Amplified Sediment waves in the Irish Sea (AmSedIS)

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Abstract

Exceptionally high, straight-crested and trochoidal sediment waves have recently been observed on shelf seas world-wide, and reach heights of up to 36 m in the Irish Sea. It is uncertain how the interplay between geological, biogeochemical and hydrodynamic processes influences the migration and extreme growth of these sediment waves. The AmSedIS project thus sets out to (1) investigate the role of sediment granulometry and sediment availability on both “extreme” and “normal” sediment wave development and (2) investigate the potential association of methane derived carbonate formation with extreme sediment wave growth. The preliminary findings are: (1) The crests of unusually high and trochoidal sediment waves still migrate over several meters per year and they consist of coarser, more poorly sorted sediments in comparison to the "normal" sediments waves; (2) Methane seepage is not considered a factor in extreme sediment wave development; (3) The excess of mobile sediment supply seems to allow for "extreme" sediment wave growth, and is linked to palaeo-tunnel valleys and the finer sediments that fill them or with converging sediment transport pathways; (4) The variation in sediment from sediment wave trough to crest to trough will form the basis for more advanced numerical modelling.

1. INTRODUCTION

Large sediment waves are striking yet poorly understood seabed features in many shelf seas. Very large sediment waves (3–18 m in height) are documented to migrate up to 70 m per year (over time scales >> the tidal period) in the Irish Sea (Van Landeghem et al., 2012). Such transport of enormous sediment volumes can endanger the stability of pylons, cables and pipes on and beneath the seabed and causes a highly mobile benthic habitat. In addition, straight-crested, trochoidal, symmetrical and unusually high sediment waves (>18 m) have recently been observed adjacent to “normal-sized” sediment waves on shelf seas world-wide (Barrie et al., 2009; Valentine et al., 2002; Van Landeghem et al., 2009) reaching heights up to 36 m in the Irish Sea and comprise over 1/3 of the water column. These immense sediment waves contrast in their cross sectional form with normally shaped sediment waves that have a gentle stoss slope and a steep lee slope. Figure 1 illustrates this contrast.

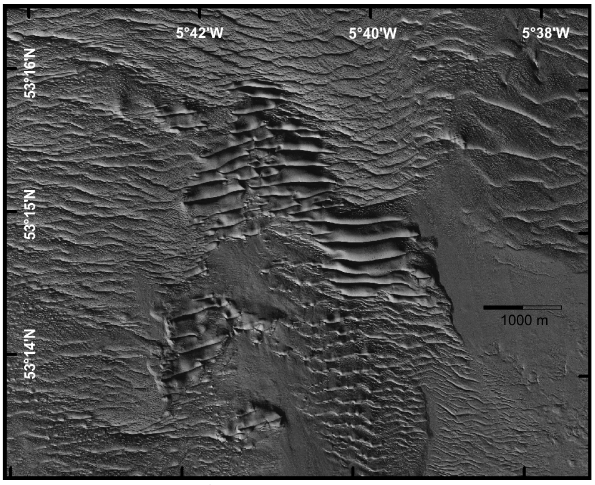

Figure 1. Pockets of straight-crested, trochoidal sediment waves amidst "normal" sediment waves. This data was collected by the INFOMAR project.

As part of the project AmSedIS (Amplified Sediment waves in the Irish Sea), a team of marine geoscientists, geochemists and numerical modellers from the UK, Italy, Switzerland and Ireland embarked on an 11-day survey on the RV Celtic Voyager in April 2012 to survey various sites in the Irish Sea (Fig. 2). The dataset collected includes swath bathymetry data, boomer and sparker seismic profiles, CTD transects, water sampling and Shipek grab sampling. Some bad luck stood in the way of collecting vibrocores.

Figure 2. Scientists and crew members on the RV Celtic Voyager about to collect data for the AmSedIS project.

1.1. Characteristics of sediment waves

From the relatively few studies on unusually high sediment waves, the suggestions thus far have been that they
(i) scale with water depth (Barrie et al., 2012),
(ii) are immobile and moribund (Van Landeghem et al., 2009),
(iii) are formed in response to the bi-directionality of tidal currents (Allen, 1980; Valentine et al., 2002; Van Landeghem et al., 2009),
(iv) are amplified as a result of gas seepage (Hovland, 1993; Judd et al., 2007),
(v) form due to standing internal waves from stratified water flowing across a step in the sea floor (Cartwright, 1959) and/or
(vi) represent differences in sediment grain sizes (Bartholdy et al., 2002; Valentine et al., 2002).

