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REPORT

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Title:
Interpretation of exposed bedrock from regional bathymetry and swath bathymetry in the Havsul I-IV areas offshore Møre og Romsdal

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Summary:

Available information on bathymetry and seabed types has been compiled within the Havsul I-IV areas off Møre og Romsdal. Only a limited amount of detailed seabed information is available, and the main database for interpretation has been a regional, digital, bathymetric database with a grid size of 50x50 m. The main objective has been to interpret areas of exposed bedrock, as such information is of importance for the early planning for offshore wind energy parks.

Swath bathymetry (3x3 m grid) from the Havsul II area documents that both large and small areas of bedrock exposures occur. Some small areas also occur within Havsul IV. Both a manual interpretation of the regional 50x50 m grid and an automatic interpretation approach show that exposed bedrock occurs at water depths shallower than 30 m in several sub-areas. Detailed mapping will be necessary to confirm and determine the extent of bedrock exposures. Such mapping will also allow classification of sediments commonly occurring in the topographic lows between bedrock exposures.

The preliminary study carried out here shows that several sites suited for foundation of wind mills probably occur in the Havsul I-IV areas.

Keywords: Marine Geology	Seabed	Sediments
Bedrock	Windmill	Electricity
Power production	Bathymetry	Sedimentology

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1. INTRODUCTION

Havgul AS is planning for offshore wind energy parks in four areas (Havsul I-IV) off Møre og Romsdal (www.havsul.no) (Fig. 1). In the past few years, offshore wind parks have become an option that is considered in many countries, and parks have been/are constructed in Denmark, the United States, Great Britain and Germany. The planning and location of offshore wind mills is dependant, among other factors, on water depth and seabed substrate.

Havgul AS has contracted the Geological Survey of Norway (NGU) to compile available information on bathymetry and seabed types within the four areas. Only a limited amount of detailed seabed information is available. High-resolution seafloor mapping has been carried out in the projects Marmodell and Sushimap, but only a few short survey lines are within the Havsul I and II areas. Norsk Hydro ASA has acquired swath bathymetry along several pipeline route corridors in connection with the Ormen Lange gas terminal. Two of these corridors cross the Havsul II area and another a minor part of Havsul IV, and these data (3x3 m grid) have been interpreted and are presented.

A digital bathymetric data set (50x50 m grid) has been used for interpretation of bedrock exposures, but the interpretation from this database is much more uncertain. Two interpretation approaches have been carried out: a) Manual interpretation based on a shaded relief seafloor image of the 50x50 m grid (ER Mapper software), and b) an automatic feature extraction of bedrock, using an algorithm to define areas with positive topography. This algorithm is described in the report, and comparisons in areas with a detailed 3x3 m grid, give an idea of the quality of this parameter in areas of different morphology. Although both approaches are uncertain, we infer that the interpretation map of "areas with 5-50% bedrock exposures" will point to areas for more detailed investigations in the future.

The bathymetry (Maps 2005.016-01 and -02) and interpretations (Maps 2005.016-03 and -04) are presented on scale 1:50 000. In addition, short descriptions of the four areas will be given, mainly focusing on the likelihood for finding exposed bedrock at the seafloor.

