European Offshore Wind Deployment Centre

Environmental Statement

Appendix 8.1: Coastal Processes Baseline Technical Report

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Aberdeen Offshore Wind Farm Ltd

European Offshore Wind Deployment Centre: Coastal Processes Baseline Report

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Creating sustainable solutions for the marine environment





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European Offshore Wind Deployment Centre: Coastal Processes Baseline Report

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Summary

ABP Marine Environmental Research Ltd (ABPmer) has been commissioned by Aberdeen Offshore Wind Farm Limited (AOWFL) undertake a coastal process study for the proposed European Offshore Wind Deployment Centre (EOWDC). The proposed EOWDC site, consisting of eleven turbines, is within Aberdeen Bay.

This report provides a description of the baseline coastal process conditions. It is shown that the proposed development site is located on a relatively shallow, flat and featureless seabed. Analysis of sediment mobility within the study area indicates that the seabed is mobile under tidal conditions and that wave processes also contribute to sediment mobility, although overall the seabed is not particularly mobile with respect to the significant sediment fractions (fine sands). In the nearshore area there is a sub-tidal ridge which is orientated parallel to the shoreline, there is evidence that this nearshore ridge modifies wave energy in its lee. The coastline is, at its closest, 2.4km from the deployment centre and exhibits a net northwards littoral transport regime which is primarily controlled by the wave regime. The intertidal area exhibits various mobile bar formations which vary in position and extent on a seasonal basis.

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1. Introduction

ABP Marine Environmental Research Ltd (ABPmer) has been commissioned by Aberdeen Offshore Wind Farm Limited (AOWFL) to undertake a coastal process study associated with the proposed European Offshore Wind Deployment Centre (EOWDC) at Aberdeen (Figure 1). The purpose of the project is to allow manufacturers to test 'first of run' wind turbines and innovative foundation solutions before commercial deployment. In addition to providing a test facility, the project will also provide electricity to the national grid.

This site is located within Aberdeen Bay, on Scotland's eastern coast. The Crown Estate Lease area applied for covers an area of approximately 20 km^2 and it is currently planned to construct 11 turbines within this area with a lease period of 22 years. This report focuses on providing a baseline understanding of the coastal process regime within Aberdeen Bay, with particular emphasis placed on the proposed EOWDC site.

This document is the baseline assessment report and provides a description of present understanding of coastal process conditions. A conceptual understanding is presented, with details provided on the hydrodynamic (wave; tidal), sedimentological and morphological regimes. Further, information is presented detailing natural variations to these regimes which may occur as a consequence of, for example, climate change and over timescales consistent with the project lease period (22 years). A consideration of these variations will provide context for comparing natural changes against any introduced by the development. The potential impacts of the development relative to this baseline regime will be reported in a subsequent impact assessment report.

As part of this work a beach profile survey was also undertaken to characterise the morphology and sediment along the foreshore adjacent to the EOWDC development, this is reported in Appendix A.

1.1 Methodology Consultation

The proposal to develop the project consisting of 11 wind turbines and associated infrastructure i.e. sub sea cables, is considered with respect to coastal processes in an area of seabed which can be considered relatively featureless, with the exception of a sub-tidal shore-parallel ridge which lies shoreward of the proposed project. This section describes the coastal process issues which require consideration as both the present, or baseline, conditions and those arising from the development of the wind farm.

It is important to consider those coastal process issues which have been raised as a result of the consultation of the Environmental Impact Assessment (EIA) Scoping Report (AOWFL, 2010). Currently responses from four organisations have been provided to ABPmer, of which all are relevant to coastal process issues. The responses received are summarised in Table 1. In addition to the responses received for the EOWDC, scoping opinions were also supplied as part of the original proposed Aberdeen Offshore Wind Farm (AOWF) development in response to the scoping report published in 2005 (AREG and AMEC, 2005). Responses from eleven organisations were provided to ABPmer, of which six are relevant to coastal process issues, these are summarised in Table 2.

Table 1. Stakeholders response with respect to coastal processes for the EOWDC project

Coastal Process Issue	Body			
	Aberdeen Harbour Board	Scottish Natural Heritage	Scottish Environment Protection Agency	Marine Scotland
Hydrodynamic (waves)		Wave shadowing	Regime	
Hydrodynamic (tides)		Directions and speeds	Speeds	
Bathymetry		Consider the nearshore bar	Extent of seabed likely to be affected by turbines and cables	
Sediment regime	Scour development		Threshold of mobility and transport pathways	Effects on the sedimentation / erosion patterns of the Ythan estuary.
Morphology				
In-combination/cumulative effects				
Coastal	Increased suspended sediment concentration (SSC) leading to increased sedimentation in harbour and along Aberdeen Beach	Littoral transport and shoreline effects	Extent of intertidal zone likely to be affected by shoreline infrastructure development	
Foundations				
Cables	Exposure on highly mobile seabed which can be subject to re-suspension throughout the tide and during storms			
General		Full consideration of baseline conditions, including the relative importance of high-energy, low frequency and low-energy, high frequency wave events.		Beach profiles recorded by the University of Aberdeen may not be representative of the ongoing processes at the beach near the development site. Instead a local survey would be more suitable for the interpretation of current processes and any potential impact of the development..

Table 2. Stakeholders response with respect to coastal processes for the previous AOWF project

Coastal Process Issue	Body					
	Scottish Executive[1]	ASFB[2]	FRS[3]	RSPB[4]	SNH[5]	MCA[6]
Temporal Scales	Short, medium, long		Numerical model should account for seasonal changes in oceanic currents and wind forcing			
Effects to consider	Perm., temp., +ve, -ve, direct, indirect					
Hydrodynamic (tides)					10m contour is a major area of up-welling Lies close to a known front	Effects upon navigation
Sediment regime	Water quality. Esp. during construction	Suspended sediment concentrations, especially during construction	Coastal sedimentation rates; Detailed sed. transport Foreshore aesthetics; Estuarine habitats; Harbour siltation rates.	High significance	Bay south of Balmedie is erosional	
Morphology	Erosion	Habitat changes				
Scour	Yes				Yes	
In-combination/ cumulative effects			Blackdog Landfill, military ranges, historical munitions dumps		Pipelines; protection works along city frontage	
Onshore connection	No impacts upon current erosion tendency of coastline				No impacts upon current erosion tendency of coastline	
General			Suggestion: also consider 10MW turbines?		Climate change (sea level rise; storminess)	
Other				This area qualifies as an SPA	SNH = statutory consultee, have consulted with JNCC	

Notes:
1: Enterprise, Transport and Lifelong Learning Department, Consents and Emergency Planning Department
2: Association of Salmon Fishery Boards (ASFB)
3: Fisheries Research Services (FRS)
4: Royal Society for the Protection of Birds (RSPB)
5: Scottish Natural Heritage (SNH)
6: Maritime and Coastguard Agency (MCA)

1.1.1 Key Guidance Documents

Guidance on the generic requirements, including spatial and temporal scales, for coastal process studies is provided in five main documents:

- 'Offshore wind farms: guidance note for Environmental Impact Assessment in respect of Food and Environmental Protection Act (FEPA) and Coast Protection Act (CPA) requirements: Version 2' (Department for Environment, Food and Rural Affairs (Defra), Centre for Environment, Fisheries and Aquaculture Science (Cefas) and Department for Transport (DfT), 2004);

- 'Guidance on Environmental Impact Assessment in Relation to Dredging Applications' (Office of the Deputy Prime Minister, 2001);

- Nature Conservation Guidance on Offshore Wind Farm Development' (Defra, 2005);

- Marine Renewable Energy and the Natural Heritage: An Overview and Policy Statement (Scottish Natural Heritage, 2003); and

- Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment (COWRIE, 2009).

It is noted that Marine Scotland recently commissioned a set of guidance documents to be produced for the marine renewable industry, specifically wave and tidal devices, which included reference to EIA requirements (EMEC & Xodus AURORA, 2010). It is considered that the advice offered can be transferred across to the Scottish offshore wind industry, and as such is referenced within this study. ABPmer is currently unaware of any similar guidance from Scottish Environmental Protection Agency (SEPA) or Marine Scotland (MS) and are therefore presently assuming that those listed above can be adopted for the EOWDC project.

The interaction of any changes in the hydrodynamic (tidal; wave) and sedimentological regimes may, consequently, result in changes to the morphodynamic regime. It is therefore recommended that the results from these assessments be investigated with regard to this regime, with consideration to, for example, bed form changes.

A consideration of these regimes is required over a range of spatial and temporal scales:

- Spatial scales:
  - Near-field (i.e. the area within the immediate vicinity of the turbine grid and along the cable route); and
  - Far-field (i.e. the wider coastal environment over which effects could potentially occur);

- Temporal scales:
  - Baseline (pre-construction phase);
  - Construction phase;
  - Post-construction phase;

- Sediment recovery phase (period during which a new equilibrium position is attained with the wind farm in place);
- Lifetime of the wind farm array;
- Decommissioning phase; and
- Post-decommissioning phase.

Within a consideration of the spatial and temporal scales listed above, the guidance requires a specific assessment to be made of the following:

- Baseline Assessment:
  - Coastal processes which maintain the existing system, explanations for past changes and the sensitivity of the system to changes in these processes;
  - Relative importance of high-energy, low-frequency (episodic) events versus low-energy, high-frequency events;
  - Coastal processes controlling morphological change;
  - Identification of sediment sources, pathways and sinks; and
  - Identification of the geological, geophysical and geotechnical sediment properties and the depth of any sediment strata within the wind farm site.

- Impact Assessment:
  - Scour around the turbine structures and consideration of scour protection;
  - Stability of buried cables under the influence of coastal processes;
  - Scour around any cabling overlying the sediment surface;
  - Effect on the spatial distribution of wave patterns, tidal flows and sedimentation (all near-field) and wave direction and energy (far-field) and any subsequent impacts on littoral transport;
  - Non-linear interaction of waves and currents and the extent of seabed sediment mobilisation;
  - Sediment mobility and the natural variability of sediment depth across the near-field and the effect on turbine foundations and cable burial depth;
  - Effect of cable laying on local levels of suspended sediment;
  - Assessment of the scales and magnitudes of processes controlling sediment transport rates and pathways; and
  - Assessment of climate change impact on the coastal process regime.

The baseline, or pre-construction, conditions include a description of the existing coastal process regimes prior to any works on the site. A consideration of natural changes (i.e. sea level rise) which may result in changes to the regime over the wind farm's operating period will be included, thus providing context for comparing natural changes against any introduced by the project.

1.2 Proposed Assessments of Cumulative Impacts

Schedule 3 of the Electricity Works EIA (Scotland) Regulations 2000 requires that the potential for cumulative impact should be considered and where appropriate, assessed. The term "cumulative assessment" is defined in the scoping document (AOWFL, 2010) and is described as follows:

> *"The cumulative assessment will address where predicted impacts of the wind farm construction and operation could interact with impacts from other industry sectors within the same region and impact sensitive receptors. This may be through direct effects or spatially/temporally separated impacts on the same population of a receptor."*

Further to this, guidance which exists from Scottish Natural Heritage (SNH) supports the guidelines published by Cefas and Defra. Here it was defined that:

- All developments, both known, under consideration and in existence must be considered; and
- Those 'cumulative' effects located within one tidal excursion of the development require assessment.

With respect to coastal processes, other developments which are typically considered are dredging and aggregate activities. The industries which exist within Aberdeen Bay include those of marine aggregate extraction and shipping. The industries which are likely to require consideration in association with the proposed EOWDC project are listed in the following sub-sections and the locations of these activities are shown in Figure 2, in relation to one tidal excursion from the development site.

1.2.1 Coastal Defence Works

Coastal defence works are located to the south of the proposed wind farm site towards Aberdeen. Recent works have been carried out to reinforce these defences through the installation of rock revetments. Immediately onshore of the wind farm, there are no hard defences installed with the natural dune system providing some protection to the hinterland.

The coastal defence works are situated to the south of the proposed development. As net sediment transport is to the north, large impacts are not expected along the Aberdeen Beach frontage as a consequence of the EOWDC. This hypothesis will be tested during the assessment where changes to littoral transport along the shoreline will be modelled as part of the impact assessment.

1.2.2 Contaminated Sediments

There are two potential regions of sediment contamination within the vicinity of the EOWDC site, any impacts of the EOWDC development upon sediment transport and mobilisation may impact on the distribution of these contaminants:

- *Oil based mud drilling fluids:* It has been noted that the Blackdog municipal landfill site was also used for the disposal of waste materials containing oil based drilling muds from the North Sea oil and gas industry; and

- *Radioactive sediments:* Sediments with raised levels of radioactivity have been found on the foreshore within Aberdeen Bay at Foot Dee beach.

1.3 Proposed Assessment of In-Combination Impacts

The term "in-combination impacts" is defined in the scoping document (AOWFL, 2010) and is used when considering any impacts of the proposal with other plans or projects on European sites. The following habitat designations are relevant when considering European sites:

- *Special Protection Areas (SPAs)* are designated under the EU Habitats Directive on the Conservation of Wild Birds. SPAs are located within the Ythan Estuary (6km north of the development site), the Sands of Forvie (6.2km north of the development site) and the coast extending between Buchan Ness and Collieston and offshore (7.5km north of the development site).

- *Special Areas of Conservation (SACs)* are designated under the EU Habitats Directive. SACs are located on the Sands of Forvie (6.2km north of the development site), along the coastline between Buchan Ness and Collieston (10.5km north of the development site) and within the River Dee (5.8km south of the development site).

1.4 Data and Information Sources

1.4.1 Surveys

1.4.1.1 Metocean surveys

A metocean survey was undertaken by Emu Ltd (Emu), with the main aim of measuring waves, water levels, tidal currents and suspended sediment concentrations (SSC) within the site area. The survey data provides a direct means to demonstrate an understanding of the waves and tides in the area, and to allow a consideration of these processes in conjunction with sediment transport. In addition, the data helps support an understanding of the occurrence and effects of major events, in particular high frequency low energy events and low frequency high energy events. The results of the survey have been presented in a draft survey report (Emu, 2008a).

The survey was undertaken using an Acoustic Wave and Current profiler (AWAC) device for the period between the 12 September 2007 and the 13 February 2008, a total of 154 days. This survey therefore records a short-term dataset spanning one winter season. The location of the device is shown in Figure 3. The data return is summarised below:

- 106 days of good current data;
- 106 days of good directional wave data;
- 154 days of good tidal data;
- 154 days of good temperature data;
- 154 days of good acoustic backscatter data; and
- 59 days of good optical backscatter data.

The use of this data has identified potential discrepancies particularly with regards to the current and turbidity measurements and as such the data should be used with caution. These discrepancies are discussed further in the relevant sections of the report (Section 2.3).

1.4.1.2 Geophysical surveys

Two geophysical surveys have been undertaken for the proposed development. The first was undertaken by Emu and designed to provide detailed information on the bathymetry, seabed morphology, obstructions and shallow geology. Undertaken in September 2007, the survey covered a previous site area to the south, the extent of which is shown in Figure 3.

This survey collected the data on the following:

- Bathymetry (multibeam echosounder) quoted relative to Chart Datum (CD) at Aberdeen;
- Seabed features, sediment type and any other targets on the seabed (Sidescan Sonar);
- Sub-Surface Geology (Seismic Survey);
- Ferrous objects (magnetometer); and
- Seabed habitat types (Acoustic Ground Discrimination System and ground-truthed using video survey).

Full details of the survey can be found in Emu (2008b).

A second survey was undertaken in October 2010 by Osiris Hydrographic and Geophysical Projects Ltd (Osiris, 2010). This survey was carried out over a different location to cover the current EOWDC site and also the adjacent nearshore area, the extent of which is shown in Figure 3. This coverage was designed to include a shore parallel ridge identified in the original geophysical survey so its impacts on the coastal process regime can be investigated in more detail. ABPmer has received the draft report and accompanying data and the results of the work have been incorporated within this report as appropriate. The survey collected data covering the same parameters as the 2007 survey but quoted to LAT (0.1m above CD).

A review of this data found that the Emu (2008b) and Osiris (2010) differ by approximately 0.25m (with the Emu dataset shallower than the Osiris dataset). Discussions with Osiris identified two possible reasons for this discrepancy:

- Different methods used to reduce the soundings, with Osiris using Real Time Kinematic (RTK) GPS and Emu using the British Oceanographic Data Centre (BODC) gauge at Aberdeen harbour; and
- Annual variations in the seabed level.

As the seabed level differences are reasonably consistent across the study area, it is determined that the difference identified between the two surveys is likely to be due to the use of two survey techniques, rather than actual changes to the seabed height between the two survey dates. To remedy this, it was determined, based on the methods used to reduce the soundings, that the Osiris dataset was likely to be more accurate. Therefore the Emu dataset was adjusted by 0.25m allowing the soundings to be more consistent across the study area. This adjusted bathymetry was subsequently used to undertake coastal process assessments.

1.4.1.3 Geotechnical survey

No site specific geotechnical information has been collected as part of this project and instead a review of existing geotechnical data was completed by Setech (2009). This review drew on both data held in Setech and British Geological Survey (BGS) archives and provided a characterisation of sub surface geology across the region based on this information.

1.4.1.4 Benthic survey

A review of existing benthic information was undertaken by Titan Environmental Surveys Ltd (Titan, 2008). The review included the intertidal zone and a previous site location (layout ref LABER011). This review included the analysis of sediment samples taken by Fisheries Research Services (FRS) in April 2006 that coincided with the old wind farm boundary and part of the output from this aspect of the study was the Particle Size Analysis (PSA) of the grab samples using sieve sizes at half-phi intervals.

A benthic survey was undertaken in October 2010 in on the current proposed EOWDC site. Undertaken by the Centre for Marine and Coastal Studies (CMACS Ltd), the survey included the collection of 14 grab samples within the wind farm array and further afield.

1.4.1.5 Beach survey

Beach profile data was collected by ABPmer between the 26 and 29 October 2010 to characterise the beach topography for purposes of numerical modelling. The data was collected using a Global Positioning System (GPS) along 23 profiles spaced around 1km apart and for each of the positions shown in Figure 3. These positions were chosen to provide typical beach profiles throughout the length of the beach. The tidal conditions during the survey ranged between 3.1 and 2.4m representing mid-range tides with a mean spring range of 3.7m and a mean neap range of 1.8m. Appendix A provides the associated survey report and results.

In addition to the profiles, sediment samples were also collected to help characterise the sediment along the shoreline adjacent to the wind farm. The locations of these samples are also shown in Figure 3. The collected samples subsequently underwent PSA whereby material coarser than 1mm was measured using manually sieved methods and material finer than 1mm was measured using laser diffraction. The results from these two methods were then combined to establish the particle size distribution of each sample.

1.4.2 Data Acquisition

Additional information has also been obtained from other sources to complement that obtained from the metocean, geophysical and benthic surveys previously described. The additional data acquisition includes:

- Aberdeen County Council (ACC) wave data. ACC funded the deployment of a wave buoy offshore in Aberdeen Bay, between the River Don and the harbour entrance. This instrument was deployed for the two periods between November 2007 to August 2008 and September to December 2008. It is noted that this buoy now forms part of the Cefas WaveNet network;

- BGS surface sediment information has been used to provide a more regional indication of the seabed material. It also provides confidence in the grab samples provided by the benthic survey;

- British Oceanographic Data Centre's (BODC) National Tidal & Sea Level Facility (NTSLF) water level data. A tide gauge is maintained at Aberdeen and information are available from 1980 to early 2005;

- BODC current meter data exists for two locations within Aberdeen Bay. Previous investigations have shown that only one of these is suitable for use in the coastal process investigations. The record (BODC References: 433464 and 433476) has a temporal resolution of 10 minutes and an uninterrupted duration of 45 days;

- SeaZone seabed bathymetry data. This data has been used to provide a regional overview of depths and base mapping for figures; and

- TotalTide tidal level data. The TotalTide numerical modelling package has been used to synthetically generate astronomical tidal level data and current speed so that measured data from the metocean surveys can be compared against the model data for an assessment of consistency.

In addition to data listed above, relevant available literature has been collated and reviewed in order to provide additional information to the Baseline Assessment. This primarily focused on key reports of relevance to coastal defences or processes within the far-field and near-field study areas. These included:

- Aberdeen Bay Coastal Protection Study (Halcrow Crouch Ltd, 1999);
- Coastal processes and management of Scottish estuaries III: The Dee, Don and Ythan Estuaries, SNH report No.52 (Stapleton and Pethick, 1996);
- Beaches of Northeast Scotland, SNH commissioned report (Ritchie *el al*, 1977)
- Coastal Cells in Scotland; Cell 2 (HR Wallingford, 2000); and
- SEA 5 (Department of Trade and Industry (DTI), 2005).

2. Baseline Description

2.1 Introduction

The Baseline Description provides a basis for assessing the potential impacts that the proposed EOWDC may have upon existing coastal processes during its 22 year lease period. It has been developed through the analysis and interpretation of data and information from a variety of sources. This section has been sub-divided into three categories:

- Seabed, coastal and shoreline features;
- Exposure conditions; and
- Sediment transport.

It should be recognised that the coastal environment responds over different spatial and time scales to both natural changes and anthropogenic interventions. Consequently, the 'baseline' is not static, but will continue to exhibit change with or without the wind farm in place. It is often useful when undertaking impact assessments, to place any scheme-related potential impacts in the context of the envelope of change that can occur naturally. An example of a large-scale natural variation which may produce a large envelope of change is that of climate change, as investigated further in Section 2.3.

2.1.1 Regional Setting

The proposed development is located within Aberdeen Bay, on the east coast of Scotland. It is positioned between 2 and 4.5km offshore. The adjacent coastline adopts a crenulated bay shape with a net northward littoral drift backed by extensive sand dunes. The coastline is intersected by three rivers; the Dee, Don and Ythan (from south to north). Of these, the Ythan is the largest in terms of shoreline length, channel length, core area and intertidal area. The Ythan is classified as a Bar Built estuary, being formed due to the development of sand bars are its mouth. The Dee and the Don are classified as open mouthed Coastal Plain type estuaries, being formed at the end of the last ice age due to the inundation of low-lying coastal river valleys by rising sea levels (ABPmer, 2009).

Aberdeen Bay is an arcuate beach (Ritchie *et al,* 1977) that stretches between the pier at the mouth of the River Don and the rock headland at Forvie. It has been suggested (Buchan & Ritchie, 1979) that Aberdeen Bay takes the form of an equilibrium log spiral bay whose development is modified by anthropogenic interventions, in the form of coastal defences.

To the north, shelter from northerly waves is provided by Peterhead. This results in the predominant wave climate coming from the southerly sectors causing net northerly transport along the shoreline.

It is important to consider both the near-field and far-field study areas, defined as the area within the immediate vicinity of the turbine grid and along the cable route (currently not defined) and the wider coastal environment over which effects due to the development potentially could occur, respectively. It is the consideration within the far-field area that must take due account of potential cumulative and in-combination effects.

2.2 Seabed, Coastal and Shoreline Features

The seabed within, and in the vicinity of, the proposed EOWDC site is relatively featureless, with the exception of a shore-parallel ridge shoreward of the wind farm. Similarly, the sediment type is relatively homogenous (Titan, 2008), and net northwardly transport rates reported to be low (HR Wallingford, 2000).

2.2.1 Bathymetry

The proposed EOWDC site is in relatively shallow water. Admiralty Charts show the depth range to be between 10 and 30m Chart Datum (CD) (Figure 1). Higher resolution data on the bathymetry within the site surveyed in 2007 and 2010 (draft only) has been combined to show variations in depth across the study area (Figure 4). This shows that depths within the wind farm site vary between -10mCD and -35mCD and demonstrates the bathymetric uniformity of the seabed and the gentle sloping gradients from the offshore to nearshore region. The geophysical data collected in 2007 (Emu, 2008a) and 2010 (Osiris, 2010) also shows evidence of a shore-parallel ridge along the shoreline adjacent to the current EOWDC site.

2.2.2 Contemporary Morphology

2.2.2.1 Offshore

The offshore region, including the wind turbine array, is considered to be relatively featureless with regard to large-scale bedforms such as sand waves or sand banks. The geophysical surveys show that bedforms are restricted to the shallower area inshore of the EOWDC site and the seabed can be summarised as flat featureless silty sand.

The geophysical surveys (Emu, 2008b; Osiris, 2010) also show the localised presence of seabed features such as depressions and scar features. Of particular note are two patches of glacial material exposed within seabed depressions that intersect with the western side of the EOWDC towards the southerly end of the proposed development. Overall the seabed gradient in the vicinity of the wind farm site varies between 1 in 7 (nearshore) and 1 in 300 (eastern offshore limit of survey area) (Osiris, 2010).

2.2.2.2 Nearshore

In order to assess the equilibrium position of the shoreline along the Aberdeen Bay frontage the ABPmer Crenulate Bay tool was applied. This approach involves the assumption that the shoreline will tend towards an equilibrium position with respect to the prevailing wave climate (Hsu *et al*., 1989). When the bay is in static equilibrium it has the form of a near tangential straight segment down coast, with a logarithmic-spiral curve which is connected to an almost circular section behind the headland curve. When the coastline is in this stable condition, the tangential section down coast is parallel to wave crests approaching the coast from offshore, so the incoming waves will refract and diffract into the bay, breaking simultaneously along the whole bay (Hsu *et al*., 1989).

Analysis of the shoreline morphology using the ABPmer crenulated bay tool within GIS indicates that in terms of an idealised equilibrium spiral, the coastline is currently seaward of an equilibrium position. This indicates that the shoreline would need to erode to achieve this idealised morphology. The construction of defences south of the Don is in response to this erosive tendency and probably prevents the bay achieving the equilibrium shape. Therefore, the predominant wave angle will continue to be oblique to the down coast straight section, thus resulting in longshore (littoral) drift predominantly in a net northerly direction.

Evidence suggests the presence of (i) glacial material exposed within seabed depressions, in addition to (ii) consolidated glacial material (Emu, 2008b and Osiris, 2010). In the case of the former, these features have been recorded shoreward of the EOWDC site boundary (i.e. between the site and the shoreline) and also in the south-western extent of the site. The latter are located approximately -0.7mCD. It may be expected that these features result from the energetic wave regime which, in these shallower water depths, acts to mobilise the surficial seabed sediments and uncover the glacial material.

The bathymetry recorded by the 2007 and 2010 geophysical surveys shows a monotonically sloping profile, with a single sub-tidal ridge feature in the nearshore zone whose crest is relatively parallel to the shoreline (Figure 4). This ridge is situated around 600m offshore, rises around 0.8m above the surrounding seabed and measures around 150m in width (cross shore). Presently available evidence from navigation charts and the project specific surveys suggest that the ridge feature is present along much of the coast at a depth of between -1.3 and -4.5mCD with an average crest height of around -2.9m. Data from the geophysical surveys (Emu, 2008b; Osiris, 2010) collected using sidescan sonar and a boomer indicates that immediately landward of the ridge, the seabed comprises consolidated glacial material and the ridge itself is made up of sandy/silty material. The latest survey results (2010) provide additional information on the internal structure and dimensions of these features with cross-sections derived from sub bottom profile data. Two cross sections have been taken through the feature and indicate that the ridge is made up of Holocene sediment resting on a till surface (Figure 5; Osiris, 2010). Therefore based on the geophysical evidence, it is determined that the position and shape of this feature is hydrodynamically rather than geologically controlled.

To demonstrate the shape of inter-tidal and nearshore zone, heights from profile A13 have been combined with the offshore bathymetric survey data to produce a single profile extending from the sand dunes through to a depth of around -33mCD at the eastern boundary of the EOWDC site. This cross-shore profile is shown on Figure 4. This data illustrates the prominence of the ridge feature relative to the otherwise flat and relatively featureless seabed.

Elsewhere, long-term analysis of features with a similar shape has shown a continuous cycle of generation, migration and degeneration (van Rijn, 1998; Wijnberg, 1995). In these environments, storm events typically transport sediment offshore, with onshore transport occurring during the intervening calmer periods. This has been observed at Aberdeen Bay in the form of seasonal changes to the beach profile, and as a function of the wave environment. During the winter, sediment is moved offshore and the profile is typically flatter than the summer profile when sediment is available to feed the backshore and allow berm/bar development within the intertidal (Halcrow Crouch Ltd, 1999). Further evidence for this behaviour was recorded during survey measurements of mussel populations (FRS, 2004). This behaviour has also been observed at beaches similar in form to that of Aberdeen Bay (for example, the Netherlands and Sandy Duck, North Carolina). It is not currently clear if this is the mechanism controlling the development of the sub-tidal ridge.

The coverage of the recent geophysical survey (2010) has been chosen specifically to record the sub-tidal ridge adjacent to the current EOWDC site and to investigate in more detail its influence on coastal processes in the study area. It is suggested that this feature provides a sheltering effect to the shoreline from larger wave events and modifies wave characteristics as they approach the shoreline; this is discussed further in Section 2.3.2.5.

2.2.2.3 Shoreline

The cross-shore profile, between mean Low Water (LW) and the base of the dune features, has been described through beach profile surveys (Appendix A). The profiles can be characterised with the following features:

- Steep slope from the dune base for a distance of approximately, 40 to 60m; followed by
- Levelling of the profile.

In some instances, the presence of ridge-runnel features has been identified, for example in Profile A12 and as presented in Figure 6. It is noted that the profiles taken along the Aberdeen Beach frontage are featureless and demonstrate the presence of a gentle sloping shoreline (Figure 6).

2.2.3 Records of Morphological Change

The contemporary morphology results from events that have occurred since the end of the last glaciation, around 10,000 years ago. This has predominantly involved a number of postglacial rises and falls in sea level, which have moved around sediments and formed various features.

Aberdeen Bay is the site for a number of features originating from the last glaciation. These include a ridge, or esker, between the Don and Dee estuaries, raised beaches and shallow inland terraces (Halcrow Crouch Ltd, 1999). During the periods of lower sea level over-deepening of the Don, Dee and Ythan estuaries occurred as a result of fluvial down cutting processes, such that all three displayed a similar morphological form. However, anthropogenic intervention on the River Dee is such that only the Don and Ythan still exhibit features from this form.

2.2.4 Geology

The succession of sedimentary and geological strata encountered within the current EOWDC site has been described through the geophysical surveys (Emu, 2007b and Osiris, 2010); no project specific geotechnical data (boreholes) has yet been collected. It is worth noting that the layers have been more clearly and identified and mapped within the 2010 survey and consequently greater confidence is placed in the results from the northern part of the EOWDC site. The results of the geophysical surveys are summarised below (Emu, 2007b and Osiris, 2010):

- *Superficial Holocene Sediments:* This unit comprises shelly, silty, gravelly sands, this layer is thickest offshore towards the eastern extent of the site with an average thickness of around 8m and a maximum thickness of 10m. In the centre of the site and near the shoreline this unit is thinner reaching a minimum of less than 1m, the exception to this is the nearshore ridge where this sediment unit reaches a thickness of around 5m. In areas near the shoreline this unit is completely absent and the underlying till layers outcrop.

- *Forth Formation:* This unit is expected to comprise fine to coarse shelly sands and the base of this unit reaches a maximum depth of 36m below the seabed in the northwestern edge of the site where it occupies a depression in the underlying bedrock. This unit is absent in areas, most notably where the underlying till outcrops at the seabed surface in the shallower areas landwards of the EOWDC site.

- *Wee Bankie Formation:* This unit is a glacial till deposit and is expected to comprise of stiff generally sandy, gravelly clay. As mentioned earlier, this unit occasionally outcrops at the seabed and has been identified under most of the wind farm site except for the NW corner. Of note is a WNW-ESE trending ridge measuring approximately 2km in length and 150m in width in the eastern part of the survey area (Osiris, 2010). It is possible that this feature is a terminal or recessional moraine, possibly the result of a seasonal glacial advance (Osiris, 2010).

- *Bedrock*: The bedrock within the EOWDC site is thought to be Devonian sandstone. The depths of this bedrock vary from 30m below CD (in the west) to 64m below CD (in the east).

The geology present along the Aberdeen Bay coastline is composed of (HR Wallingford, 2000):

- River Dee to Balmedie. Fluvio-glacial sands and gravels which in turn overlay the bedrock;
- River Dee to Collieston. Extensive post-glacial blown sand deposits overlay the fluvio-glacial deposits;
- Collieston to Peterhead. Erosion resistant cliffs; and
- Collieston to Peterhead. Thin layer of boulder clay with morainic drift interspersed.

2.3 Hydrodynamic Regime

It is the combination of the tidal and wave regimes that form the hydrodynamic regime, and provide forcings and controls upon the sedimentological regime (sediment transport; morphological features). These can also be known as the exposure conditions, and are discussed, with relevance to the proposed EOWDC site, in the following sections.

2.3.1 Tides

The tidal regime is defined here as the behaviour of bulk water movements driven by the action of tides and non-tidal influences, such as river flows and meteorological conditions (e.g. winds, atmospheric pressure and storm events). The baseline tidal regime has been characterised in terms of:

- Water elevations (due to tidal patterns, non-tidal influences and sea level rise); and
- Currents (due to both tidal and non-tidal influences).

The baseline is defined not only by the present coastal process characteristics, but also by any natural changes in key processes or morphological features that might be anticipated over the operation life of the scheme. This provides context for comparing scheme-related changes against the natural variability within the coastal system.

2.3.1.1 Water elevations

Astronomical Tidal Influences

Regional summary information on tidal levels in the Aberdeen area is available from the UKHO Co-tidal Chart (UKHO Chart No. 5058) and the Renewables Atlas (ABPmer *et al.*, 2008). This information shows that tidal conditions within the North Sea are governed by a tidal amphidrome (a nodal position with zero tidal influence) situated south-west of Stavanger in Norway approximately 450km from the study area. The tide enters the study area from the north and travels in a southerly direction through the region.

The primary source of measured data relating to water levels within the array, is the site specific data collected by Emu using an AWAC at a single location in the southwest of the site (see Figure 3 for location) between 12 September 2007 and 13 February 2008 with 154 days of good quality data (Emu, 2008a). The data collected between 12 September and 1 November 2007 underwent tidal harmonic analysis by Emu (Emu, 2008a), a summary of the basic parameters derived is provided in Table 3. The tidal regime is semi-diurnal and follows a spring-neap cycle. During spring tides the tidal regime is mesotidal and during neap tides it is microtidal.

For the purposes of comparison the tidal parameters for Aberdeen Harbour (approximately 8.9km from the AWAC) are presented in Table 4, these are sourced from the United Kingdom Hydrographic Office (UKHO, 2009) and are based on tidal measurements collected between 1988 and 2007.

When comparing the data from Table 3 and 4 it is important to consider the tidal ranges as opposed to the absolute heights, this is because the two datasets are quoted to a slightly different datum, are from two different locations (approximately 8.9km) and represent statistical values for different periods of data. Overall the data in Tables 3 and 4 indicate that slightly higher tidal levels are found at Aberdeen Harbour with a difference of approximately 0.2m.

Table 3. Derived tidal parameters

Parameter	Height Relative to LAT (m)
Highest Astronomical Tide (HAT)	4.6
Mean High Water Springs (MHWS)	4.1
Mean High Water Neaps (MHWN)	3.2
Mean Sea Level (MSL)	2.4
Mean Low Water Neaps (MLWN)	1.5
Mean Low Water Springs (MLWS)	0.7
Lowest Astronomical Tides (LAT)	0.0
Parameter	Ranges (m)
Spring Tidal Range (MHWS - MLWS)	3.4
Neap Tidal Range (MHWN - MLWN)	1.7
Largest Tidal Range (HAT - LAT)	4.6

(Emu, 2008a)

Table 4. Tidal characteristics at Aberdeen Harbour

Parameter	Height Relative to CD (m)
Highest Astronomical Tide (HAT)	4.9
Mean High Water Springs (MHWS)	4.3
Mean High Water Neaps (MHWN)	3.4
Mean Sea Level (MSL)	2.6
Mean Low Water Neaps (MLWN)	1.6
Mean Low Water Springs (MLWS)	0.6
Lowest Astronomical Tides (LAT)	0.1
Parameter	Ranges (m)
Spring Tidal Range (MHWS - MLWS)	3.7
Neap Tidal Range (MHWN - MLWN)	1.8
Largest Tidal Range (HAT - LAT)	4.8

Climate Change Effects on Mean Sea Level

Tidal levels will also be affected over the lifetime of the development by relative sea level rise. Over relatively short time periods (e.g. months) the tidal signal can be regarded as varying relative to a stationary level, referred to as mean sea level (MSL). However, over longer time periods (e.g. several years) MSL varies in response to both long period tidal trends (e.g. 18.6 year lunar nodal cycle) and sea level rise over geological timescales.

Past and anticipated future changes in relative sea level in the study area will be the result of the interaction between a number of mechanisms, as follows:

- Eustatic changes: these changes in absolute water elevation tend to be relatively uniform geographically and are caused, for example, by glacio-eustacy (ice melt) or thermal expansion (changes in water volume due to warming); and

- Local changes: these are due to changes (both positive and negative) in the elevation of the land surface. Such changes are likely to be the result of isostatic adjustments (changes in land elevations due to the redistribution of weight on the land surface e.g. due to glacier ice). In Scotland the land is rising due to isostatic adjustment.

The relative rate of sea level rise will therefore be made up of a component of both eustatic changes in sea level and local changes due to isostatic land movements. The most recent climate change data is available from the UKCP09 which provides modelled future changes to sea level as a result of both climate change and isostatic land movement under a range of emission scenarios. The relative sea level rise during the lifetime of the development for a medium emissions scenario at a 50 percentile level is shown in Table 5 relative to 2010.

Table 5. Modelled sea level rise during the lease period of the EOWDC relative to 2010 (UKCP09)

Year	Relative Sea Level Rise (m)
2020	0.025
2040	0.083

Non-tidal Influences

Superimposed on the regular tidal behaviour, various random non-tidal effects may be present. Many of these non-tidal effects originate from meteorological influences. Persistent winds can generate wind-driven currents, set-up water levels and develop sea states that lead to wind-wave generation. Atmospheric pressure variations can also depress or raise the water surface to generate positive or negative surges, respectively.

Surges are formed by rapid changes in atmospheric pressure with an inverse relationship, i.e. low atmospheric pressure raises the water surface (positive surge) and high atmospheric pressure depresses the water surface (negative surge). These effects can cause water levels to fluctuate considerably above or below the predicted tidal level.

The North Sea is particularly susceptible to storm surges and there is a long history of such events, with recorded evidence ranging back to at least the 13th Century (van Malde, 1997). Dixon & Tawn (1995) defined water levels for a number of return periods based on the analysis of the tide gauge record at Aberdeen Harbour, the results of this analysis are shown in Table 6.

Table 6. Return levels for 1990 based on tidal gauge records

Return Period Level m Above Chart Datum (mACD)							
1 in 10 year	1 in 25 year	1 in 50 year	1 in 100 year	1 in 250 year	1 in 500 year	1 in 1,000 year	1 in 10,000 year
5.09 (0.019)	5.20 (0.030)	5.27 (0.038)	5.37 (0.057)	5.47 (0.082)	5.53 (0.100)	5.61 (0.126)	5.85 (0.233)
Brackets Denotes standard error							

(Dixon and Tawn, 1995)

2.3.1.2 Currents

Currents across the study area vary temporally as a function of the tide and tidal range. In addition, non-tidal effects may alter tidal currents, for example effects from river discharge, wind or lateral density currents. In general, the significance of such non-tidal effects is more likely to be evident during periods of neap tides when the tidal signal is at its weakest. In order to investigate the tidal current flows across the study area, the Danish Hydraulic Institute (DHI) MIKE21-FM model has been used.

Plots from the model at both peak flood and peak ebb are shown in Figure 7A and B. The tidal regime in Aberdeen Bay exhibits the characteristics of a standing oscillation whereby the peak flow occurs approximately 1.5 hours before high and low water and slack water occurs at roughly mid-tide. Because of this Figure 7A shows tidal velocities at around high water and Figure 7B shows tidal velocities at around low water. The plots show that peak speeds vary between 0.3 and 0.6m/s within the proposed EOWDC site and decrease in magnitude towards the shoreline. During the flood, the tidal vectors are directed towards the south-southwest and towards the north-northeast during the ebb, this axis is also reflected in the tidal ellipses shown in Figure 2. Figure 2 also shows a tidal excursion distance of around 900m during a mean spring tidal event.

The near-field current regime, as measured during the survey campaign, supports the far-field pattern. The maximum near-surface (~21m above the seabed at the AWAC location) current recorded over the deployment period was of the order of 1.1m/s, whilst the minimum current recorded was 0m/s recorded during slack water. Average bed speeds recorded are approximately 0.22m/s for each whilst average surface speeds are approximately 0.33m/s. Current speeds and directions at the near-surface are presented graphically as a current rose and a scatter plot in Figure 8. This indicates that the surface currents are fairly rectilinear, orientated along a south-southwest to north-northeast axis. Scatter plots from the mid and lower water column (approximately 11 and 2m above the seabed, respectively) show that the level of scatter reduces from that recorded near the water surface, with lower velocities decreasing and the rectilinear nature of the currents increasing (Figure 9).

The timeseries shows that the current velocities generally exhibit variations relative to the spring-neap tidal cycle, however in places this cycle is disrupted during storm events showing the relative importance of wave and wind processes in this area. However, during these events the AWAC also shows some unusual behaviour with evidence of the frame moving and possible recording of erroneous values during these episodes. Because of this data from the AWAC must be considered with caution in this study, especially with respect to the recorded current velocities.

2.3.2 Wave Regime

The establishment of a baseline wave regime allows any changes that could occur during the construction and operation of the wind farm to be assessed and placed in context of the existing regime. Changes to the wave regime may result in the alteration of patterns of accretion and erosion and changes to littoral transport along the shoreline. The wave regime is defined here as the combination of swell waves moving into, and propagating through, the study area (having been generated remotely from the area) and more locally generated wind-waves. The proposed EOWDC site is exposed to a large swell window with large fetches from the sector extending from the southeast to the northeast. The headland at Peterhead offers some shelter from the north resulting in a predominantly southerly wave direction within Aberdeen Bay.

2.3.2.1 Offshore waves

Generalised wave data (based on 10-year averages) was extracted from the Marine Renewables Atlas (ABPmer *et al*, 2008), the location of the grid cell was around 34km to the east of the proposed EOWDC site in a water depth of between 50 and 100mCD.

A wave rose produced from this data demonstrates the dominant northerly wave axis, although waves are also common from all sectors ranging from north to the southwest (Figure 10). Relatively few waves are recorded from the westerly sectors due to the sheltering effect of the Scottish coast and hence the reduced fetch distance in this direction.