Unusually high sediment waves do not scale with water depth, they are not always associated with a step in the seafloor and they are still mobile with migration rates of up to 2 meters per year (Van Landeghem et al., 2009; 2012). The biogeochemical aspects of methane oxidation are complex and the causal link with sediment wave growth remains un-tested. To improve our understanding on the dynamics of these sediment waves, we thus investigate the effect of sediment grain size variability, mobile sediment supply and gas seepage.

1.2. Influence of sediment size and sorting on sediment wave dynamics

The sediment wave sizes are reported to increase with grain size until about 0.5 mm, after which they decrease (Dalrymple and Rhodes, 1995). This relationship has been further quantified (Bartholdy et al., 2002), but the correlations are likely site-specific and the question remains what the variation of grain size is within sediment waves. In unusually high sediment waves, the variation in grain size in the series of deposits within the bedform will influence its stability.

In sediments with mixed grain-sizes, coarser grains become more exposed to the near-bed currents, while the finer grains become hidden behind or in between large grains. This hiding-exposure effect alters the threshold of entrainment of differently sized sediment in a layer and will define which proportion is actively mobile (Van Oyen and Blondeaux, 2009), thus allowing sediment waves to grow larger. As mixed sediments are progressively sorted during sediment wave formation, this hiding-exposure effect is expected to change over time. Well-sorted sediment would accommodate faster growth rates. Poorly sorted sediment would dampen growth in weak tidal currents and strengthen it in strong currents (Van Oyen and Blondeaux, 2009). This time-dependent effect thus likely plays a more significant role in sediment wave dynamics than previously thought and is represented by the dimensions of sediment waves and the nature of the sediments inside them.

1.3. Influence of sediment availability on sediment wave dynamics

The infill of flooded landscapes scoured by glacial processes in the Irish Sea is expected to increase the amount of mobile sediment available for sediment wave formation. The spatial relationship of tunnel valleys and unusually high sediment waves has been documented tentatively (Van Landeghem et al., 2009), but is investigated further in this work.

In the Juan Fuca Strait (British Colombia), the occurrence of unusually high sediment waves is related to the entrapment of coarse sand in seafloor depressions (Barrie et al., 2009). These seafloor depressions occur in the Irish Sea as well, and so it is investigated whether these seafloor depressions host amplified sediment wave formation or if they are created subsequently from intensive scour around the huge sediment waves.

1.4. Influence of gas seepage on sediment wave dynamics

When methane migrates upwards through the sediment column (cold seeps), it may be oxidised with sulphate, leading to the precipitation of methane-derived authigenic carbonates (MDAC). These carbonate minerals cement the seabed sediments to a hard, rock-like structure. Cold seeps and the mechanism of methane oxidation has tentatively been linked to extreme sediment wave growth in the North Sea (Hovland, 1993). The cemented layers would make the sediment more difficult to displace, accommodating aggradation rather than migration and therefore amplifying sediment wave growth. The presence of shallow gas seeps and MDAC coincide with the presence of sediment waves in the Codling Fault Zone and in the Western Trench (Judd et al., 2007). Recent work by the Joint Nature Conservation Committee identified a large area with MDAC in the central Irish Sea. Between these "Croker Carbonate Slabs", abnormally high sediment waves also occur. We thus investigate, for the first time, evidence for past and present methane seeps in the sediments of sediment waves and, if methane by-passes the benthic microbial filter, in the water column above the bedforms.

2. SURVEY RESULTS

2.1. Overview of survey areas

Figure 3 illustrates the several areas in the Irish Sea and Liverpool Bay where swath bathymetry data, seismic profiles, CTD transects and Shipek grab samples were collected.

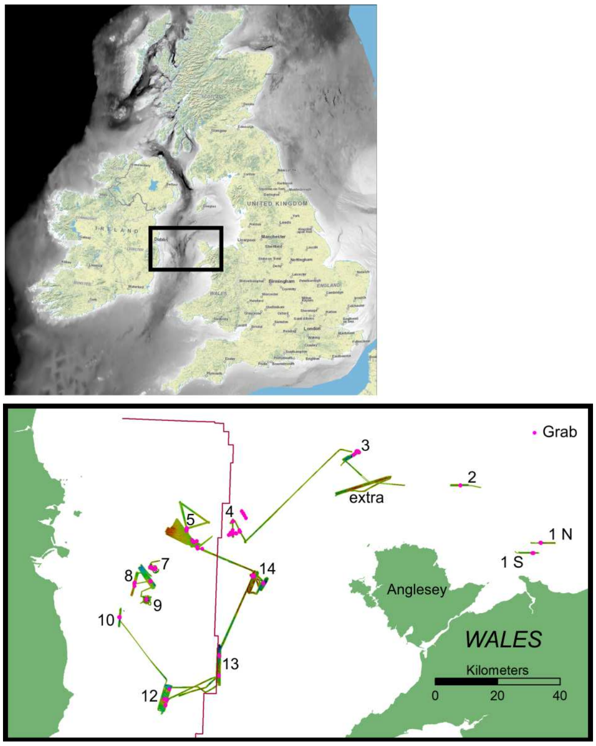

Figure 3. Overview of survey areas in the Irish Sea during the AmSedIS survey in April 2012.

