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Shetland Islands Field Trip May 2014 - Summary of Results

ENERGY AND MARINE GEOSCIENCE
Report OR/15/017

BRITISH GEOLOGICAL SURVEY

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D.R. Tappin, D. Long, G.D.O. Carter

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National Grid Reference

SW corner 410000,1108000
Centre point 450000,119000
NE corner 472000,1222000

Map

Sheet 999, 1:99 000 scale, Shetlands

Front cover

Tsunami deposit at Whale Firth

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Foreword

This report presents the preliminary findings from a 13 day field excursion to the Shetland Islands between the 11th and 24th May 2014 to research tsunami sediments. The field work was a contribution to the NERC funded consortium project, 'Will climate change in the Arctic increase the landslide-tsunami risk to the UK?' It was part of Work Block 2 (WB2): 'What is the timing of tsunami deposits on the UK coastline, and how is it related to the age of major Arctic slides'? The objectives of WB2 are to investigate possible tsunami deposits in Mainland Scotland and Shetland that post-date the Storegga Slide; such as those dated at ~5,500 and ~1,500 cal years BP (Bondevik et al., 2005) to constrain estimates of the frequency of tsunami events striking the coast of the UK during the Holocene.

Scientists from the BGS and Dundee and Aberdeen Universities formed the research team:

BGS: Mr Dave Long, Prof. Dave Tappin, Mr Gareth Carter

University of Dundee: Dr Sue Dawson, Dr Fraser Milne, Ms Charlotte Gilles

University of Aberdeen; Prof. Alistair Dawson

Acknowledgements

This report is part of a much larger project on tsunami hazard in the North Atlantic that is supported through a NERC Consortium grant led by Principal Investigator, Dr Peter Talling of the National Oceanographic Centre (NOC), Southampton whose ongoing support we wish to acknowledge together with Dr James Hunt, also of NOC, the Project Manager.

The tsunami sediments work block 2 is led by Dr Sue Dawson, Dundee University who also led the 2014 fieldtrip to the Shetlands, with Post-Doctoral Research Associate (PDRA), Dr Fraser Milne, both of whom we wish to thank for their comradeship and friendship in the field and for the discussions on the science that took place on Shetland, most notably during our lively and very convivial evening dinners on Yell.

Professor Alistair Dawson, of Aberdeen University shared with us his considerable knowledge of Shetland geology and geomorphology during the first part of the fieldwork and guided us to the new locations he discovered in 2013 with Dr Pedro Costa (the previous PDRA) now of the University of Lisbon.

The views expressed in the report are of course those of the authors, who look forward to developing these further during the next phase of field work in 2015 and thereafter as the field observations are further developed through age dating and Laboratory analysis. Our Dundee colleagues sampled at many of the locations described in the Report and we look forward to the forthcoming results on the sediments and the new age dating that should resolve some of the problems we outline here.

The authors would like to thank the Shetland islanders who allowed access to their land, particularly Mrs Jamieson, who owned the 'Red Hoose' and Mr Johnson for his lively conversation and access to vital coastal exposures.

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FIGURES

Summary

This report provides a record of a field excursion to the Shetland Islands in May 2014 to investigate sediments deposited from tsunamis generated from submarine landslides mainly located off the coast of Norway. The research was funded under a NERC Consortium Grant for a project entitled 'Will climate change in the Arctic increase the landslide-tsunami risk to the UK?' It was part of Work Block 2 (WB2): 'What is the timing of tsunami deposits on the UK coastline, and how is it related to the age of major Arctic slides'?

The best known and most studied tsunami from the Norwegian submarine landslides is the Storegga event dated at 8,200BP. Sediments deposited from this tsunami are commonly found along the west coast of Norway, east coast of mainland Scotland, and also on the Shetland and Faeroe islands. However, there are other landslides off of Norway for which no associated tsunami has been identified, which poses the question as to whether these events did not generate a tsunami or whether the evidence for a tsunami has not yet been found.

Although evidence for seabed slumping off Norway was first discovered in the 1950's (Holtedahl, 1955, 1971) and the scale and morphology of a massive submarine landslide, subsequently termed Storegga, mapped in the 1970's (Bugge, 1983), it was not until 1985 that an associated tsunami was first proposed (Svendsen, 1985). The first supporting sedimentary evidence of the tsunami was first identified on mainland Scotland in 1988 (Dawson et al., 1988) then, subsequently, similar sediments were identified on the Shetland Islands (Smith, 1993a). The Storegga Slide has been dated to 8,150BP (Haflidason et al., 2005), however more recent research on the deposits on the Shetlands suggests that some may not all be from Storegga, because ^{14}C age dating gives younger ages of ~5,000 and 1,500 cal yr BP (Bondevik et al., 2005). A major challenge posed by the ages of these younger dates is that they are confined to the Shetlands; there is no indication of these younger tsunamis on mainland Scotland. If the dating is correct and the sediments are indeed from tsunamis, then the submarine landslides off Norway would be an unlikely source, so a local source seems most likely, but none has yet been identified. Alternatively a non-tsunami source for the sediments may explain their presence.

The objectives of WB2 therefore are to investigate the tsunami deposits on Shetland that post-date the Storegga Slide, to validate their ages and, if possible, identify possible source locations of the submarine landslides that generated the tsunamis. On Shetland research on tsunami sediments was mainly based on evidence from coastal exposures around Sullom Voe where tsunami sands are dated as coeval with Storegga. The younger sands are

mainly preserved in lake cores at locations on Shetland Mainland (Bondevik et al., 2005) where those of 5,000 BP overlie sands of Storegga age at 8,200 years BP age. At coastal sites along Basta Voe on Yell and at a mainland site at Dury Voe very young age dates of ~1,500 BP suggest an additional and very recent, late Holocene event (Bondevik et al., 2005; Dawson et al, 2006).

A preliminary field excursion to the Shetlands carried out in 2013 discovered possible new tsunami deposits preserved in peat on central Yell at Whale Firth, Mid Yell Voe and Kirkabister. Subsequent ^{14}C age dating of these deposits resulted in a variety of ages, many much younger than that of Storegga. The ^{14}C method is known to be subject to major uncertainties because of contamination, for example initial age dating in the 1990's at sites around Sullom Voe returned ages of around 5,000 years BP, although these were subsequently rejected in favour of the earlier, 8,200 BP Storegga event.

Thus, validating the ages of the deposits on Yell, prospectively from a number of deposits laid down successively at one site (thereby reducing the sole reliance on ^{14}C dating) was critical in validating the presence of more than one tsunami event on Shetland. The objective of the 2014 field visit to the Shetlands, therefore, was to return to Yell and validate the preliminary results from 2013; revisiting the sites at Whale Firth, Mid Yell and Kirkabister and searching the coastlines of Unst, Fetlar, Yell and north Mainland for additional sites where tsunami sediments might be preserved. Just before the visit new ^{14}C dates from Mid Yell from samples collected in 2013 confirmed the previous results from other locations that had given a wide range of ages; at Whale Firth a single date gave a 'young' age of ~5,000 years BP, a range of ages with the oldest at 8,200 years BP were returned from Mid Yell Voe.

We first visited sites on north Mainland around Sullom Voe, as it was here that the first indications of the Storegga tsunami were identified on Shetland in 1992. The deposits are classic as they contain rip-up clasts characteristic of tsunami deposits elsewhere. We then visited the sites at Basta Voe, Whale Firth, Mid Yell and Kirkabister. We carried out reconnaissance surveys on Unst, Fetlar, Yell and north Mainland.

Preliminary results:

1. The new evidence supports the presence of tsunami sediments on Yell at Mid Yell Voe and Whale Firth, but the age of these sediments requires further research to confirm previous dating and their possible sources,
2. The youngest dated sediments (~1,500 BP) at Vasta Voe are most likely from a tsunami, but their limited areal extent suggests a local source, as yet undetermined,
3. The presence of three events at Mid Yell Voe based on surveys in 2013 was not confirmed,
4. The similarity of the deposits on Mid Yell with those around Sullom Voe on Mainland are suggestive of a similar source,
5. The wide range of the preliminary age dating at the Mid Yell sites (Whale Firth and Mid Yell Voe) is analogous to the early age dating of coastal deposits around Sullom Voe, suggesting the possibility of contamination of the peat material dated,
6. Whereas the 5,500BP event is identified in lake cores, no strongly supportive evidence for sands of this age were identified in the coastal sections,
7. Of the proposed three tsunami events proposed for Shetland only one, Storegga, has a confirmed source,
8. Further analysis of the peat stratigraphy at the coastal sites, reflects vegetation changes over the past ~8,000 years related to climate change, and these could be used to provide a broader context for the ^{14}C age dating that may resolve the present dating issues,
9. Newly discovered sediments at Kirkabister require further research to determine their origin,
10. The origin(s) of the laminated deposits at Whale Firth, Mid Yell and Vatsetter is/are uncertain, but they are probably not from a tsunami,
11. No additional coastal exposures of peat with tsunami sands were located during the reconnaissance surveys on Mainland, Yell, Unst and Fetlar.

Postscript; Immediately after this report was finalised, age dating of peat sections at Whale Firth and Mid Yell Voe confirmed that the sands preserved in the woody peat here are of Storegga age, ~8,200 cal yr BP.

1 Introduction

There is general agreement that the present day exposed Storegga Slide is the last of a series of large-scale submarine slides that have affected the mid-Norwegian margin over the past million years. It disturbed an area of approximately 95,000 km^2 and displaced a sediment volume of 2400–3200 km^3, making it one of the largest submarine slides in the world. It has been dated to 8150 cal yr BP offshore (Haflidason et al., 2005). According to many AMS ^{14}C dates of plant fragments the most accurate age for the tsunami onshore Norway is 7250–7350 ^{14}C yr BP (Bondevik et al., 1997), the youngest age of which correlates with the 8150 cal yr BP date from Haflidason et al. (2005).