2.3.2.2 Nearshore waves

As offshore waves move from deep water into shallower water a number of important modifications occur as they begin to interact with the seabed and the coast. These are:

- Sheltering due to the orientation of the coast (the headland at Peterhead)
- Shoaling and refraction (due to both depth and current);
- Energy loss due to breaking (shoreward of the development);
- Energy loss due to bottom friction; and
- Momentum and mass transport effects.

Waves affected in this way are normally termed shallow water waves.

The data collected by Emu in 2007 within the site is shown in Figure 11A as a wave rose which relates significant wave height to peak coming direction and shows that waves tend to arrive from the northeast to south sectors, this is co-incident with the sites exposure with shelter provided by Buchan Ness to the north and the Aberdeen coast to the west. The data from offshore (Section 2.3.2.1) shows that the offshore wave climate includes a significant component from the north which is not apparent in the AWAC dataset, further illustrating the importance of the headland at Peterhead in sheltering the site from these northerly wave events. A frequency analysis of significant wave height (in bins of 0.5m) versus peak wave direction (in bins of 45º) shows that:

- The primary direction for waves is from the southeast (112.5-157.5ºN) direction; and
- The largest waves occur from the easterly direction (67.5 and 112.5ºN).

Further frequency analysis of significant wave height against zero up crossing wave period shows that:

- The most frequent wave period is in the range of 4 to 4.5s, accounting for approximately 30% of all waves. There are no waves recorded with a period of more than 7.25s; and

- More than 45% of wave heights are between 0.5 to 1.0m whilst the largest waves recorded are approximately 5.5m.

These relatively short wave periods indicate that much of the wave climate measured at the AWAC is locally generated storm swell as opposed to swell propagating into the area.

The depth of closure can be defined as the depth beyond which no significant transport of sediment occurs due to littoral processes and therefore can be defined as the seaward boundary of the littoral zone (Mangor, 2004). The depth of closure can be estimated based on equations by Hallermeier (1978 and 1981) and Birkemeier (1985) which takes into account the significant wave height exceeded 12 hours per year (here taken to be the 1 in 1 year extreme event in Table 7) and the typical sediment density. When this equation is applied to the annual storm wave event (6m and 12.2s) the depth of closure is between 9 and 12m. This means that the typical wave event only influences littoral transport processes in depths of less than, approximately 10m and therefore may intersect with the shoreward part of the wind farm.

2.3.2.3 Comparison of AWAC to a long-term dataset

Some caution should be expressed when considering the above results, as the short-term deployment may not necessarily be representative of the longer-term conditions. With awareness of this, analysis was undertaken to determine whether the data collected within the vicinity of the proposed wind farm site would sufficiently represent the range of results expected over a longer time scale.

To address this, wave data was extracted from the MIKE spectral wave (SW) model at the same location as the Emu AWAC, the data extended over a 30 year period (1979-2009) and was driven by spatially varying wind data sourced from the Climate Forecast System Reanalysis (CFSR) developed by the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Prediction (NCEP). Thus, an analysis of the longer-term offshore wave record from the CFSR was compared with the Emu data, the data sets overlap sufficiently between November 2007 and January 2008 to enable a direct comparison to be made between the data sets.

CFSR was chosen in preference to the Met Office archive data for the following reasons:

- The Met Office data are an archive of operational forecast data and therefore:
  - Can not have made as good use of forward looking measured data assimilation; and
  - Is affected by operational dropouts resulting in some data gaps.

- The Met Office can provide either 20 years of data at 3 hourly intervals or 10 years of data at hourly intervals. The CFSR provides 30 years of data at hourly intervals; and

- Met Office data are typically used as a time-series of wind and wave parameters at one location only. If the data are used at face value, this limits the options available to achieve good model calibration.

Firstly comparison can be made using the wave roses from the AWAC (Figure 11A) and CFSR (Figure 11B). These figures indicate that the wave directions captured by the AWAC are very similar to those captured over a longer timescale from the CFSR data with the principal wave direction from the southeast and all waves approaching from sectors ranging from northeast to the south. A detailed frequency analysis was undertaken between the wave height and wave direction, from which it is evident that:

- The primary direction for offshore waves is from the south to northeasterly sectors in particular the southeasterly sector; and
- The largest waves occur from the easterly direction between 67.5 and 112.5Nº.

This frequency analysis further shows that the AWAC has collected a representative dataset in terms of direction during its shorter deployment.

Key Events

It is considered that for the purpose of this assessment, a wave height that is only exceeded 5% per annum is necessary to adequately represent low-frequency, high-energy oceanographic conditions at the proposed site (but probably not adequate in terms of engineering design parameters).

Analysis of the CFSR wave frequency data over the 30 year period shows that this wave height falls within the 3 to 3.5m bin and analysis of the shorter AWAC dataset shows that the maximum wave height falls within the 5 to 5.5m bin indicating that the AWAC has captured a storm event of sufficient magnitude.

A number of key events have been identified to ensure that the data not only represented a sufficient magnitude in terms of significant wave heights, but also contained a range of different episodes. Thus, waves with a significant wave height above the 5% exceedance level were recorded as a key event. In total, four key events have been identified. It is shown that the metocean data collected in the proposed area contains a sufficient number of wave events covering a variety of directions, wave heights and tidal ranges.

2.3.2.4 Extremes analysis

Although it has been established that the AWAC has sufficiently characterised the wave climate over a relatively short deployment period, the record is too short to enable the adequate derivation of extremes. Because of this the CFSR data has been used to calculate extreme wave events, the most frequent and severe wave events are summarised in Table 7.

Table 7. Extreme wave events from analysis of CFSR data

Return Period (yr)	30ºN		90°N		135ºN	
	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp(s)
0.1	2.1	7.3	4.9	11.0	4.3	10.4
1	2.6	8.1	6.0	12.2	5.4	11.6
10	3.1	8.8	6.8	13.0	6.1	12.3
50	3.4	9.2	7.2	13.4	6.4	12.6
100	3.6	9.4	7.3	13.5	6.5	12.7

2.3.2.5 Assessment of influence of near-shore ridge on the wave climate

The nearshore region of the study area is characterised by a shore-parallel ridge. This ridge extends along much of the sub-tidal adjacent to the EOWDC, with a maximum crest height of around -1.3mCD and an average height of around -2.9mCD. The ridge is nearly absent in one location towards the north of the EOWDC, at this point the depth reaches -4.5mCD.

To assess the influence of this ridge on the propagation of waves, a series of equations have been applied to a relatively common storm wave event (10 in 1 year) under the following scenarios during both a MHWS and a MLWS tide:

- Maximum ridge height: -1.3mCD;
- Average ridge height: -2.9mCD; and
- No ridge: -5.0mCD.

In addition, wave statistics have been calculated at the AWAC site to provide a further means of comparison.

The wave event used is based on the analysis of the longterm wave record from CFSR at the location of the Emu AWAC (see Section 2.3.2.4) and is defined as follows:

- Significant wave height (Hs) of 2.1m;
- Peak period (Tp) of 7.3s; and
- Approach angle of 45°.

These parameters were then used with the University of Delaware Wave Calculator (http://www.coastal.udel.edu/faculty/rad/wavetheory.html) to calculate the potential impacts of the bathymetry on wave angle, wave height and bed velocity. This application was developed by Robert Dalrymple and the calculations are based on the dispersion relationship for progressive linear water waves and Snell's Law for straight and parallel offshore contours (Dean and Dalrymple, 1994). The results of this analysis are summarised within Table 8.

The results of this analysis indicate the significance of the shore-parallel ridge on wave propagation, with the maximum ridge height scenario causing the waves to refract by 30° and the hypothetical scenario without the ridge in place causing the waves to refract by only 20° (during a MLWS tide). The ridge also impacts on wave heights whereby the resultant wave heights indicate that waves are likely to break over the shore-parallel ridge but would not break without the ridge during a MLWS tide.

Table 8. Summary of changes to the wave climate

Scenario	Water Depth (m)	Wave Angle (°)	Resultant Wave Height (m)	Bed Velocity (m/s)
MHWS maximum ridge height	5.6	25	1.8	1.0
MHWS average ridge height	7.2	28	1.8	0.8
MHWS no ridge	9.3	32	1.8	0.7
MHWS AWAC site	26.5	43	2.0	0.2
MLWS maximum ridge height	1.9	15	1.5 (breaking)	1.6
MLWS average ridge height	3.5	20	1.9	1.5
MLWS no ridge	5.6	25	1.8	1.0
MLWS AWAC site	22.8	42	1.9	0.3

The implication of this is that the shore-parallel ridge modifies waves before they reach the shoreline, this impact is greatest during a low tide event where the water is shallower. This will also have implications for sediment transport with greater seabed velocities and hence a greater potential for sediment transport at the crest of the shore-parallel ridge.

It was noted in Section 2.3.2.2 that the depth of closure is between 9 and 12m and therefore the shore parallel ridge is within the zone of littoral transport.

2.3.2.6 Climate change effects on waves

It is possible that climate change could impact on the present day wave regime in the future. Modelling as part of the UKCIP09 (Lowe *et al*, 2009) currently gives the best projection of the likely future wave climate in the region of EOWDC. The modelled future changes to mean annual and winter maxima of significant wave height around the UK is shown in Figure 12 and shows that a reduction of, approximately, 0.25 to 0.5m is predicted in the region of the EOWDC.

2.4 Sediment Regime

The contemporary sediment regime within the study area comprises:

- Beach sediments;
- Seabed surface sediments; and
- Sediments suspended in the water column.

The behaviour of these sediment populations is dependent upon their respective response to the forcing conditions (waves; currents). Over the longer-term, the sediment behaviour will determine the morphological development of the area.

Sediment mobilisation occurs when the hydrodynamic conditions exert a shear stress that exceeds a threshold relevant to the specific material type. When the shear stresses then fall below this threshold, the material begins to fall out of suspension and is deposited. Finer sized materials are typically suspended at lower shear stresses than coarser sized sediments, and thus are likely to remain in the water column over longer periods of time. It is more likely that the coarser materials are transported as bedload. The forcing mechanisms responsible for the mobilisation and transport of these different sediment sizes may vary over spatial and temporal scales.

The consideration of the sediment regime over the study area is an important aspect of the impact assessment of the proposed development upon coastal processes. To describe the sediment regime and evaluate any potential changes resulting from the proposed EOWDC, the following issues have been considered:

- Composition and distribution of seabed sediments across the proposed EOWDC site and the wider far-field study area;
- Sediment transport pathways in the vicinity of the proposed site in the form of a conceptual understanding of the sediment regime; and
- Key process controls on sediment mobility and thresholds of sediment motion.

2.4.1 Seabed Sediment Composition and Distribution

From a consideration of the available data and literature sources it is possible to make an assessment of the seabed surface sediments (Figure 13). BGS provide a large scale representation of the offshore seabed material, with detail of sediment texture provided by geophysical surveys (Emu; 2008b and Osiris, 2010) and sediment samples situated to the south of the site (collected by FRS in April 2006; presented in Titan, 2008) and within the site (collected by CMACS in 2010). It is noted that BGS information does not provide information on the sediments on the beach and intertidal zones and within the nearshore area the sediment type is described by samples taken by ABPmer along the beach fronting the recent works at Aberdeen Beach and during project specific surveys for this investigation (Appendix A).

Regionally, the BGS mapping shows that sediment coverage within Aberdeen Bay is mainly sand and coarsens in an offshore direction. The grab samples taken within the vicinity of the site (collected by FRS and CMACS) also show that the predominant sediment is sand but also identifies small proportions of gravel (<1%) and mud (<40%) in the vicinity of the proposed EOWDC site. It is important to note that the samples taken in 2006 and 2010 do not entirely agree, the 2006 samples tend to exhibit a combination of sands (60 - 97%) and fines (3 - 40%) whereas the 2010 samples show a coarser sediment with both gravels (<1%), sands (86 - 99% and only a relatively small proportion of mud (1 - 14%). This disparity is likely to be due to different sampling and measuring techniques, although preceding wave conditions may also influence the surface sediments. Overall, it can be concluded from the various sources of data that seabed sediments are predominantly sand with some mud and gravel in places.

Along the shoreline the grab samples show that sediments are almost entirely sand with some gravel (ranging between 1 and 43%) in the samples towards the southern end of the bay (Figure 13). This demonstrates a pattern of reduced sediment size in the net direction of littoral transport towards the north.

2.4.2 Suspended Sediments

Indices of suspended sediment concentrations (SSC) were collected using both Optical Back Scatter (OBS) and Acoustic Back Scatter (ABS) data. The OBS unit was mounted 0.6m above the seabed and recorded changes in sediment concentrations by producing a pulse of light and measuring the resultant intensity of the reflected light from any suspended sediment. The ABS data was collected using the acoustic signal from the AWAC and has been supplied in bins depending at various heights above the seabed. In general an OBS will respond more to finer particles whereas an ABS will respond to coarser particles. Both datasets were converted to absolute values (mg/l) using water samples, full details on the methodology can be viewed in Emu (2008a). A review of the processing methodology (in so far as allowed by the available information) shows that the following:

- The relationship between SSC from water samples and the OBS count is fairly weak and the regression line used may have been forced to fit the origin of the line to zero; and
- Additional water samples from an unspecified source were used to calibrate the higher suspended sediment values for the ABS due to a lack of water samples at these higher concentrations.

As a result of the above, the data presented below has some uncertainty associated with it, especially at higher concentrations. No uncertainty values have been supplied so it is difficult to assign a confidence level to the available data.

ABS data from immediately above the seabed, the mid water column and the near-surface were analysed and the response of SSC was compared to both the current velocities and significant wave height to identify the principal forcing condition causing the suspension of sediments. This analysis indicated that out of the three bins the near bed values were most reliable with the other bins displaying an unusual lower threshold and anomalous high levels of suspended sediments when compared to the lower bin. This is likely to be due to the distance of the sensor from the mid and upper part of the water column and therefore the following analysis discusses the values from bin 2 only (1.5 to 2m) above the seabed.

It is shown that near bed suspended sediment concentrations varied between 0.1 and 43.1 mg/l, with an average value of 20.7 mg/l (Figure 14A). These SSC showed a similar response to both tidal currents (Figure 14B) and significant wave height (Figure 14C) showing that energy from both wave processes and tidal processes are important in the suspension of particulate matter at the seabed.

The OBS data record (Figure 15A) was shorter than the ABS with a significant proportion showing no data return, in addition to this the sensor data is less stable than the ABS with probable sensor overload between 26 September 2007 and the 2 October 2007 and between 27 October 2007 and the 1 November 2007 resulting in excessively high values of SSC during these time periods (Emu, 2008a). It has been suggested that the second period of elevated SSC are a response to a storm event (identified from rapidly fluctuating residuals in the tidal record) although the absolute levels are excessive and may also result from sensor degradation (Emu, 2008a). Correlation of these elevated levels of SSC with wave events is not possible as the two datasets do not coincide.

Analysis of the OBS data collected between 15 December 2007 and 22 December 2007 shows values ranging between 2.0 and 28.4mg/l and an average of 6mg/l. When compared to the near bed ABS values over the same period, this showed a good agreement between thee two datasets in terms of absolute SSC.

With regard to the OBS data, the SSC recorded by the OBS was compared (where available) to the concurrent current (Figure 15B) and wave regime (Figure 15C) to identify the forcing mechanisms responsible for the suspension of sediments, this comparison showed a relatively strong correlation between SSC levels and significant wave height.

The predominant sandy nature of the beach sediments suggests that any riverine sediment input is likely to be relatively small in the context of the overall sediment regime. A discussion of the relative contributions of the rivers within the study area to the sediment regime within Aberdeen Bay is provided in Section 2.4.3.3.

2.4.3 Conceptual Understanding of Sediment Regime

The sediment regime can be divided into the behaviour which occurs in the different coastal zones:

- Offshore;
- Shoreline, or littoral; and
- Estuarine.

2.4.3.1 Offshore sediment transport

Transport Pathways

Evidence from the asymmetry of bedforms indicates that offshore bedload sediment transport is directed in a northerly direction towards a bedload convergence zone which is situated to the south of Peterhead (BGS, 1984). These sandwaves have maximum heights of over 10m and average wavelengths of around 200m (BGS, 1984). It has been shown that the asymmetry and orientation of these features is consistent with the direction of the tidal currents indicating that the offshore sediment transport regime is controlled principally by tides (BGS, 1984; Kenyon & Cooper, 2004).

Further analysis of the AWAC tidal velocity data in the context of a typical sand particle (150 µm) shows a tidal asymmetry towards the north at the seabed resulting in a net northerly transport of seabed sediment within the proposed EOWDC site. This potential for transport is very small with a potential transport distance of less than 300m during the entire AWAC record; it is important to remember that this analysis does not take into account transport due to waves. This direction of transport is in agreement with the regional understanding previously presented.

Source / Sink Relationship

As discussed in Section 2.4.1, the seabed comprises mainly Holocene sands and therefore represents a large potential source of sediment. However there is little evidence of any large transfer of sediment between the nearshore and offshore environments.

2.4.3.2 Sediment transport along the shoreline

Transport Pathways

In the context of the overall hydrodynamic regime, tidal currents in the littoral zone are relatively weak and modelling studies (ABPmer, 2006) have shown that tidal currents alone are insufficient to mobilise beach sediments although, at times of high water, tidal processes may also contribute (Halcrow Crouch Ltd, 1999). Therefore, wave processes provide the overall dominant form of transport in the nearshore area.

The analysis of wave data collected by Emu (Emu, 2008a) has shown that the most common wave direction is from southeast, although waves are also common from the sector between southeast and the northeast (see Section 2.3.2). The southeast wave direction results in a net northerly direction of transport as evidenced by the numerous small streams along the embayment that have been deflected to the north due to the deposition of sediment at the mouths. However, the southerly orientation of a spit across the mouth of the River Ythan at the northerly end of the bay indicates the potential for localised net southerly directed littoral transport in this part of the bay. In addition the orientation of the coast at the southern end of the bay (immediately north of the Dee estuary) results in wave refraction causing a localised southerly sediment transport pathway which carries sediment into the mouth of the Dee estuary (Stapleton and Pethick, 1996)

The rate of littoral transport decreases towards the north of Aberdeen Bay as a consequence of its changing alignment, this is due to a partially developed log-spiral morphology (Section 2.2.2), this is reflected in the fining of beach sediment towards the north as recorded in the ABPmer survey (Appendix A). However, under extreme storm events, the potential alongshore transport potential is much greater in the north of the bay than the south (Stapleton & Pethick, 1996). Estimates of rates of longshore transport are not available from the literature although modelling by ABPmer (2006) along the coastline between Aberdeen Harbour and the River Don indicates that potential transport rates can reach above $900m^3/yr$. Due to the lack of longshore transport data, this model was not calibrated with respect to transport rates. This potential rate will reduce to the north due to the changing orientation of the beach.

Aberdeen Bay is characterised by dune backed sandy beaches. Sediment exchange occurs between the dunes and the beaches as a consequence of aeolian transport. Analysis of wind data from the Met Office between December 2005 and January 2009 shows that the most common wind direction is from the south, accounting for around 17% of the wind record. It is also from this direction that the largest winds originate. Due to the beach orientation, this predominant wind direction will facilitate the transfer of sediments between the beach and the dunes indicating that the dune could be a sink for sand sized material. It is reported that material in the range 70µm and 152µm will be transported between these features (Halcrow, 1999). The sediment contained within the dunes is released onto the beach under periods of high wave activity.

Source / Sink Relationship

As outlined above sediment is exchanged between the dune and the beach with the beach supplying sediment to the dunes under 'normal' wind and wave activity. This sediment is then released back onto the beach during storm events through wave erosion. The overall erosion of the beach indicates that current sources of sediment are not adequate to maintain the beach profile this is probably due to the limited transfer of sediment from offshore.

2.4.3.3 Sediment transport at estuary mouths

Transport Pathways

The contemporary sediment transport pathways around the Don and Ythan estuaries are complex due to the interaction of riverine, tidal and wave effects (Halcrow Crouch Ltd, 1999). The Don is currently characterised by a spit at its mouth, formed in the direction of the net littoral drift, whose growth occurs from sediment transported from alongshore, and also from the onshore movement of the nearshore bars. Both spits and bars are presently found at the mouth of the Ythan with sediment predominantly transported into the waterway, resulting in the growth of intertidal areas (Halcrow Crouch Ltd, 1999). It has also been reported that the Ythan represents a semi-closed system in which sediment is transported from the western peninsula via the river onto the spits and bars and ultimately onto the estuary mouth spits and bars for transport onto the foreshore (Weatherhill, 1980).

Limited suspended sediment data could be found detailing the amount of sediment supplied to the system via fluvial flows from the three rivers. Relative values derived from sampling, at predominately monthly intervals, between 1975 and 1983 indicates that the annual sediment yield is of the order of 9.6, 18.4 and 17.8 tonnes / km^2 for the Rivers Ythan, Don and Dee, respectively. The respective catchments for these rivers are 448, 1273 and 1844 km^2 (McManus and Duck, 1996). It is considered that, typically, the riverine sediment load is likely to be fine sediments.

Source / Sink Relationship

Sediment data within these three estuaries is limited although the estuaries are likely to sinks for both fine and sand sized material from river and marine sources, respectively. The periodic dredging within the Dee confirms that the estuary is a sink (Stapleton and Pethick, 1996).

2.4.4 Process Controls on Sediment Mobility

Sediment transport is under the control of both waves and tides, with the relative contribution dependent upon the strength of the processes and the relative water depth (Soulsby, 1987). Typically, tidal processes dominate sediment transport in the deeper water depths and waves control this process in the shallower regions. It is noted that the long-term sediment transport is not under the control of extreme events, but rather by "fairly large, but not infrequent, waves superimposed on currents lying roughly between the peak speeds of mean neap and mean spring tides" (Soulsby, 1987).

An assessment has been made of sediment mobility within the proposed EOWDC site by identifying the modal sizes of all available sediments, derived from grab sample data, and calculating the combined wave and tide bed shear stresses required to initiate transport (using standard methods described in Soulsby, 1997). The purpose of this assessment is to determine the relative importance of tidal and wave processes in mobilising sediments within the wind farm area and also the amount of time these sediments are mobile during a tidal cycle.

A review of the grab sample data collected by FRS and CMACS has shown that the sediments within the proposed EOWDC site are largely comprised of sand with a lesser (but still significant) fine component. An analysis of the modal sizes of sediment has shown that the typical size of sand sediment is around 150µm (with some modal sizes being slightly smaller and some slightly larger). In terms of the mode, the finer fraction (<63µm) is not represented but still represents a component of the overall sediment composition (accounting for between 4 and 26% of the sample composition). Further analysis of this finer component shows that the majority of this sediment is at the upper end of this fraction and a representative size of 60µm has been chosen. As the fine component is likely to have cohesive properties and the equations used for this analysis relate to non-cohesive sediments the results for the 60µm sediment will be conservative. The consideration of the 60µm sediment also offers a conservative representation of the sand sediments as some grab samples had a modal size of less than 150µm.

The results of this analysis are depicted as a time series for the duration of the AWAC deployment (Figure 16) and as a ranked plot showing the percentage exceedence during which a particular sediment particle is mobilised (Figure 16). From these figures the following can be concluded:

- Waves increase the shear stress exerted on the seabed when compared to currents alone showing that waves contribute to the mobilisation of bed sediments;

- During times of lower wave activity, the resultant bed shear stress is also lower (Figure 16); and

- When taking into account both tides and waves (mean tau) recorded during the project specific metocean campaign, both the 60 and 150 micron sediments have limited mobility. The smaller sediments are mobile for longer periods of time than the larger. The presence of finer material provides a form of armouring on the seabed. It can be concluded therefore that the seabed sediment transport regime within the wind farm boundary is not particularly active with respect to these size fractions.

The relative lack of significantly sized bedforms within the area is probably due to a combination of weak tidal currents not creating bedforms and wave events flattening the seabed during storm events.

3. Summary of Baseline Assessment

3.1 Background

The EOWDC is proposed for development within Aberdeen Bay, between 2 and 4.5km offshore comprising 11 turbines, a Request for Scoping Opinion was distributed in August 2010 for consultation (AOWFL, 2010), against which four responses have been received. All four responses raised concerns regarding the potential effects of the proposed development upon the existing coastal processes. These include for effects upon the tides and waves and associated effects upon the sediment regime, both within the array and along the shoreline.

The first stage in the determination of the potential effects of the EOWDC upon the coastal processes is the assessment of baseline, or pre-development, conditions. This report draws upon all available, and relevant, data and information sources and presents the coastal process regime.

3.2 Cumulative and In-combination Effects

There are no other marine activities or European sites within one tidal excursion of the proposed EOWDC site that will require assessment for cumulative or in-combination effects. In-direct effects upon the European sites to the north of Aberdeen Bay (Figure 2) will be considered.

3.3 Data Availability and Suitability

There are a number of project specific surveys which can be used to determine the coastal process regime within the wind farm array and over the near-field. These include bathymetric, benthic, geophysical and metocean surveys. With the exception of the metocean survey, the other surveys were undertaken for both the previous (2007) and the current (2010) site locations, such that data exists for an area larger than the EOWDC turbine array.

A review of the geophysical data has shown some issues of consistency between the two surveys relating to both the bathymetry and the classification of seabed types due to different processing methods.

Some caution should be used when applying the results of the metocean surveys (Emu, 2008a) as there is some evidence that some of the recorded parameters may be subject to error.

The project specific surveys support other data sources which are considered more high-level, or broad-scale, in their coverage providing regional, or far-field, information.

3.4 Baseline Coastal Process Regime

The proposed EOWDC is located within Aberdeen Bay, on the east coast of Scotland. Aberdeen Bay is characterised by dune backed sandy beaches which undergo some aeolian transport. Sediment is exchanged between the dune and the beach, with the beach supplying sediment to the dunes under 'normal' wind and wave activity. This sediment is then released back onto the beach during storm events through wave erosion. The overall erosion of the beach indicates that current sources of sediment are not adequate to maintain the beach profile this is probably due to the limited transfer of sediment from offshore.

The proposed development is located between 2 and 4.5km offshore in water depths ranging from 10 to 30mCD. The seabed has a gentle gradient from the offshore to the shoreline, which increases in a shoreward direction. There is no evidence of large-scale bedform features within the proposed EOWDC site and towards the shore, with the exception of a shore-parallel ridge. This ridge extends along much of the sub-tidal adjacent to the EOWDC, with an average height of around -2.9mCD. The ridge is nearly absent in only one location towards the north of the EOWDC where the water depth reaches -4.5mCD. The ridge acts to modify waves before they reach the shoreline and is particularly evident during a low tide event when the water is shallower. In the shallower areas west of the site some features are present including wave-induced ripples and areas of exposed glacial material.

Tidal range within the proposed site is 3.4m and 1.7m for the spring and neap tidal phases, respectively. Peak tidal currents have been measured at less than 1.1m/s (near-surface) within the proposed EOWDC site and decrease in magnitude towards the shore. Average bed and surface speeds recorded are approximately 0.22m/s and 0.33m/s, respectively. The peak flow occurs at, approximately, high and low water with slack water occurring at mid-tide. The flood and ebb tide is directed towards the south-southwest and north-northeast, respectively. The rectilinear nature of the tide increases from near-surface to the mid-water column. The analysis of tidal currents at the seabed shows that tidal asymmetry within the lower water column results in a net northerly transport of seabed sediment (in the context of a typical sand particle, 150 µm).

The most frequent waves within the proposed EOWDC site (based on the relatively short AWAC record) are between 0.5 and 1.0m (in significant wave height) originating from the southeast. The maximum waves recorded are of the order of 5.5m and originate from the east. Further offshore, northerly wave directions are predominant.

Analysis of the exposure conditions (tides; waves) in view of the surficial seabed sediments experienced within the array has been undertaken to assess the potential mobility of the seabed. Within the proposed EOWDC site, the seabed material has been observed to be predominantly sand with some mud and gravel in places. It is shown that both tidal and wave processes influence sediment mobility, although there is limited mobility for medium and fine sands during low energy conditions. It is shown that the seabed sediment transport regime within the wind farm boundary is not particularly active with respect to these size fractions.

Longshore transport has been shown to be in a northerly direction and under the control of waves (the more frequent waves originate from the southeast). This is evidenced by the numerous small streams along the embayment that have been deflected to the north due to the deposition of sediment at the mouths. However, the southerly orientation of a spit across the mouth of the River Ythan at the northerly end of the bay indicates the potential for net southerly directed littoral transport in this part of the bay and wave refraction causes some southerly directed transport in the far southern part of the bay adjacent to the mouth of the Dee. The rate of littoral transport decreases towards the north of Aberdeen Bay as a consequence of its changing alignment and is supported by the fining of beach sediment towards the north. However, under extreme storm events, the potential alongshore transport potential is much greater in the north of the Bay than the south.

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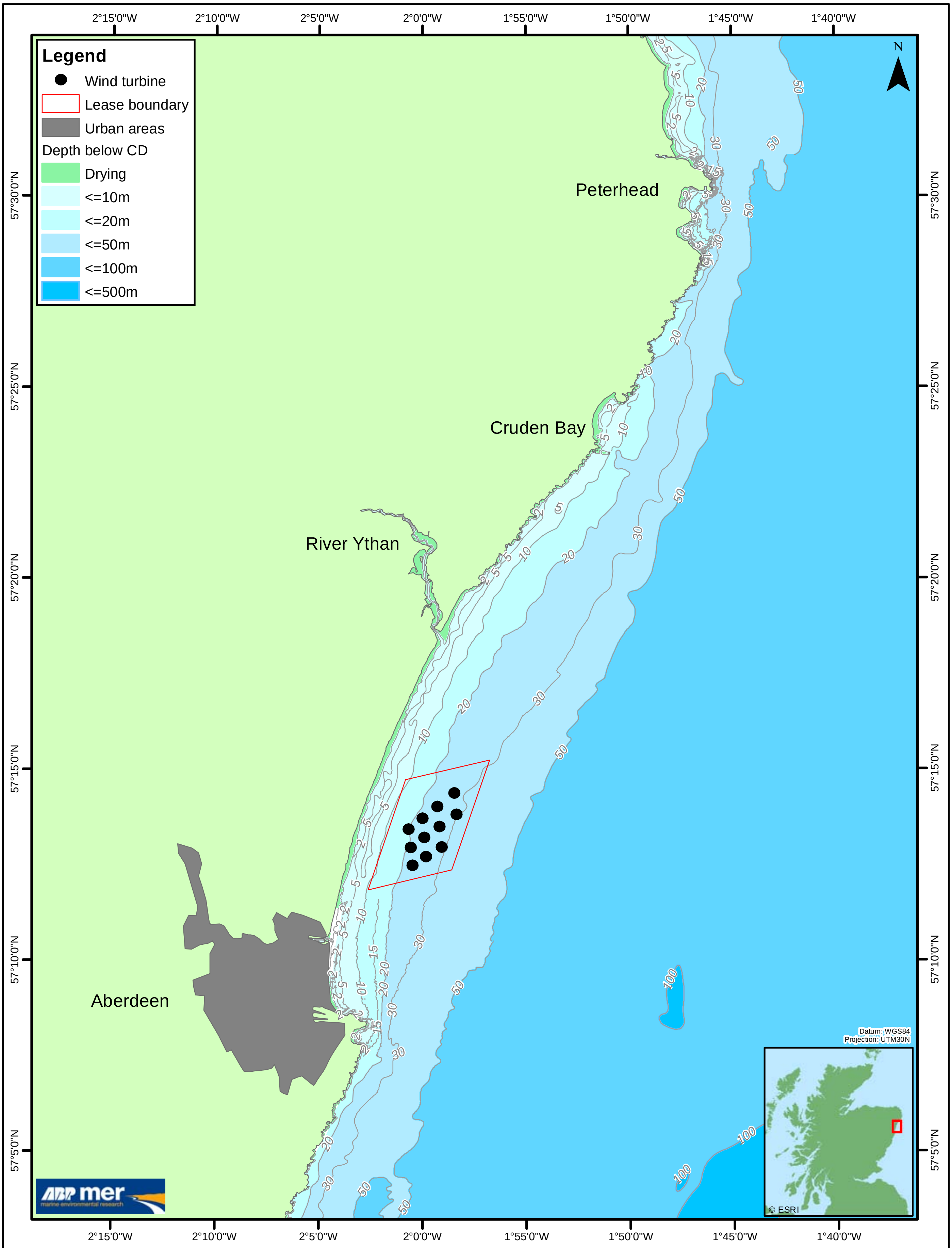
Figures



VATTENFALL

areg — Aberdeen Renewable Energy Group

Technip

0 1 2 km

0 0.5 1 nm

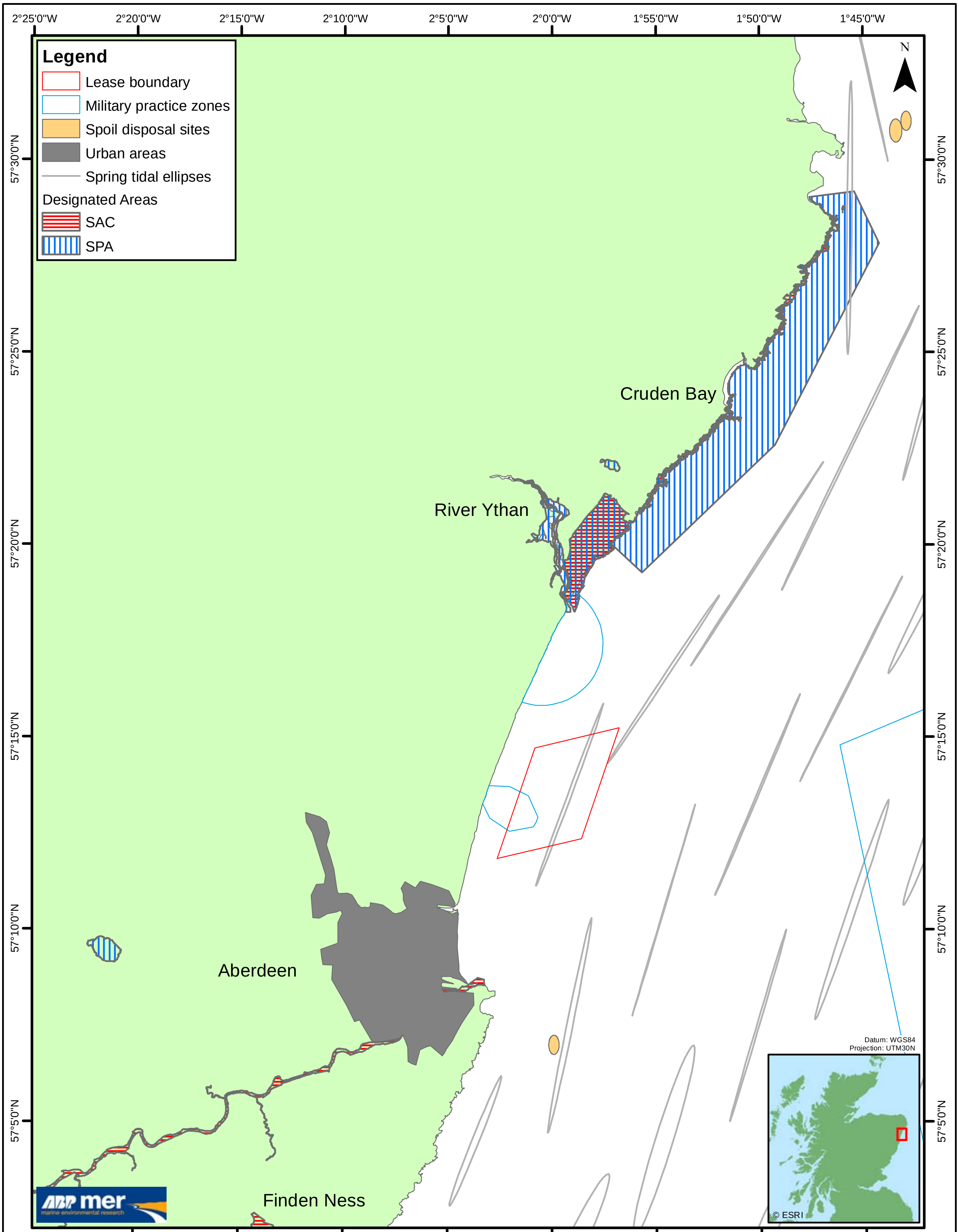
Original A4
Plot Scale
1:250,000

European Offshore Wind Deployment Centre

Location Map

Layout	By	Date	Rev	Dwg No.
LABER039	SCB	26/11/2010	C	6129-530-PM-001

Figure 1



VATTENFALL

areg Aberdeen Renewable Energy Group

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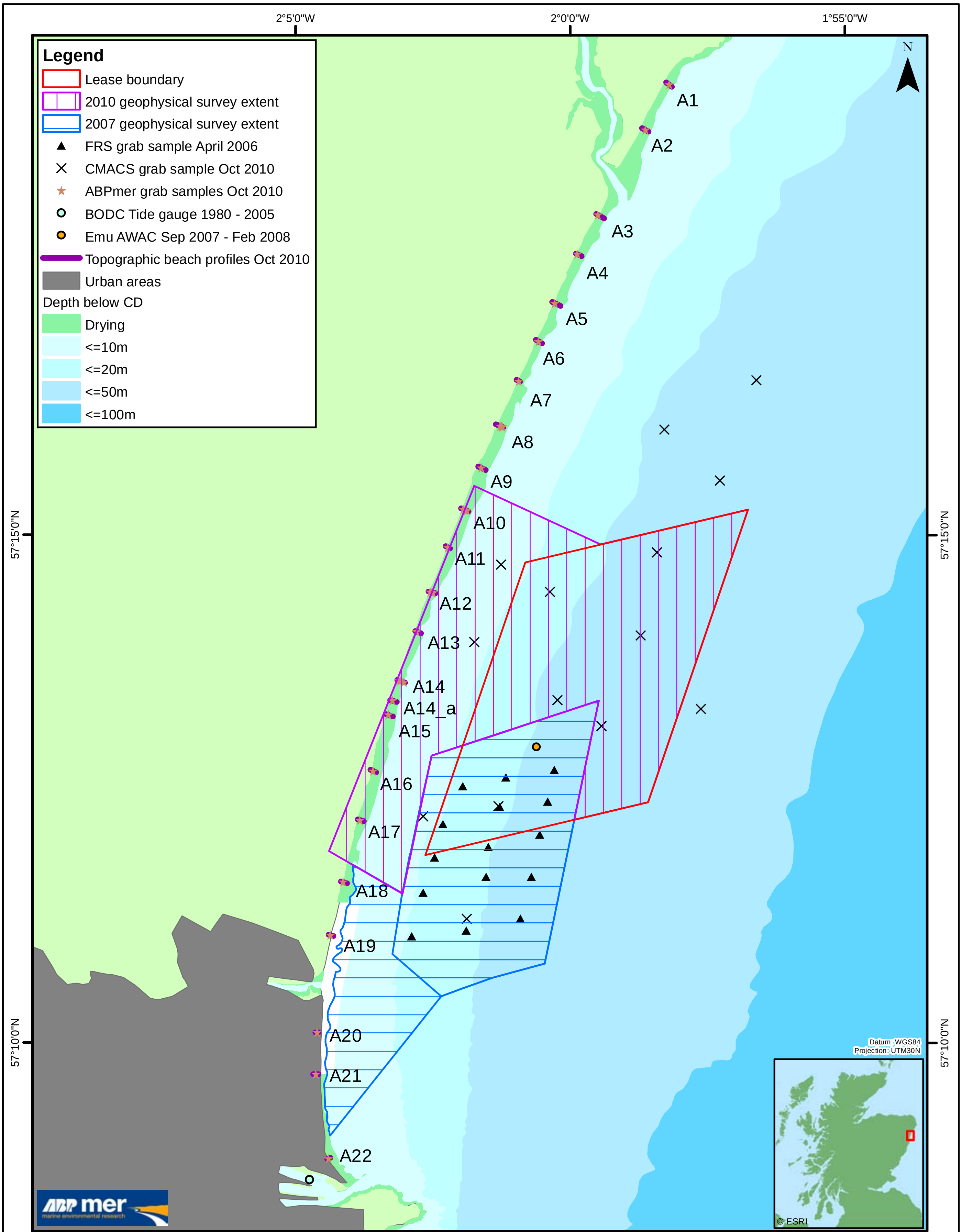
Original A4
Plot Scale
1:250,000

European Offshore Wind Deployment Centre

Cumulative And In-Combination Assessment

Layout	By	Date	Rev	Dwg No.
NA	SCB	26/11/2010	C	6129-530-PM-002

Figure 2



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European Offshore Wind Deployment Centre

Dataset Locations

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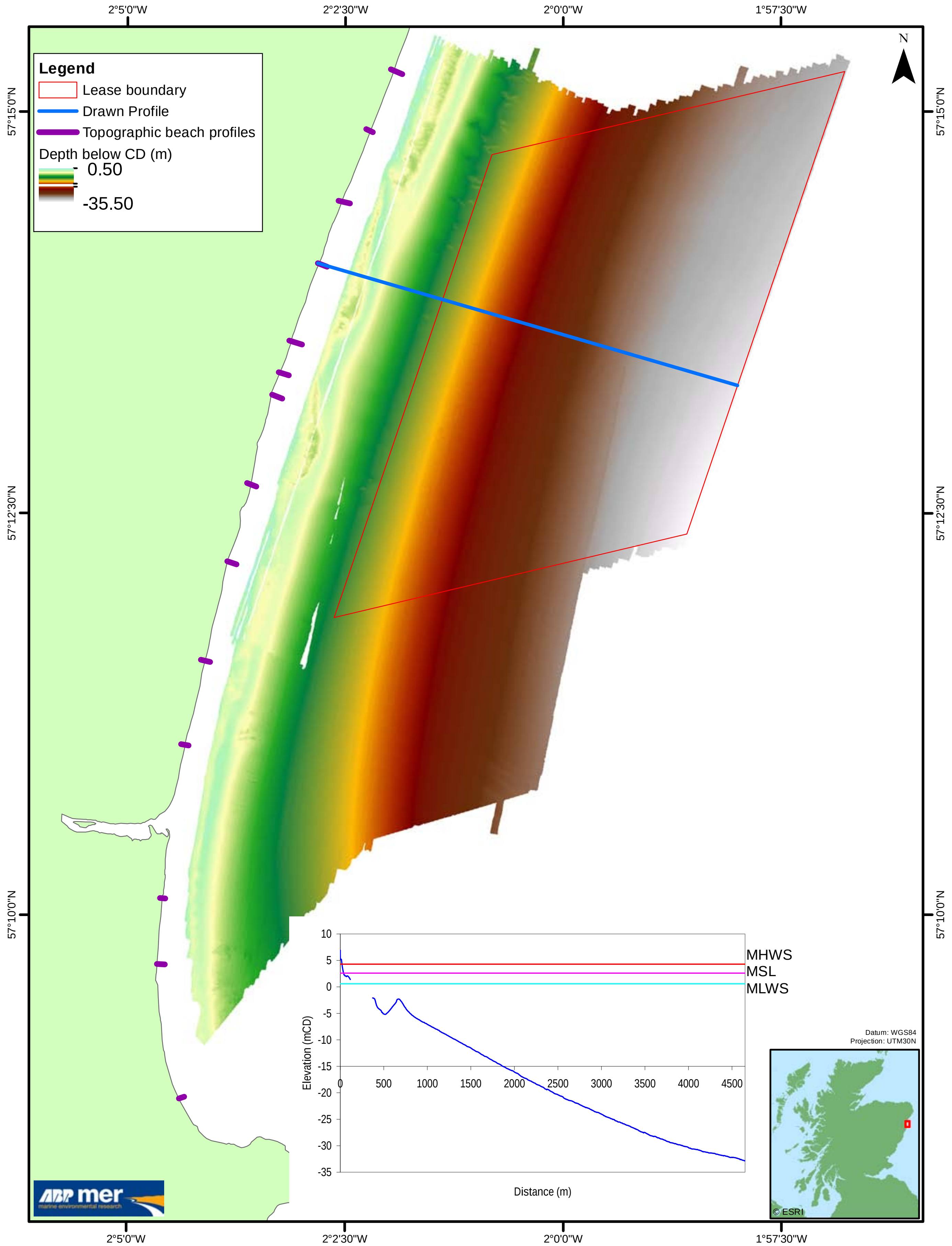
Figure 3



