South West of England Regional Development Agency

Wave Hub Development and Design Phase

Interpretation of geotechnical and geophysical conditions of the Wave Hub Site and Offshore Cable Route

May 2006

Contents Amendment Record
This report has been issued and amended as follows:

<table>
<thead>
<tr>
<th>Issue</th>
<th>Revision</th>
<th>Description</th>
<th>Date</th>
<th>Signed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>Draft</td>
<td>11.04.06</td>
<td>AJM</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Revised following review by Nick Harrington and Jim Price</td>
<td>31.05.06</td>
<td>AJM</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Final</td>
<td>15.06.06</td>
<td>PRF</td>
</tr>
</tbody>
</table>
Contents

Executive summary i

1 Introduction 1
  1.1 Background to study 1
  1.2 Scope of work 2
  1.3 Summary of data sources 2
  1.4 Report structure 3

2 Site context 4
  2.1 Regional geology 4
  2.2 Offshore geology 5
  2.3 Offshore geomorphology 5

3 Seabed ground conditions 7
  3.1 Methodology 7
  3.2 Description of seabed conditions 7

4 Seabed geomorphology 13
  4.1 Interpretation 13
  4.2 Summary 16

5 Assessment of seabed geo-constraints 17
  5.1 Cable properties and proposed hub design 17
  5.2 Geo-constraints along cable route 17
  5.3 Geo-constraints within proposed hub area 18

6 Conclusions and recommendations 22
  6.1 Conclusions 22
  6.2 Recommendations 22
  6.3 Limitations 23

7 References 24

8 Figures 25

9 Appendices 39
List of Tables

Table 1. Seabed conditions for the cable route and deployment areas
Table 2. Soil properties in Zones 1 and 2 (cable route)
Table 3. Soil properties in Zone 3 (cable route)
Table 4. Soil properties – Proposed Wave Hub Area
Table 5. Geo-constraints to cable routing and hub structure foundations

List of Figures

Figure 1. Wave Hub location map, showing original and revised sites
Figure 2. Characteristics seabed zones and geotechnical sample locations for cable route and wave hub area
Figure 3. Zones 1 and 2 (cable, nearshore)
Figure 4. Zone 3 (cable, nearshore)
Figure 5. Zone 4a (cable, offshore)
Figure 6. Zone 4b (cable, offshore)
Figure 7. Zones 4c and 4d (cable, offshore)
Figure 8. Zone 5 (cable, offshore)
Figure 9. Zone 6 (cable, offshore)
Figure 10. Zone 7 (cable, offshore / original deployment area)
Figure 11. Zones 8 and 9 (original deployment area)
Figure 12. Zone 10 south (revised cable, offshore)
Figure 13. Zone 10 north (revised cable, offshore)
Figure 14. Schematic long profile of the seabed showing cable route from landfall to Wave Hub
Figure 15. Summary of geo-constraints along the cable route and hub site
Executive summary

The South West Wave Hub is a proposed renewable energy scheme located 25km offshore of the north Cornwall coast. The scheme comprises the Wave Hub itself, which is a seabed-mounted socket for a number of wave energy converter devices (WECs) and a cable that runs from the hub to the shoreline.

This study provides an assessment of seabed features and ground conditions that are likely to be encountered at the Wave Hub deployment area and cable route. The assessment is based on geomorphological mapping and interpretation of offshore geophysical and geotechnical surveys undertaken in July 2005 and October 2005.

No significant geohazards have been identified along the cable route or hub location, although attention is drawn to a series of geo-constraints that should be considered before the construction phase. Seabed ground conditions, whilst variable, are unlikely to cause significant installation difficulties, providing careful attention is given to variations in seabed sediments. Careful selection of sites for facilities will enable avoidance of geo-constraints.

Key geo-constraints identified in this report include: thin or absent sediments providing limited opportunity for cable burial; continuous outcrops of jointed and bedded rock along the cable route, with changes in relative elevation typically of 0.1 to 1m but up to 2m, local outcrops of harder (igneous) rocks often with changes in relative elevation of over 5m; and local scour and/or deposition of sediments in the nearshore and offshore zone which may expose or bury the seabed structures.

Further acquisition of geotechnical and geophysical data is recommended in the revised Wave Hub deployment area as this area was not covered by the highest resolution surveys undertaken in July and October 2005. The revision in deployment area does not affect the interpretation along the cable route.
1 Introduction

1.1 Background to study

The South West Wave Hub is a proposed renewable energy scheme located 25km offshore of the north Cornwall coast. The scheme comprises the Wave Hub itself, which is a seabed-mounted socket for a number of wave energy converters (WECs) and a cable that runs from the hub to the shoreline. In the offshore zone the cable will be buried where possible, or will otherwise rest on the seabed. Inshore of landfall it will be buried beneath the beach at Hayle in St Ives Bay.

This study provides an assessment of the geomorphological and geotechnical constraints to the project, specifically related to seabed features and ground conditions that are likely to be encountered at the Wave Hub deployment area and cable route. The data discussed in the report are derived from staged offshore geophysical and geotechnical surveys undertaken in July 2005 and October 2005 respectively. These surveys were specified along a ‘cable corridor’ identified during the Technical Feasibility Study in which regionally-identified constraints were avoided, where practicable (Halcrow Group Ltd, 2005).

Subsequent to collection of survey data, the location of the Wave Hub site was altered to accommodate concerns generated by new shipping lane data. The new proposed Wave Hub deployment area is located approximately 2km east of the former location, which falls outside the detailed geophysical survey coverage and geotechnical sample sites. Assessment of seabed conditions for the new proposed site and cable route is based on the regional geophysical survey lines which are tied-back and calibrated with the available geotechnical and bathymetry data obtained for the initial proposed site and cable route.

The data used in this report comprise seabed bathymetry derived from multibeam sonar, sub-surface seismic profiles illustrating seabed sediment depths, and CPT and Vibrocore samples indicating seabed soil types and strength characteristics. The survey reports are attached in Appendices 1 and 2. Interpretation of these data is presented in this report with specific focus on detailing the following:

- Geophysical features of the seabed;
- Anticipated ground conditions; and
- Specific geo-constraints to the proposals.
This report complements other studies prepared for the project on the coastal geomorphology of the landfall site near Hayle in St Ives Bay, the coastal hydrodynamic processes operating in the offshore region, and the onshore geotechnical conditions.

