Geophysical Survey of the Loch of Stenness, Orkney

Richard Bates[1], Martin Bates[2], Sue Dawson[3], Caroline Wickham-Jones[4]

Summary

The Loch of Stenness, Orkney, is located to the west of the World Heritage sites of the Ring of Brodgar and Stones of Stenness. The loch was targeted for investigation as a potential drowned palaeo-landscape based on preliminary results from a series of sediment cores acquired in 2008 that indicated inundation by the sea to have occurred at approximately 2000 – 1500 BC thus indicating the possibility of an archaeological footprint relating to sites and monuments on the present seafloor. In addition, photographic evidence suggested that certain loch shore earthwork sites might continue into the water.

The archaeological survey first reviewed aerial photographic records, satellite images, historic maps, and local knowledge followed by a visual inspection of the shoreline to design a detailed land and marine geophysical archaeological survey. The land geophysical survey was targeted on the Peninsula of Unstan where an incomplete ring or circular feature was identified extending into the loch. Electromagnetic and electrical imaging geophysics were used to map the feature and to determine its depth extent. The imaging showed a ground disturbance associated with the feature however this did not appear to be deeply founded with its base above the bedrock outcrop on the west side of the peninsula. No evidence was found offshore.

A multibeam sonar survey was conducted in September 2011 and February 2012. Both surveys were compromised by poor weather conditions (summer work is impractical due to nesting birds), however a number of useful results were acquired. The area immediately to the west of the Ring of Brodgar showed a large (100m diameter) circular structure. To the north of the loch at Voy small (<30m) diameter submerged mounds were mapped at 50-60m from the present shoreline. To the west side of the loch a long (50x20m,) smooth sided, 2.5m high mound occurs in 4m water depth approximately 200m from the shore. Future work will include diving and further survey to help interpret these features.

[1] *Scottish Oceans Institute, University of St Andrews*
[2] *Department of Archaeology, University of Wales Trinity St David*
[3] *Department of Geography, University of Dundee*
[4] *Department of Archaeology, University of Aberdeen*

Background
This work is part of a larger project using Orkney as a case study by which to develop methods to understand the submerged landscapes of the UK and in particular northern Doggerland.

Previous research in Orkney has demonstrated considerable sea-level rise through the Holocene, coinciding with the period of human settlement here (Dawson et al. in prep). Relative sea-level has risen from c. -30m c. 11,000 BP to reach present heights c. 3100 BP meaning that significant archaeological sites may have been submerged (Bates et al in prep).

The Loch of Stenness provides the background to the World Heritage Sites of Neolithic Orkney, including the Ring of Brodgar and Stones of Stenness, as well as the newly discovered ceremonial site of Ness of Brodgar. Sediment analysis suggests that when work started on the monuments of Neolithic Orkney such as Ness of Brodgar the Loch of Stenness was not a marine loch as today, but rather that it encompassed lower water levels with stands of open fresh water and reed beds, only becoming fully marine around 1500 BC (Dawson et al in prep).

In addition, RCAHMS records indicate a number of earthwork monuments around the loch, some of which, such as the promontory forts at Unstan and Nether Bigging in the south west, have earthworks extending into the loch. In the winter of 2010 aerial photographs taken by a local amateur archaeologist provided possible visual support for this theory (Figure 1).

Figure 1: Aerial view of the earthwork at the Point of Onstan, illustrating possible extension into the loch (Photo: Andrew Appleby).

Aims
The aim of the present project is as follows:

- To create a seamless palaeo-landscape model of the Loch of Stenness and its immediate surroundings against which Holocene landscape change and archaeology, including World Heritage Orkney, can be tied

Archaeological awareness of the changing landscape of Neolithic Orkney is undeveloped so the results of the project are highly significant.

Survey Objectives
The project was designed to further understanding of the drowned palaeo-landscape submerged by marine inundation at approximately 2000 – 1500 BC.

Four objectives were identified to meet this aim.

- To provide detail of landscape change and the inundation of the loch by marine waters
- To record features of palaeo-geographic significance to aid landscape reconstruction
- To record upstanding, archaeological features on the loch bed
- To provide a more detailed interpretation of the earthwork sites that border the loch shores including in particular Point of Onstan and Nether Bigging

Each of the objectives was addressed using different appropriate geophysical methods for terrestrial and marine investigation following careful analysis of background information from satellite imagery, air photography, historic maps and site walk-overs. The geophysical surveys were conducted during two field seasons in September 2011 and February 2012.

Geophysics Methods
Stenness Loch Geophysics
The loch survey had three primary objectives:

- to determine the general bathymetry in particular close to where previous cores had been taken for palaeo-environmental reconstruction
- to map upstanding features such as large individual stones
- to map accumulations of stones.

For this survey a very high resolution multibeam type swath sonar was chosen as the most appropriate geophysical survey instrument.