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Original A4
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European Offshore Wind Deployment Centre

Bathymetry

Layout	By	Date	Rev	Dwg No.
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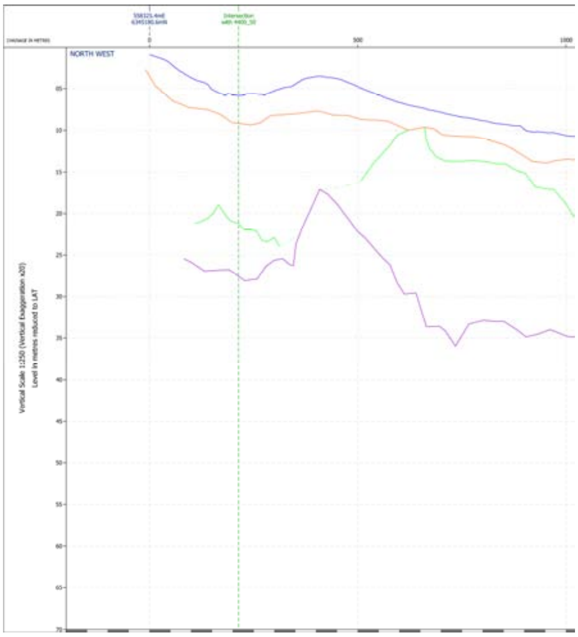
Figure 4

Profile X2



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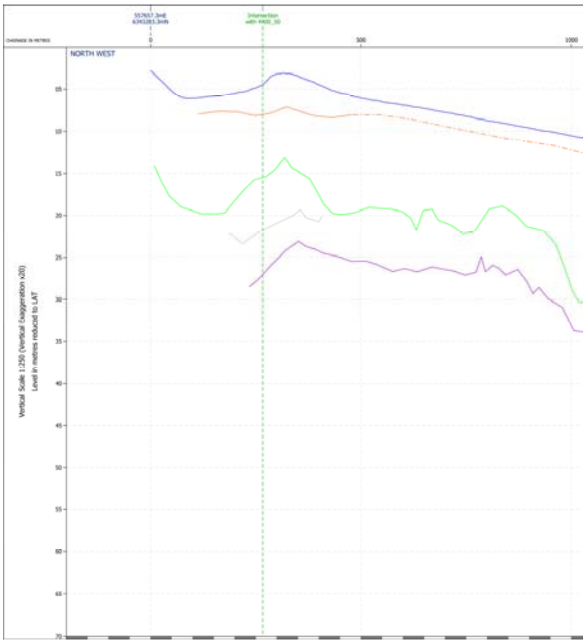


Date	By	Size	Version
Jan 2011	SNH	A4	1
QA		NA	
3890 - Fig_BSS.xls			
Produced by ABPmer Ltd			

GEOLOGICAL SECTIONS

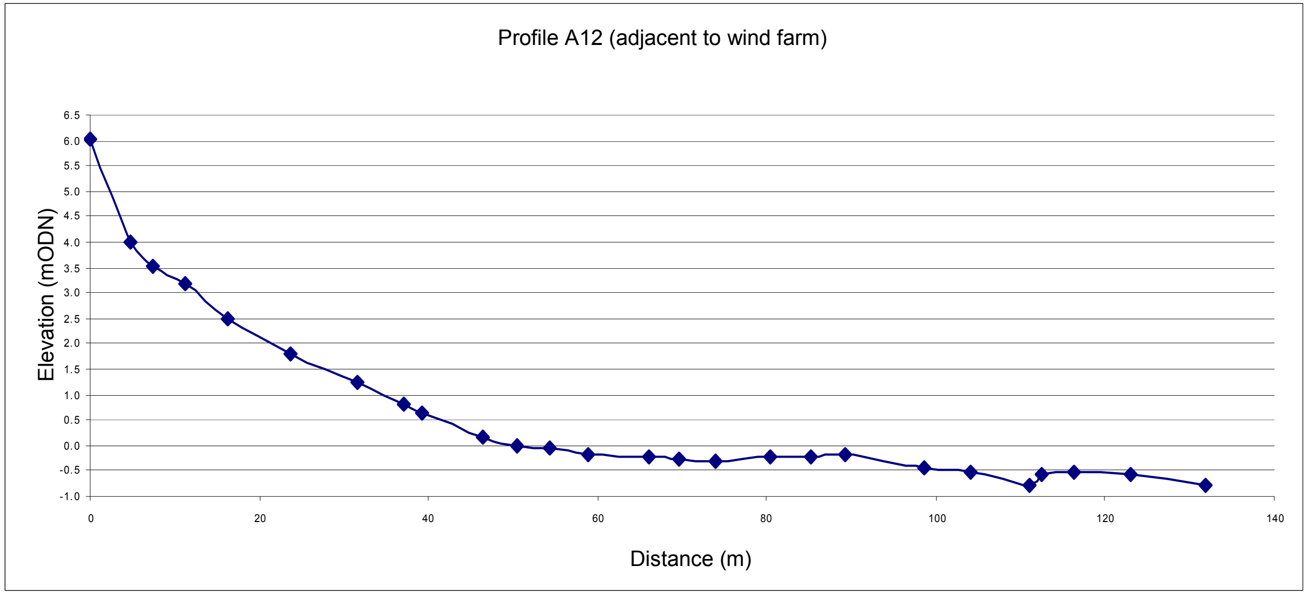
- Seabed
- Base of Holocene
- Base of Forth Formation (Bedded Deposits)/ Top of Wee Bankie (Clayey Till)
- Base of Wee Bankie (Clayey Till)/Top of ROCK
- Internal reflector

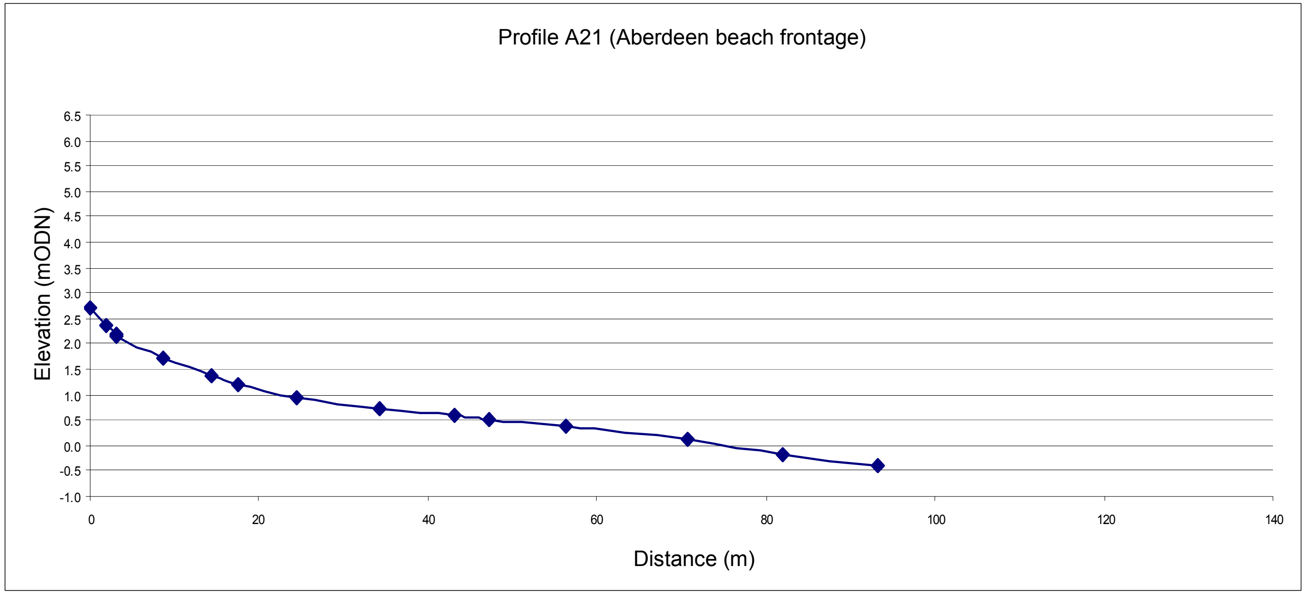
Dashed lines indicate interpolated boundaries

ABP mer marine environmental research

Geological cross sections taken through near-shore ridge feature

Figure 5





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QA		SCB	

3890 - Fig_Profiles.xls

Produced by ABPmer Ltd

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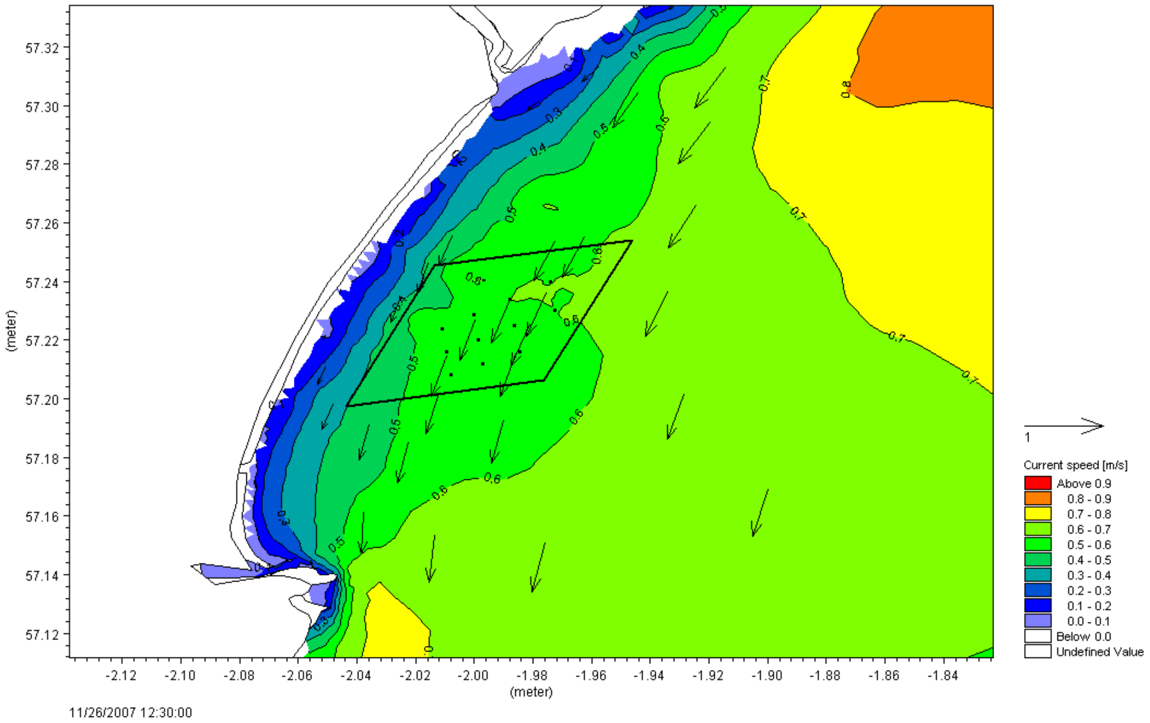
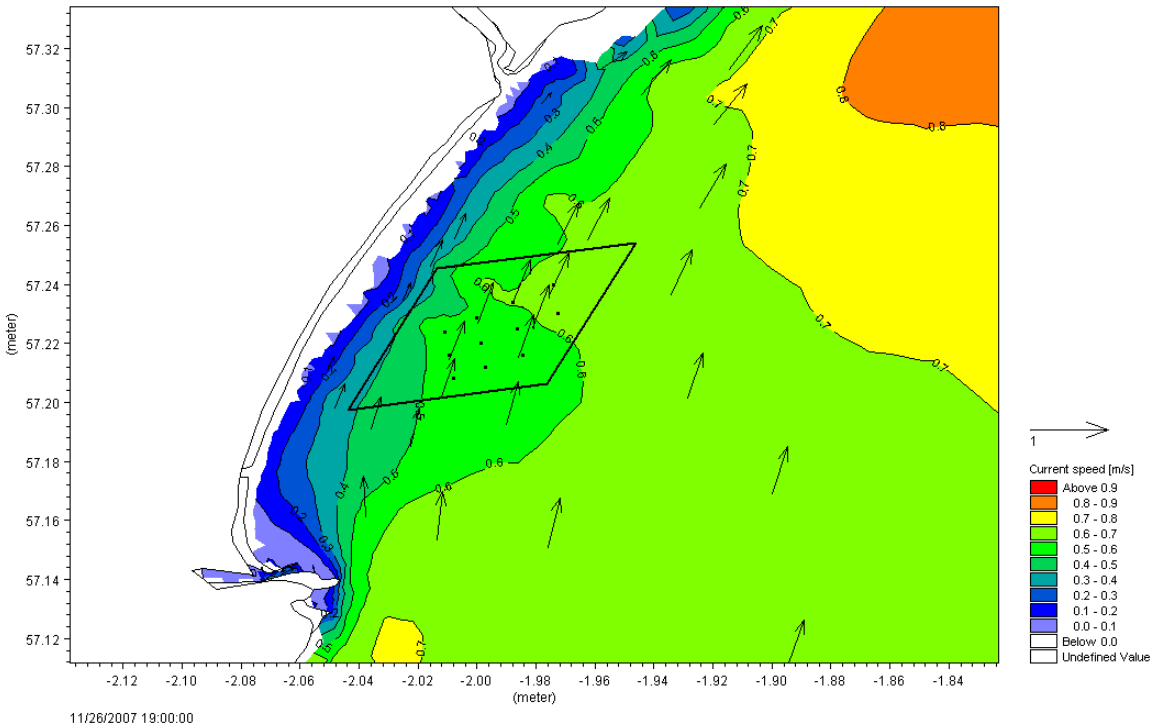
Examples of cross shore profiles

Figure 6

A



B



Date	By	Size	Version
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QA		SCB	
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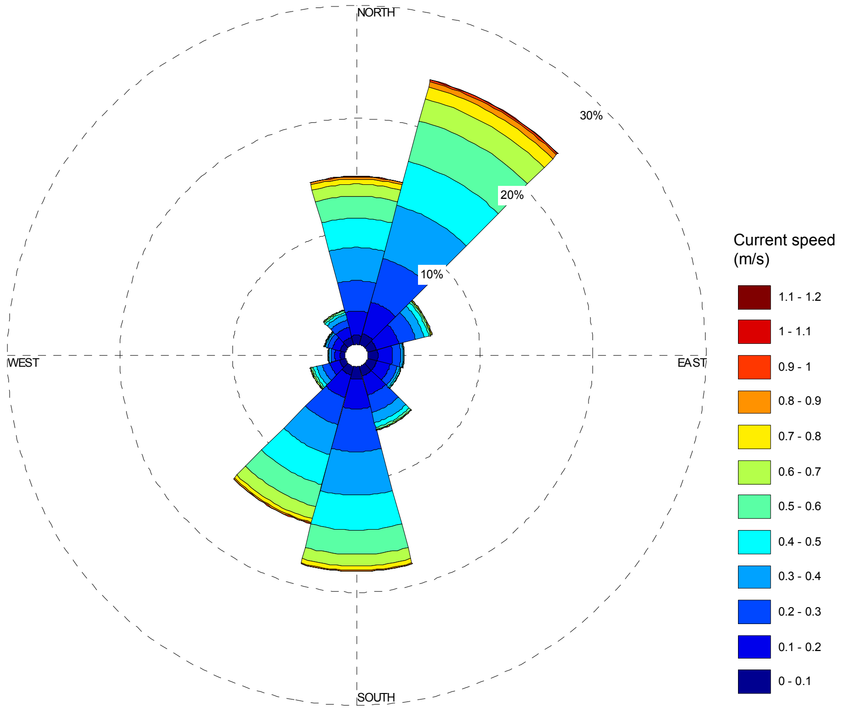
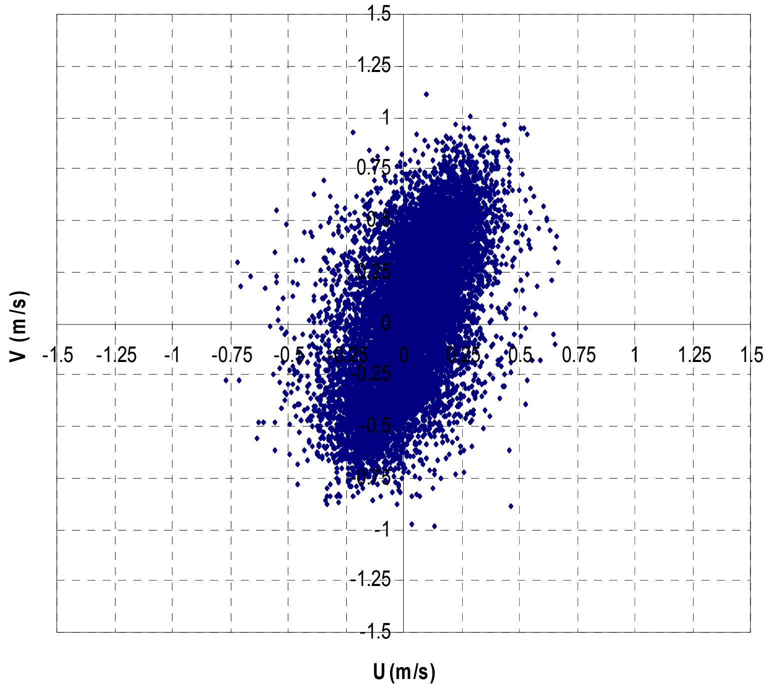
Produced by ABPmer Ltd			

Modelled current speeds during peak flood (A) and peak ebb (B)

Figure 7





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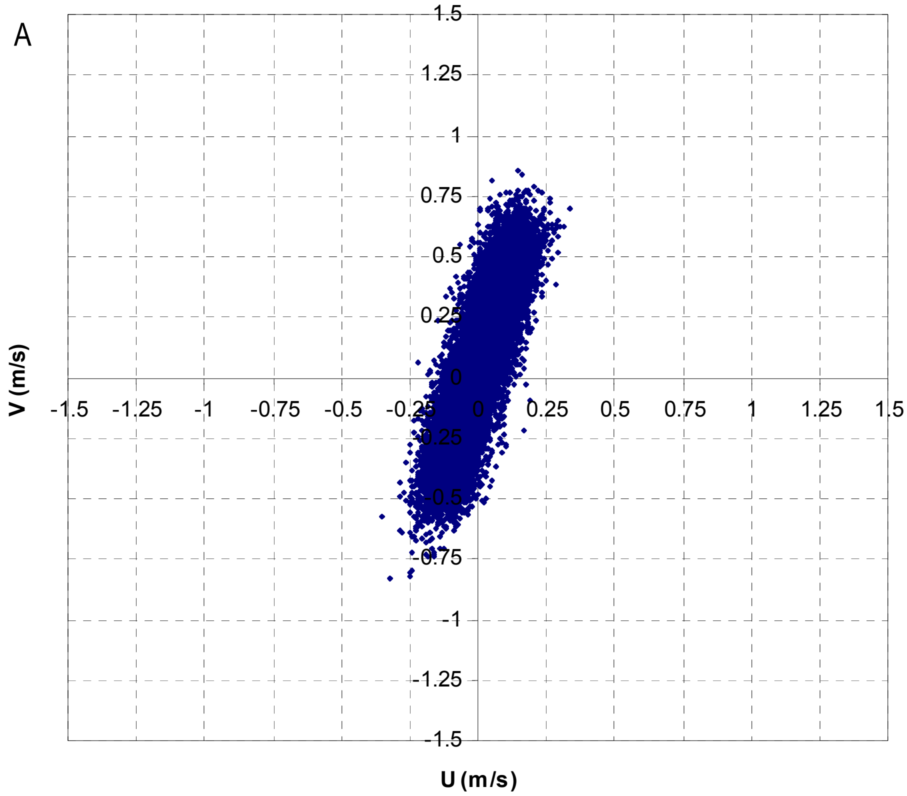
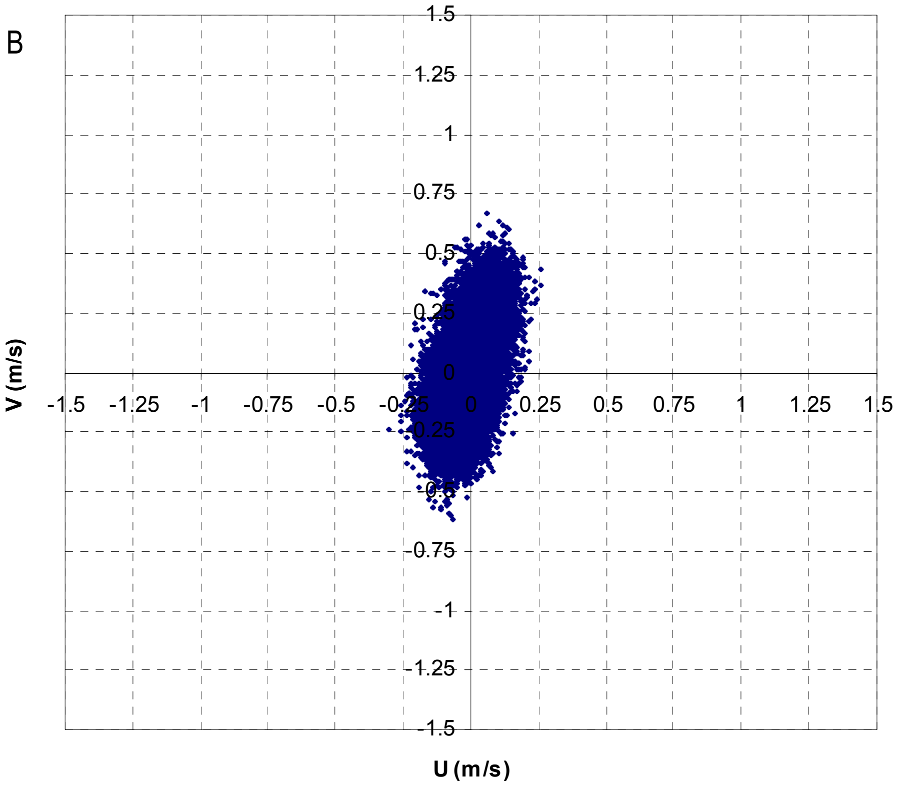
Current speeds from AWAC data (EMU, 2008a) approximately 21m above the seabed

Current Speeds and Direction in the Upper Water Column

Figure 8





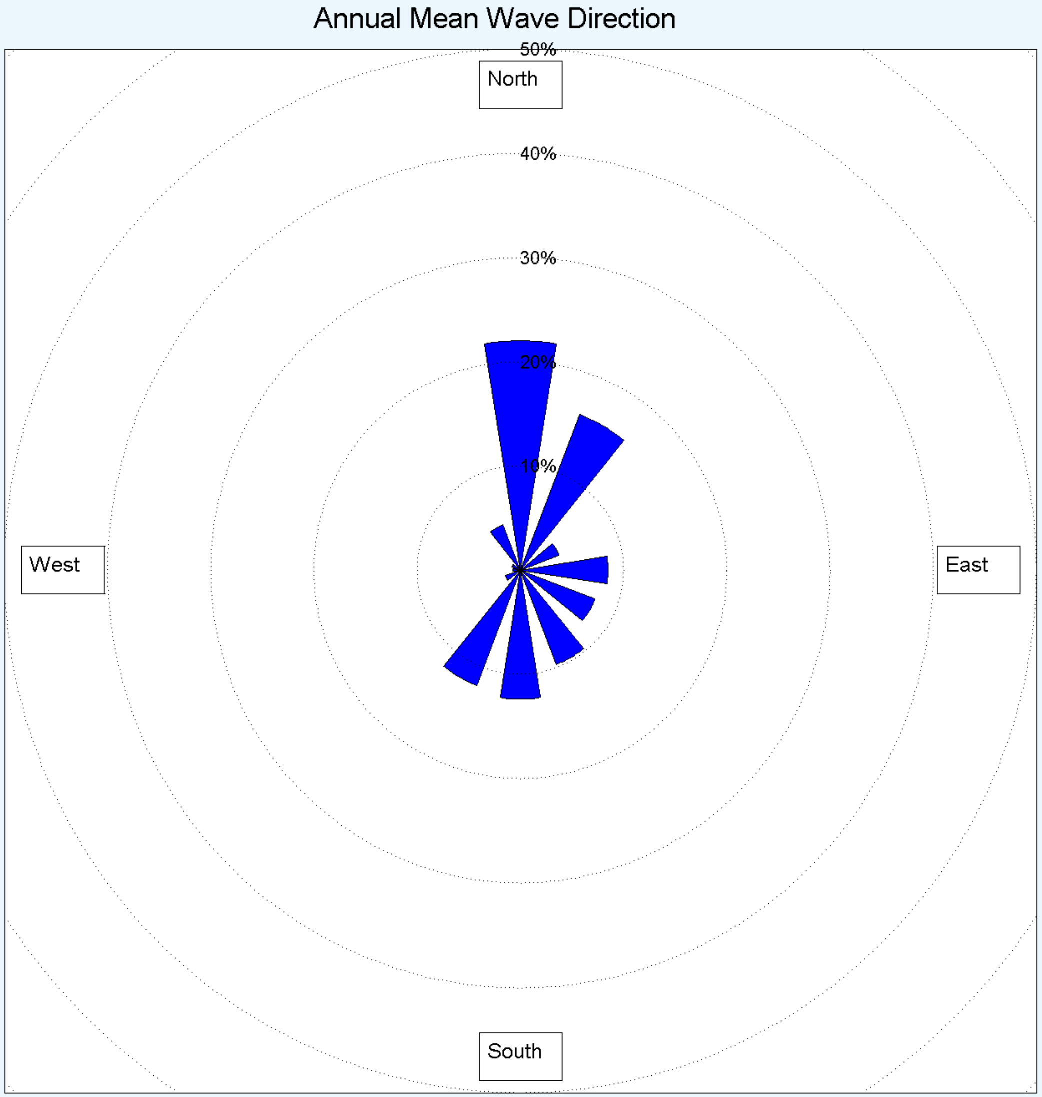
Date	By	Size	Version
Nov 2010	SNH	A4	1
QA		SCB	

3890 - Fig_mid&low_currents.xls

Produced by ABPmer Ltd

Current Speeds and Direction in the Mid (A) and Lower (B) Water Column

Figure 9



Cell 3075 Lat 57.28°N, Long -1.41 °W

Cell co-ordinates refer to the centre of the selected cell

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Primary Component Device

Wave data are based on hourly model hindcast values over 7 years

Source: Atlas of UK Marine Renewable Energy Resources 2

Extract Data

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		SCB	

3890 – combined_figures

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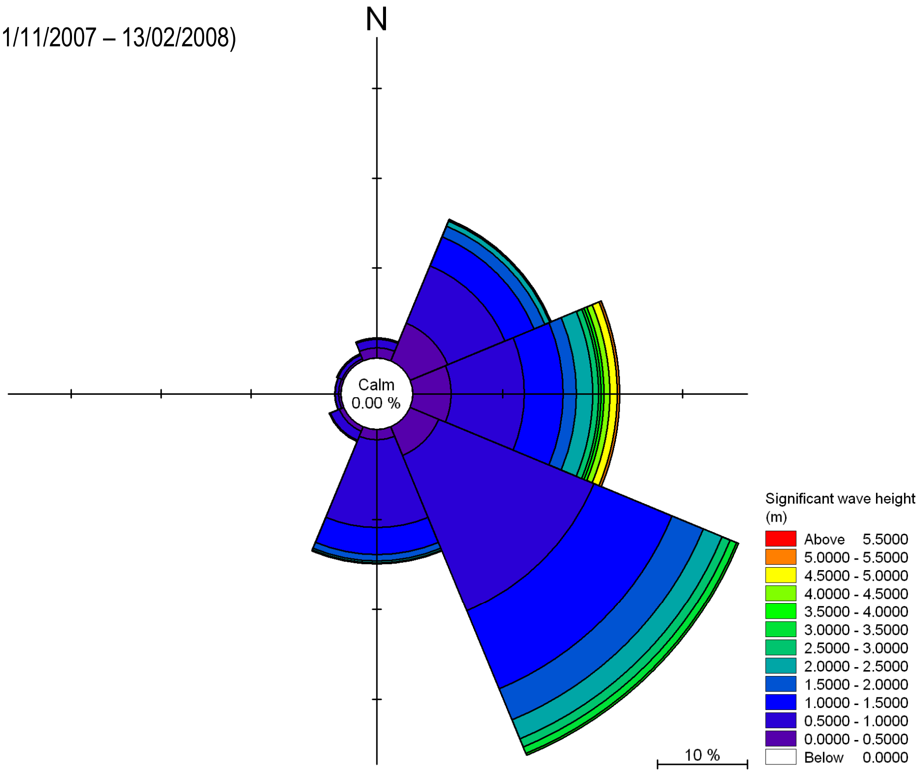
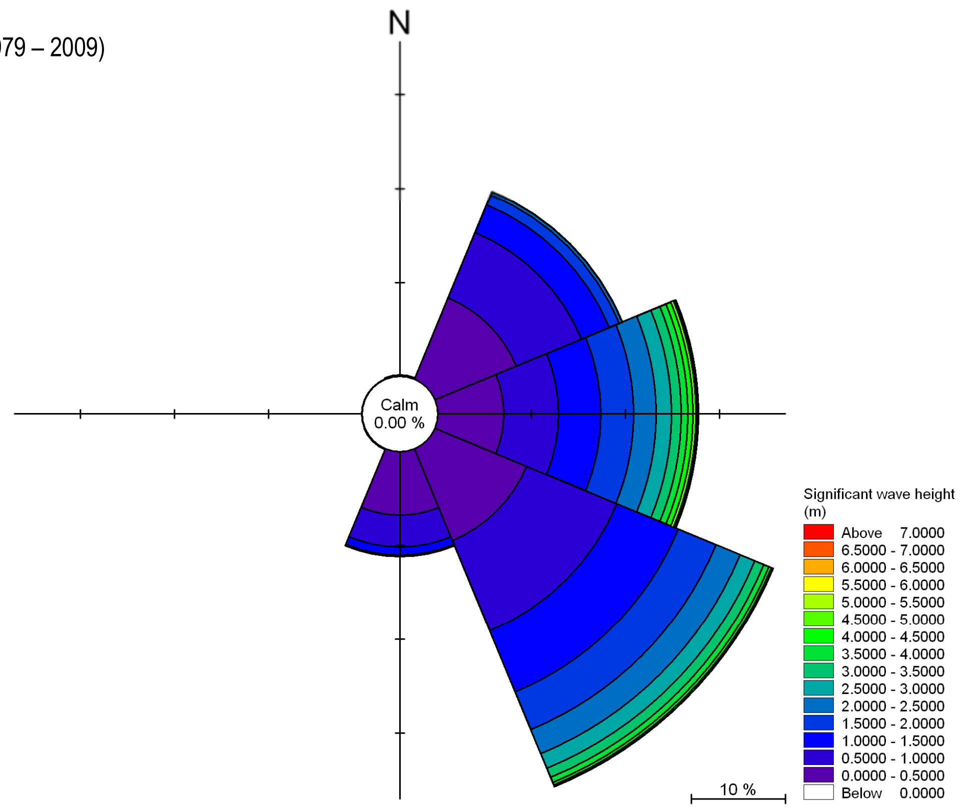
Wave rose showing offshore wave direction from the Renewables Atlas

Figure 10

A: Emu AWAC (1/11/2007 – 13/02/2008)



B: CFSR (1979 – 2009)



Date	By	Size	Version
Nov 2010	SNH	A4	1
QA		SCB	
3890 – combined_figures_potrait			
Produced by ABPmer Ltd			

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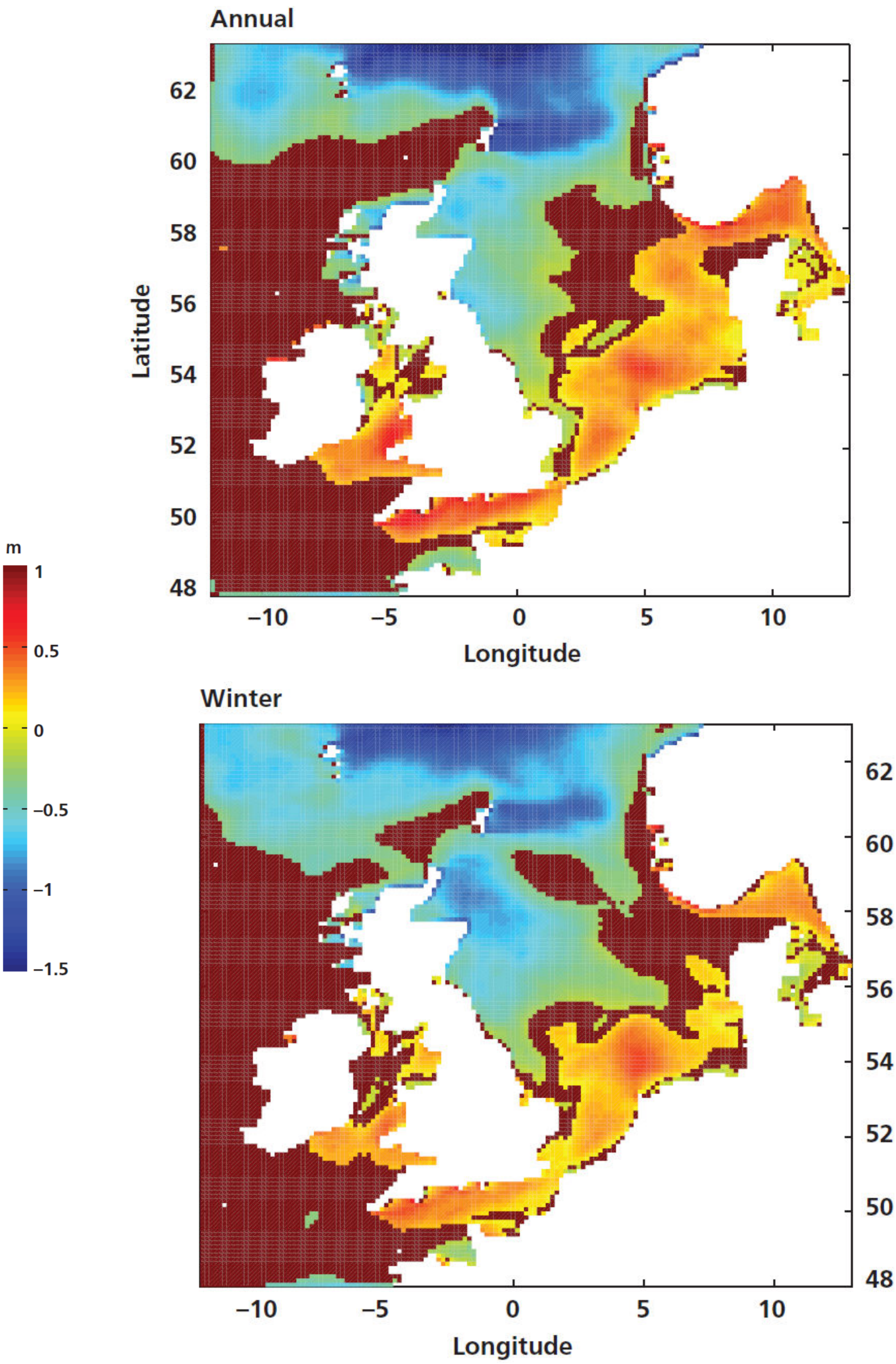
Wave roses showing nearshore significant wave height and peak wave direction from the AWAC and Seastates

Figure 11



Date	By	Size	Version
Nov 2010	SNH	A4	1
QA		SCB	
3890 - Fig_upper_currents.xls			
Produced by ABPmer Ltd			

Source: Lowe *et al*, 2009

Note: These graphs show the differences in significant wave height based on a comparison between the statistics for two 30 year time slices (statistics for the 1960-1990 time slice compared to statistics for the 2070-2100 time slice)

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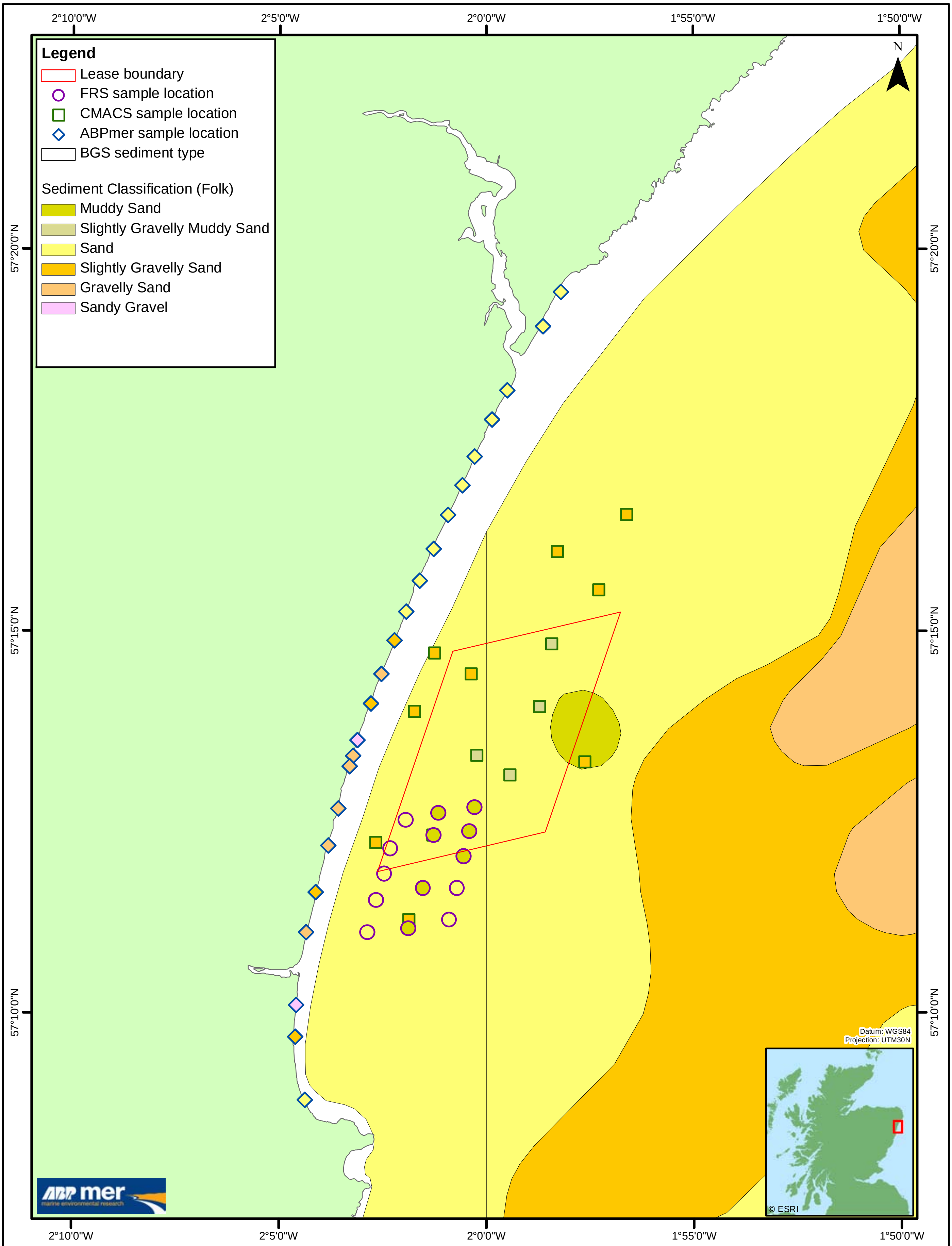
Changes in mean annual and winter maxima of Significant wave height from 1960-1990 to 2070 -2100.