1.2 **Scope of work**

The geophysical and geotechnical surveys described herein provide reconnaissance level indications of seabed terrain and soil conditions. The quality of data is sufficient to identify geotechnical and geomorphological constraints to cable routing at a reconnaissance scale. Accordingly, this report has the following objectives:

- Identify geotechnical conditions for cable routing and founding of seabed structures (i.e. soil conditions);
- Identify geomorphological conditions for cable routing and founding of seabed structures (i.e. active seabed processes such as sediment transfer, seabed instability, irregular or steep topography); and
- Identify future survey requirements for detailed design.

1.3 **Summary of data sources**

The data sets commissioned for the current study include:

- Seabed bathymetry derived from single and multibeam echo sounder at 1m ground resolution for the cable route (27 x 0.6km), hub site (2.1 x 4.3km) and for the broader area (single strip grid survey covering the 9 x 8km around the hub site). This data provides a detailed elevation model of the seabed;
- Geophysical logs derived from seismic boomer, and collected for seven parallel lines along the cable corridor, in a grid over the deployment area (formerly ATBA) and on single lines for a regional grid centred on the deployment area;
- 44 Intrusive Piezo-Cone Penetration Tests (PCPTs) to assess the strength characteristics of seabed sediments at 33 locations along the cable route and within the deployment area; and
- 26 vibrocore samples at 22 locations and four seabed grab samples at four locations indicating sediment composition and calibre.
1.4 Report structure

Chapter 2 provides a summary of the study area based upon published data, primarily available from the British Geological Survey. Chapter 3 provides factual maps and data derived from the geophysical and geotechnical surveys commissioned for this study. Chapter 4 provides an interpretation of seabed conditions and Chapter 5 identifies the potential geohazard constraints to the cable route and seabed structures associated with the hub. Chapter 6 summarises the limitations of this study and makes recommendations for further work that will be necessary to support the detailed design and construction of the wave hub and facilities.

The EGS Ltd geophysical survey (EGS International Ltd, 2006) and Alluvial Mining Ltd (Alluvial Mining Ltd, 2005) geotechnical survey reports are contained in entirety in Appendices 1 and 2 respectively.
2 Site context

2.1 Regional geology

In this report, the ‘study region’ is defined as that shown on the BGS 1:250,000 map of Land’s End (BGS, 1987) showing the southern part of the Celtic Sea. The ‘study area’ is defined as that covered by and immediately adjacent to the hub site and the cable route (Figure 1).

The solid geology of the region comprises Upper Devonian slates with occasional interbeds of sandstone and limestone (BGS, 1985). The region has been greatly influenced by the volcanic batholith which underlies much of Cornwall, and which was intruded during the Carboniferous to Permian periods. Granite crops out across much of the area west of St Ives to Land’s End and there are sporadic outcrops of lava around its margins at St Ives. The Devonian sedimentary rocks have also been affected by volcanism, both through contact metamorphism and
through a series of intrusive dolerite and microgranite sills aligned at 060º, which pass from Penzance to Redruth, inland of St Ives Bay.

2.2 Offshore geology

2.2.1 Solid

The offshore geology is described in Evans (1990) and mapped on BGS (1985). The granite batholith described above underlies much of the region and crops out west of the Cornish mainland to form the Isles of Scilly and the submarine Haig Fras reef. Outcrops of igneous rock are not shown on the seabed north of the Cornish coast (BGS, 1985), but this may be a result of the small scale of the mapping. The region in the area of the Wave Hub is mapped as undivided Devonian to Carboniferous rocks which continue to around 50km offshore. Cretaceous rocks crop out beyond this point.

The BGS map indicates that bedrock does not crop out on the seabed in the region of the hub or cable route.

2.2.2 Quaternary and Recent

Seabed sediments mapped by BGS (1987) comprise sand in the vicinity of St Ives Bay. Over the next 20km, offshore sediments become progressively coarser, with coarse sand passing into slightly gravely sand, gravely sand and sandy gravel. In the hub and cable route area the sand fraction is specified by the BGS as 75 to 100% carbonate, while 50 to 100% of the gravel fraction is formed of shelly carbonate material.

The sea-bed in the study area is predominantly an erosion surface cut in glacial sediments, and was formed by post-glacial sea-level rise over the last 10,000 years (Evans, 1990). There is evidence for glacial deposition on the north Devon coast at Barnstaple Bay, to the north of Padstow at Trebetherick and on the Isles of Scilly (Charman et al., 1996; Harrison and Keen, 2005), suggesting that the whole of the offshore region was formerly covered in a drape of till and meltwater sediments. The timing of the glaciation is generally thought to be Late Devensian (i.e. around 26,000 to 10,000 years before present), with the area being covered by a lobe of the Irish Sea ice sheet which flowed in a generally SE direction from the Irish Sea basin and South Wales.

2.3 Offshore geomorphology

The seabed geomorphology of the study region is described in Evans (1990) and comprises a very shallow slope of the inner continental shelf. The main features of
geomorphological interest in the study region are a series of discontinuous submerged cliff lines of the Southwest Peninsula which lie up to 25km from the present coastline. Three cliffs are recognised: an Upper cliff line at depths of 38 to 49m, a Middle cliff line at 49 to 58m and a Lower cliff line at 58 to 69m below ordnance datum (OD). The variation in depths is due to the base of cliffs deepening towards the west, which is probably a result of the regional neotectonic pattern of greater subsidence to the west of southwest England (Shennan and Horton, 2002).

The characteristic submerged river valleys (rias) of the Southwest Peninsula continue to depths of no more than 37m below OD and appear to relate to the base of the Upper cliff line. A radiocarbon assay of peat from the base of ria in Mounts Bay on the south coast of Cornwall gave a date of 12,070 years BP, which suggests that the Upper cliff line predates the Holocene, and is probably associated with low sea-levels at the end of the Devensian glaciation.

In the study area, a submerged cliff line is recognised at depths from 49 to 52m below ordnance datum. No dating evidence is available for the formation of this cliff, but the evidence presented above suggests it is likely to be pre-Holocene. Regional bathymetric surveys reveal a relatively smooth, low-gradient seabed with local rugged rocky features. Large sand ridges are recognised further offshore on the outer continental shelf around the Haig Fras reef.
3 Seabed ground conditions

3.1 Methodology

This chapter presents maps and data tables summarising the seabed ground conditions along the cable corridor and within the deployment area. Interpretation of available geophysical (seismic profiles and bathymetry) and geotechnical data is provided in Chapter 4.

The geophysical and geotechnical datasets have been integrated in ArcView GIS to produce maps of seabed characteristics. The seabed has been grouped into a series of zones with similar sediments and morphology. The boundaries between the zones are generally transitional, and they are therefore indicated by dashed lines on the maps.

