

Seabed mapping and seafloor processes in the Kish, Burford, Bray and Fraser Banks area, south-western Irish Sea

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ABSTRACT

Mapping of the seabed and sub-seabed strata in an area comprising offshore banks and intervening sediments in outer Dublin Bay is presented. Bathymetric comparisons suggest that the offshore banks are quasi-stable over time probably maintaining their position due to the interaction between wave and current regimes. Seven acoustic seabed facies are defined on the basis of side-scan sonar characteristics reflecting differences in bedforms and bottom types. Sediment waves indicative of a mobile substrate are common both on and between banks. Maximum sediment wave development occurs on bank flanks and outer limits. The effects of wave action on seabed morphology are clearly discernible in the structure and appearance of the bank crests. Grain-size data and bedform interpretations suggest a northerly sediment transport system with gravel dominant in the south of the area (Bray Bank) grading to sands in the north (Kish and Burford Banks). Sub-bottom profiling reveals a consistent upper unit overlying a hard reflector allowing unit thickness (isopachs) to be defined. No internal structures or 'hard' cores were revealed within banks. Two shipwrecks were also imaged. Relationships are drawn with models of offshore bank evolution suggesting that the Irish examples are quasi-stable dependent on a relatively consistent input of sediment and metocean variables. Banks genesis, however, may relate more to former conditions of post-glacial rapid sea-level rise and high sediment input.

Key index words: Offshore banks, sediments, acoustic facies, geophysical.

Introduction

The southern Irish Sea is characterised by a series of NNE-SSW trending bedforms and sedimentary facies reflecting the principal tidal current direction. In the western Irish Sea, on the south-eastern seaboard of Ireland, at a distance of approximately 10km offshore, a series of coast-parallel north-south trending offshore-banks. These banks stand in 20-30m of water and rise to within a few metres of the water surface. The banks form a punctuated line along the eastern Irish coast south of Dublin with breaks maintained by strong currents and sediment movements. They offer wave protection to the coast and have a strong control on tidal flow pathways along the coast. The banks are quasi-stable features in dynamic equilibrium with tidal and wave conditions and are an integral part of the coastal system resulting from coastal erosion and the remobilisation of land-based gravel deposits in north county Wicklow (Warren and Keary, 1989).

The largest of the banks in the survey area are the Kish Bank and Bray Bank, the Bray Bank being a southerly continuation of the former (Figure 1). The Kish Lighthouse marks the

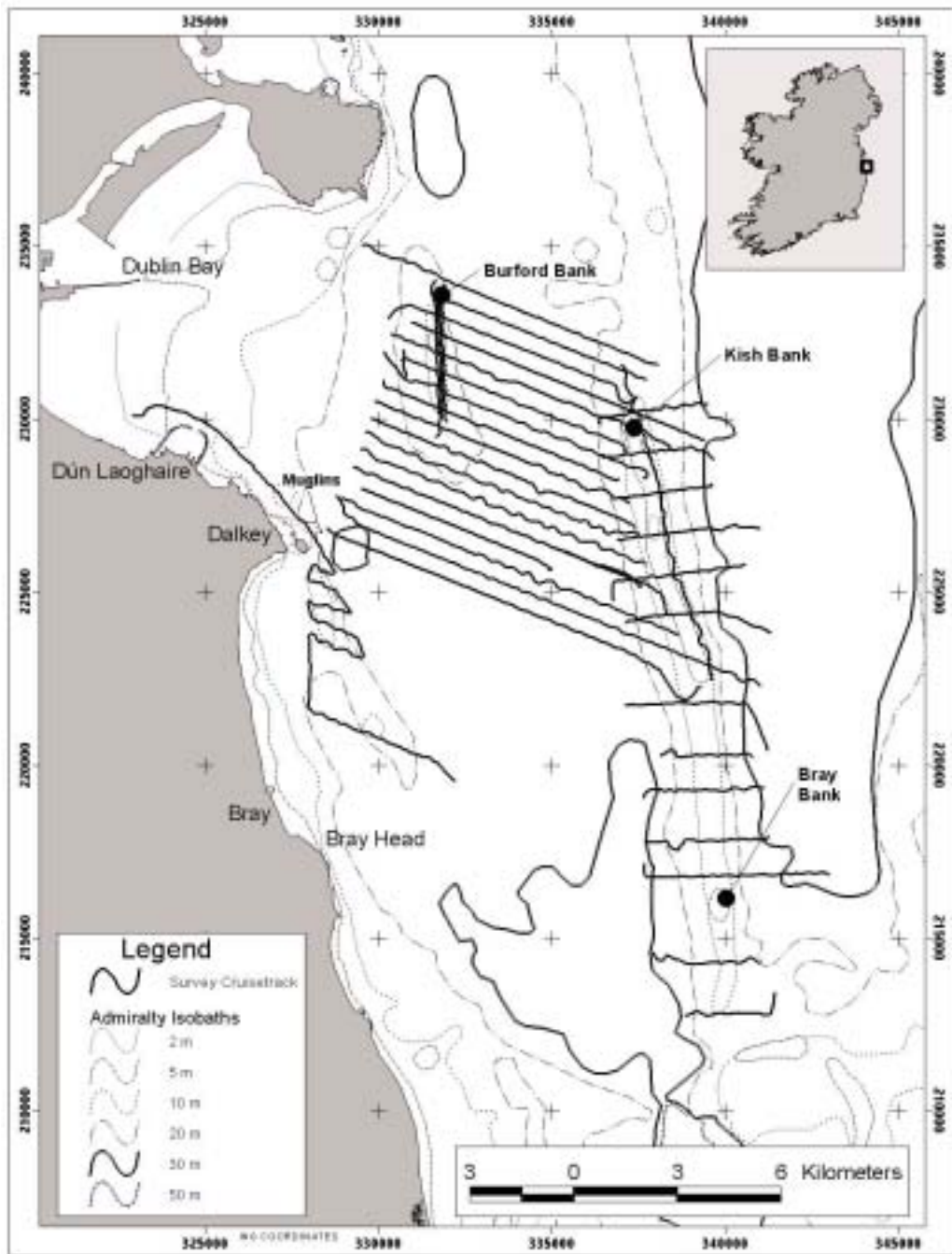


Figure 1: General location mapping showing survey vessel cruise track.

northern end of the Kish Bank and the Codling Bank (a shallow platform of scoured seabed) marks the southern end of the Bray Bank. The Burford Bank is c.5km landward of the Kish Lighthouse and sits centrally across the mouth of Dublin Bay that forms a semi-circular

embayment 8km across bordered by rocky coastline to the north (Howth) and south (Dún Laoghaire and Dalkey). South of Dalkey exists the smaller Fraser Bank which is only *c.* 2km offshore, immediately south of Muglins.

Limited public-domain data exists for the survey area although extensive datasets exist for adjacent areas with occasional survey lines impinging upon, and samples taken within, the limits of the survey area. Relevant geological survey cruise data from areas adjacent to the survey area include the R.V. Lough Beltra Regional Mapping Cruises 10.10.76; 5.9.78; 29.10.79, and GSI cruise 2/84 and 5/84 (Geoghegan, 1986) which are held by the Geological Survey of Ireland in its GEOMAN database. Pertinent details of these cruises can also be visualised in a database and GIS (Sutton and Wheeler, personal communication). These cruises primarily concentrate on areas south of the survey area. Existing sample coverage (61 samples) for the area is documented in the BGS commercial samples database, the metadata of which are also presented within the sand and gravel database (Sutton and Wheeler, personal communication). Of these samples, 36 percent are diver samples concentrated on the Kish Bank and towards the Burford Bank, 8 percent are dredge samples from the Kish and Bray Bank, 8 percent are shipek samples between the Banks and 48 percent are of an unknown type. Some of this data is also discussed in Harris (1980).

