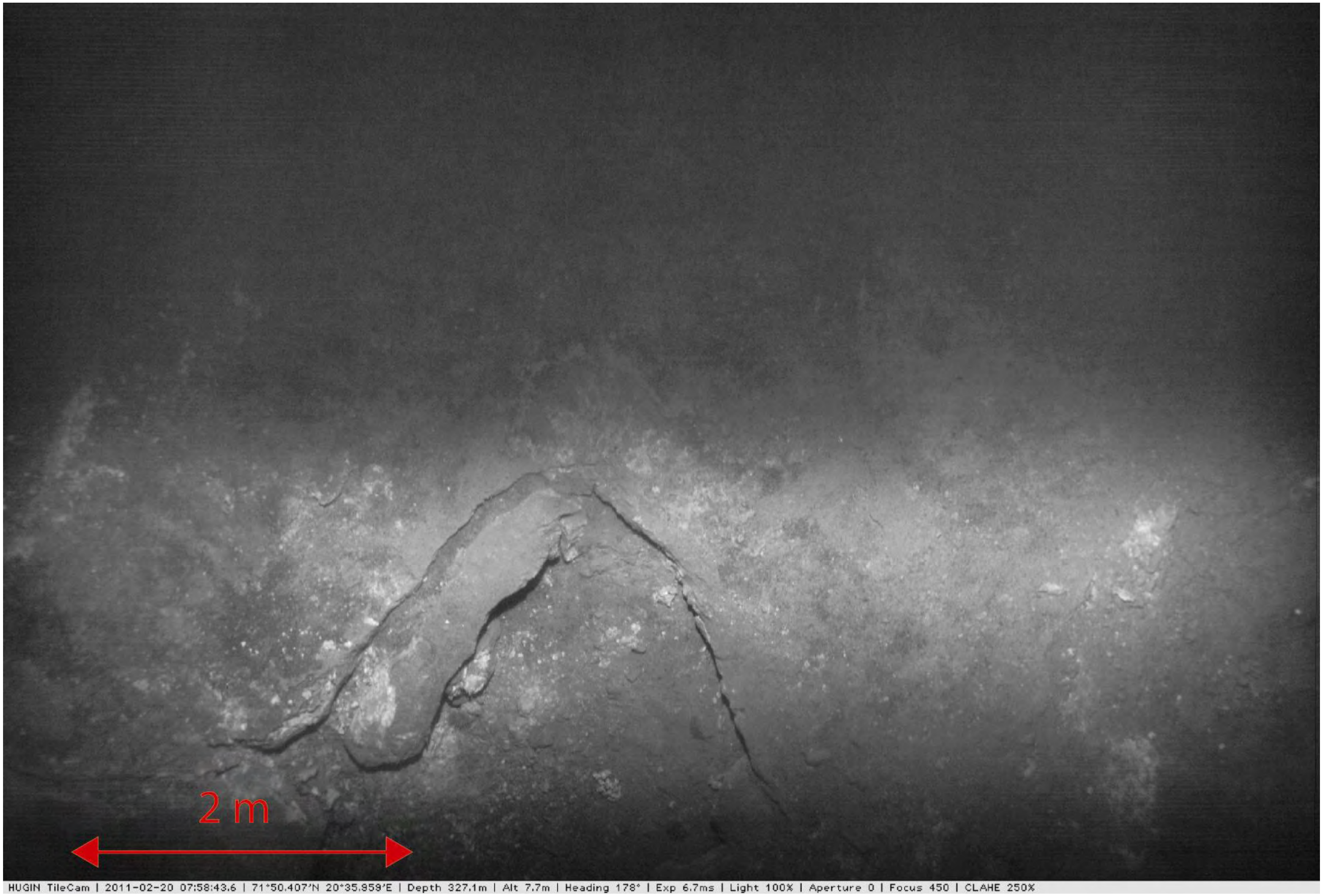


Figure 8.11 Example of hard substrate from the vicinity of the survey area.