Between the 11th and 24th May 2014 scientists from the BGS and Dundee and Aberdeen Universities visited the Shetland Islands to research tsunami deposits generated by the Storegga submarine landslide and two other recently discovered sandy 'event' beds dated at ~5,000 BP and 1,500 cal yr BP (Bondevik et al., 2005). The research was funded under the NERC consortium project, 'Will climate change in the Arctic increase the landslide-tsunami risk to the UK?' and was a part of Work Block 2 (WB2): 'What is the timing of tsunami deposits on the UK coastline, and how is it related to the age of major Arctic slides'? WB2 aims to investigate possible tsunami deposits in Mainland Scotland and Shetland that post-date the Storegga Slide (such as those dated 5,500 and 1,500 cal yr BP).

1.1 EVIDENCE FOR TSUNAMIS IN THE UK

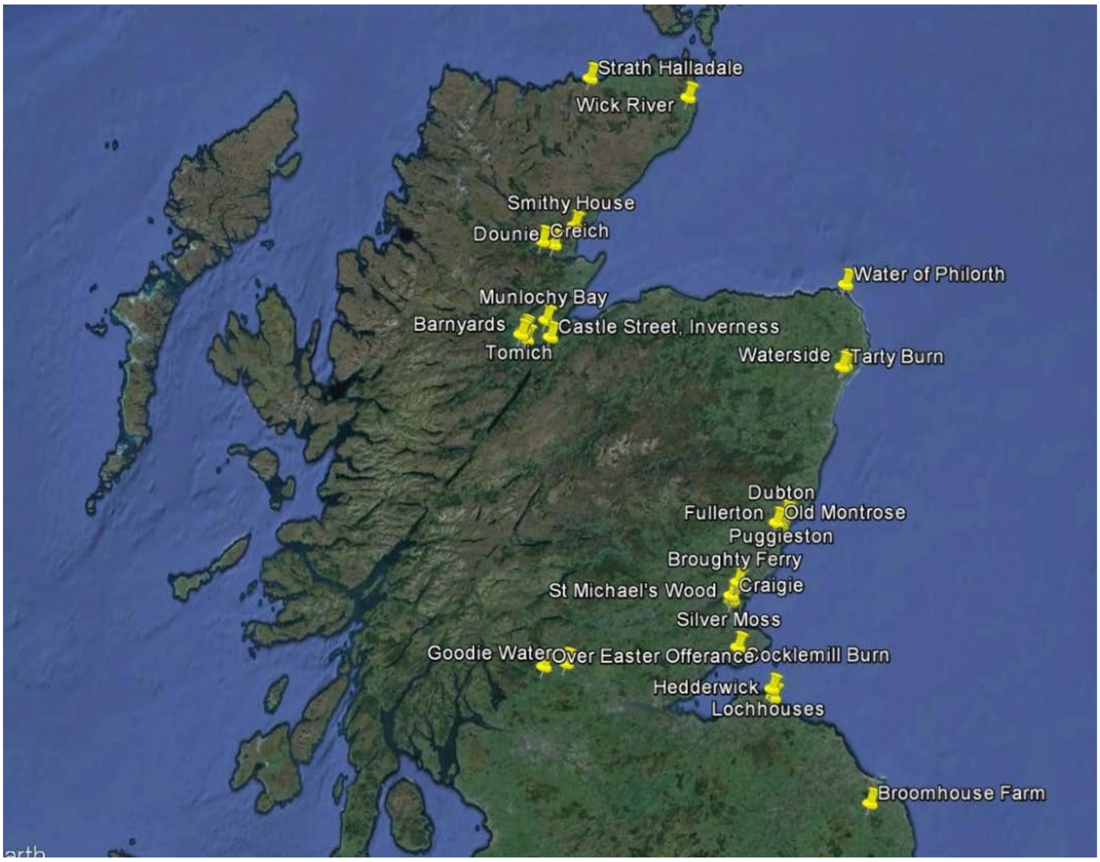

Figure 1 Google Earth Image of mainland Scotland and northern England with locations of Storegga tsunami deposits

The UK's north and east coasts (mainly Scotland) are vulnerable to tsunamis from the Norwegian Sea and there is good evidence for tsunamis from Arctic sources striking the UK (Long and Wilson, 2007). The bulk of the evidence in Scotland (Fig. 1) relates to the tsunami associated with the Storegga Slide of 8,150 cal yr BP (Dawson et al., 1988). However, at a few sites, sedimentary deposits attributed to tsunamis younger than the Storegga event have recently been located in Shetland and dated at 5,500 and 1,500 cal yr BP (Bondevik et al., 2005). They include sites where both Storegga and one of the younger events have been recorded (Bondevik et al., 2005). The young age of these more recent events is of considerable importance because if validated, the mechanism of tsunami generation during post glacial climate change proposed to explain the Storegga event maybe compromised. In this context the research is of vital importance to planners and engineers concerned with estimating the magnitude and frequency of coastal flooding from tsunamis and how this should be mitigated. Proving the presence of younger tsunami event layers within the last 10,000 years, later than the proven Storegga event, that increases the frequency of tsunamis, would require a re-evaluation of the hazard from tsunamis to the northern UK and a reconsideration of the potential risk. It is thus essential to check the validity of published tsunami sediment layer interpretations and if possible to locate further examples to validate those discovered and constrain the spatial extent of known events and their possible source(s).

On Shetland, Mainland (Fig. 2), tsunami event layers are found in peat at Sullom Voe and in lake sediments in cores from Garth Loch, a marine embayment, and Loch of Benston, a freshwater body about 0.5 km to the west. Tsunami sediments from both these sites have been dated at ~8,200 and ~5500 cal yr BP (Bondevik et al., 2005). A third, younger, sand layer preserved in peat outcrops in Dury Voe (Mainland) and 40 km north at Basta Voe on Yell is dated at ~1500 cal yr BP (Bondevik et al., 2003). All deposits are laterally extensive, landward thinning beds of marine origin and exhibit sedimentary features characteristic of tsunami deposition, including; rip-up clasts, sand layers, redeposited material and marine diatoms. An aeolian origin is considered unlikely because of the presence of boulders at one site and the deposits undoubted marine affinities. The absence of other non-marine event beds in an area that is subjected to frequent strong winds supports a non-aeolian origin. Within the Holocene record of sediments on Orkney and mainland Scotland there are no deposits coeval with those on Shetland. Only the ~5500 cal yr BP event has a possible equivalent in a deposit near Bergsøy in Norway (Bondevik et al., 2005). The ~1500 cal yr BP deposit at Dury and Basta votes is unique to Shetland. Neither of the younger events correlates with any other dated large-volume landslide off Norway, such as Traenadjupet (4000 cal yr BP). A few minor slide/slump events have been identified along the northern Storegga Slide escarpment and, dated at 5700 and 2200–2800 cal yr BP (Haflidason et al., 2005) might be the source of these sediments except that as the total volume of these events is less than 1 km^3 they are far too small to generate a tsunami that would propagate so far . An absence of a correlative source, therefore suggests that either the young dates are artefacts and the result of contamination, or that there is a local source, such as a submarine landslide within the Shetland archipelago.

Figure 2 Google Earth Image of Shetland with locations of coastal tsunami deposits (white) and lake cores (red)

1.2 SURVEY OBJECTIVES AND PLAN

The objectives of the 2014 field research therefore were to:

- re-examine coastal sediment sequences in Shetland to determine the regional extent of the possible tsunami deposits dated at ~1,500 and 5,500 cal yr BP and possibly younger than the Storegga Slide (8,200 cal yr BP), and

- collect further samples for sedimentary analysis and age dating to confirm (or not) the tsunami origin of the deposits.

The work plan was to carry out an initial field visit on Shetland to determine the extent of the younger events, followed by a coring and sampling campaign to recover good quality material for analysis. Palynological and sedimentary analysis of the recovered sediments will validate or not their tsunami origin, and ^{14}C dating of material, either within, above or below the tsunami deposits will provide further evidence on their ages and hence the possible links with the Dury Voe (1,500 cal yr BP) and or Garth (5,500 cal yr BP) events on Mainland.

2 Field surveys in 2013

The first survey on Shetland funded by the NERC Consortium project was undertaken in June 2013 by Prof. Alastair Dawson and Dr Pedro Costa (Dawson and Costa, 2013). Sites on Mainland (Garth's and Scatsta voes) and Yell (Basta Voe, Kirkabister, Whale Firth and Mid-Yell Voe) (Fig. 3) were visited.

2.1.1 **Yell**

Figure 3 Google Earth Image of Yell with locations of tsunami deposits (in red), possible deposits (yellow), no deposits (white)

At Mid Yell Voe (Figs. 3 and 4) three sand layers were identified with sedimentary characters diagnostic of palaeotsunami deposits. ^{14}C dating of these sands (Fig. 5) confirmed previous results that the sediments were younger than Storegga, but there was a considerable range in ages. At site Mid Yell 3a ^{14}C age of 780±30 cal yr BP was obtained. From a core south of the road at Site Mid Yell 1 a peat sample below a sand layer returned an age of 6,060±40 cal yr BP. At Mid Yell Site 7a, on the northern side of the Voe, a peat sample from below the upper sand returned an age of 5,800±40 cal yr BP and a twig sample above the bottom sand a ^{14}C age of 8,120±40 cal yr BP. On the southern side, at Site Mid Yell 5 a peat sample above a sand layer gave an age of 3,320±30 cal yr BP.

