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REPORT

Report no.: 2005.067	ISSN 0800-3416	Grading: Open

Title:
Sediment classification by acoustic methods - ACOUSEC final report

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County:	Commune:

Map-sheet name (M=1:250.000)	Map-sheet no. and -name (M=1:50.000)

Deposit name and grid-reference:	Number of pages: 20 Price (NOK): 165,- Map enclosures:

Fieldwork carried out: 2002-2003	Date of report: 25.10.2005	Project no.: 294400	Person responsible: Reidulv Bøe

Summary:

Acoustic classification of sediments using single beam and multibeam echo sounders has been under intense development over the past two decades. In the ACOUSEC project, led by Kongsberg-SIMRAD and co-financed by NFR, the goal has been to improve methods and algorithms for acoustic classification, and try to establish acoustic libraries that could minimise the need for ground truthing. NGU has acquired single beam data, evaluated software for multibeam echo sounder classification, and provided sediment samples and sediment maps for calibration of results. Field data have been acquired from the Sula Reef, the Røst Reef Complex, from the TESI area at Møre, from Harstad, Trondheimsfjorden and around Jøa. The evaluation of classification software reveals that backscatter data quality is a critical factor for acoustic classification. This applies both to calibration during data acquisition, and the software used for processing and interpretation. The report concludes that there are important improvements to be done before a semi-automatic classification can be performed on the backscatter data, providing a reasonably reliable sediment map.

Keywords: Sediment classification	Remote sensing	Seabed sediments
Software	Geophysics	Seafloor topography
Backscatter	Multibeam bathymetry	Acoustic classification

CONTENTS

FIGURES

Figure 1. Backscatter and bathymetry showing coral mounds from the Røst Reef Complex and sponge communities at Jøa.

Figure 2. Sponge communities at Jøa. ROV photos, TBS.

Figure 3. Triton sediment map, TESI/Møre.

Figure 4. Poseidon backscatter mosaic, TESI/Møre.

Figure 5. Triton automatic sediment classification, TESI/Møre.

Figure 6. Sediment map, manual interpretation, TESI/Møre.

Figure 7. Comparison between Triton sediment map and manually interpreted map, TESI/Møre.

Figure 8. Comparison, Triton maps using variable filter settings, TESI/Møre.

Figure 9. Backscatter strength versus pulse lengths, Jøa.

Figure 10. Striping in backscatter mosaic, TESI/Møre.

Figure 11. Striping in backscatter mosaic, area 2503, Harstad.

Figure 12. Striping in backscatter mosaic, area 2403, Harstad.

Figure 13. Striping in backscatter mosaic, area 2703, Harstad.

1.   INTRODUCTION

ACOUSEC (ACOUstic SEabed Classification) commenced in 2001 as a three-year project for testing and developing automatic classification software for single and multibeam echo sounders. Kongsberg-SIMRAD has been the lead partner. SINTEF has been a co-operating partner in feature extraction and data fusion algorithms. On the user side, both the Geological Survey of Norway and the Institute of Marine Research has participated to evaluate the software and propose improvements. In addition, they have collected field data as well as selected representative seafloor samples, and ground-truthed the corresponding classes. Evaluation of the software has been done in areas of large seabed sediment variation. Backscatter mosaics generated by Poseidon software were far better than mosaic generated by other commercial products. The seabed classification using Triton has some clear limitations, but the product has been well received by FFI and other users, who are interested in large-scale mapping and classification. Both types of software have a user-friendly interface, but this is unfortunately not described in manuals and documentations. The work has focused on the limitations of automatic classification and methods for improving the software, and methods for automatic classification using multibeam backscatter.

2.   DATA ACQUISITION AND PROCESSING

2.1 Single beam echo sounder

FF Seisma was utilised for acquiring single beam echo sounder data (EA400) in two stages. A crew from NGU and Kongsberg-Simrad mobilised FF Seisma in Trondheim for a single day cruise in the summer of 2002. Data were also acquired on behalf of Kongsberg-Simrad in the autumn 2003 around Jøa, in an area with large sediment variation.

2.2 Multibeam echo sounder

Testing of the Triton software (Kongsberg-SIMRAD 2001, Huseby *et al*. 1993) was initiatily planned using data from the SulaReef, but the data from this area were abandoned due to strong noise generated during data acquisition (poorly calibrated sounders) and limited variation in seabed sediment types. In order to obtain better test results, data were acquired by FFI (the Norwegian Defence Research Institute) and NGU from four areas, located in Møre, around Jøa in Nord-Trøndelag, Røst Reef Complex and west of Harstad. These data were all acquired by EM 1002 mounted on H.U. Sverdrup II. The bathymetry was processed using Neptune by FFI, and backscatter data were processed using Poseidon before classification in Triton.

2.3 Ground truthing

Grab samples were acquired in all areas, both utilising H.U. Sverdrup II and R/V Seisma. Samples were analysed onboard by a geologist from NGU, while samples of special interest were analysed at the NGU laboratory to determine grain size, organic content and carbonate content (NGU 2002, 2003 and Longva *et al*., 2003).

A free fall gravity penetrometer (STING) was used in the Møre area to measure hardness and homogeneity of the seabed sediments.

A specially designed rig, with two cameras and a grab, was used in Møre and Jøa. Visual information was used to pin-point sediment boundaries, while sediment properties were determined from the recovered grab samples.