High resolution bathymetric surveys are typically acquired using techniques that allow full seafloor data coverage rather than by using digital information from single beam sonar (Bates et al. 2001). The swath sonar relies on making acoustic measurements using hull-mounted acoustic transducers to measure a swath of seafloor on either side of the survey vessel. The swath bathymetry system is an extension of high-resolution digital sidescan that not only enables a picture of the seafloor to be produced across a swath sampled by the transducers along the boat track (known as the backscatter or amplitude map), but also a measure of the bathymetry across the swath through the use of multiple transducers. Since the transducers are hull mounted with the addition of a motion reference unit and dGPS it is possible to locate features on the seafloor with a high degree of accuracy (Bates and Oakley 2004). For the Stenness survey the following swath bathymetry system was used:

> ***Swath system*** – SEA SwathPlus High Frequency System. The chosen sonar system has a central frequency of 468kHz and a ping rate of up to 30 pings per second giving a potential footprint of less than 5cm at standard survey speeds. Data was acquired with this system using SwathPlus acquisition software. SwathPlus was also used for the initial stages of data processing.
>
> ***Motion Reference*** – TSSDMS205. This system was mounted immediately above the sonar transducer heads to ensure that no lever arm motions are encountered that could degrade the final bathymetry solution.
>
> ***Sound Velocity*** – Applied Microsystems MicroSV sound velocity probe mounted at the sonar head to record changes in velocity due to mixing of different water (and thus potential salinity changes) in the enclosed waters of the bays.
>
> ***Positioning –*** real time positioning (RTK) was provided by a Topcon Hiper RTK dGPS solution with base relays at 1Hz.
>
> ***ZegoBoat –*** the swath bathymetry system was fitted to a shallow water survey boat (Figure 2) for easy deployment in the loch with the advantage of being able to survey in water depths of less than 1m.

Figure 2: Preparing to survey, Loch of Stenness, Orkney.

Terrestrial Geophysics
Terrestrial geophysics was focussed on the existing sites at Point of Onstan and Nether Bigging. Two types of geophysical methods were chosen for the Point of Onstan. The methods, namely electromagnetic conductivity survey and electrical resistivity imaging, were chosen based on the primary survey objectives being a clarification of the nature of earthworks. Both methods measure changes in ground conductivity, or its inverse, ground resistivity and thus can be used to infer different types of ground condition such as changes in soil type,

changes in rock type and changes in moisture content. Both methods are appropriate also to determine where these natural ground conditions have been altered by human construction.

Electromagnetic Surface Conductivity - Electromagnetic surface conductivity measurements were made using a Geonics EM38 Ground Conductivity meter (figure 3). This instrument uses a small electrical coil to generate an electromagnetic wave that propagates within the ground. When the wave is distorted by changes in ground conditions the amount of distortion is measured and related to the ground conductivity. The equipment is operated together with a dGPS with measurements recorded 5 times per second. Surveys are conducted by making measurements along line profiles or transects separated by 2-3m. The results are digitally recorded in the field using a handheld computer and are subsequently manipulated using the programme ArcGIS to extrapolate maps of ground conductivity.

Figure 3: Geophysics work at the Point of Onstan.

Electrical Resistivity Imaging - Electrical resistivity imaging uses combinations of electrodes to directly impart an electrical field to the Earth. The electrodes are spaced along a line such that the results from the survey can be interpreted using a 2D cross-sectional model of the Earth along the line. For this survey an ABEM Terrameter was used with 80 electrodes spaced at 0.5m to measure resistivity sections across the site to a depth of 10m. Three sections were made at 90degree to the main ditch feature in order to ensure maximum possible discrimination of the feature with respect to background geology (Figure 4).

Figure 4: Line locations at the Point of Onstan

Results: Stenness Loch

Survey of the loch was only possible outside of bird breeding season and so, after preliminary work in June 2011, surveys were first conducted in September 2011 with a follow-up campaign in February 2012. Due to the size of the loch, and the consequential open conditions at the centre, it was decided that the focus of the geophysical survey would initially target areas closer to shore at locations where archaeology had previously been identified. The initial success of this strategy was continued throughout the marine mapping.

Five main areas were targeted with a number of cross-loch profiles acquired.

- Brodgar – south and west of the Ring of Brodgar
- Stenness – west of the Stones of Stenness
- Unstan – offshore around the Point of Onstan
- Seatter (West coast) – into an area on the far west coast of the loch
- Voy – an area near the previously reported crannog sites

These areas are shown on Figure 5 and discussed in further detail below. At each area, the geophysical lines were surveyed as close to shore as the draft of the vessel would permit and as far offshore to map the transition from upstanding features and rock seafloor into the soft, uniform muds and sands.