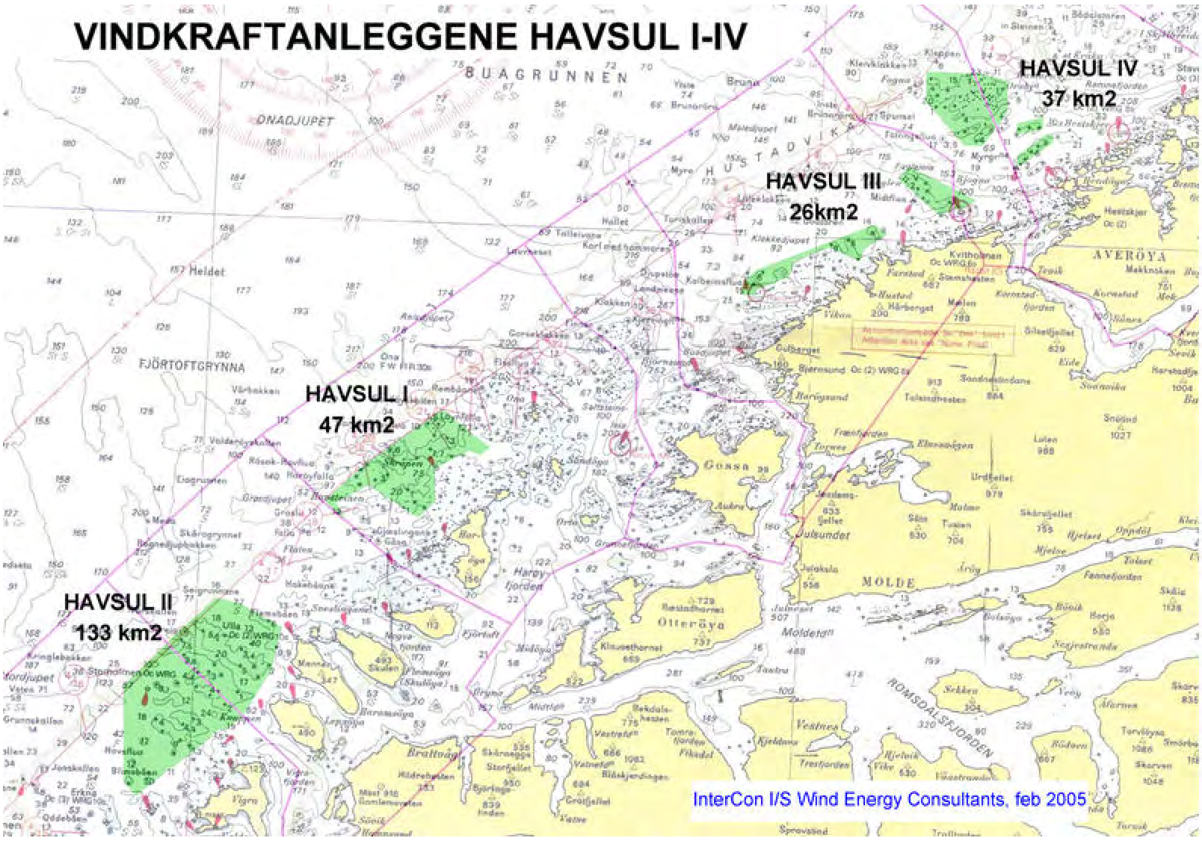

Figure 1. Map from www.havsul.no showing the locations of Havsul I-IV.

2. DATA AND METHODS

2.1 Regional bathymetry

The digital bathymetric database has been bought from the Norwegian Hydrographic Service (Maps 2005.016-01 and -02). The data (either depth contours or single data points) are digitised from hydrographic originals, mainly in the scale 1:20 000. Most of the bathymetric surveys were probably collected before GPS became common, and we have no information on navigation systems applied. Comparison of the regional and detailed bathymetry (data from Norsk Hydro within parts of Havsul II) indicates that a spatial deviation of up to 100 m may occur.

2.2 Seabed data from the projects Marmodell and Sushimap

In the projects Marmodell and Sushimap some minor areas were surveyed with GEOSWATH interferometric sonar, yielding detailed bathymetry (1x1 m grid) as well reflection amplitude data for interpretation of the substrate (hard, medium, soft). In some areas, seabed sampling and video inspection supplied additional data for interpretation control. Only a few survey lines occur within Havsul I and II, and these data contribute with limited information to the present project. The dark-shaded areas in Map 2005.016-03 represent either hard till, till with a surface lag of gravel/stones, or exposed bedrock

2.3 High-resolution swath bathymetry from Norsk Hydro (Havsul II)

Two, ca. 2-3 km wide corridors surveyed with swath bathymetry cross the Havsul II area (Map 2005.016-03). Due to confidentiality these data have been gridded to a 50 meters grid for charting, which causes a slight widening of the corridors (c. 50 m). Interpretation was however performed, using 3x3 m shaded relief seafloor image maps (ER-Mapper), based on a 3x3 m grid. These maps yield a very good definition of the seafloor, and areas of outcropping crystalline bedrock features are easily seen (Fig. 2).