3.   RESULTS AND INTERPRETATIONS

3.1 Røst Reef Complex and Jøa

Data from the Røst Reef Complex were acquired for testing the possibility of using backscatter data for identification of coral reefs. Mounds considered as likely coral reefs were initially interpreted using the morphology from multibeam bathymetry (non-geogenic mound structures) and verified using ROV from the Institute of Marine Research. Coral reefs on the outermost part of the shelf at Røst have classic mound morphology and are frequently positioned along the iceberg plough marks, which make it possible to map morphology from multibeam bathymetry (Fig. 1a). Mound features with morphology similar to coral reefs were also found north of Jøa. These mounds are associated with low backscatter strength (Fig. 1b) unlike the high backscatter observed at both the Sula Reef and the Røst Reef Complex (Fig. 1b). ROV studies showed that sponges, with little or no corals, dominate these mounds.
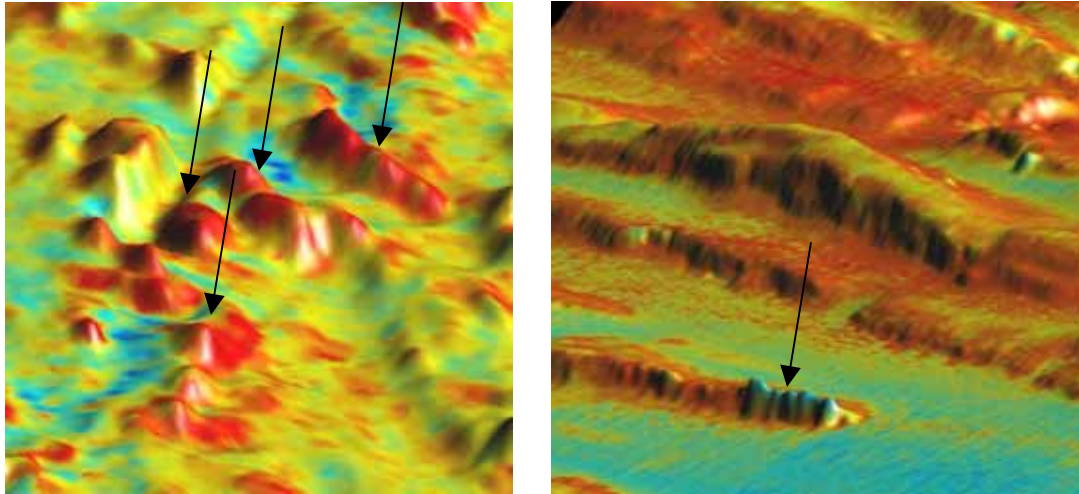
Figure 1. a) (left) Backscatter data draped on multibeam bathymetry terrain model, Røst Reef Complex. Coral mounds display high backscatter, marked by arrows. Multibeam backscatter data processed by Robert C. Courtney. Water depth between 290 and 310 metres. b) (right) Unprocessed backscatter draped over bathymetry, north of Jøa. Note mounds with low backscatter, marked by an arrow. The ridge is approximately 30 metres highs, with the shallow parts at a water depth of 140 metres.

Figure 2. Close-ups of sponges, up to 75 cm in diameter, that covers approximately 30% of the seafloor-mounds north of Jøa. These are believed to explain the extremely low backscatter response shown in Fig. 1bROV-pictures by Johanna Järnegren and Martin Ludvigsen, Trondheim Biological Station).

3.2 Møre

An area of approximately 38.1 km^2, covering parts of Nogvafjorden, Longvafjorden and Haramsfjorden, was surveyed by FFI using an EM1002 multibeam echo sounder in February 2002. This small area comprises numerous sediment types in water depths of 15-100 metres.

Multibeam backscatter data were processed by Poseidon and classified by Triton. The apparently "most sensible and geologically most correct" map was obtained using four classes

and heavy lateral filtering of the classification as shown in Fig. 3. The sediment properties of each class were determined by grab samples and penetrometer tests. Eighteen grabs and ten penetrometer tests were acquired over the area, following the multibeam acquisition.
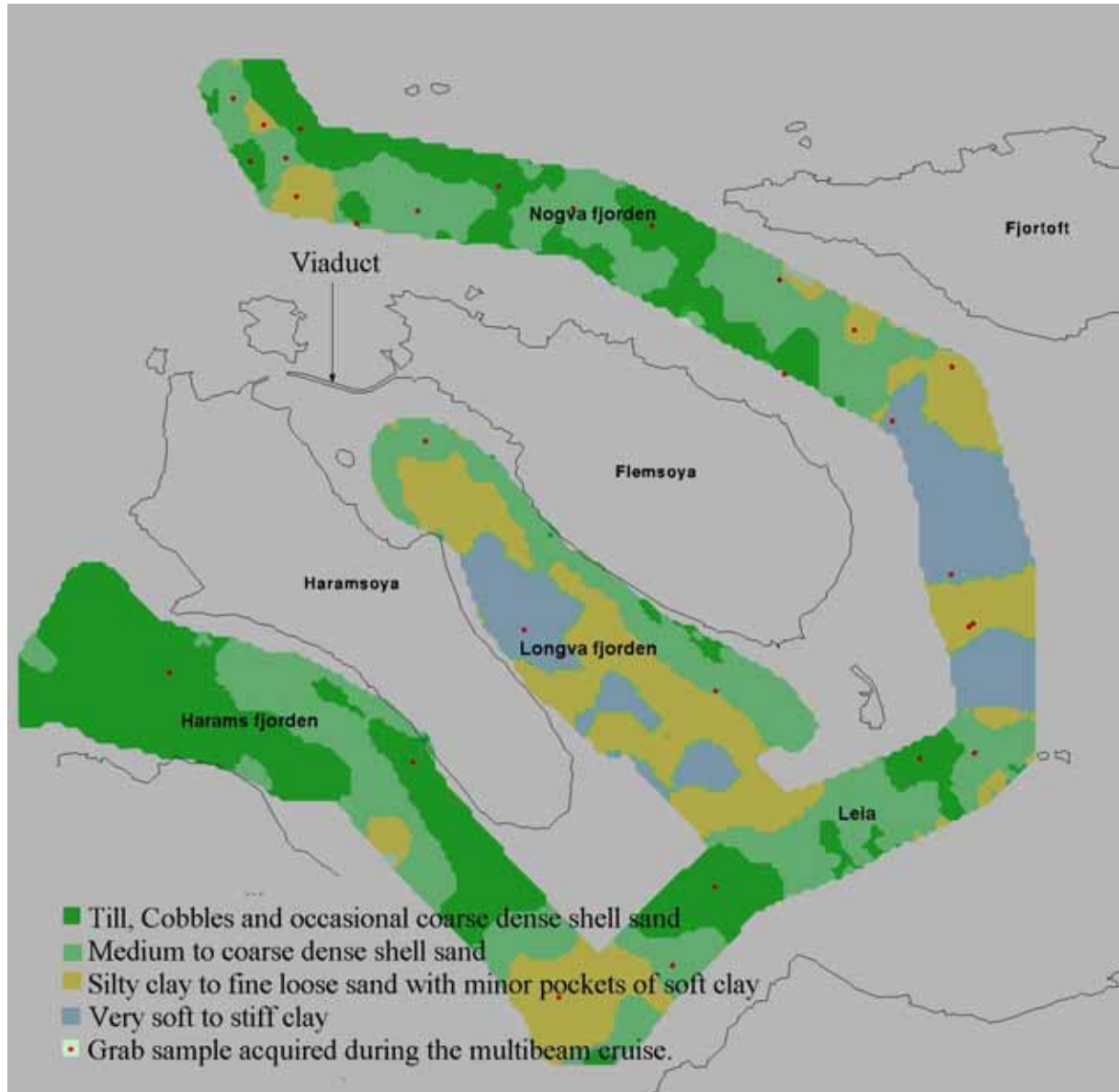