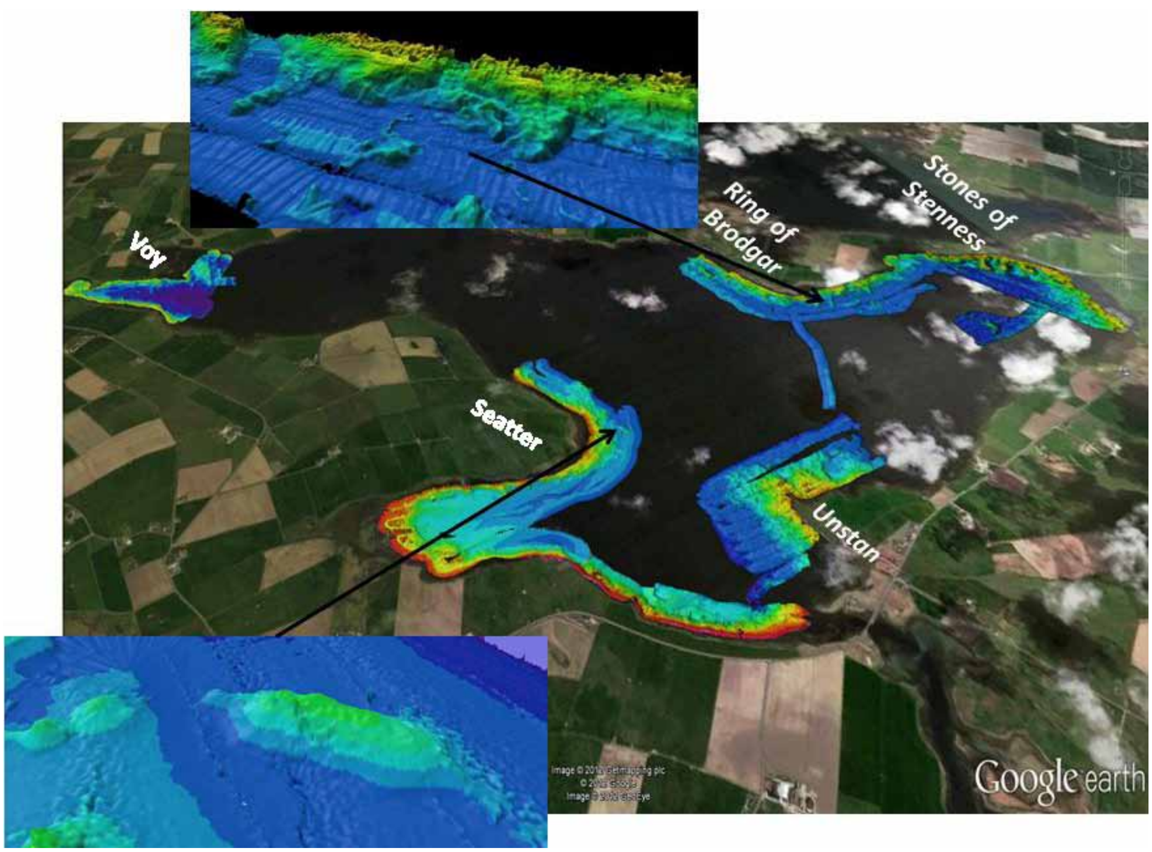


Figure 5: Loch of Stenness with main areas of survey identified

Brodgar

The data acquired to the south and west of the Ring of Brodgar and the Ness of Brodgar sites showed a rugged seafloor topography with skerries extending over 100m into the loch. A number of discrete and isolated low mounds were mapped and interpreted to be stone covered on the backscatter images. At a location due south of the Ring of Brodgar an arcuate to circular depression or ditch and low rise was mapped. The approximate diameter of this was 100m as shown in figure 6.

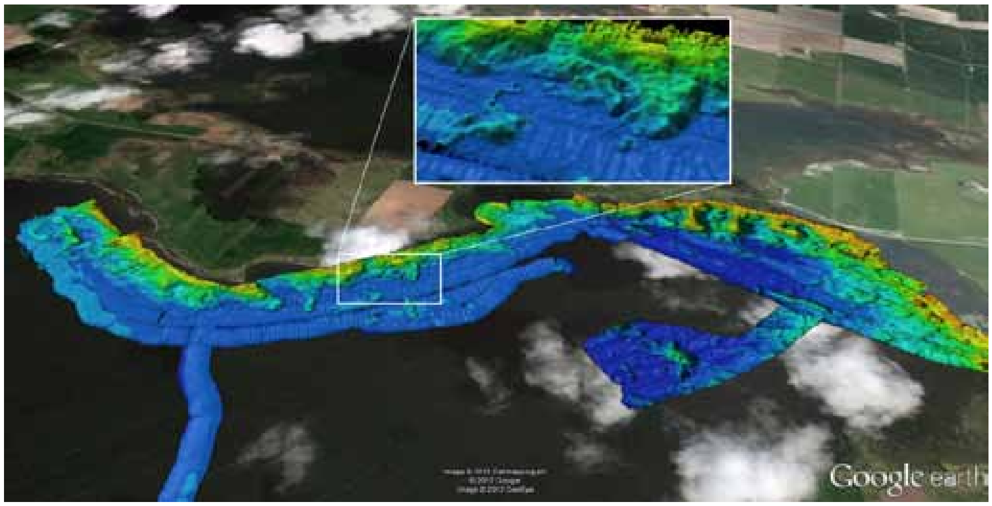


Figure 6: Brodgar showing circular feature

Stenness

To the west of the Stones of Stenness very shallow sea floor extends offshore for approximately 300m (figure 7). This area contains three distinct ridges extending westwards from the shore with the most northerly ending in a raised platform area. There are a number of discrete upstanding features on the seafloor, generally less than 2m in size. These are likely mostly isolated rocks that will require further mapping and ground truthing to establish their significance. To the west near the centre of this bay a single isolated mound approximately 50m long and 40m wide was mapped. The mound appears to be covered with small broken stones. This area would merit further ground truth investigation by survey and diving.