1.1.1 Mid-Yell Voe

Figure 4 Google Earth Image of Mid Yell with core and sample locations (Location Fig. 3)

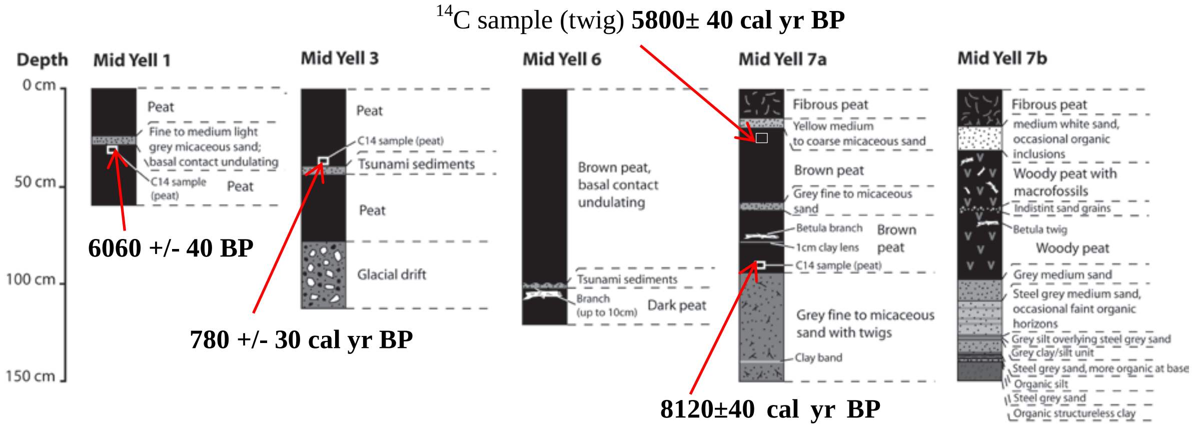

Figure 5 Cores from mid Yell with lithology's and 14C dates

(Mid Yell 5 – 3320±**30** cal yr BP c. 40cm depth above Tsunami sand, same stratigraphy as Mid Yell 3)

2.1.2 Whale Firth

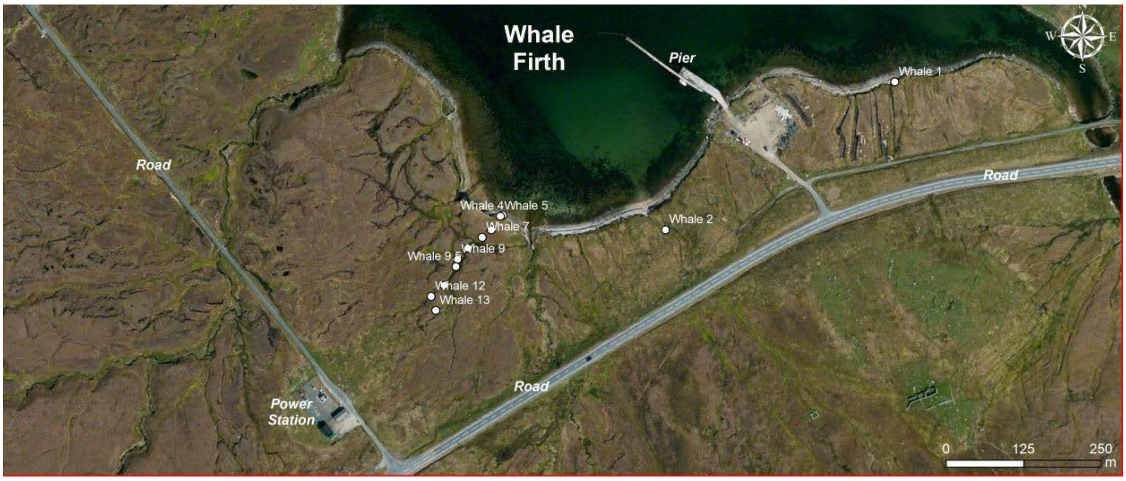

Figure 6 Google Earth Image of Whale Firth with core locations (Location Fig 3)

At Whale Firth (Fig. 6) a twig overlying a sand at Site Whale 4 returned a ^{14}C age of 4,760±20 cal yr BP (Fig. 7).

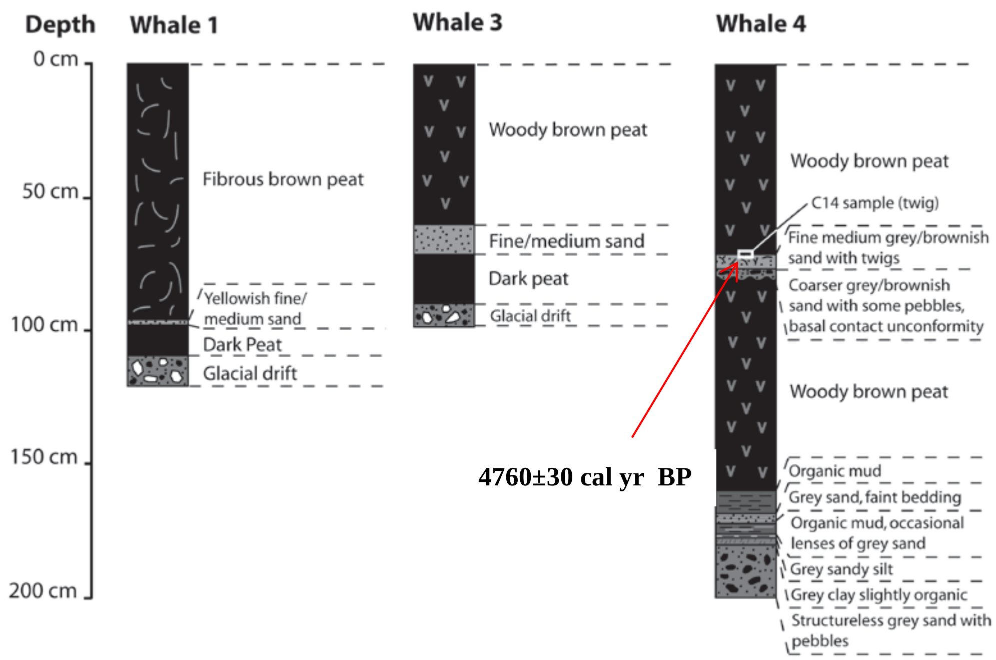

Figure 7 Cores from Whale Firth with lithology's and ^{14}C dates

Detail of the sand (palaeotsunami?) layer and dated twig at Whale Firth 4 (Fig. 8). Note the twig in a horizontal position in the contact between the peat and the sand layer (but still within the sand layer).

Figure 8 Photograph of tsunami sand at Whale Firth

In addition to Mid Yell and Whale Firth, Burra Voe (Fig. 9) on the south coast of Yell and Gloup, at the northern tip of Yell, were visited but only cursory examinations were carried out and no samples acquired.

2.1.3 Burra Voe

Figure 9 Google Earth image of Burra Voe (Location Fig. 3)

3 Field Survey - May 2014

In May 2014 we returned to the Shetlands to further investigate the sediments previously identified on Mid Yell and also to carry out reconnaissance surveys on the islands of Fetlar, Unst and Mainland. We planned to acquire further cores and samples of the possible tsunami sediments and, of particular importance, we were to investigate and determine the stratigraphic relationships between the three event beds previously identified in 2013 at Mid Yell, with a primary objective to determine whether these beds could be found in one vertical succession at one location. We also planned to survey between Whale Firth and Mid Yell Voe to determine whether this area, a narrow isthmus, was inundated by the Storegga tsunami.

3.1 MAINLAND

On Mainland we revisited locations where Storegga tsunami deposits had been previously identified; mainly around Sullom Voe and southward to Dury and Garth voes (Fig. 10). We also carried out reconnaissance in the north and central areas to determine whether there were any other exposures of tsunami sand in coastal peats not previously found. We visited locations where lake cores had sampled sands dated at 8,200 cal yr BP, coeval with the Storegga event and where younger sediments dated at ~5,000 cal yr BP had been found (Bondevik et al., 2005).

3.1.1 North Mainland

Around Sullom Voe (Fig. 10) the tsunami sediments are preserved in coastal peat sections (Bondevik et al., 2005). This was the area where the Storegga tsunami sediment was first identified in 1988 (Fig.11). On the east side of the Voe at Scatsta (Fig. 12), a 6-10 cm thick, massive, medium-coarse muddy sand is exposed in a small channel cut into the peat (Figs. 13-16). The channel lies just above sea level and below the information board (Figures 13 and 14). The enclosing peat is structureless and immediately below the sand there is birch branch in the peat (Figure 14). Similar sediments were once visible at Garths Voe to the east of Scatsta (Birnie, 1992) but now have been covered/destroyed by new road construction.

Figure 10 Shetland, north Mainland with locations visited marked

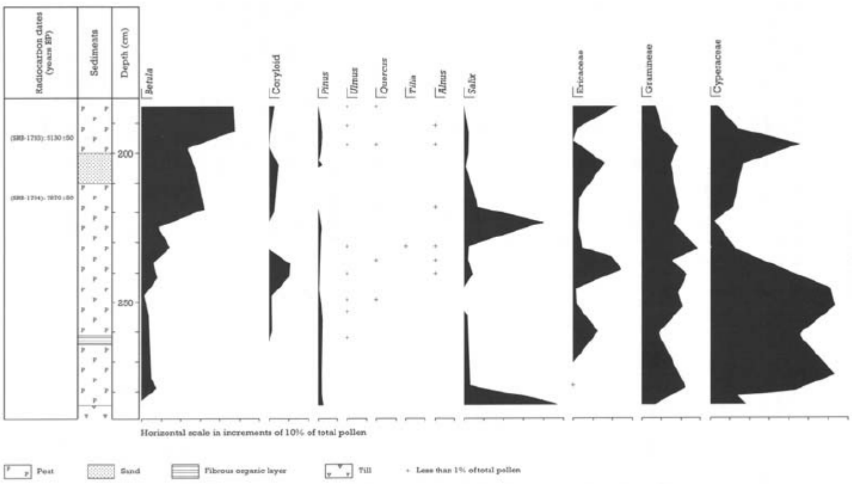

Figure 11 Garths Voe: relative pollen diagram showing selected taxa as percentages of total pollen (from Birnie, 1981).

