Seabed Characterization - Developing Fit for Purpose Methodologies

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SUMMARY

We briefly describe three methods of seabed characterization which are 'fit for purpose', in that each approach is well suited to distinct objectives e.g. characterizing glacial geomorphology and shallow glacial geology vs. rapid prediction of seabed sediment distribution via geostatistics. The methods vary from manual 'expert' interpretation to increasingly automated and mathematically based models, each with their own attributes and limitations. We would note however that increasing automation and mathematical sophistication does not necessarily equate to improve map outputs, or reduce the time required to produce them. Judgements must be made to select methodologies which are most appropriate to the variables mapped, and according to the extent and presentation scale of final maps.

Introduction

Detailed and accurate mapping of seabed geology and habitats is important for a number of stakeholder groups including energy companies (*oil & gas as well as renewables*) who plan the emplacement and monitoring of seabed installations, policy groups who require environmental data for resource and conservation management, and academic researchers who aim to better understand the processes which initially formed, and actively influence those environments. Multibeam echosounder (MBES) (*swath bathymetry and backscatter*) data came into wide use over 20 years ago and serve as the baseline data layer for the production of these maps. Scientists have been active in applying new data processing techniques (e.g. Calder and Mayer, 2003; Brown and Blondel, 2009) and interpretation methods (e.g. Goff et al., 2004; Lark et al., 2012; Diesing et al., in press) to improve the resolution, accuracy, and repeatability of these interpretations of seabed character. Encouragingly, scientists have also been increasingly coordinating their efforts with user groups (e.g. Industry or Government partners) to apply methods and produce map outputs which are 'fit for purpose' (e.g. MAREMAP acoustic mapping workshop - http://www.maremap.ac.uk/index.html), mareano seabed workshop - http://www.ngu.no/upload/Arrangement/mareano_workshop_2012_programme.pdf).

Here we present three different interpretation techniques applied by scientists at the British Geological Survey to characterize different aspects of seabed geology intended for diverse user groups, exploring the benefits and limitations of each method. These include: 1) Using 'expert' (*manual*) interpretation to map the submarine glacial geomorphology around the Inner Hebrides, Scotland from MBES data, and informed by near-seamless stitching to terrestrial airborne radar data; 2) Applying unsupervised backscatter image classification using cluster analysis in combination with 'expert' interpretation to map the distribution of seabed sediments around the Inner Hebrides; and 3) Using geostatistical methods which employ co-registered MBES data and benthic grab samples to automatically predict seabed sediment distribution in the central North Sea.

Method 1: Submarine Glacial Geomorphology

Approximately 7,000 km² of new MBES bathymetry acquired by the Civil Hydrography Programme (CHP) on behalf of the UK's Maritime Coastguard Agency (MCA) have been stitched together with onshore airborne radar data, both gridded at 5m resolution, to map and describe the submarine glacial landscape of the Inner Hebrides sector of the former British-Irish Ice Sheet (BIIS) (Figure 1a). Mapping, via direct digitizing and building on the work of Howe et al. (2012), has revealed an extensive array of well-preserved glacigenic landforms on the seabed associated with key stages of ice flow and retreat of the BIIS following the Last Glacial Maximum. On multiple submarine rock platforms and within overdeepened troughs, diverse assemblages of glacially streamlined landforms are present, forming a geomorphic continuum between rock drumlins and mega-flutes (Figure 1b).

The availability of extensive and continuous high-resolution bathymetry data is providing unprecedented opportunities to map seabed geomorphology over broad scales, in this case over a sufficiently large area to understand flow dynamics at the ice-sheet scale. Terrestrial glacial geomorphology is a well established field which has drawn on field observations for at least one hundred years (see examples in Hubbard and Glasser, 2005). It has only been over the last two decades, however, that the principles could be adequately applied in a marine setting, where geophysical data have become sufficiently high resolution. Also, glacigenic features are often better preserved in a submarine setting as they have not been subject to millennia of subaerial erosion, and thus marine observations are critical for reconstructing the extent and flow dynamics of past glaciations (Ó Cofaigh, 2012).

Detailed geomorphological mapping over continuous bathymetric data is key for more a more nuanced characterization of the shallow geology in many parts of the UK, or any formerly glaciated margin where glaciation provides an extremely efficient mechanism for erosion and deposition over seasonal to millennial time scales. Geomorphology provides a window into past ice-sheet dynamics, and gives an improved framework for understanding the occurrence of shallow geological features and characteristics that effect the emplacement of any seabed installations including: overconsolidated sediments, glacitectonic structures, and channel systems. The high-res bathymetry data also give renewed value to legacy seismic data where seabed geomorphology may draw attention to previously undescribed sub-seabed features. By conducting this mapping in the Inner Hebrides we not only describe unique constraints on the past dynamics of the BIIS, but also provide a practical environmental baseline for the renewables and aquaculture industries within the region.