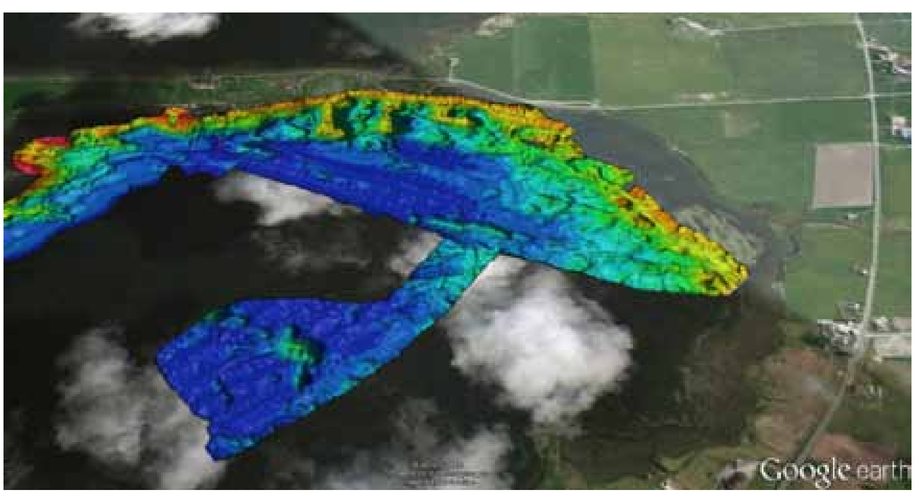


Figure 7: Area offshore the Standing Stones of Stenness and Ness of Brodgar.

Unstan

The area immediately offshore from the Point of Onstan shows shallow skerries extending for approximately 100m (figure 8). The skerries have a clear structural grain that is oriented north-south. The natural rock surface showed no indentation or excavation at either place where the onshore curved ditch meets the shoreline.

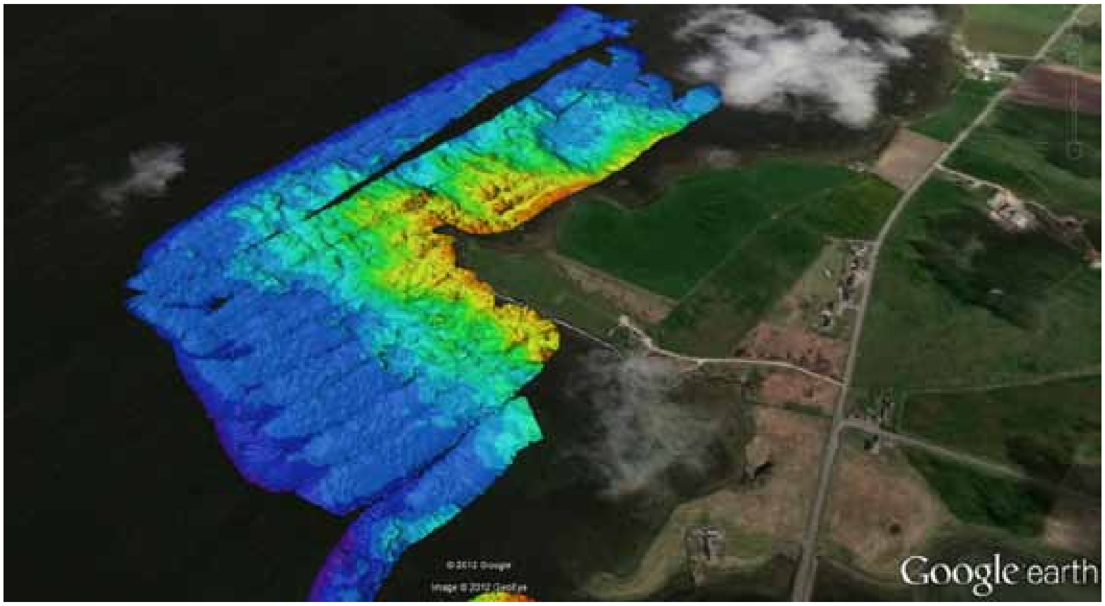


Figure 8: Point of Onstan

To the southwest of the Point of Onstan, on the far side of the Brig o'Waithe a number of potential features are visible along the shore in Google Earth and several of these can be seen in the bathymetry (figure 9). At the southern end is a striking circular feature, resembling a sharply sided mound and with some suggestion of an arcuate structure reaching towards the shore. To the north, a broader, gentler mound is defined both visually and in the bathymetry. Features along this shore may be related to the briefly active seaplane station based in Stenness village during World War I, but are of interest nonetheless.