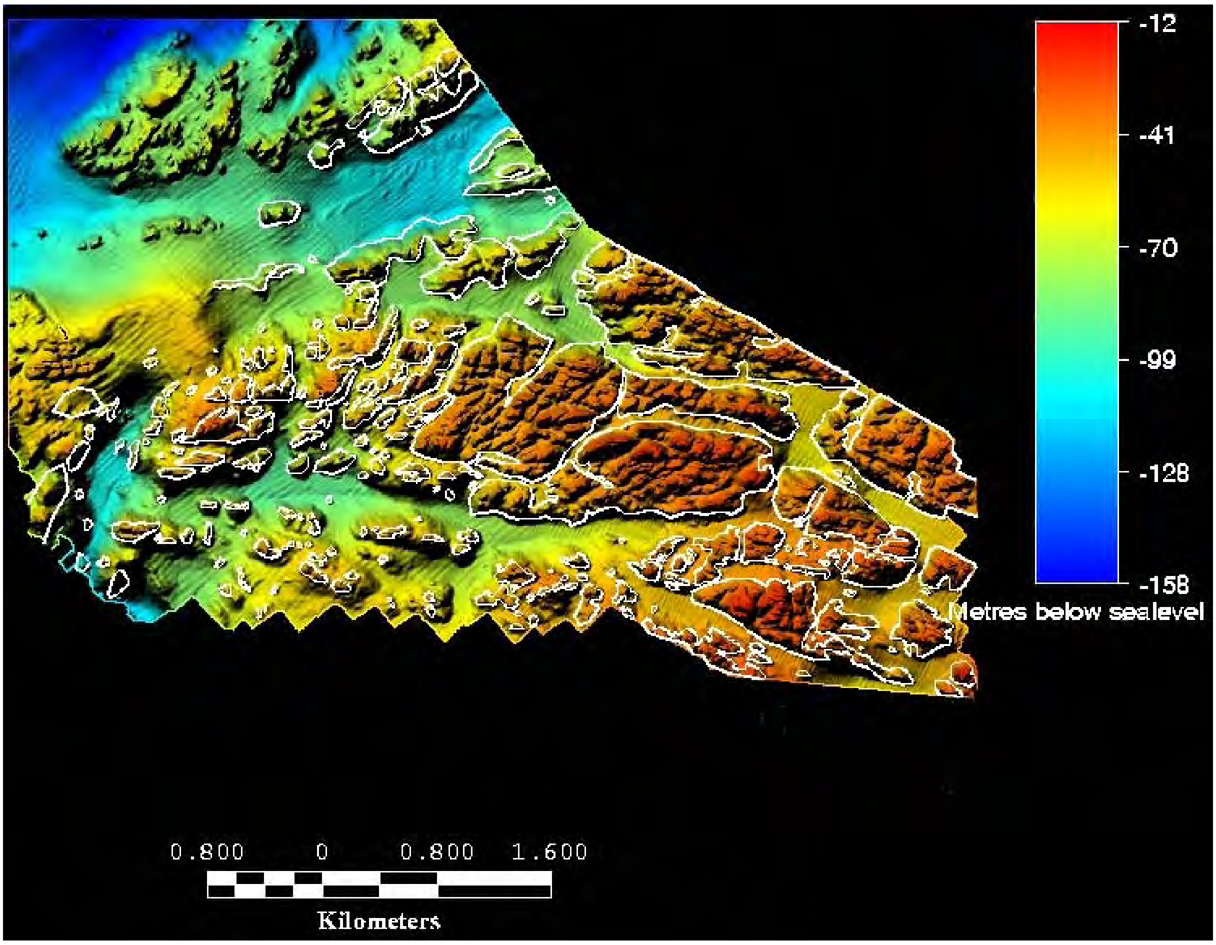

Figure 2. ER-mapper bathymetric image from the central part of Havsul II (3x3 m grid) with interpretation of outcropping bedrock (white polygons).

2.4 Manual interpretation of exposed bedrock

The shaded relief seafloor image map based on the 50x50 m grid gives a poor definition of the seafloor (Fig. 3), and comparison with the detailed interpretation (Fig. 2), show that manual interpretation underestimated the amount of outcropping bedrock. We chose a conservative manual interpretation, interpreting outcropping bedrock only where clear "positive structures" occurred. It is evident that that the real bedrock outcrop areas are at least three times larger than what is interpreted manually in Fig. 3.