Figure 3. Triton generated classification map from Møret, with grab samples and
      penetrometer tests marked as red dots. The distance from east to west is ca. 15 km.

The sampling program was designed using the Triton generated classification map. Grab samples and penetrometer tests were positioned in the centre of acoustically uniform areas (Fig. 3). Grab samples and penetrometer tests did therefore not provide information on the location of sediment boundaries.

The location and shape of sediment boundaries generated by Triton were compared with a backscatter mosaic created by Poseidon (Fig. 4). Sediment boundaries were determined using

the backscatter strength. Mosaics generated in Poseidon were compared with the classification in Triton. Smoothing was not used in Poseidon, in order to maintain the maximum resolution. Triton is however merging data points into cells and thereby reducing the lateral resolution. This is necessary to perform the statistical analysis the classification is based on.
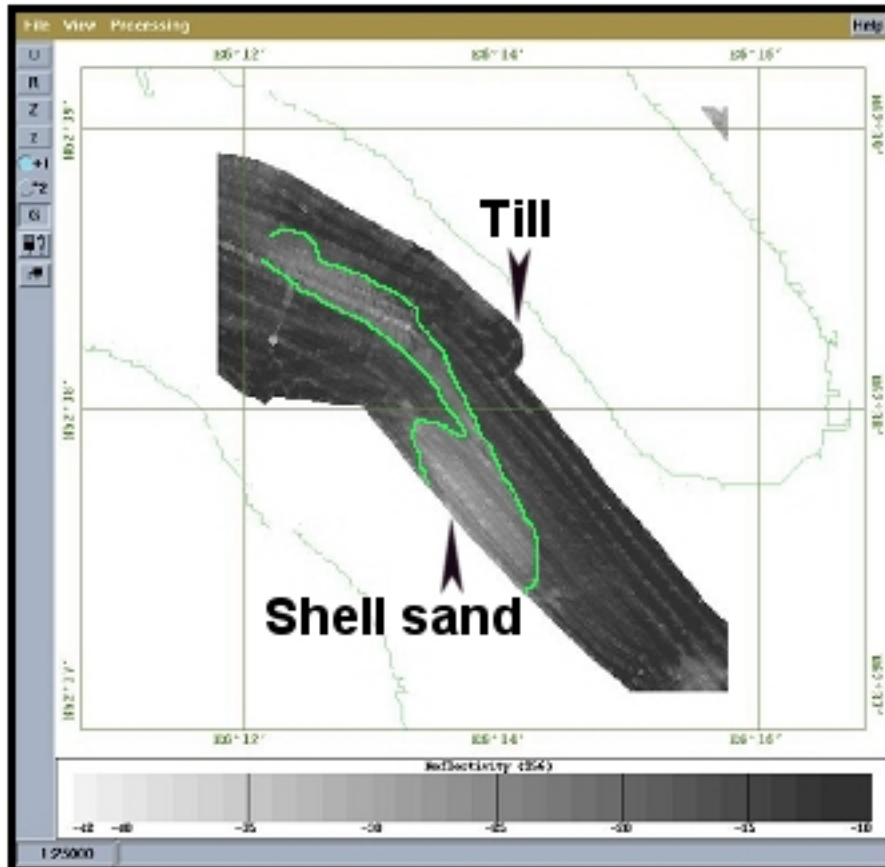
Figure 4. Multibeam backscatter mosaic created by Poseidon, from Haramsfjorden. The backscatter strength varies between - 45 dB and -10 dB. Manual interpretation of the Poseidon mosaic shows two clear sediment types. The areas of low backscatter strength (lighter areas), comprise shell sand on top of till. Areas of high backscatter strength (darker areas) are confirmed to comprise till.

The shell sand area marked on the Poseidon mosaic (Fig. 4) was also picked out by Triton, as shown in Fig. 3, even though the outline varies considerably. This was interpreted to be a possible effect of merging data points and lateral filtering performed in Triton. In order to test this, a second run with reduced filtering in Triton was performed (Fig. 5). This gave a better correlation between Triton sediment boundaries and the Poseidon mosaic boundaries, but also artefacts and more blocky sediment boundaries.