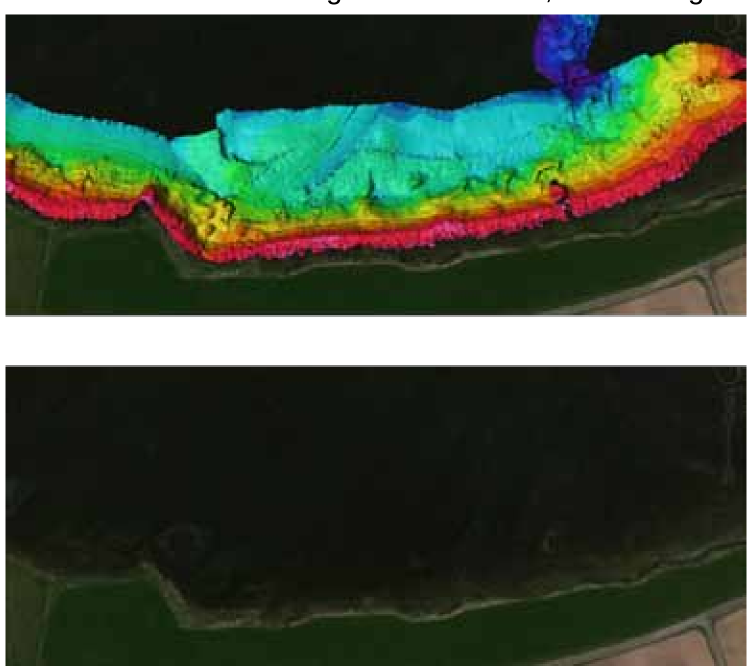


Figure 9: Loch bed to the west of Stenness and Point of Onstan

Seatter

This small bay on the west side of the loch shallows to a sandy bay in the far west and is ringed by rock skerries on the north and south shores (figure 10). A number of rock skerries extend from the shore with two in particular terminating in low mounds approximately 80m from the shore. The natural rock skerries show a structural trend oriented approximately north-south within the bay and southeast-northwest along the northern shoreline. Approximately 200m to the east of the Ness of Seatter a long (50m) narrow (18m) low (2.5m high) mound was mapped. The mound has smooth sides that are partially stone covered. Small mounds of stone extend from the north and south ends of the mound in a curved pattern for 3-4m. The mound is isolated from near shore skerries and surrounded by fine grained sediment. The mound is unusual as it is symmetric in contrast to the local geology that tends to show asymmetry with respect to the dipping rock beds.

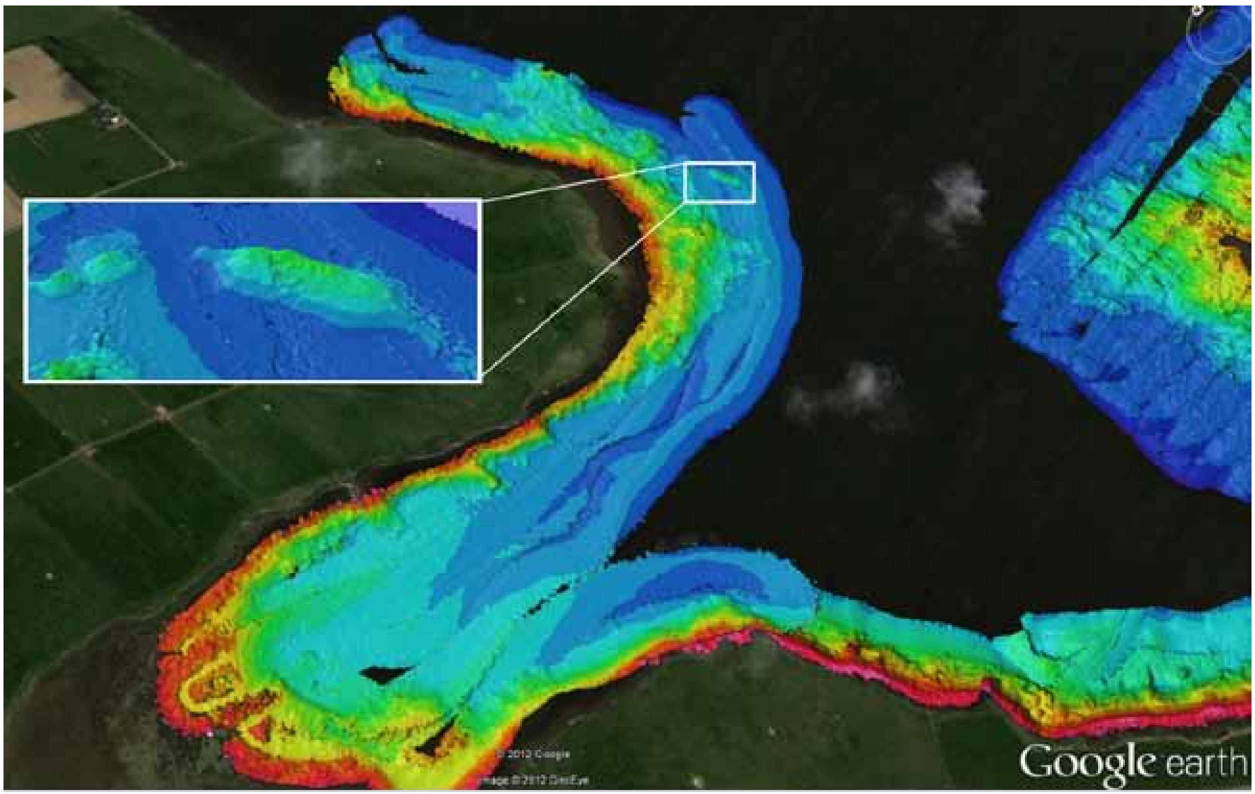


Figure 10: The Seatter embayment, showing the elongated mound anomaly.

Voy

The western bay at Voy was mapped (Figure 11). Sediment cores were obtained from this area in 2007 and the survey provides a wider context for these. A series of rocky skerries run across the entrance to the bay, possibly linking to the potential crannog sites in this area. Towards the top of the bay a low mound is visible on a promontory, identified in RCAHMS as a chapel site (Veron Point, HY21SE 27). In this area the loch bed shallows and a number of stony features are visible.

