SUPPLEMENTARY STUDY
AUGUST 2015

GEOLOGICAL, HYDROGEOLOGICAL

BASELINE DESK STUDY BRIMS

TIDAL ARRAY

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August 2015

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GEOLOGICAL, HYDROGEOLOGICAL BASELINE DESK STUDY BRIMS TIDAL ARRAY

PROPOSED TIDAL DEVELOPMENT

IN ORKNEY

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EXECUTIVE SUMMARY

A recent study by this author, February 2015, suggested that a location at Melsetter links and Sheep Skerry could be a more suitable cable landing area than the previously examined eastern corridor for the Brims Tidal Array. However information already gathered from the seabed to the east of Sheep Skerry was not sufficient to assess its suitability.

It was therefore recommended that the Developer (Brims Tidal Array Ltd) undertake a further Multibeam Echosounder survey. This survey was completed by Aquatera in July 2015 and is the basis of this reinterpretation. At the same time Aquatera undertook an environmental and habitat study (Crossley, 2015). This study was also incorporated into the new hydrogeology interpretation of the landward zone of Sheep Skerry.

The majority of the general issues of geology and hydrogeology were addressed in the original report. Therefore this study will only integrate new information from the new studies. The hydrogeology characteristics for the Sheep Skerry study area needed a more detailed digitisation of the water table. This was used to create an "Altitude minus Watertable" map to compare with the plant distribution from the habitat map. Unfortunately because of the lack of watertable control points in this area and the fact the dunes had been in small-scale commercial industrial use made correlations less than ideal. Nevertheless there is broad concordance between the plant communities indicative of wet environments. Nothing in this study was found to contradict the conclusions reached by Aquatera.

Not discussed in previous studies is the presence of a prominent storm beach 250 m in length and 20 m broad on the western margin of the area. This storm beach was studied from photographs given to the author. It was concluded that the upper part of the beach with some large rocks up to 6 tonnes in weight, have not moved for many decades. Further it probably formed when the sea level was much higher, that is around 1000 years ago. Therefore the conclusion is that this storm beach does not represent a present danger to a cable landing solution in this area.

The previous study created a draft interpreted geology map for the whole region but in the Sheep Skerry area it lacked enough data to accurately map the geological contacts.

The new seabed survey shows clearly the fault pattern dying out southwards crossing the Sheep Skerry study area. Also clear is a pronounced rugosity with pillars of rock oval shape and about 5 m in height over the area. The pillars are interpreted as remnants of weathered lava flows with deep notches and weathering created by faults and cracks. It was also possible to map sand cover in the area confirmed by photographs from the ROV video log for the benthic study. The new faults and the rugosity of the seafloor has enabled the remapping, with more confidence, the subsea geology in the study area.

A median path was selection for the western corridor which follows a relatively gentle route, through the sands and between the rock pillars, 2.5° average slope, from 0 to 45 m water depth. This route and one for the eastern corridor through Aith Hope to the top end of the Bay are recommended by this study.

SHEEP SKERRY CORRIDOR AND LANDFALL

INTRODUCTION

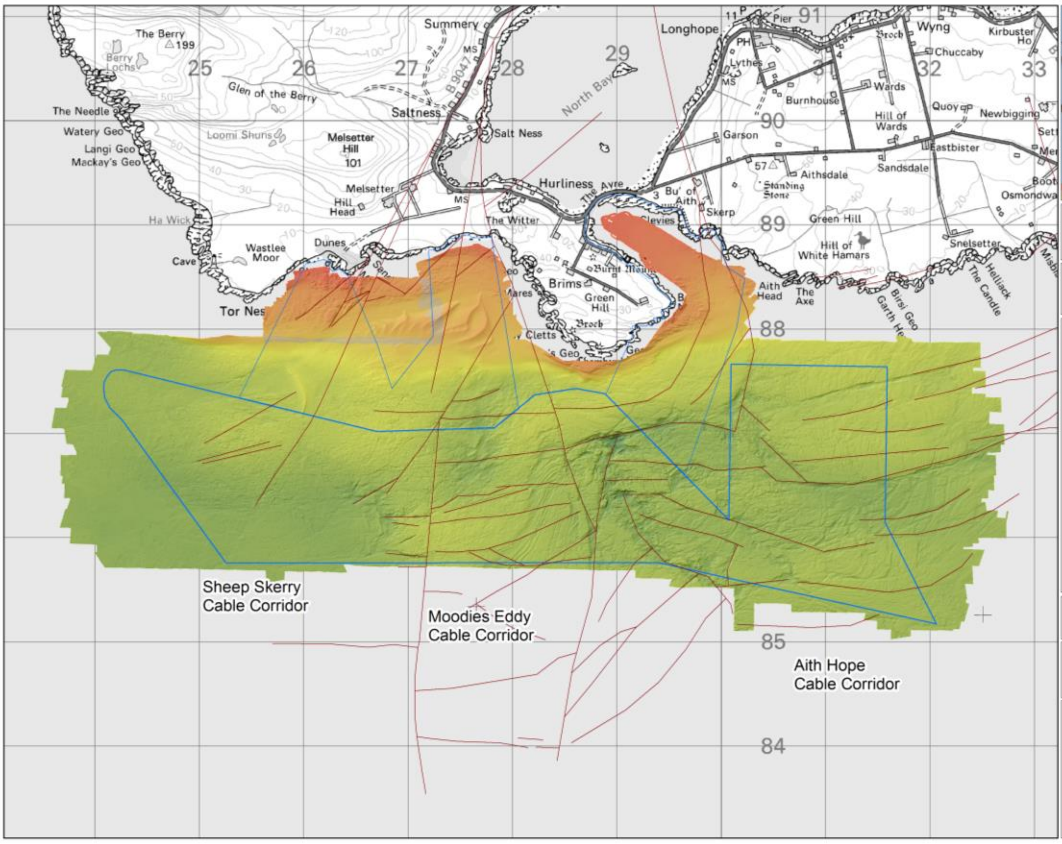


Figure 1 location of multibeam studies for the three proposed cable corridors and the AfL onshore and offshore faults shown as red lines

A recent study by this author (Brown, 2015) examined the topography, potential flooding, regional geology, structural geology, hydrogeology and groundwater flow with statutory hazard evaluation onshore and offshore within the study area.

The goal was to recommend cable landing locations along the coast from Melsetter Shoreline to the east side of Aith Hope. Such landfalls for underwater cables need careful choosing in order to:

1. *Minimise risk of damage to cables by Marine operations such as ships anchors and trawling operations.*
2. *Satisfy the need for gently sloping sandy or silty seafloor approaches enabling burial of the cable.*
3. *Provide a landing which lacks strong wind and tide currents that would uncover buried cables.*
4. *Avoid areas where cable landing points and associated infrastructure could be susceptible to flooding by freshwater or saltwater.*

There are two methods by which, conventionally, a cable can be brought across a beach and intertidal zone. First, simple trenching and backfill along low gradient paths.

The second method requires drilling a low angled borehole from a clifftop out into the ocean with emergence below wave base. This latter method requires careful selection of an exit hole not affected by wave or tidal action, enabling ROV operations. It should be located on a stable seafloor (no mobile sediment). Cable trenching is the preferred method as a trench can allow many separate cables to come ashore simultaneously.

The above study noted that it would be possible to bring cables ashore on the eastern side of the area namely at the head of Aith Hope. Detailed discussion of each of the shoreline segments to the west of Aith Hope determine that none were suitable for a cable trenching landfall.

However the study noted that a possible western corridor existed approximately 500 m to the west of the original zone of investigation. The decision was made to investigate this potential by completing the missing information from the previous studies.

Environmental and habitat issues were addressed by John Crossley MCIEEM (Crossley, 2015) in a report to Aquatera. Simultaneously a study of the marine environment within this new corridor was undertaken by Aquatera (Runciman, 2015).

This current study will extend the interpretation from Brown (2015) linking the new habitat and subsea environmental data to a geological and hydrogeological interpretation of the cable corridor from the Brims Agreement for Lease area (AfL).

GENERAL GEOLOGY

The oldest rocks found in Orkney are 'basement' granitic-gneiss, migmatite and schist exposed in the West Mainland at Yesnaby, Stromness and Graemsay. They represent the metamorphic core of an old mountain chain. These rocks bear a strong likeness to migmatised Moine rocks of the Loch Eil Group, found in eastern Sutherland, with a sedimentary age of about 950 million years.

After uplift, exhumation and erosion these hills of metamorphic rocks formed islands in the middle Devonian (± 380 million years) Lake Orcadie. Rivers flowed into the lake, bringing mud and silt. This settled on the lake bottom, forming flagstone. This facies within the Orcadian Basin is lacustrine and developed as a series of monotonous cycles. These cycles alternate from deep permanent lake, Laminites (±1.5m thick) to shallow playa lake sediments with ripple marks and mud cracks. They follow the Milankovitch, 100,000-year, orbital eccentricity cycle of the Earth-Sun system.

In Orkney, we find 108 lacustrine cycles in the Stromness, Rousay and Eday Flagstone Formations each cycle averaging about 9m thick. Laminites represent a time when a deep permanent lake existed in all parts of the Orcadian Basin. The 20m thick Sandwick Fishbed level represents one extra-large lake system that lasted for three cycles (300,000 years) and yielded most of the sixteen fish species found. The Orcadian Basin continued to subside through the Carboniferous and early Permian and eventually covered by 2000 m of sediment. During upper Permian times (250 million years ago), uplift of the basin occurred with erosion of these sediments. Simultaneously a suite of ± 200 Lamprophyre Dyke Rocks (Brown, 1975; Lundmark et al., 2011) were intruded.