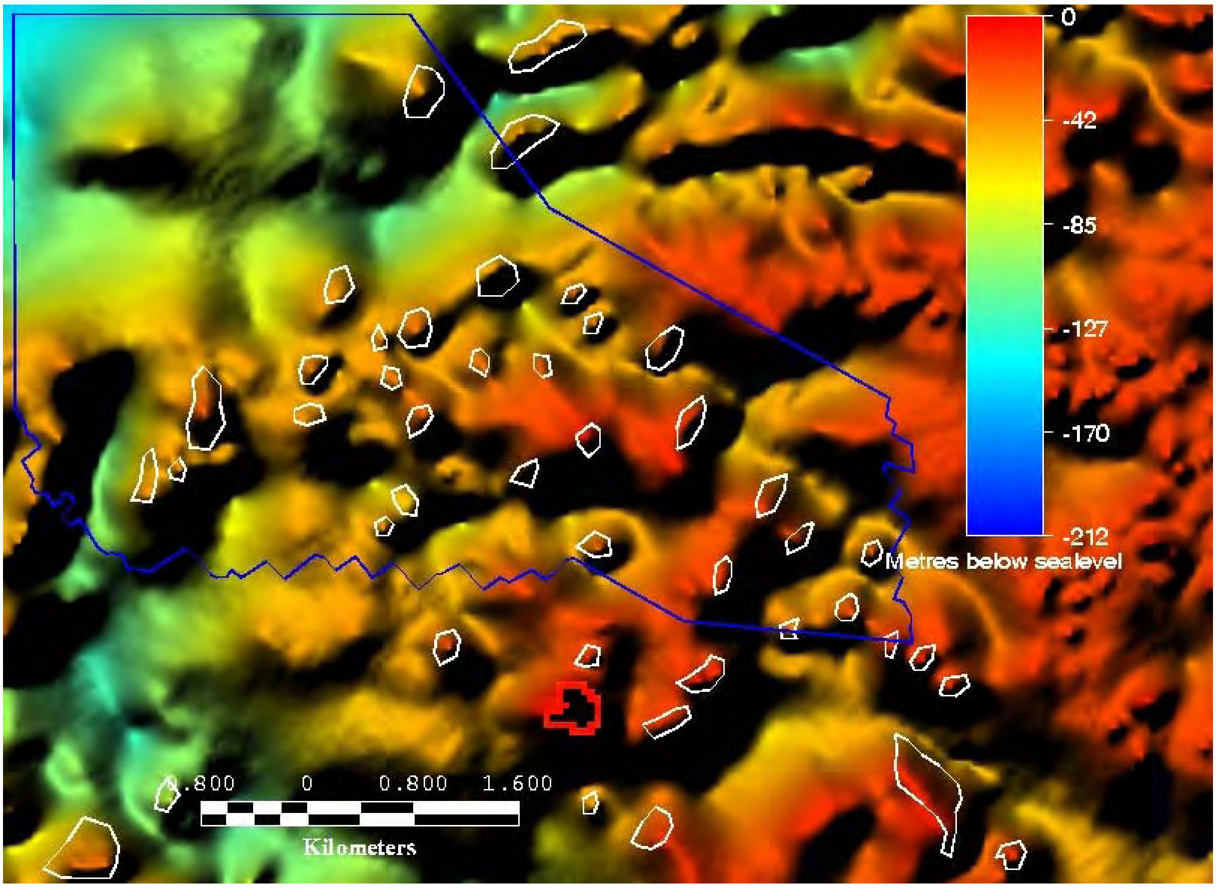

Figure 3. ER-mapper bathymetric image from the central part of Havsul II (50x50 m grid) with a conservative interpretation of outcropping bedrock (white polygons). Blue line shows the extent of the 3x3 m grid (Fig. 2).

2.5 Automatic interpretation based on terrain algorithms

We tested various algorithms in order to try to find the "best" automatic interpretation of outcropping bedrock from the 50x50 m grid. Calibration was carried out in the area of the Norsk Hydro 3x3 m grid (Havsul II area) in order to evaluate the best "interpretation approaches". The Terrain Elevation Index (TEI) appeared to give better correlation than the Terrain Ruggedness Index (TRI) for values of TEI>1 m. TEI is based on the difference between a central reading of the water depth and the average water depth within a chosen square. Various sizes of the square were applied (Fig. 4), from 3x3 pixels (150x150m) to 15x15 pixels (750x750m). The 3x3 and 5x5 pixel models underestimate areas of outcropping bedrock, particularly in large areas of bedrock exposure. The 15x15 pixel model gives possibly the best correlation in large areas of bedrock exposure, but appears also to include flat areas with a variable topography (inferred sediments deposited in depressions). The 7x7 and 10x10 pixel models appeared to give the best correlation (Fig. 4), and we applied the latter for map presentation (Maps 2005.016-03 and -04). From comparison with the 3x3 m reference area (Map 2005.016-03, Fig. 4), it is obvious that also this model automatically "map" both more and less rock outcrop than the "real". In large areas of bedrock exposure (Fig. 4), TEI>1 m underestimates the amount of exposed rock. From Map 2005.016-03, however, it appears to be more common that exposed bedrock occurs only locally within areas with TEI>1 m. The elevation model on a 500x500 m square must be regarded a tentative approach in order to find outcropping rocks. Within areas shallower than 30 m where TEI>1 m, we infer that there is commonly is between 5 and 50% of exposed bedrock. It is also obvious that the manual interpretation of outcropping bedrock, most commonly occurs within areas of TEI>1 m (Maps 2005.016-03 and -04).

Within the Norsk Hydro 3x3 m grid area, some small areas of bedrock exposure are mapped also in areas where TEI<1 m (Map 2005.016-03).