Input data were x-y-z format bathymetry processed to create a digital elevation model (DEM) at 1m postings (i.e. each pixel on the screen measures 1x1m on the seabed). To aid interpretation, additional processing of the DEM was undertaken to create hillshade, slope angle and slope aspect layers. Using GIS, these layers were interpreted and mapped individually or as overlays, and compared with additional spatial data, such as that produced in the Technical Feasibility Study (Halcrow Group Ltd, 2005) and collected during the geotechnical survey.

3.2 Description of seabed conditions

3.2.1 Cable Corridor and Deployment Area

On the basis of seabed geotechnical and geomorphological conditions, the cable route and deployment area is divided into ten characteristic zones, illustrated in overview in Figure 2 and in detail in Figures 3 to 13. Seabed topography (depth and gradient) and conditions (materials and morphology) are described in detail in Table 1. The transition from one seabed province to the next is also described (contact with adjacent zones). All descriptions presented below are based on interpretation of bathymetry and sediment samples cross-referenced against seismic profile data, which was viewed using C-View software loaned by EGS International Ltd.

Geotechnical data from core samples taken along the seabed corridor and deployment area are provided in Tables 2, 3 and 4.
<table>
<thead>
<tr>
<th>Province</th>
<th>Length of cable (km)</th>
<th>Seabed depth (m below CD)</th>
<th>Gradient (degrees)</th>
<th>Material types</th>
<th>Material description</th>
<th>Seabed morphology</th>
<th>Contact with adjacent zone</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>5 to 11</td>
<td>0.34</td>
<td>Sand</td>
<td>Sand approximately 5.5m thick underlain by bedrock. The sand is medium dense becoming dense; fine to medium with a little silt content and occasional shells and shell fragments. The sand layer thins out in the northern direction. Bedrock is weathered mudstone/shale of Cornubian Massif. PCPT tests together with recovered samples suggest that the uppermost bedrock unit is highly weathered and appears as stiff to very hard sandy gravelly clay. The gravel (core-stones of parent bedrock) are angular and at some locations platy. This unit may instead represent glacial sediment.</td>
<td>Gently sloping, smooth sea bed with undulating shore-parallel ridges</td>
<td>Gradational to Zone 2</td>
<td>Refer to Figure 3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>11 to 20</td>
<td>0.26</td>
<td>Sand and gravel with occasional rock outcrop</td>
<td>Sand and gravel with occasional rock outcrop</td>
<td>Smooth gently sloping sea bed with occasional shallow depressions (&lt;0.5m) some of which contain low rock outcrops. Rocks have a rough surface with no clear jointing or bedding</td>
<td>Marked by shallow step (&lt;0.5m) to Zone 3</td>
<td>Refer to Figure 3</td>
</tr>
<tr>
<td>3</td>
<td>4.5</td>
<td>20 to 28</td>
<td>0.10</td>
<td>Sand and gravel with numerous rock outcrops</td>
<td>The superficial sand and gravel layer in this province, which extends to approximately 44000mN, is much thinner, typically 0.5m to 1.0m. This layer consists of dense to very dense gravelly sand or sandy gravel becoming clayey at certain locations. This layer is likely to be completely weathered bedrock or a weathered till. Underlying bedrock appears to be of the same characteristics and weathering grade as for provinces 1 and 2.</td>
<td>Predominantly smooth, gently sloping sea bed, comprising sediment with common outcrops of rock. Occasional shallow linear depressions in seabed sediments aligned 050º. Rock has a rough surface with no clear jointing or bedding</td>
<td>Gradual reduction in sand cover over bedrock of Zone 4</td>
<td>Refer to Figure 4</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>28 to 32</td>
<td>0.02</td>
<td>Rock with occasional patches of sand and gravel</td>
<td>The majority of the PCPT tests and vibrocore samples penetrated very short distances throughout provinces 4a to 4d and did not recover any sediment</td>
<td>Seabed dominated by rough rock outcrops with occasional thin patches of sand and gravel. Rock surface gently sloping offshore with sections of convex, concave and flat seabed. Rock has clear vertical bedding and has visible folding and jointing. Dominant strike of bedding allows characterisation of four sub-provinces: 4a (2km long) sub-vertical gently folded bedding strike 030º; 4b (4km long) sub-vertical linear bedding strike 150º; 4c (3km long) sub-vertical highly contorted bedding. No clear strike; 4d (1km long) sub-vertical gently folded bedding with dominant strike of 110º.</td>
<td>Gradual smoothing of rock surface to Zone 5</td>
<td>Refer to Figures 5 to 7</td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>33 to 36</td>
<td>0.07</td>
<td>Rock with localised drape of sand and gravel</td>
<td>The majority of the PCPT tests and vibrocore samples penetrated very short distances and did not recover any sediment</td>
<td>Seabed dominated by rock outcrop with very gently sloping gradient often covered with thin drape of sand and gravel. Rock is highly jointed, but has less visible bedding that is in zone 4. Surface is also less rough than in zone 4. Bedding gently folded, with general strike of 120º.</td>
<td>Gradual increase in sand cover to Zone 6</td>
<td>Refer to Figure 8</td>
</tr>
<tr>
<td>6</td>
<td>2.5</td>
<td>35 to 48</td>
<td>0.30</td>
<td>Rock with common patches of sand and gravel</td>
<td>Seabed dominated by rock outcrop with common patches of sand and gravel. Rock surface gradually steepens offshore. Rock is moderately well jointed and has some visible bedding that is moderately contorted with a general strike of 180º.</td>
<td>Seabed dominated by rock outcrop with common patches of sand and gravel. Rock surface gradually steepens offshore. Rock is moderately well jointed and has some visible bedding that is moderately contorted with a general strike of 180º.</td>
<td>Sharp change in sediment cover associated with a gently sloping step of around 4m to Zone 7</td>
<td>Refer to Figure 9</td>
</tr>
<tr>
<td>Province</td>
<td>Length of cable (km)</td>
<td>Seabed depth (m below CD)</td>
<td>Gradient (degrees)</td>
<td>Material types</td>
<td>Material description</td>
<td>Seabed morphology</td>
<td>Contact with adjacent zone</td>
<td>Notes</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------</td>
<td>--------------------------</td>
<td>-------------------</td>
<td>----------------</td>
<td>---------------------</td>
<td>-------------------</td>
<td>--------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>49 to 58</td>
<td>0.13</td>
<td>Sand and gravel with occasional outcrops of rock</td>
<td>The area is covered with a layer of sand and gravel with some clay (up to 1.0 m) as confirmed by PCPT tests and vibrocore samples. Sand is medium dense becoming dense or very dense with varying content of gravel. The underlying weathered bedrock/till is thicker (approximately 2.0m) and comprises a layer of gravel underlain by hard becoming very hard gravelly sandy clay</td>
<td>Seabed with smooth surface of clay, sand and gravel and occasional outcrops of rock, including a well-defined fold structure. Seabed is gently sloping except for the fold structure which is slightly convex. Sediment surface includes occasional shallow linear to slightly sinusus depressions aligned approx 045°. Fold structure plunges towards 045°. Bedding not visible elsewhere on seabed</td>
<td>gradual change to coarser sediment of Zone 8 (hub area)</td>
<td>refer to Figure 10</td>
</tr>
<tr>
<td>8</td>
<td>n/a</td>
<td>49 to 55</td>
<td>0.17</td>
<td>Sand and gravel with occasional rock outcrop</td>
<td>A very thin layer of marine sand and gravel (approximately 0.5m thick) overlying bedrock. PCPT tests indicate a 0.5m to 1.0m thick weathered section of bedrock/till below which tests were refused in the less weathered rock</td>
<td>Smooth surface of coarse sediment that has a very gently sloping gradient. Common shallow, linear depressions aligned 030° to 070°. Seabed broken by a series of elongate rock outcrops up to 8m above seabed generally aligned between 050° and 060°. Rock outcrops are very rough and do not have clear bedding</td>
<td>gradual reduction in sand cover as rocks become more common</td>
<td>refer to Figure 11</td>
</tr>
<tr>
<td>9</td>
<td>n/a</td>
<td>55 to 60</td>
<td>0.08</td>
<td>Rock with occasional patches of sand and gravel</td>
<td>Very gently sloping seabed surface with generally smooth rock and sporadic cover of sediment. Occasional outcrops of rough rock. Flat rock surface is characterised by wide, open channel-like depression filled with sediment</td>
<td>Not applicable</td>
<td>refer to Figure 11</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>n/a</td>
<td>52 to 58</td>
<td>0.07</td>
<td>Rock with occasional patches of sand and gravel</td>
<td>No geotechnical samples are available from this Zone. Available evidence from seabed morphology suggests materials are similar to those of Zones 8 and 9, with a very thin layer of marine sediment overlying bedrock</td>
<td>Very gently sloping seabed surface predominantly covered by sand and gravel and with occasional outcrops of smooth rock. Sand and gravel dominated seabed is characterised by a series of linear depressions c. 0.5m deep and up to 50m wide that trend at around 045°</td>
<td>Not applicable</td>
<td>refer to Figures 12 and 13</td>
</tr>
</tbody>
</table>
Table 2. Soil properties in Zones 1 and 2 (cable route)