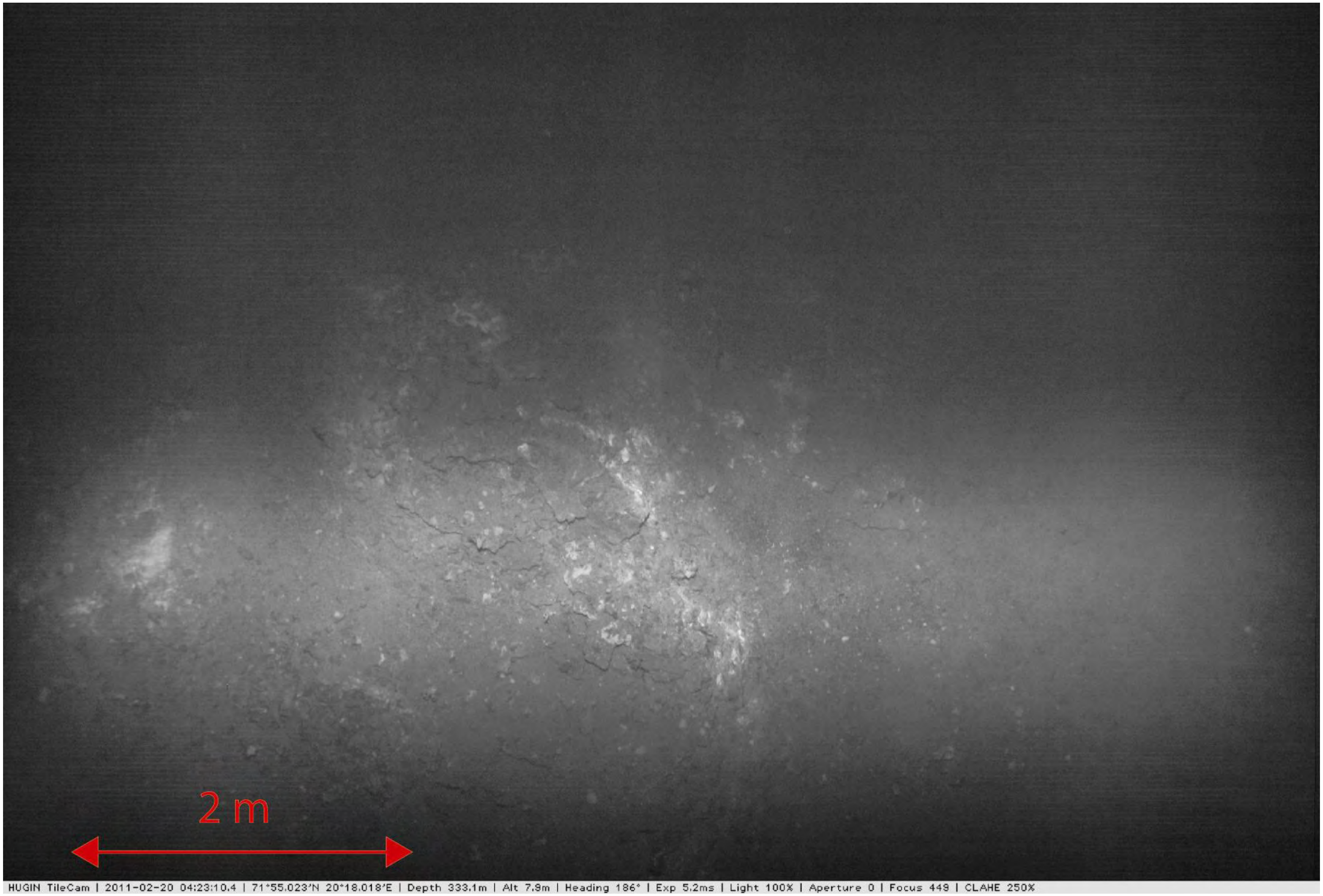


Figure 8.12 Example of hard substrate from the vicinity of the survey area.