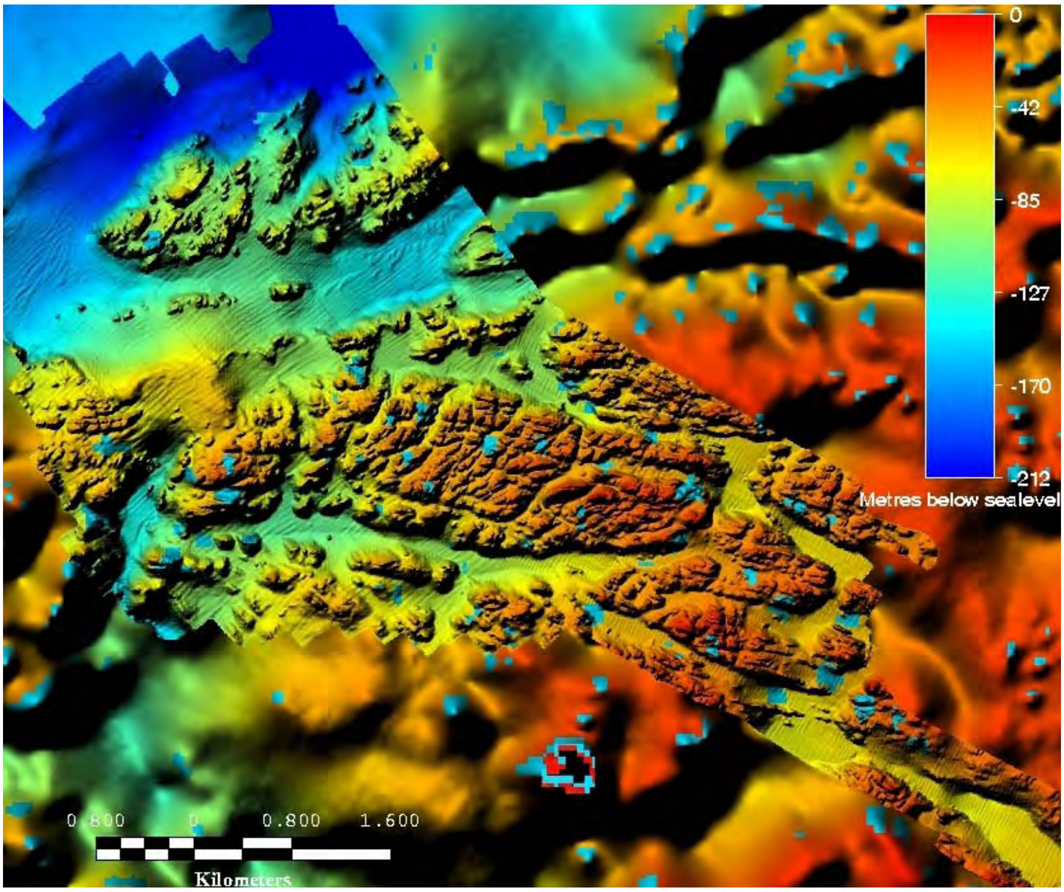

Figure 4a.

Figure 4. ER-mapper bathymetric images from the central part of Havsul II (central 3x3 m grid, else 50x50 m). Blue colour shows where the Terrain Elevation Index (TEI) is larger than 1 m. TEI is based on four different grid sizes: a) 3x3 pixel – 150x150 m; b) 7x7 pixel – 350x350 m; c) 10x10 pixel – 500x500 m; d) 15x15 pixel – 750x750 m. We applied 10x10 pixel for automatic interpretation of the regional 50x50 m grid (Maps 2005.016-03 and -04), and infer that between 5% and 50% of bedrock exposures commonly occur in areas where TEI is larger than 1m.