It is noteworthy that the reduction of filtering resulted in significant striping parallel to the survey lines in the softer sediment within Longvafjorden (Fig. 5). This is associated with acquisition/processing and is not related to the geological properties of the area.
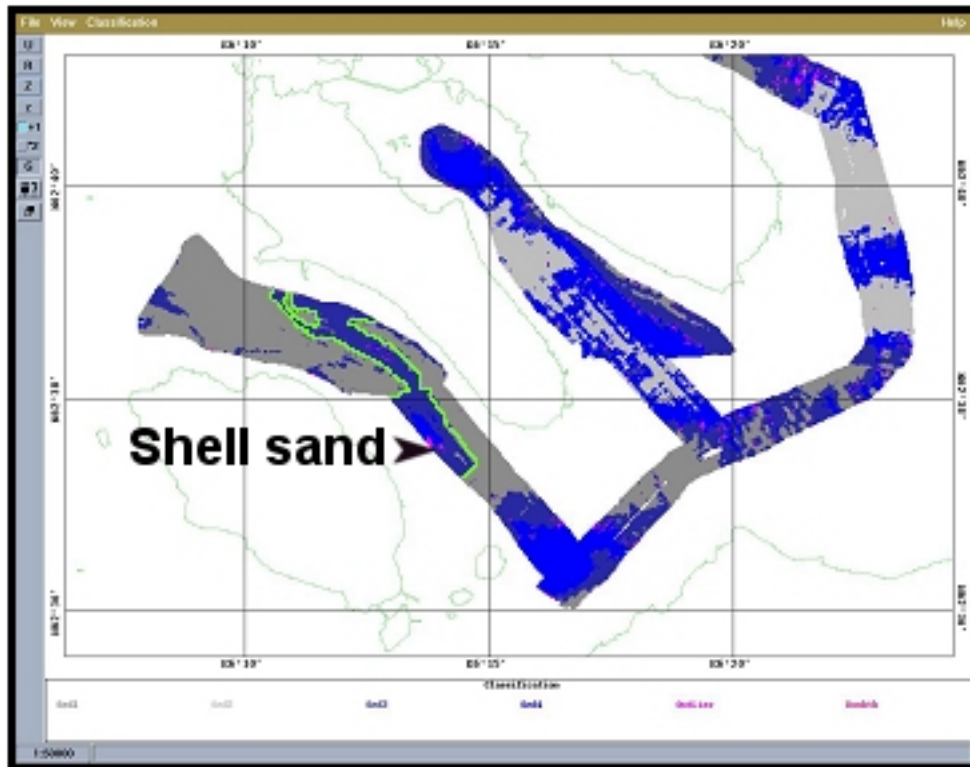

Figure 5. Screen dump from Triton, showing the southern part of the Møre area, with reduced lateral filters. The shell sand in Haramsfjorden is marked by dark blue and outlined by yellow. Also note the striping effect in Longvafjorden (the central fjord).

The striping is caused by the high backscatter strength at the centre of the beam. Poseidon was not capable of removing this effect, apparently because Poseidon normalised the backscatter using Lamberts Law. Lamberts Law is an optic approximation (Hansen 1967), and does therefore not take into account volume scattering or attenuation. Lamberts Law has been used successfully for deep-towed sonars, but these sonars obtain most of their useful data from grazing angles lower than the critical angle and therefore have only surface scattering contribution (Stanic *et al.* 1988, Stanic *et al.* 1989). Multibeam echo sounders receive the smallest part of the data from this domain and the main data from the domain where both volume and surface scattering contribute to the overall scattering strength. A minor part comes from the domain dominated by specular reflection. Among other effects, this results in high backscatter response from the nadir region (near normal incidence), dominating the backscatter more (Clarke Hughes *et al.* 1997). Furthermore, Lamberts Law can be used only as an approximation in sediments where scattering is caused by surface scatter, i.e. in harder

sediments. In soft sediments, volume scattering contributes significantly, and the method is not suitable.

The difference between sediment boundaries derived from the Poseidon mosaic and the Triton classification is not only explained by lateral filtering. In order to evaluate the effect of the reduced resolution in Triton, a manual interpretation was created for comparison (Fig. 6). This manual interpretation was based on all available data – morphology from bathymetry, raw backscatter data, grab samples, penetrometer and video profiles. The use of raw backscatter data was a result of the very limited export facilities within Poseidon, meaning that the raw data had to be imported into the manual seabed interpretation software (ArcGIS, ErMapper). Using the manual approach, it was possible to interpret ten different sediment classes. The higher resolution in this map allowed dredged till (anthropogenically re-deposited till, for construction purposes) in Longvafjorden to be distinguished from naturally deposited till.
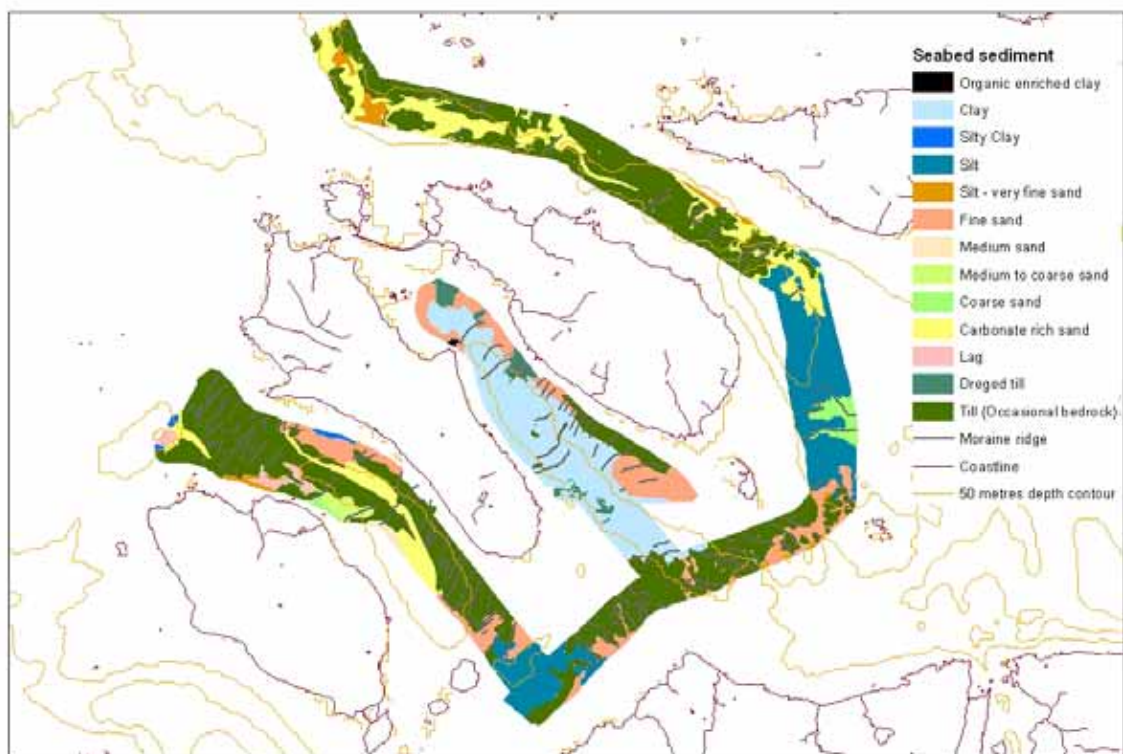
Figure 6. Geological map from Møre. Sediment boundaries were manually interpreted from unprocessed backscatter data, bathymetry and video inspection, while sediment classification was performed on the basis of grab samples, video inspection, penetration tests and acoustic analysis.