In addition, the entrance to the eastern bay was surveyed. This area has been investigated previously and it is speculated that it contains a number of crannogs and possible other structures. The area is typical in showing rock skerries extending 50-100m from the shoreline. The area also contains a number of discrete low mound areas near to shore and towards the centre of the bay. None of these show strong evidence of causeways linking them to the shore but further ground truth investigation will be necessary to determine if this type of stone work exists. Further in lies a single mound with causeway, identified as a crannog (Forbes pers com) but it was not possible to survey this area due to the shallow nature of the water.

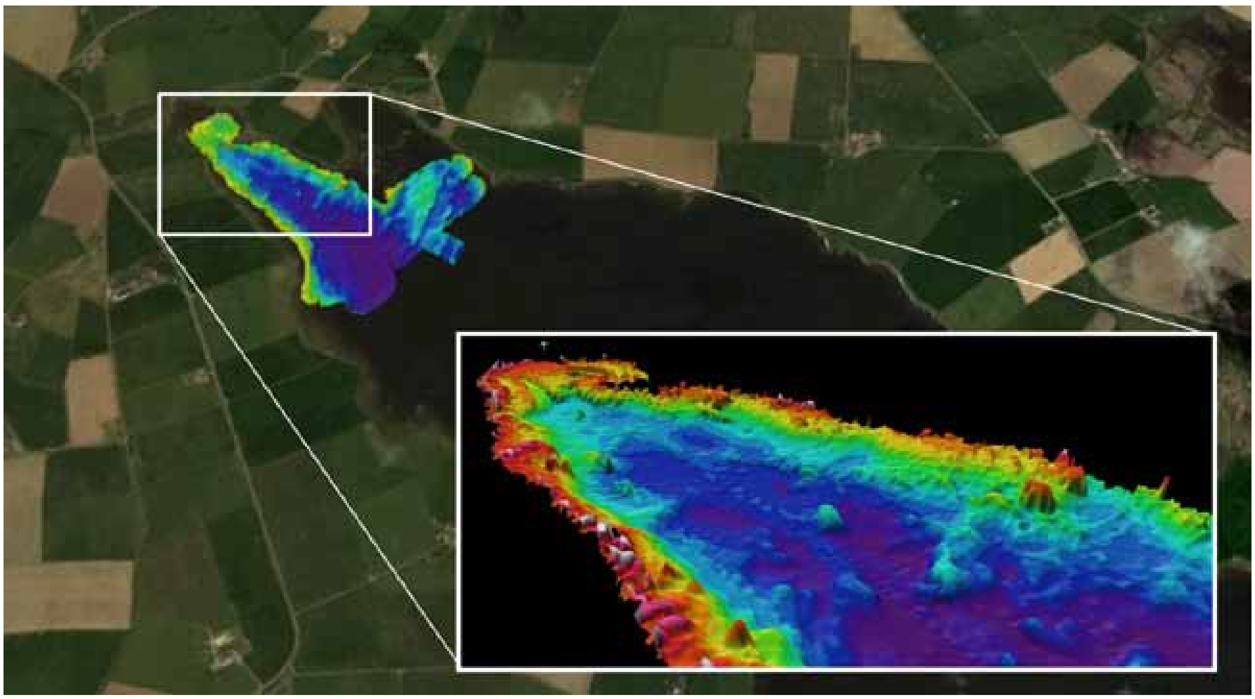


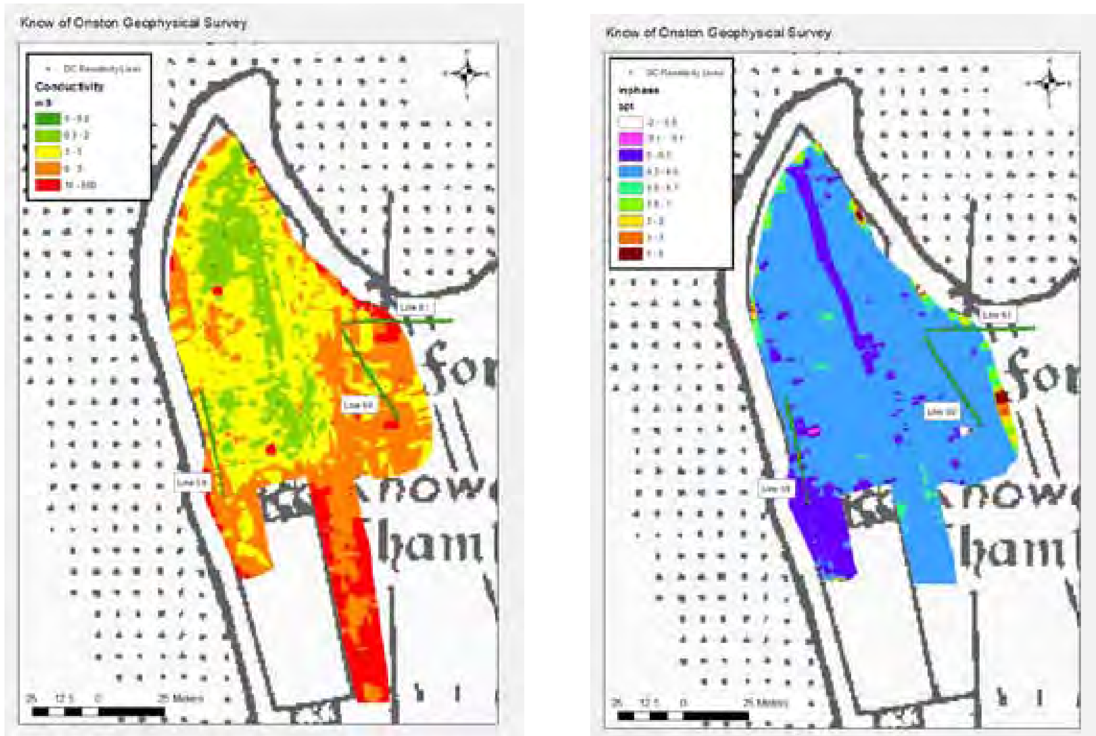
Figure 11: Voy, western arm of the bay.