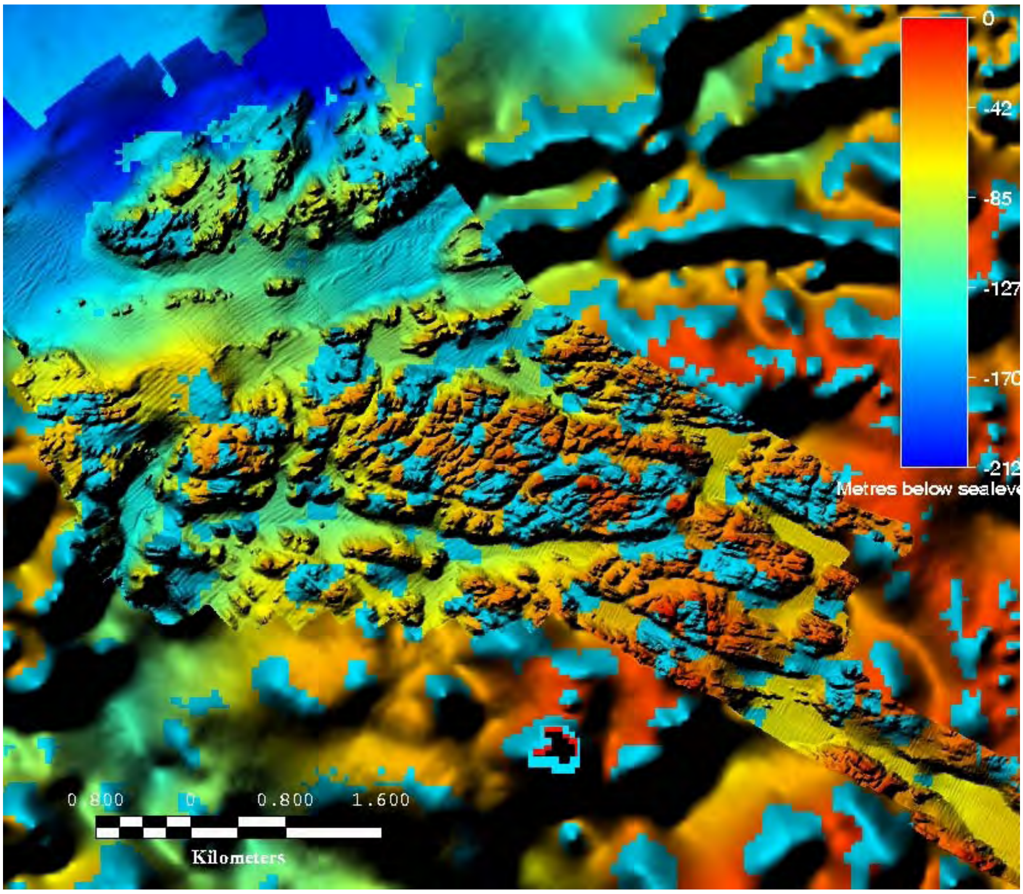

Figure 4b.

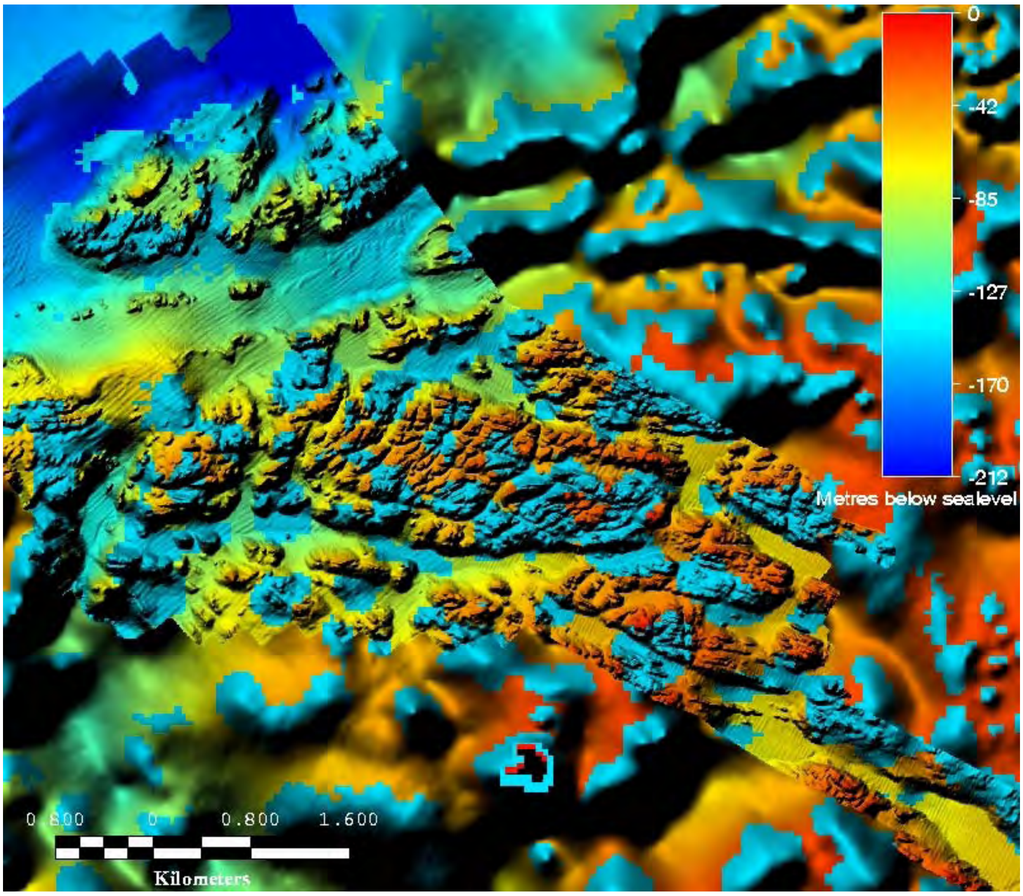

Figure 4c.