Figure 12



VATTENFALL

areg Aberdeen Renewable Energy Group

Technip

0 0.5 1 km

0 0.5 1 nm

Original A4 Plot Scale 1:125,000

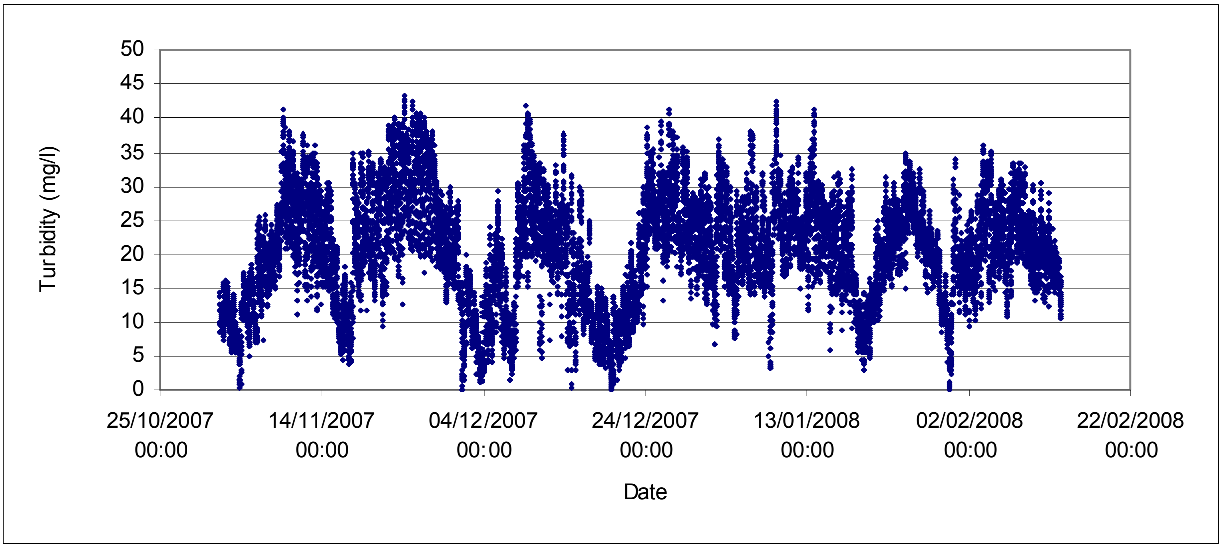
European Offshore Wind Deployment Centre

Sediment Distribution

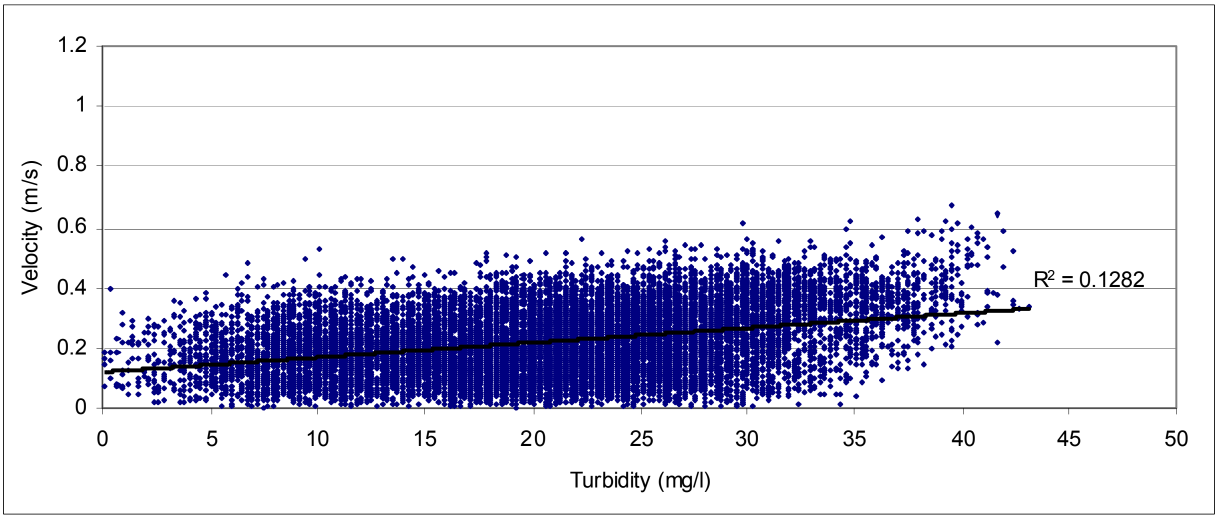
Layout	By	Date	Rev	Dwg No.
NA	SCB	26/11/2010	C	6129-530-PM-005

Figure 13

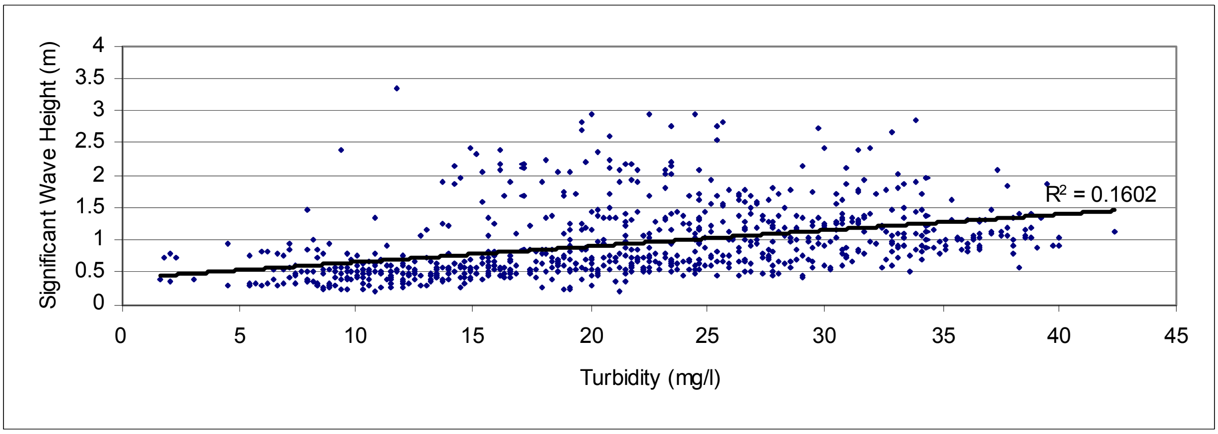
A



B



C



Date	By	Size	Version
Nov 2010	SNH	A4	1
QA		SCB	
3890 - Fig_mid&low_currents.xls			
Produced by ABPmer Ltd			

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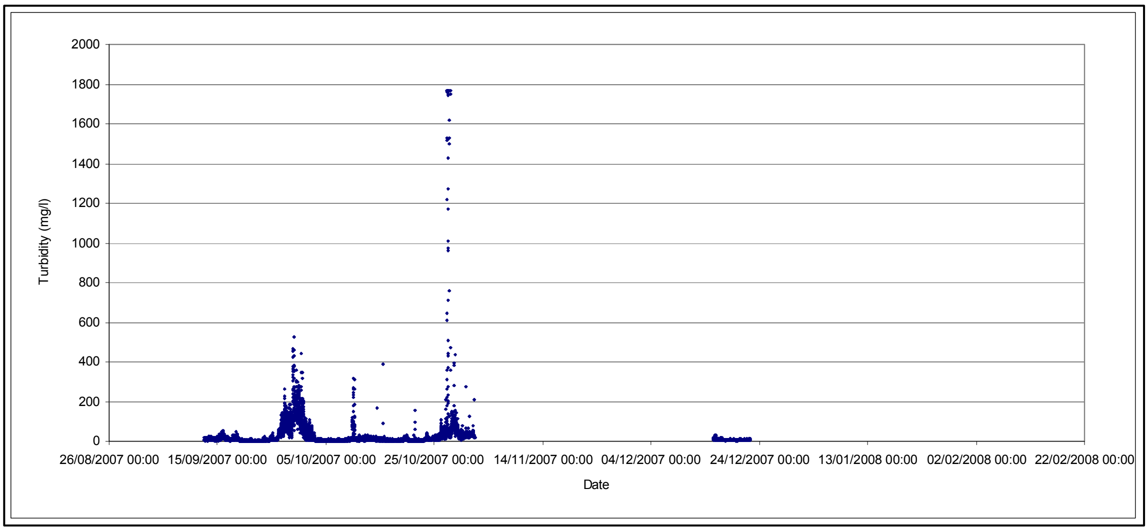
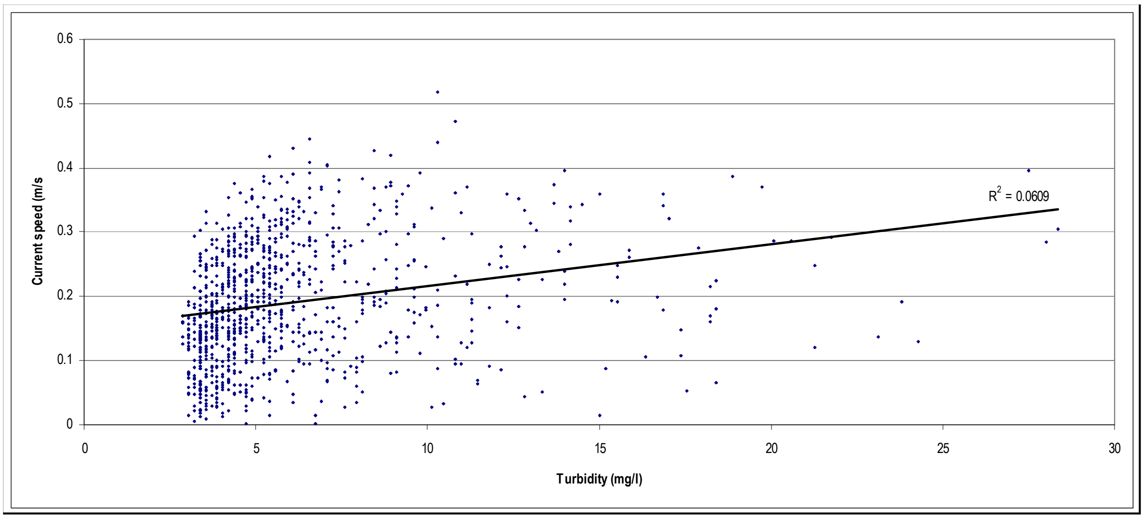
Suspended sediment concentrations as recorded by the ABS 1.5-2m above the seabed

Figure 14

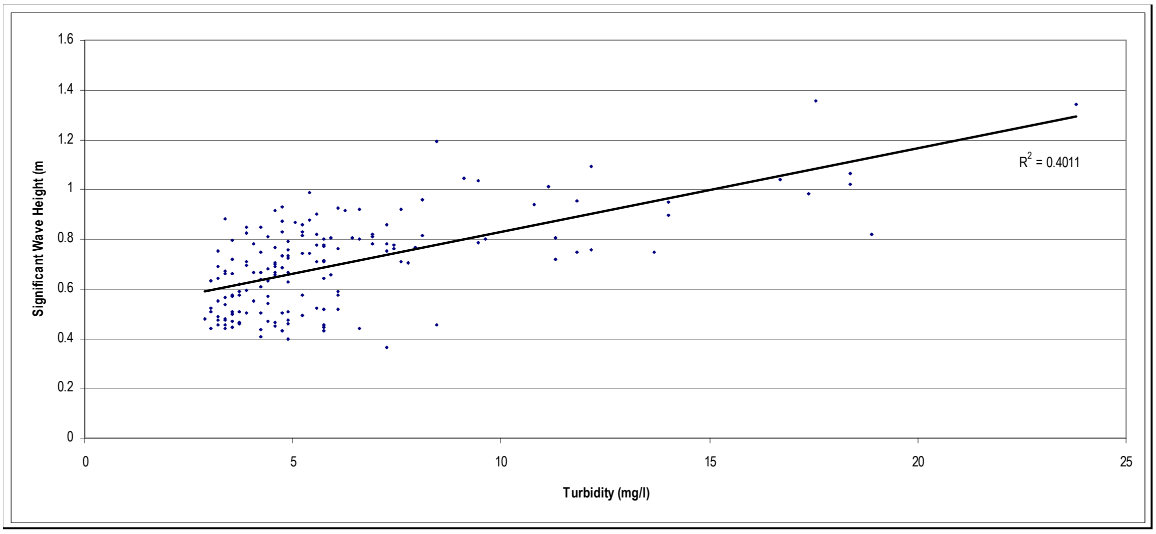
A



B



C



Date	By	Size	Version
Nov 2010	SNH	A4	1
QA		SCB	
3890 - Fig_mid&low_currents.xls			
Produced by ABPmer Ltd			

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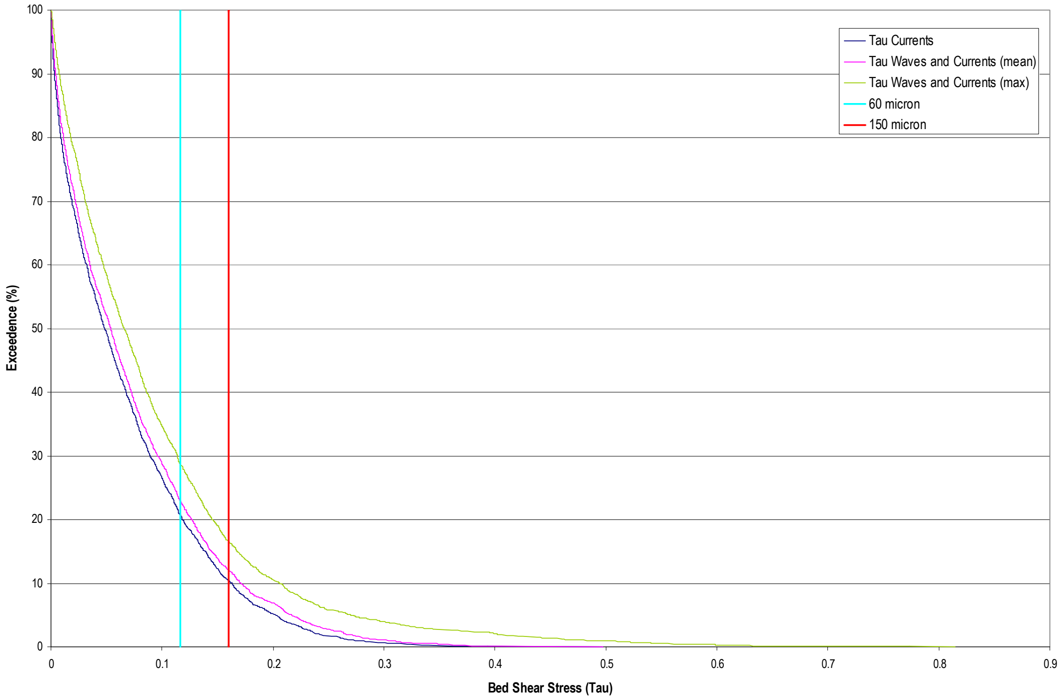
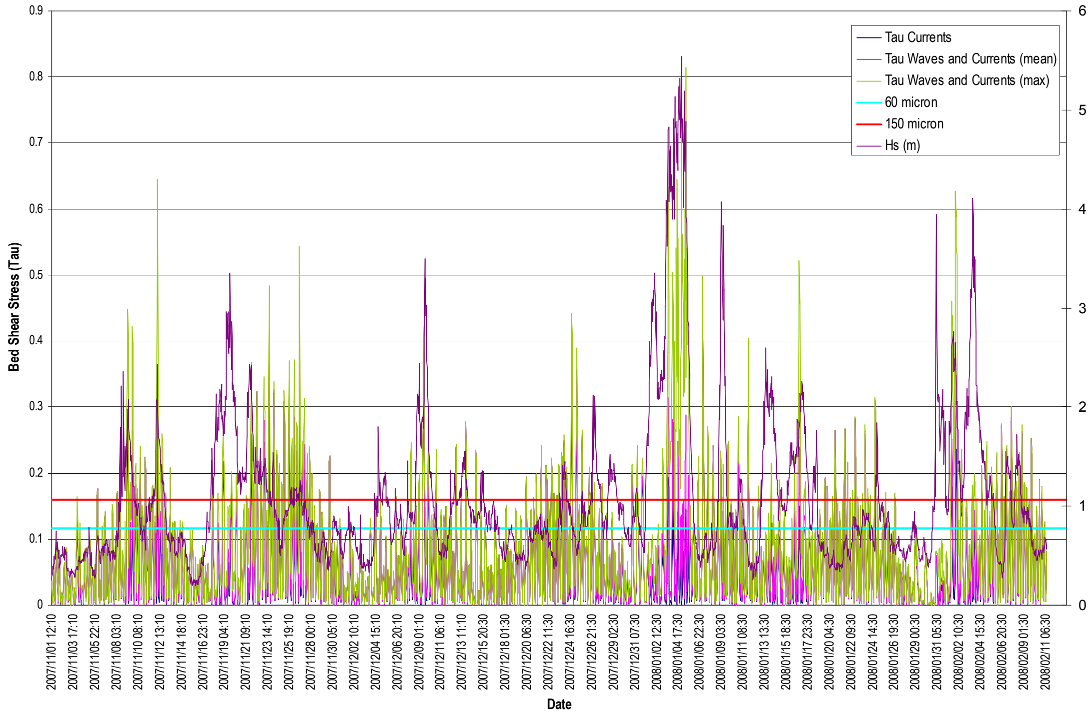
Suspended sediment concentrations as recorded by the OBS 0.6m above the seabed

Figure 15

Percentage Exceedence



Time Series



Date	By	Size	Version
Nov 2010	SNH	A4	1
QA		SCB	
3890 - Fig_BSS.xls			
Produced by ABPmer Ltd			

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Bed shear stress expressed as a time series and as an exceedence plot

Figure 16

Appendix A

Aberdeen Bay
Beach Profile Survey Report

Appendix A. Aberdeen Bay Beach Profile Survey Report

1. Introduction

1.1 Project Background

ABP Marine Environmental Research Ltd (ABPmer) was commissioned to undertake a topographic survey to support the coastal process studies currently being undertaken for the European Offshore Wind Deployment Centre (EOWDC). There were 23 beach profiles identified along which to take elevation measurements, extending from the seaward edge of the sand dune to Mean Low Water (MLW), or as near as possible depending on tidal conditions. At each profile, a sediment sample was also taken to establish the sediment distribution. Further, photographic evidence was also collected to support the field work, providing visual evidence of the topographic environment.

1.2 Survey Location

The survey was carried out in Aberdeen, with profiles starting North of the River Ythan and extending to the South of the River Don at Aberdeen Bay, Figure A1. Figure A2 displays the location of the profiles and Figure A3 the positions of the sediment samples. The profiles were selected by dividing the coastline affected by the largest and most common waves passing through the proposed project into sections of different beach type characteristics so that an equal number were surveyed in each. The different beach characterises included wide and narrow beaches with groynes, beach sections with a ridge and runnel, areas with smooth gradients with berms and beach sections with a ridge, runnel and berm. The highest density of profiles was selected directly opposite the proposed site. The location of the sediment samples were chosen to most represent the sediment distribution of the whole beach. Additional sediment samples were taken along Profiles 8, 10, 12 and 14, and within the dune system, to provide further detail of the cross-shore sediment distribution if required.

2. Methodology

2.1 Equipment

A Magellan Z Max RTK (Real Time Kimatic) GPS (Global Positioning System) system was used for the measurement of elevation data. The equipment comprised of a master station left on a control point and a rover station used to measure the elevations of the survey profiles to a repeatability of around 30mm. The data recorded includes the time, easting, northing, elevation. Positions are correct to British Nation Grid (OSGB36) and elevations to mODN (Ordnance Datum, Newlyn).

A trowel was used to collect sediment samples to a depth of 35cm. A Malvern Mastersizer 2000 was then used in the laboratory, along with sieves, to determine the particle size of the sediment.

2.2 Survey Methodology

2.2.1 Topographic

The position of the 23 beach profiles were established in the office prior to the survey commencing. These profiles were configured onto the GPS equipment so to locate these positions in the field; however the start and end points for each of the profiles were adjusted in the field depending on field conditions and tidal state. A number of locations were established as control points for the master station to be set up on and provide data to the rover station for the duration of the survey, Figure A2. A temporary position was measured at the control point by the master GPS station; and the master station was then configured to log static data which was then post processed in the office to establish the precise position.

The GPS rover was used to take measurements along the beach profiles. A measurement was taken at every elevation change and every 10 to 15 paces on the flat sections. The positions recorded by the rover were adjusted after the survey had been completed and the exact location of the control points had been calculated; to allow for the difference between the temporary position used and the exact control position. These results were then plotted graphically to display the elevation profiles, Figures A4 to A15.

2.2.2 Sediment Samples

The sediment samples collected on site were analysed in the ABPmer laboratory using a 1mm sieve. Material that passed through the sieve was then passed through a Malvern Mastersizer 2000 to establish the relative percentage of silts and clays and fine, medium and coarse sand and cobbles within the sample. Material greater than 1mm was placed in an oven overnight at 100^{o}C and manually sieved.

The results of the two methods were combined to establish the particle size distribution of the samples. The size fractions separated out by the Mastersizer and the manual sieves are given in Table 1. All results were then plotted graphically, Annex 1

Table 1. Particle size analysis classifications

Clays (µm)	Silts (µm)			Sands (µm)			Gravel (mm)		Cobbles (mm)
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Coarse	
<2	2-6	6-20	20-60	60-200	200-600	600-2000	2-6	20-60	>63

3. Results

3.1 Survey Log

Table 2 displays a log of the survey activities and observations made.

Table 2. Survey log

Date	Survey Activity	Notes	Conditions
26/10/2010	A reconnaissance for a suitable secure position for the GPS master instrument was carried out and a location was identified close to Balmedie Country Park in a mushroom farm. Topographic beach profile survey started; landward sections of profiles A10 - A6 completed. A new base station position located at Newburgh Golf Club was identified for the following days survey work.	The GPS master station was set up and configured to log static data. Starting at Balmedie Country Park, elevation measurements with the GPS rover began at profile A10. Due to the flooding tide, data was obtained from the base of the dunes to the waters edge (landward half of the beach only). Working northwards at 750 meter intervals further measurements were carried out on profiles A9 to A6. As the GPS master would have to be moved over the survey duration to maintain contact with the GPS rover, a reconnaissance was undertaken in Newburgh for a suitable location. A site was found at Newburgh Golf Club.	Light rain during the morning - overcast with sunny intervals during the afternoon - strong winds. Sea state - large swell breaking over the shallow intertidal area.
27/10/2010	Continuation of topographic beach profile survey; profiles A10 - A15 completed and the seaward end of profiles A10 - A6 completed. Base station remaining at the mushroom farm but retrieved to be moved the following day. Samples were taken for Particle Size Analysis (PSA) on profiles A6 to A15.	Starting at Blackdog Links measurements commenced 2.5 hours before Low Water (LW) on the ebbing tide. Beginning at profile A15 and continuing northwards at 750 meter intervals to complete profiles A14 to A11. As far as practical, complete profiles were measured, from the base of the dunes to the waters edge. On profiles A15 and A13 large circular pools were found on the seaward side of the profiles, elevations were not recorded as the sand was very soft and considered unsafe. Additionally the seaward half of the profiles A10 to A6, started on the 26/11/2010, were completed. A trowel was used to collect sediment samples, three quarters along each beach profile, as well as additional samples in the dunes and at profiles A8, A10, A12, and A14.	Bright sunshine during the morning - overcast with sunny intervals during the afternoon - strong winds. Sea state - large swell breaking over the shallow intertidal area.
28/10/2010	Continuation of topographic beach profile survey; profiles A1 - A6 completed. GPS master station was set up at Newburgh Golf Club. Samples were taken for PSA on profiles A1 to A6.	Starting north of the River Ythan in the Forvie National Nature Reserve, measurements commenced 2.5 hours before low water on the ebbing tide at profile A1 and A2. These profiles were approximately 900 metres apart. Moving back south of the River Ythan, measurements continued southwards at 900 meter intervals to complete profiles A3 to A5 and to extend profile A6. Problems were encountered with the connection between the GPS master and rover, due to the width and height of the dunes. A further reconnaissance was undertaken in Aberdeen for a suitable location to complete the survey. A site was found at Aberdeen Royal Golf Club.	Bright sunshine during the day - strong winds. Sea state - large swell breaking over the shallow intertidal area.
29/10/2010	Continuation of topographic beach profile survey; profiles A16 - A22 completed. GPS master station was set up at Aberdeen Royal Golf Club. Samples were taken for Particle Size Analysis (PSA) on profiles A16 to A22.	Starting from Blackdog Rock measurements commenced 2.5 hours before LW on the ebbing tide at profile A16. Moving south along the beach a further three profiles, A17 to A19 being approximately 800 metres apart, were completed. Then moving south of the River Don, completing profiles A20 to A22. These last three profiles were mid-way between groynes fronting Aberdeen Esplanade.	Heavy rain during the first part of the morning becoming overcast for the duration of the survey - strong winds. Sea state - large swell breaking over the shallow intertidal area.

3.2 Data Analysis

3.2.1 Post processing

Post processing software, GNSS Solutions, was used in the office to compute the precise positioning of the control points the GPS master stations was set up at. Rinex data from the five nearest Ordnance Survey Active Stations was downloaded from the official Ordnance Survey website, along with the data logged by the master station in order to fix the locations of the control points. The baselines between all the stations were processed and adjusted accordingly. Once calculated, the differences between the processed positions and the temporary ones used in the field were calculated and the rover measurements were adjusted respectively. Table 3 displays the adjustments and corrections applied.

Table 3. Adjustments and corrections applied

Site	Date	Observed Position		Computed Position		Correction
Farm	26/10/2010	Eastings	397279.6	Eastings	397279.7	0.043
		Northings	818250.7	Northings	818249.7	-1.007
		Height	26.1	Height	12.1	-14.028
Farm	27/10/2010	Eastings	397279.6	Eastings	397279.7	0.046
		Northings	818250.7	Northings	818249.7	-1.007
		Height	26.1	Height	12.1	-14.02
Newburgh GC	28/10/2010	Eastings	399767.8	Eastings	399770.2	2.437
		Northings	824398	Northings	824400	1.988
		Height	38	Height	28.2	-9.756
Royal GC	29/10/2010	Eastings	394976.2	Eastings	394976.8	0.597
		Northings	809787.5	Northings	809786.6	-0.929
		Height	25.8	Height	16.6	-9.189
Height refers to Elevation mODN Eastings and Northings correct to OSGB36						

3.3 Data Presentation

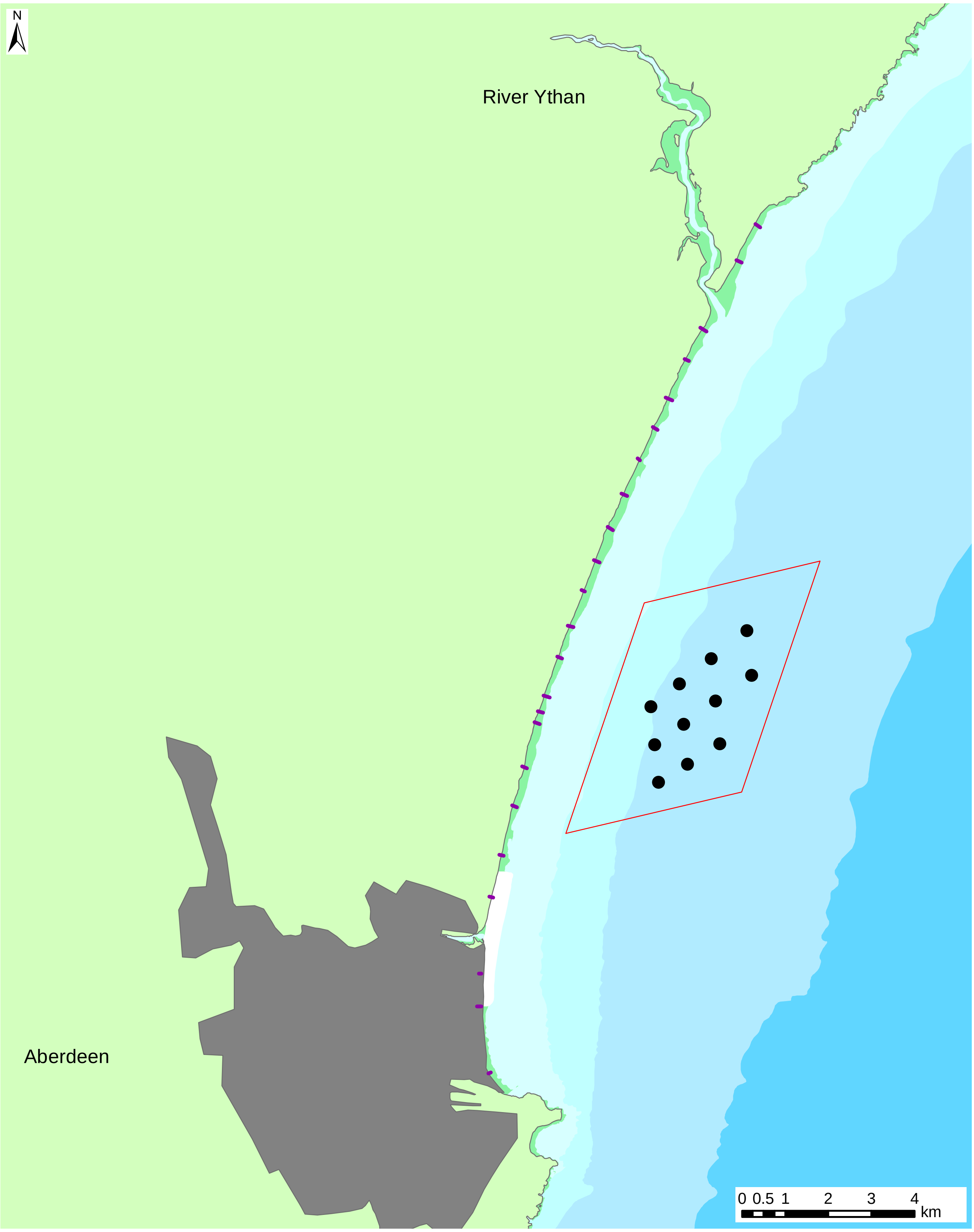
Figures A4 to A15 present the profile data, Annex 1 the sediment sample results and Annex 2 the photographs taken of Profiles 1 to 22.

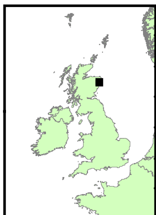
4. Discussion and Conclusions

The beach profiles highlight the elevation variability along the cross-section. Generally, the profiles show the beach levelling out between 40m to 60m from the base of the sand dunes. On a number of the profiles, namely 6, 10 and 16 berm features can be identified.

The results from the PSA highlight that the samples taken at Profiles 1 to 8 are comprised of mainly medium sand, with a small percentage of fine and course sand. Samples taken from profiles 9 to 22 show a similar distribution, but also contain varying percentages of fine and in some cases medium gravel. Sediment samples taken from Profiles 16 and 20 also show a percentage of coarse gravel.

Appendix A. Figures





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Projection		OSGB 1936	
Scale		1:130,000	
QA		FMM	
3890 - Survey_Area.mxd			
Produced by ABPmer Ltd			

- Wind Turbines
- Topographic Beach Profiles
- Lease Boundary
- Urban Areas

Depth Below CD
- Drying
- <=10m
- <=20m
- <=50m
- <=100m
- <=500m

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Survey Location

Figure A1

Date	By	Size	Version
Nov 10	SCB	A4	2
Projection		OSGB 1936	
Scale		Various	
QA		FMM	
3890 - Aberdeen_Profiles.mxd			
Produced by ABPmer Ltd			

Lease Boundary
Control Points
Topographic Beach Profiles

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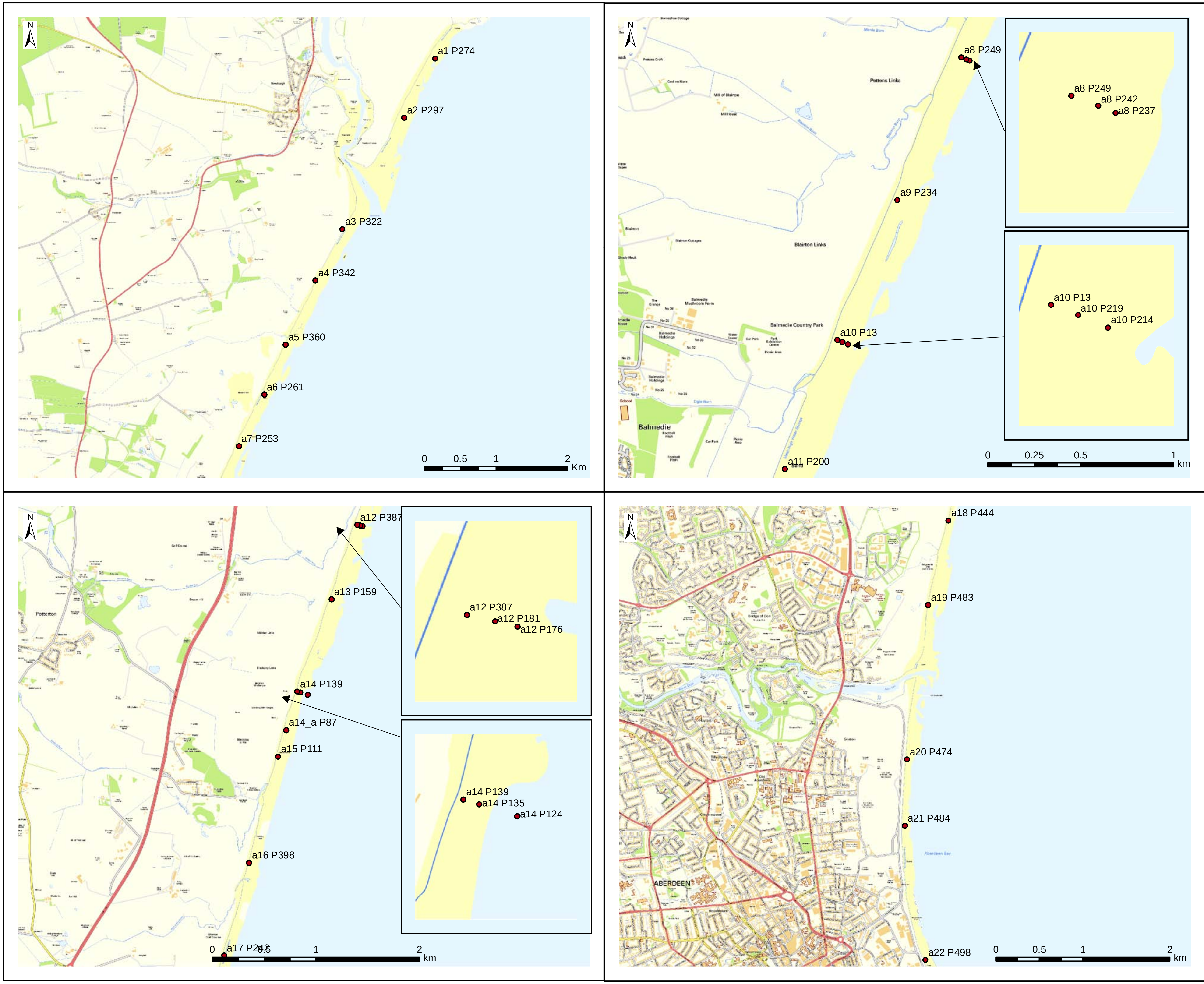
Topographic Beach Profiles

Figure A2



● Sediment Samples

Date	By	Size	Version
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Scale		Various	
QA		FMM	
3890 - ABPmer_PSA_Survey.mxd			
Produced by ABPmer Ltd			

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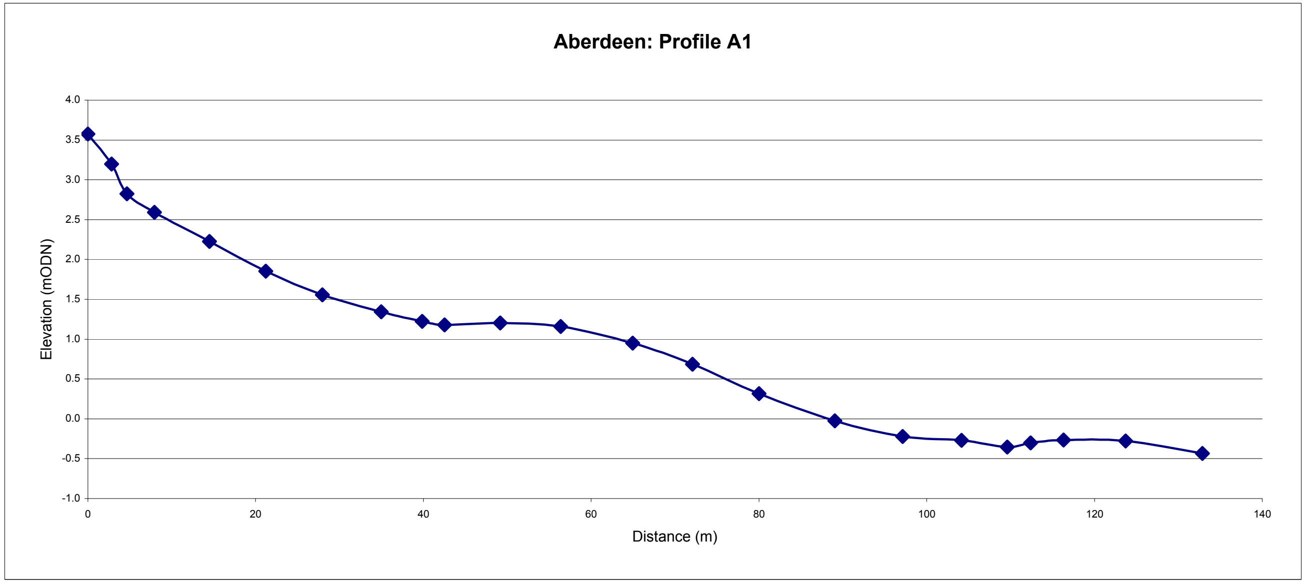
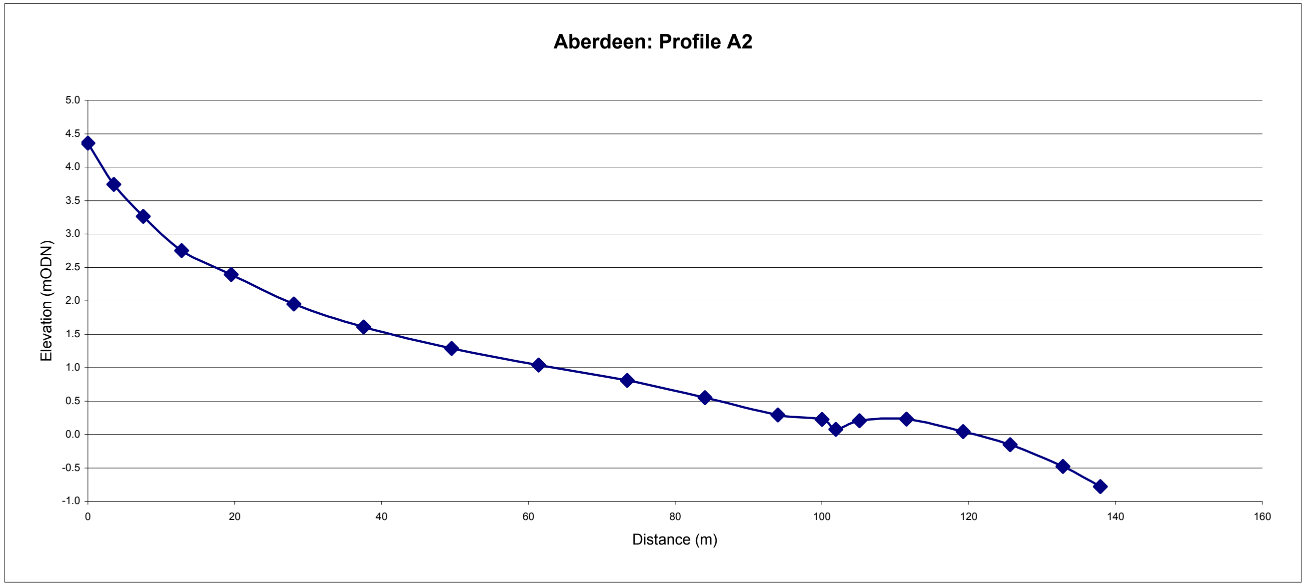
Sediment Sample Positions

Figure A3

Aberdeen: Profile A1



Aberdeen: Profile A2



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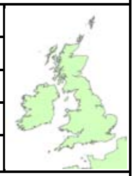

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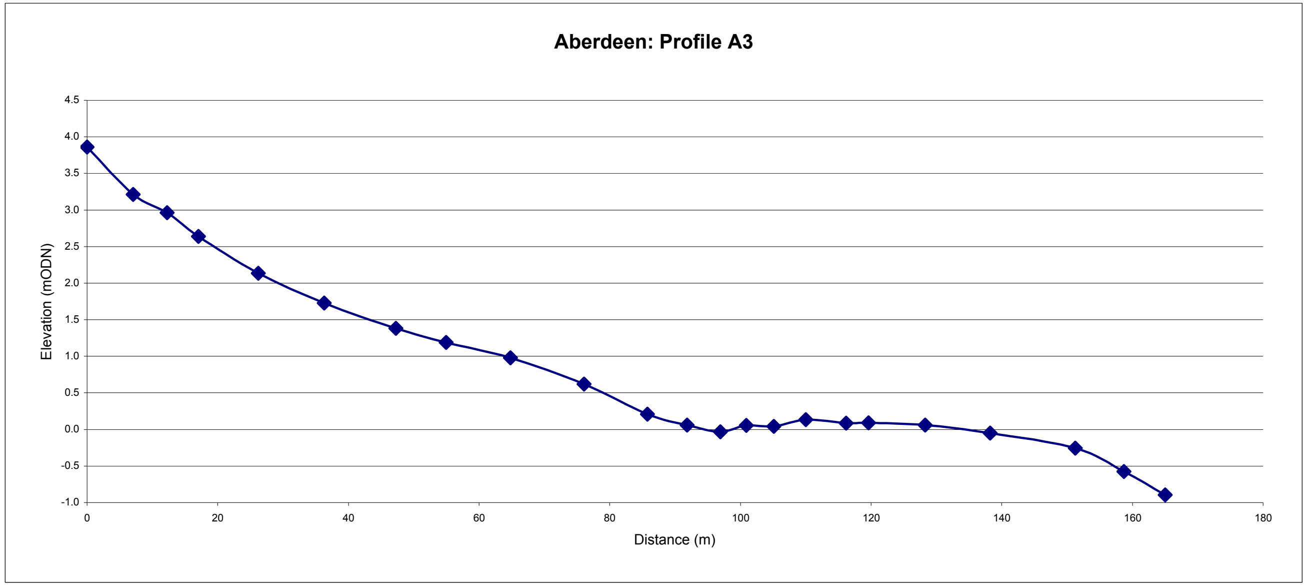
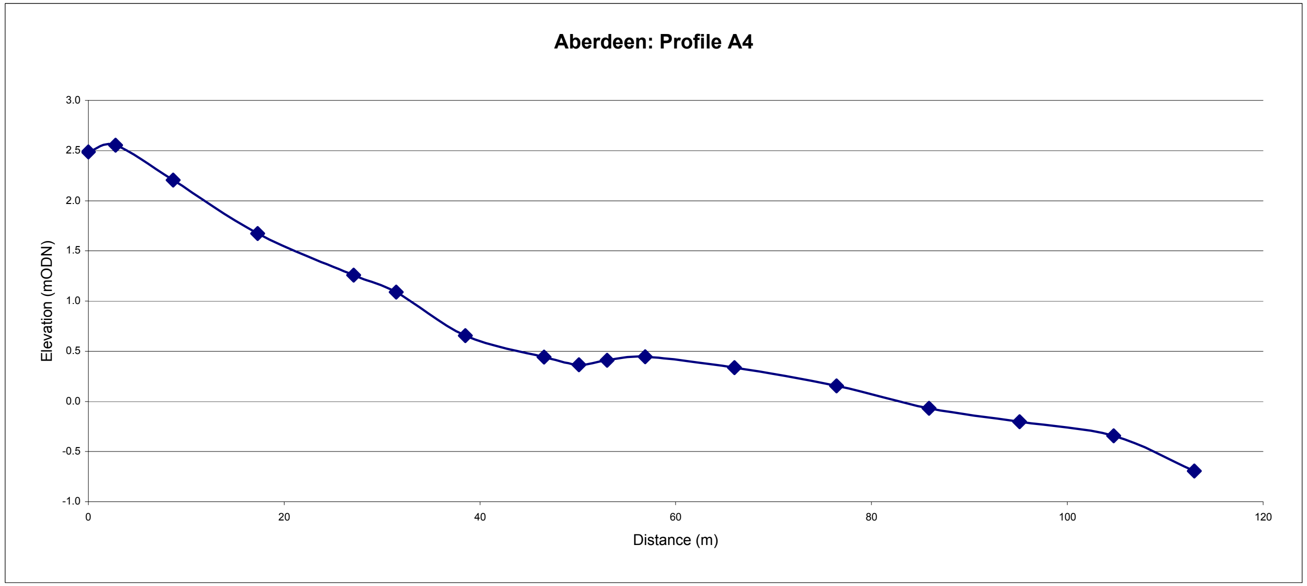
Aberdeen Beach Profiles