The section at Garths Voe is described in detail in Burnie (1992) and dating of *Salix* wood in peat underlying the sand (Fig. 11) show this to be 8980–8523 cal yr BP (Smith, 1993). Above the sand *Betula* wood is dated at 5987–5745 cal yr BP. The sample material dated seems to represent different botanical communities (clearly seen on Fig. 11), with the older organic layer beneath dominated by Cyperaceae (Sedges) and *Salix* (Willow) and above the sand *Betula* (Birch) becoming dominant and *Salix* almost absent. The birch was initially associated with ferns, but then heaths appeared at the site, and at some time after 5130 cal yr BP shrubs or trees disappeared and heath- and sedge-dominated blanket peat communities predominated.

Figure 12 Sites visited on northeast mainland

Subsequent dating of peat above and below the sand at Scatsta and Garth's Voe by Smith (1993b) further confused the issue as these returned dates of 6715–6448 cal yr BP and 6635–6548 cal yr BP for the lower contact, and 6266–5946 cal yr BP and 4406–4087 cal yr BP for the upper.

Figure 13 View from Scatsta site towards Sullom Voe with the channel-cut in the foreground. Location on Fig. 11.

Figure 14 Storegga tsunami sand, note the underlying birch branch (trowel blade 12 cm long).

Figure 15 Tsunami sand at Scatsta

Figure 16 Notice board at Scatsta

Further dating was carried out by Bondevik et al. (2005) from samples at the Houb on the west side of Sullom Voe. The sand layer is interpreted to be deposited by the same tsunami as described from Garths and Maggie Kettle's Loch (Bondevik et al., 2003). Just above the sand at the Houb there is a horizon in the peat containing remains of birch trees; from here a root in growth position was ^{14}C dated to 7720–7960 cal yr BP (7025±60 ^{14}Cyr BP). Seeds from the peat immediately below the sand layer were dated to 7820–8030 cal yr BP (7120±60 ^{14}C yr BP). Based on these dates Bondevik et al., (2005) concluded that the sand layer was deposited by the Storegga tsunami.

We visited the northern point on Mainland at Isbister (Figs. 17 and 18) where the beach at Sand Voe, a north facing inlet, is backed by a thick till, but with no evidence of sand. This area is mainly grassland that suggests a minimal peat cover; till and bedrock form low coastal cliffs. Behind the beach is the Loch of Flugarth (Figure 17) which has the potential to preserve tsunami sediments, but lake coring would be necessary to prove this.

Figure 17 Isbister, view south towards Loch of Flugarth (location on Fig. 18)

Figure 18 Sites on North Mainland – red dot is location of Fig 17.

3.1.2 East Mainland

Examination of various inlets on the eastern side of Mainland (Fig. 19) revealed no evidence of tsunami deposits and an absence of coastal peat, with till and bedrock exposed along the shoreline. Sites visited included Colla (Fig. 20), Firth, Vidlin (Fig. 21), Swining, Dury and Garth Lochs.

Figure 19 East Mainland sites

Both at Vidlin Voe and Colla Firth, the valley sides are sculptured, there is little peat and the pastureland sweeps down to the sea. We didn't visit Dury Voe where Bondevik et al. (2005) found a sand layer in numerous peat outcrops along the shore and some 400m inland at the Ayre of Dury. The sand layer is 1–5 cm thick, with a sharp lower boundary. It is fine to medium-grained and rests on ca 1m of peat. The sand fines inland. It was dated at between 1540–1820 cal yr BP (1745±60 ^{14}C yr BP) and 1290–1420 cal yr BP (1460±50 ^{14}C yr BP).

Loch of Benston (Fig. 22) and Garth Loch (Fig. 23) were cored and sampled by Bondevik et al (2005) who identified two sand units (Fig. 24). At Garth Loch the lower unit was dated at 7970–8210 cal yr BP (7320±70 ^{14}C yr BP) and attributed to the Storegga landslide. The upper sand they dated to 5280–5490 cal yr BP (4645±65 ^{14}C yr BP) and attributed to a younger event, not defined. At Loch of Benston the Saksunarvatn Ash was found below the lower sand (Fig. 25). The Ash has previously been described in lake sequences on Shetland (Bennett et al., 1992). It is dated elsewhere to ca 9000 ^{14}C yr BP (Birks et al., 1996) and 10,18±760 ice core years (Grönvold et al., 1995).

Figure 20 Head of Colla Firth looking northeast (WP 661)

Figure 21 Vidlin Voe looking northeast

Figure 22 Loch of Benston looking southwest

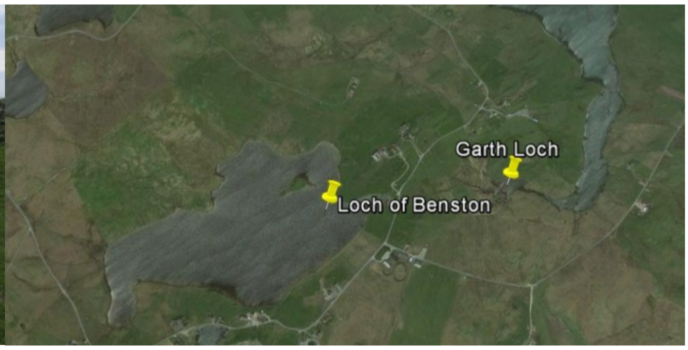

Figure 23 map of Loch Benston and Garth Loch

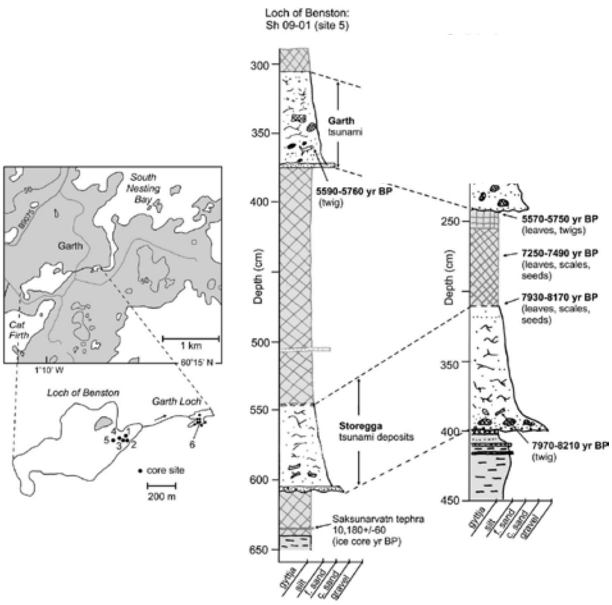

Figure 24 Loch of Benston and Garth Loch. Garth Loch is just above the high tide level, while Loch of Benston is found 1.6m higher and drains into Garth Loch. Both basins have tsunami deposits dated to between 5300 and 5700 cal yr BP.

3.1.3 Eshaness

On the return journey home we visited Eshaness Headland, NW Mainland, site of the famous cliff top storm deposited boulders (Hall et al., 2006) (Figs. 25, 26 and 27). Here boulders up to >1m^3 have been lifted up from the cliff face and thrown onto on the cliff top ~22m above sea-level (Hall et al., 2008).

Figure 25 Eshaness Peninsula

Figure 26 Eshaness cliffs looking east

Figure 27 Boulders on the cliff top, note the grass covered example in the foreground

3.2 YELL

On Yell the previous visit in 2013 identified a number of potential locations where tsunami sands are preserved or where they are suspected (Fig. 28). The schist and gneiss bedrock of the islands has resulted in excellent acidic conditions that have allowed a thick peat cover to form over the entire island. The regional geological guide (Flinn, 1994) suggests that previously 97% of Yell was peat covered and that currently 63% of the island has more than half a metre thickness of uncut peat. Flinn notes "*layers of sand and /or gravel, generally up to 10cm thick, are commonly visible in the peat along the banks of streams high up in the hills. Such occurrences extend down to the shores without change of character, and all appear to be the result of streams overflowing their banks as a result of heavy falls of rain*." Such an interpretation is in conflict with the presence of marine diatoms within the sand layers (Sue Dawson, *pers comm*), which on the coast may well be the result of tsunami inundation.

Figure 28 Yell with locations visited. Red text where tsunami sediments are found and yellow where they are suspected