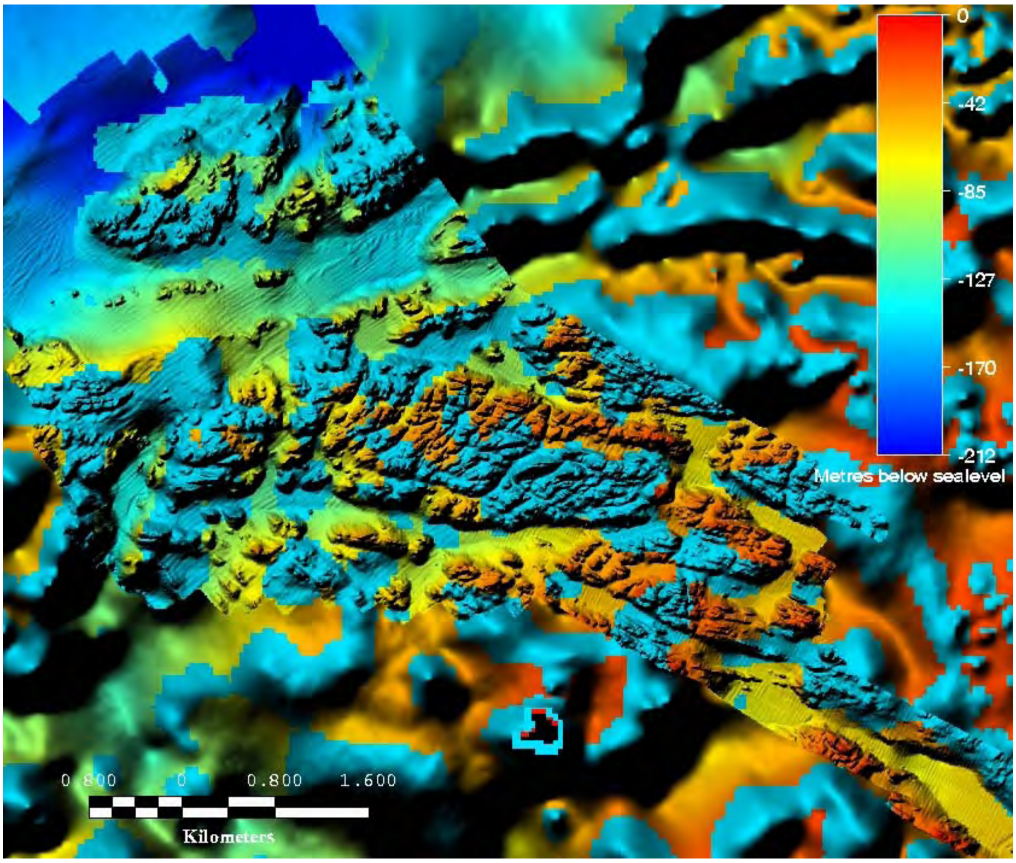

Figure 4d.

3. RESULTS

3.1 Havsul II (Maps 2005.016-01 and -03)

Approximately 1/3 of the Havsul II area has water depths shallower than 30 m, and areas shallower than 20 m extend up to ca. 10 km northwest of the islands (Map 2005.016-01). Norsk Hydro ASA has collected swath bathymetry in two 2-3 km wide corridors in the northern part of this area. A 3x3 m grid has yielded excellent seafloor images, and numerous small and several large areas of crystalline rock exposures have been mapped (Map 2005.016-03, Fig. 2). Most of the surveyed areas are deeper than 30 m, but large areas of rock exposures also occur at shallower water depth than 30 m in the outer part of Havsul II (southern survey corridor). Both manual interpretation of outcropping bedrock from the 50x50 m grid, and automatic interpretation based on the Terrain Elevation Index (TEI>1 m, indicating areas of positive topography), shows that many rock exposure areas occur in water depth shallower than 30 m (Map 2005.016-03). Several areas of exposed bedrock may be hundreds of meters wide, and some of these occur also in water depths shallower than 20 m (Map 2005.016-01). Some minor areas of exposed bedrock probably also occur in areas where TEI is less than 1 m.

3.2 Havsul I (Maps 2005.016-01 and -03)

Approximately 40% of the Havsul I area has water depths less than 30 m (Map 2005.016-01). Two short survey lines from the Marmodell and Sushimap projects occur in the northeastern corner of Havsul I, and three small areas of "hard sediments" (i.e. possible exposed bedrock) are found. Both the manual interpretation and the automatic interpretation from the 50x50 m grid (TEI>1 m) show that many locations of exposed bedrock occur at water depth shallower than 30 m (Map 2005.016-03). The manual interpretation indicates that the largest areas of exposed bedrock occur in the northernmost area. Some minor areas of exposed bedrock probably also occur in areas where TEI is less than 1 m.

In the area close to Ona Fyr, ca. 4 km north of Havsul I, high-resolution seafloor mapping have been carried out in the Marmodell and Sushimap projects (Bekkby et al. in prep). Here, exposed bedrock is mapped in several areas, which are up to 1 km long and several hundred meters wide. The Terrain Elevation Index (TEI) calculated from the 50x50 m grid, is commonly larger than 1 m in these areas (Map 2005.016-03).

