The Royal Society of Edinburgh
Marine Environmental Mapping Programme (MAREMAP)

Our Hidden Geology and Geomorphology:
Sea Bed Mapping in the 21st Century

Thursday 21 November 2013

Report by Jennifer Trueland

This was a joint event with MAREMAP partners: British Geological Survey (BGS), Scottish Association for Marine Science (SAMS) and the National Oceanography Centre (NOC)

Session 1 – Coastal Geology and Geomorphology
Chaired by Robert Gatiff, Director, Energy and Marine Geoscience, BGS

Dr Keith Westhead, Marine and Coastal Geologist, BGS

Pushing the Boundaries: Integrating Swath Bathymetry and Topographic Laserscan Data in Mapping the UK’s Coastal Zone

We are, said Dr Westhead, at the start of a new generation of producing offshore geological maps. We are learning more about the UK coastline all the time, and much effort is being made to extend that from onshore to offshore. Techniques such as swath bathymetry and airborne LIDAR technology are being used to survey the coast in greater and greater detail. The challenge, said Dr Westhead, is to interpret this observational data and use it to maximum effect. This could include answering new scientific questions, and could help in the effective management of the complex coastal zone.

Dr Westhead used geological mapping case studies to demonstrate the potential of this new generation of data. He described a Defra-funded coastal monitoring programme which aims to achieve 100 per cent seafloor coverage of the nearshore zone, to around one kilometre offshore. The data is being brought together with BGS data as part of MAREMAP. The aim is to get a seamless visualisation, whereby nearshore and offshore data are merged to form one digital elevation surface, using innovative techniques.

He showed a seamless elevation surface of an area of coastline in Bridport in West Dorset. The 3D map “lets us look at lots of geology”, he said, explaining that the Jurassic coast is being used to try to extend the mapping from offshore to onshore. The famous geologists of the past “would have been astonished to see what we see on the sea floor”, he said, adding that you get a “huge sequence of geology in a short distance”. The challenge is that different methods use different scales, and different datum systems, so getting the seamless visualisation involves ‘stitching’ them together. He described experimental mapping taking place in two areas of Dorset, where the idea is to build a seamless bedrock geological map across the coastal zone.

There are a number of benefits of improved coastal mapping. These include better marine special planning, better management of marine resources, better conservation of the marine environment, shoreline management and engineering, and the potential to do research into climate and landscape change. It also provides great opportunities for education on the coastal–marine environment.

He concluded by reiterating that the UK coastline is increasingly rich in observational data, which is allowing seamless visualisation across the coastal zone. New digital surveying technologies are enabling innovative uses of this data, and there is great potential for improved study and management of the UK coast.
During questions, Dr Westhead was asked how data was collected from depths of zero to one metre, and responded that boats were used when tide was high and LiDAR used at low tide. You take the best data, which tends to be bathymetry, and make it overlap.

Dr Christopher Vane, Head of Organic Geochemistry, BGS

*The Rise and Fall of Organic and Metal Contamination in Thames Estuary Sediments*

Londoners have been polluting the tidal parts of the River Thames for more than 1,800 years; this includes waste from industry and from human sewage. Studying sediments in the Thames Estuary and mapping their rise and fall gives valuable insight into the history of London and important information to aid river management. Dr Vane described work to show the distribution of persistent pollutants in Thames foreshore sediments covering a 102 km tidal stretch from Richmond to Maplin Sands.

The aims of the project are to improve understanding of sediment quality, establish a chronology, map organic contamination concentrations, map metal contamination, and benchmark the results against established criteria. The work involves taking samples of shallow core and analysing them – so far, more than 400 samples have been analysed. The reason why this is important is that pollutants can be toxic and, in some cases, carcinogenic to humans and to wildlife living in the Thames Estuary. It has been partly-funded by the Port of London Authority, which will use the results to, for example, inform decisions on dredging licensing.

There is a high tidal range in the Thames and “there’s lots going on”, said Dr Vane. There are obvious man-made structures which will have had an impact, such as the Thames Barrier, and chemicals deposited there change in accordance with the rise and fall of industries. “We can use them to make sense of what’s going on”, he said.