<table>
<thead>
<tr>
<th>Soil Description</th>
<th>Thickness (m)</th>
<th>Bulk Density (Mg/m³)</th>
<th>Plasticity Index (%)</th>
<th>Internal friction angle (°)</th>
<th>Undrained Shear Strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DENSE fine to medium SAND with little silt and occasional gravel and shells. Gravel content increasing with depth.</td>
<td>2.5 increasing over 6.0</td>
<td>1.95</td>
<td>N/A</td>
<td>34</td>
<td>N/A</td>
</tr>
<tr>
<td>DENSE to VERY DENSE sandy GRAVEL with occasional shells.</td>
<td>1.0</td>
<td>1.90</td>
<td>N/A</td>
<td>35</td>
<td>N/A</td>
</tr>
<tr>
<td>STIFF sandy gravely CLAY (CPT2a location only)</td>
<td>0.7</td>
<td>no data</td>
<td>no data</td>
<td>N/A</td>
<td>150</td>
</tr>
<tr>
<td>Highly weathered BEDROCK</td>
<td>No Data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The second area corresponds to Zone 3, which is transitional between sandier inshore sediments and generally rock terrain offshore (Table 3).

Table 3. Soil properties in Zone 3 (cable route)

<table>
<thead>
<tr>
<th>Soil Description</th>
<th>Thickness (m)</th>
<th>Bulk Density (Mg/m³)</th>
<th>Plasticity Index (%)</th>
<th>Internal friction angle (°)</th>
<th>Undrained Shear Strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DENSE to VERY DENSE sandy GRAVEL with occasional shells.</td>
<td>0.5 to 1.0</td>
<td>1.90</td>
<td>N/A</td>
<td>35</td>
<td>N/A</td>
</tr>
<tr>
<td>VERY WEAK completely to highly weathered MUDSTONE/SHALE with wide apertures infilled with sandy clay</td>
<td>No representative data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The third area comprises the remainder of the cable route (Zones 4 to 6, and the southern extent of Zone 7). Most of the PCPT tests and vibrocores refused in the top 0.5m below the seabed level, the exception being location no. 14. The PCPT probe penetrated 2.4m below the sea-bed level and the vibrocore returned 0.3m at this location. Based on a particle size distribution test superficial soil can be described as a mixture of sand and gravel with some clay. The highly weathered bedrock can be described as Very Weak becoming Weak Mudstone / Shale with moderately-wide infilled apertures.
In the original deployment area, soil conditions were variable from north to south of the geophysical data coverage. Consequently, the soil profile in Table 4 below was not observed in all exploratory locations within the area (locations from 18 to 22), however it is thought to be typical of the area given the zoning achieved using the geophysical data. It is notable that the superficial gravelly sand layer is absent at these sample locations, and was only proven at location 22. The high density of the sandy gravel suggests that it is completely weathered mudstone bedrock, given typical densities of Tertiary or Quaternary gravels less than 1.90Mg/m³.

Table 4. Soil properties – originally proposed Wave Hub Area

<table>
<thead>
<tr>
<th>Soil Description</th>
<th>Thickness (m)</th>
<th>Bulk Density (Mg/m³)</th>
<th>Plasticity Index (%)</th>
<th>Internal friction angle (°)</th>
<th>Undrained Shear Strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DENSE fine to medium very gravelly SAND with little silt and occasional shells.</td>
<td>0.5</td>
<td>2.00</td>
<td>N/A</td>
<td>34</td>
<td>N/A</td>
</tr>
<tr>
<td>DENSE to VERY DENSE sandy GRAVEL with occasional shells.</td>
<td>1.0</td>
<td>2.10</td>
<td>N/A</td>
<td>35</td>
<td>N/A</td>
</tr>
<tr>
<td>VERY WEAK completely to highly weathered MUDSTONE/SHALE with wide apertures infilled with sandy clay</td>
<td>1.0</td>
<td>no data</td>
<td>no data</td>
<td>N/A</td>
<td>apparent value from 800 to 1200</td>
</tr>
</tbody>
</table>

3.2.2 Possible Hub Anchoring Locations

Six anchoring locations were included in the scope of the geotechnical survey. All were located to the east of the originally proposed hub area and were aligned north-south. Each location was investigated with a single vibrocore and PCPT test. There are no geotechnical data from the revised hub and anchoring positions. Apart from location 23 (Figure 2) all other investigated anchoring locations produced similar results. In general, the sediment profile consists of an upper layer of medium dense becoming dense gravelly sand underlain by highly weathered bedrock. The sand layer is on average 1.0m thick and contains numerous shells and shell fragments. The bedrock weathering grade reduces with depth relatively quickly, because all CPT tests refused within 2.0m below the ground level. As the sediment conditions observed at the proposed device anchoring locations are generally similar it is assumed the sediment profile shown in Table 4 is representative for the whole deployment area.