The shape of sediment boundaries is important in order to document the geological processes that have deposited the sediments. When these processes can be interpreted, it opens the possibility for determining the properties in a better way and to increase the number of sediment classes. As part of the software evaluation, a comparison between the Triton

generated sediment map, the sediment map generated from the Poseidon mosaic, and the manually interpreted sediment map was made (Fig. 7). This illustrates that Triton is not able to reproduce the sediment boundaries generated by manual interpretation nor is it able to match the resolution of the Poseidon mosaic. However, it is noteworthy that the grab samples showed consistent sediment types for the four Triton classes, meaning that Triton indeed is able to separate different sediments to a certain level (even though the algorithm fails to predict boundaries with the same precision as a manual interpretation).
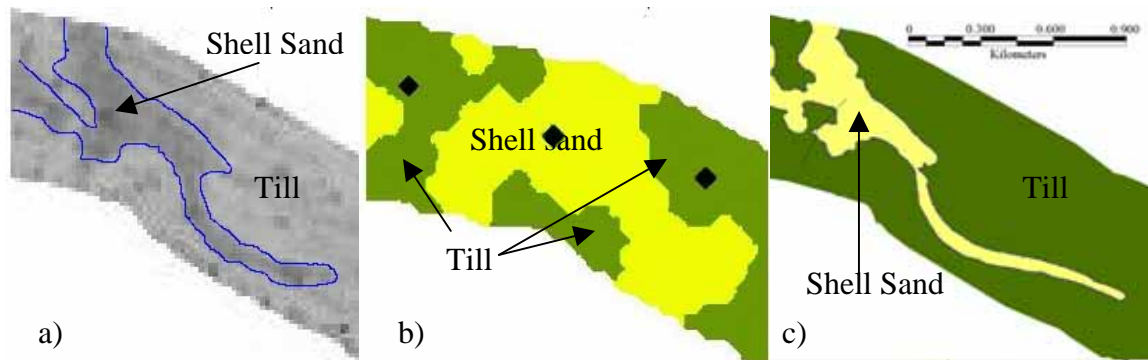
Figure 7. a) Poseidon mosaic, with confirmed shell sand inside blue polygon and till outside the polygon. b) Triton classification generated over the same area, with grab samples marked as black diamonds. c) Manual classification of the same area .

The likely explanation for Tritons poor ability to confidently estimate sediment boundaries is probably that it splits each swath into four sectors, rather than using all 111 beams. In contrast, in the manual interpretation, all beams were used to provide the backscatter mosaic, subsequently imported into the GIS system. The mosaics generated in Poseidon reveal smooth sediment boundaries (Fig. 8a), which are linear and blocky when classified in Triton (Figs. 8b and 8c). Using extensive smoothing filtering in Triton can smooth sediment boundaries, but this will also remove minor features. This is illustrated in Figs. 8b and 8c, where the increased filter size smoothens the sediment boundaries. The minor blue patch located in the pink area (Fig. 8b) disappears during the filtering (Fig. 8c).

Figure 8. Backscatter mosaic and automatic interpretation of a single multibeam line acquired using an EM1002. a) Backscatter mosaic created using Poseidon. b) Automatic interpretation using Triton and subsequently using a filter size of 5. c) Same interpretation as in b, but using a filter size of 15.

The merging of data points achieved by dividing the swath into four sectors is not described in Kongsberg-Simrad manuals. Each Triton pixel contains 4000 data points (pers. Comm. J. O. Bakke, Kongsberg-Simrad, 2005), meaning the along track merging is larger than the across track merging using a standard survey speed, open angle and sampling rate. Clearly, the method reduces the resolution of the resulting Triton maps, and an approach taking better care of the original resolution should be considered.

3.3 Jøa

Single beam echo sounder data were acquired around Jøa, as the seabed sediments comprise larger variation in this area. Data in raw format and high-resolution geological maps were provided to Kongsberg-Simrad.

Multibeam echo sounder data were acquired around Jøa to test the EM1002 multibeam backscatter depth dependency. The pulse length varies according to depth, using a 0.2 ms pulse length in water depth less than 200 metres, 0.7 ms in water depth between 200 and 600 metres and 2.0 ms for deeper waters (Hare 2001). The pulse length jumps are likely to improve the bathymetrical resolution, but these jumps effect backscatter mosaics (Preston *et al*. 2001). The frequency at a beam angle of 50º is problematic, but is not considered further as it is a system weakness with the EM1002.
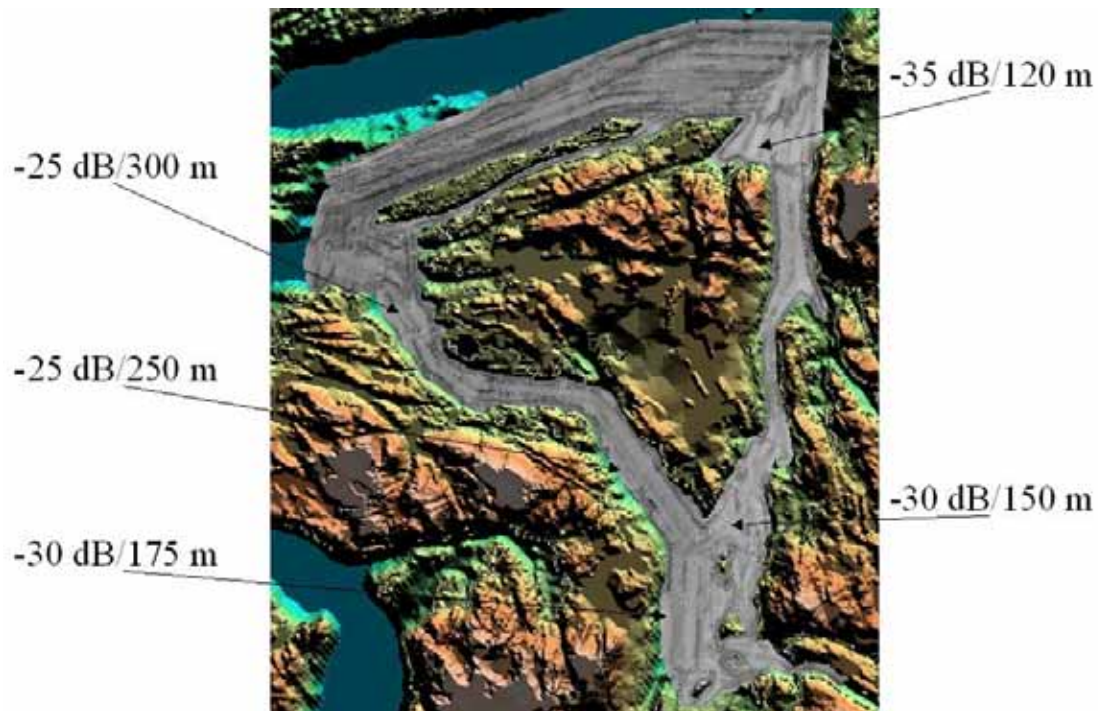
Figure 9. Unprocessed backscatter from Jøa. Five grab samples all comprised clay is marked by arrows. The average backscatter strengths were interpreted from an angle of approximately 45 degrees. The variation is believed to associate with water depth.