Dr Vane spoke in particular about three types of pollutant: total petrol hydrocarbons (TPH); polyaromatic hydrocarbons (PAH); and polychlorinated biphenyls (PCB). He also considered the rise and fall of metals including mercury. The results show the impact that the rise and fall of various industries have had on the Thames. For example, PCBs, used in capacitors and hydraulics, first went into production in 1929, and there was evidence in UK sediments in the 1940s. Peak production was in 1969, and there was a partial ban in the 1980s, which is reflected in sediment levels. Collecting the sediments is a “mucky job”, he said, but the analysis is fascinating. For example, lead levels in the Thames increased after lead was added to petrol, then a decrease was observed after it was banned. “It helps with chronology”, he added.

Most surveys look just at the top 10 cm, but you really need to look at the core to see what’s going on, and whilst many chemicals came from former gas works, there are a large number of other sources. Organotins, for example, were used in boats, but banned in the 1980s. “You can see the rise and fall”, he added.

Local knowledge can be key to understanding what’s going on, he said, adding that Cliffe was used as a weapons dump in World War Two, so there is lots of mercury. It’s important to know what sediments are present, and in what quantities, because then you can measure toxicity and decide when to take action on water quality. Sewage also has the dual benefit of telling us more about history and informing what we do today. Examination at a molecular level means that we can measure human faecal pollution dating back to the Roman occupation.

So far, the project has led to the conclusions that sediments show a clear rise and fall in organic contaminants, and that this needs to be viewed in the wider context of toxicity and river management. It’s important that the results are known both to the public and to those responsible for river management, he said.

Questions included how much the findings could be used to constrain development. Dr Vane said it should be fed into coastal and river management plans.
Session 2 – Sediment Mobility on the Shelf
Chaired by Dr John Howe, Head of the Biogeochemistry and Earth Science Department, SAMS

Dr Ken Games, Geophysical Director, Gardline Geosurvey Limited
Building on Substrates in the North Sea

Building or placing structures offshore is always going to be challenging. As well as coping with the weather, there’s a question of the mobility of the sea bed; this means that you can’t rely on a fixed platform. The oil and gas industry has many decades of experience in making this happen in an effective way, and has developed expertise in siting both platforms and a 30-inch pipeline, whilst controlling sea bed scour.

The burgeoning offshore windfarm industry faces many of the same challenges, magnified. The major difference is the number of turbines – rather than one or two fixed platforms and one pipeline, there can be several hundred turbines, and the 30-inch platform is being replaced with electrical cable. Some early developers chose badly when it came to siting windfarms, believing that it would be good to use sandbanks because they are closer to the surface. In one instance, sand movement meant they lost the cable.

Dr Games described two case studies. The first was a windfarm development off the UK east coast. A survey was first conducted in 2004 to provide detailed information on the bathymetry, sea bed morphology and obstructions and shallow geology in the survey area, using a variety of equipment including MBES (multi-beam echo sounders), side-scan sonar, boomer, and magnetometers. The second survey was carried out five years later to investigate a proposed cable route, and to assist in licence requirements for environmental monitoring.

The windfarm was split into two main areas, measuring 12x10 km and 9x5 km. Each was dominated by NNE/SSW sandbanks. The data from the surveys meant it was possible to find out how mobile the sands were over the five-year period. Getting the positioning right was crucial, so GPS measurements were augmented by physical observation of two fixed wrecks.

Whilst the position of the sandbanks had not changed significantly, the shape, particularly along the edges, had altered. The shape, position and orientation of the sandwaves had changed considerably. “You wouldn’t think it was the same area”, said Dr Games. Typical rate of migration were up to 70 m over five years, or 14 m per year, but this varied depending on the particular areas surveyed – up to 31 m per year in one place. The results are similar to the movement of barchans on land, but very little is known about migration rates of submarine barchans.

Dr Games said that the sand waves were clearly controlled by currents around the sandbanks, and that currents were predominantly in a clockwise rotation around the sandbanks and were greatest in the north and centre of the area. Behaviour of other features (which had become separated from the main sandbank area) were more extreme, so these should be taken into account; in particular when planning turbine positions.