Figure 29 Yell with GPS waypoints

3.2.1 Mid Yell Voe

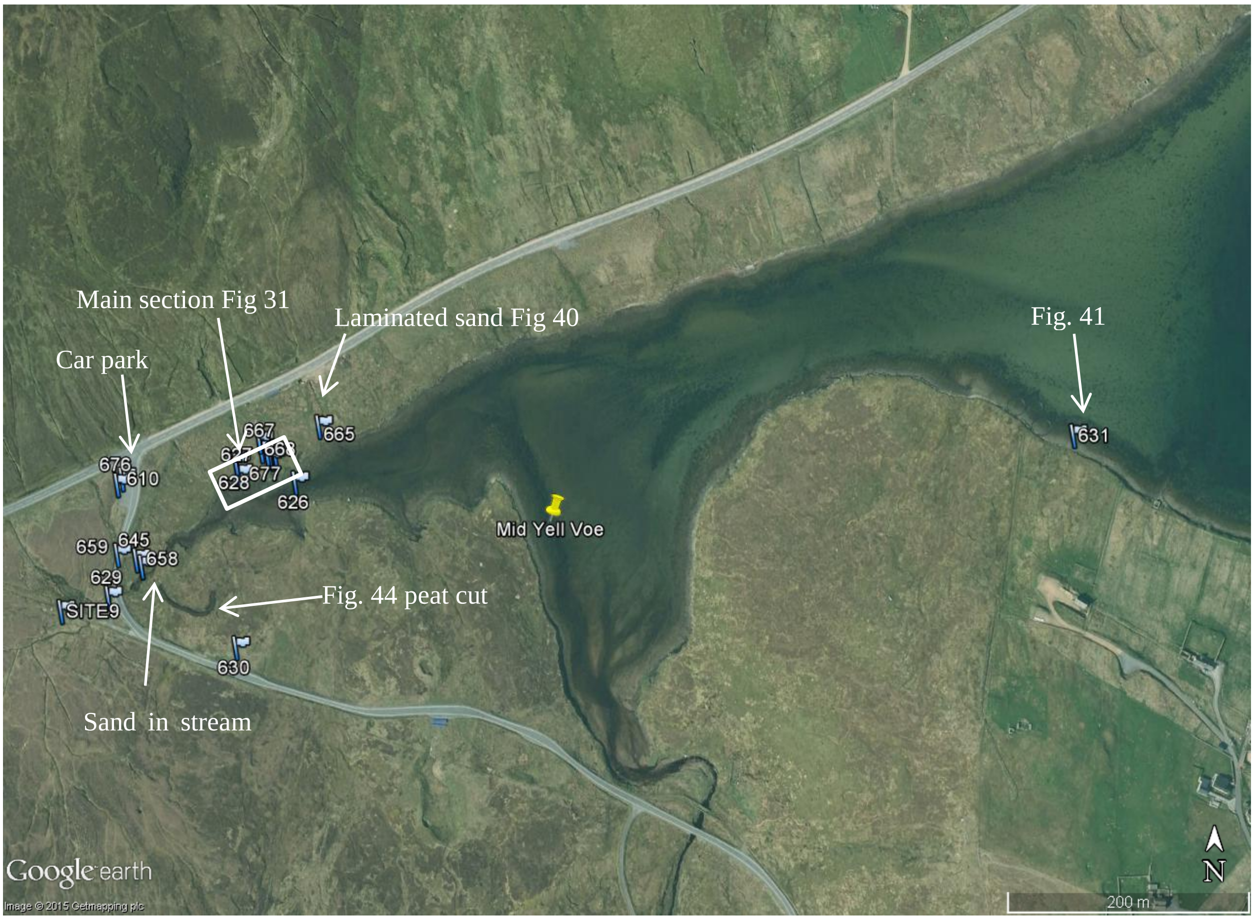

Figure 30 Mid Yell Voe showing main way points, locations and figures described in the text

Figure 31 Mid Yell north section (Box in Fig. 30)

At Mid Yell (Fig. 30) we returned to the sites examined in June 2013. ^{14}C age dates of peat and twig samples at this location (Mid Yell 7a, Figs. 4 and 5) range from 8120±40 to 5800±40 cal yr BP. On the north side of the Voe, exposed intermittently along a ~50 m peat bank up to 2-3m high we found only one continuous 5-10 cm thick sand bed within the peat (Figs. 32 and 33) which we traced along section; the sand is laminated, poorly sorted, micaceous and organic rich with clay or peat clasts. Both upper and lower contacts are diffuse, but show no significant erosional relationships with the peat. The bed varies in elevation from 0.5 m above the beach (in the east) to approximately one metre below (centre), indicating that the sand is draped over a pre-existing, uneven, topography. Birch wood is buried within the peat both above and below the sand layer.

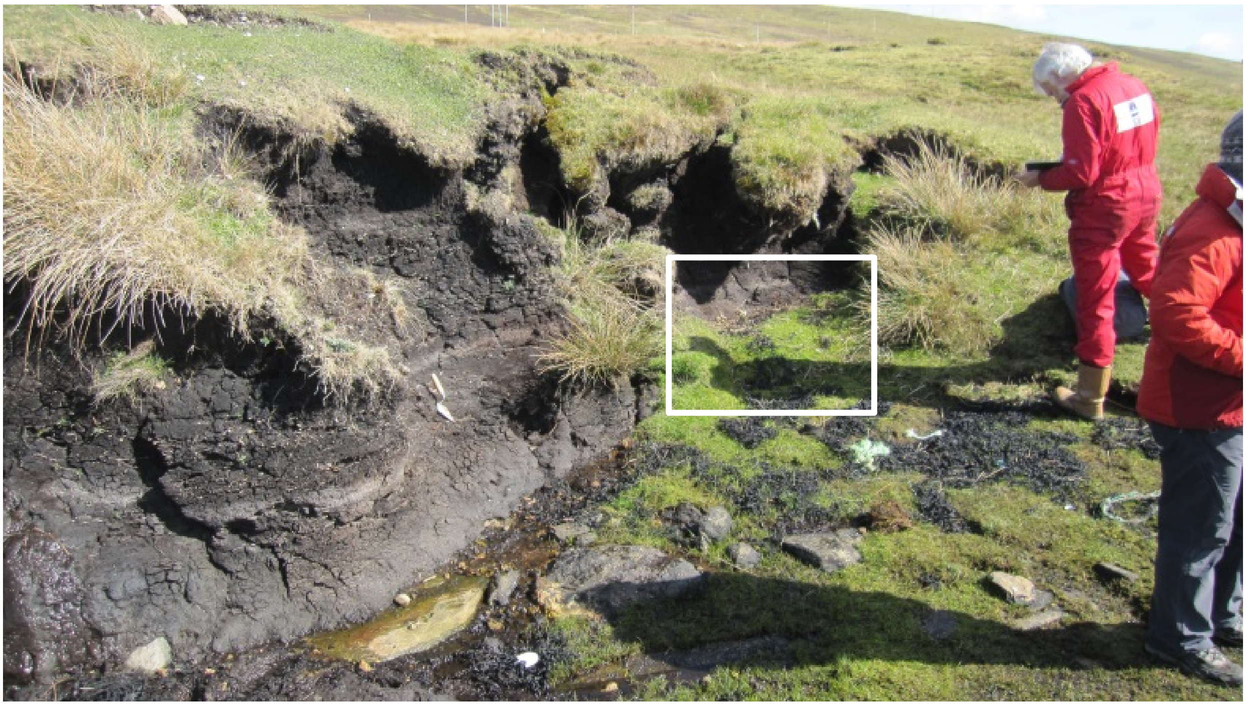

Figure 32 Mid Yell east; main sand bed before east pit (white box) dug (Fig 33). Location on Fig. 34.

We dug two pits along the section (Figs 33, 34) to review the results from the fieldwork in 2013. East of the headland (See Figs 32, 33 and 34) at Pit east the undulating sand bed in the peat described above is at beach level. The bed is ~5-7 cm thick, muddy, fine-coarse grained, with diffuse upper and lower boundaries.

Figure 33 Mid Yell east; sand at beach level at top of pit – located in Fig. 32 and 34. Diffuse upper and lower contacts and the birch wood in the peat both above and below the sand. (Nejiri-gama 23 cm long for scale)

Figure 34 Mid Yell, north shore, view west with headland in centre behind which the 2013 pit was located (Fig 4) and the location of the pits west and east of May 2014. Box is location of Figs 32 and 33.

Within the section to the east of Pit east we also found a sand injection (Neptunian) dyke or downward penetrating sand (Fig. 35).

Figure 35 ?Neptunian (injection) dyke or downward sand penetration, in the section at Pit east

In the centre of the section, beneath the cliff (Headland of 2013 in Fig. 34) where there are stones on top forming a small headland (identified as the same location sampled in 2013 – Mid Yell), clearing the peat revealed contorted sands at beach level (Fig. 36). A gouge core taken at the back of the pit penetrated the contorted sand, a sand layer at 0.39-0.44m and, at the base, a lower sand layer ~0.25 m thick, silty, but predominantly medium- to coarse-grained, micaceous with lithics up to 3cm diameter (Fig. 37). The basal sediment becomes clayey and may be till. In the peat above the exposed (upper), contorted, sand layer there are birch branches and logs up to 12cm in diameter (Fig. 36). A gouge core above this location on the top of the peat cliff sampled thin sand within the peat, just above the base.

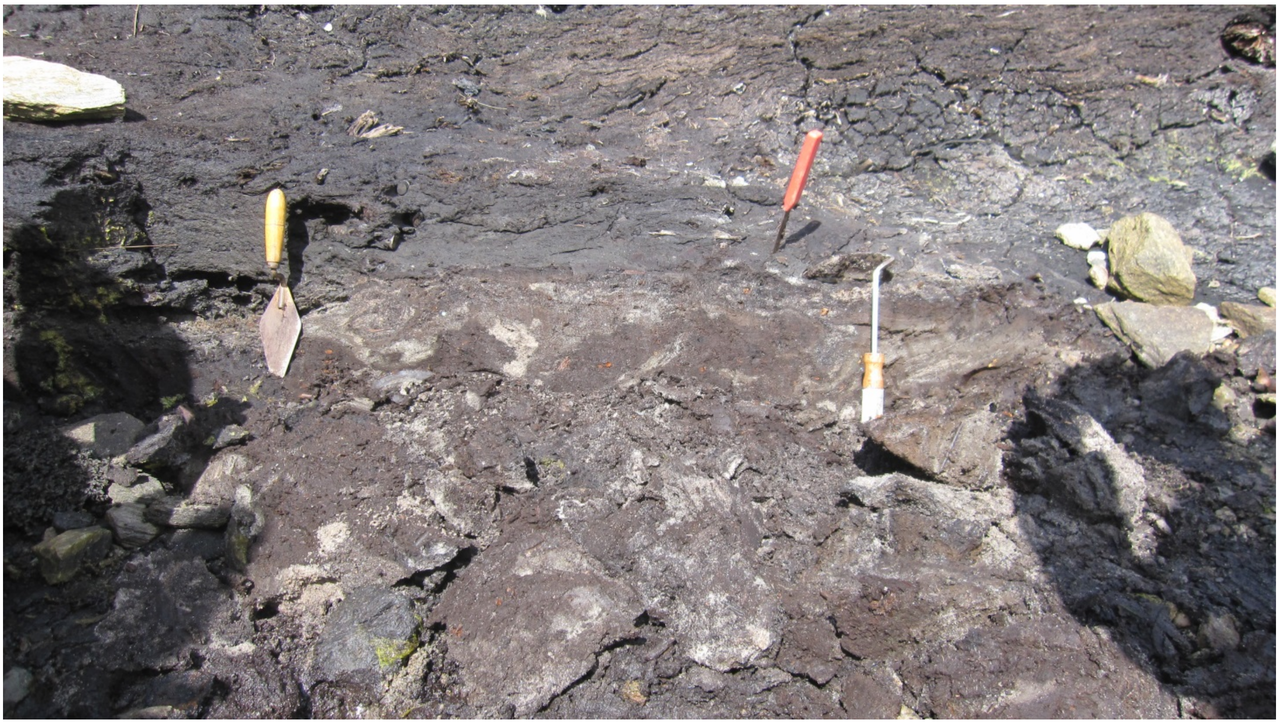

Figure 36 Centre pit section: contorted sands (Nejiri-gama 23 cm long for scale)