2.2. Variation in sediment wave sizes and migration speeds

Repeated swath bathymetry data permits sediment wave sizes and migration rates to be documented. The data from April 2012 largely confirmed the distribution of sediment wave sizes and migration rates previously published (Van Landeghem et al., 2012), with sediment waves of all sizes typically migrating a few meters per year, locally amplified where currents are deflected around regional bathymetric changes. In the deep central Irish Sea (areas 12 and 13), the largest of Irish Sea sediment waves (25–35 m high) are still mobile (Fig. 4). The migration of the lateral edges is usually significantly higher than the migration of the highest part - the middle part- of the sediment wave. These lateral edges thus seem important in the overall sediment transport mechanism from one bedform to another.

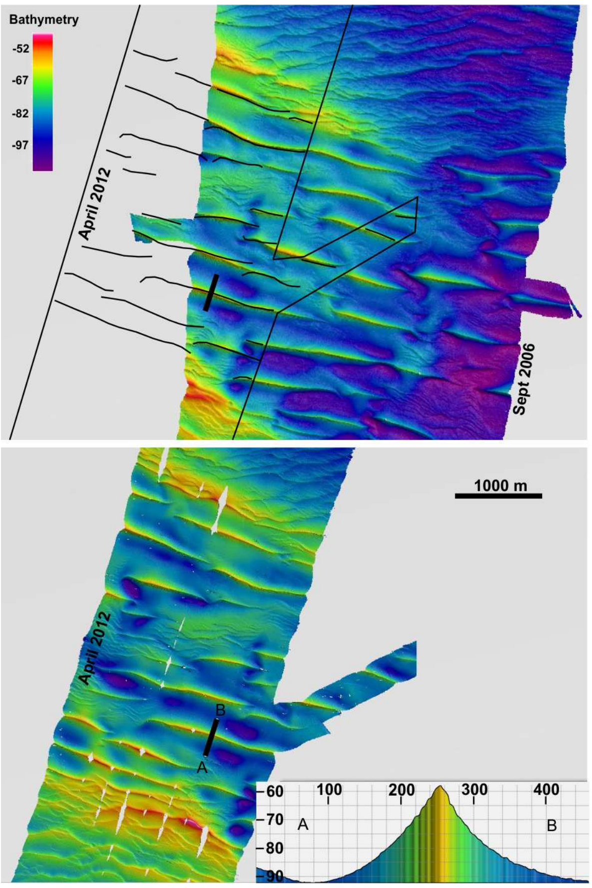

Figure 4. Repeated swath bathymetry data in the central Irish Sea (area 12). The unusually high sediment waves with their trochoidal shape (see profile) have moved and re-arranged a little in the 5.5 years' time difference between both surveys.

2.3. Variation in grain size distribution over differently sized and actively migrating sediment waves.

Granulometric variations across sediment waves can be indicative of differences in effective sediment transport, which defines the potential of the sediment waves to migrate over time. Sand-sized sediment is usually better sorted than gravel and mud as it is easier transported in the energetic shelf sea environments. Gravel is often too "heavy" to be transported, while silts are often aggregated in clusters. As a consequence, from silt to sand we see a coarsening of the sediment with better sorting, whilst from sand to gravel we see a coarsening of the sediment with poorer sorting.

From 22 sediment waves in various places of the Irish Sea, sediment grabs were collected in transect and analysed for granulometric variations. The coarsest sediments -coarse sands to fine gravels- are found in the central Irish Sea (Area 12), where also the largest bedforms occur. Both the mean sediment grain size and the sorting are more variable in the fields of trochoidal sediment waves. With likely stronger currents in the past, perhaps the initially poorly sorted sediments would have strengthened sediment wave growth due to the hiding-exposure effect.

Many of those grab samples were taken in transect over sediment waves of various shapes and sizes. Compared to the sediments over normal sediment waves, the average sediment over trochoidal sediment waves is coarser, and the sediment sorting is highly variable from one sediment wave to the next. Particle size distributions over the trochoidal sediment waves are multi-modal, while the neighbouring "normal" sediment waves are mostly composed of uni-modal sediments.