The second case study, another windfarm development off the east coast, which was surveyed in 2007 and 2012, also showed significant migration of the whole sand wave field, generally to the south but with some local variation. Scouring around the turbines is very symmetrical – which wasn’t expected given the predominant current.

Dr Games concluded that there are regions in the southern North Sea where the mass movement of the surficial sands is significant. The oil and gas industry has successfully adopted ways of coping with this mobile sea bed and the windfarm industry faces similar challenges.

Questions included whether there is any correlation between the magnitude of the current and the magnitude of the movement. Dr Games said that work is ongoing.
The time is right to reassess what we know about the geology of the UK Continental Shelf, said Dr Dix. The last ten years or so have seen a step change in the amount of investigation and surveying taking place offshore; indeed, there has been a great deal done in the last 40 years. The old survey work stands up to scrutiny, but the detail obtained with multibeam bathymetry takes our understanding to a different level. The fresh volume of survey work in the last decade has been driven primarily by the offshore construction industry (for example, the renewables sector, including windfarms), the minerals industry and the civil hydrography programme. The volume of sea bed bathymetry and sub-surface geophysical and geological investigation has led to new datasets which, when combined with more traditional marine geophysical datasets, allow us to revisit fundamental questions associated with the Holocene evolution of the sedimentary environments on the UK Shelf.

Dr Dix said that his interest went beyond the sea bed to sub-bottom data, and welcomed the fact that more data, including core data was getting into the public domain. In this talk he concentrated on sandbank evolution. The amount of survey data available (though sometimes of variable quality) gives the opportunity to look at sandbank evolution on a whole-shelf, broad basis, but also more locally.

The aggregates industry has been producing data for a long time, he said, but there are now a growing number of surveys carried out for the windfarm industry. Pre- and post-construction surveys of what are large infrastructure projects are providing good data in this area – and all sectors are interested in sandbanks, or “mountains under the sea”. That might be because people want to build on them, or because they see them as a mineral resource. The new data can be usefully combined with ‘old’ information, for example, seismic data, to provide a fuller picture.

There is also an application closer to land – we can look at offshore sandbanks to predict what would happen at the shoreline, which could help with coastal defence. There has been a lot of work published on sandbanks and they have been subdivided and categorised according to factors including their position and shape. There is a range of different bank systems.

Dr Dix then described a survey of a wind farm area at Outer Gabard, which gave valuable insights into the magnitude and direction of sediment transport. This has many practical applications. What is interesting about this case study is the setting of the sand bank, he said, adding that it is 12 km in length (although he added that defining the length can be tricky). It is particularly interesting because it sits astride a palaeochannel system, he added.

Although many of his findings on sediment transport chime with those of Dr Games, Dr Dix is able to add some new information, including how the sediment is moving on the surface. Interestingly, the survey work shows that there is a stacking up of the sand waves.

In order to see how it ties in with hydrodynamics and sediment pathways on a regional scale, Dr Dix and colleagues modelled the UK Shelf. They pulled together information to look at, for example, how water would flow (variable roughness). As well as looking at what is happening now in terms of sand migration, we can also look at what happened in the past, using modelling based on all the available data. That means it is possible to model what was happening as the banks formed, he concluded.

Questions included why you get ‘rogue’ directions of sediment movement against the prevailing movement direction. Dr Dix said that it can’t really be explained, but it could be a slight difference of grain size, or changes over subtle threshold levels.
Session 3 – Quaternary Geology and Geomorphology
Chaired by Dr Russell Wynn, Head of Marine Geoscience and Chief Scientist, Marine Autonomous and Robotics Systems (MARS), NOC, University of Southampton

Dr Tom Bradwell, Quaternary Geologist, BGS
Ice Sheet Decay around Northern Scotland Recorded in Sea bed Geomorphology

These are exciting times for ice sheet research, said Dr Bradwell. The British–Irish Ice Sheet is well studied, but there is growing interest in ice sheet retreat rates in Britain and the rest of Europe. There are a number of important studies taking place, including the NERC Consortium Grant Britice–Chrono study (to collect and date material constraining the timing and rates of change of a collapsing marine-terminating ice sheet) and the GLANAM (Glaciated North Atlantic Margins) study, which aims to understand the evolution of the glaciated North Atlantic margins.