Results: Terrestrial Geophysics

Point of Onstan Field Site

The site at the Point of Onstan had been highlighted as of interest from RCAHMS records and an initial analysis of air photographs. The photographs (Figure 1) showed the impression of a large curved feature to the north of the main tomb oriented in a roughly west-east arc with the hint that it might continue underwater into the loch. Offshore from Onstan, skerries generally less than 2m depth extend out to at least 50m from the shore and are partially visible at low tide.

The EM38 ground conductivity survey was conducted using both a vertical coil arrangement and horizontal coil arrangement. By using the two different orientations it is possible to map conductivity changes at two depths within the ground, namely approximately at 0.75m and 1.5m. Contour maps of ground conductivity are shown in Figures 12 and 13. While both show variations in ground conductivity neither indicated large conductivity differences directly associated with the ditch.



Figures 12 & 13: Ground Conductivity at Point of Onstan.

The direct resistivity imaging surveys conducted on three lines perpendicular to the ditch are shown in figure 14. Resistivity variations of 10 to 3000 ohm-m were recorded across the site.

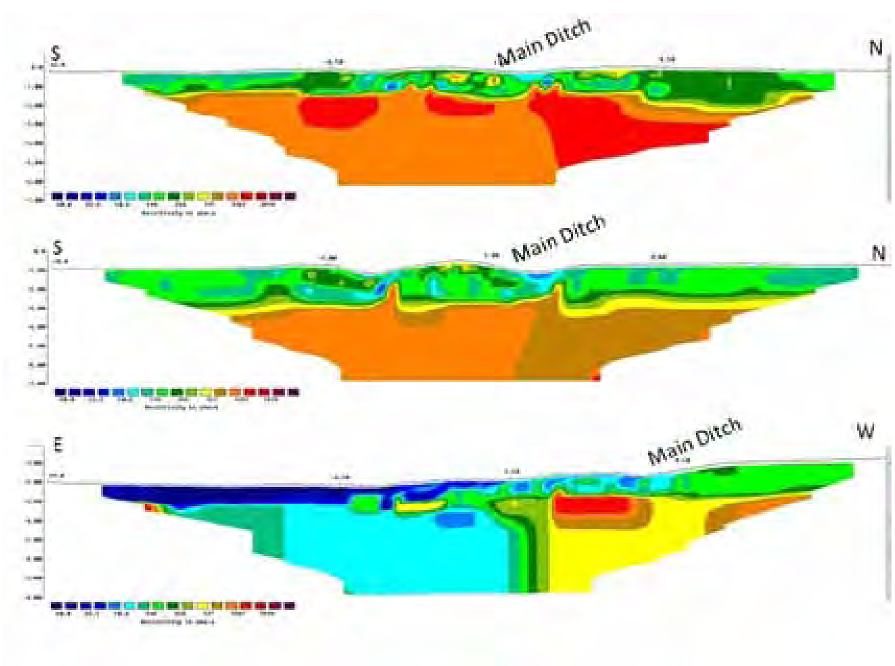


Figure 14: Resistivity variation across the ditch at Point of Onstan

The DC resistivity imaging here showed a strong signature for bedrock with high resistivity values. The ditch was manifest by lower resistivity material infilling the surrounding unconsolidated till material (resistivities of 100-500ohm-m). Both north-south lines showed a complex form to the ditch with the impression of a second ditch to the south of the main feature. The lower resistivities at the centre of both ditches would imply either a clay material or conversely a coarser material that has become saturated with the saline ground water. Interestingly both ditch locations show upraised higher resistivity protrusions from the bedrock surface to the north of each ditch infilling. These warrant further investigation as they could be interpreted as walling constructed from the bedrock material.

Nether Bigging Field Site

The earthworks on this promontory have been identified as a Norse castle on the basis of excavation (Clouston 1925). In 1966 RCAHMS noted that it is frequently flooded and further survey work was undertaken by Grieve who commented on the poor condition and lack of clearly identifiable structures (Grieve 1999, 70-75), concluding that it was more likely to represent a multi period site with remains from prehistory into the Norse period.

Geophysical survey by Grieve was inconclusive, and when visited as part of the present project ground cover was too high to permit more detailed survey.

Discussion

While full survey of the loch was not possible, work around the shore does provide an indication of landscape features pertinent to a time when relative sea levels were lower. In addition, areas of potential sediment accumulation were recorded.

Archaeologically, it is clear that the marine survey work provides a strong indication of the potential of the loch bed.