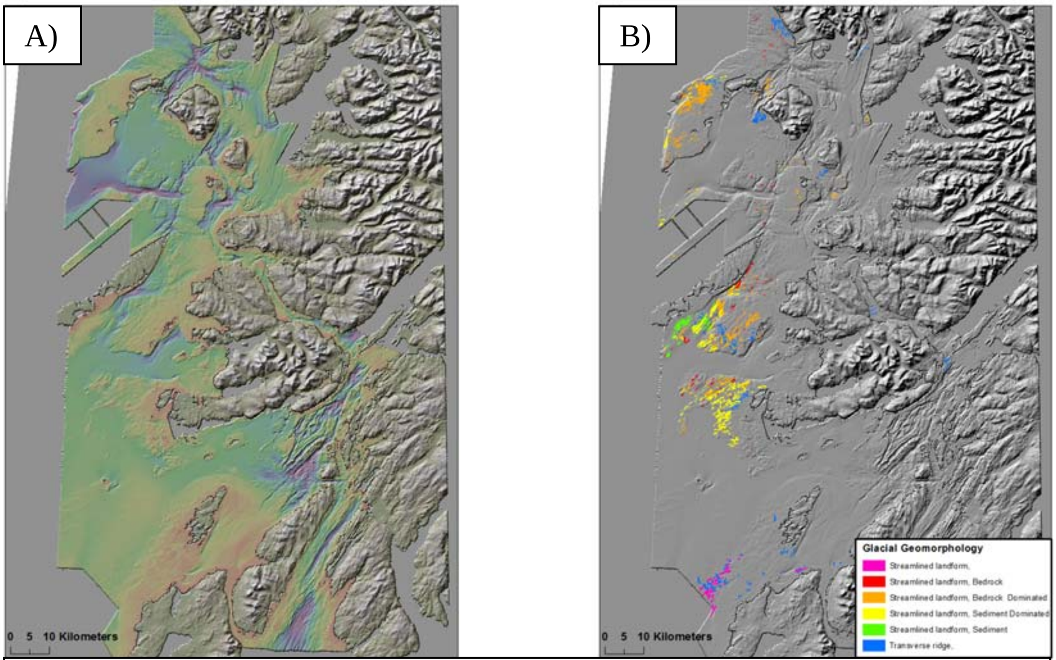

Figure 1a: Bathymetry and Topography of the Inner Hebrides Scotland. 1b: Preliminary Interpretation of Glacial Geomorphology. Bathymetry data provided courtesy of the Maritime & Coastguard Agency's UK Civil Hydrography Programme © Crown copyright. Terrestrial topography data derived from Intermap Technologies NEXTMap Britain elevation data.

Method 2: Iso unsupervised cluster analysis of backscatter data for seabed sediments

The process is a combination of two approaches, auto-classification (image analysis) and expert interpretation. The routine for auto-classification is flexible and dependent on site-specific data, allowing for application of a bespoke routine to maximize the acoustic data available. ArcGIS was used to perform an initial unsupervised classification on MBES backscatter imagery. The single band backscatter mosaic is filtered and smoothed prior to the application of an Iso cluster/maximum likelihood classification routine. Python scripting language is used to automate the workflow. This method is complimented by sense-checking this interpretation using 'expert' interpretation of MBES bathymetry and derived data layers e.g. rugosity.

Within BGS we've made good use of this method as it increases efficiency of mapping and reduces interpretation times for producing seabed sediment maps which underpin the habitat mapping effort ongoing in defining the UK's Marine Protected Areas (MPAs) (e.g. Green et al., In Press). The advantage of the method is that the auto-classification step completes the heavy lifting of producing internally consistent sediment boundary line work, but retains the role of the geologist to attribute and modify this line work according the bathymetry and knowledge of local seabed processes and sub-seabed geology.

Backscatter mosaics are down-sampled to a coarser resolution and focal statistics are used to populate the cell values of a new grid based on the mean of a user defined neighbourhood. The initial coarse resolution is an attempt to remove any 'striping'/noise while maintaining the general trend. The parameters used at this stage are totally reliant on the quality and resolution of the backscatter map available. Converting back to a finer resolution is essential for the production of smooth, realistic vector output.