Chemical tests to determine soil aggressiveness to concrete produced very uniform
results and one design sulphate class can be assigned to the whole of the site. As the pH value is constantly above 8.5 and the content of sulphate (SO₄) extract from soil is always less than 0.4 g/l but in one sample the design sulphate class for the site is AC-1.
4 Seabed geomorphology

4.1 Interpretation

Interpretation of the seabed data along the cable route and within the deployment area is provided in Figures 3 to 13. This interpretation makes full use of available seabed sediment samples, and seismic data. A conceptual diagram of seabed conditions from landfall to the hub site is provided in Figure 14.

![Schematic long profile of the seabed showing cable route from landfall to Wave Hub](image)

Figure 14. Schematic long profile of the seabed showing cable route from landfall to Wave Hub

4.1.1 Zones 1, 2 and 3 (cable, nearshore)

The nearshore section of the cable route in Zones 1, 2 and 3 is interpreted as a sand-filled embayment constrained by headlands, and which is probably dominated by ebb tide delta processes associated with the River Hayle. Nearshore sands probably derive from contemporary estuary and coastal processes, and contained completely within the bay and are probably afforded some protection from offshore currents and waves. A series of sand bars have been formed in Zone 1,
probably marking the offshore limit of intertidal and estuary currents. The thinner sand cover in Zone 2 reveals occasional bedrock outcrops at seabed, usually in hollows in the sand. Hollows without bedrock outcrops also occur towards the seaward margin of this zone. Both types of hollow may relate to scour of the seabed by tidal and estuary currents.

The transition from Zone 2 to Zone 3 is characterised by a marked step, which corresponds with the headlands at the margins of the bay, and which therefore may relate to erosion by offshore currents in an area not protected by headlands or exhumation of a former cliff feature. Sediments may be rapidly transported away from this zone and/or not generally deposited.

Linear hollows observed in areas of sand cover in Zone 3, which are aligned at approximately 050º, are considered to indicate scour by currents. This alignment is perpendicular to the direction of currents originating from the estuary region but similar to the dominant direction of surface currents identified by the BGS.

4.1.2 Zones 4, 5 and 6 (cable, offshore)

Bedding is clearly visible as evenly-spaced ridges on the seabed forming ‘saw tooth’ morphology. This pattern indicates that rocks are probably of sedimentary origin and have a near-vertical dip. Visible bedding planes are generally spaced between 5 and 30m apart, indicating either massive bedding or variation in rock hardness with softer beds not forming clear bedding ridges. The change in relative elevation on the sea bed with ridges is typically between 0.5 and 1m, but occasionally reaches 2m. Variable strike of rock bedding in Zone 4 is likely to have resulted from ancient folding, but faulting may also have had a role in geological history. The overlying thin and discontinuous sediment veneer found throughout Zone 4 is likely to represent reworked remnants of glacial sediments eroded as sea-levels rose during the Holocene (last c. 10,000 years).

Zones 5 and 6 are similar to Zone 4 but have smoother bedrock exposed with a more extensive cover of sediment. Near-vertical bedding is occasionally seen in the bedrock, which generally constrains the sediment drape. Jointing, identified by breaks in the beds, is very common. A relict cliff line can be traced across the study area. The sediments in the area of seabed fronting the cliff line are clay-rich sands and probably represent an accumulation of fine-grained marine sediment infilling the former cliff front.
4.1.3 Zones 7 and 8 (cable offshore / original deployment area)

The majority of rocks in Zones 7 and 8 have limited bedding or jointing cropping out as linear ridges with relative elevations of up to 8 m aligned at between 040° and 060°. The exception to this pattern is a well defined fold structure seen in Zone 7 which plunges towards the northeast. Data from shallow cores in this area suggests the bedrock is a hard mudstone, however the craggy linear ridges have the appearance of intrusive volcanic rocks and may represent dykes associated with the Cornish granite batholith; volcanic intrusions on the land follow a similar trend. This interpretation is also made by EGS in their summary interpretative report (EGS International Ltd, 2006)

Accumulations of sand, gravel and clayey sand probably represent a surface eroded from glacial deposits, including till and meltwater sediments. Shallow, linear depressions in the surface of the seabed continuing for over 1 km and generally running parallel to each other may represent scour hollows focused between outcrops of resistant rock.

4.1.4 Zone 9 (original deployment area)

The central part of Zone 9 is dominated by an area of generally smooth rock platform with an intermittent cover of sediment. The area of rock platform is characterised by a series of linear incisions up to 3 m deep and around 60 m wide which cross the outcrop. The rock is also highly jointed and shows no sign of apparent faulting. Zone 9 also contains occasional outcrops of linear craggy rock which follow the same alignment as those seen in Zone 8. No data is available from the sediments covering the rock platform, but the smooth platform material appears different to the rock exposed in Zone 7, which appears as linear crags, and in Zone 4, which has clearly visible and distorted vertical bedding. This pattern of outcrop may represent horizontally bedded sedimentary rock intruded by a series of dykes, but additional data is required before a more confident interpretation can be made.

4.1.5 Zone 10 (area of regional survey incorporating revised deployment area)

The seabed data covering Zone 10 is limited to the regional survey, which comprises 100 m-wide swathes spaced over a 2.5 km grid. These data provide sufficient information to show the seabed is generally similar to Zones 8 and 9, comprising sand and gravel with occasional low rocky outcrops.

The sand and gravel regions of the seabed are characterised by a series of shallow linear channels around 0.5 m deep but up to 50 m wide, and aligned around 045°.
These features are tentatively interpreted as scour hollows, but further information is required to confirm this.