Perhaps most exciting are the anomalies recorded in the vicinity of the archaeologically rich area of the Brodgar isthmus. Both negative and positive features were recorded in this area, along the eastern shores of the loch. These include the large circular feature to the south of the Ring of Brodgar, striking both for its parallels to the henge site and for its location within the early landscape. To the south-east of this the shore alongside the excavation site at Ness of Brodgar is of particular interest in view of the possibility of matching marine and land survey to provide a seamless archaeology. In this area the complexity of the seafloor and presence of stony mounds would repay further investigation.

To the east along the southern shores of the loch the initial focus of interest around the Point of Onstan proved to be less rewarding as neither onshore nor offshore survey work confirmed the potential underwater extension of the Unstan earthworks. It is likely that these would have been constructed in the sediment sitting on the bedrock surface, and thus with this now eroded away any manifestation of the original structure has also been eroded. Nevertheless, onshore survey did emphasize the potential for more detailed analysis as an aid to understanding the site itself, including the possibility that the ditch construction was complex and might include walling or revetment material. Further east in this zone a combination of visual observation from satellite imagery and marine survey highlighted a number of clear cut anomalies near to the shore.

Survey of the Seatter embayment was perhaps of most use in providing a wider context for the sediment cores already taken in this area. A single large anomaly just outside this bay, at the Ness of Seatter sits in notable isolation that suggests high archaeological potential.

Finally, survey at Voy at the northern end of the loch was designed both to provide a context for the sediment cores from this area and to provide detail of the possible crannog and other marine sites in the area. Shallow waters and poor weather proved difficult here, but the results suggest that the area is not without potential.

Overall, fieldwork has gone a considerable way towards completing the original objectives and achieving the project aim. While confirmation that existing earthwork sites contained an underwater component was not forthcoming, a suite of upstanding features was recorded on the loch bed. This included both potential archaeological sites and palaeo-geographical material. In this way the earthwork sites under consideration might perhaps be confirmed as land-based sites alone. There is abundant evidence for the previous existence of the loch basin as a fresh water basin, home to significant human occupation. Progressive inundation of the area by marine water, and subsequent adaption of human activity has clearly left a lasting mark in the landscape. This is particularly exciting given the close proximity of the World Heritage Sites of the Ring of Brodgar and Standing Stones of Stenness as well as the newly discovered Neolithic ceremonial complex at Ness of Brodgar.

Conclusions and Recommendations

Marine geophysics has revealed a hitherto unsuspected complexity to the landscape history of the Loch of Stenness. While precise interpretation of this submerged landscape is premature at this stage, it is clear that the environmental history and past human use of the area cannot be fully understood from an analysis of sites on land alone. In some areas existing sites may have been complemented, or even preceded, by other remains. Elsewhere, new sites may be indicated. Given the importance of the known sites on land as World Heritage Sites, this work carries significant implications for their proper understanding and landscape context.

The results of this work carry considerable weight both for a proper interpretation of the archaeology of Orkney and for other areas where similar conditions pertain. It is no longer possible to ignore the contribution of the seabed to archaeological understanding.

Recommendations for further work around the Loch of Stenness in order to enhance understanding of the submerged landscape and its archaeological contribution include:

- Seismic survey of the Brodgar area in the vicinity of the Ring of Brodgar and Ness of Brodgar in order to provide structural detail of potential anomalies.
- Seismic survey of the Ness of Seatter mound in order to elucidate potential structural detail.

- Detailed sonar swath survey of Voy in the vicinity of the crannog sites.
- Sonar swath survey of remaining areas of the loch shore in order to complete coverage.
- Ground truthing by diving of anomalies of high potential including: Brodgar circle, Ness of Brodgar mounds; Stenness mounds; Ness of Seatter.
- More detailed survey of the earthworks at Point of Onstan.

Acknowledgements

Thanks are due to Andrew Appleby, Heather Bond, Brian Cordingley, Sarah Jane Gibbon, Sue Ovenden and Alistair Wilson of Rose Geophysics, and the Orkney Trout Fishing Association for their permissions, photographs, information and support for this project. Satellite images all courtesy of Google Earth.

Funders

The work was financed by the Royal Archaeological Institute and the Society of Antiquaries of London.

References

Bates, M.R., Bates, C. R., Dawson, S., Hughes, R., Huws, D., Nayling, N., & Wickham-Jones, C.R. *A multi-disciplinary approach to the archaeological investigation of a bedrock dominated shallow marine landscape: an example from the Bay of Firth, Orkney, UK*

Bates, C. R. and Byham, P. 2001. Swath-sounding techniques for near shore surveying. *The Hydrographic Journal*, v. 100, pp. 13-18

Bates, C. R. and Oakley, D. 2004. Bathymetric sidescan investigation of sedimentary features in the Tay Estuary, Scotland. *International Journal of Remote Sensing*, v 25, pp. 5089-5104

Clouston JS 1925 An Early Orkney Castle, *Proceedings of the Society of Antiquaries of Scotland*, 60, 281-300.

Dawson S, Wickham-Jones CR & Dawson A in preparation *Late Holocene relative sea level change in Orkney, Scotland: the case study of the World Heritage Sites of the Heart of Neolithic Orkney.*

Grieve SJ 1999 *Norse Castles in Orkney*. Thesis presented as part of an MPhil degree at the University of Glasgow, Department of Archaeology.