Dr Bradwell gave a short history of ice sheet research, mentioning in particular an influential 150-page article by Professor JK Charlesworth, which was published in the 1950s. This paper, on the late glacial history of the Highlands and islands of Scotland was a ‘monumental piece of work’, said Dr Bradwell, and still stands up today. Nowadays, however, we have access to much better data, from shelf-wide echosounder bathymetry.

“Access to futuristic digital datasets makes my job possible”, said Dr Bradwell, adding that the data give new insight into landscape and sea bed and the impact of ice sheet decay.

New mapping of the seafloor around northern Scotland reveals the detailed pattern of submarine glacial landforms, particularly moraines that were deposited by the ice sheet that covered Scotland during the Late Pleistocene period. The new data have tremendous possibilities. The new sea bed mapping is at a higher resolution over a wider area than ever before, and reveals the landscape and seascape in unprecedented detail. It also allows us to get more out of legacy data, and to test existing hypotheses. This, in turn, means we can develop better models.

Dr Bradwell spoke in particular about the West Shetland and Hebrides ice sheets, saying that although they have been well studied, he believes it is still possible to get more from the seismic data. “I’ve been doing geomorphological mapping, starting from first principles – you don’t want to make assumptions”, he said. Reconstruction of the ice sheet decay pattern shows the important role played by topography and bathymetry in governing ice sheet dynamics. There is a complex interplay between sea level, ice sheet retreat, mass balance and flow dynamics.

In conclusion, Dr Bradwell said that echosounder bathymetry is key to unravelling ice sheet retreat pattern and history, and that new interpretations of ice sheet decay have been possible, based on sea bed morphology. These new findings are consistent with the seismo-stratigraphic framework of the 1990s, and onshore mapping can be guided by offshore data and interpretations. However, chronology is needed to see whether the new model stands up or not.

But questions remain. For example, did the mountains of northwest Scotland deglaciate before the low ground? Did deglacial sea level rise cause ice sheet break up? And can these results inform modern ice sheet modelling?

Dr John Howe, Marine Geologist and Head of the Biogeochemistry and Earth Science Department, SAMS
Geology and Geomorphology of the Firth of Lorn

Recent and ongoing research is transforming our knowledge of the pattern of deglaciatiion in parts of the former British-Irish ice sheet, said Dr Howe. He described findings from the INIS Hydro programme (Ireland, Northern Ireland and Scotland Hydrographic Survey), which is part of a major 3.2 m-euro EU-funded INTERREG IVA Programme (which also
as funding from NERC, the Northern Lighthouse Board and the Maritime and Coastguard Agency).

The areas chosen for this ambitious hydrographic survey have high environmental significance, pose a risk to navigation, have implications for marine-based renewables, and for tourism, and are currently poorly surveyed. In Scotland, the areas chosen include 553 km$^2$ of the Firth of Lorn, covering the area from Oban to Scarba, with depths from two to 200 metres. This is being surveyed by SAMS.

Dr Howe presented results from a 120-day survey of the Firth of Lorn, which took place in 2012. The survey included the Corryvreckan whirlpool between Scabra and Jura. This was the first comprehensive bathymetric survey in this area, which is a predominantly bedrock-dominated sea bed, characterised by a series of narrow, fault-controlled troughs (part of the Great Glen Fault Complex). There is strong and well-preserved evidence of past glaciation, including moraines and overdeepened basins. Amongst other things, the survey found 20 wreck sites, with 13 new wrecks being identified, and also recorded 46 ‘Notices to Mariners’ (previously uncharted hazards).

The survey found that the Firth of Lorn is dominated by an exposed fault line with up to 170m high vertical expression, which extends for around 20 km. The Garvellachs contain the best-preserved section of Neoproterozoic glaciation in the world, and further sequences may be present offshore, Dr Howe said. Evidence for Quaternary glaciation is widespread, and moraines and glacial landforms are common. This is a dense area, and there’s lots of work still to do, he concluded, and it has potential to be of importance to a lot of fields, including industry.