Triton software recognises the use of the three different pulse lengths, which might prevent incorrect classification caused by the depth dependency. This causes significant inconvenience when Triton generates sediment maps, as different pulse lengths can cause different interpretations (Fig. 9). Triton does not provide any function for merging these interpretations. The main problem is however to set up the automatic classification, which must be performed for each of the three pulses separately. The pulse lengths are a function of depth and therefore not overlapping, i.e. the classification boundaries have therefore to be set up without firm basis and the quality of correlation of the three areas is dependent on the ability to guess.

3.4 Histogram correction at Harstad and Møre

Histogram correction is described very shortly in the manuals - neither theory behind this function nor how this function affects the data is properly explained. This function has been tested for improving the Poseidon images, especially reducing the stripe effects. It was first tested on the data from Møre, which provided very limited or no improvements at all (Fig. 10).

Figure 10. Screen dump of backscatter mosaic from Møre. The histogram function has been applied two times, with a correction factor of 90%. The mosaic has a reflectivity between –60 dB to –5 dB. The stripe effect is present throughout the survey area, but is most prominent within the till area in Haramsfjorden, as shown. The area is approximately 5 km from east to west.

The disappointing results of the histogram correction might be due to incorrect use, but even so the function was tested on all acquired sites. Test on three newly acquired surveys around Harstad showed various results. A histogram correction of 80% on area 2503 produced some improvements (Fig. 11).

a)

b)
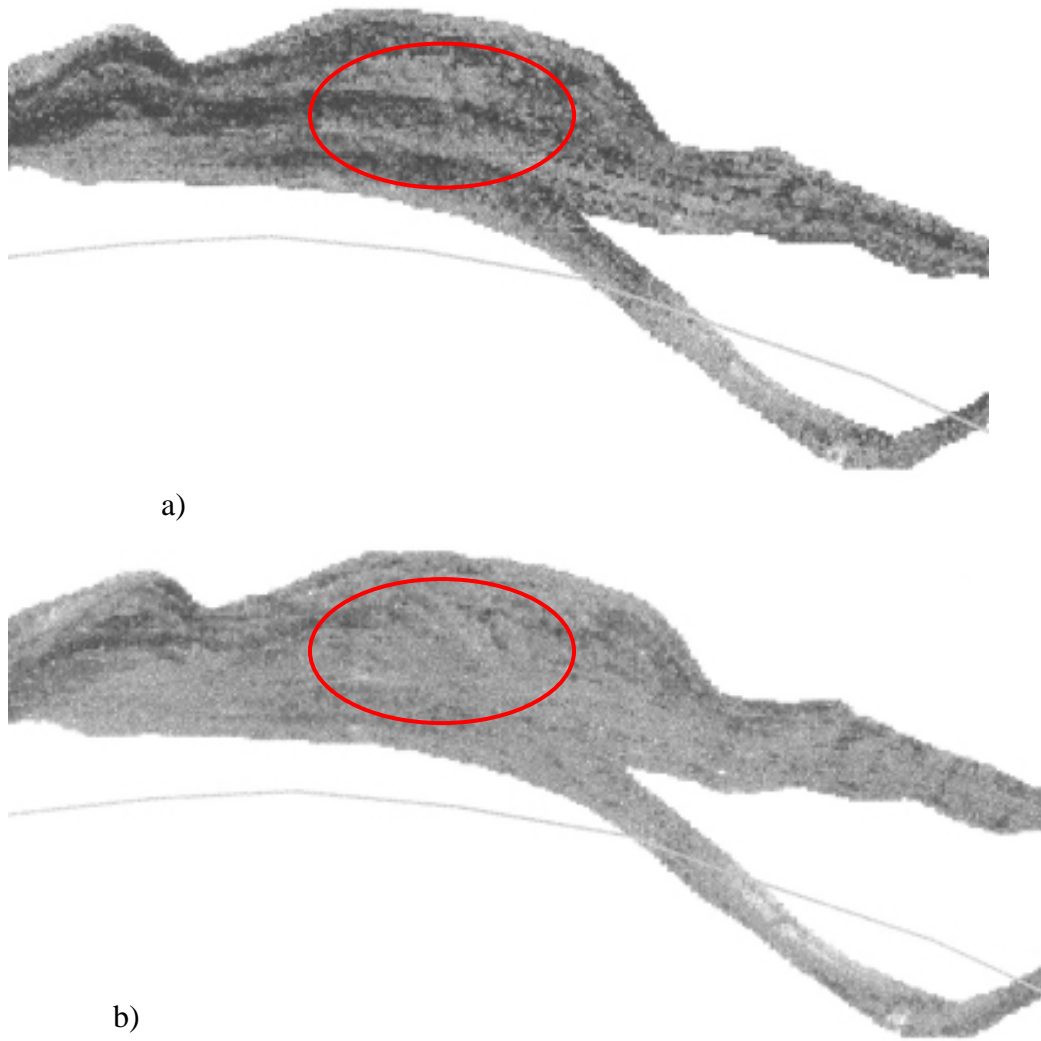
Figure 11. Backscatter mosaic of area 2503 created by Poseidon. a) No histogram correction, with clear striping effect in the central part of the survey area, marked with a red circle. B) The same survey using a histogram correction of 80%, which not only removed some of the striping effect in the central survey area, but also improved the resolution. The shown area is approximately 5 km from east to west.