### 4.2 Summary

The offshore area, through which the cable is routed and in which the Wave Hub will be sited, is relatively benign with respect to geohazards. There is some evidence for bottom current scour or deposition processes which may expose or bury the cable, and which may therefore create issues for the hub foundation or anchoring. There is minor evidence for transport of seabed sediments in the form of ripples or dunes, and there are no significant bedrock offsets indicative of active faulting. Apparent ‘scour hollows’ may indicate the presence of contemporaneous or past bottom current activity with the potential to erode and transport sediments. However, in the absence of data on bottom currents, this interpretation cannot be validated.

Consequently, the presence of geomorphological or geotechnical constraints will relate to the physical and chemical characteristics of the seabed soils and rock in the offshore area. The following chapter identifies these ‘geo-constraints’ for each Zone along the cable route and at the potential hub location.
5 Assessment of seabed geo-constraints

5.1 Cable properties and proposed hub design
Both the cable specification and the foundation requirements for the hub structure were unconfirmed at the time of writing. Accordingly, the assessment of geo-constraints (i.e. geotechnical or geomorphological constraints) provided in this chapter is based on the following general assumptions:

(a) The cable will be buried where possible, and where not buried will be armoured if either seabed conditions or local anthropogenic marine activity indicate this to be a requirement;
(b) The hub structures will be either anchored, or supported by mud-mats, and accordingly, sediments into which anchors or mud-mat skirts may penetrate are a requirement.

Section 5.2 considers the constraints in the development area, firstly for the cable route, and secondly for the original and revised hub locations. Table 5 provides an account of geo-constraints and associated mitigation measures for each of the seabed provinces. A summary map of geo-constraints is provided in Figure 15.

5.2 Geo-constraints along cable route
The provisionally specified 24kV cable for the main cable route will weigh approximately 20kg per metre in water, and is therefore likely to rest where it falls on the sea bed. Metre to sub-metre scale placement of the cable is therefore unlikely to be possible. Accordingly, the cable is likely to be armoured against damage and will be insufficiently flexible and too heavy to be curved around bedrock ridges. Given its armouring and weight, the cable is likely to be strong enough to be draped over the more significant areas of rock ridges (which have relative elevation generally of up to 2m and crop out between 5 and 30 m apart) and lie flat on the seabed (e.g. Zones 4 to 6; Table 5). Furthermore, it is unlikely to be moved by marine currents (e.g. Zones 1 to 3 and 8 to 10; Table 5). Where the cable rests on weathered bedrock ridges (Zones 4 to 6; Table 5), it is generally more likely that the cable will erode the rock, rather than the rock damage the cable. Particularly hard rocks (e.g. igneous intrusions) may be more resistant, potentially leading to abrasion of the cable in the long-term, or spanning issues if it is routed over such geology which has often has relative elevation in excess of 5 m (Zones 7 to 10; Table 5). The 11kV cables linking the wave energy converters to
the hub will be smaller and weigh approximately 7kg per metre in water.

These smaller cables will probably require armouring to inhibit damage and prevent movement that might be expected to occur under local currents (provinces 7 to 10; Table 5). Smaller cables can be pinned to the ground if movement is expected in extreme conditions. This process usually involves manual installation of a stainless steel u-bolt over the cable secured in holes drilled in bedrock.

Appropriate mitigation measures for cable routing between land and the hub site, and between the hub sub-components would involve armouring in rocky areas, selection of a route that avoids significant hard rock intrusions where possible, and specification of a cable with sufficient rigidity or flexibility to withstand placement on a sea bed comprising rocky ridges of up to 2m relative elevation.

5.3 Geo-constraints within proposed hub area

Key geo-constraints to the hub location relate to likely thin sediment cover at both the original and revised hub sites (Zones 7 and 8, and Zones 10 respectively; Table 5), and local occurrences of more resistant rock intrusions, possibly igneous in origin (Zones 8 and 9; Table 5). At the time of writing, the proposed site for the hub seabed components lies in the southwest corner of the revised deployment area (Figure 13). Geophysical survey data coverage is limited at this location, but extrapolation of local seabed conditions would suggest founding of structures in sand and gravel deposits with northeast-southwest aligned depressions possibly related to scour.

Anchoring in thin sand and gravels may not be sufficient to hold structures in place. Also, erosion and scour may result in undermining and exposure of cables and facilities. Consequently, anchors may need to penetrate through any weathered horizons and overlying sediment into more resistant bedrock. Mud-mats or structures with penetrating skirts may encounter resistant bedrock close to the seabed.