Figure 37 Centre section gouge core sand at 80cm (pen = 14cm)

At the location of the western pit (Fig. 34) there was no sand in the peat at beach level, but at the base of the pit we found sand at ~ 1m depth that we interpret as a continuation of the sand bed traced to the east. The sand is up to 10 cm thick, the base is sharp and undulating with faint internal lamination; it is very micaceous with organic clay or peat clasts. Above the sand there is a peat bed (~50 cm) with sparse twigs and then a peat layer with contains numerous twigs and logs (10-15cm diameter). A gouge core taken at the base of the pit sampled a sand layer 60-90cm extending below the base of the pit. Lack of core penetration suggests this sand immediately overlies till or bedrock. Above beach level the peat has a different texture (?Sphagnum moss blanket peat) and extends to top of the cliff which has a hummocky topography and is, covered with modern grass.

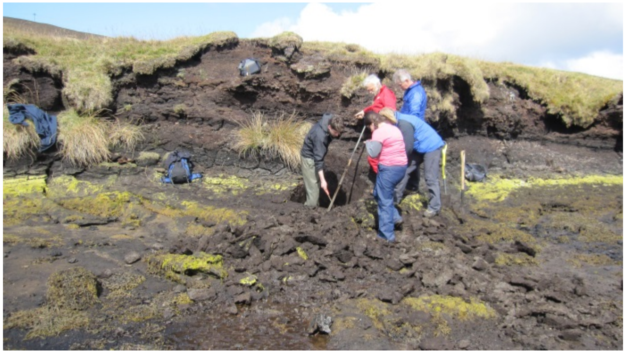

Figure 38 West Pit (location Fig. 28) detail on Fig. 32

Figure 39 West pit sand at base – note the birch wood in the peat

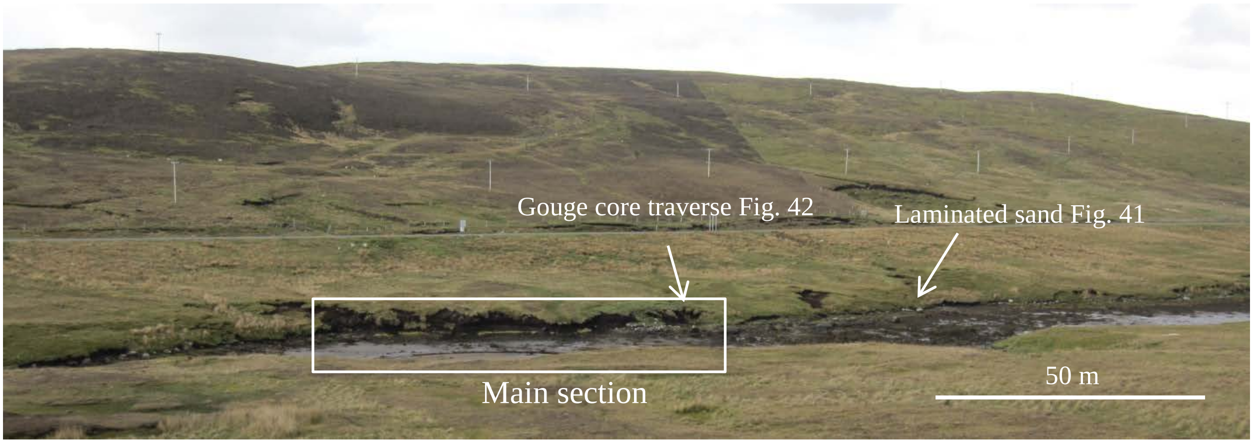

Figure 40 View north across Mid Yell Voe to main section with tsunami sands (outlined) and the laminated sand location to the east.

Figure 41 Laminated sand located east of mid-peat sands - location Fig. 40

Figure 42 Gouge core at traverse inland of east pit.

To the east of the main Mid Yell section and the eastern pit, there was a site with laminated sand within the peat (Figs. 40 and 41). The sand was up to 10 cm thick with sharp contacts at both the base and top. The relationship of the sand with the sand bed in the main section to the west is uncertain because of cliff collapse between, but both thickness and internal structure suggest that the two beds are not connected.

Landward of east pit we gouge-cored a traverse inland to trace the extent and elevation of the sand within the peat (Figs. 40 and 42). The sand was traced in two cores to 10 m inland (Fig. 42). At site 1, the sand was found 1.14 m below ground level, with base peat at 1.64m. At Site 2 the sand was sampled at 0.74m and the base peat at 1.14m.

A reconnaissance along the south side of the Voe found opposite the main exposure on the north bank further sand beds within the low peat banks (Fig. 43).

Figure 43 Archaeological remains on the south side of Yell Voe at WP 631 on Fig. 30. Thin sand bed within peat

3.2.2 South west Mid Yell

At the west of Mid Yell Voe (see Fig. 30) in the stream bed at the head of the Voe and in a peat cut on the south bank there is a thin (cm) sand laminae (Figs. 44 and 45) very similar to the sand a Basta Voe (see below).

Figure 44 Sand laminae in peat cut shown in Fig. 45

Figure 45 Peat cut - west Mid Yell (Location Fig. 30)

3.2.2.1 MID YELL – COMMENTS

Our re-evaluation of the sections at Mid Yell found evidence for only one laterally continuous sand bed within the peat section on the north side of the Voe that is most likely deposited from a tsunami. This sand is exposed within the peat cliff and can be traced 50m along section. The change in elevation of the sand we attribute to depositional draping over an uneven topography; a mode of formation that is strong evidence for a tsunami origin. The two other sands found at this location, one at the base of the peat section sampled in a core, and the second at the back of the beach, are probably not from tsunamis.

We consider the sands at the base of the peat section are more likely to be either weathered till, fluvial sands deposited before peat accumulation, lacustrine deposits (Fraser Milne pers. Comm.) or a combination of all three processes. Our arguments against a tsunami origin are that the basal sands are thicker than other tsunami sands found elsewhere on Shetland (except for the 1,500BP event), there are a number of individual beds, and the sands do not lie within the peat, a significant characteristic of other tsunami sands elsewhere, such as those at Whale Firth and Sullom Voe. With regard to the upper sand, again this is not laterally extensive and also that it is contorted and with a similar structure to some other, laminated sands, considered not to be from tsunami, found at other locations such as at the Loch of Vatsetter. Comparison of our results with those from the 2013 survey is difficult because the two section logs illustrated in Fig. 46 and 47 (Mid Yell 7a and 7b) are quite different with two intra peat sands in 7a and only one in 7b.

Figure 46 Mid Yell Voe with sites sampled in 2013 for dating

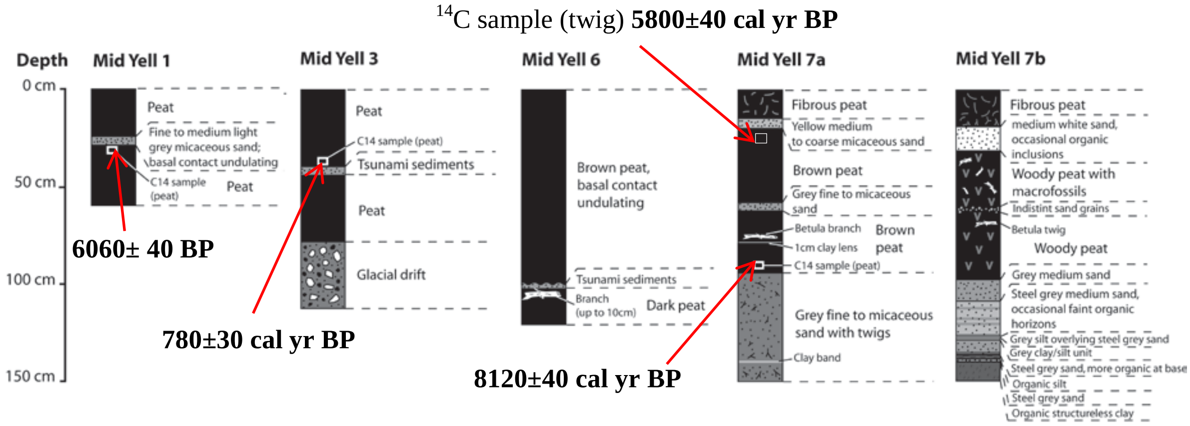

Figure 47 Previous 14C dating at Mid Yell – locations in Fig. 46 (Log from 2013 fieldwork)

The new age dating at Mid Yell is somewhat similar to the initial dating at Garth's Voe (Birnie, 1992) with an older date (8120±40 cal yr BP) at the base that suggests a Storegga age, and a younger, mid-Holocene age (5800±40 cal yr BP) below an upper sand layer (Fig. 47). Age dating of peat is well known to be compromised by contamination, but the 2013 identification of two upper sands within the peat at Mid Yell 7a is problematic although the upper sand could be the contorted sand bed we describe above. If so then the intra peat sand at 0.60m depth would equate with Storegga. Perhaps comparison to the Sullom Voe does provide an explanation; here later dates of ~5,000 BP, in the absence of positive identification of multiple and overlying sand beds as sampled in Loch cores, led to an interpretation that the younger dates were erroneous and due to contamination (Bondevik et al., 2005).