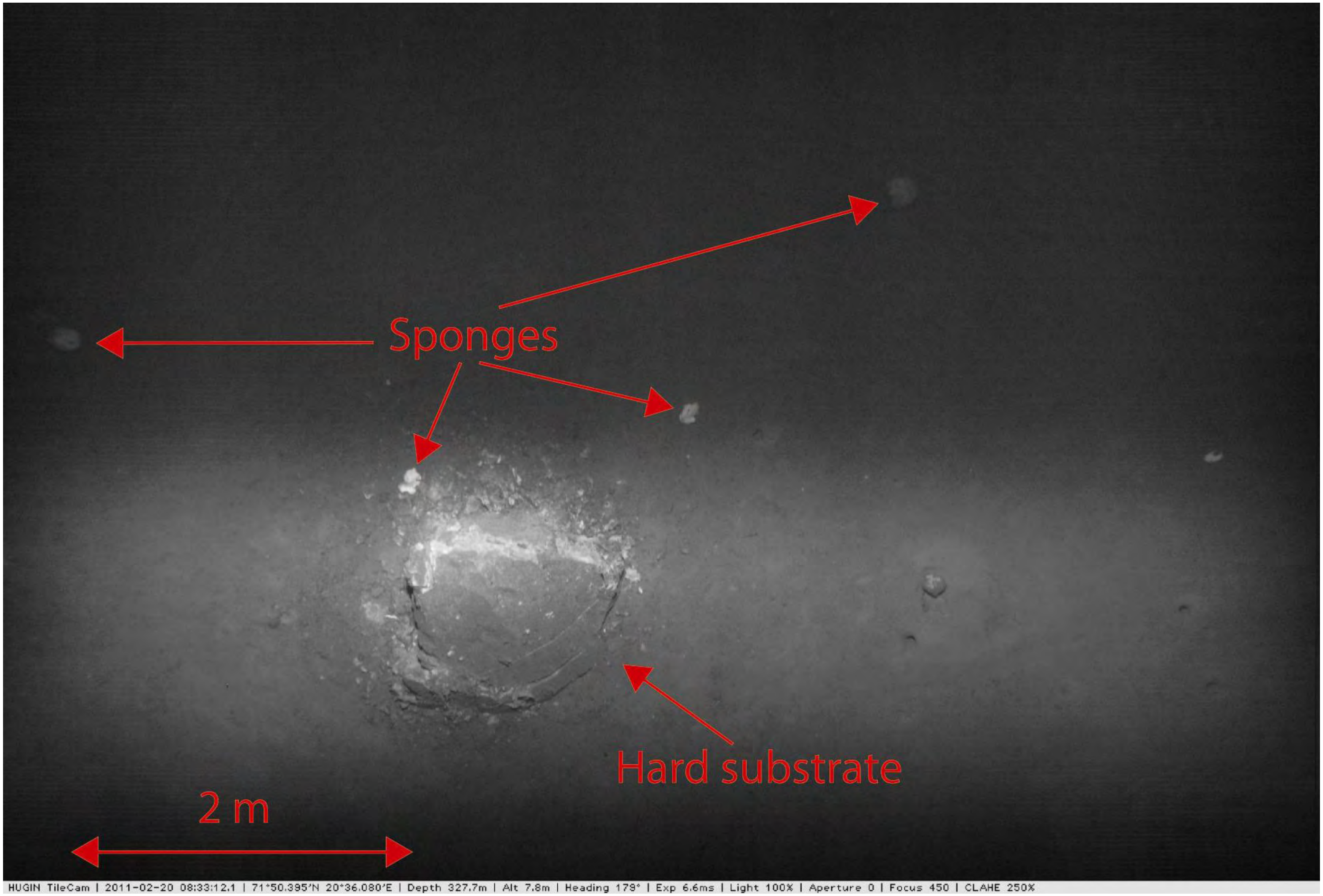


Figure 8.13 Example of hard substrate and sponges from the vicinity of the survey area.