Figure A 4





Date	By	Size	Version
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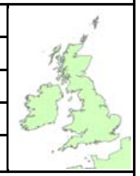

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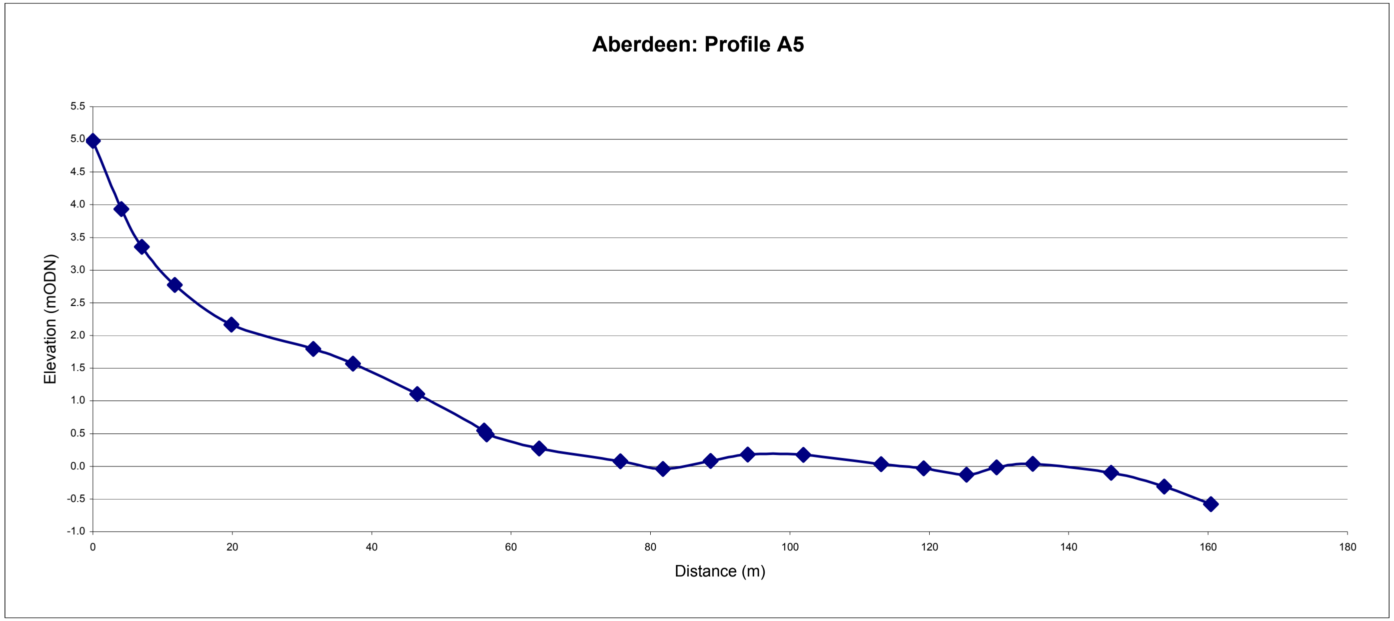
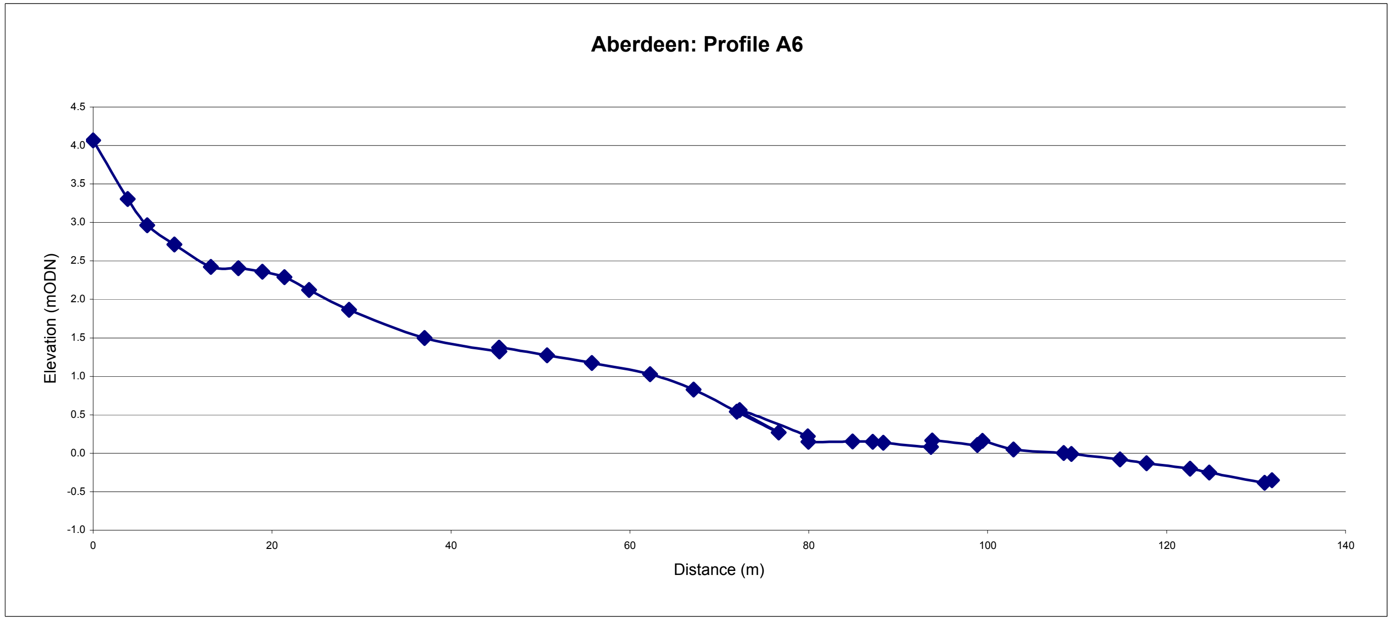
Aberdeen Beach Profiles

Figure A 5





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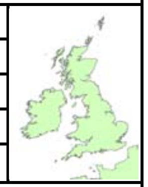

Reference

3890 - Profile_Plots.xls

Produced by ABPmer Ltd.

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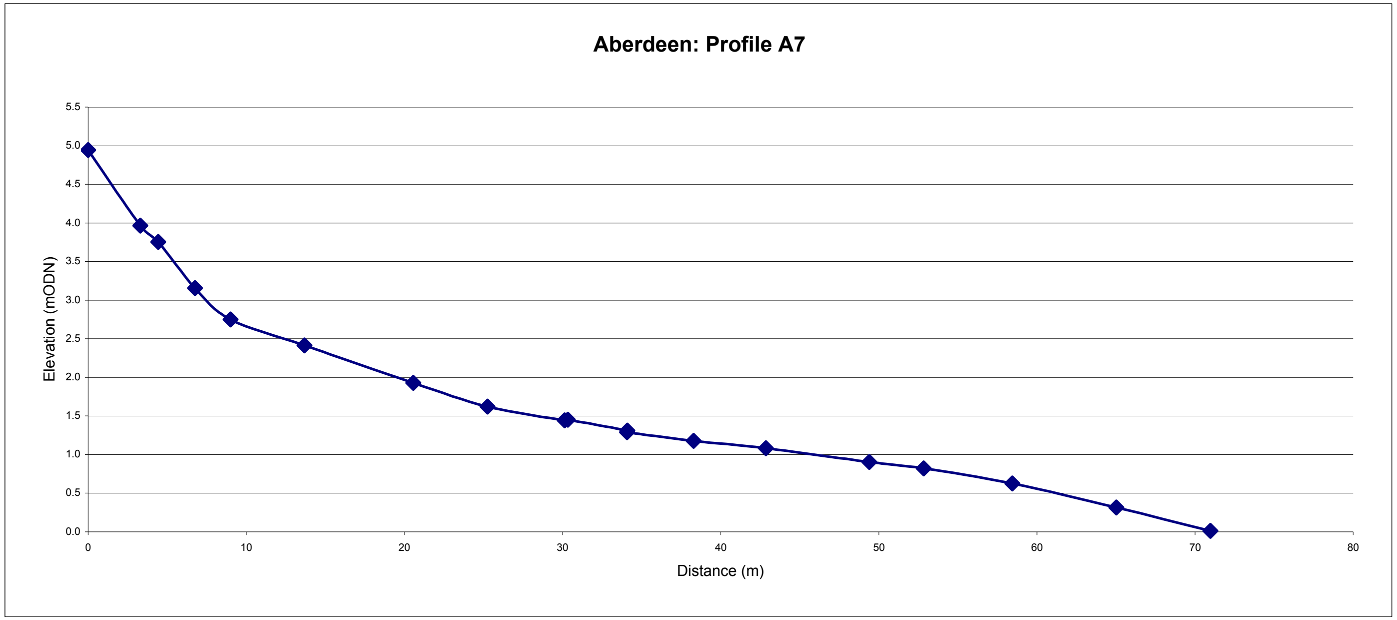
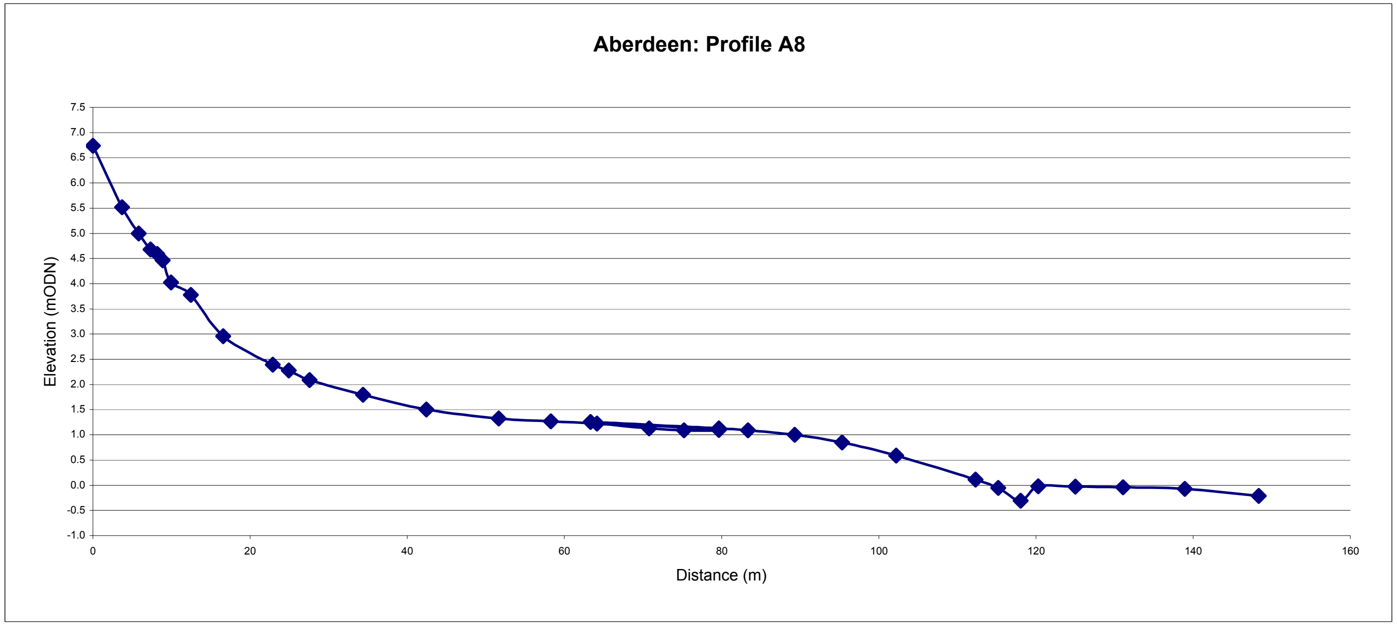
Aberdeen Beach Profiles

Figure A 6





Date	By	Size	Version
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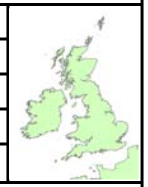

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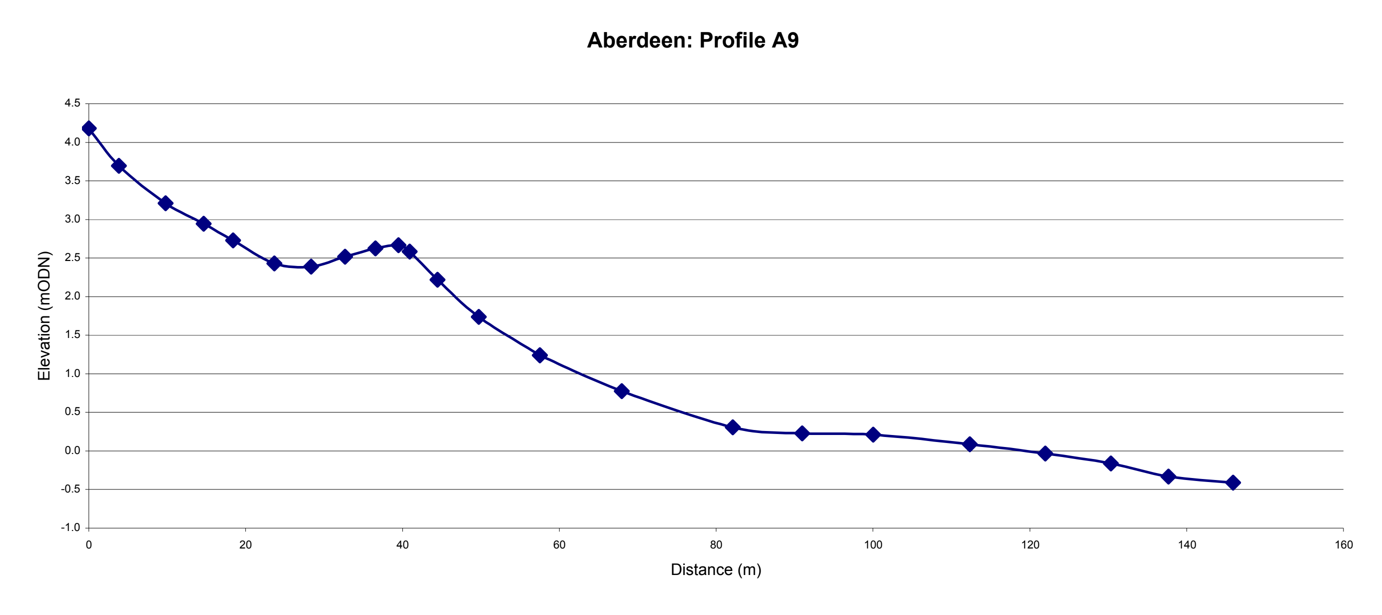
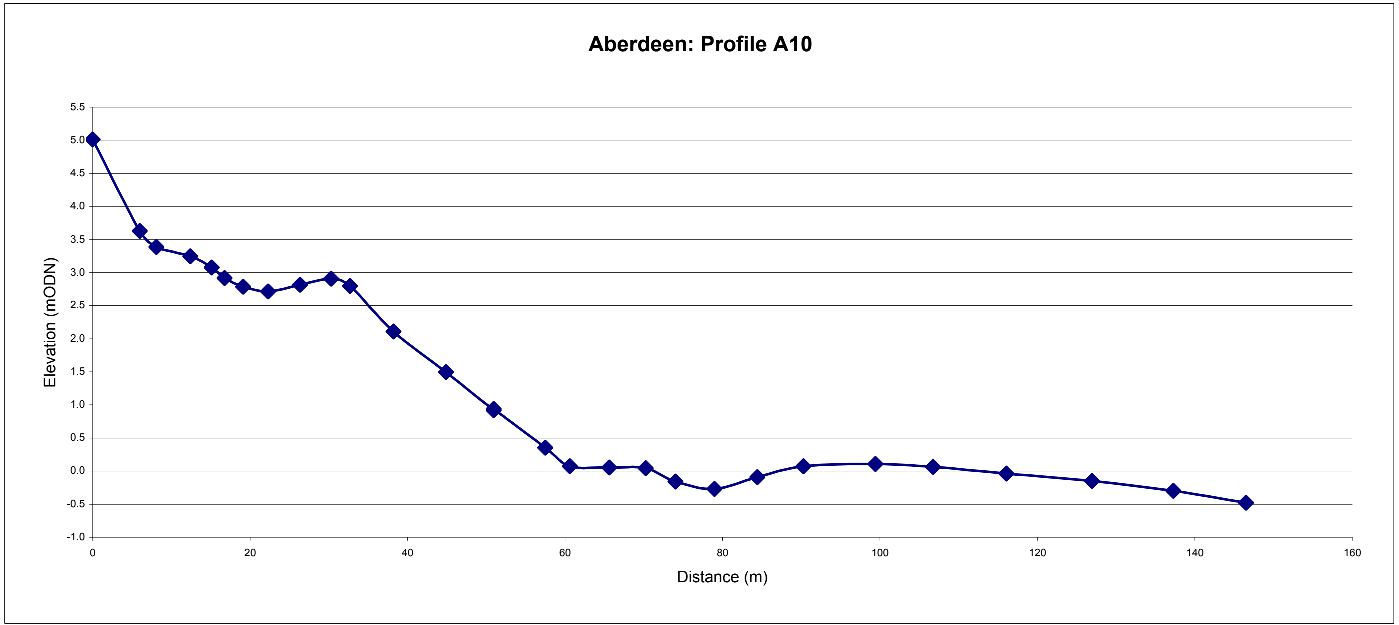
Aberdeen Beach Profiles

Figure A 7





Date	By	Size	Version
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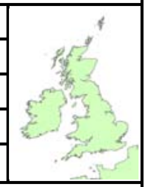
3890 - Profile_Plots.xls			
Produced by ABPmer Ltd.			



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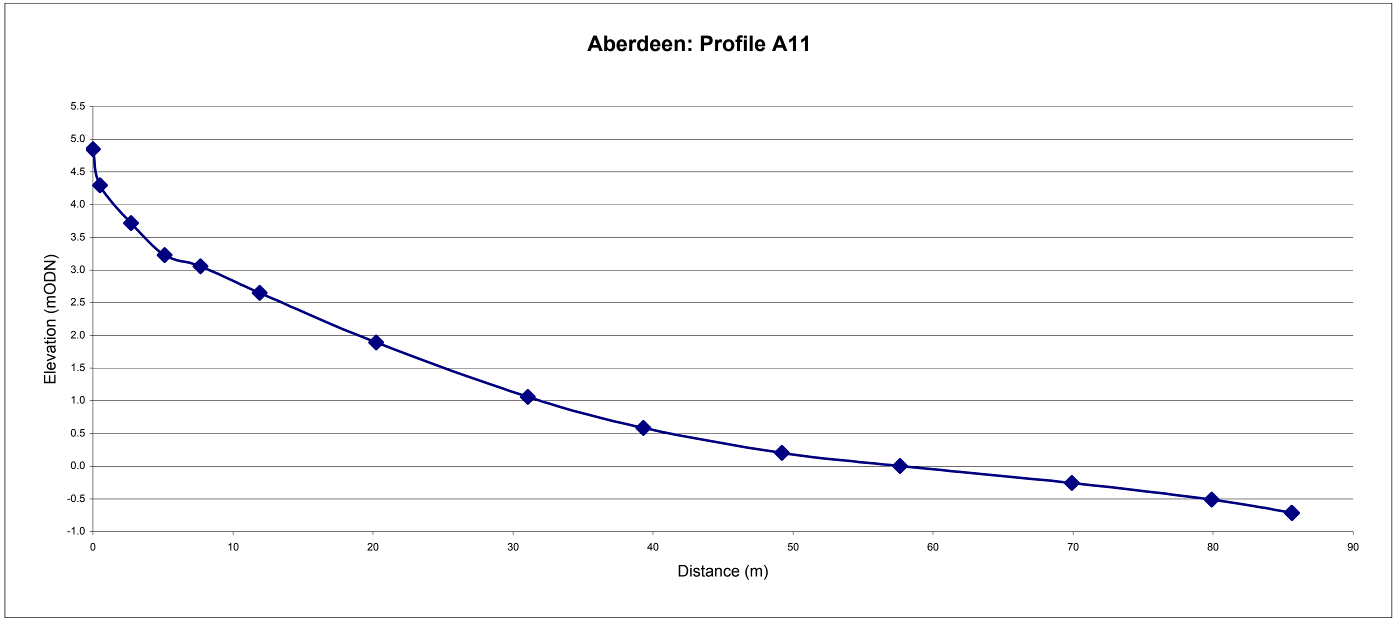
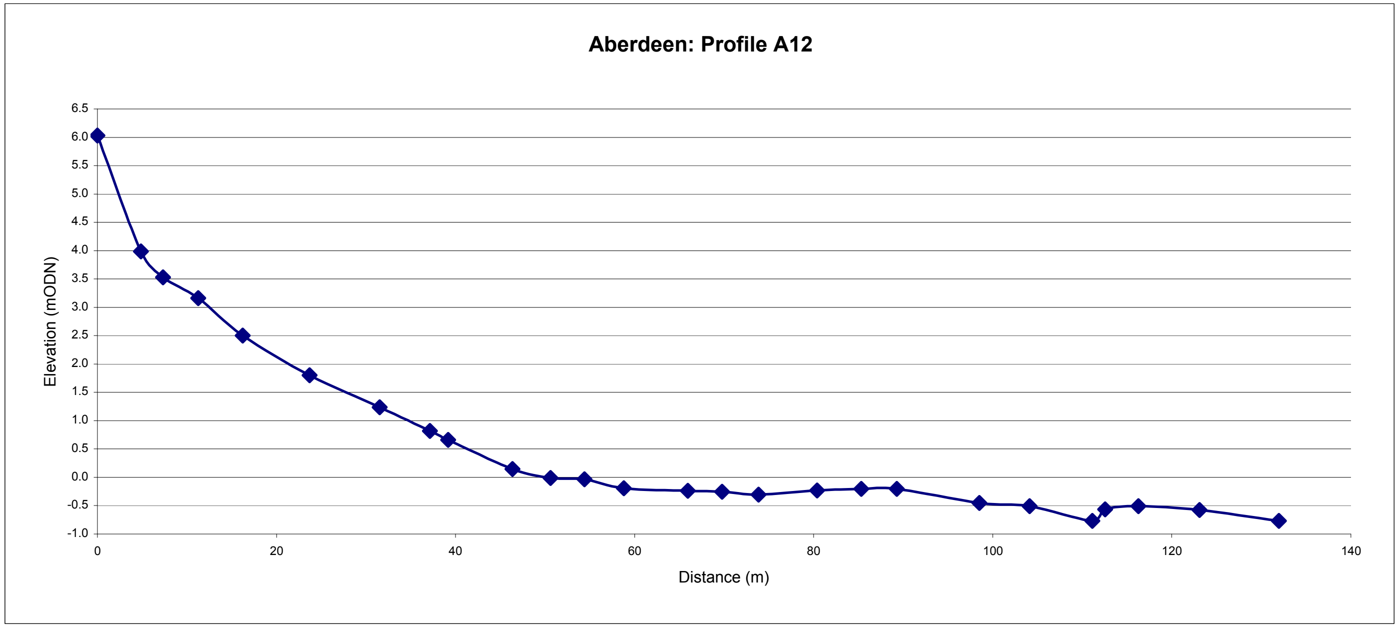
Aberdeen Beach Profiles

Figure A 8





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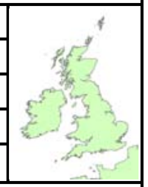

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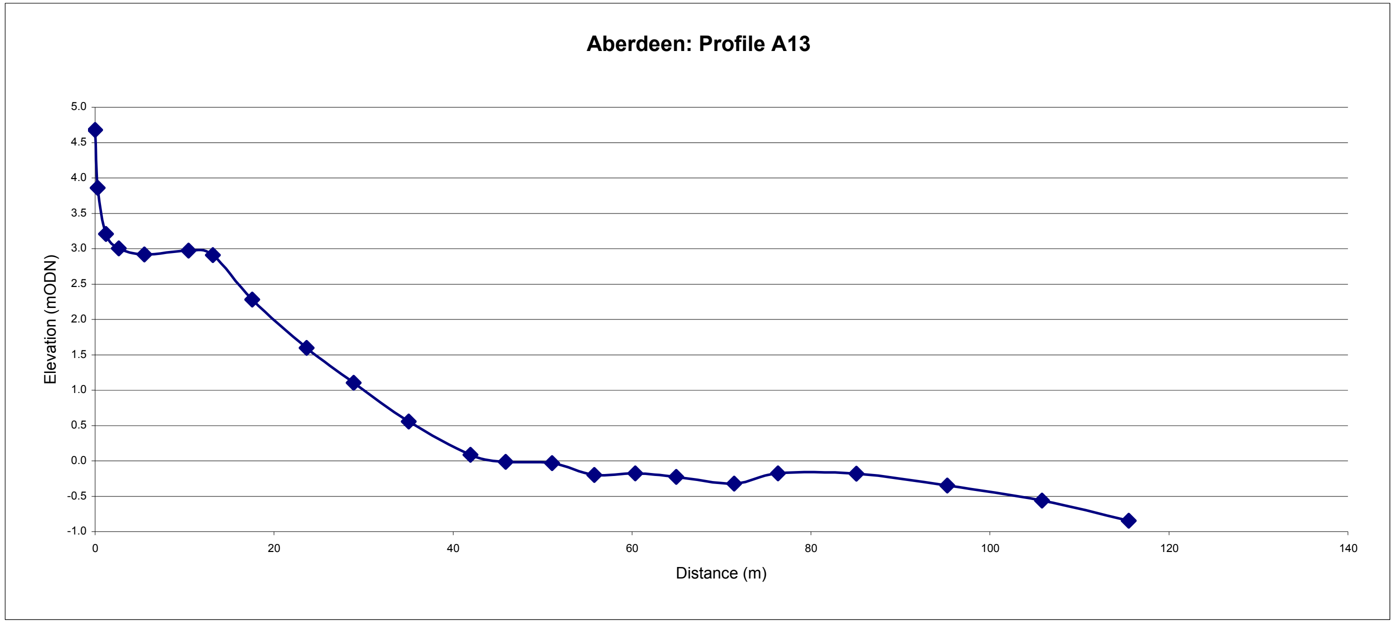
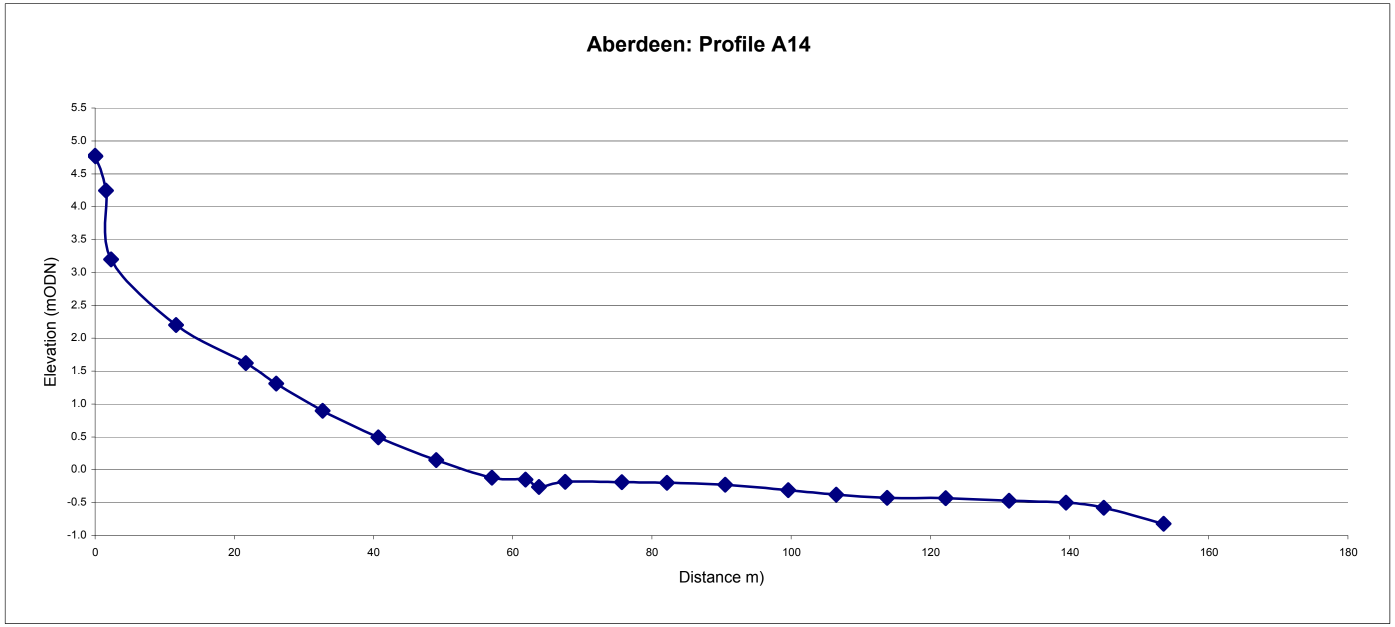
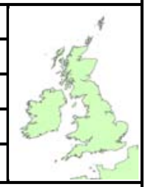
Aberdeen Beach Profiles

Figure A 9





Date	By	Size	Version
Nov 2010	SCB	A4	1



Reference

3890 - Profile_Plots.xls

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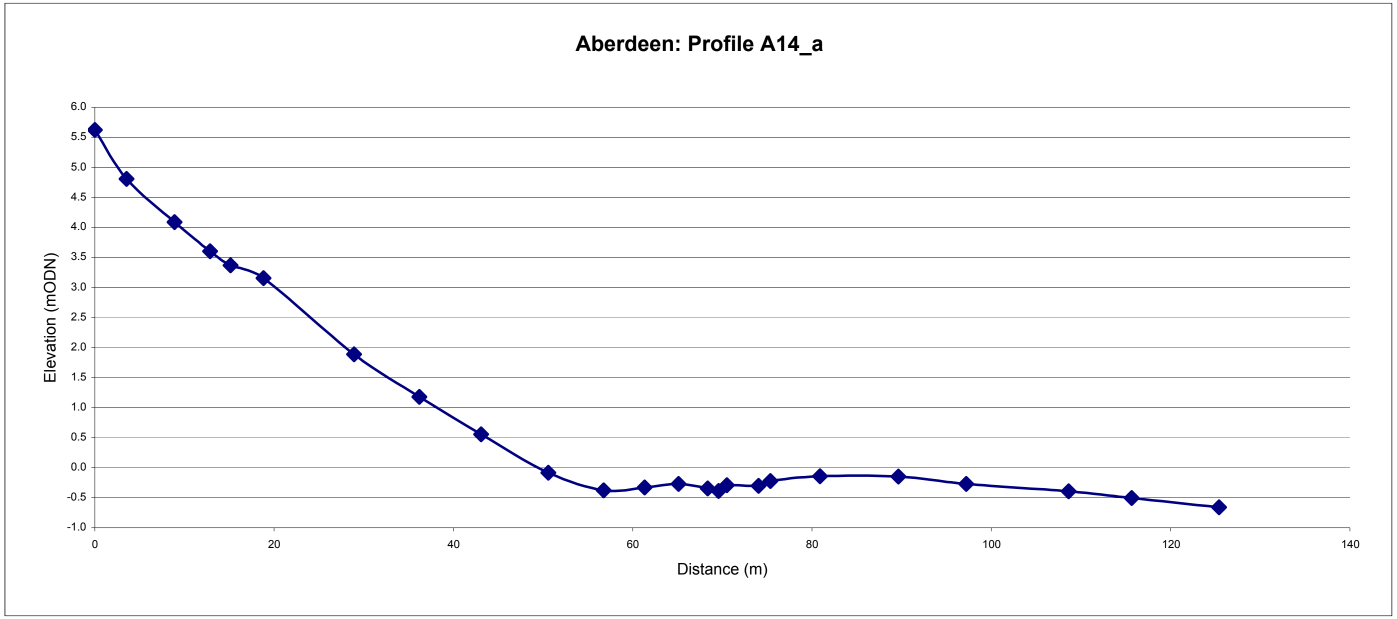
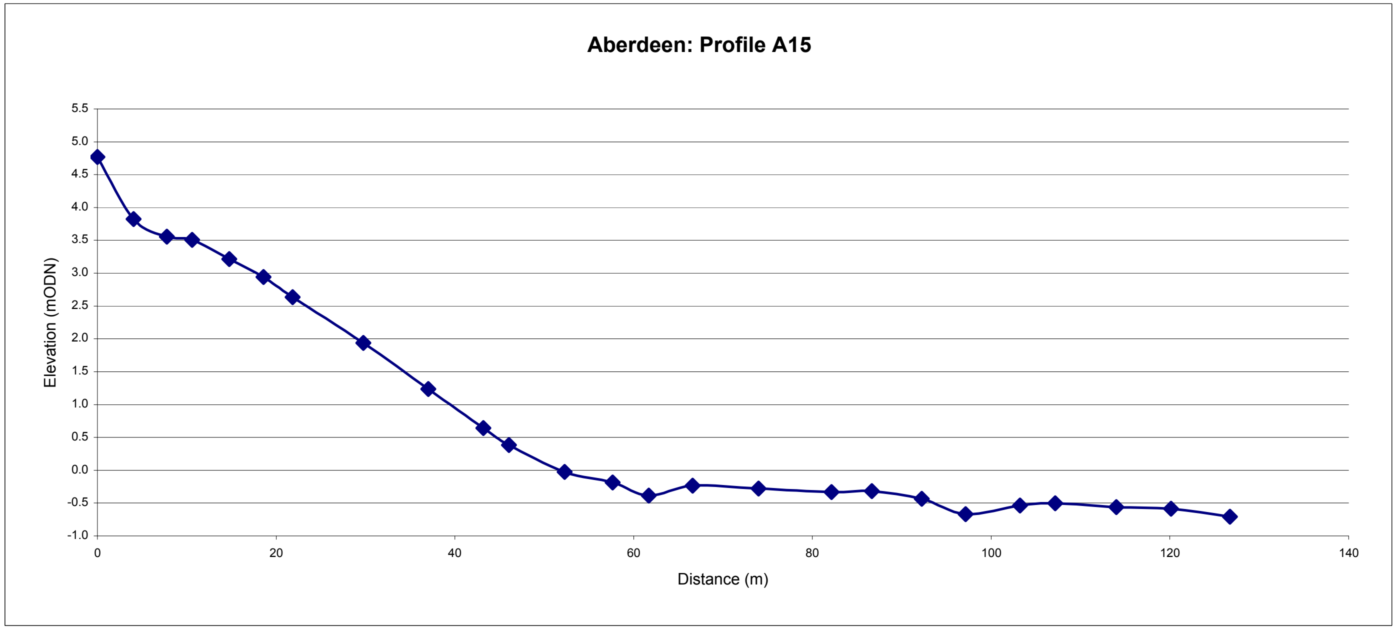
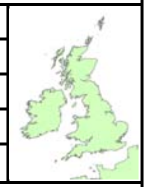
Aberdeen Beach Profiles

Figure A 10





Date	By	Size	Version
Nov 2010	SCB	A4	2
Reference			
3890 - Profile_Plots.xls			
Produced by ABPmer Ltd.			