In this case, there is a clear improvement of the mosaic after applying histogram correction. Even so, further tests were carried out, first in areas of soft sediments, where earlier results have shown the poorest quality due to this effect. The seabed sediments at the second site (area 2403) comprise both soft and hard sediments. The histogram correction was applied three times, with varying results. In the northern part of the area, where the seabed comprises mainly hard sediments, a clear improvement was achieved (Figs. 12a, b, c). In the southern part of the area, where the seafloor comprises soft sediments, the histogram did not improve the mosaic (Figs. 12d, e, f).
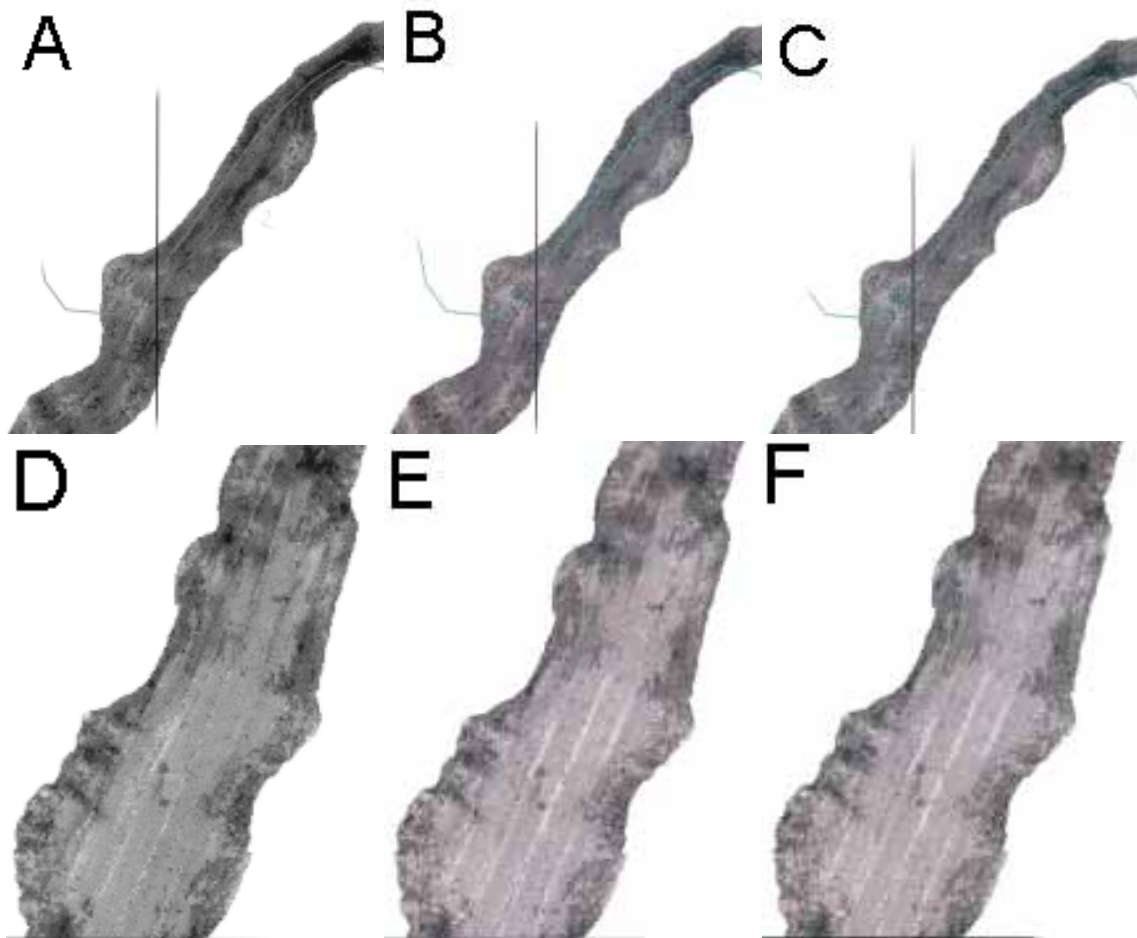
15

Figure 12. Poseidon generated backscatter mosaic from area 2403 comprising a reflectivity between -39 dB to -5dB. A, B and C) show the Poseidon mosaics from the northern part of the area. A) No histogram correction applied, B) histogram correction of 90% applied twice and C) histogram correction of 90% applied three times. D, E and F) show the Poseidon mosaics from the southern area. D) No histogram correction applied, E) histogram correction of 90% applied twice and F) histogram correction of 90% applied three times. Each of the shown areas is approximately 7 km north-south.

Tests from these two areas show some improvements using the histogram correction. Neither of the tests provided a result that could provide a basis for a high-resolution automatic classification, as the striping effect is clearly present. The best mosaic achieved using Poseidon is from area 2703, where the sediment boundaries are clear. It is possible to map four types of sediments by Poseidon (Fig. 13). The striping effect is still present, and is too strong to allow an automatic classification. If automatic classification should be used, the correction from angular response should be improved. However, correcting for angular dependence of backscatter intensity for building imagery of large, "multi-swath" areas is still not resolved (Parnum *et al*. 2004). Algorithms have been developed by Robert Courtney, Canada Geological Survey Atlantic, reduces the grazing effect so much that automatic classification on the basis of the normalised backscatter strength can segment the seafloor into