The laminated sands (Fig. 44) to the east of the main section at Mid Yell seem different (laminated) to the massive sands at the main section to the west around the headland, suggesting a different origin, but these sands appear similar to those at the base of west pit. There is further discussion of this below in the broader context of evidence from other locations, and a storm origin proposed only on the evidence from Mid Yell.

3.2.3 Whale Firth south (1)

Figure 48 Whale Firth south end with WP locations of photographs

Figure 49 Whale Firth section, looking south west with sand bed just above beach level

The section at the southern end of Whale Firth was as described in 2013 (Figs. 48 to 51) and now dated at 4760±30 ^{14}C cal yr BP. West of the jetty there is a persistent sand bed up to 12 cm thick within the peat that can be traced 50 .m along the coast. The sand bed has an undulating, but sharp, base and a fairly planar top; in places the sand is faintly laminated. The sediment is up to granule size, poorly sorted and organic rich and there are clasts of peat and clay. There was no evidence for the major rip up of the size clasts of the size seen at Sullom Voe, however, the enclosing peat is again very woody.

Figure 50 Sand bed at Whale Firth

Figure 51 Whale Firth; Birch roots below sand bed

At WP 703, we sampled the sand bed with the Russian corer (Fig. 52).

Figure 52 Whale Firth, Russian Core at WP 703 with sand between 13 and 24 cm

Further to the north at WPs 669-671 there were further disrupted and laminated sand beds (Figs 48, 52-53) similar to those seen at the east end of Mid Yell Voe section. The sand was just above beach level and formed discontinuous lenses with a combined thickness if 10-12 cm. At one location there was a cobble of mica schist enclosed. The peat inland of these sites was very hummocky, possibly due to extensive peat flows.

Figure 53 Discontinuous (?disrupted) sand layer within the peat at WP 671 (Nejiri gama 23 cm)

Figure 54 Discontinuous sand layers with cobble of schist within the peat (WP 671)

3.2.4 **Central Whale Firth (2)**

We also visited a small bay (Grimister) half down the loch (WPs 622-624) Figs. 28, 29 and 55. There was no peat at shore level, and the pasture land descended to the sea terminating at low rock cliffs; the beach was bouldery, but the valley feeding into the Firth was regarded as a possible coring site (later sampled in August 2014).

Figure 55 Whale Firth from Grimister Beach

3.2.4.1 COMMENTS – WHALE FIRTH

The significant thickness of the sand in the peat at the head on the Firth suggests a major tsunami event - ?Storegga, but there is an absence of rip up clasts as seen at Sullom Voe. There is only one ^{14}C date that suggests this to be the younger ‘Garth’ tsunami but the thickness and the absence of an older sand (as in the lakes) suggest that the age may be due to contamination as at Sullom Voe. The discontinuous sands north of the main sand are at about the same level and may be laid down from a tsunami but also from other mechanisms such as storms or peat bursts (see discussion below).

3.2.5 **Mid Yell core traverse**

To investigate the possibility that the Storegga tsunami (or any other event), inundated the col between Mid Yell Voe and Whale Firth we cored between the two locations (Fig. 56).

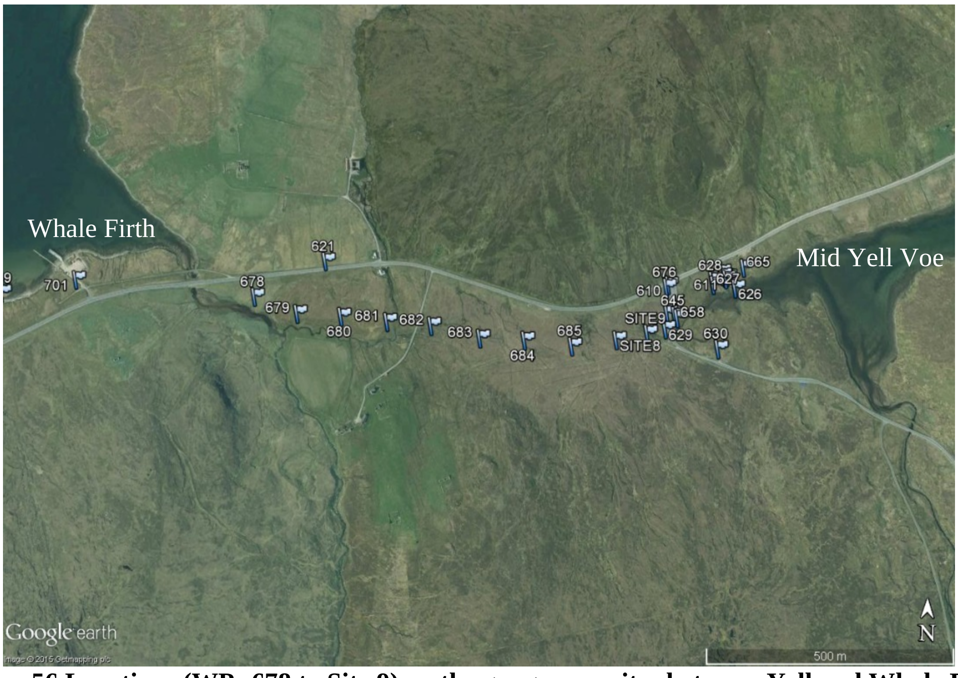

Figure 56 Locations (WPs 678 to Site 9) on the gouge core sites between Yell and Whale Firth

No definite indications of tsunami sediments were encountered. The results from the sites are presented in Milne et al. (2014).

3.2.6 Basta Voe

Basta Voe is an enclosed inlet on the east side of Yell (Fig. 57). Previous research has identified three sand layers in the low coastal peat cliffs (Fig. 58); but only the upper one has any great areal extent (Bondevik et al., 2005; Dawson et al., 2006). In a low coastal cliff, on its west side towards its northern termination we confirmed the presence of a thin (1-2cm) layer of sand within the upper section of peat (Figs. 59 and 60) as previously described. The sand is very fine-grained, very well sorted. The enclosing blanket peat shows several variations in composition, possibly reflecting environmental change. There is a dried peat layer about 25cm above the sand layer. The sand is mainly massive, but at one coastal site had a flame structure. The sand at the coast was traced landward in an extensive peat cutting extending orthogonally from the coastal peat cliff to the road (a distance of ~25m). The cutting reveals the sand layer (with possible climbing ripples – Fig 56) rising up slope at a fairly uniform depth below present surface of the peat and penetrating inland 70-80 m. The sand layer creates a line of weakness at which the peat blocks break as they dry out. Cut peat on the other side of the road also shows the same sand layer.

Figure 57 Basta Voe north with WPs

Figure 58 Coastal peat at Basta Voe – note multiple sand layers with the upper one dated at 1500BP

Walking up the west side of Dalsetter stream at the head of the Voe beyond the old bridge and up the Burn of Gossawater (Fig. 57), we traced a sand layer in the peat similar to that at the coast ~ 600m inland (limit is WP 615 on Fig. 57), thinning laterally up the valley side. The highest elevation is at +9 m OD ((Dawson et al., 2006). The sand is coarsest in the centre of the valley.

Figure 59 Basta Voe, peat cutting with thin sand bed

Figure 60 Sand bed in peat with ?climbing ripples travelling left (coast) to right

We looked for sands on the west bank of the Voe farther south of the sands at the head (Figs 63 and 57, WPs 643 and 644) but found none. At WP 643 (Fig. 61) bedrock was overlain by grey till and one to two metres of peat. At WP 644, only peat was exposed (Fig. 62). The peat is massive and there is no evidence of tree material at the Basta Voe sites, perhaps indicating the peat to be much younger here than at other locations at Mid Yell.

Figure 61 Coast at WP 643 (Location Fig 63)

Figure 62 Coast at WP 644 (Location Fig 57)

3.2.6.1 COMMENTS - BASTA VOE

The upper sand at Basta Voe has been dated previously at ~1500 cal yr BP and its origin proposed as from a locally generated tsunami (Bondevik et al., 2005; Dawson et al., 2006). The restricted areal extent of the lower sands led Dawson et al. (2006) to propose a storm origin for these. They traced the upper sand around the head of the Voe and suggested a local source. These interpretations are not disputed.

3.2.7 Kirkabister 1 and Burra Ness (Kirkabister 2)

Kirkabister is located southeast of the sands at the head of Basta Voe, on the end of the head land (Fig. 63 – WPS 616-618). In the cliff section (WP 616. Fig. 63) southeast of the old farm buildings at the back of the beach, there is a sequence of till overlying interbedded, peat, sand, gravel and clay (Fig 64).