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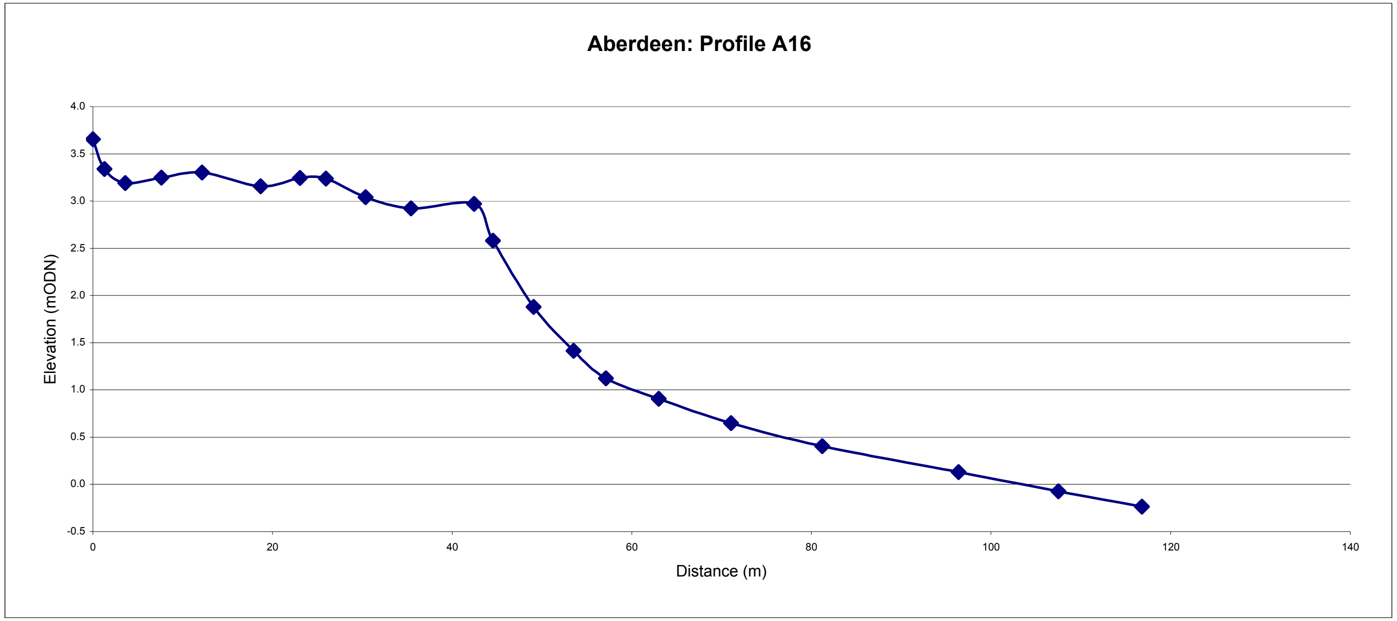
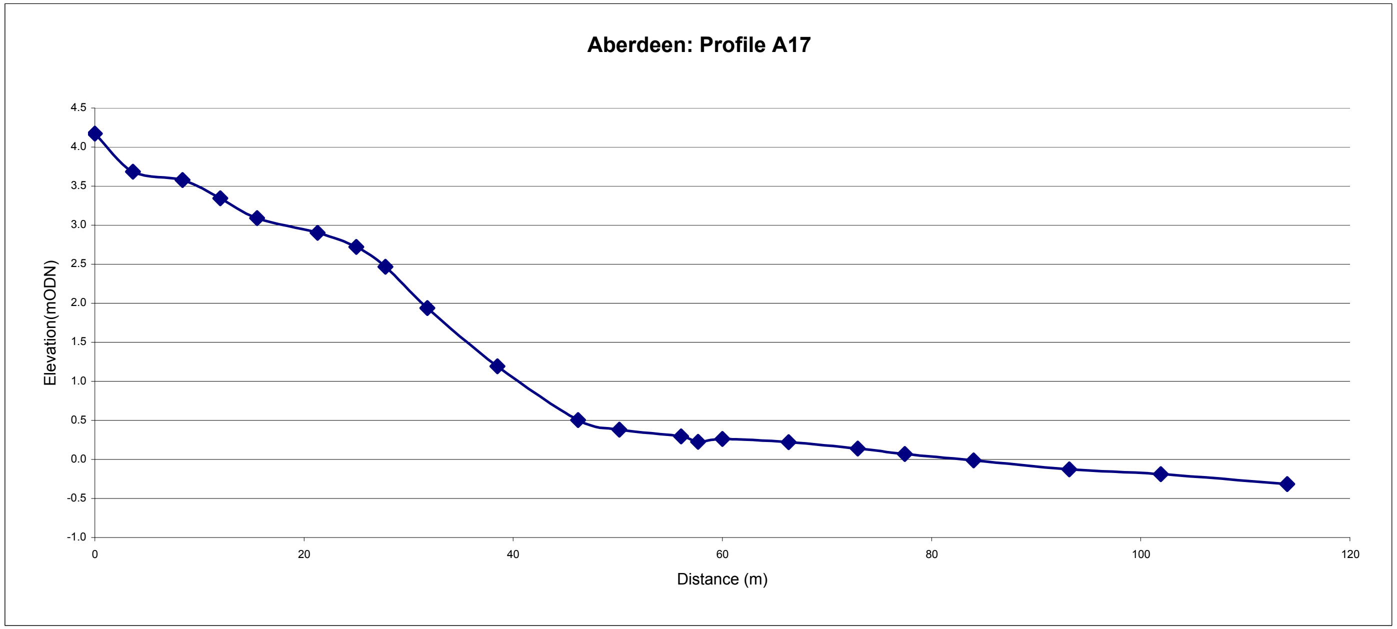
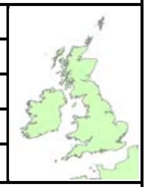
Aberdeen Beach Profiles

Figure A 11





Date	By	Size	Version
Nov 2010	SCB	A4	1



Reference

3890 - Profile_Plots.xls

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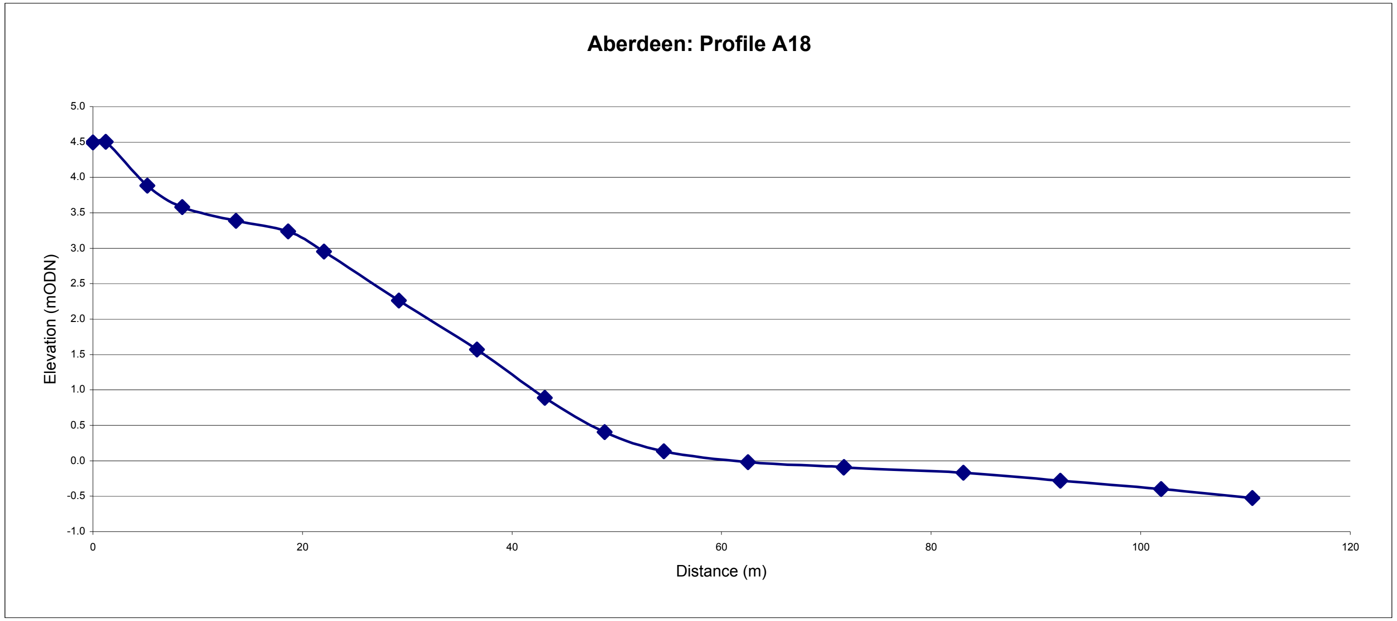
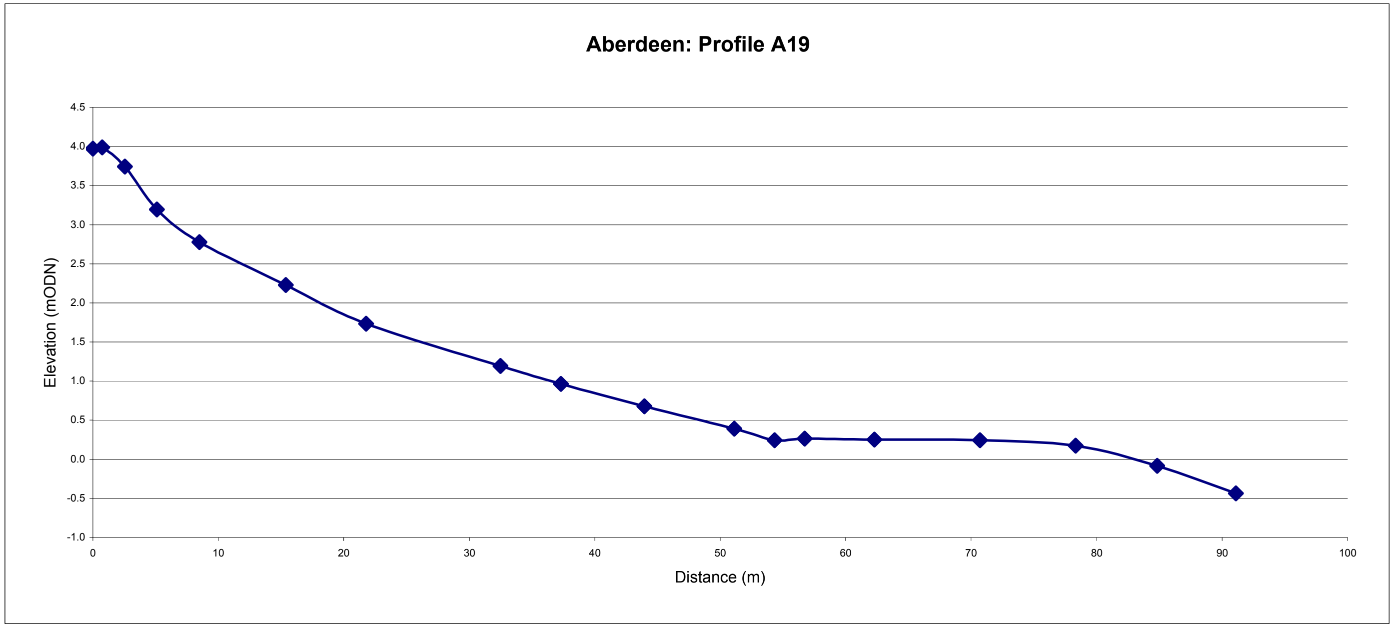
Figure A 12





Date	By	Size	Version
Nov 2010	SCB	A4	1

Reference

3890 - Profile_Plots.xls

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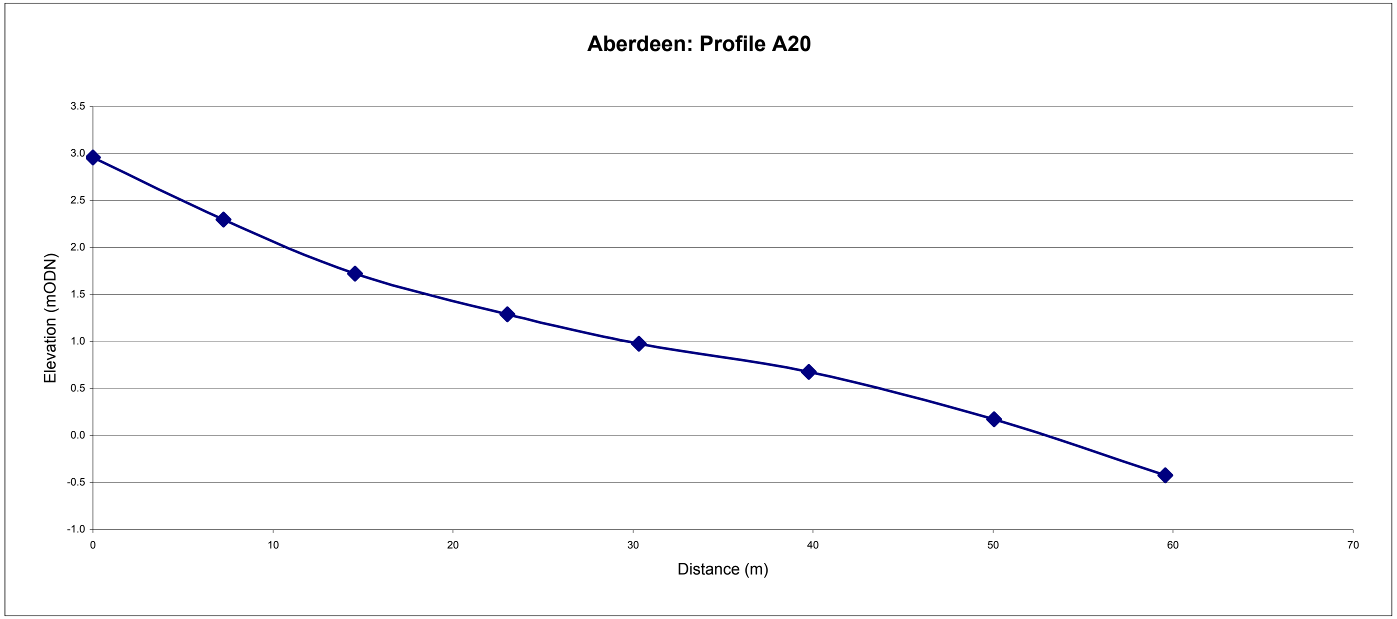
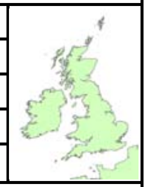
Figure A 13



Date	By	Size	Version
Nov 2010	SCB	A4	1
Reference			
3890 - Profile_Plots.xls			
Produced by ABPmer Ltd.			



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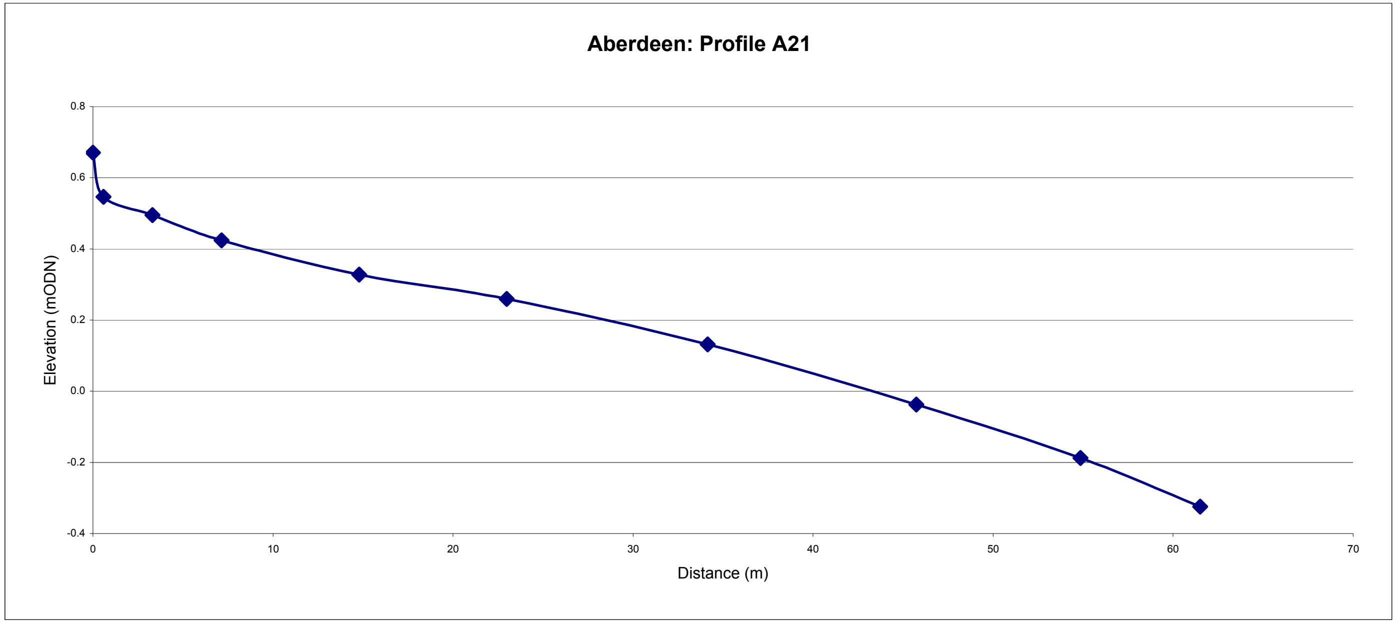
Aberdeen Beach Profiles

Figure A 14



Date	By	Size	Version
Nov 2010	SCB	A4	1

Reference

3890 - Profile_Plots.xls

Produced by ABPmer Ltd.

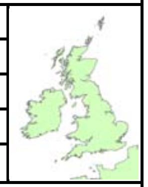


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Figure A 15

Annex 1 Sediment Sample Results

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Result Analysis Report

Sample Name: A1_P274 - Average

Measured: 18

Sample Source: Aberdeen

Measured by: SBelcher

Obscuration: 9.60 %

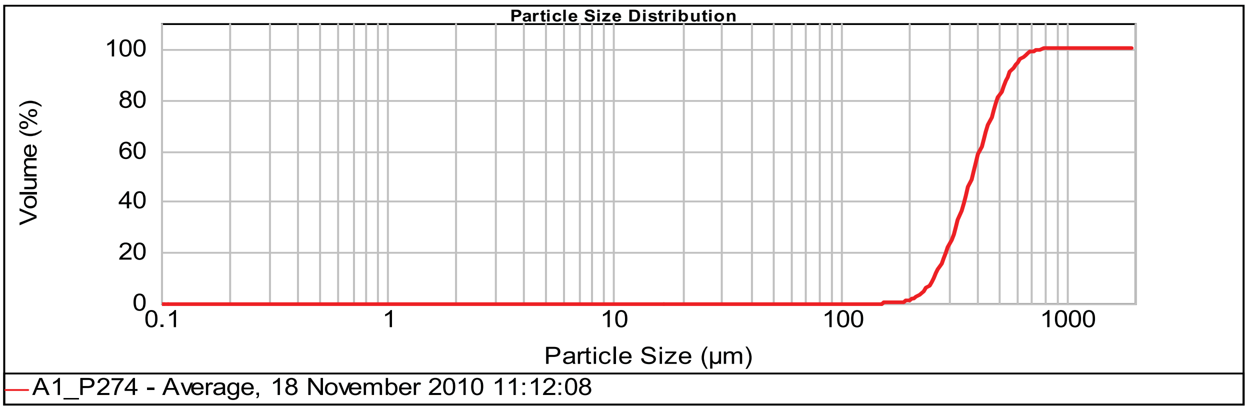
Location: 27\10\2010

Weighted Residual: 4.804 %

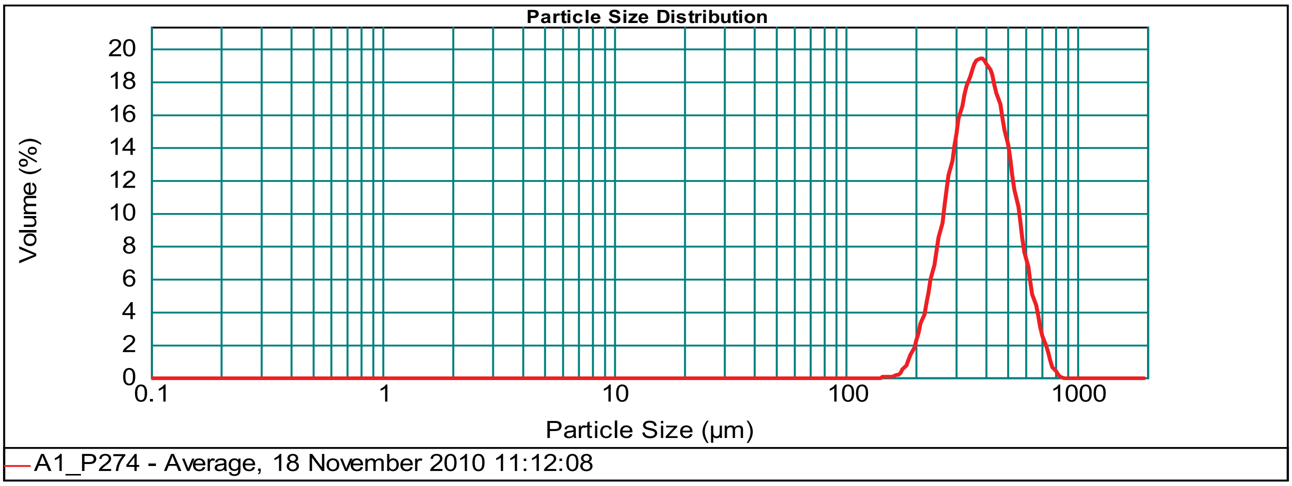
d(0.1): 259.336 um

d(0.5): 382.521 um

d(0.9): 560.549 um



Clay	Silt			Sand		
	Fine	Medium	Coarse	Fine	Medium	Coarse
0 %	0 %	0 %	0 %	1 %	93 %	6 %



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Result Analysis Report

Sample Name: A2_P297 - Average

Measured: 18

Sample Source: Aberdeen

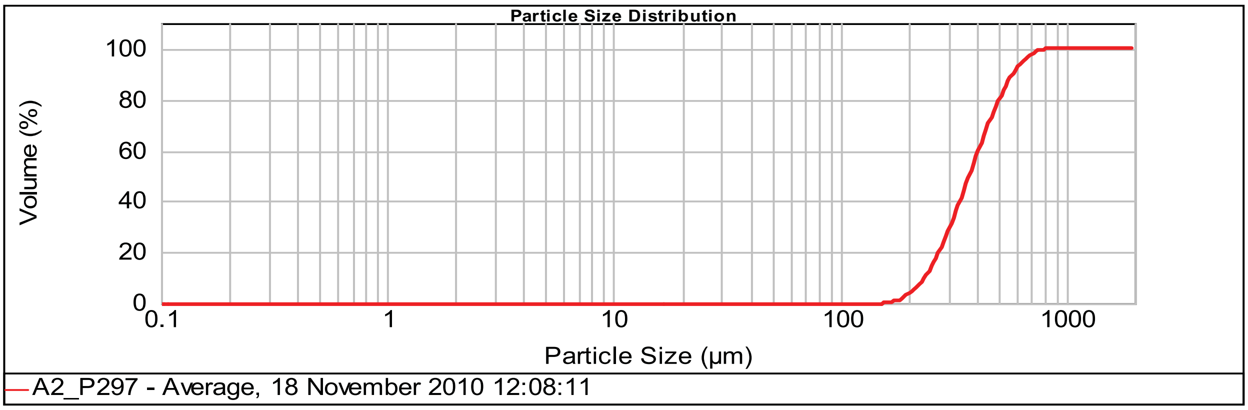
Measured by: SBelcher

Obscuration: 10.10 %

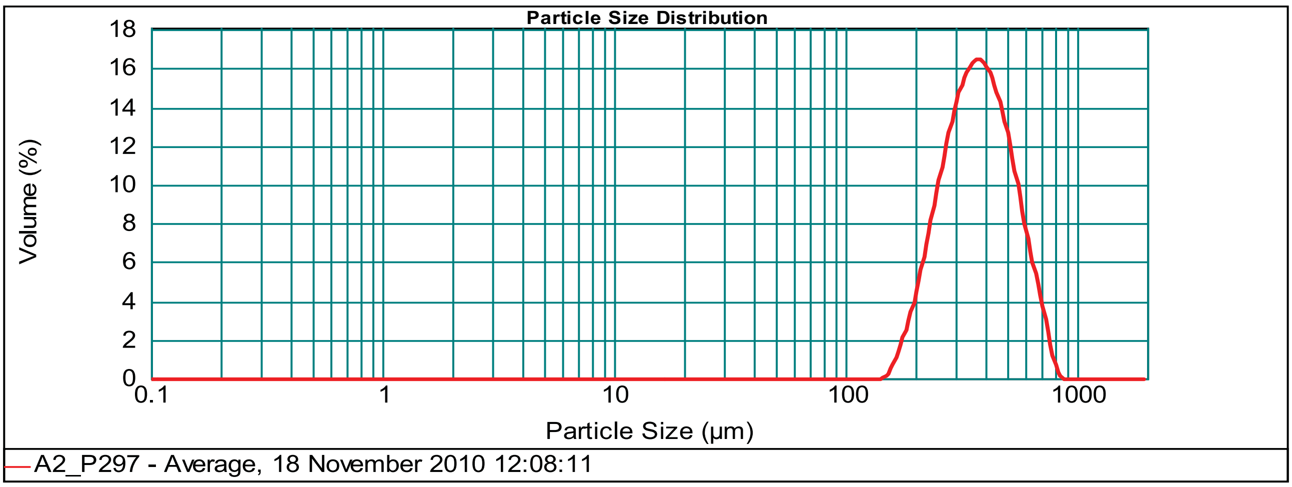
Location: 27\10\2010

Weighted Residual: 5.239 %

d(0.1): 234.904 um **d(0.5): 370.617** um d(0.9): 577.774 um



Clay	Silt			Sand		
	Fine	Medium	Coarse	Fine	Medium	Coarse
0 %	0 %	0 %	0 %	3 %	89 %	8 %



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Result Analysis Report

Sample Name: A3_P322 - Average

Measured: 18

Sample Source: Aberdeen

Measured by: SBelcher

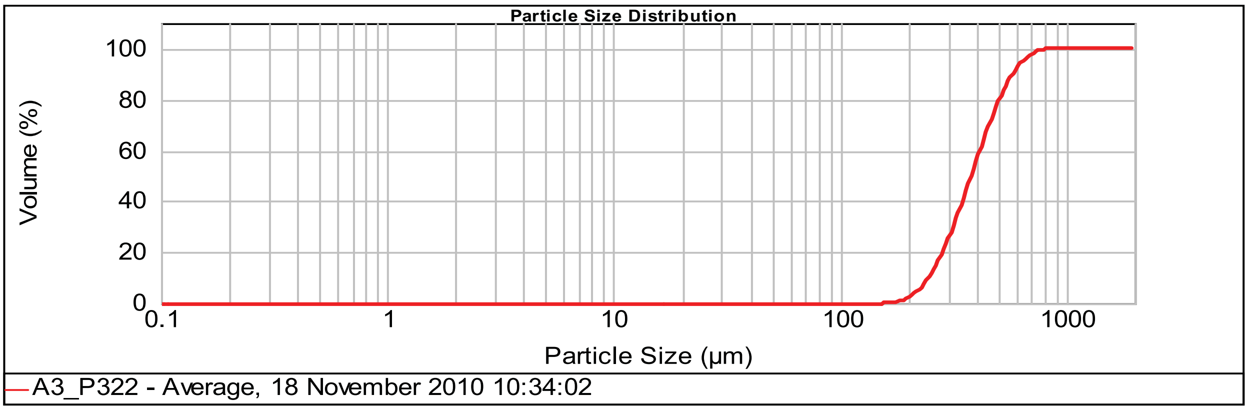
Obscuration: 9.22 %

Location: 27_10_2010

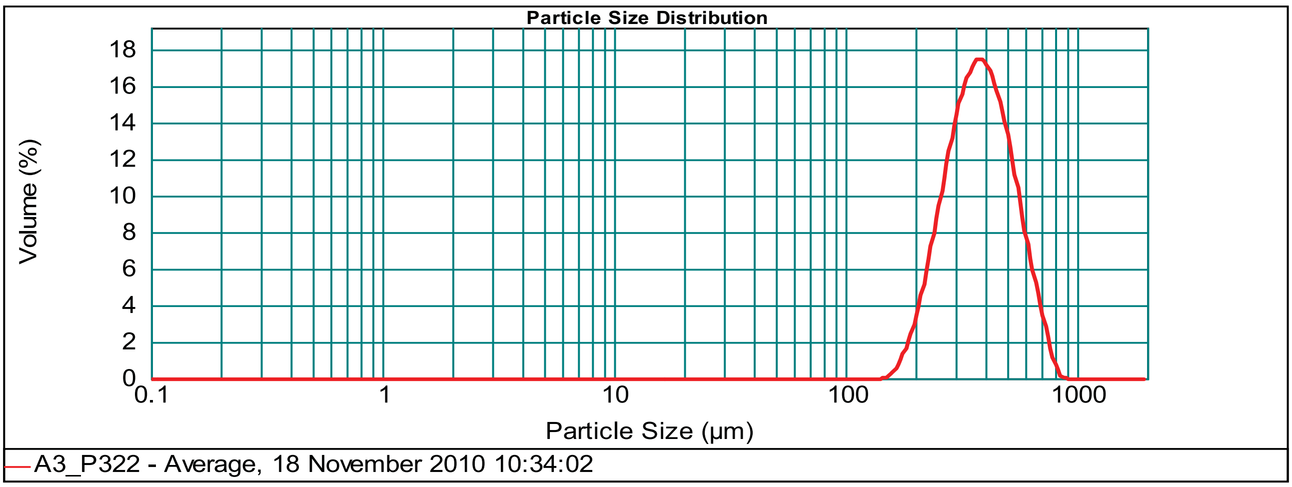
Weighted Residual: 5.093 %

---

d(0.1): 245.872 um **d(0.5): 378.010** um d(0.9): 576.525 um



Clay	Silt			Sand		
	Fine	Medium	Coarse	Fine	Medium	Coarse
0 %	0 %	0 %	0 %	2 %	90 %	8 %



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Result Analysis Report

Sample Name: A4_P342 - Average

Measured: 18

Sample Source: Aberdeen

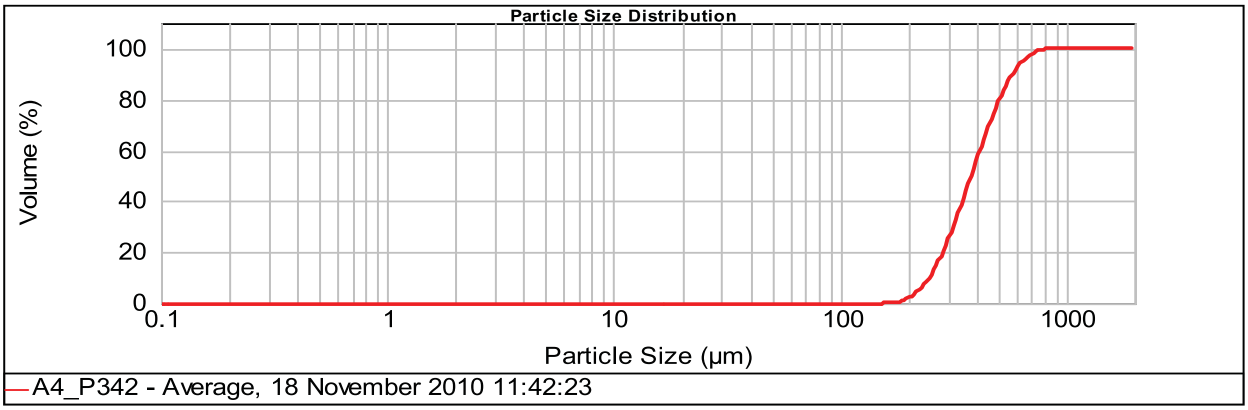
Measured by: SBelcher

Obscuration: 9.76 %

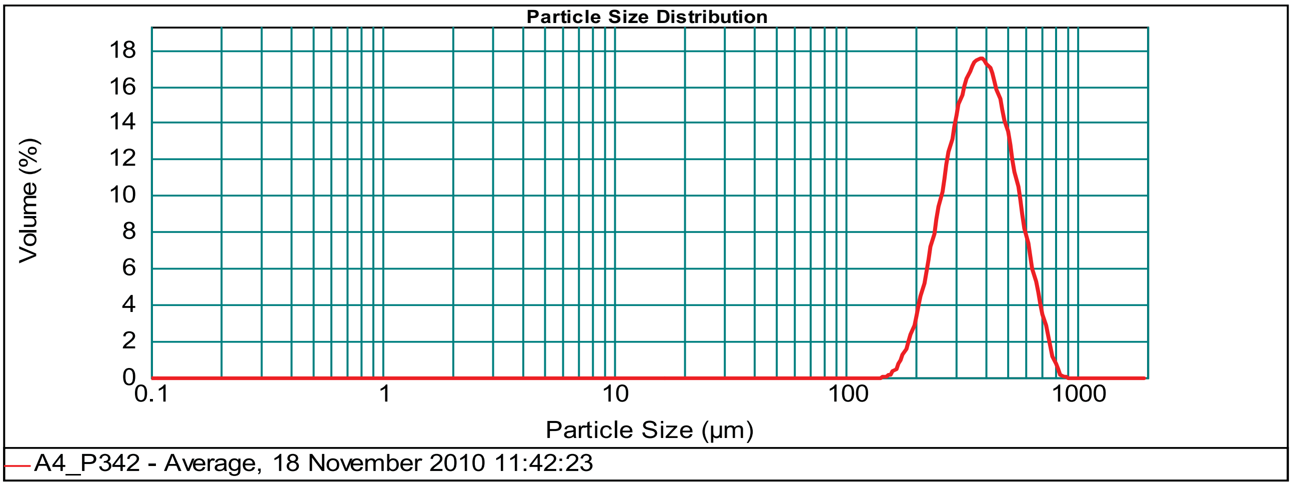
Location: 27\10\2010

Weighted Residual: 4.492 %

d(0.1): 246.669 um **d(0.5): 379.084** um d(0.9): 577.463 um



Clay	Silt			Sand		
	Fine	Medium	Coarse	Fine	Medium	Coarse
0 %	0 %	0 %	0 %	2 %	90 %	8 %



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Result Analysis Report

Sample Name: A5_P360 - Average

Measured: 18

Sample Source: Aberdeen

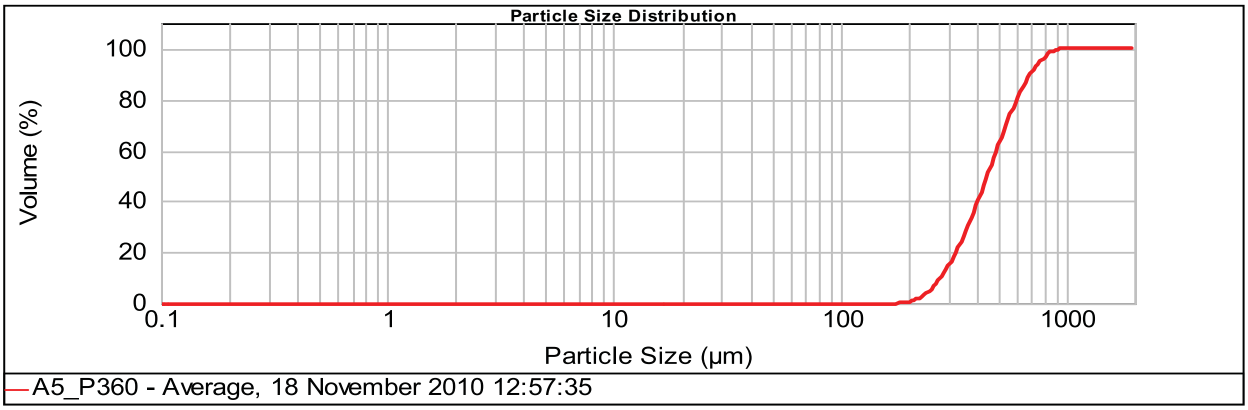
Measured by: SBelcher

Obscuration: 10.26 %

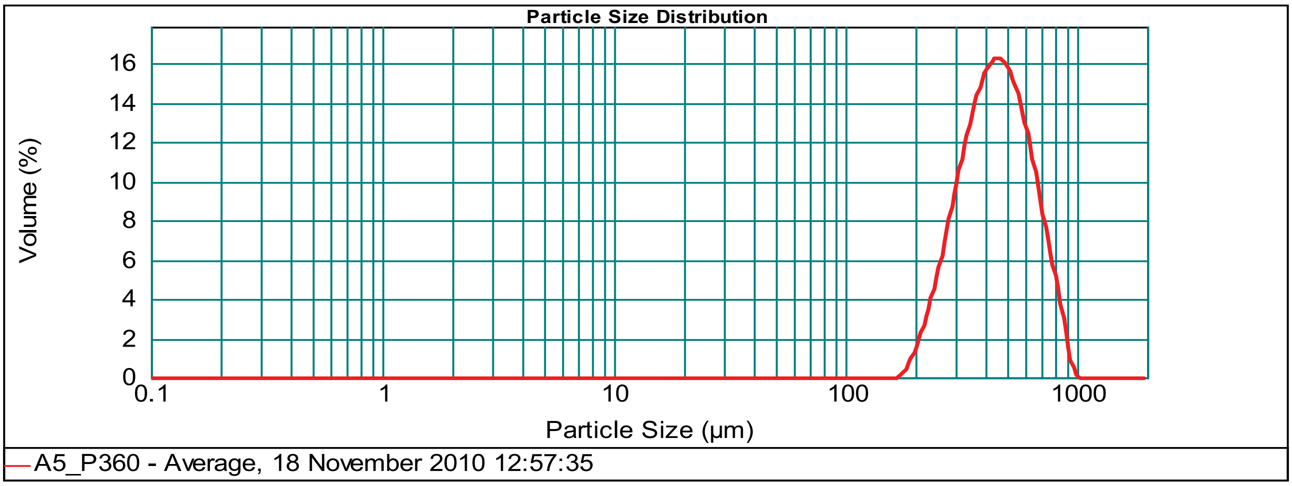
Location: 27\10\2010

Weighted Residual: 5.768 %

d(0.1): 278.784 um **d(0.5): 445.316** um d(0.9): 692.346 um



Clay	Silt			Sand		
	Fine	Medium	Coarse	Fine	Medium	Coarse
0 %	0 %	0 %	0 %	1 %	79 %	20 %



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Result Analysis Report

Sample Name: A6_P261 - Average

Measured: 18

Sample Source: Aberdeen

Measured by: SBelcher

Obscuration: 9.22 %

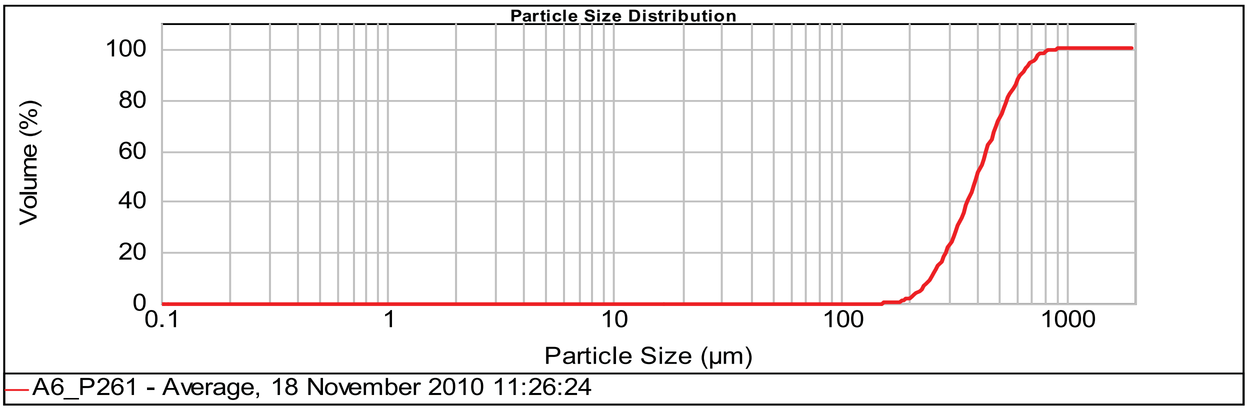
Location: 27\10\2010

Weighted Residual: 5.300 %

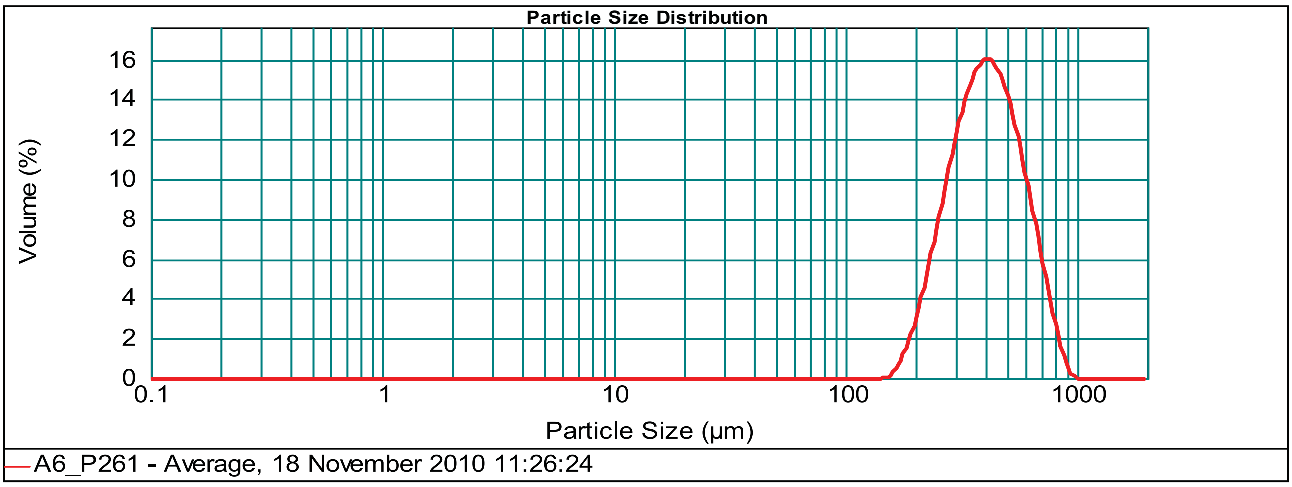
d(0.1): 251.622 um

d(0.5): 402.803 um

d(0.9): 633.933 um



Clay	Silt			Sand		
	Fine	Medium	Coarse	Fine	Medium	Coarse
0 %	0 %	0 %	0 %	2 %	85 %	13 %



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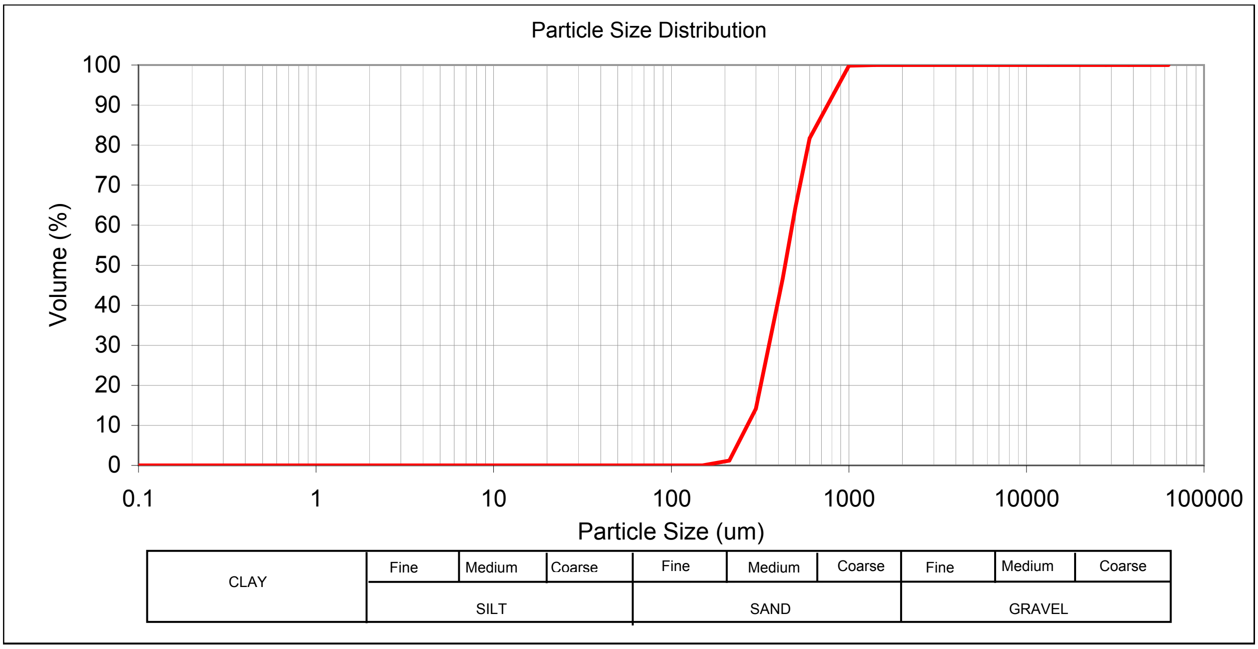
Result Analysis Report

Sample: A7 P253

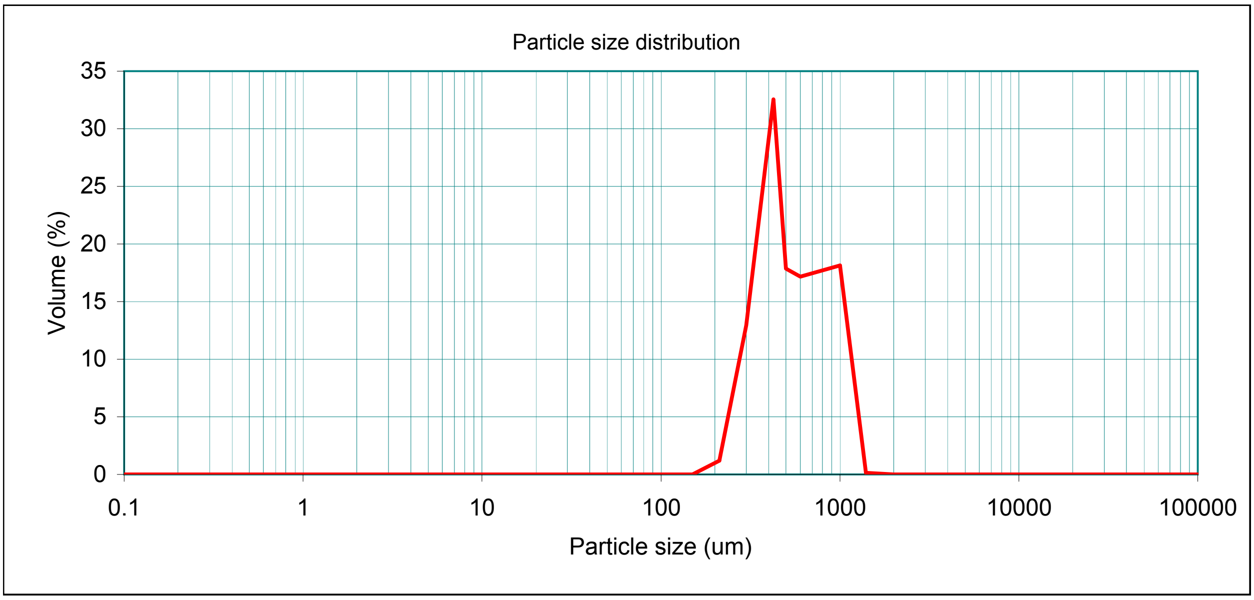
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 0.07g

d(0.1): 271.87 um **d(0.5): 438.83 um** d(0.9): 782.39 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	1.19	80.54	18.27	0.00	0.00	0.00	0.00