The regional seabed sediment map (British Geological Survey and Geological Survey of Ireland, 1990) includes coverage of the survey area and is compiled from a number of sources. Sample sites (dredge, grab and diver samples) are marked on the map with details held by the Geological Survey of Ireland in its GEOMAN database. The map depicts the survey area as covered by 'sand' with a tongue of 'slightly gravelly sand' extending up the western side of the Kish Bank. West of the Bray Bank, this facies forms a continuous coverage towards the coast with sediments in a deep scour adjacent to the bank characterised by 'gravelly sand' and 'sandy gravel'. This deep scour was formed due to Weichselian ice margin processes (Wingfield, 1990) or, more specifically, by glacial melt-water channel activity (Warren and Keary, 1989). A small area of gravelly sand is also identified southeast of the Fraser Bank.

A regional Quaternary stratigraphy for the area is presented in Whittington (1977) based on nearshore survey data south of Dublin. He identifies the four seismostratigraphic units:

- Unit IV banks and other sand bodies that may include stiff clay or gravel layers and mud and silt in some hollows.
- Unit III horizontal or 'draping' events, depositional in origin with no recognized erosional phases (due to the nature of deposition may include 'softer' soils).
- Unit II glacial till, few internal reflectors, with point source diffractors suggesting boulders.
- Unit I pre-Pleistocene bedrock.

A study by McKenna (1984) has been performed south of the area which confirms and adds detail to the above seismostratigraphy.

A detailed site survey exists in a 2km² area immediately north-east of the survey area (Irish Shell Petroleum Development Company, 1979) based on echo-sounder, side-scan sonar and seismic sparker data. This study was performed for hydrocarbon exploration purposes in the Kish Bank Basin where coal reserves have also been found (Jenner, 1981; McArdle and Keary, 1986; Geoghegan *et al.*, 1989). The report identifies a consistent reflector (reflector A)

within Whittington's Unit IV. This is correlated with 'stiff clay' at 15 to 16m in a borehole at the Kish Lighthouse. This borehole documents 15m of 'fine sand' overlying the 'stiff clay' unit and more than 11m of 'dark grey cohesive silt with some sand' underlying the 'stiff clay' unit. Irish Shell Petroleum Development Company (1979) extrapolates this unit to a minimum depth of 45m (the base of Whittington's Unit IV). Side-scan sonar and bathymetric data identified asymmetrical sediment waves, 1 to 1.5m high with a wavelength of about 600m trending east-west with lee slopes facing northwards (Irish Shell Petroleum Development Company, 1979). The recorded wavelength of 600m is questioned here and suggested that a wavelength of 60m may have been intended. Rippled fine sands with gravel patches in their troughs are documented. The ripples are again asymmetrical being 0.8m high with a wavelength of 10m (Irish Shell Petroleum Development Company, 1979). The wavelength or definition of ripples is also questioned here and suggested that the reference to ripples relates to smaller scale sediment waves. Gravel patches covering 20m² were also imaged. Measurements of current strengths suggest that for at least 8-hours over spring tides, current velocities exceed the 1/3 to 1/2 knot speed (0.17 to 0.25ms⁻¹) necessary to transport these fine to medium sands.

Repeat biological and geological surveys of Dublin Bay, west of the study area, have been performed mainly for assessing the fate and impact of dredge and sewage spoil (e.g. Naylor, 1965; Max *et al.*, 1976; Harris, 1980; Keegan *et al.*, 1983; Wilson, 1984; Keegan, 1989). These studies document the presence of rippled fine sand covering most of the bay. A dredge spoil site exists c.5 km due west of the Burford Bank.

One of the highest concentrations of shipwrecks found in Irish waters exists on the banks in the survey area. This density reflects both the navigational hazard associated with these natural barriers and the scale of Dublin port traffic. A National Maritime Sites and Monuments Record is held by Dúchas - The Heritage Service that lists the site of all known shipwrecks in the area, many of which are also listed in Bourke (1994; 1999).

Materials and methods

The vessel used for this survey was the M.V. Kilquade, a steel-hulled Clovelly class Ex. R.M.A.S. fleet-tender. She is 24.08m long, with a draft of 2.44m and beam of 6.70m, capable of a top speed of 10 knots. Positioning was accomplished by means of a Trimble NT300D DGPS with 1-2m accuracy. Navigation data was logged (with bathymetric signal) through Hypack software to a computer hard disk.

The survey used side-scan sonar to map the seabed, elucidating bedforms that are suggestive of sediment mobility, inferring sediment type based on truthed acoustic facies and locating shipwrecks. A Geoacoustics dual frequency (100kHz and 410kHz) side-scan sonar system was used with the 100kHz frequency employed and the signal sent to an Ultra Electronics Wideline 200 Series thermographic recorder. The side-scan sonar operated well although there was some channel fall-out in high currents when run parallel to the bank due to angling of the tow-fish.

Boomer seismic coverage was generated and recorded concurrently (metocean conditions permitting) to provide stratigraphic data and generate isopachs (contours of equal sediment thickness) for the upper sand and gravel facies. A boomer plate mounted on a catamaran was powered by an Applied Acoustic Engineering CSP 1000 capacitor discharge power supply. Return signals were detected with an EG&G Model 262-J hydrophone and

processed with an Octopus Marine Systems 360 Sub-bottom processor system. Hardcopy recording was made on an Ultra Electronics Wideline 200 Series thermographic recorder. The system failed to operate under relatively high wave regimes due to air-trapping under the boomer plate and also connection failures caused by excessive strain. In calmer conditions, the boomer performed well. The side-scan sonar towfish was moved closer to the vessel when operating over the banks.

Bathymetric data was collected using an Odom Echotrac Model 3100 (200kHz) echo sounder. Online survey guidance, and simultaneous logging of bathymetric and positioning data were handled through a PC running the Coastal Oceanographics Hypack survey program. An Odom Digibar Model 1100 was used to measure the speed of sound in the water column to provide calibration data for the echo sounder. The system performed well although initial problems were encountered holding the transducer in position during relatively high wave states. Tidal levels were recorded at Dún Laoghaire and Dublin Port with a time correction of -20 minutes applied for data reduction at the working site. An independent manual check on the tide gauge was performed.

A Van Essen Grab was used to collect all sediment samples. Samples collected were then subjected to particle size analysis using laser granulometry for grains less than 2mm on a Malvern Instruments Mastersizer X particle sizer (Jantschik *et al.*, 1992). Grains greater than 2mm were wet sieved and the two datasets subsequently integrated. Percentage carbonate determinations were performed by loss-on-ignition (Dean, 1974) at 1000°C for two hours.

An attempt was also made to acquire underwater video imagery along the banks to assist in the interpretation of acquired datasets and provide additional biological information. This was abandoned due to operational problems associated with the high current regime. It was also realised that the mobility of the seabed sediment during the majority of the tidal cycle would severely occlude visibility and therefore limit the usefulness of the video imagery.

Surveying was carried out during spring tides (between 3.11.98 and 10.11.98) to enable the vessel to effectively clear the banks at high tide. Weather conditions were changeable and included periods of NE gales force 6-7 swinging around to SW gales force 7-8. Moderate conditions existed which were operational between these peak events. Work on the banks was strongly dictated by the height of the tide and the relationship of the tidal flow to wind direction governing wave height.

Isobaths and isopachs were produced from gridded data using standard contouring computations.