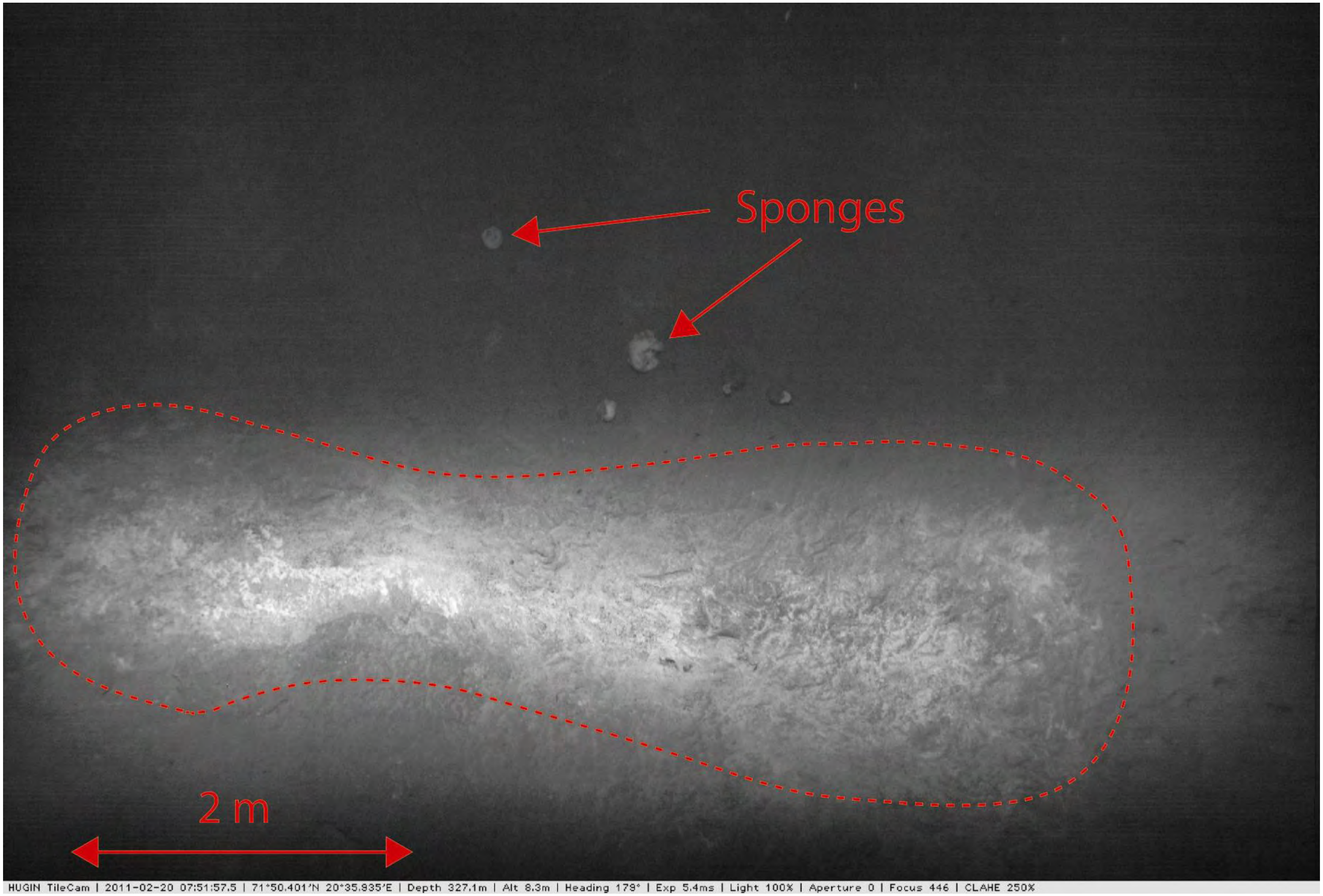


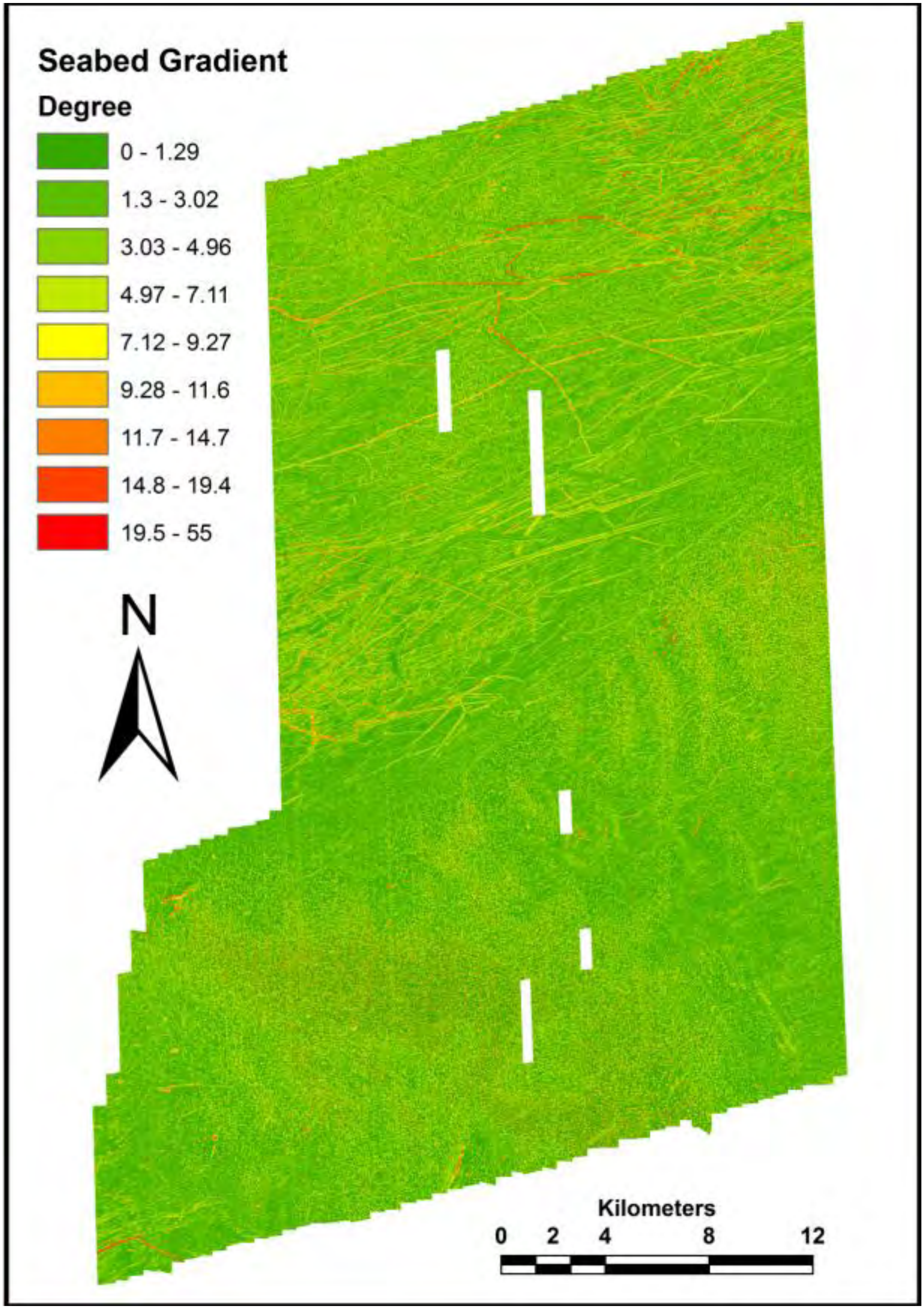
Figure 8.14 Example of seafloor with eroded structure and sponges.