Appropriate mitigation measures for founding structures in thin sediments and weakly weathered bedrock would involve specification of gravity anchors. In these locations, penetrating anchors would not be sufficient, to ensure a good hold.
Table 5. Geo-constraints to cable routing and hub structure foundations.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Length of cable (km)</th>
<th>Chainage (km offshore)</th>
<th>Seabed depth (m below CD)</th>
<th>Geo-constraints</th>
<th>Constraints to cable routing / structure foundations</th>
<th>Mitigation / comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0 - 1</td>
<td>5 to 11</td>
<td>• Minor scour/sediment transport and deposition associated with tidal and estuarine currents</td>
<td>• Localised and periodic exposure / burial of cable by transport of sands within Hayle bay</td>
<td>• No mitigation required, cable burial is likely to be possible</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1 – 3</td>
<td>11 to 20</td>
<td>• Minor scour/sediment transport and deposition associated with tidal and estuarine currents</td>
<td>• Localised and periodic exposure / burial of cable by transport of sands within Hayle bay</td>
<td>• No mitigation required, cable burial is likely to be possible and should be routed around rock outcrops</td>
</tr>
</tbody>
</table>
| 3    | 4.5                  | 3 – 7.5                | 20 to 28                  | • Minor scour/sediment transport and deposition associated with longshore currents | • Cable burial is unlikely to be possible  
• If burial is achieved, the cable is likely to become periodically exposed by erosion | • Cable should be armoured if routed in proximity to bedrock outcrops |
| 4    | 10                   | 7.5 – 17.5             | 28 to 32                  | • Exposed bedding planes, with relative elevation of up to 2m, perpendicular to cable alignment | • There will be friction between the cable and underlying bedrock  
• The cable will be subject to local changes in relative elevation throughout this zone | • Cable should be armoured if routed in proximity to bedrock outcrops  
• Cable specification should allow for draping over rock ridges up to 2m relative elevation |
| 5    | 2.5                  | 17.5 – 20.0            | 33 to 36                  | • Exposed bedding planes, with relative elevation of up to 2m, perpendicular to cable alignment | • There will be friction between the cable and underlying bedrock  
• The cable will be subject to local changes in relative elevation throughout this zone | • Cable should be armoured if routed in proximity to bedrock outcrops  
• Cable specification should allow for draping over rock ridges up to 2m relative elevation |
<table>
<thead>
<tr>
<th>Zone</th>
<th>Length of cable (km)</th>
<th>Chainage (km offshore)</th>
<th>Seabed depth (m below CD)</th>
<th>Geo-constraints</th>
<th>Constraints to cable routing / structure foundations</th>
<th>Mitigation / comments</th>
</tr>
</thead>
</table>
| 6    | 2.5                  | 20.0 – 22.5            | 35 to 48                  | • Exposed bedding planes, with relative elevation of up to 2m, perpendicular to cable alignment | • There will be friction between the cable and underlying bedrock  
• The cable will be subject to local changes in relative elevation throughout this zone | • Cable should be armoured if routed in proximity to bedrock outcrops  
• Cable specification should allow for draping over rock ridges up to 2m relative elevation |
| 7    | 4                    | 22.5 – 26.5            | 49 to 58                  | • Possible localised igneous intrusions with significant relative relief (>5m)  
• Possible minor scour/sediment transport associated with bottom currents  
• Cable burial will be locally possible  
• There will be friction between the cable and underlying bedrock | • Where burial is achieved, the cable may become periodically exposed by transport of sediments  
• Cable routing over igneous intrusions may lead to significant wear to cable armour in the long term and lengths of draped cable  
• Limited depth for founding of mud-mat skirts for hub structures | • Cable route should avoid igneous intrusions  
• Mud-mats should be specified for coarse granular materials  
• Cable should be armoured if routed in proximity to bedrock outcrops |
| 8    | n/a                  | n/a                    | 49 to 55                  | • Possible localised igneous intrusions with significant relative relief (>5m)  
• Possible minor scour/sediment transport associated with bottom currents | • Where burial is achieved, the cable may become periodically exposed by export of sediments  
• Cable routing over igneous intrusions may lead to significant wear to cable armour in the long term and lengths of draped cable  
• Limited depth for founding of mud-mat skirts for hub structures  
• There will be friction between the cable and underlying bedrock | • Cable route should avoid igneous intrusions  
• Mud-mats should be specified for coarse granular materials  
• Cable should be armoured if routed in proximity to bedrock outcrops or if a risk to cable integrity is identified as a function of trawling (or other) activity in this Zone |
<table>
<thead>
<tr>
<th>Zone</th>
<th>Length of cable (km)</th>
<th>Chainage (km offshore)</th>
<th>Seabed depth (m below CD)</th>
<th>Geo-constraints</th>
<th>Constraints to cable routing / structure foundations</th>
<th>Mitigation / comments</th>
</tr>
</thead>
</table>
| 9    | n/a                  | n/a                    | 55 to 60                  | • Local outcrops of rough rock (igneous intrusions) with significant relative relief (>5m)  
• Possible minor scour/sediment transport associated with bottom currents. | • Cable burial will be locally possible  
• Where burial is achieved, the cable may become periodically exposed by export of sediments  
• Cable routing over igneous intrusions may lead to significant wear to cable armour in the long term  
• Limited depth for founding of mud-mat skirts for hub structures | • Cable should be armoured if routed in proximity to bedrock outcrops or if a risk to cable integrity is identified as a function of trawling (or other) activity in this Zone  
• Cable route should avoid igneous intrusions  
• Mud-mats should be specified for coarse granular materials |
| 10   | n/a                  | n/a                    | 52 to 58                  | • Local outcrops of weathered rock  
• Possible minor scour/sediment transport associated with bottom currents | • Cable burial will be locally possible  
• Where burial is achieved, the cable may become periodically exposed by erosion of sediments  
• Limited depth for founding of mud-mat skirts for hub structures | • Cable should be armoured if routed in proximity to bedrock outcrops or if a risk to cable integrity is identified as a function of trawling (or other) activity in this Zone  
• Cable route should avoid igneous intrusions  
• Mud-mats should be specified for coarse granular materials |
6 Conclusions and recommendations

6.1 Conclusions
This report has not identified any significant geohazards along the cable route or hub location, although attention has been drawn to a series of geo-constraints that should be considered before the construction phase. Seabed ground conditions, whilst variable, are unlikely to cause significant installation difficulties, providing close attention is given to the subtle variations in sediment cover and rock outcrop. Careful selection of sites for facilities will enable avoidance of these geo-constraints. Further acquisition of geotechnical and geophysical data is recommended in the revised site location to support detailed design.

The key geo-constraints to the Wave Hub and cable identified in this report are as follows:

- Thin to locally absent sediments providing limited opportunity for cable burial or founding of structures;
- Continuous outcrops of jointed and bedded weathered rock spaced between 5 and 30m apart, locally perpendicular or oblique to the cable route, with changes in relative elevation of up to 2m, but more typically between 0.1 and 1m;
- Local outcrops/intrusions of harder (igneous) rocks which may abrade the cable in the event of contact, often with change in relative elevation of over 5m;
- Local scour and/or deposition of sediments in the nearshore and offshore which may expose/bury the cable/structures/foundations.

Mitigation measures will primarily require appropriate specification of cable armour and mode of foundation suitable to these conditions.

6.2 Recommendations

6.2.1 Further data for the cable route
It is unlikely that further survey will be required along the cable route for the purposes of identifying geotechnical or geomorphological constraints. If the Wave Hub location is moved again, sufficient information is enclosed in this report to provide guidance so long as the cable is contained within the preferred corridor.
6.2.2 Further data for the Wave Hub deployment area

Data and interpretation provided in this report indicate a significant degree of variability in depth, location and extent of sediment cover in the original and revised deployment areas. Accordingly, if detailed geotechnical parameters are required for adequate foundation design for the hub seabed components, a further geotechnical site investigation at the revised site location is recommended. This site investigation should consider:

(a) Soil characteristics (including texture, density and strength);
(b) Stratigraphy (depth of layers); and
(c) Bedrock characteristics (hardness, jointing)

It is considered unlikely that geotechnical data collected in the original deployment area are representative of the conditions at the new site. In addition, it has not been possible to identify the origin of the seabed depressions that cut into sand and gravels at the new site. These may be indicative of active seabed scour and this may have implications exposure or burial of foundations and structures. It is recommended that bottom current data is collected for the final hub location to ensure that sediment winnowing or accumulation do not compromise the seabed structures during their design life.

6.2.3 Further data for wave energy converters

Survey data collected for the original deployment area provided sufficient coverage to inform the specification of seabed anchoring for wave devices. The revised deployment area does not afford this level of coverage. It is recommended that additional geophysical survey of the revised site location is undertaken to inform anchoring requirements for these structures.