3.3 Havsul III (Maps 2005.016-02 and -04)

The Havsul III comprises two areas, both ca. 5 km west of the mainland coastline. High resolution seafloor data do not exist in Havsul III. Approximately 30% of the southern area has water depth shallower than 30 m, and several areas there have TEI>1 m (Maps 2005.016-02 and -04). Exposed bedrock is interpreted manually in some small areas.

The likelihood for finding exposed bedrock is possibly even better in the northern area. Large areas have water depths between 10 m and 20 m, and nearly half of this area has TEI>1 m. Several small areas of exposed bedrock are interpreted manually, but we infer that areas of exposed bedrock are several times larger. Some minor areas of exposed bedrock probably also occur in areas where TEI is less than 1 m.

3.4 Havsul IV (Maps 2005.016-02 and -04)

Havsul IV is located northwest of Averøya, at water depth mainly less than 30 m (Map 2005.016-02). The main area extends more than 10 km from the mainland coastline. High-resolution seafloor data do not exist in Havsul IV. Both the manual and automatic interpretation (TEI>1 m) show that exposed bedrock is likely to occur in several areas (Map 2005.016-04). Some minor areas of exposed bedrock probably also occur in areas where TEI is less than 1 m.

4. CONCLUSIONS

Based on high-resolution swath bathymetry, exposed bedrock areas of varying size have been documented at the seabed within the Havsul II area.

Accurate interpretation of exposed bedrock from the regional bathymetric data set (50x50 m grid) is not possible. A conservative manual interpretation (Maps 2005.016.03 and -04), underestimates the amount of exposed bedrock. The best automatic approach to "map" bedrock appeares to be the Terrain Elevation Index (TEI), applied on a 500x500 m square (TEI = central depth reading minus the average of 99 surrounding depth readings). Areas with TEI>1 m have generally a positive topography, and we tentatively infer that 5-50% of these areas, where the water depth is less than 30 m, may contain exposed bedrock. In large areas of bedrock exposure, we have also seen that TEI>1 m may underestimate the amount of outcropping rocks (Fig. 4). The high-resolution bathymetric data show that small areas of bedrock exposures also occur where TEI is less than 1 m.

Based on the interpretations and our general knowledge of the seafloor in similar areas, we conclude that several sites are suited for cost-effective and safe foundation of wind mills with Havsul I-IV.

For an effective planning of a windmill park, and in order to secure a good communication with fisheries etc, we recommend detailed mapping of the most well-suited areas at an early stage.

5. REFERENCES

Bekkby et al. (in prep.): Effekten av skala og kriterier for inndeling i marine substrattyper. Paper to the journal "Vann".

N
W
E
S
Area of interest
30 metres contour
Depth below sealevel
>20 metres
10 - 20 metres
4 -10 metres
0 - 4 metres
HAVSUL I
HAVSUL II
AVERØY
GOSSA
FJØRTOFT
VIGRA
325000
330000
335000
340000
345000
350000
355000
360000
365000
370000
375000
HAVSUL I & II
1:50 000
Map1 of 4 (2005.016-1)
Bathymetry
WGS84 UTM32
Map based upon regional 50 metres grid


N
W
E
S
Area of interst
30 metres contour
Depth below sealevel
> 20 metres
10 - 20 metres
4 - 10 metres
0 - 4 metres
HAVSUL IV
HAVSUL III
HAVSUL I
AVERØY
GOSSA
VIGRA
HAVSUL III & IV
1:50 000
Map 2 of 4 (2005.016-2)
Bathymerty
WGS84 UTM32
Map based upon regional 50 metres grid


Area of interest
Area with 5 to 50% of exposed bedrock where water depth is less than 30 metres
Interpreted bedrock
30 metres contour
Interferometric data
Soft sediments
Hard sediments
Multibeam data (Norsk Hydro ASA)
Shallow
Deep
HAVSUL I
HAVSUL II
FJØRTOFT
VIGRA
N
W
E
S
HAVSUL I & II
1:50 000
Map 3 of 4 (2005.016-03)
Interpretation and data
WGS84 UTM32

Area of interest
Area with 5 to 50% of exposed bedrock where water depth is less than 30 metres
Interpreted bedrock
30 metres contour
Interferometric sonar data
Softer sediments
Harder sediments
Multibeam data (Norsk Hydro ASA)
Shallow
Deep
N
W
E
S
HAVSUL IV
HAVSUL III
AVERØY
370000
375000
380000
385000
390000
395000
400000
405000
410000
415000
420000
HAVSUL III & IV
Map 4 of 4 (2005.016-03)
1:50 000
Interpretation and data
WGS84 UTM32