Period		Unit Thickness	Local Stratigraphic Units SE	Local Stratigraphic Units NE	Unit Thickness
MIDDLE DEVONIAN	FRASNIAN	640m	Trowie Glen Sandstone Member	Upper Eday Sandstone Formation	200m
	GIVETIAN	20m	The Haist Pebbly Sandstone Member	Eday Marl Member	40m
		25	Lyra Geo Sandstone Member	Middle Eday Sandstone Member	0 - 200m
		100m	Lang Geo Sandstone Member	Eday Flagstone Formation	180m
		100m	Eday/Hoy Volcanics	Eday/Hoy Volcanics	10m
		30 - 450m	Lower Eday Sandstone Formation	Lower Eday Sandstone Formation	200m
		420m	Upper Stromness/ Rousay Flagstone Formation	Upper Stromness/ Rousay Flagstone Formation	475m
	EMSIAN	20m	Sandwick Fishbed	Sandwick Fishbed	20m
		250m	Lower Stromness Flagstone Formation	Lower Stromness Flagstone Formation	277m

Figure 2 Brims Stratigraphic Column

In the western, Sheep Skerry, cable landing corridor the rocks encountered are mainly of the middle Devonian lacustrine, volcanic and river deposits encompassing the Rousay Flagstones, lower Eday Sandstone, Hoy volcanics and the sandstones of the Lyra Geo and Lang Geo Sandstone Members.

HYDROLOGY

The main features of the regional hydrogeology were discussed in the previous report (Brown, 2015). Rainfall, aquifers, flooding potential, soils and hydrogeology looks at the role of groundwater in the environment. By producing surface flow maps and a water table map it was possible to create watershed and flow direction maps both for the aquifer watertable and surface. Through an innovative mapping process, involving the subtraction of the water table from the surface altitude map, results in a map of waterlogged land and dry land above the water table.

In the series of following maps this methodology (Workflow) is applied to the local area at the Sheep Skerry Landfall (Figures 3 to 7). The detailed study of the plant communities in the habitat report (Crossley, 2015) are compared with the "***altitude minus water table***" map.

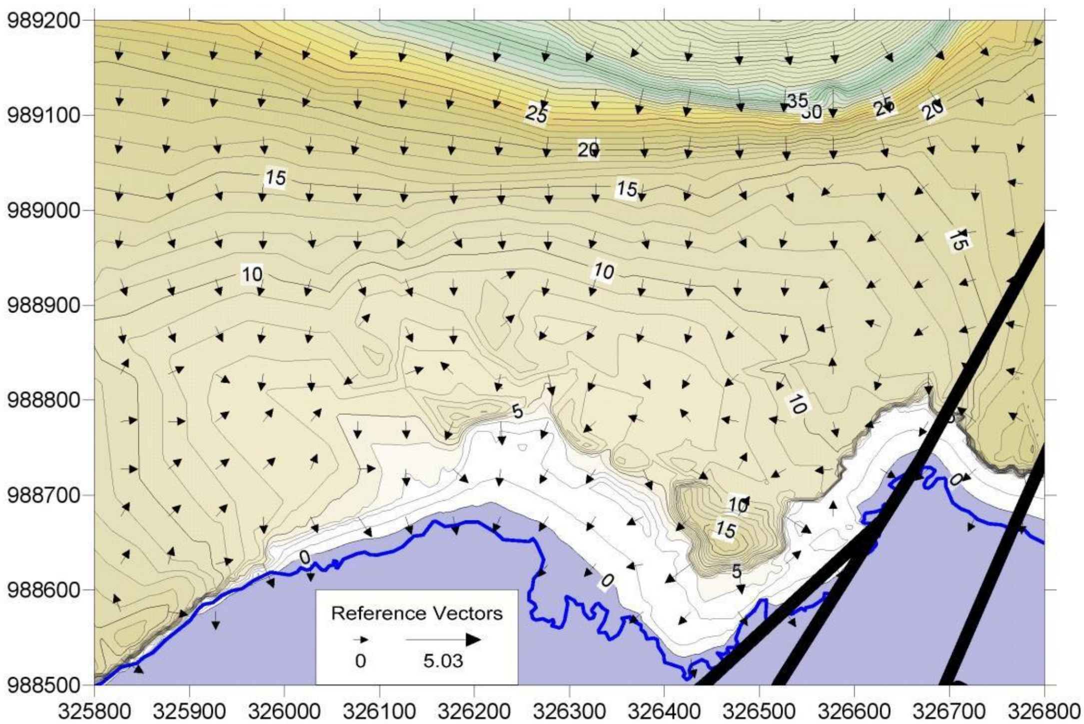


Figure 3 Sheep Skerry altitude with slope - flow vectors (black lines show trace of Sheep Skerry faults)

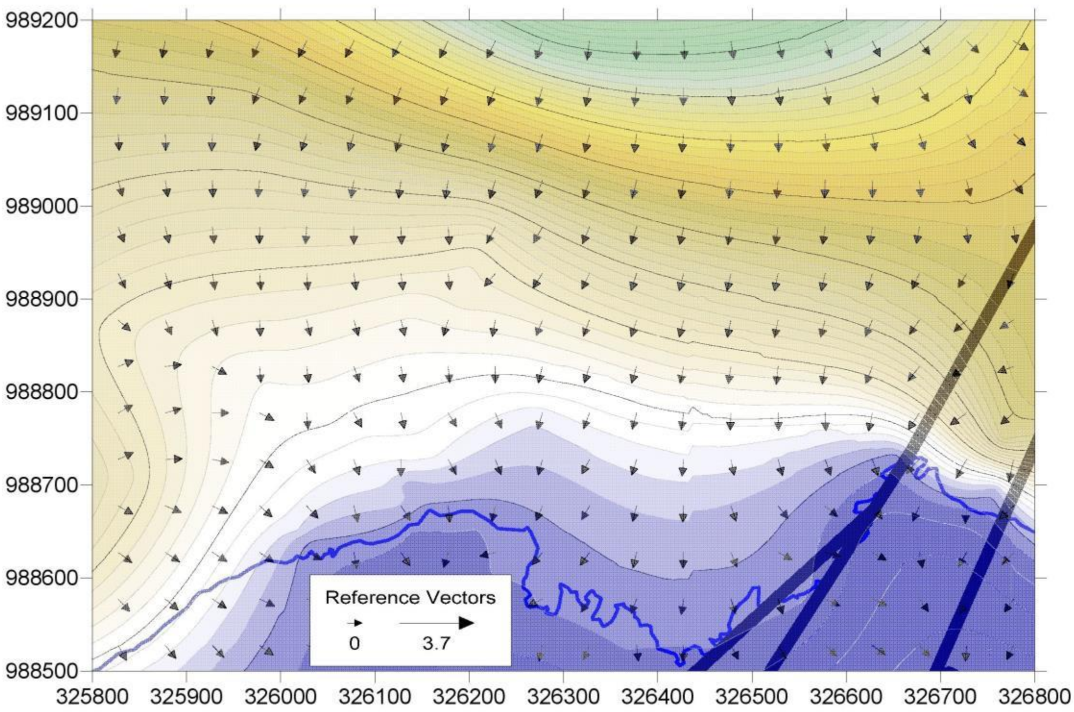


Figure 4 Sheep Skerry watertable with slope - flow vectors (black lines show trace of Sheep Skerry faults)

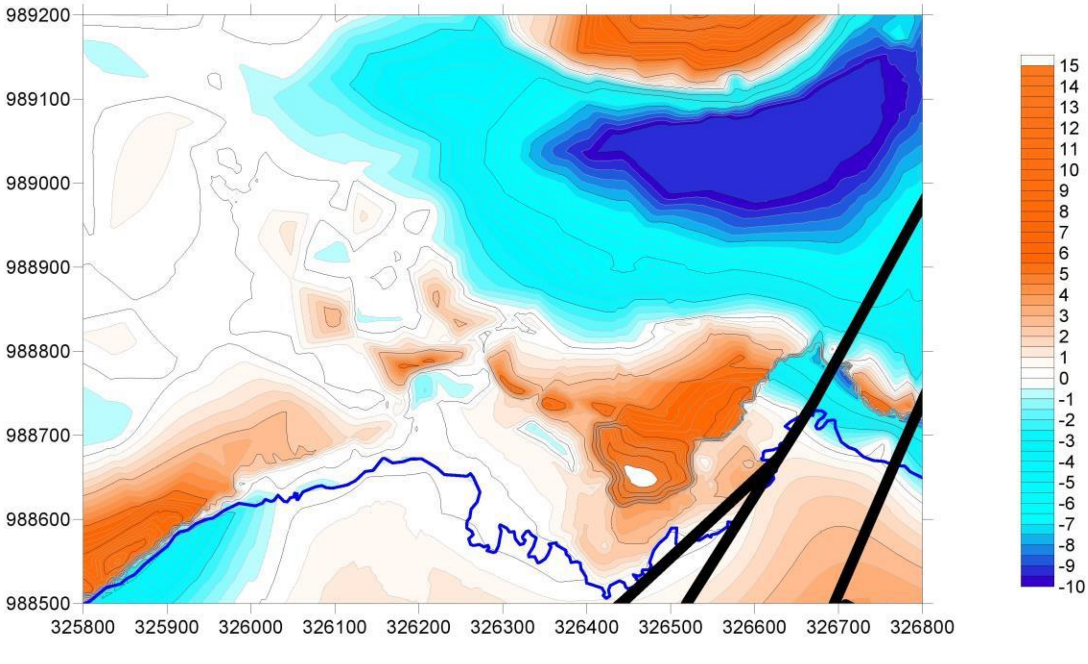


Figure 5 Sheep Skerry altitude minus watertable (black lines show trace of Sheep Skerry faults)