Bathymetric Changes

New bathymetric data was collected during the survey and compared with existing bathymetry available on Admiralty navigation charts (Hydrographic Office, 1978). This intercomparison was performed to assess whether there was a discernible shift in bank location and altitude. Isobaths were produced from the gridding of the acquired bathymetric data and are presented overlying the existing Admiralty isobaths (Figure 2). The existing Admiralty isobaths were compiled from data collected between 1843 and 1911. The intercomparison reveals a close match implying that no substantial movement has occurred on the Burford Bank. The intercomparison on the Kish Bank and Bray Bank is also good for deeper isobaths but less so in the shallower waters and on the crest. The new bathymetric data suggests the Admiralty charts reliably locate the banks although differences in crestal

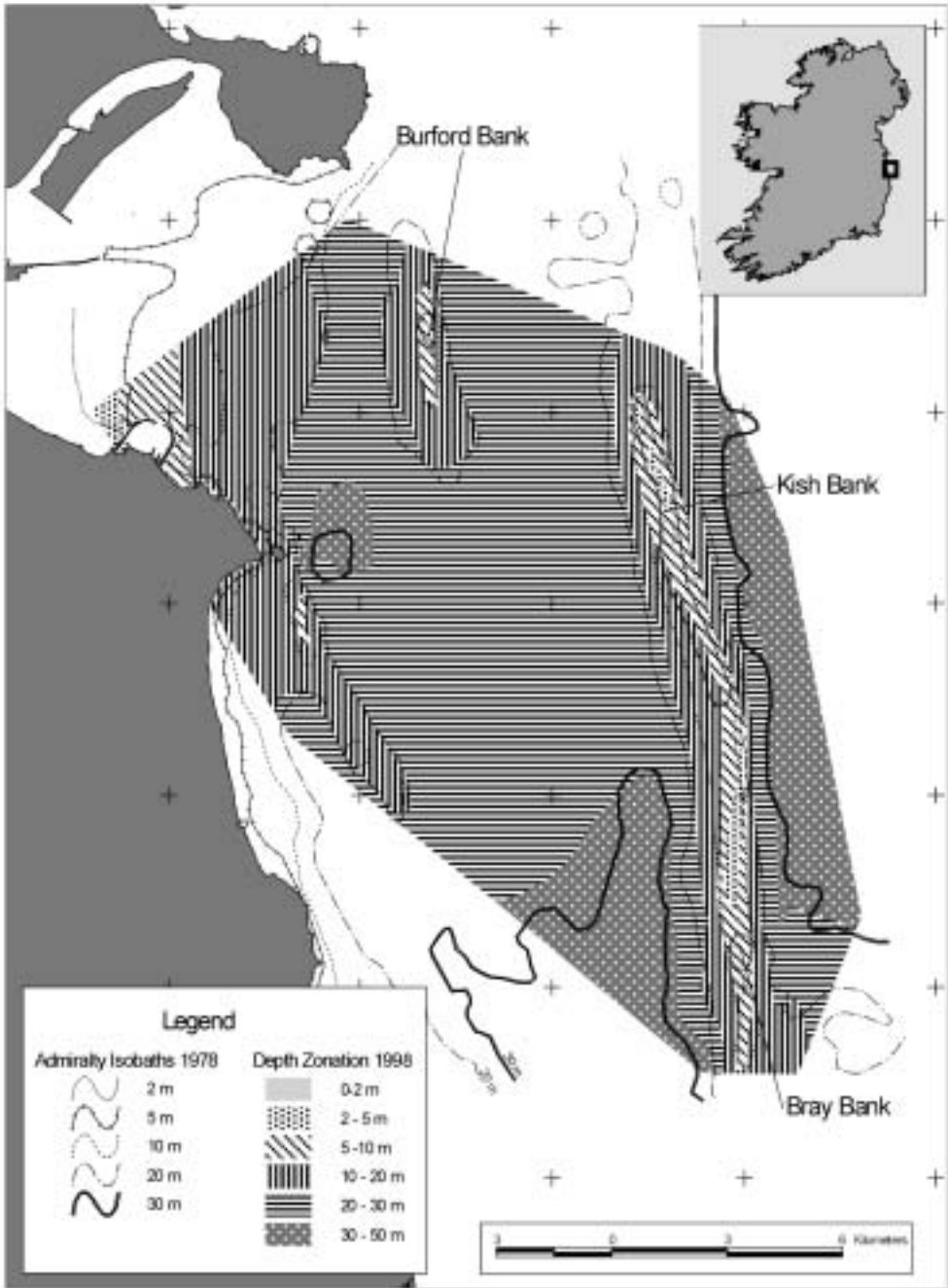


Figure 2: Bathymetric intercomparison.

elevations make the charts unsuitable for across-bank navigation. These conclusions are presented with the caveat that there are inherent differences between the systems used to derive and chart positions associated with the two datasets, and an unqualified difference between the respective methods used to generate isobaths.

Seafloor facies, bedforms and sediment mobility

Side-scan sonar was used to map the seafloor on and between the banks. This was done to assist in fundamental geological mapping as well as to elucidate the nature of geological processes through facies allocations and the interpretation of bedforms. Side-scan sonar coverage was at a minimum of 25 percent of the total seabed within the survey area, with 75 percent coverage generated for most areas including the Kish Bank, Burford Bank and intervening seabed. The coverage includes across-bank and crest-parallel swathes on the Burford and Kish Banks with across-bank lines only for the Fraser and Bray Banks.

Side-scan sonographs were ascribed to facies based on a consideration of backscatter intensity and bedforms. Acoustic facies (Figure 3) show a predominantly north-south or bank-parallel zonation suggesting that controls on bank processes extend to contiguous areas. Several facies are defined and described below. It is appreciated that facies allocations are mildly affected by variable data quality due to changing metocean conditions during surveying. This factor may help to explain in part the limited presence of the 'stippled stable seabed facies' and apparent extensions to the 'stippled sediment wave facies' between the Kish and Burford Banks (Figure 3).

Stable seabed facies

The 'stable seabed facies' is found in areas between the banks and is so called because no bedforms were imaged with the side-scan sonar. The facies probably represents stable or non-mobile seabed although small scale ripples may exist that were too small to be detected by the side-scan sonar. Side-scan sonar backscatter returns are characteristically homogeneous. Ground-truthing implies that this featureless facies represents a flat sandy to silty seafloor.

Sediment wave facies

The 'sediment wave facies' describes a mobile seabed that occurs on the outer limits of the bank complex and Fraser Bank. Figure 4a shows a representative sonograph from this facies which is characterised by lunate asymmetrical sediment waves implying northerly net sediment transport. The wavelength and amplitude of the sediment waves in this facies are variable with sediment wave fields often forming onlapping domains. This facies also exhibits clearly delimited sand ribbons surrounded by seabed with lower relief bedforms. Small sediment waves are more common at the edge of the facies where it borders the 'stable seabed facies'. The larger sediment waves, sand ribbons and mixed sediment wave fields are common near the outer limits of the banks. This pattern suggests that the strongest tidal flows are found closest to the bank, probably due to acceleration in tidal flows around the obstruction. Stable bank locations are probably dependent on the dynamic interaction of wave action causing up-bank sediment migration and strong tidal boundary currents preventing further landward sediment migration. One ridge of sand exists between the Burford and Kish Banks representing a linear accumulation of sand where two sediment transport domains meet.