6.3 Limitations

The data reviewed in this report were collected with reference to the original Wave Hub deployment area and a modified cable route corridor based on alignments selected in the Technical Feasibility Study (Halcrow Group Ltd, 2005). Following data collection, the location of the deployment area, and by necessity, the cable route leading to it, were modified. Data coverage for the revised deployment area is limited and comprises regional geophysical survey lines of limited overlap.

Accordingly, knowledge of seabed conditions and geo-constraints in the new area (which straddles the areas of data coverage) is limited. There is no geotechnical coverage at this location.
References


British Geological Survey (1985) 1:250 000 Series, Land's End, Sheet 50°N-06°W, Solid geology, Ordnance Survey, Southampton


8 Figures
Bathymetry (MbCD) Interpretation

-58 to -55
-54.9 to -50
-49.9 to -45
-44.9 to -40
-39.9 to -35
-34.9 to -30
-29.9 to -25
-24.9 to -20
-19.9 to -15
-14.9 to -10

- Depression
- Rock outcrop in sediment depression
- Rough rock outcrop
- Rough rock outcrop with sand and gravel cover
- Sand
- Sand and gravel
- Sand and gravel with occasional low rock outcrop
- Sand with occasional low rock outcrop
- Smooth rock outcrop
- Smooth rock outcrop with sand and gravel cover
- Bedding plane in sedimentary rock

Notes: Interpretation based on bathymetry and seismic lines.
Figure 4. Zone 3 (Cells, Numbers)

Notes: Interpretation based on bathymetry and seismic lines
Notes: Interpretation based on bathymetry and seismic lines

Figure 5: Zone 4a (Cable, Offshore)
Bathymetry (Mcd) Interpretation
- 58.9 to -65: depression
- 54.9 to -50: rock outcrop in sediment depression
- 49.9 to -45: rough rock outcrop
- 44.9 to -40: rough rock outcrop with sand and gravel cover
- 39.9 to -35: sand
- 34.9 to -30: sand and gravel
- 29.9 to -25: sand and gravel with occasional low rock outcrop
- 24.9 to -20: sand with occasional low rock outcrop
- 19.9 to -15: smooth rock outcrop
- 14.9 to -10: smooth rock outcrop with sand and gravel cover
- Bedding plane in sedimentary rock

Notes: Interpretation based on bathymetry and seismic lines

Figure 6. Zone 4b (Cable, Offshore)
Figure 7. Zones 4c and 4d (Cable, Offshore)

Notes: Interpretation based on bathymetry and seismic lines.
Bathymetry (M&CD) Interpretation

-58.9 to -65
-54.9 to -50
-49.9 to -45
-44.9 to -40
-39.9 to -35
-34.9 to -30
-29.9 to -25
-24.9 to -20
-19.9 to -15
-14.9 to -10

- depression
- rock outcrop in sediment depression
- rough rock outcrop
- rough rock outcrop with sand and gravel cover
- sand
- sand and gravel
- sand and gravel with occasional low rock outcrop
- sand with occasional low rock outcrop
- smooth rock outcrop
- smooth rock outcrop with sand and gravel cover

Bedding plane in sedimentary rock
*** buried cliff line
- depression in sediment
- lineament in bedrock (joint or fault)
- sand bar
- Sedimentary depth

Notes: Interpretation based on bathymetry and seismic lines

Figure 8. Zone 3 (Cable, Offshore)
Bathymetry Interpretation

-58.9 to -65  depression
-54.9 to -60  rock outcrop in sediment depression
-49.9 to -45  rough rock outcrop
-44.9 to -40  rough rock outcrop with sand and gravel cover
-39.9 to -35  sand
-34.9 to -30  sand and gravel
-29.9 to -25  sand and gravel with occasional low rock outcrop
-24.9 to -20  sand with occasional low rock outcrop
-19.9 to -15  smooth rock outcrop
-14.9 to -10  smooth rock outcrop with sand and gravel cover

- Bedding plane in sedimentary rock
  - Buried cliff line

- Depression in sediment
- Lineament in bedrock (joint or fault)
- Sand bar
  - Sediment depth

Notes: Interpretation based on bathymetry and seismic lines

Figure 9. Zone 6 (Cable, Offshore)
Bathymetry (MbCD) Interpretation:

-58.9 to -55  
-54.9 to -50  
-49.9 to -45  
-44.9 to -40  
-39.9 to -35  
-34.9 to -30  
-29.9 to -25  
-24.9 to -20  
-19.9 to -15  
-14.9 to -10  

- Depression
- Rock outcrop in sediment depression
- Rough rock outcrop
- Rough rock outcrop with sand and gravel cover
- Sand
- Sand and gravel
- Sand and gravel with occasional low rock outcrop
- Sand with occasional low rock outcrop
- Smooth rock outcrop
- Smooth rock outcrop with sand and gravel cover
- Bedding plane in sedimentary rock
- Buried cliff line

---

Notes: Interpretation based on bathymetry and seismic lines.

Figure 19: Zone 7 (stable offshore/ original deployment area)
Figure 11. Zones 8 and 9 (original deployment area)

Notes: Interpretation based on bathymetry and seismic lines
Figure 12. Zone 10 South (Revised cable, Offshore)
Possible hub seabed components

Bathymetry (MbCD)
-58.9 to -55
-54.9 to -50
-49.9 to -45
-44.9 to -40
-39.9 to -35
-34.9 to -30
-29.9 to -25
-24.9 to -20
-19.9 to -15
-14.9 to -10
rock
gravel over rock
sand and gravel over rock

Interpretation
depression
rock outcrop in sediment depression
rough rock outcrop
rough rock outcrop with sand and gravel cover
sand
sand and gravel
sand and gravel with occasional low rock outcrop
sand with occasional low rock outcrop
smooth rock outcrop
smooth rock outcrop with sand and gravel cover
bedding plane in sedimentary rock
buried cliff line

Notes: Interpretation based on bathymetry and seismic lines
Figure 15. Zone 16 North (Revised hub array exclusion area)
Figure 15. Summary of geotechnical constraints along the cable route and deployment area.
The CD attached to the inside back cover of this report contains the full electronic versions of the Geotechnical Site Investigation, undertaken by Alluvial Mining Ltd in October 2005 (Appendix 1), and the Geophysical Survey undertaken by EGS Ltd in July 2005 (Appendix 2).

The full survey dataset (five DVDs), viewing software and dongle are available on loan from EGS Ltd, if required.