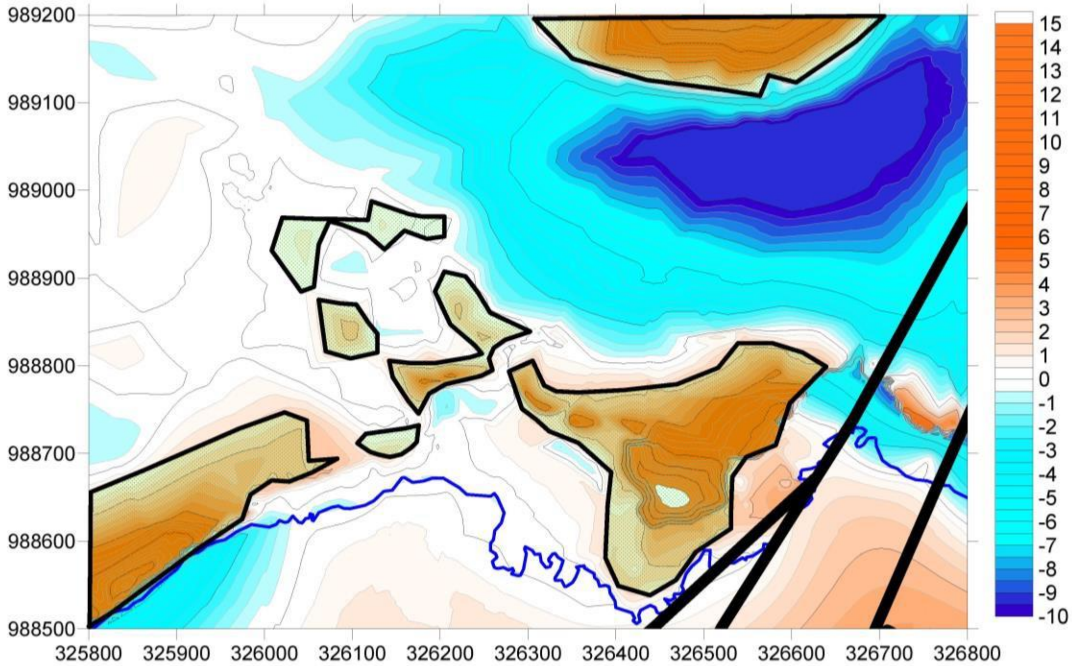


Figure 6 Sheep Skerry altitude minus watertable with black polygons showing zone above watertable

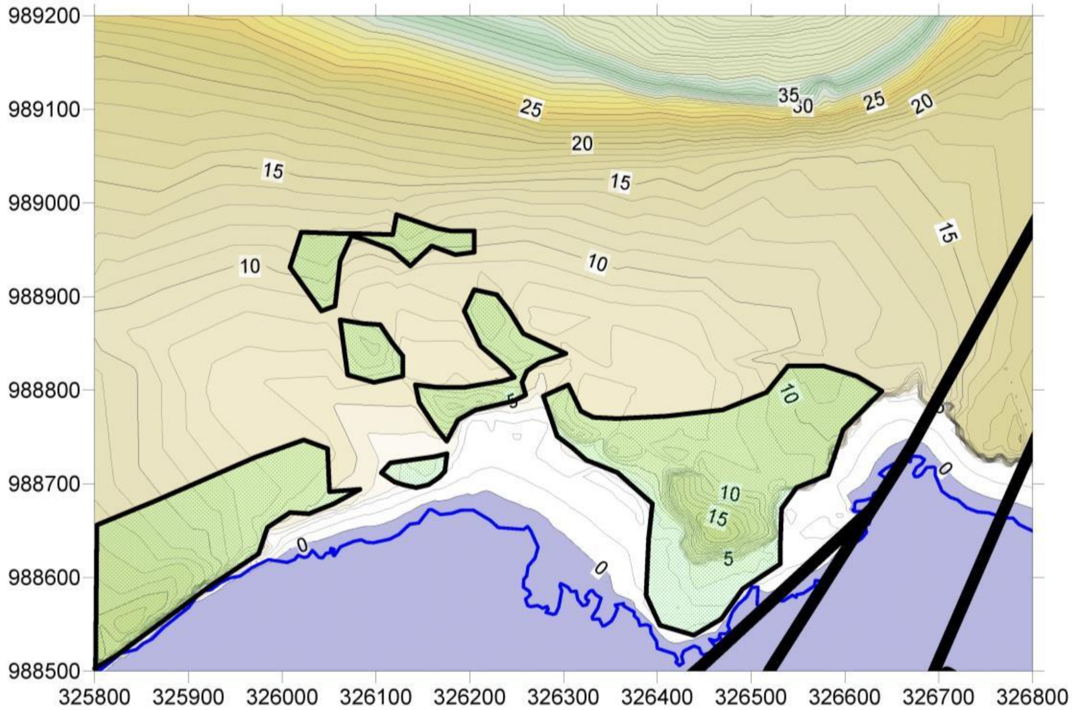


Figure 7 Sheep Skerry altitude with black polygons showing zone above watertable

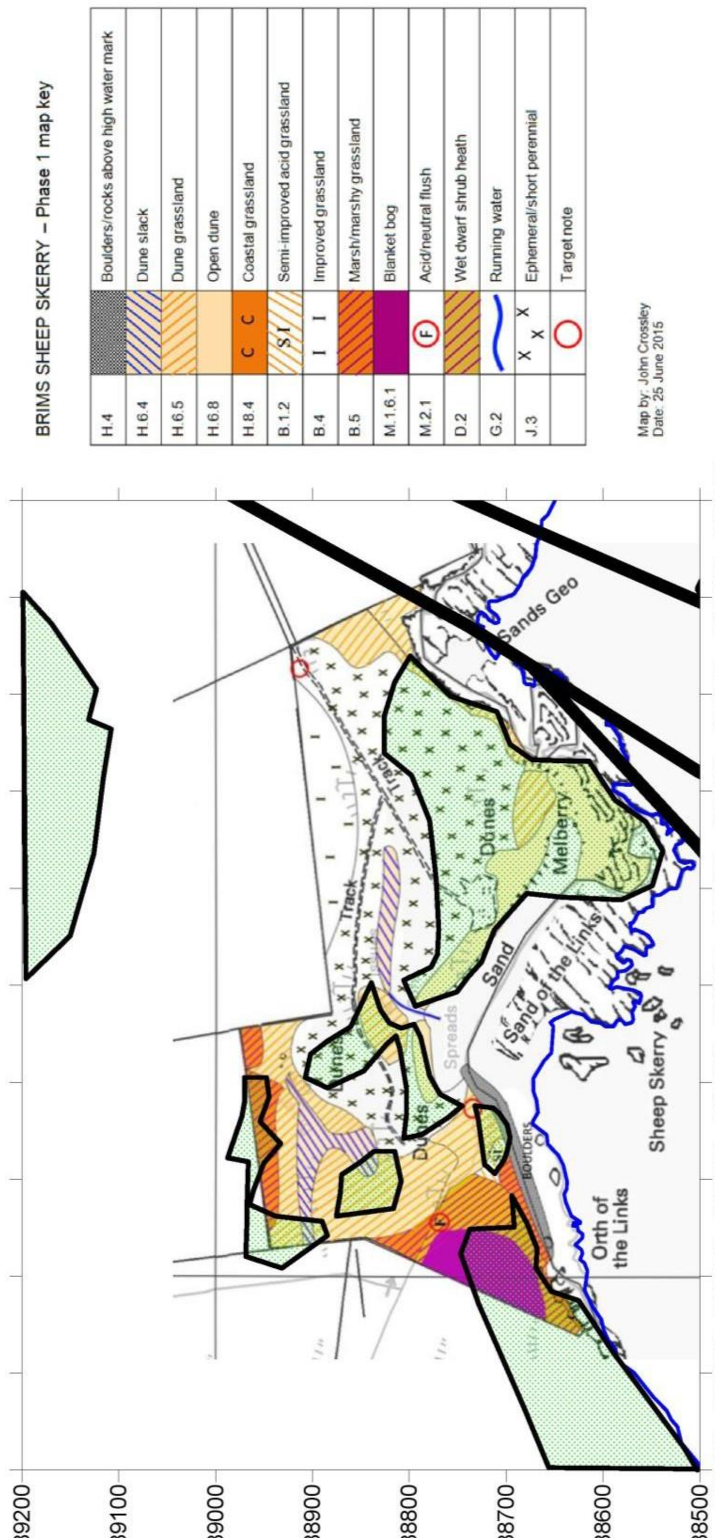


Figure 8 Sheep Skerry Habitat Map (J Crossley - June 2015) areas above watertable black polygons

WORKFLOW METHODOLOGY

Interpretation of habitats and the assessment of wet and boggy ground to be avoided or mitigated in any infrastructure development requires knowledge of the water table in an area of study. In particular one should be able to answer the question "is the water table at or above the local ground level"? The following workflow has been used in this study to ascertain the answer to this question.

1. Altitude (ground level)
    a. Altitude data for Scotland is available without charge from the British Ordnance Survey on a 5 x 5 metre grid. This grid was imported into various GIS applications to be rectified and eventually imported to "Surfer" for final presentation (Figure 3).
2. Water table altitude
    a. Combining the altitude map (item 1 above) with various maps and Google Earth images enables the digitisation of points where the water table intersects the ground surface i.e. spring lines, streams and lochs. These digitised water table elevation data are randomly distributed with spacing on the order of 100 – 500 m in the study area.
    b. The digitised water table points are then interpolated by kriging methods to create a 5 x 5 metre grid (Figure 4) with the same extents as the ground level grid.
3. Grid subtraction
    a. It is now possible to superimpose both grids mathematically and subtract water table altitude from ground level altitude which yields the difference map (Figure 5).

SOILS

The vast majority of lowland West Mainland is covered by soils whose parent materials are greyish brown drifts derived from the middle Devonian flagstones and sandstones. The soils are dominated by poorly drained non-calcareous gleys (compact bluish-grey) accounting for 40% of Orkney and peat covering 20% of the area. 15% of the area is covered by brown soils and a further 12% is peaty gleys. The gleys are generally surface water gleys in which the downward movement of water is hindered.

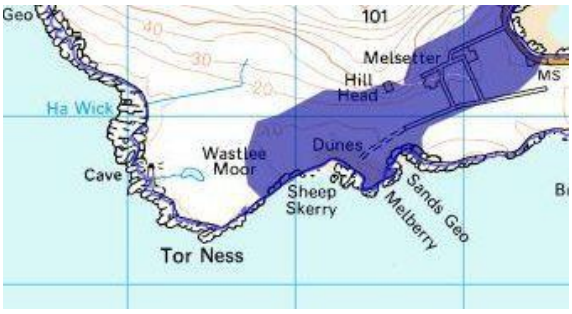


Figure 9 Sheep Skerry gleys soil (blue shading)

At Sheep Skerry and to the north and east underlying the areas of blown sand and sand dune formation the principal soil is the poorly drained surface water gleys (Figure 9) which is consistent with the "altitude minus water table" map (Figure 7) which demonstrates that this whole area lies at or below the water table.