Stippled bank crest facies

The 'stippled bank crest facies' characterises the crest of the Kish and Burford Banks and is represented by a transition from sediment waves, on the edge of the bank, to planar beds with numerous small patches of highly reflective seabed (probable gravel patches) (Figures 4b). The patches of highly reflective material occur in discrete areas of variable size although

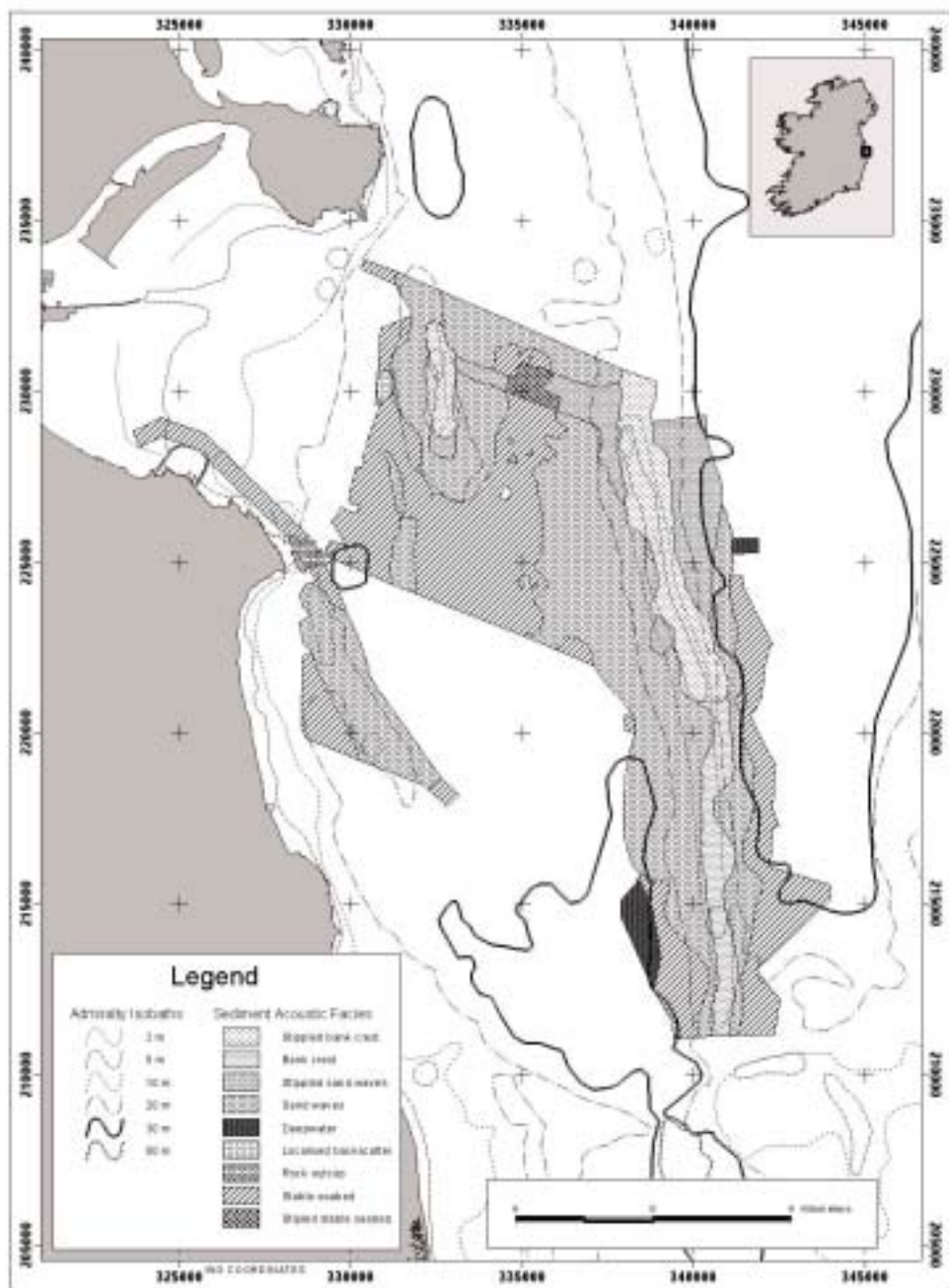


Figure 3: Acoustic facies based in an interpretation of geophysical data.

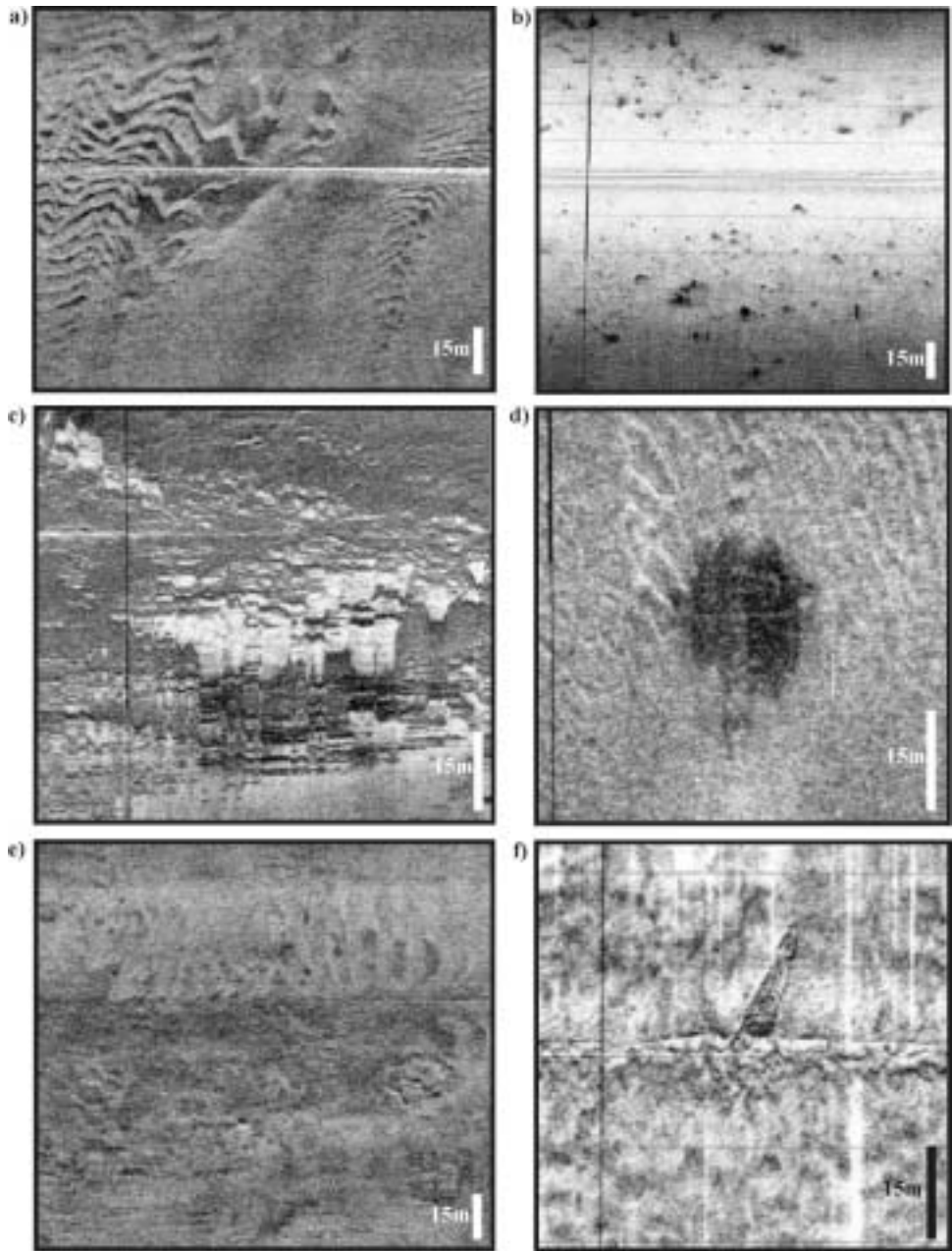


Figure 4: Examples of side-scan sonar images showing (a) discrete domains of sandwaves and sand ribbons in the 'sediment wave facies', (b) planar beds with probably high backscatter gravel patches in the 'stippled bank crest facies', (c) rock outcrops from near Muglins, (d) the localised backscatter facies revealing an isolated patch of high backscatter overlying sandy sediment with sediment waves, (e) disturbance of the seabed probably caused by vessel activity, and (f) a shipwreck on the crest of the Kish Bank.

larger patches are apparent in shallower water. Sediment waves in this facies have sinuous crests implying a northerly sediment transport direction along the crest of the Banks. Where water-depths are shallowest overlying the banks, planar beds often replace sediment waves.