coarser geological classes (Christensen *et al*. 2005). Unlike the statistical approach, where data points are merged, this classification will maintain the lateral resolution.
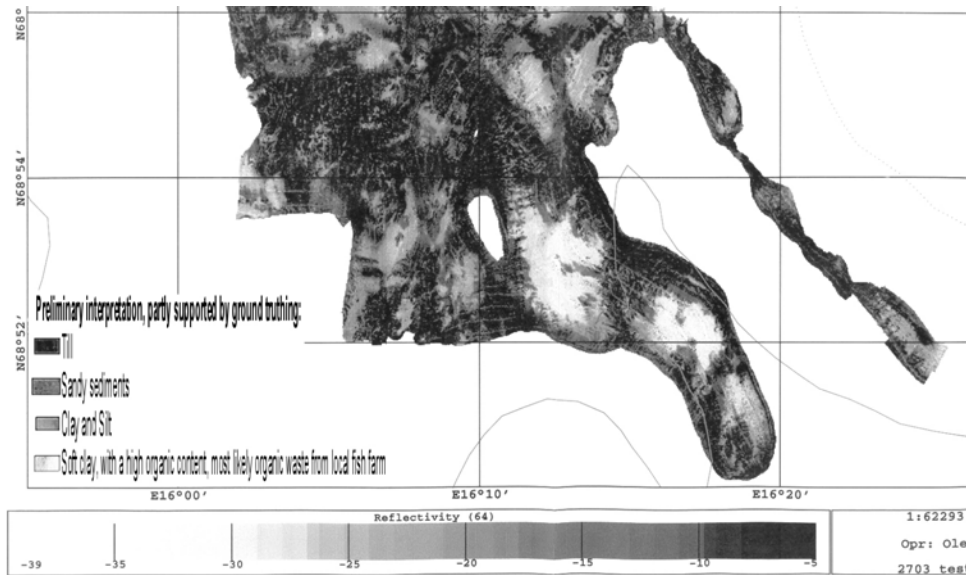
Figure 13, Poseidon mosaic from area 2703, created by using two times histogram correction. This plot illustrates the high resolution and the ability to differentiate very soft clay, clay, sand and till from backscatter data. The striping effect is clear, but this mosaic is a good basis for manual interpretation.

4.   CONCLUSIONS

This report lists numerous problems and poor experiences by using Poseidon and Triton for automatic sediment classification. However, it is important to note that other software, such as QTC, also has been tested (not documented in this report), and Poseidon/Triton perform significantly better.

For large-scale surveys, such as rapid environmental exercises, where minor details are of less importance, the Triton-generated classification was extremely useful.

Triton produces sediment maps with low resolution. Attention should be given to maintaining the original resolution in the backscatter data sets, both during processing and in the final products.

The normalisation of backscatter data in Poseidon using Lamberts Law is not satisfying, particularly not in soft sediments and near the Nadir Region. Improved backscatter normalisation will be a key to facilitate automatic classification.

The histogram correction function improved some of the Poseidon mosaics, while it had less effect on others. The best results were achieved in areas of hard sediments, while little or no effect was achieved in areas of soft sediments. Further analysis will have to be performed before final conclusions or recommendations can be drawn.

The manuals provide good guides for the software, but due to poor technical specification of functions, it is likely that people will used these results wrongly. Especially the reduced lateral resolution due to merging of data points as well as the lack of technical description of the filtering process should be addressed.

5.0   RECOMMENDATIONS

- There should be a function that enables the classification set-up to use one pulse length, or to convert to the other pulse length.
- The classification maps made in different pulse lengths should be merged together in Triton
- Both Poseidon and Triton should have better output functions, so that they can be used in other software.

Both Poseidon and Triton are very easy to use, but the manuals are very poor in explaining the procedures and techniques behind the functions. There should be a clear warning of the limitations of the software, preventing users from performing non-optimal analysis.

5. REFERENCES

Bunchuk, A., V. & Zhitkovskii, 1980: Sound scattering by the ocean bottom in shallow-water regions (review). Soviet Physical Acoustics, 26, 363-370.

Christensen, O., Fosså, J., H., Longva, O. et al. 2005: Multibeam backscatter classification of seafloor properties – examples using angular response on *e.g.* deep-water coral reefs, Paper for the F.O.R.T.H., Heraklion, Crete, June, 2005.

Clarke Hughes, J., E., Danforth, B., W., & Valentine, P. 1997: Areal seabed classification using Backscatter Angular Response at 95 kHz: In: Pace, N. G., Pouliquen E., Bergem, O. and Lyons, A. P. (eds.): High Frequency in Shallow water, NATO SACLANTCEN, conference proceedings series CP-45, 243-250.

Hansen, H., M. 1967: Lærebog I Fysik, Nyt Nordisk Forlag Arnold Busck, København, 760 pp.

Hare, R.: 2001: Error Budget Analysis for US Naval Ocenanographic Office (NAVOCEANO) Hydrographic Survey Systems. Final Report from Task 2, FY 01. Kongsberg Simrad, 2000. Operator Manual, Poseidon, Sonar mosaicing software. Horten Norway, 87 pp.

Huseby, R.B., Milvang, O., Solberg, A.S. & Bjerde, K.W.: 1993: Seabed classification from multibeam echosunder data using statistical methods. Proceedings, OCEANS '93, Victoria, Canada 18-21 Oct. 1993.

Kongsberg-SIMRAD 2001: Instruction Manual, Triton, Seafloor classification. Horten Norway, 62 pp.

Longva O., Christensen O., Dahl J. A. & Totland O. 2003. Hasut-prosjektet I Fosnes og Flatanger; djupner, seismikk, prøvetaking og video-opptak – toktrapport og tolkning av botntyper. NGU Rapport nr. 2003.095

NGU 2002: Analysekontrakt 2002.023 NGU, Sushimap Prosjektnr. 294400

NGU 2003a: Analysekontrakt 2003.0004, NGU, Sushimap Prosjektnr. 294400

Parnum, I.M., Siwabessy, P.J.W. & Gavrilov, A.N. 2004: Identification of seafloor habitats in coastal shelf waters using a multibeam echosounder. Proceedings of ACOUSTICS, 3-5 Nov 2004.

Preston, J., M., Christney, A., C., Bloomer, S., F. & Beaudet, I., L. 2001: Seabed Classification of Multibeam Sonar Images. Oceans 4, 2616-2623.

Stanic, S., Briggs, K., B., Fleischer, P., Ray, R., I. & Sawyer, W. B. 1988: Shallow-water high-frequency bottom scattering off Panama City, Florida. The Journal of the Acoustical Society of America, 83, 2134-2144.

Stanic, S., Briggs, K., B., Fleischer, P., Sawyer, W., B. & Ray, R., I. 1989: High-frequency acoustic backscattering from a coarse shell ocean bottom. The Journal of the Acoustical Society of America, 85, 125-136.