FLOODING

The 1:200 year flood envelope of the SEPA Interactive Flood Map (Figure 10) does not suggest any major areas of flooding within the application boundary. However, resolution of the map does not account for smaller catchments and burns with a catchment area of less than 3 km^2. Therefore, there could potentially be other areas within or near to surface water features which may be at risk of flooding.

Superimposing this map on the detailed 0.5 m contour interval altitude map for the local area at Sheep Skerry (Figure 11) indicates that the region liable to flood is positions below the 3 m contour. Therefore it would be wise to locate infrastructure at least 4m above the present high tide level.

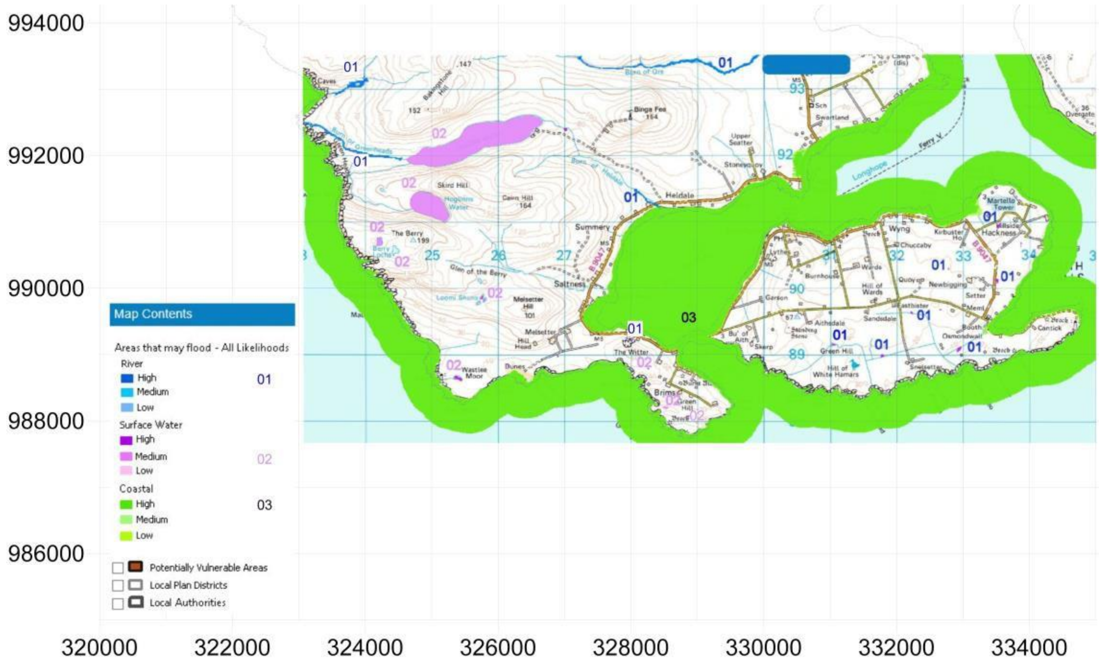


Figure 10 SEPA Flood Map coastal, river and surface flood risk with map contents

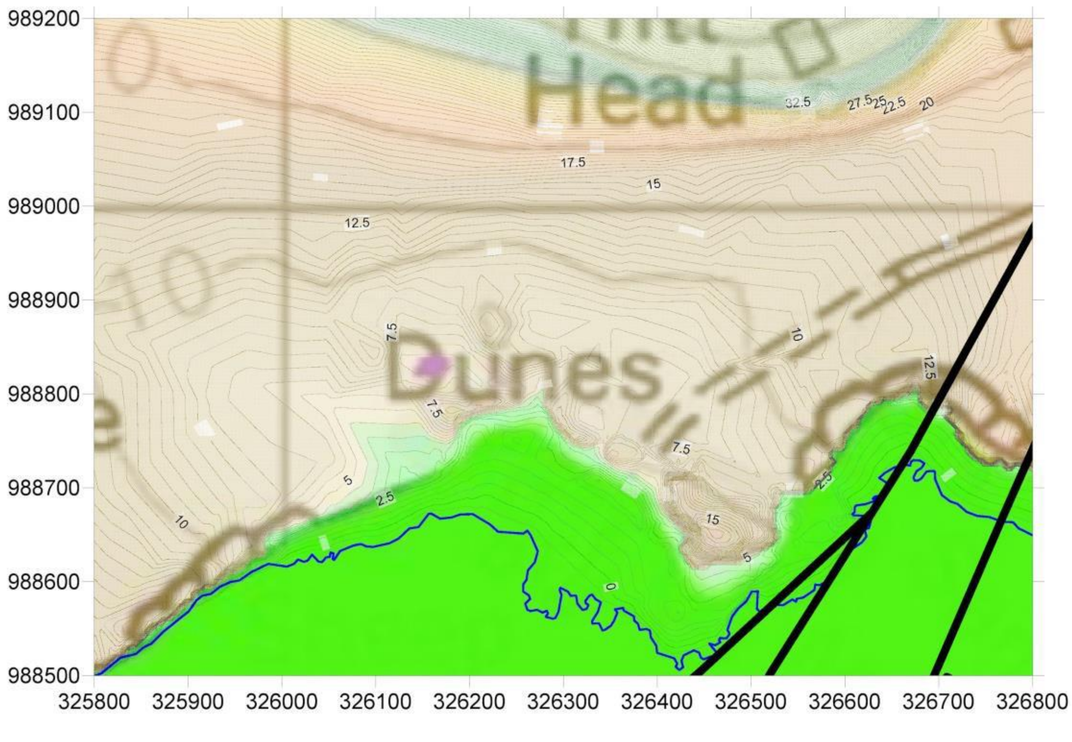


Figure 11 SEPA Flood Map on altitude map (ci =0.5m) flood levels in green

HYDROLOGY DISCUSSION AND CONCLUSIONS

Interpretation of the "altitude minus water table" map (Figure 5) requires the recognition of the reddish areas (warm colours) as representing dry ground while the blues are wet and boggy ground. The water table varies from season to season often on the order of 2 m as represented by the white areas on the map.

On further inspection of the map and in order to enable clearer comparison with the habitats map from Aquatera (Figure 8) the high ground in the area of the Habitat map is identified by black polygons (Figure 6). For comparison these polygons are shown on the altitude map as well (Figure 7) which shows the intuitively obvious conclusion that higher elevations of the dune system are dry.

Unfortunately the lack of sufficient water table control points in this area along with the fact that the dune system has, over many years, been in small-scale commercial/industrial use rendered the correlation poor compared to other recent detailed studies by Aquatera (Brown, 2014; Crossley, 2014).

Nevertheless it is noted that there is broad concordance between the plant communities indicative of wet environments and the spaces between the dry zones (Figure 8). Therefore nothing is indicated within the above hydrogeology study that would contradict the conclusions reached by Crossley (2015), namely:

- Over much of the site the habitats comprising improved grassland, weedy, ephemeral vegetation and modified dune grassland, all much altered from former semi-natural habitats by sand quarrying followed by grazing and eutrophication are of low or negligible ecological importance, but there are some local areas of more importance.
- Much of the central and eastern part of area, with habitats of low or negligible ecological importance, is suitable for development.
- Particular features, notably a dune ridge, a storm beach, peatland habitats and the scarce grass species should be conserved.
- Mitigation can best be achieved by development in the least important habitats and re-instatement if development affects areas of more importance.

STORM BEACH

A very prominent storm beach around 250 m in length extends south-west from the burn mouth. It is about 20 m broad and rises to 5 m above sea level.

The size of the boulders range from 0.50m to 1.00m within the tidal zone up to 2 m at the top of the beach.

Figure 12 Melsetter Hoy storm beach

From the point of view of hazard risk it is important to understand the timing and mobility of this body of rock containing boulders weighing up to 6 tonnes.

WEATHERING AND LICHEN GROWTH

Weathering of exposed rocks provides an indicator of the relative exposure age of the surfaces of blocks. Lichen cover provides additional information about the duration of exposure of rock surfaces. For example, *Verrucaria maura* is characteristic of extremely exposed rock shorelines in the north Atlantic (Fletcher, 2006) and its cover is a useful indicator of the recent stability of rock surfaces subject to frequent spray on cliff faces and clifftop.

Figure 13 Lichen cover indicative of long period with zero movement

Small colonies of *Verrucaria maura* develop on roughened surfaces within the first 10 years of exposure yet older surfaces indicate that a 50–100% cover of *Verrucaria*, with blackening of the rock surface, requires around 70 years. Orange *Caloplaca marina* (orange lichen) quickly colonises relatively sheltered surfaces on cliffs reaching an average of 30 mm in 10 years.

Grey *Lecanora* colonises relatively sheltered surfaces and after 25 years growth reaches a maximum diameter of 38 mm so blocks with thalli of greater diameter on the boulder ridges are regarded as already being stable previously.

Figure 14 Tapered southern end of storm beach showing age profile from the foreground and right-hand side of picture to the lichen covered upper beach left – intertidal and salt splash zone clearly delineated

This suggests that the lichen cover at the back of the beach at Torness indicate that those boulders have not been turned over for many decades. Differences across the boulder beach from more angular blocks on the upper side to more rounded blocks imbricated on one another are common of the intertidal zone. This is quite common on boulder storm beaches - the landward blocks have been eroded in big storms and then thrown high up, so they do not get rounded.

Figure 15 Sandstone Boulders here are Hoy Sandstones and not Eday Sandstones which are orange and yellow in this area

SUBSEA ZONE

In the subsea zone the Google Earth image shows the dark shadow which is thought to be the extension of this Boulder Beach out into the bay where it lies on ripple marked sand. As far as can be surmised from the photographs the sandstone boulders here are Hoy Sandstones rather than Eday Sandstones which are much more orange and yellow in this area. This observation means that the source of the boulders, which cannot be seen in any quantity on the subsea photographic images but can be traced on the Google Earth image could have been moved by longshore drift from the Ha Wick beach to the west of Torness (where similar boulders are observed on the images) or from the cliffs at Torness. We do note that the Geo at the natural arch is filled with similar material.

It has been noted that (Pérez-Alberti *et al.,* 2012) some boulder detachment and movement occurs today during storms, when significant deep water wave heights exceed 8 to 10 m.