Stippled sediment wave facies

Patches of highly reflective material (probable gravel patches) are also present away from the banks in areas dominated by sediment waves ('stippled sediment wave facies'). This facies occurs on the edges of the Kish Bank and in a narrow strip between the Kish and Burford Banks (Figure 3).

Stippled stable seabed facies

Patches of highly reflective material lying on the seabed that has an otherwise homogeneous backscatter define a narrow strip of 'stippled stable seabed facies' (Figure 3).

Bank-crest facies

The 'bank-crest facies' describes the crest of the Bray Bank and the outer edges of the Burford Bank. This facies is similar to the 'stippled bank crest facies' except there is an absence of highly reflective material (probable gravel patches).

Minor facies

Several other minor facies are also defined; these include the 'deep-water facies' which occurs on the edge of a deep scour west of the Bray Bank. In common with the 'stable seabed facies', this facies is characterised by a uniform featureless acoustic backscatter signal although a generally higher degree of backscatter is exhibited, probably reflecting an increase in grain-size. A small area of 'rock outcrop facies' is imaged near Muglins where exposed rock generates a strong return signal (Figure 4c). Other distinct but localised facies include the 'localised backscatter facies' (Figure 4d) which reveals an isolated area of high backscatter sediment west of the Burford Bank. This may represent a sewage dump. In the 'stable seabed facies' localised concentric features are present which were probably caused by boat moorings or possible prop-wash disturbance from large vessels (Figure 4e).

Also imaged during the survey are two shipwrecks (Wheeler, in press). The two shipwrecks are of comparable size and are located on the crest of the Kish Bank (Figure 4f). The third potential shipwreck target stands proud of the seabed and is probably a rock pinnacle lying east of the Muglins.

Seismostratigraphy

Seismic sediment profiling provides seismostratigraphic correlation with adjoining stratigraphies and allows an assessment of temporal processes. Due to operational difficulties, the internal stratigraphies of offshore banks on the east coast of Ireland are poorly understood. This study therefore provides valuable insights. The coverage of boomer seismic lines is coincident with the centre of side-scan sonar swathes. Profiling was performed across all banks and intervening seabed although less boomer than side-scan coverage was obtained, owing to boomer susceptibility to data loss under poor sea conditions.

A simple seismostratigraphy was revealed comprising an upper layer of sand with weak internal reflectors (Unit A) suggesting that density contrasts within the unit are minimal. This

unit overlies a thin unit with a strong response (Unit B) that is present at a comparable altitude throughout the survey area. Below Unit B are poorly imaged strata with few internal reflectors (Unit C), which occasionally contain other thin beds comparable with Unit B although spatially discontinuous. Unit A and Unit B are correlated with Unit IV of Whittington (1977): banks and other sand bodies that may include stiff clay or gravel layers and mud and silt in some hollows. Furthermore, Unit B can be correlated with Reflector A (Irish Shell Petroleum Development Company, 1979) which is a 'stiff clay'. The planar nature of the unit suggests that it may represent early Holocene low energy marine facies. The underlying and overlying sands and silts probably represent interglacial marine deposits.

A typical seismic profile is presented in Figure 5a between the Burford and Kish Banks. The seabed in this profile shows sediment waves with characteristic crossbedding expressed as internal reflectors in Unit A.

Figure 5b shows a seismic profile from across the Kish Bank and reveal that Unit B retains a consistent altitude as the seabed rises over the Bank. The banks contain no additional internal reflectors suggesting that the Kish, Burford, Bray and Fraser Banks are composed of sand/gravel with no density contrasts and are not founded on a glacial morainic core as in the case of the Arklow Bank (R. Keary, personal comm.).

Other features apparent on the boomer profiles include the presence of a buried erosion feature (Figure 5c) suggesting that the deep scour west of the Bray Bank has become infilled at its northernmost extent. Figure 5d shows chaotic return signals generated by rock outcrops at the seabed near Muglins.

Isopachs for Unit A (measured from the seabed to the upper surface of Unit B) are presented in Figure 6. The thickest accumulations occur over the Kish (38m), Bray (37m) and Burford (37m) Banks. It should be noted that the irregular nature of the isopach map in the vicinity of the banks is due to a paucity of data. Unit B has an average thickness of *c.*20m between the banks and thins towards Dublin Bay.

Sediment properties

As well as providing essential ground-truthing to the geophysical data, the sediment properties in themselves provided important information with respect to geological processes. Samples were subjected to particle size analysis that classified most of the sediments as 'medium sand' with a mean particle-size of 2 phi (0.25mm) to 1 phi (0.5mm). Three dominant particle size modes are revealed whose variable representation dictates overall sediment type: a gravel mode (<-3 phi or <8mm), a sand mode (centred on 1 phi or 0.5 mm) and a silt mode (centred on 6.5 phi or 0.012mm). Samples were ascribed to sediment types based on the Folk (1954) classification scheme (Figure 7).

Defined sediment types are plotted spatially in Figure 8 and show a dominance of sandy sediment both on the banks and in the intervening areas. Gravelly sediments are concentrated on the bank crests (i.e. the Kish Bank and especially the southerly Bray Bank) and silty sediments are restricted to deeper waters away from the banks. It should be noted that when the Van Essen Grab is used, large clasts may get caught in the jaws of the grab and cause fine sediments to be under-sampled. This may result in an apparent exaggeration of the degree to which samples coarsen on bank crests and towards the south. However, a coarsening of sediments to the south (and increase in sediment lag) is still implied - which is also supportive

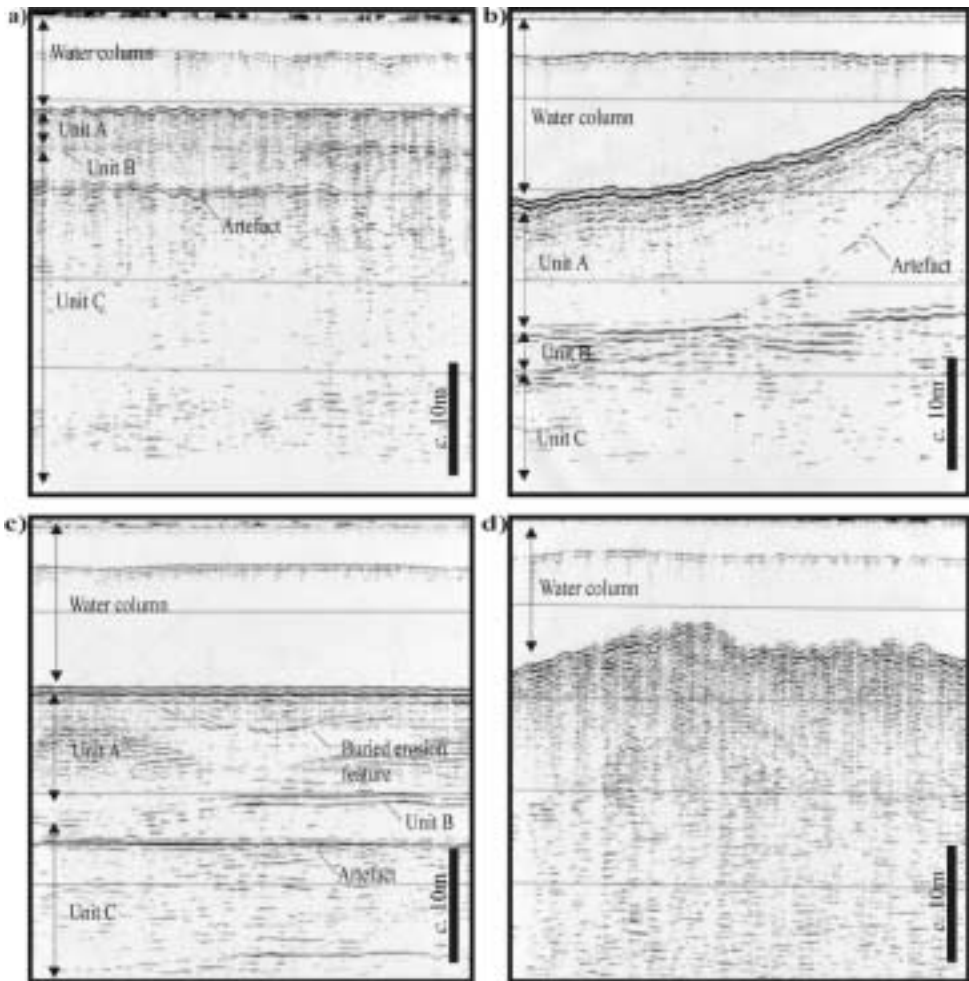


Figure 5: Typical boomer profiles (a) from between the Kish and Burford Banks, (b) over a bank, (c) showing a buried erosion feature and (d) over rock outcrops.