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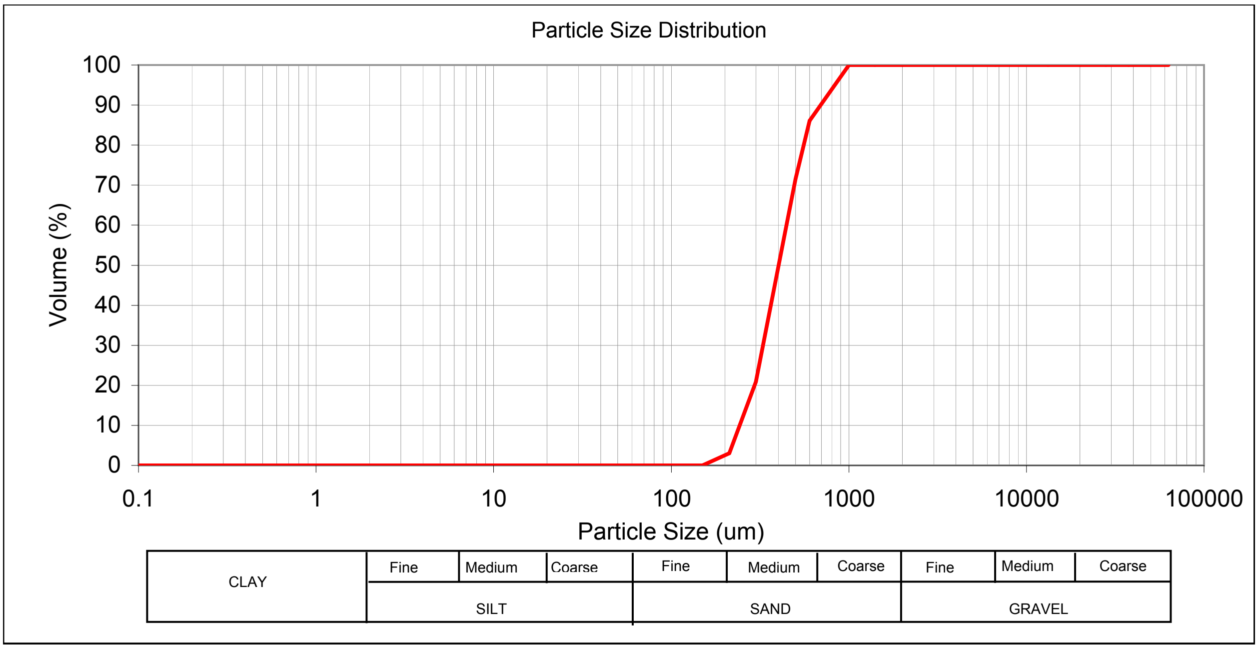
Result Analysis Report

Sample: A8 P250

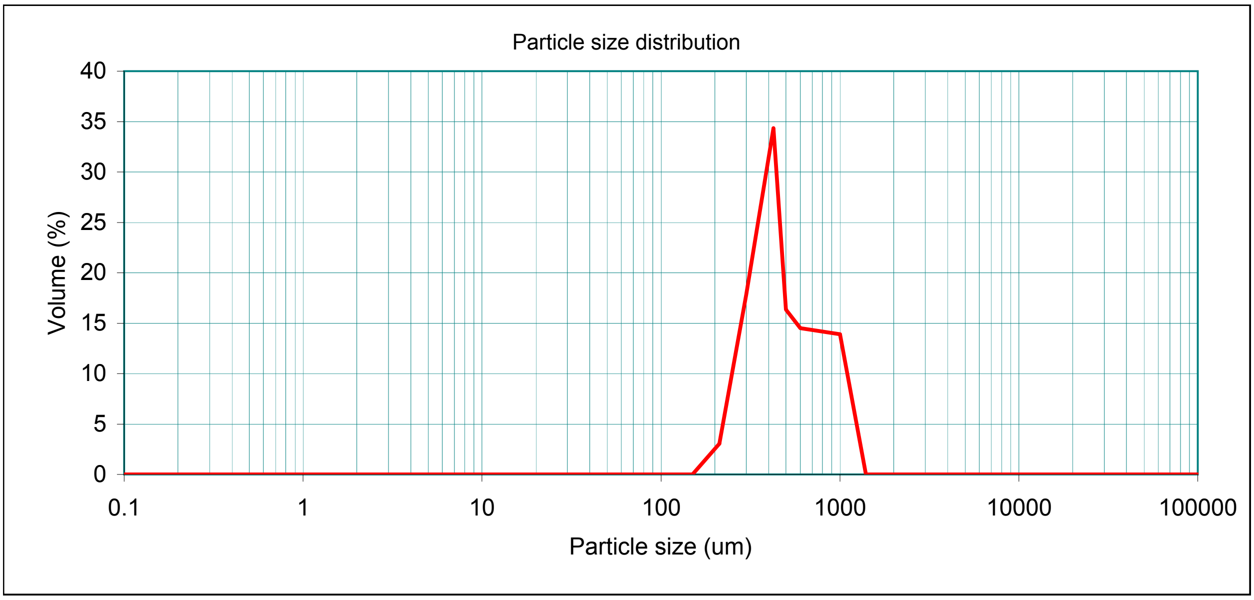
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:**

d(0.1): 246.29 um **d(0.5): 405.93 um** d(0.9): 712.80 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	3.04	83.03	13.92	0.00	0.00	0.00	0.00



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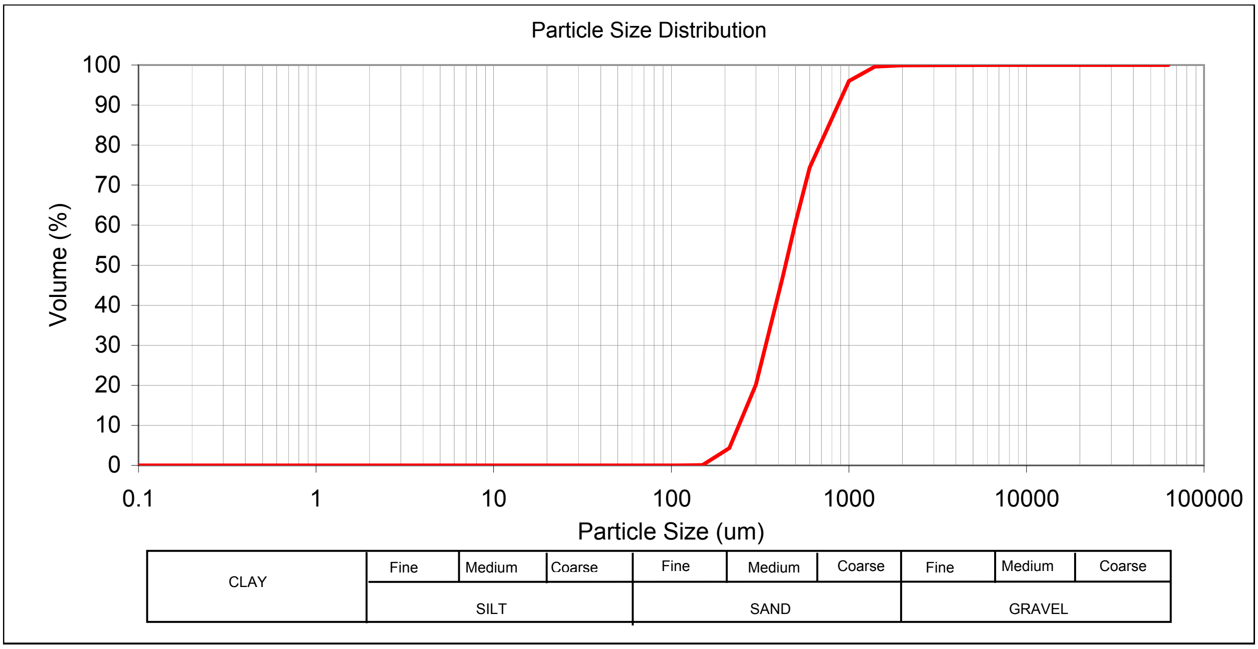
Result Analysis Report

Sample: A9 P234

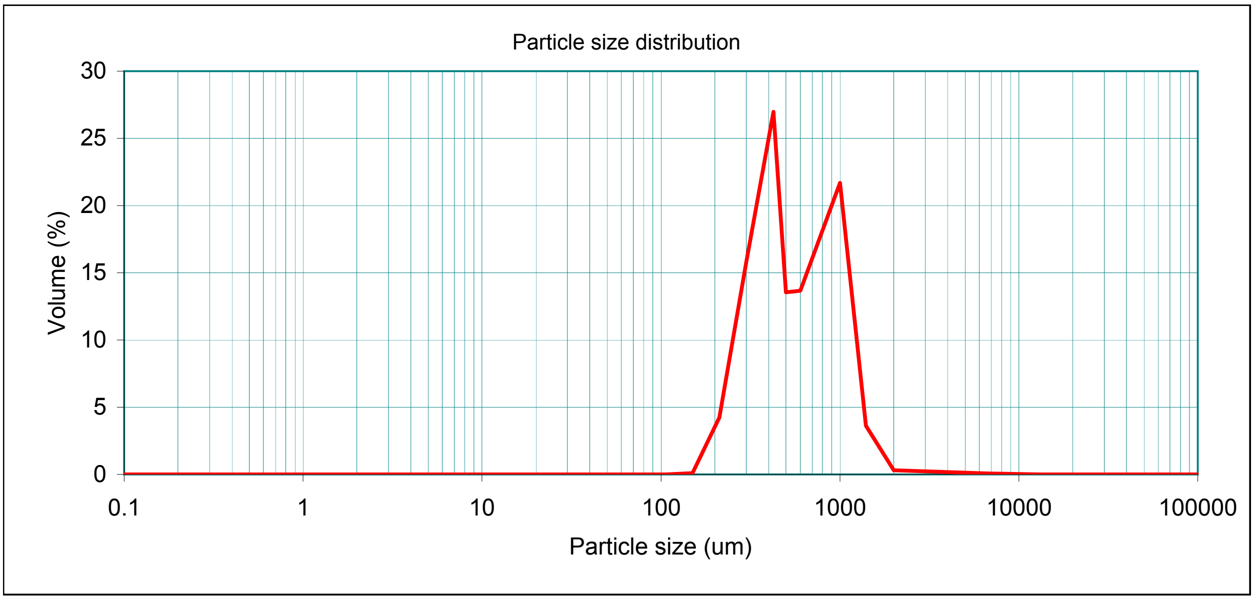
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 0.74g

d(0.1): 243.52 um **d(0.5): 440.99 um** d(0.9): 889.05 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	4.33	69.99	25.60	0.06	0.00	0.00	0.00



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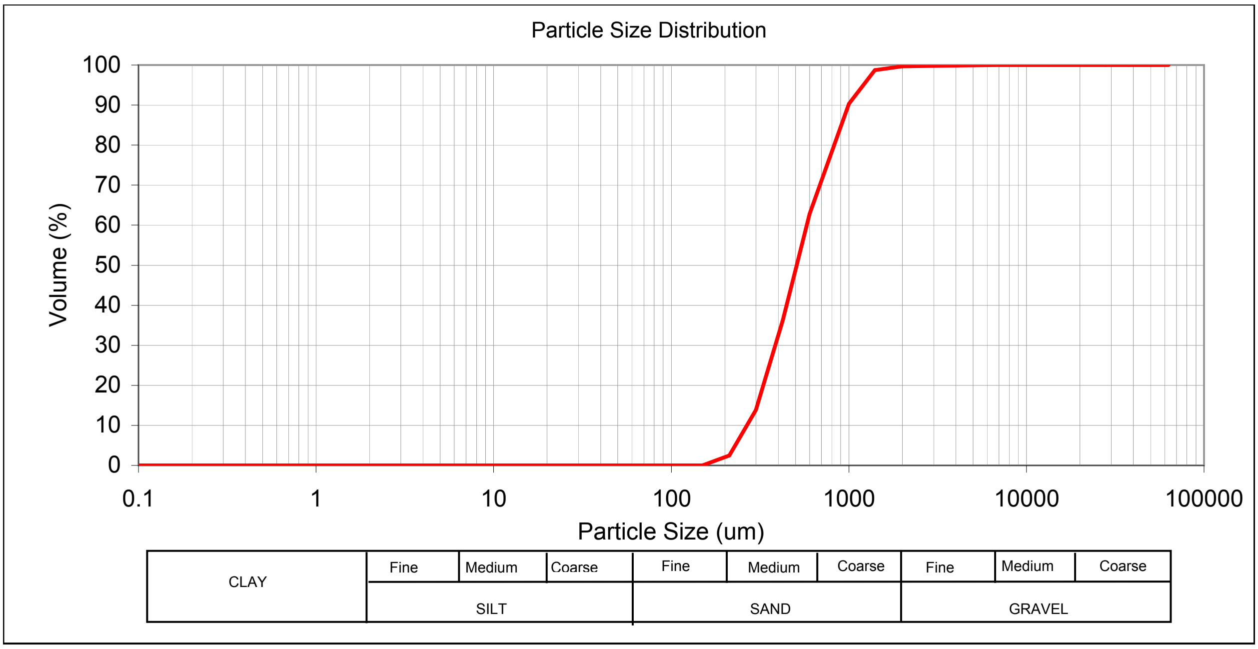
Result Analysis Report

Sample: A10 P13

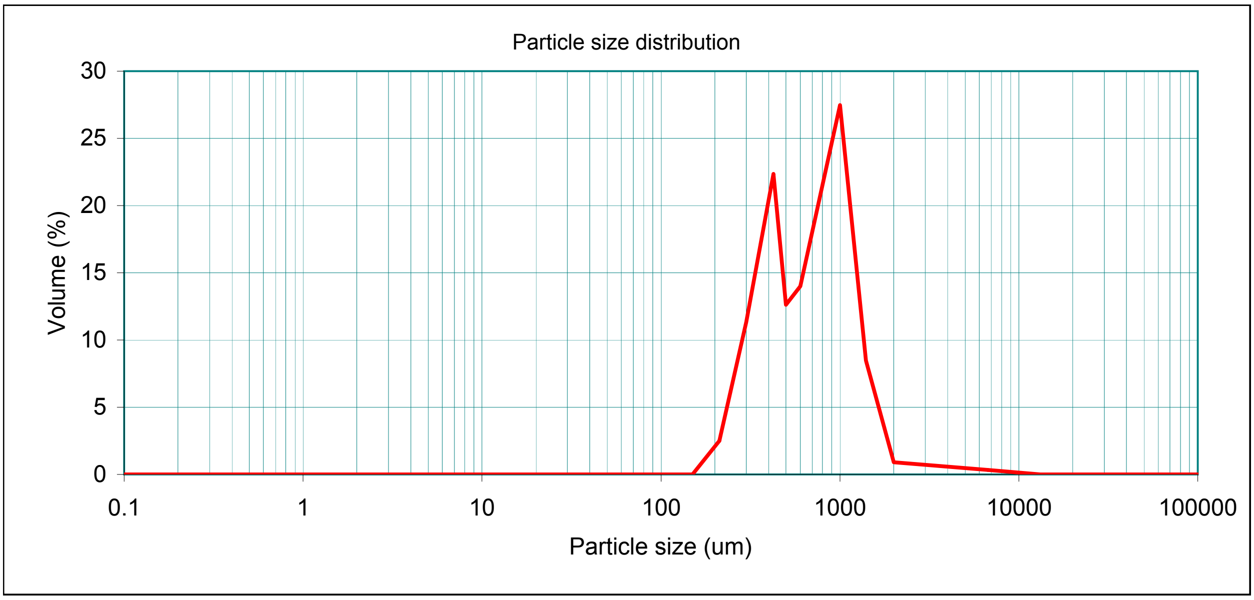
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 0.82g

d(0.1): 270.17 um **d(0.5): 508.39 um** d(0.9): 995.77 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	2.50	60.32	36.83	0.34	0.00	0.00	0.00



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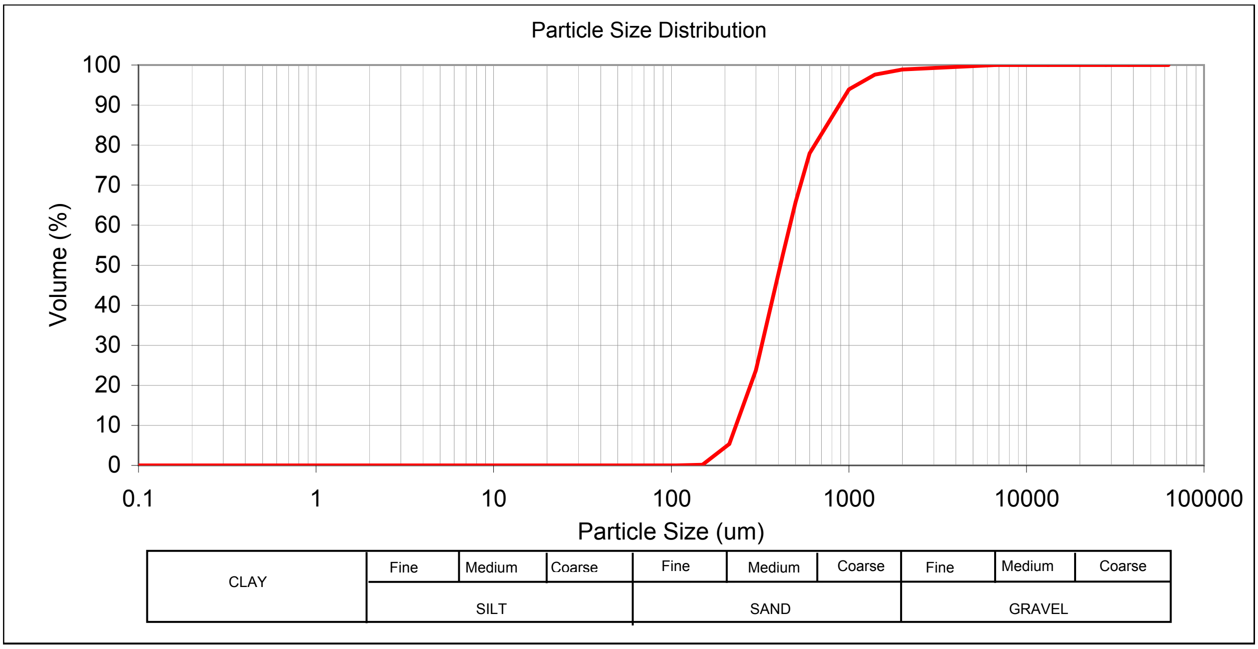
Result Analysis Report

Sample: A11 P200

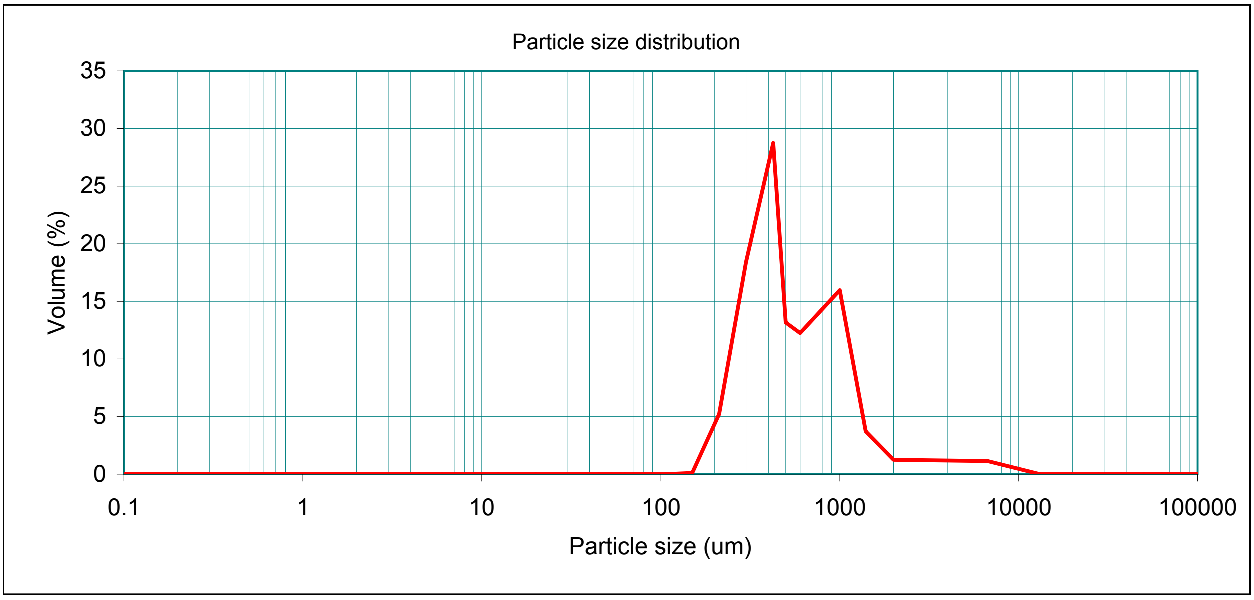
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 0.27g

d(0.1): 234.24 um **d(0.5): 414.08 um** d(0.9): 902.45 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	5.34	72.58	20.93	1.14	0.00	0.00	0.00



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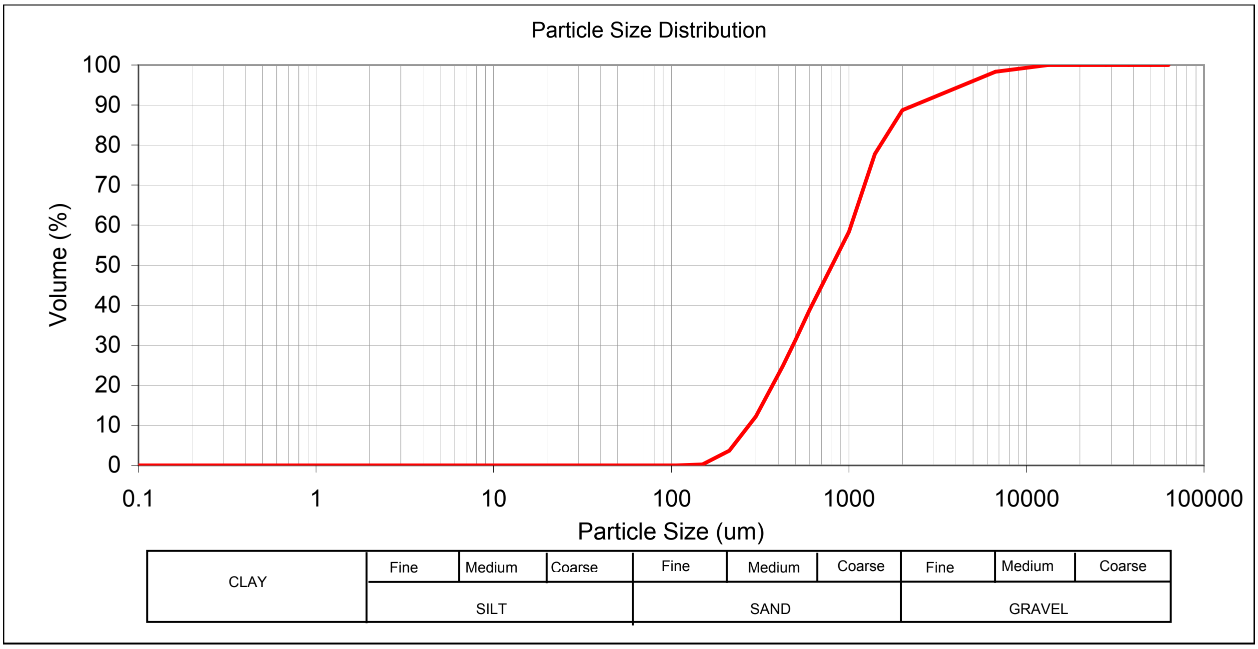
Result Analysis Report

Sample: A12 P387

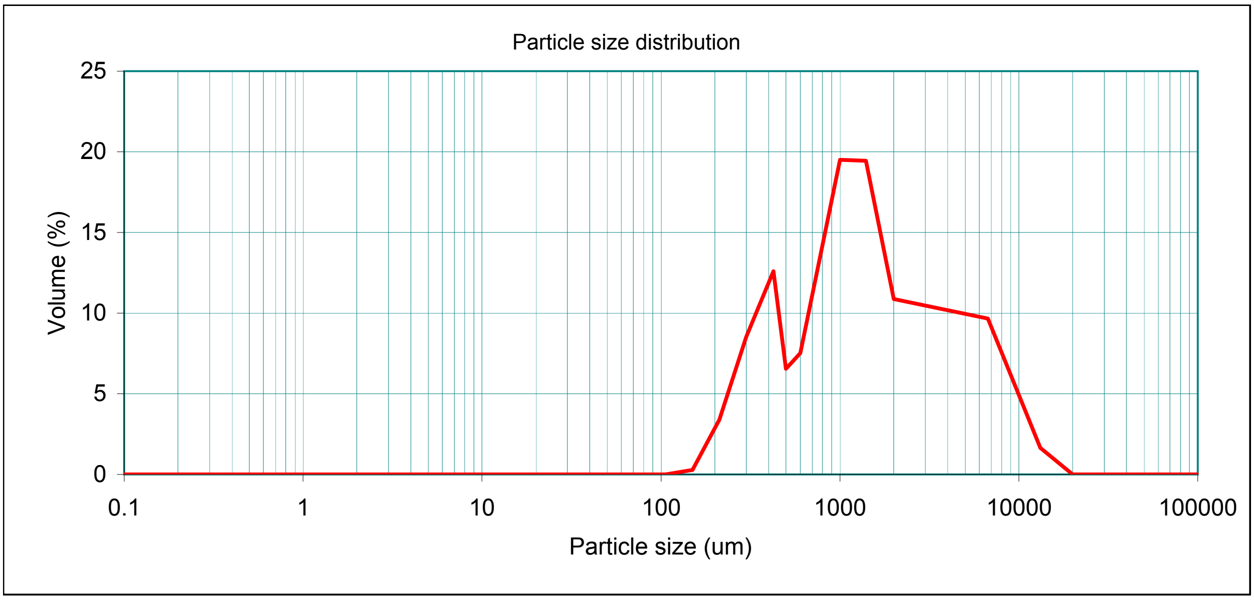
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 2.07g

d(0.1): 277.24 um **d(0.5): 828.49 um** d(0.9): 2635.27 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	3.67	35.19	49.83	9.66	1.65	0.00	0.00



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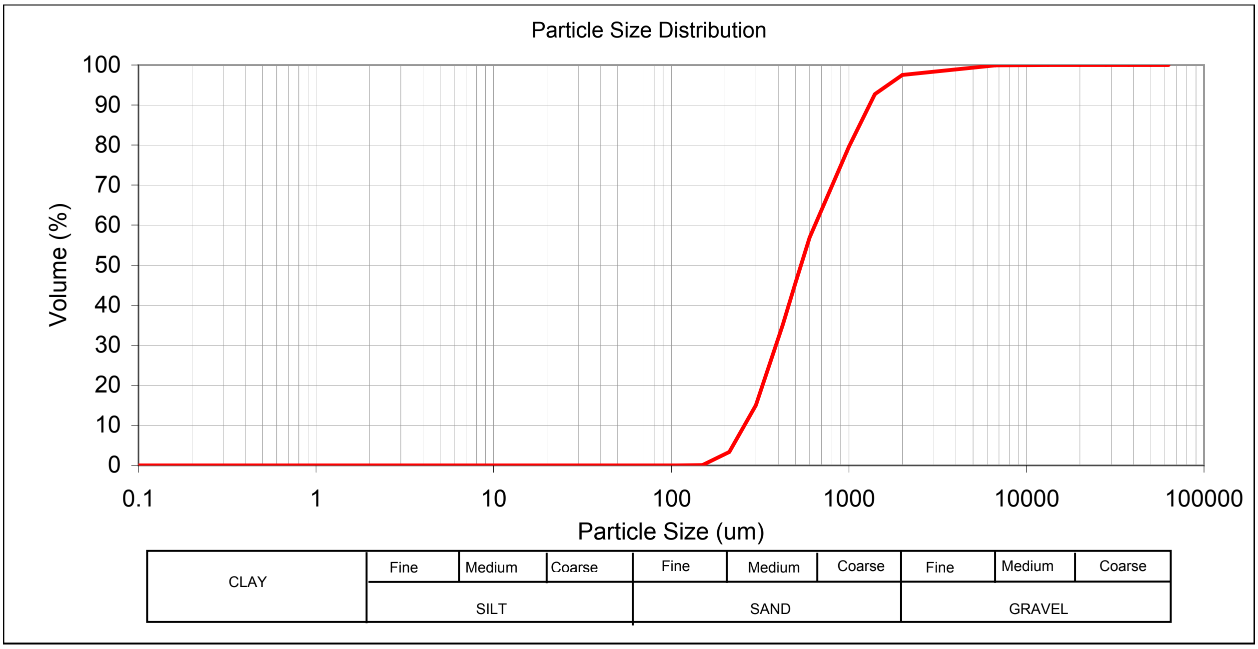
Result Analysis Report

Sample: A13 P159

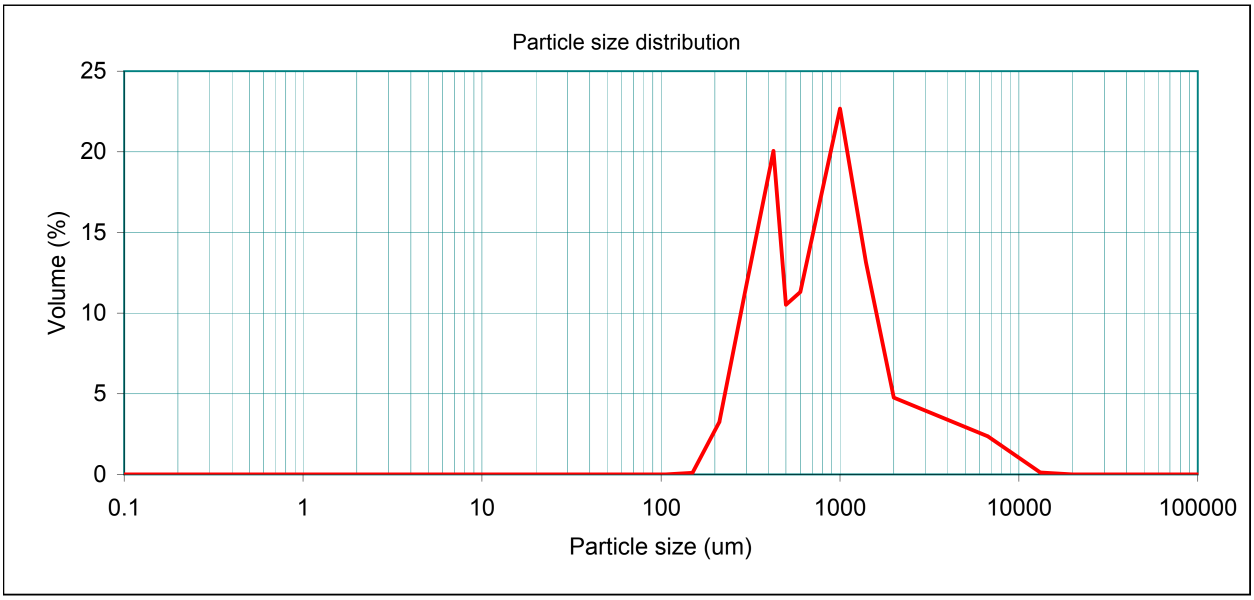
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 0.26g

d(0.1): 262.06 um **d(0.5): 538.82 um** d(0.9): 1316.30 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	3.37	53.56	40.61	2.37	0.11	0.00	0.00



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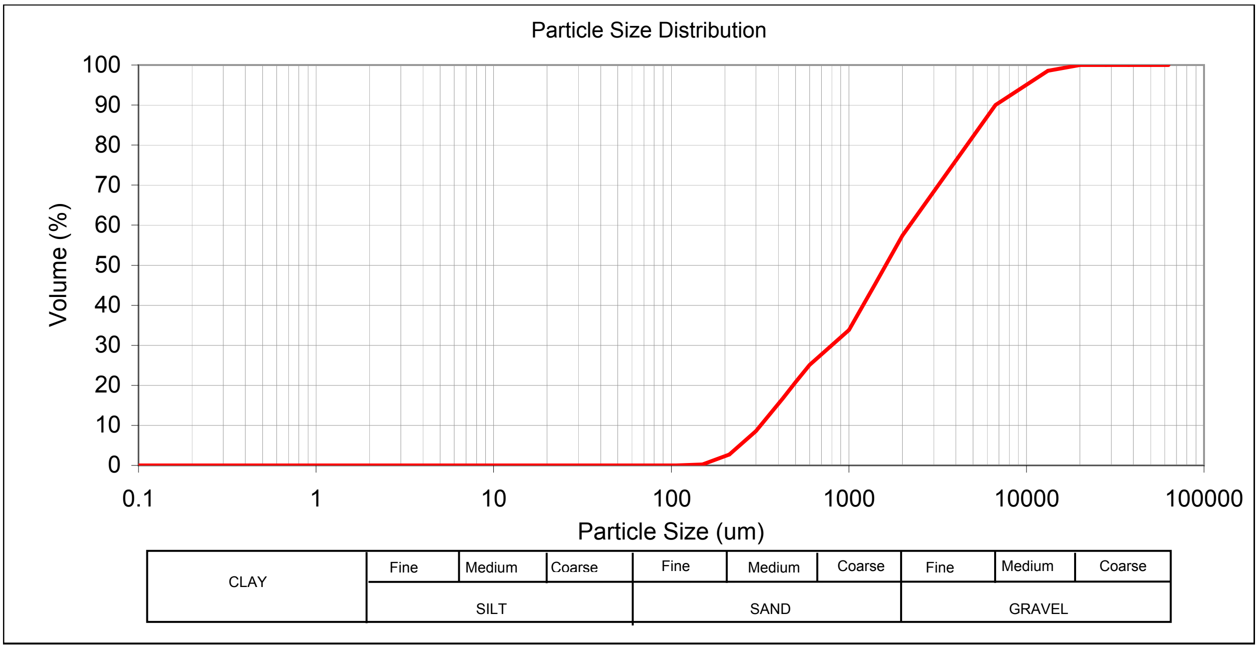
Result Analysis Report

Sample: A14 P139

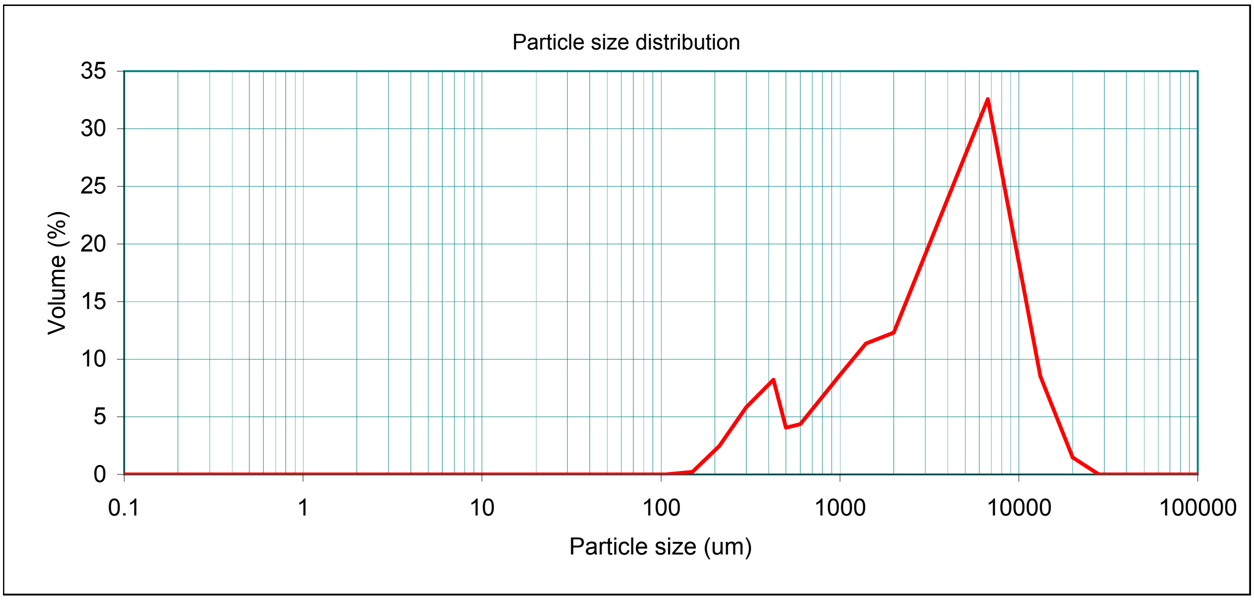
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 1.0g

d(0.1): 322.56 um **d(0.5): 1637.91 um** d(0.9): 6698.12 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	2.70	22.44	32.28	32.59	9.99	0.00	0.00



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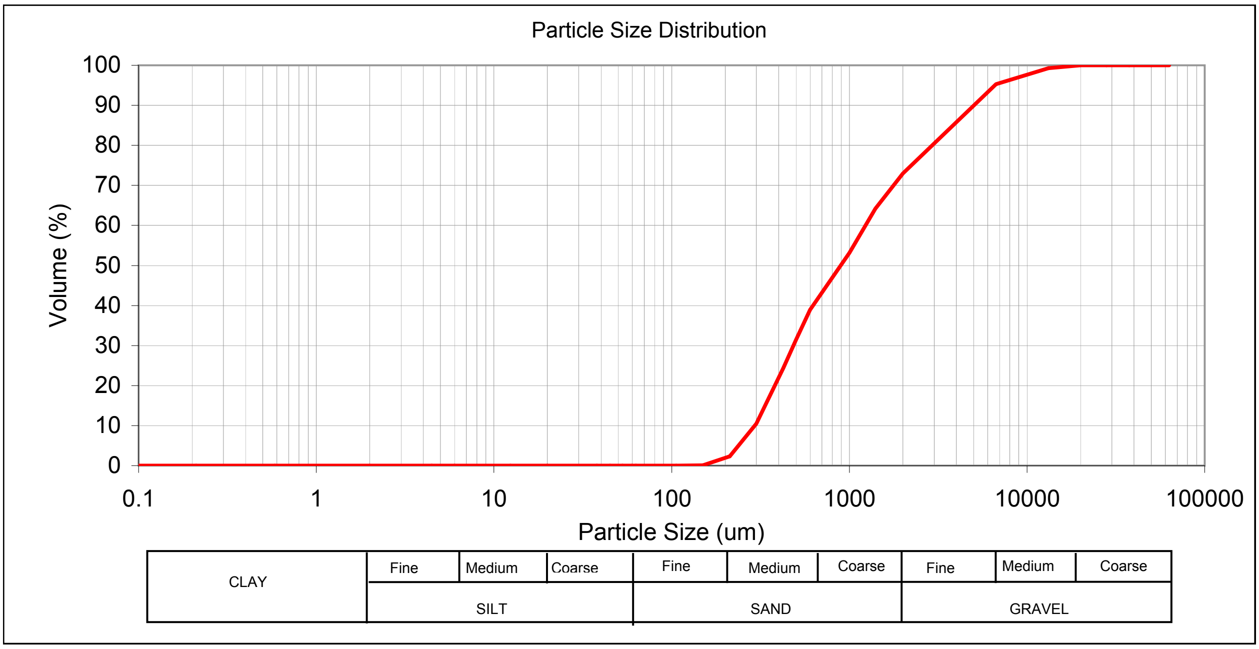
Result Analysis Report

Sample: A14a P87

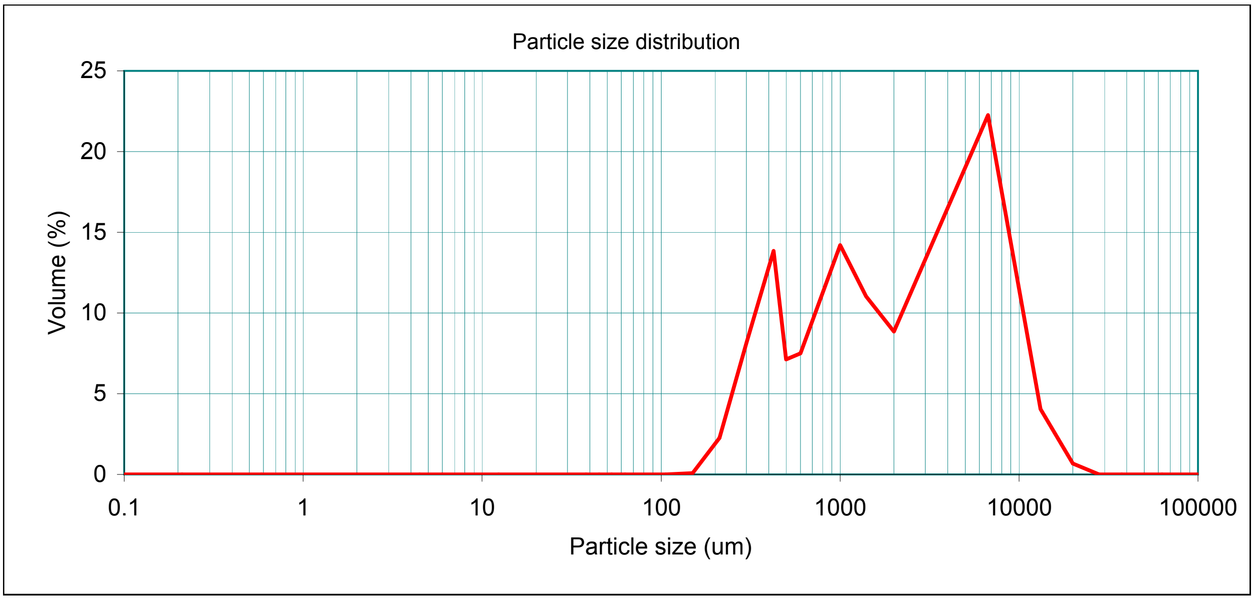
Collected: 27/10/2010 **Processed:** 16/03/2011

Location: Aberdeen **Notes:** Shell 1.07g

d(0.1): 294.94 um **d(0.5): 911.76 um** d(0.9): 5586.12 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	2.34	36.60	34.09	22.26	4.72	0.00	0.00