Despite some abrasion of the shore platforms, the primary effect of large boulder accumulations in Spain is protective.

This study is clearly pertinent to knowledge of the master boulder beach but at this time without further detailed study we cannot be more conclusive.

Nevertheless we can say for example, there is a predominance of boulders oriented towards the south and south-east, corresponding to the direction of the storm waves. Imbrication, with slopes typically between 30° and 70°, is evident in many places the steepest imbrications are at the high tidal level.

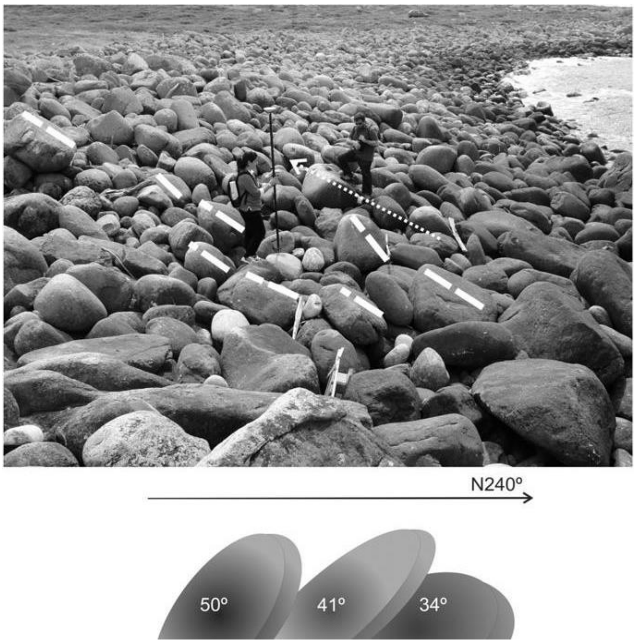


Figure 16 GPS surveying of the boulder beach over a steeply sloping shore platform at Laxe Brava on the Barbanza Peninsula. The arrowed line shows the orientation of boulder imbrications and the thicker dashed lines individual boulder gradients. Although most large boulders are apparently immobile there are some smaller boulders with abraded, unweathered surfaces and impact scars on larger boulders in the foreground.

CONCLUSIONS

The main conclusions of the paper (Pérez-Alberti *et al.,* 2012) which we can ascribe to the Melsetter storm beach are:

(1) Large boulders to megaclasts are being moved across the shore platforms by large storm waves, to elevations extending well above the present high tidal level.

(2) These boulders play an important erosional, and probably more importantly, protective role in the evolution of the shore platforms.

(3) Sediments in transport-limited environments play an important role in the development of shore platforms.

(4) The relationship between sediment grain size and equilibrium slope, the gradient of shore platforms tends to increase with the coarseness of the sediment that covers them.

(5) The Melsetter Boulder Beach formed a long time ago with present movement restricted to rearrangement of the intertidal and subtitle rocks during major storm surges. It is not expected that this beach will prove a hazard to the cable landing as it is considered to be currently stable.

GEOLOGY OF THE SHEEP SKERRY CABLE LANDING

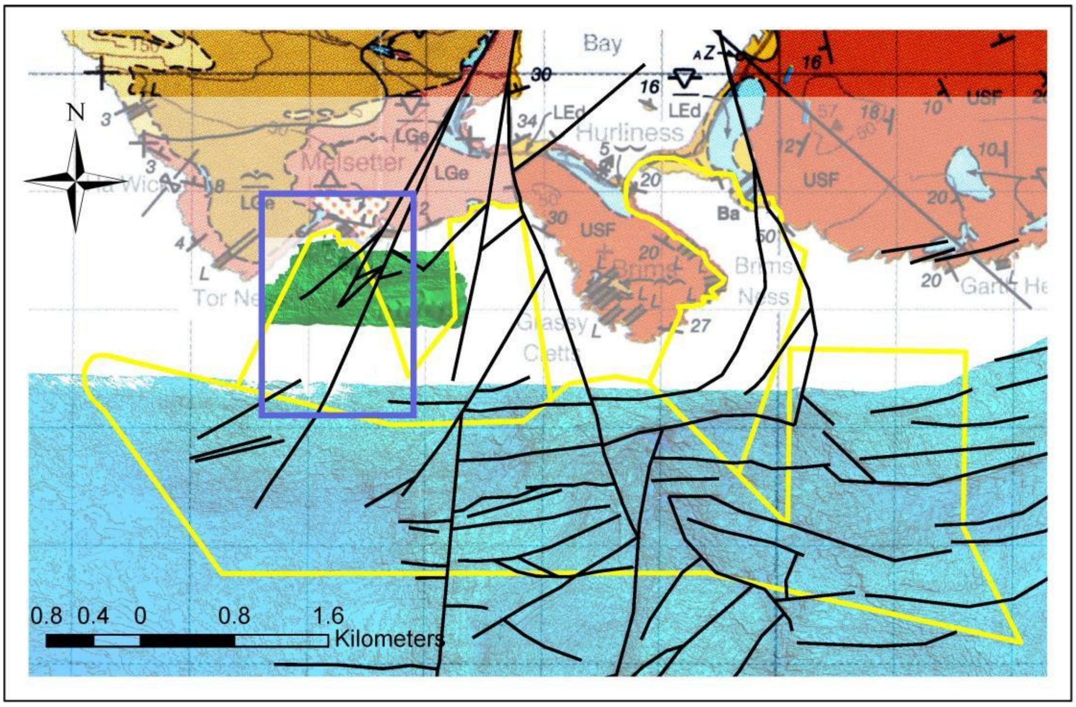


Figure 17 Sheep Skerry Local Geology - Base Map 1 100 000 Orkney Islands Solid and Drift Geology - blue rectangle area of study

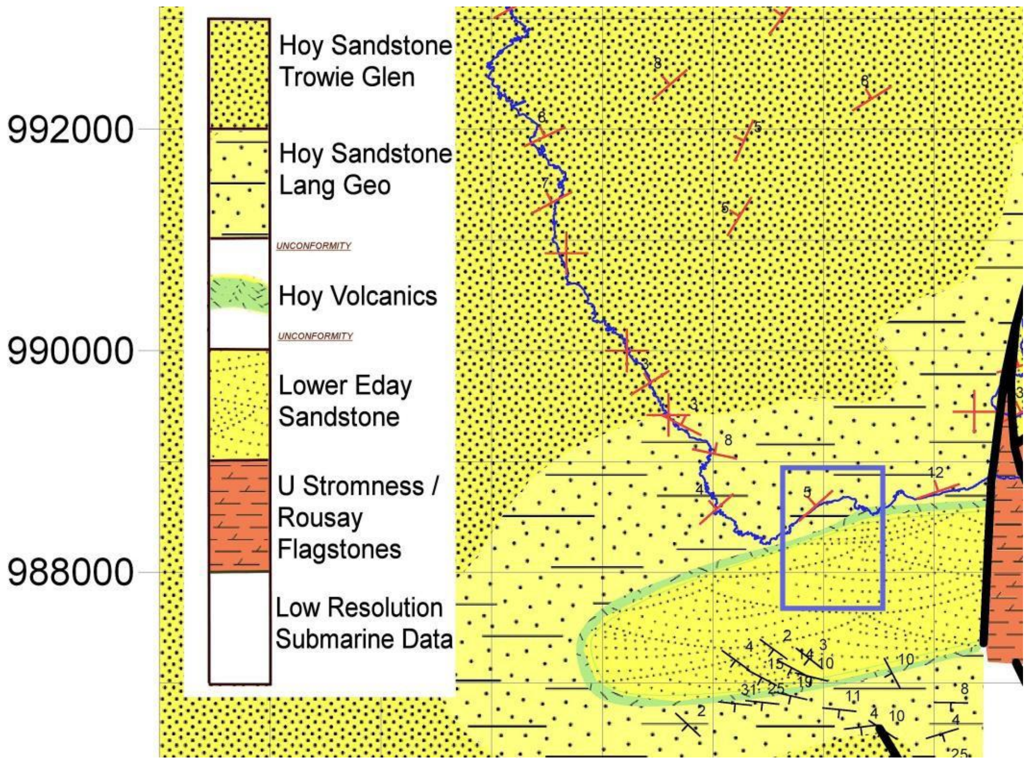


Figure 18 Draft Interpreted Geology Map (from Brown (2015) blue rectangle is Sheep Skerry Area of Study New data on the faults from the MBES serve to make more sense of the geology (Figure 20)

INTERPRETATION OF THE NEW DATA

A new Multibeam Echosounder (MBES) survey over the Sheep Skerry Cable Landing Corridor (Aquatera, 2015[2]) produced some interesting features which can be geologically interpreted. This gives a much greater understanding of the area. In particular the faulting because it connects these new faults to the previous survey faults. In the following pages a number of images (Figures 19 to 26) are presented to show the train of thought and how the interpretation has come about.

Concurrent with the MBES survey a photographic and video survey (Aquatera, 2015[1]) was conducted which yielded information on the benthic fauna and the physical condition i.e. sand or rocks noted in the subsurface. This information was also included within this current survey.

In the draft geological map (Figure 18) it can be seen that the main rock types to be found in the Sheep Skerry cable corridor study area are from bottom to top – upper Eday Sandstone; Hoy Volcanic sequence; and the overlying Lyra Geo Member of the Hoy Sandstone. The reinterpretation from this new data does not change the broader understanding but does give much more spatial confidence in the rock distribution.