of a northerly net sediment transport direction as implied by imaged bedforms.

Percentage carbonate determinations were also performed on the sediments and reveal a variation of between 0 percent and 15 percent with most samples containing between 1 percent and 5 percent carbonate. Zero carbonate samples were obtained from lithic- gravel samples (probably under-represented in fines) whereas those samples with high carbonate value also represent coarse-grained sediments with a detrital shell component. No clear relationship exists between carbonate content and grain-size.

Discussion and conclusions

The results outlined above detail, in three dimensions, the geological attributes of an area of offshore banks and intervening seabed east of Dublin. The seismic data revealed the upper mobile sands (Unit A) attaining considerable thicknesses and resting on a planar strong reflector (Unit B). Bank formation occurred after the deposition of Unit B with banks

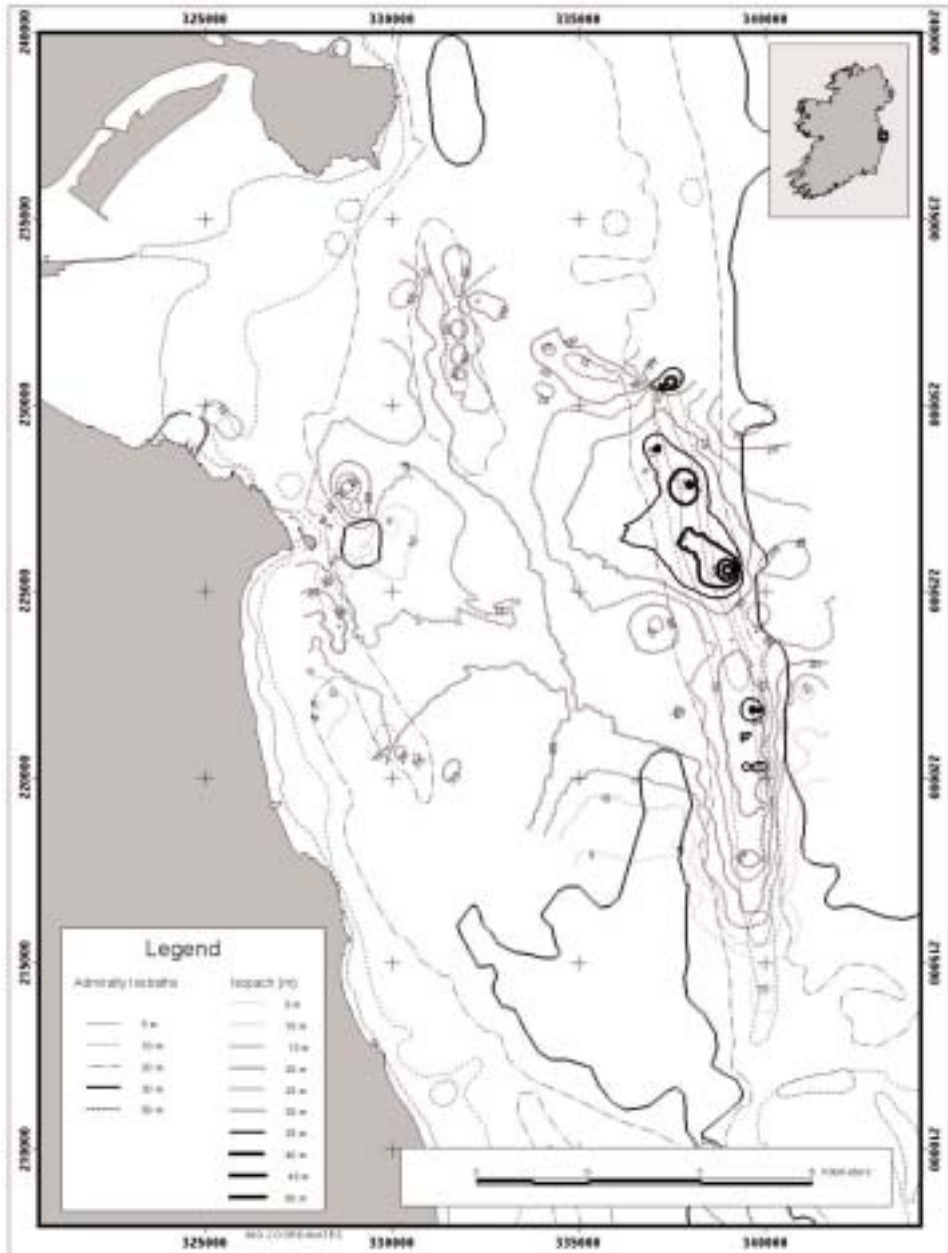


Figure 6: Isopach map showing the thickness of unit A, the uppermost stratigraphic unit.

composed of poorly stratified sand/gravel. Unit A and Unit B are correlated within Unit IV of Whittington (1977). Unit B is further correlated with Reflector A (Irish Shell Petroleum Development Company, 1979) which is a 'stiff clay'. The planar nature of the unit suggests that it probably represent early Holocene low energy marine facies with the underlying and overlying sands and silts representing Pleistocene and Holocene marine deposits respectively.

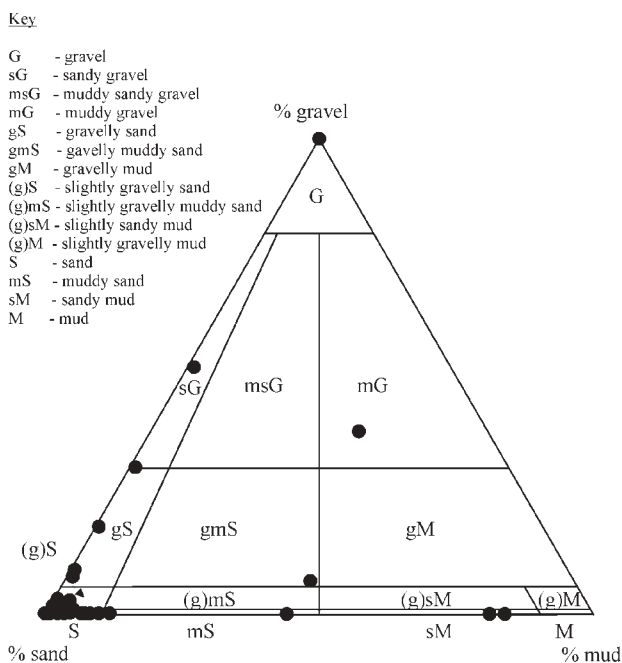


Figure 7: Sediment type classification based on percentage gravel, sand and mud (after Folk, 1954).