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Result Analysis Report

Sample: A15 P111

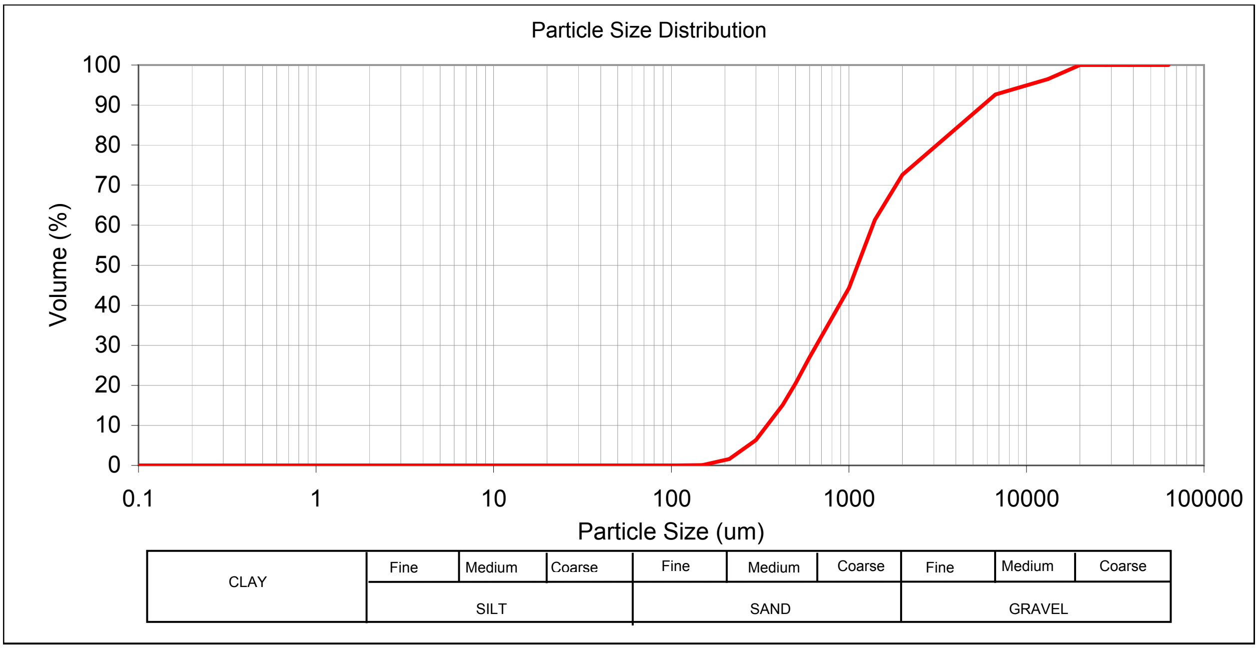
Collected: 27/10/2010

Location: Aberdeen

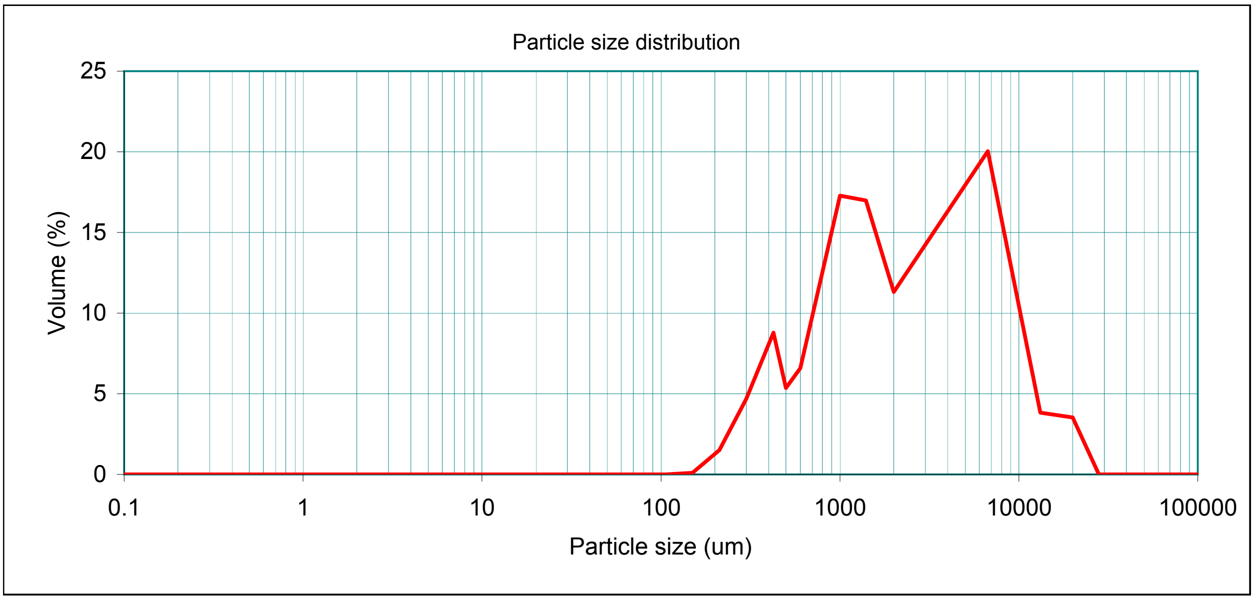
Processed: 11/03/2011

Notes: Shell 1.73g

d(0.1): 352.87 um **d(0.5): 1134.26 um** d(0.9): 6080.34 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	1.60	25.42	45.59	20.04	7.36	0.00	0.00



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Result Analysis Report

Sample: A16 P398

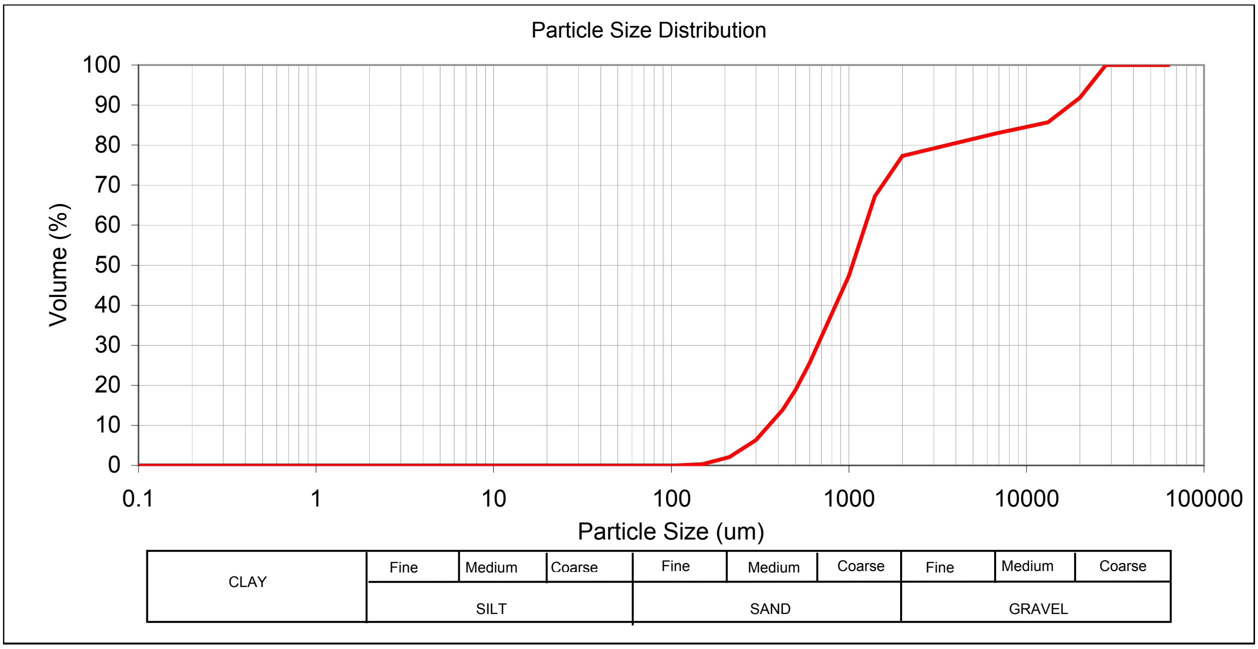
Collected: 27/10/2010

Processed: 11/03/2011

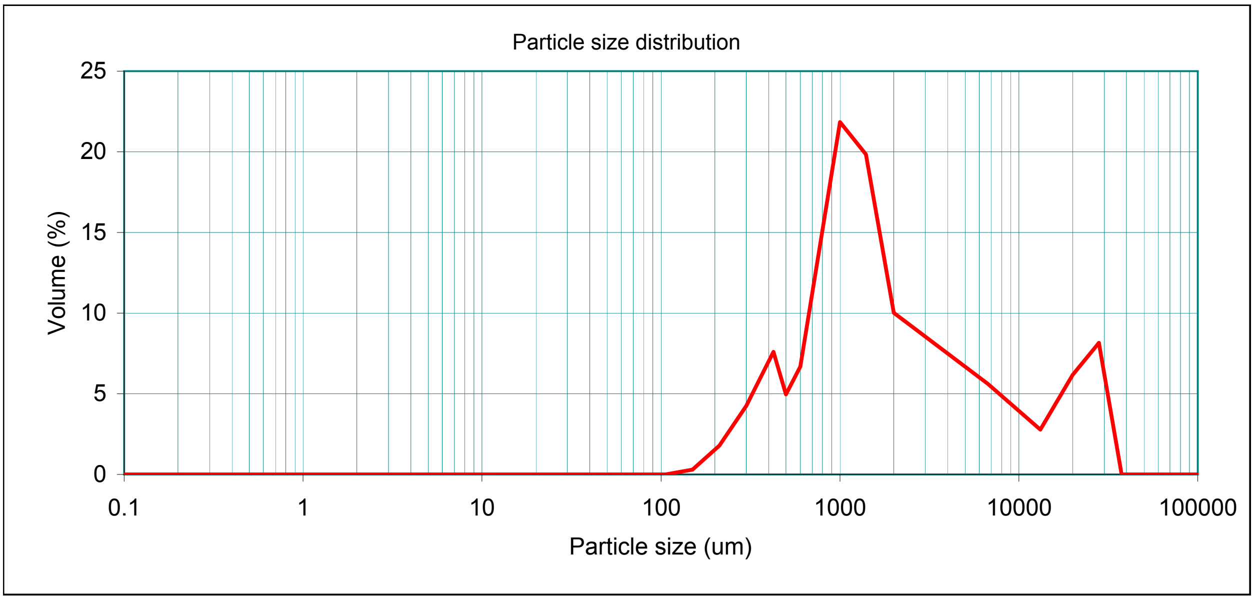
Location: Aberdeen

Notes: Shell 0.63g

d(0.1): 360.34 um **d(0.5): 1052.09 um** d(0.9): 17973.71 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	2.09	23.49	51.70	5.62	8.94	8.16	0.00



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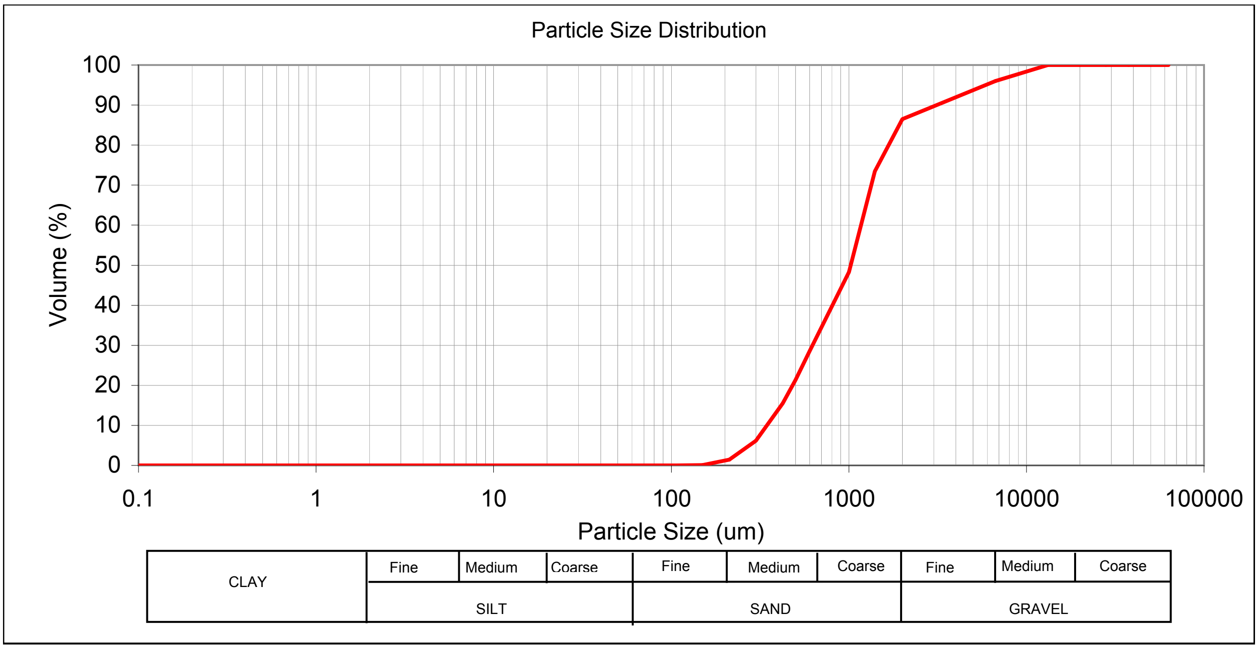
Result Analysis Report

Sample: A17 P242

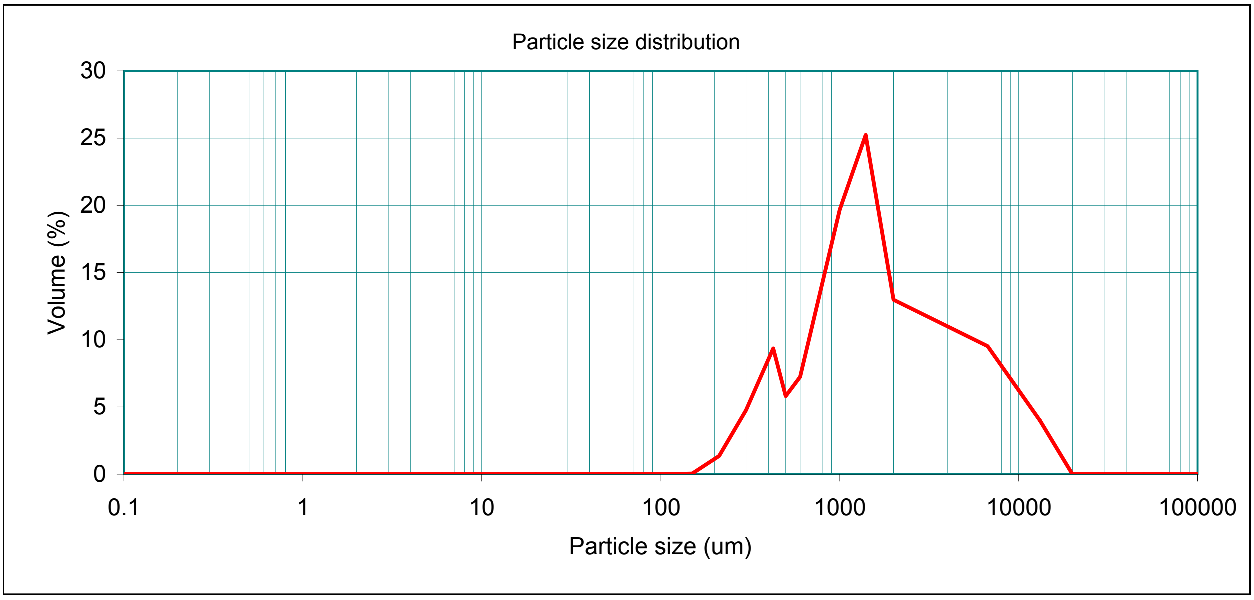
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 2.78g

d(0.1): 351.16 um **d(0.5): 1027.57 um** d(0.9): 3732.81 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	1.41	27.16	57.92	9.53	3.99	0.00	0.00



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Result Analysis Report

Sample: A18 P444

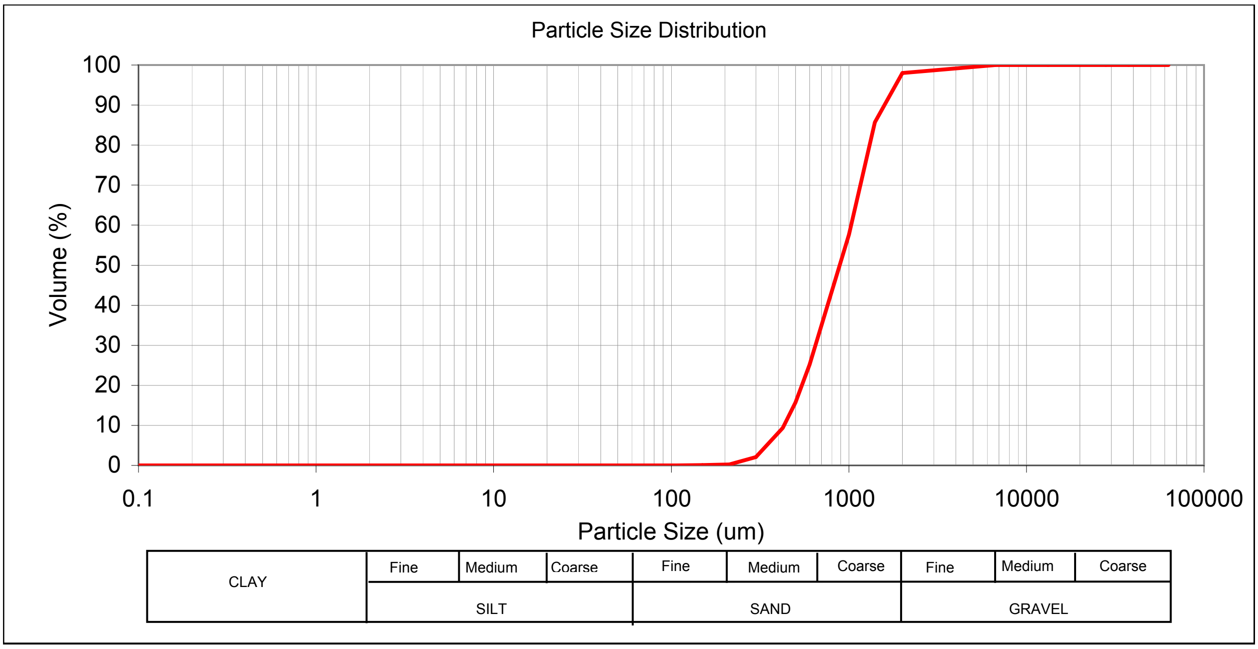
Collected: 27/10/2010

Location: Aberdeen

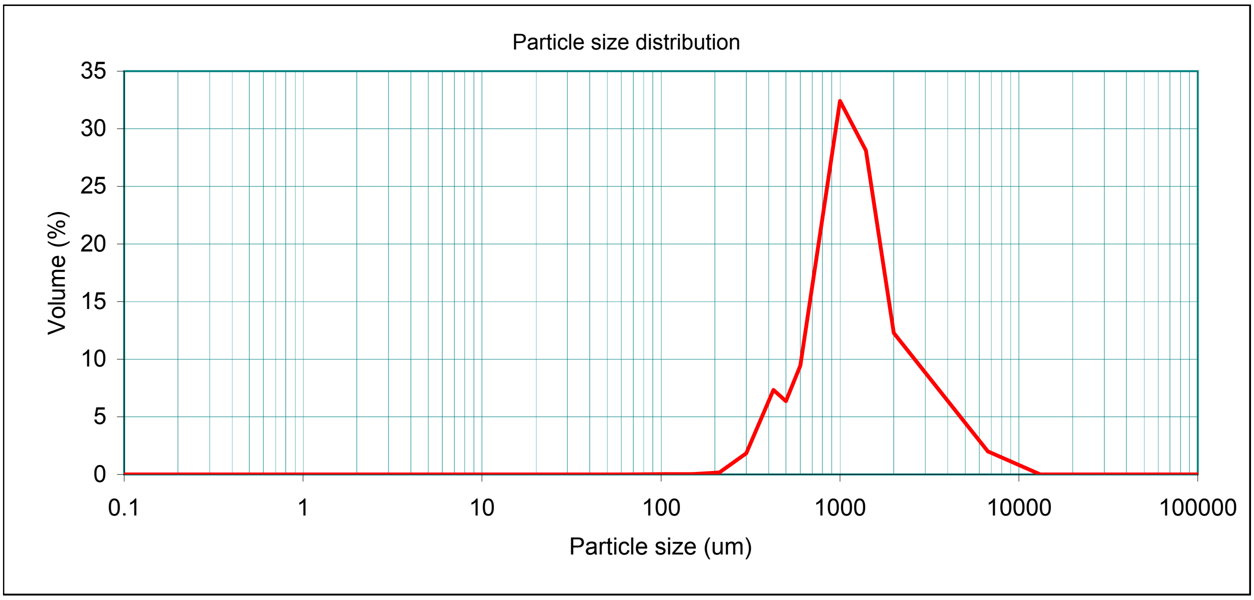
Processed: 11/03/2011

Notes: Shell 0.04g

d(0.1): 432.33 um **d(0.5): 906.12 um** d(0.9): 1608.63 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	0.22	24.99	72.81	1.99	0.00	0.00	0.00



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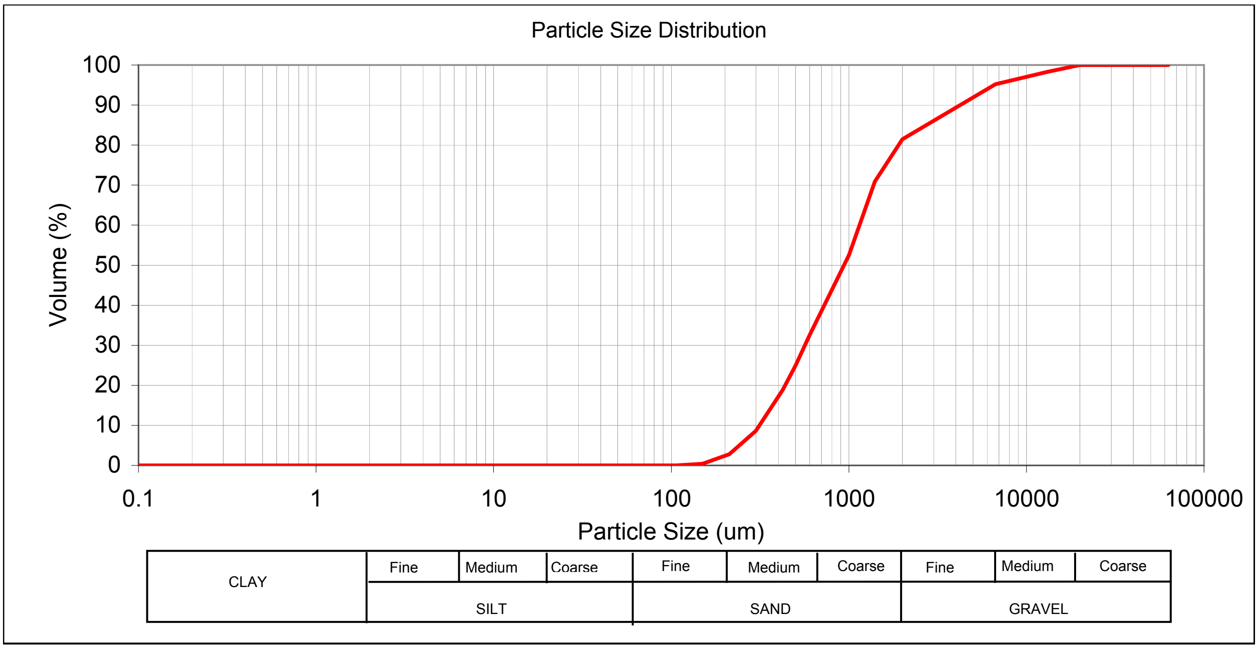
Result Analysis Report

Sample: A19 P483

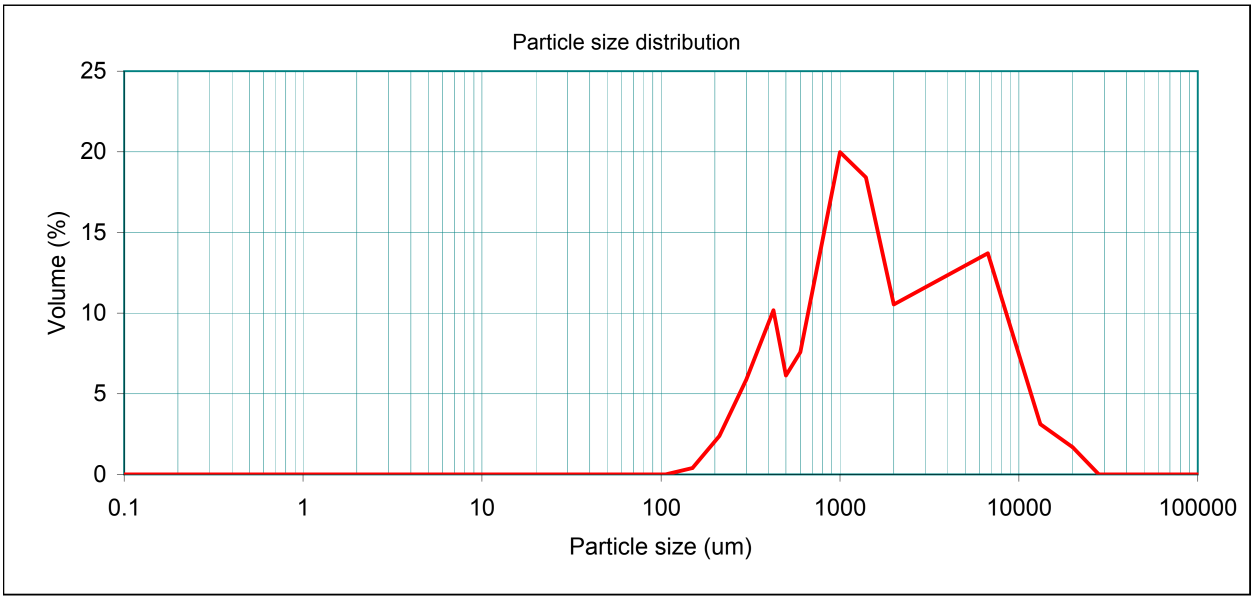
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 0.38g

d(0.1): 316.47 um **d(0.5): 949.45 um** d(0.9): 4923.89 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	2.78	29.76	48.92	13.72	4.82	0.00	0.00



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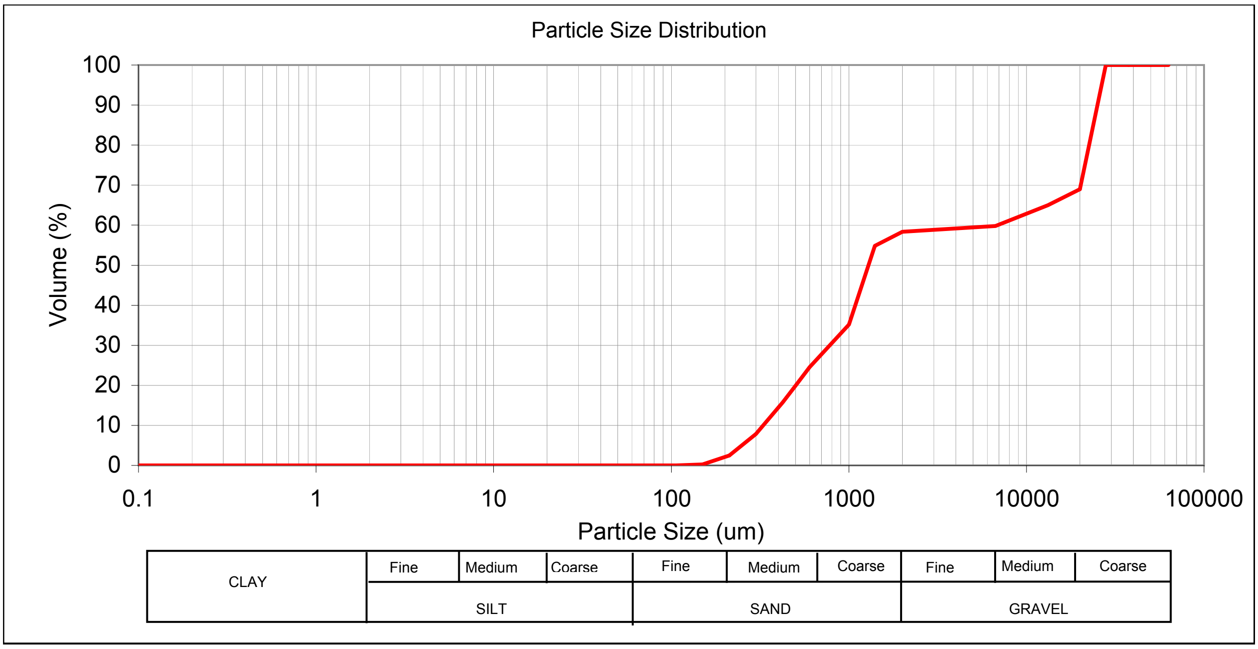
Result Analysis Report

Sample: A20 P474

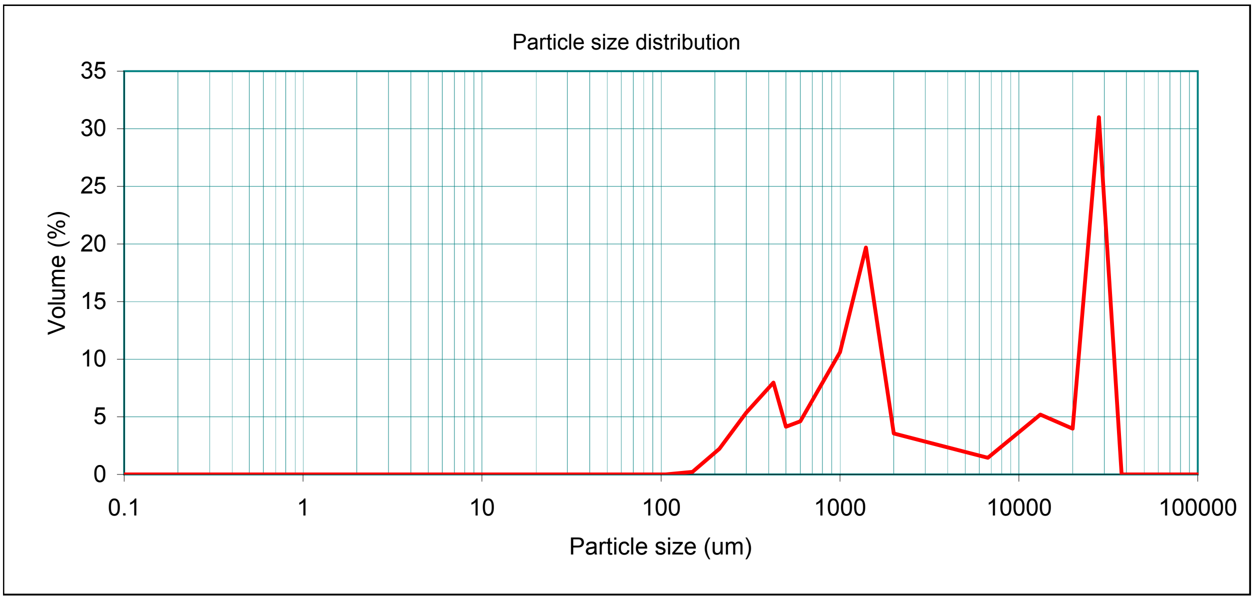
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 0.43g

d(0.1): 334.31 um **d(0.5): 1301.57 um** d(0.9): 25419.26 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	2.46	22.07	33.86	1.44	9.17	31.00	0.00



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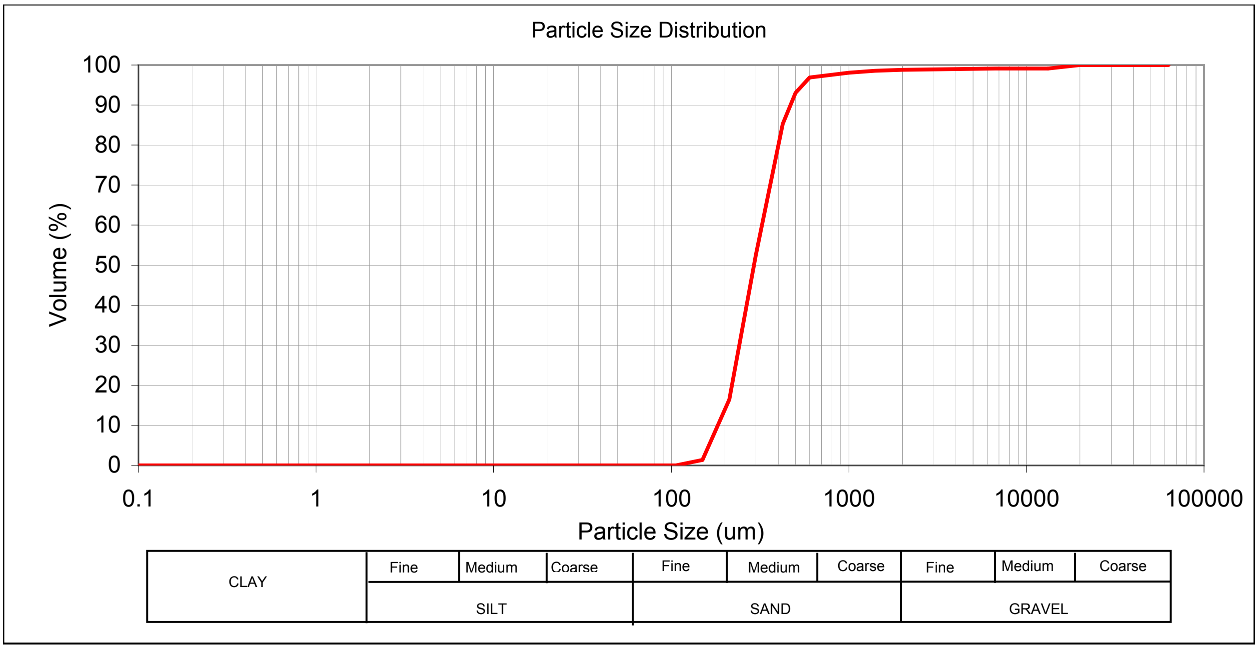
Result Analysis Report

Sample: A21 P484

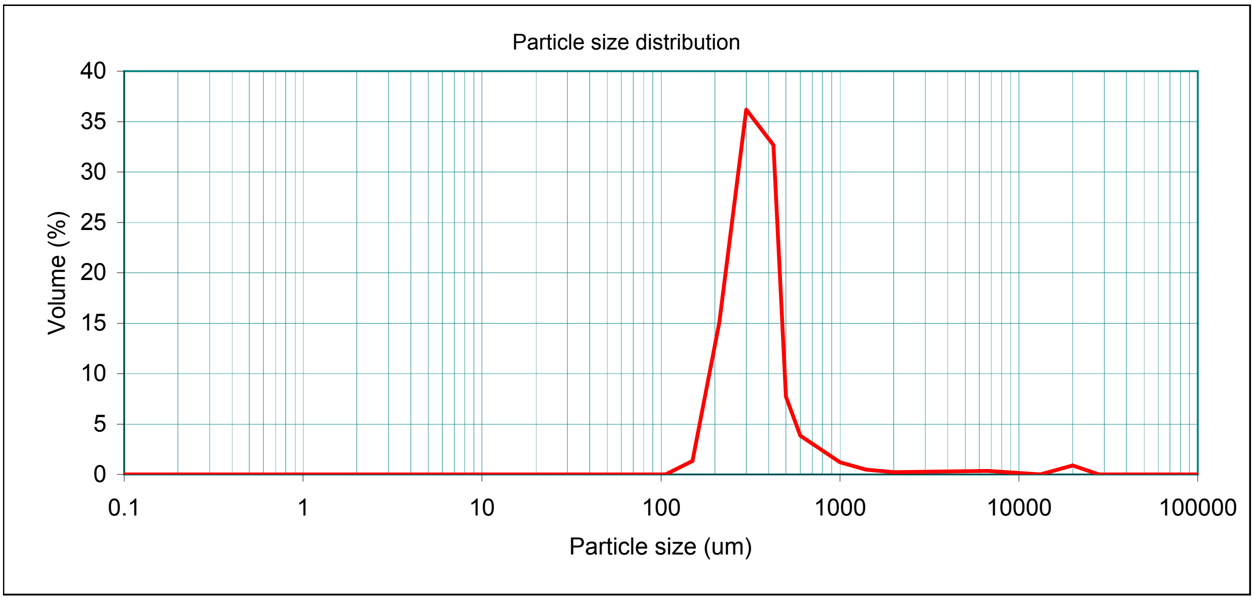
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 0.09g

d(0.1): 185.59 um **d(0.5): 293.60 um** d(0.9): 470.68 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	16.44	80.42	1.91	0.35	0.89	0.00	0.00



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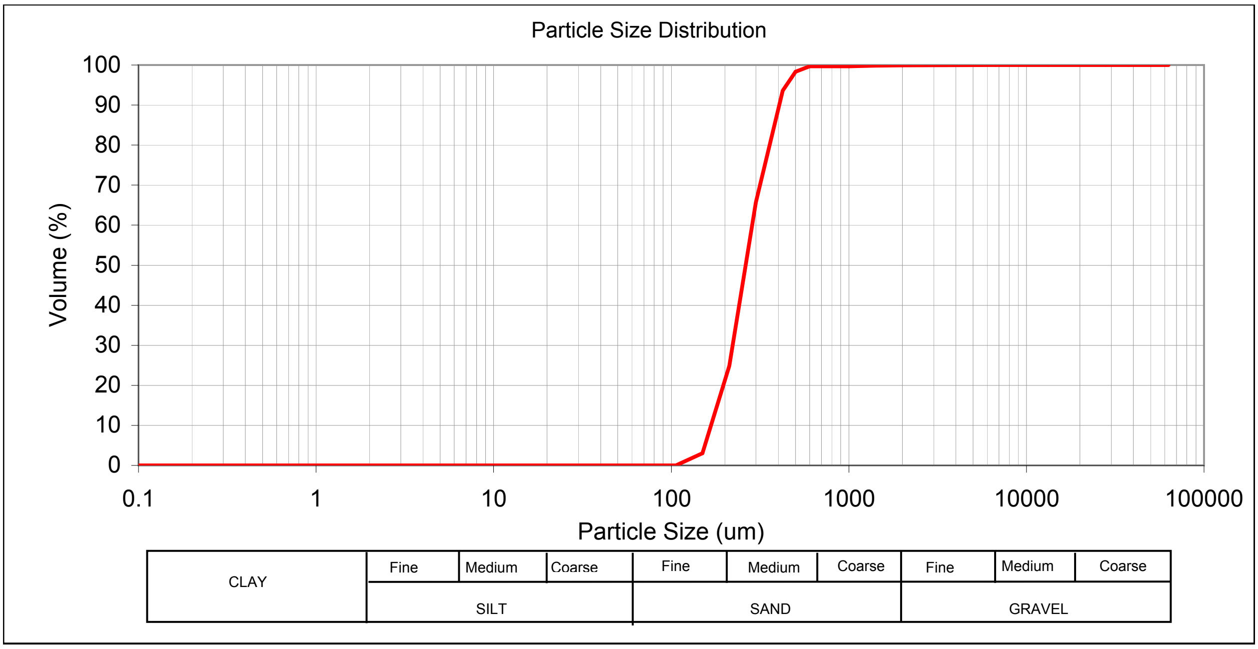
Result Analysis Report

Sample: A22 P498

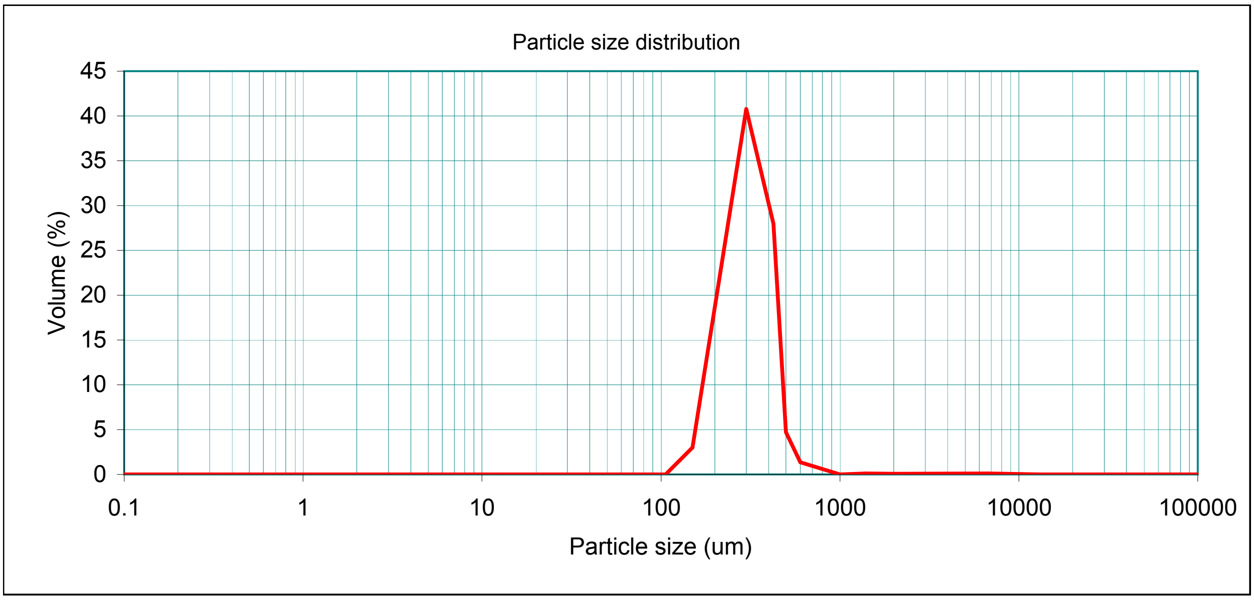
Collected: 27/10/2010 **Processed:** 11/03/2011

Location: Aberdeen **Notes:** Shell 0.15g

d(0.1): 169.81 um **d(0.5): 266.18 um** d(0.9): 408.75 um



% Clays	% Silts			% Sands			% Gravel			% cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
<2um	2-6 um	6-20 µm	20-60um	60-200um	200-600um	600-2000 um	2-6 mm	6-20 mm	20-60 mm	>63 mm
0.00	0.00	0.00	0.00	24.87	74.81	0.20	0.11	0.00	0.00	0.00



Annex 2 Profile Photographs

A1

A2

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
Produced by ABPmer Ltd			

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Site Photos

Figure 1

A3

A4

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
Produced by ABPmer Ltd			

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Site Photos

Figure 2

A5

A6

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
Produced by ABPmer Ltd			

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Site Photos

Figure 3

A7

A8

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
Produced by ABPmer Ltd			

Site Photos

Figure 4

A9

A10

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
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Site Photos

Figure 5

A11

A12

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
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Site Photos

Figure 6

A13

A14

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
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Site Photos

Figure 7

A14a

A15

Date	By	Size	Version
Nov 2010	SCB	A4	2
QA		FMM	

3890 – Photos_appendixB.ppt

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Site Photos

Figure 8

A16

A17

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
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Site Photos

Figure 9

A18

A19

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
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Site Photos

Figure 10

A20

A21

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
Produced by ABPmer Ltd			

Site Photos

Figure 11

A22

Date	By	Size	Version
Nov 2010	SCB	A4	1
QA		FMM	
3890 – Photos_appendixB.ppt			
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Site Photos

Figure 12

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