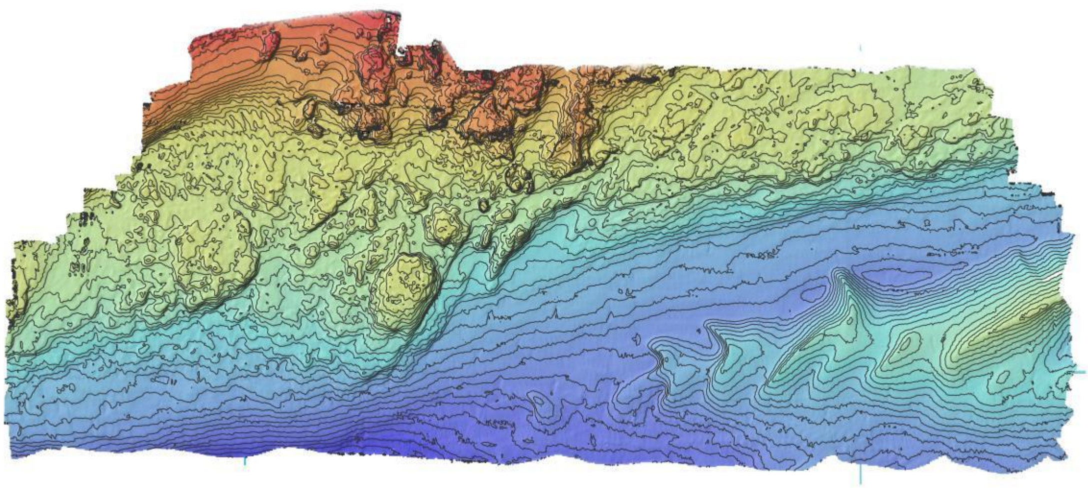


Figure 19 Brims New Survey Area un-interpreted

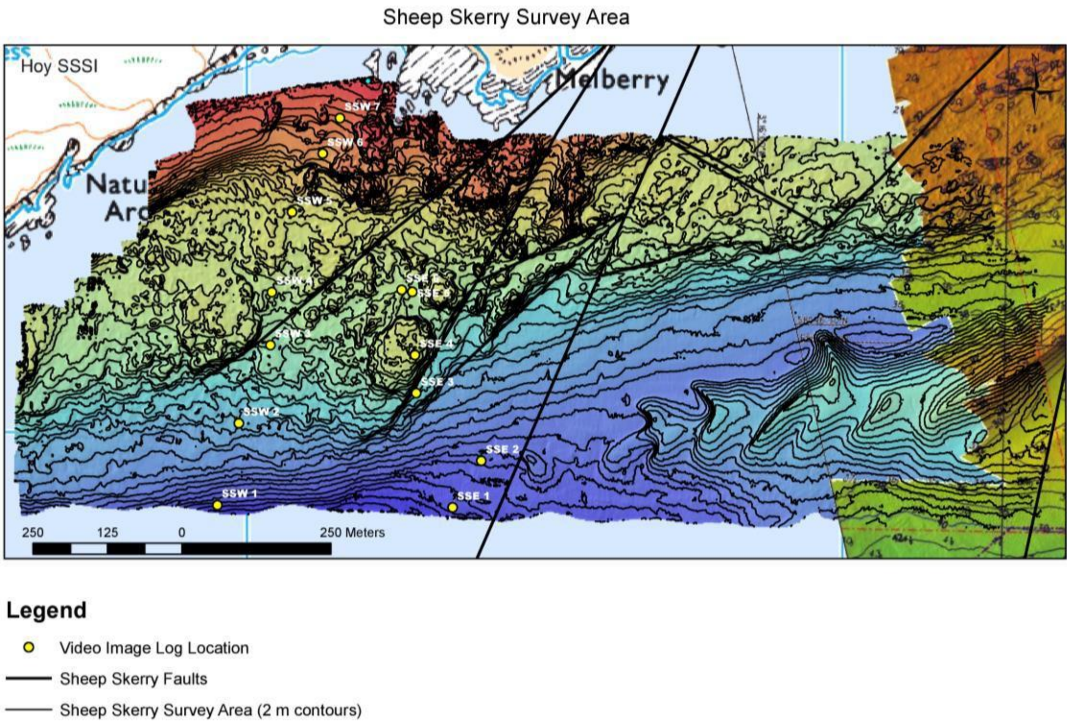


Figure 20 Sheep Skerry Survey Area first pass tracing the obvious larger faults as linear features

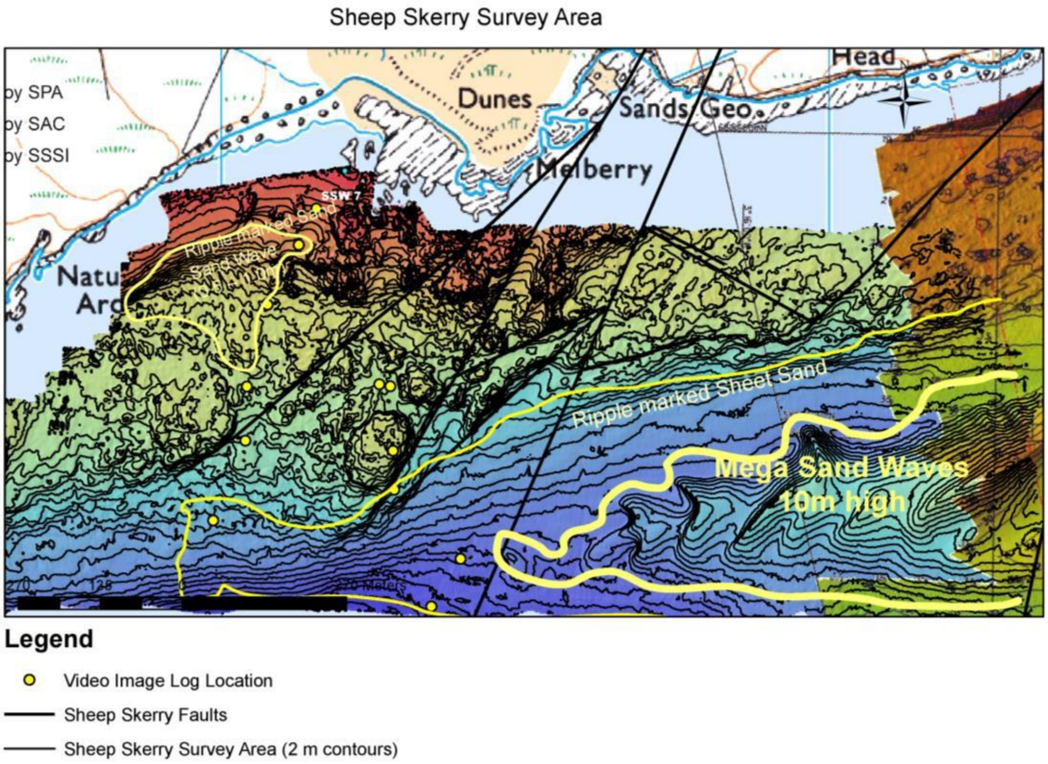


Figure 21 Sheep Skerry Survey Area first pass tracing the mobile sand features which range from 10 m high mega sand waves in the south-east through 1 m high sand waves and in the shallow water Normal ripple marked sand. Over the rest of the study area the sea floor sand cover is very thin occurring between boulders and rocks.

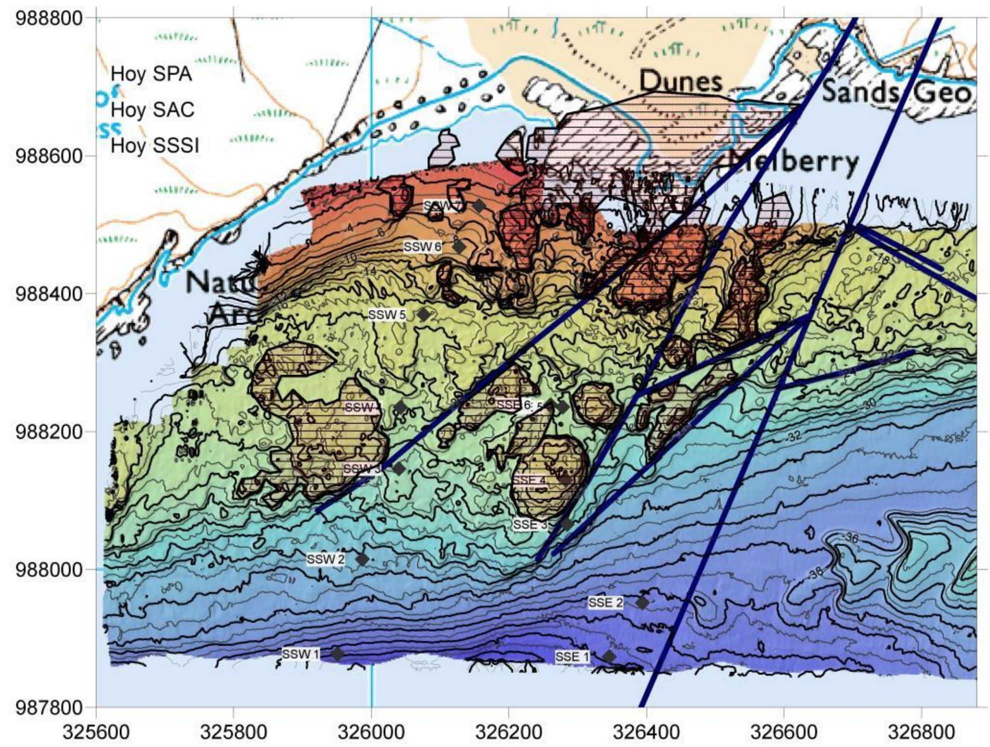


Figure 22 2015-08-11 Sheep Skerry igneous rocks topography and rugosity show the volcanics