The Iso cluster tool was chosen within ArcGIS 10.1 as it produced the best results from the single band image of backscatter intensity. The tool uses an iterative clustering procedure, also known as a migrating means technique, to find the natural groupings of cells and produce a signature file to be used as an input requirement for the maximum likelihood tool. The maximum likelihood classification tool uses the output signature file from the Iso cluster procedure to create a classified raster. The tool will consider the variance and co-variance of the class signature when assigning each cell to one of the classes. The classified raster obtained from the above steps is converted to a vector polygon shapefile to produce a final fully attributed, topologically clean, smooth vector dataset (Figure 2). The vectorised output of the semi-automated process is then reviewed manually to assign sediment classifications according to other data and a priori knowledge.

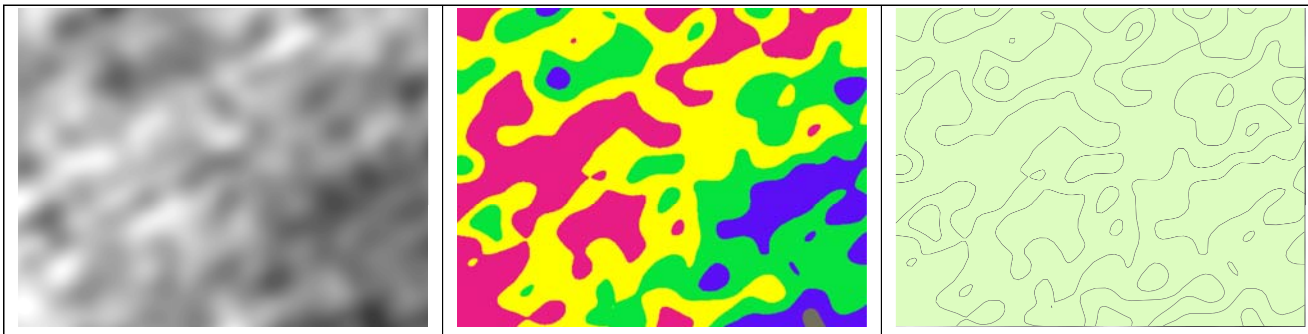

Figure 2: Semi-automated classification: Generalized sequence.

Method 3: Geostatistical methods

It has already been shown (Lark et al., 2012) how geostatistical methods can be used to make local predictions of the textural composition of seabed sediments by compositional cokriging. The proportions of gravel, sand and mud constitute a three-part composition. This is transformed to two additive log ratios which can then be treated as coregionalized random variables and predicted by cokriging (Pawlowsky Glahn and Olea, 2004). By sampling from the joint prediction distribution of the two log ratios at each prediction site one may compute a probability that the sediment at that site corresponds to a particular texture class. From this one may identify the most probable class, and quantify the uncertainty in any decision that is based on the predicted class at that site.

We extended this approach to incorporate acoustic MBES data, in this case within the central North Sea. Bivariate linear mixed models were fitted for the additive log ratios with the joint mean either a constant vector or expressed as a function of either bathymetry or backscatter or both, and the residuals from the fitted means modelled as linearly coregionalized random variables (Marchant and Lark, 2007). Such a model can be used for prediction, which combines a regression-type prediction from the geophysical variable and a cokriging-type prediction of the residual component. Comparison of the models on likelihood ratios showed that both bathymetry and backscatter should be included in the model. The model with both predictors was then cross-validated, as was the model with a constant mean (acoustic data not used). The cross-validation comprised of using the fitted models to predict each observation in the data set in turn, from all the other data. The cross-validation prediction distributions were sampled, as described above. The most probable class, according to this distribution, corresponded to the observed class in 65 % of cases, by comparison with 58% of cases when the acoustic data were not used. Random allocation of sites to classes in proportion to their marginal frequency would give correct allocations in 31% of cases. This shows that the MBES data improve the prediction of sediment texture classes and that the linear mixed models are an effective way to do this.

This method enables the practitioner to readily assess multiple classification schemes for characterizing seabed sediment distribution. An example where this is useful is in habitat mapping, for determining the relative success of different classification schemes in predicting the distribution of benthos. The method provides an unbiased approach to sediment mapping providing intrinsic confidence assessments, with clear advantages working over multiple survey areas and/or with time-series data.

Conclusions

We have briefly described three methods of seabed characterization which are 'fit for purpose', in that each approach is well suited to distinct objectives e.g. characterizing glacial geomorphology and shallow glacial geology vs. rapid prediction of seabed sediment distribution via geostatistics. The methods vary from manual 'expert' interpretation to increasingly automated and mathematically based models, each with their own attributes and limitations. We would note however that increasing automation and mathematical sophistication does not necessarily equate to improved map outputs, or reduce the time required to produce them. Judgements must be made to select methodologies which are most appropriate to the variables mapped, and according to the extent and presentation scale of final maps.

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