B. Coordinates for groundtruthing locations

Groundtruthing object	Start Northing	Start Easting	End Northing	End Easting
Area A -Video Transect 1	7257309	415798	267	415951
Area A -Video Transect 2	7258017	414822	197	414840
Area A -Video Transect 3	7258994	416165	270	416093
Area A -Video Transect 4	7259361	416320	246	416551
Area A -Video Transect 5	7259299	416045	341	415930
Area A -Video Transect 6	7257391	415918	167	415927
Area A -Video Transect 7	7258112	414865	111	414789
Area A -Video Transect 8	7257166	414878	847	414952
Area B - Side scan sonar 1	7942156	480232	088	471097
Area B - Side scan sonar 2	7942088	471097	674	471105
Center of chosen photos				
Area C - Location 1	7987091	481859		
Area C - Location 1	7987089	481859		
Area C - Location 1	7987088	481859		
Area C - Location 2	7987064	481901		
Area C - Location 2	7987062	481901		
Area C - Location 2	7987061	481901		
Area C - Location 2	7987058	481901		
Area C - Location 3	7987145	481915		
Area C - Location 3	7987142	481915		
Area C - Location 3	7987140	481915		
Area C - Location 3	7987138	481915		
Area C - Location 3	7987136	481915		
Area C - Location 3	7987134	481915		
Area C - Location 3	7987132	481915		
Area C - Location 4	7986970	481901		
Area C - Location 4	7986969	481901		
Area C - Location 4	7986967	481901		
Area C - Location 4	7986965	481901		
Area C - Location 4	7986963	481901		
Area C - Location 4	7986962	481901		
Area C - Location 4	7986959	481901		
Coarse sediment	7987619	481729		
Debris -(fish net)	7987105	481867		
Debris - (buoy)	7987102	481888		
Debris - (pipe)	7987032	481922		
Debris - unidentified object	7987019	481922		
Fauna - crab and sponge	7987051	481817		
Fauna - fish and flat fish	7986996	481968		
Fauna - jellyfish	7986995	481872		

Groundtruthing object	Start Northing	Start Easting	End Northing	End Easting
Outside survey area				
Fauna - sponges	7971077	485983		
Hard substrate 1	7971144	486062		
Hard substrate 2	7979821	475760		
Hard substrate 3	7971121	486131		
Seafloor with eroded structure	7971134	486047		

C. Seabed gradient map from survey Area C


Seabed Gradient
Degree
0 - 1.29
1.3 - 3.02
3.03 - 4.96
4.97 - 7.11
7.12 - 9.27
9.28 - 11.6
11.7 - 14.7
14.8 - 19.4
19.5 - 55
N
Kilometers
0 2 4 8 12