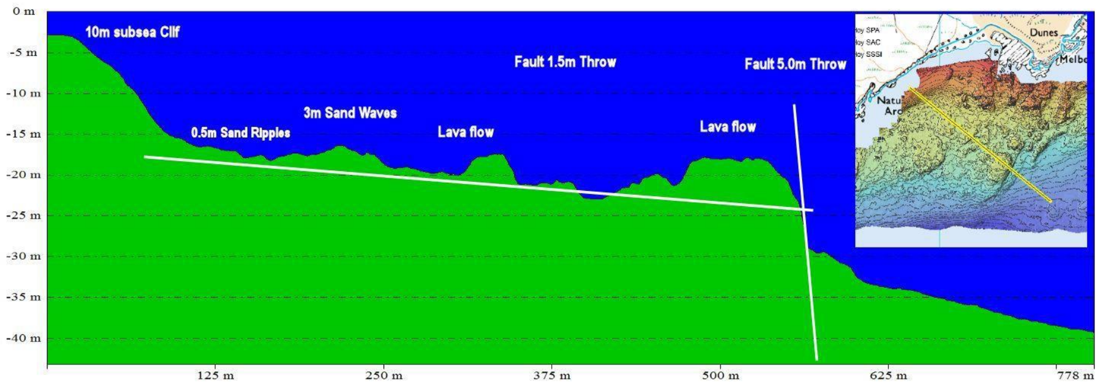


Figure 23 Cross section showing outcrop of Volcanic Rocks

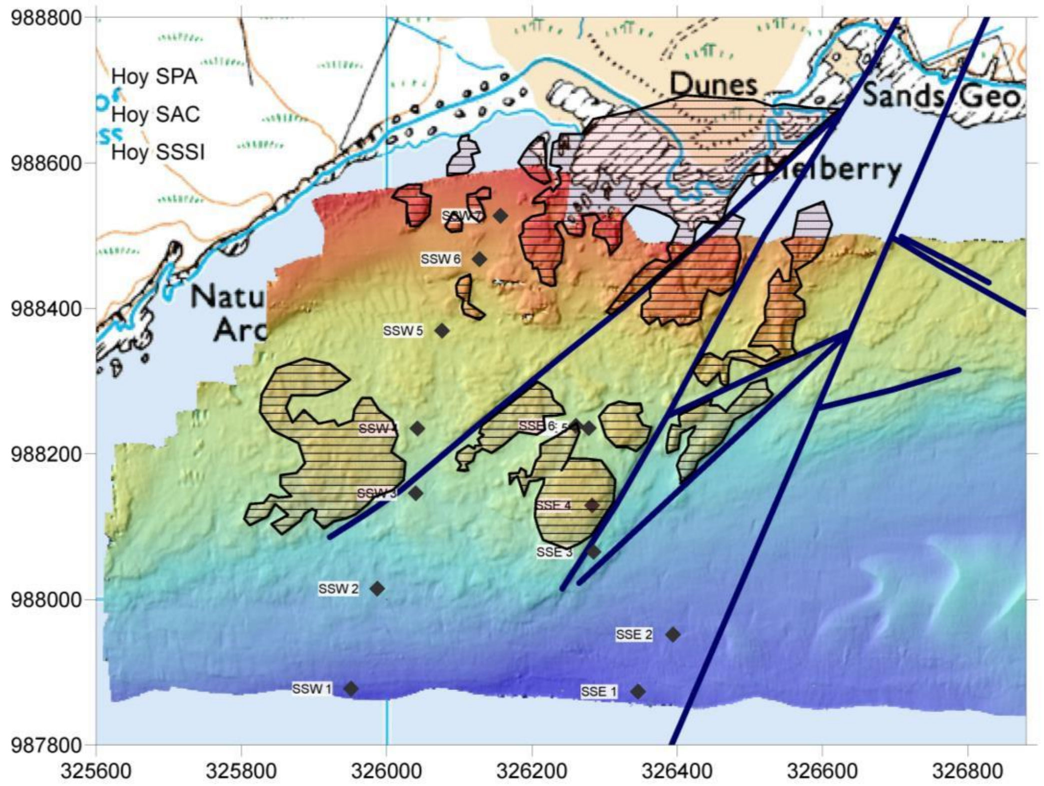


Figure 24 Sheep Skerry showing outcrop of lava

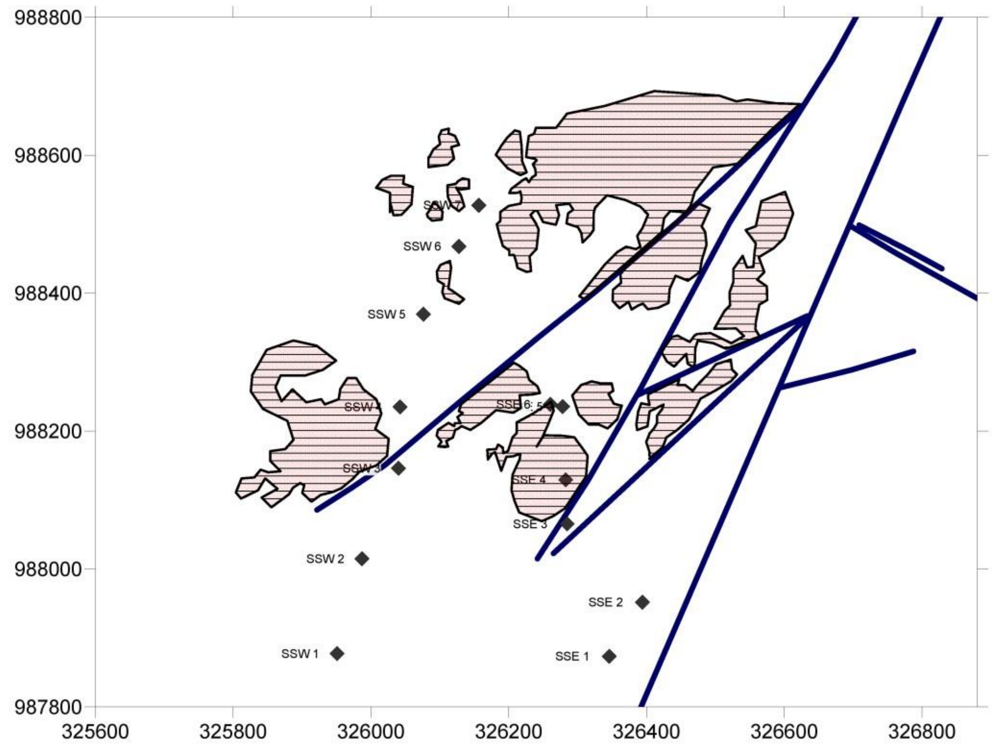


Figure 25 Sheep Skerry igneous rocks with the video image log locations

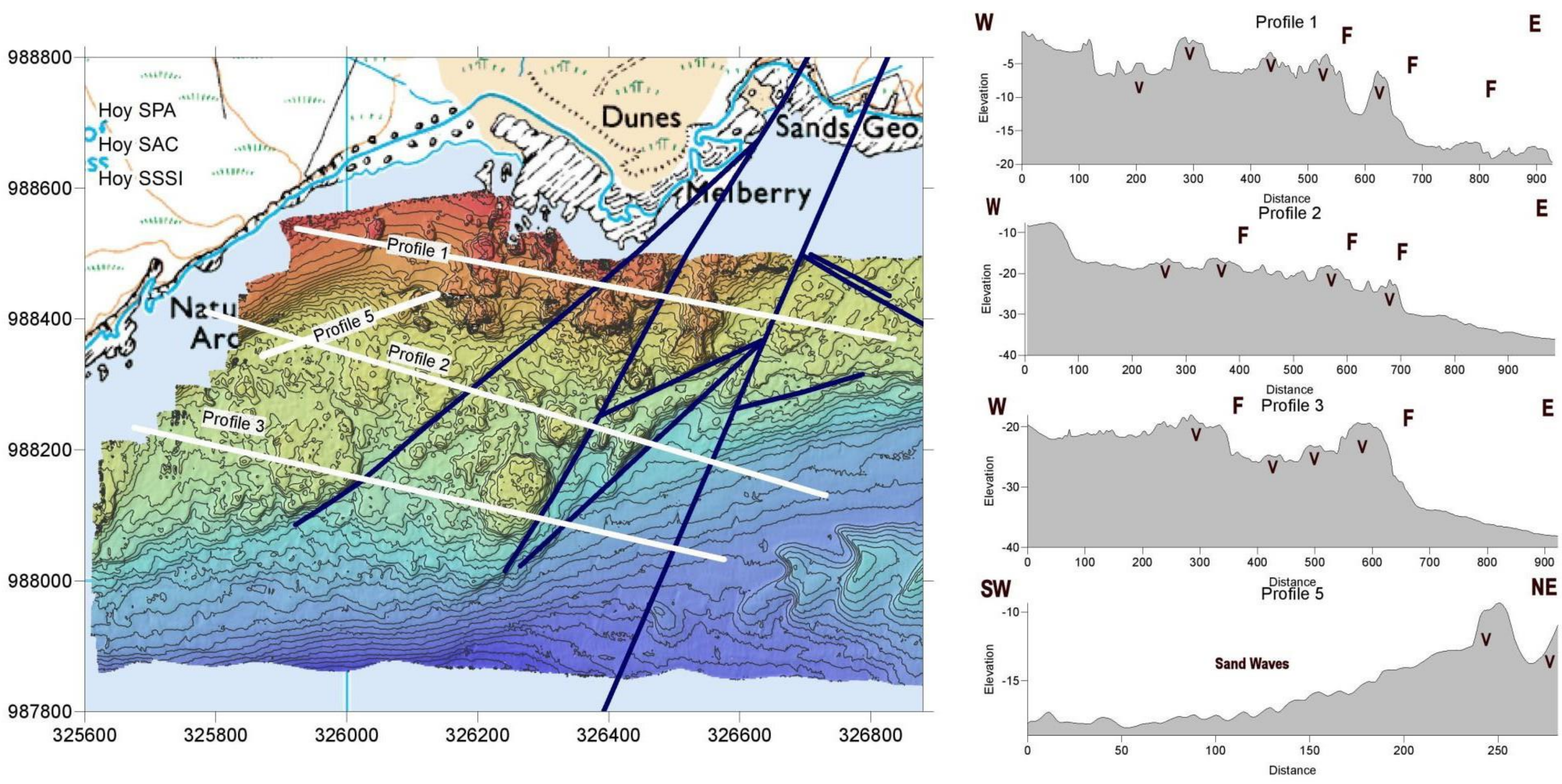


Figure 26 Sheep Skerry Profiles of the Sea Bed - V = Volcanic Rock Pillar F = Fault (NOTE vertical and horizontal scales on Profiles are different)

DETERMINATION

It is clear from the above figures that the MBES survey at Sheep Skerry gives strong indications of the distribution of the volcanic rocks in this area. Although none of the rock pillars have been sampled directly we can see that from the Google Earth image a direct link between the mapped igneous rock structures and the nearshore subsea rocks linking directly to the Melberry onshore outcrop (Figure 27).