2.4. Sediment availability underneath unusually high sediment waves.

The field with the largest Irish Sea sediment waves, the middle of area 12, is flanked both in the south and the north by normal sediment waves that migrate towards that field. Mobile sediment is thus steadily supplied towards this field with the world's largest sediment waves. In area 13 and in area 9, the same sediment convergence occurs where the sediment waves are straight-crested, trochoidal and unusually high (Van Landeghem et al., 2012). This systematic abundance in mobile sediments must thus be a critical factor in extreme sediment wave growth.

In area 9 (see Figure 1), seismic profiles were collected to investigate the depositional architecture of the sediment wave field. Was there a pre-existing depression in the seafloor to "trap" the sediment in this convergence zone, or has subsequent erosional scour created somewhat of a depression around the unusually high sediment waves? It seems now that in fact that both factors play an important role. The scour around the coarse grained sediment waves has cut in the originally horizontal sediment layers around the field, and will have over time remobilized a considerable amount of sediment. This is an additional source of the mobile sediment fraction needed to build such large sediment waves.

In area 5, the seismic profiles indicate the presence of a steeply dipping layer (roughly coinciding with the glacial incision delineated by the British Geological Survey). The incision in the subsurface is expressed by a change in sediment wave orientation and an increase in sediment wave height. The sediment waves in this area are completely immobile. The medium sands can either no longer be mobilised by the relatively weak currents in area 5, or the shallow gasses in this area (Croker, 1994) have dampened the mobility of the bedforms via methane-derived authigenic carbonate (MDAC) cements in between the sand grains. The sediments from the sediment waves have, however, shown no evidence of MDAC and there is no increase of methane concentrations relative to the background values, see section 2.5.

2.5. Methane concentrations in sediment wave fields.

The sediments from the unusually high sediment waves in the Irish Sea do not show any increase in methane concentrations compared to background values. Only in area 4 (fig. 5), shallow gas was clearly observed underneath sediment waves.

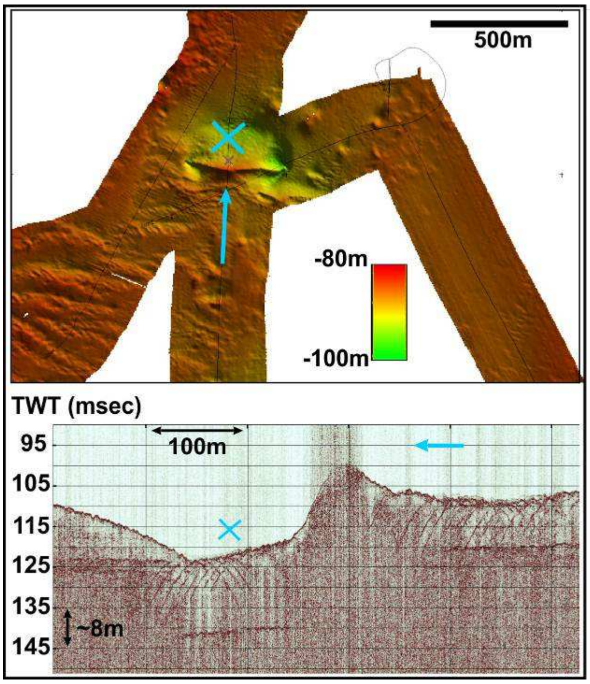

Figure 5. Boomer seismic profiles under the seabed in area 4. The acoustic signal (a strong, consistent top reflection and acoustic turbulence below) is indicative of shallow gas.

High concentrations of methane in sediments near sediment waves were found in this area 4 (the Croker MDAC slabs), but no increase in methane values were found in the sediments that make up the unusually high sediment waves.

3. CONCLUSIONS

Unusually high, straight-crested and trochoidal sediment waves reach unique heights of up to 36 m in the Irish Sea. The preliminary findings on these bedforms that differentiate them from normal sediment waves is that (1) they consist of considerably coarser, more poorly sorted sediments, (2) a continuous and abundant supply of mobile sediment is crucial. This abundant mobile sediment is likely supplied to the sediment wave fields from glacially scoured channel-fills, due to convergence in sediment transport pathways and/or due to scour around coarse-grained sediment waves additionally dislodging the mobile fraction from the coarse lag deposits. Methane seepage is not considered a defining factor in the development of these enigmatic features. Instead, AmSedIS' efforts to better understand these bedforms will focus on the underlying geology, sediment transport pathways and the mixture of sediments found from sediment wave crest to trough. This dataset is envisaged to allow for more advanced numerical modelling of sediment wave development in these particular circumstances.

4. ACKNOWLEDGMENT

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