 Asked about the next steps for the project, Dr Howe said the results would be published, probably in March 2014.

Dave Long, Team Leader of Marine Geohazards, BGS

*Shallow Geology and Marine Renewables*

Marine renewables – such as offshore windfarms, and tidal and wave energy – are a relatively new, but growing industry. Although four decades of oil and gas development in the North Sea have improved our understanding of the shallow offshore geology, the marine renewable industry requires a different type of information. There are differences between the oil and gas and marine renewables industries, with the latter working in different environments, and often occupying very large areas.

Although there are different forms of marine renewables development, all have their challenges. For example, although the idea of floating wind turbines might seem to avoid some of the hazards of having a fixed wind turbine (eg sand bank migration), you still need to have an anchor, and you still need the cable to bring the power back to shore. Similarly, tidal energy also requires an anchor and a means of exporting the resulting power. And although most wave power systems are floating, they also require shallow geological information for anchoring and for power export routes.

Marine renewable developments often cover large areas with multiple foundation locations, and are often in areas without previous detailed investigation. Frequently, said Dr Long, they are in areas that are difficult to survey. For example, an area chosen to be productive because of its strong current will inherently be difficult to survey – because of its strong current.

Dr Long said that what is needed is a geological model to understand the range of processes which have influenced the physical properties of the sea floor. This is particularly important when deciding where to site marine renewable developments, and also in working out what potential constraints might be. “It’s important to understand the geological history, and glaciation is just one part”, he said. “Lots of processes have had an impact on ground conditions”.


The sea floor is often active geologically, he said, with erosion, sedimentation and fluid and sand migration among the many potential hazards for developments. Sandbanks, shallow gas, sub-glacial channels, bedrock and landslides are potential problems. Modern survey techniques such as multibeam mapping and the on-going development of 3D high-resolution seismic will help visualisation of the sea floor geology and extend it into the sub-sea bed. This will help to inform foundation design.

Session 4 – Putting the Sea Bed to Work – News from the Deep
Chaired by Alan Stevenson, Marine Geology Team Leader, BGS

Dr Kerry Howell, Deep Sea Marine Ecologist, Plymouth University

Mapping the Deep: the Distribution of Vulnerable Marine Ecosystems in the NE Atlantic

Protecting vulnerable marine ecosystems (VMEs) is a conservation priority. A UN General Assembly resolution in 2006 called on all states to take steps to protect VMEs. But in order to design successful conservation management systems, you have to have a good idea of the distribution and extent of deep-sea habitat.

Predictive species distribution modelling techniques, which provide estimates of distribution and extent, are an essential pre-requisite for this to happen, said Dr Howell. The model, however, will only be as good as the information used to build it. By looking at what is known about habitats, you can predict the sorts of places where one is likely to be; likewise, you can predict where it is unlikely to be. “Absence data is also important”, she said.

In her talk, Dr Howell concentrated on cold-water coral reef, deep-sea sponge aggregations and xenophyophore aggregations. In trying to map where cold-water coral reef is likely to be found, factors such as temperature, sediment, hydrodynamics and topographical features are amongst those taken into account. For deep-sea sponge, factors include depth, proximity to areas of high bottom current and slope. For xenophyophore, factors include high carbon flux, proximity to topographical features and flat topography.

Looking for markers which can be used as surrogates for factors is also important. Cold-water coral reef tends to be found on rugged ground, at the top of a slope, in cold water, on bedrock, 900 metres below the surface of the sea, she said. To build the model you use distribution data, continuous layers of relevant environmental data and bathymetry data. But the model is only as good as the information used to create it. “Any fool can make a map, you really have to go and test it”, she said.

Dr Howell described a current piece of work to see if increased data resolution makes better maps. The researchers used a real-world scenario to investigate the effect of increased grid cell size on the modelled maps, measured by model performance, estimates of habitat extent, predicted spatial distribution and assessment of percentage of habitat protection. They made models of the predicted distribution of the three deep-sea habitats in UK and Irish waters, using either General Bathymetric Chart of the Ocean (GEBCO) bathymetry (coarse-scale grid) or multibeam bathymetry (fine-scale grid).