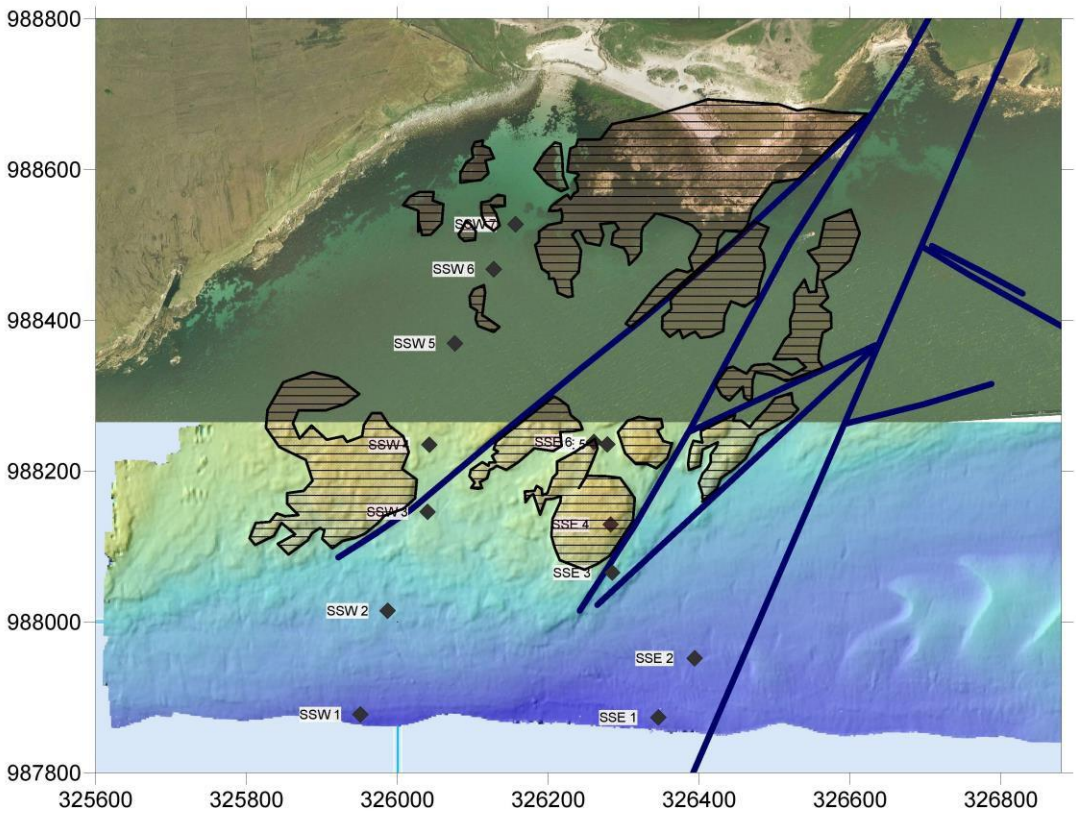


Figure 27 Offshore – onshore linking of the rugose outcrops indicating that they are in all probability igneous in nature

NEW GEOLOGY MAP

The original draft geology map (Figure 18) did not have sufficient information to properly and confidently map the area from Sheep Skerry Melsetter Shore. The new faults locations enable us to terminate the volcanics outcrop at Melberry where previously they were stretching along the Melsetter Shore.

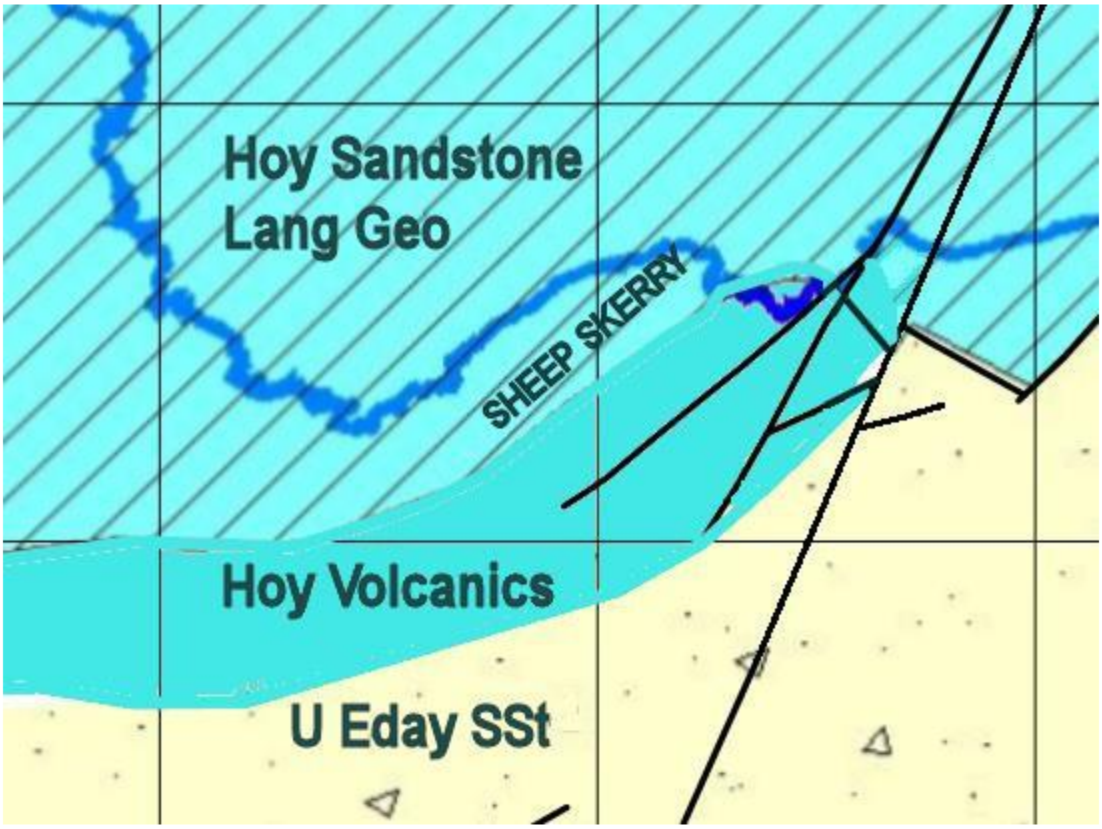


Figure 28 New geology map Sheep Skerry

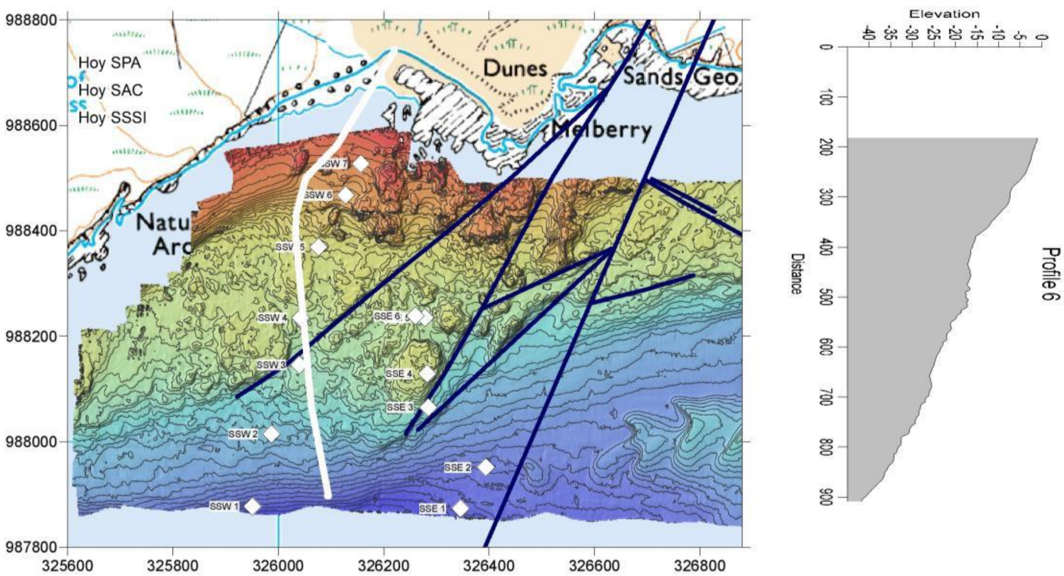
The British Geological Survey in the memoir (Wilson et al., 1935) state that the lava, of which about 12 m are seen, is highly vesicular and the amygdales are filled in with calcite. It is also of a distinctly ropey nature and presents all the features associated with the top of a lava flow. The western contact is somewhat compromised by the presence of three small trap Dykes. Nevertheless given the subsea outcrops noted in this study it is that the western margin directly overlain by the Hoy Sandstones.

RECOMMENDED LANDFALL ROUTE

This study has examined the rugosity and makeup of the sea floor in the Sheep Skerry potential landfall area and has determined that a suitable route for cable trenching is to be found here that will satisfy all the criteria mentioned at the beginning of this report (Page 8).

A number of potential routes from the burn mouth to the area where the tidal turbines will be located were considered in this current study and from the evidence available a number of possible routes exist close by each other. The final one should be selected by fine tuning the paths at the time of construction. A median path has been selected (Figure 29) which follows a relatively gentle path, 2.5° average, from 0 to 45 m water depth.

This route is recommended for the western cable landing whereas the eastern cable landing, as recommended in the previous report should be through Aith Hope to the top end of the bay.



Video Image Log Western Track

Image	Easting	Northing	depth m	Descriptive notes
SSW 1	483682	6514711	47	Boulders and rock outcrops interspersed with sand, encrusting biota and faunal turf on rock surfaces
SSW 2	483716	6514849	37	Mixed sediment and occasional rock outcrops, encrusting biota and faunal turf on rock surfaces
SSW 3	483767	6514981	30	Mixed sediment and occasional rock outcrops, encrusting biota and faunal turf on rock surfaces
SSW 4	483768	6515070	25	Rocky seabed with areas of sand veneer, kelp and other seaweeds, encrusting biota and faunal turf on rock surfaces
SSW 5	483800	6515205	22	Rippled sandy sediment with occasional rock outcrops and boulders
SSW 6	483850	6515304	12	Rippled sandy sediment with large kelp covered boulder
SSW 7	483878	6515364	9	Rippled sandy sediment

Figure 29 Video-Image Log western track preferred route.

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