A Holocene age for banks formation is in agreement with comparable features in the southern North Sea and English Channel. De Batist *et al.* (1993) and Anthony (2000) describe such examples which contain internal shoreward dipping reflectors, representing a phase of shoreward migration under rising sea-level, and a upper unit comprising coast-parallel reflectors resulting from more recent alongshore transport processes. These banks present a similar coast-parallel configuration and are also covered by shore-parallel megaripples (Beck *et al.*, 1991; Augris *et al.*, 1995). Anthony (2000) suggests that bank formation occurred under a rising sea level up to 4000BP. This may have also been facilitated by greater sediment supply as the marine transgression reworked fluvio-glacial and glacial depositions associated with the last ice retreat. Post 4000BP, the English Channel banks became stranded offshore as sea-level continued to rise. A comparison between sea-level curves for the north Belgium coast (Denys & Baeteman, 1995) and the east coast of Ireland (Carter *et al.*, 1987) would place a similar Irish inflection in the sea level rise rate at 5000BP when the inferred offshore stranding of the Kish, Burford and Bray Banks would have occurred.

In this context, the Kish, Burford and Bray Banks formation processes are interpreted as being both allocyclic (responding to external influences) and autocyclic (maintained by internal dynamics) having features inherited from both sea-level changes and modern hydrodynamic processes. Side-scan sonar records reveal evidence of seabed mobility on, and adjacent to, the banks. Furthermore, sediment waves increase in amplitude towards the edge of the banks suggesting that currents are highest close to the banks. A comparison is made with banks (Glassgorman and Arklow Banks) and associated sediment waves further to the south in the western Irish Sea (Max, 1969). This intensification of current speeds is both caused by the obstacle that the banks represent and is a process that maintains banks' position. Away from the banks, current activity is less influential and a finer-grained seabed with small

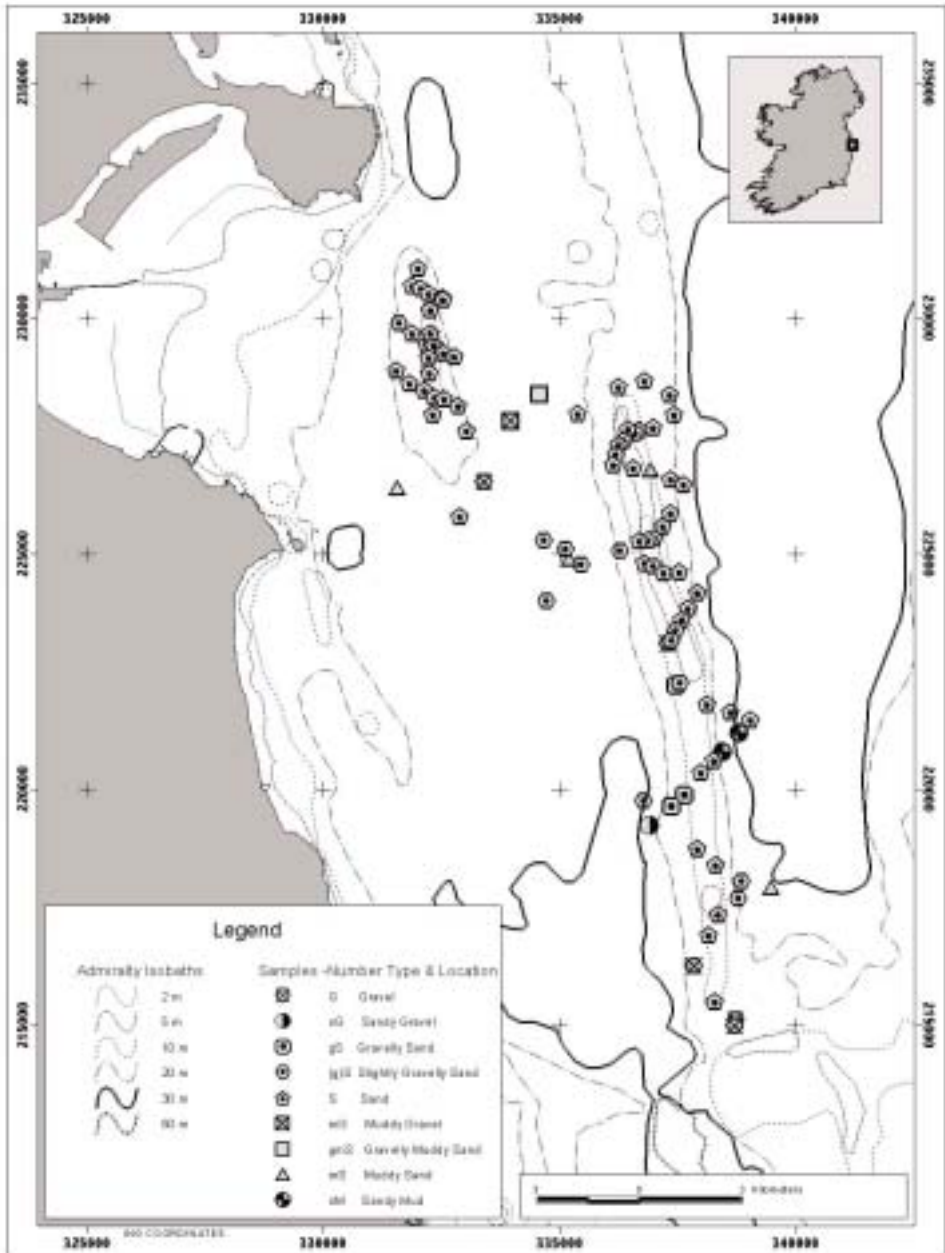


Figure 8: Sediment sample locations with ascribed sediment types.

or no bedforms is encountered. On, and adjacent to, the banks high backscatter small patches, interpreted as gravel, were imaged.

Grain-size variations show a tendency for coarser grain-sizes to be dominant on the southern Bray Bank fining northwards and away from the banks. This is in agreement with

sediment wave orientation suggesting a northerly sediment transport direction. The intensity of the current implies that surface sediment is undergoing renewal. Seismic data suggest that erosion and redeposition on the sides of the banks are also prevalent, although the centre of the banks are probably older and undisturbed.

Although it is not reliably possible to say if the Banks have changed their position over the last 100 years, changes in bank heights are apparent to the extent that the existing charts are unreliable for across-bank navigation. This suggests that the banks exist in a quasi-stable domain maintaining their configuration due to the current interplay between their topography, tidal currents and the wave regime. Once formed, the banks interaction with metocean conditions is sufficient to maintain their spatial and altitudinal configuration within certain limits. Bank height and spatial position may migrate within certain boundaries but unless metocean conditions exceed a certain thresholds e.g. due to an increase in the rate of sea-level rise, reduction in along-shore sediment supply, or change in the wave energy regime. If this threshold is crossed then a rapid turnover of the system may ensue until a new littoral equilibrium is reached. Were the banks to be removed, not only would a reconfiguration of the tidal current occur and wave energy become more focused on the present protected coastline, but it is unlikely that the present metocean conditions would facilitate a regeneration of the banks.

Under future greenhouse-induced climate scenarios (Houghton *et al.*, 2001), adjustment in both the rate of sea-level rise and wind-wave energy are envisaged (Watson *et al.*, 2001) although a present it is not possible to say with certainty the degree of change or the threshold tolerances of these banks. Anthropogenic interference in littoral processes could also affect this balance although current management philosophy prohibits significant removal of the bank sediment or southerly sediment supply areas (Gary McGuinn, personal communication). Future uses of the banks for offshore wind farms are currently under evaluation although there are no current plans to license large scale offshore aggregate extraction (Gary McGuinn, personal communication). Offshore aggregate extraction is subject to ongoing policy development although it is unlikely, at this stage, that extraction could occur with the 20m isobath due to coastal erosion considerations (Gary McGuinn, personal communication).