Results suggest that models built using fine-scale multibeam data perform better than those using coarse-scale GEBCO data. Estimates of habitat extent are variable and there are differences in predicted distribution of habitats between models built on coarse-scale and fine-scale grids. Estimates of the percentage area of each habitat protected by the existing Marine Protected Areas (MPA) network were lower when based on a coarse grid (as opposed to a fine grid) which has implications for marine environmental management.

Dr Howell concluded that predictively modelled maps, ideally made using high resolution multibeam, offer a way forward, but she warned: “We need to be a bit cautious; although the metrics may suggest that models perform well, we don’t have any real idea if they are any good. We need to go out and test them”.

In response to questions, she said that there are rarely resources available to test maps in the field. Maps “can look pretty”, but might not be any good.

**Dr Russell Wynn, Head of Marine Geoscience and Chief Scientist, Marine Autonomous and Robotics Systems (MARS), NOC, University of Southampton**

*New Techniques for Mapping Submarine Geohazards and Marine Protected Areas in the Deep Ocean*

Mapping and monitoring our marine environment is a large and growing problem for a number of reasons, ranging from policy drivers to environmental and economic change. Yet only around 40 per cent of the UK offshore is mapped at a resolution that is fit for purpose, said Dr Wynn. That creates the very real and current challenge of improving coverage to meet compelling need.

Marine autonomous and robotic systems (MARS) are revolutionising the way in which mapping and monitoring data are measured, he said. These include autonomous underwater vehicles (AUVs), submarine gliders, unmanned surface vehicles and remotely operated vehicles. NOC has 16 such vehicles, due to increase to 40 by the end of 2014/15, due to a £10 million investment over the next two years. Although the equipment is expensive, there is an economic and environmental justification for investing in it, he said.

In his talk, Dr Wynn described some recent scientific advances which have resulted from the use of AUVs and gliders, including in some very hostile environments. For example, he showcased innovative under-ice and deep-sea vent studies with Autosub AUV, adding that such dramatic projects provide great opportunities for outreach and education of the wider public. He cited projects ranging from investigating hydraulic jumps in sediment-laden density flows in the Black Sea to mapping and monitoring the impact of trawling on cold-water coral mounds.

New techniques also bring the opportunity of using AUVs to get high resolution photomosaics of the deep seafloor at 5,000 metres depth, creating the largest continuous deep-sea photo. He described the outputs from AUV surveys of the Haig Fras rMCZ (regional Marine Conservation Zone) off the southwest of the UK, where multibeam bathymetry and sidescan sonar data compares well with equivalent Cefas (Centre for Environment, Fisheries and Aquaculture Science) vessel-based data from the same area. The instrument collected valuable water column data and 15,000 full-colour seafloor photos, with the integrated dataset showing the vehicle’s potential for producing ground-truthed habitat maps. Importantly, the process will be repeated in 2014 to assess natural change. He also described shallow-water glider surveys over the Celtic Deep to monitor onset of density stratification and the phytoplankton response.

There is great potential for British industry in this field, said Dr Wynn. Customers include defence, Defra, science, oil and gas and offshore wind. Scientists are keen to engage with UK industry on this. There are cost benefits to using marine autonomous systems, he added, saying that Defra has found that the systems can collect data of evidence-based policy needs at lower costs than conventional platforms. Asked how reliable the equipment is, Dr Wynn said AUVs are very reliable, gliders less so.

Summing up at the end of the conference, *Dr Wynn* said that the key issues are where we want to be in ten years’ time. Amongst other things, he said it “would be nice” to have 100 per cent mapping of the UK offshore area; to have more examples of successful and comprehensive surveys, and a fit-for-purpose monitoring network. “I think it will be achievable but we need more people and organisations to get involved”, he concluded.

**Opinions expressed here do not necessarily represent the views of the RSE, nor of its Fellows**

The Royal Society of Edinburgh, Scotland’s National Academy, is Scottish Charity No. SC000470