Given the high incidence of shipwrecks in the area, these lag deposits may also contain components of shipwreck debris. Although shipwreck incidence on the banks is high, only two shipwrecks were imaged (both on the Kish Bank) suggesting a low preservation potential for maritime heritage due to the intensity of physical environmental conditions (Wheeler, in press).

The current findings provide baseline data supporting hypothetical models for bank generation and functioning. Further research is needed to validate these models and add additional detail to existing discoveries. Strategic to these aims is the provision of long cores through the banks sampling early stages of bank development, quantified sediment transport studies in the bank area and hydrodynamic modeling under various metocean conditions and bank modification scenarios.

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References

- ANTHONY, E.J. (2000) Marine sand supply and Holocene coastal sedimentation in northern France between the Somme estuary and Belgium, *In: Pye, K. and Allen, J.R.L. (eds) Coastal and Estuarine Environments: sedimentology, geomorphology and geoarchaeology*. London: Geological Society, Special Publications, 175, 87-97.
- AUGRIS, C., CLABAUT, P. and TESSIER, B. (1995) *Le domaine marin côtier du Nord-Pas de Calais: Carte des formations superficielles au 1:100000*. IFREMER/Region Nord-Pas de Calais/Université de Lille I.
- BECK, C., CLABAUT, P., DEWEZ, S., VICAIRE, O., CHAMLEY, H., AUGRIS, C., HOSLIN, R. and CAILLOT, A. (1991) Sand bodies and sand transport paths at the English Channel-North Sea border: morphology, dynamics and radioactive tracing, *Oceanologica Acta*, 11, 111-121.
- BOURKE, E.J. (1994) *Shipwrecks of the Irish Coast 1105-1993*. Dublin: E.J. Bourke.
- BOURKE, E.J. (1999) *Shipwrecks of the Irish Coast, Volume 2, 932-1997*. Dublin: E.J. Bourke.
- BRITISH GEOLOGICAL SURVEY and GEOLOGICAL SURVEY OF IRELAND (1990) *Sea Bed Sediments Map*. Anglesey Sheet 53°N – 06°W including Dublin 53°N – 08°W., 1:250,000. Southampton: Ordnance Survey.
- CARTER, R.W.G., JOHNSTON, T.W., MCKENNA, J. and ORFORD, J.D. (1987) Sea-level, sediment supply and coastal changes: examples from the coast of Ireland, *Progress in Oceanography*, 18, 79-101.
- DEAN, W.E. (1974) Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods, *Journal of Sedimentary Petrology*, 44, 242-248.
- de BATIST, M., MARSSET, T., REYNAULD, J., TESSIER, B. and CHAMLEY, H. (1993) *Large- and small-scale internal structures of the Bassure de Baas Bank: recording by high resolution seismics and sub-bottom profiling*. Annual Report Project MAST-Starfish MAS-CT92-0029, 77-83.
- DENYS, L. and BAETEMAN, C. (1995) Holocene evolution of relative sea level and local mean high water spring tides in Belgium— first assessment, *Marine Geology*, 124, 1-19.
- FOLK, R.L. (1954) The distinction between grain size and mineral composition in sedimentary-rock nomenclature, *Journal of Geology*, 62, 344-359.
- GEOGHEGAN, M. (1986) Geological and geophysical surveys on the east and south coasts of Ireland, *In: O'Sullivan, G. (ed.) Lough Beltra - 1984*. Proceedings of the 1984 Lough Beltra Workshop, Galway. Dublin: National Board for Science and Technology, 95-106.
- GEOGHEGAN, M., GARDINER, P.R.R. and KEARY, R. (1989). Possibilities for commercial mineral deposits in Irish offshore area, *Marine Mining*, 8, 267-282.
- HARRIS, C.R. (1980) Recent sediment distribution in Dublin Bay and its approaches, *Journal of Earth Sciences*, Royal Dublin Society, 2, 41-52.
- HOUGHTON, J.T., DING, Y., GRIGGS, D.J., NOGUER, M., VAN DER LINDEN, P.J. and XIAOSU, D. (eds) (2001) *Climate Change 2001: the Scientific Basis*. Contribution to Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge: Cambridge University Press.
- HYDROGRAPHIC OFFICE (1978) *Admiralty Chart*. Republic of Ireland – east coast, Arklow to the Skerries Islands, 1:100,000 at Latitude 53°30'. Taunton: Hydrographic Office.
- IRISH SHELL PETROLEUM DEVELOPMENT COMPANY (1979) *Site Survey, Kish Bank, Ireland*. Dublin: Irish Shell Petroleum Development Company.

- JANTSCHIK, R., NYFFELER, F. AND DONARD, O.F.X. (1992) Marine particle-size measurement with a stream-scanning laser system, *Marine Geology*, 106, 239-250.
- JENNER, J.K. (1981). The structure and stratigraphy of the Kish Bank Basin, *In*: Illing, L.V. and Hobson, G.D. (eds) *Petroleum Geology of the Continental Shelf of Northwest Europe*. London: Heyden, 425-431.
- KEEGAN, B. (1989) *Remote Reconnaissance Survey of Dublin Sewage Sludge and Dredge Spoil Disposal Grounds, July 1988*. Dublin: Report for the Dept of Marine.
- KEEGAN, B.F., DINNEEN, P., COSTELLOE, M. and CUNNINGHAM, P. (1983) *Benthic Characterisation (1983) of the Dublin Bay Dumping Grounds*. Galway: University College Galway.
- MAX, M., HARRIS, C.R., GEOGHAN, M.A., CATHCART, G.S., NÍ CONCHUIR, M.E. and FAHY, C.J. (1976) *A Preliminary Report on the Recent Sedimentation on the Sea Floor Immediately to the east of Dublin*. Geological Survey of Ireland Report Series, RS 76/1.
- McARDLE, P. and KEARY, R. (1986) *Offshore Coal in the Kish Bank Basin: its Potential for Commercial Exploitation*. Geological Survey of Ireland Report Series RS 86/3.
- McKENNA, P. (1984) Shallow Seismic Interpretation of the Kish Bank Basin. Unpublished MSc thesis, Dept of Applied Geophysics, University College Galway.
- NAYLOR, D. (1965) Pleistocene and post-Pleistocene sediments in Dublin Bay, *Scientific Proceedings of the Royal Dublin Society*, A2, 175-188.
- WARREN, W.P. and KEARY, R. (1989) The sand and gravel resources of the Irish Sea Basin, *In*: Sweeney, J. (ed.) *The Irish Sea Basin: A Resource at Risk*. Dublin: Geographical Society of Ireland, Special Publication No. 3, 65-79.
- WATSON, R.T., ZINYOWERA, M.C. and MOSS, R.H. (2001) *IPCC Special Report on The Regional Impacts of Climate Change. An Assessment of Vulnerability*. Cambridge: University Press.
- WENTWORTH, C.K. (1922) A scale and grade of class terms for clastic sediments, *Journal of Geology*, 30, 377-392.
- WHEELER, A.J. (in press) Environmental controls on shipwreck preservation: the Irish context, *Journal of Archaeological Science*.
- WHITTINGTON, R.J. (1977) A late-glacial drainage pattern in the Kish Bank area and postglacial sediments in the Central Irish Sea, *In*: Kitson, C. and Tooley, M.J. (eds) *The Quaternary History of the Irish Sea*. Liverpool: Seel House Press, 55-58.
- WILSON, J.G. (1984) Benthic Studies on the east coast, *In*: O'Sullivan, G. (ed.) *Lough Beltra – 1984*. Proceedings of the 1984 Lough Beltra Workshop, Galway. Dublin: National Board of Science and Technology, 60-67.
- WINGFIELD, R.T.R. (1990) Glacial incisions indicating Middle and Upper Pleistocene ice limits off Britain, *Terra Nova*, 1, 538-548.