Figure 63 Basta Voe WPs in the top left) and Kirkabister 1 (WP 616) and Burra Ness (617- 618)

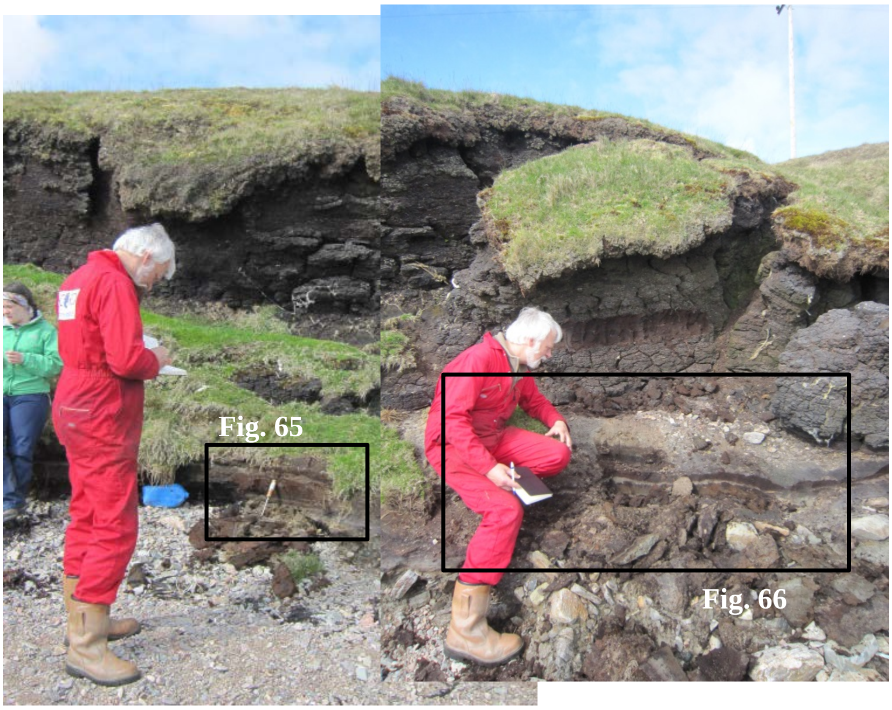

Figure 64 Cliff section at Kirkabister (WP 616) using overlapping images to show relationship between sections shown in Figs 65 and 66

The upper section in the coastal cliff is mainly soft peat with no sand (Fig. 64) approximately two to three metres thick, that overlies a more consolidated section at the base of the cliff where muddy peat is interbedded with laterally variable polymict gravels and mainly thin beds of grey sandy clay shown in detail in Figs. 65 and 66.

The section in Figure 65 (Located in Fig. 64) shoes a lower varicoloured grey laminated sequence of sandy clay (~3 cm) not seen in Fig 66, overlain by ~10 cm of brown muddy peat, within which (near the top) is a 2-4 cm thick pale grey-brown, muddy sand with a ?climbing ripple feature similar to the sand at Basta Voe (see Fig. 60); this unit is traced quite clearly into Fig 66. Overlying the muddy peat (see Fig 66) is an up to 10 cm bed of pale grey brown sandy clay. From Fig 64 it appears that this bed varies in thickness. The grey sandy clays are similar to the Storegga sand/clay at Maryton, near Montrose on mainland Scotland (Figure 67).

Figure 65 Kirkabister section. Note the pale, sand layer within the peat (top of Nejiri-gama) with a ?climbing ripple similar to the sand at Basta Voe in Fig 54, and grey muddy-sand at the base of the handle of the Nijiri gama

Figure 66 Kirkabister to the right of Fig 5865. Beneath the weathered peat (where Dave Long's arm is resting and bottom of spade handle) there is a sandy gravelly section (on the ledge) underlain by muddy brown peat within which is a thin (2-3cm) grey muddy sand that overlies till.

Figure 67 the Storegga tsunami deposit at Maryton in Scotland (Location on Fig.1)

3.2.8 Kirkabister 2 – Burra Ness

On the north side of Burra Ness (the headland east of Kirkabister – Fig 63; WPs 617-618) there are storm beach deposits (large stones) and back-beach (?aeolian) sands underlain by peat within which is a thin (2 – 3cm) sand layer – slightly muddy (Figs. 68 and 69). The peat surface on the beach may have been exposed in recent storms. These deposits were first discovered in 2013.

Figure 68 Close up of sand layer (at head of Nejiri gama) in Fig. 69.

Figure 69 Beach section on north side of Burra Ness at WPs 617-618. Box is close up in Fig. 68.

3.2.8.1 COMMENTS ON KIRKABISTER AND BURRA NESS

The section at Kirkabister is complex and requires more research to validate any tsunami origin of the sediments at the base of the coastal cliff. The lower section beneath the peat is quite unique; there could be two tsunami sediment deposits here, with the grey, sandy clays apparently very similar in appearance to the Storrega deposit on the east coast of Scotland at Maryton. There seemed to be considerable lateral variation in sediment thickness of the upper sandy clay. The absence of any birch wood compromises this interpretation however.

At Burra Ness (or Kirkabister 2) there was no strong evidence for tsunami deposits, except for the sand beneath beach level, however the similarity in appearance of the back-beach sands and the sands within the peat may suggest a common mode of formation.

3.2.9 **Loch of Vatsetter**

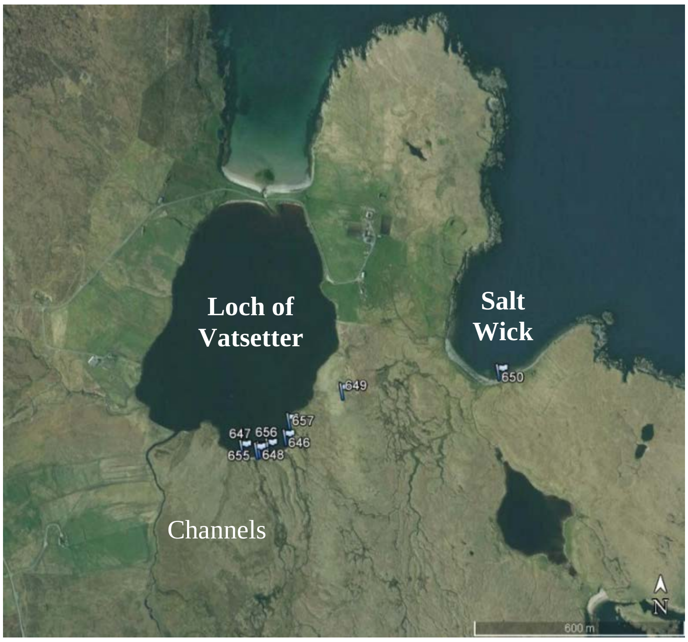

Figure 70 Loch of Vatsetter with WPs

The Loch of Vatsetter (Fig. 70) is on the east side of central Yell, cut off from the sea by a tombolo. On the southern side of the Loch at the base of a low coastal peat cliff there are limited exposures (20 m long) and up to 30 cm thick, of thinly (cm) laminated, fine-grained sands interbedded with peat (Figs 71 and 72) (WP 648 in Fig. 70).

Figure 71 Vatsetter Beach (WP 648) sand laminae at base of peat

The laminated sands units appeared to be preserved as channel fills (Fig. 71). In places the laminae are deformed (Figs. 72 and 73).

Figure 72 Vatsetter Beach. Deformed laminae at base of peat cliff (WP 648) cut out by overlying block

Figure 73 Vatsetter Beach. Close up deformed laminae (see Fig 66 for location)

The laminated sediments have a contorted base suggesting infilling of an irregular surface. The upper surface is cut and overlain by darker sand free peat (Fig. 72). The peat with the laminations is interpreted as a fallen or transported block.

Figure 74 Vatsetter Beach. Bedded peat with large birch wood and roots as described in the text

The location is at the coastal margin of a series of channels (Fig. 70) which may explain the features observed. The peat at this location is formed of a number of layers (Figs. 74 and 75): at the top there is one metre of fibrous peat overlying 70 cm of peat with Betula branches on clayey peat with large Betula branches at beach level; the block with the laminae seems to have slipped over this sequence.

Figure 75 Vatsetter Beach. The bedded peat lies behind the figure and the slipped block with the contorted beds is in the foreground

We augered landward of the edge of the peat cliff but found no evidence of sand.

We investigated Salt Wick on the outer west coast of central Yell (Figs. 70 and 76) for evidence of sand in the peat, but found none. On the storm beach at this location there are only a few patches of peat cliff extending to the shoreline; there is no evidence of old peat or sands, suggesting rapid erosion of the cliff.

Figure 76 Storm Beach at Salt Wick with eroding peat (Location on Fig. 64)

3.2.9.1 COMMENTS – VATSETTER BEACH

The sands at Vatsetter Beach are preserved in displaced peat blocks, with the displacement possibly associated with the streams at this location. Their origin is uncertain, but their very localised extent and the absence of any tsunami sediments at the locality discounts a tsunami origin. They are thus of either of marine origin or deposited by stream action; the absence of any extent landward suggests the former; further examination of their mineralogy is required to confirm this.

3.2.10 Other locations on Yell

Figure 77 Other Locations on Yell

We carried out a reconnaissance of the coastline of Yell Island (mainly in the east, north and south) to investigate for other sites where tsunami sands might be preserved (Fig. 77).

Gutcher (HU549993) (Fig. 78). No sign of potential preservation at Gutcher even in coastal inlet (Loch of Gutcher) at the ferry terminal.

Figure 78 View from road to east across Loch of Gutcher

The coast along Bluemull Sound (Fig. 77) didn't show promise. It was noted that this area had had improvements to the agriculture quality of the land such that blanket peat was rare and that worked fields extended to the coast.

Wick of Breakon (HP528051). Here (Fig. 79) there are extensive dunes that appear to sit directly onto bedrock with no evidence of peat. The sands here seem richer in carbonate than on other beaches.

Figure 79 Wick of Breakon view north west showing sand dunes, pasture and rock at the coast

Mouth of the Gloup Voe at Kirks of Gloup ((HP507050) (Fig. 80) there is an extensive storm beach of cobbles and larger clasts.

Wick of Whallerie. There is a thin till on top of the bedrock either side of the beach but no peats at the coast to preserve any potential tsunami deposit. There possibly was peat behind the storm beach but the ground rises up quickly and almost certainly the peat has been cut to produce pasture land.

Figure 80 Mouth of Gloup Voe, storm beach below headland

Southern end of Gloup Voe (HP506030). Here there is some peat but much wind-blown sand (Fig 81). It was noted that the Gloup inlet has several ayres at the northern end and at low tide the water is very shallow (Fig. 82). The position of tracks on either side suggests that it is easily fordable at low tide. The inner part of the Voe appears much deeper. If a tsunami wave entered this inlet it is likely to have become very broken up at the entrance and any wave reaching the southern end to be quite confused.

Figure 81 Southern end of Gloup Voe – note mainly pastureland

Figure 82 View north down Gloup Voe, a U-shaped glaciated valley, mainly pastureland

North Ay Wick (approx. HU537867) (Fig. 83). Looked at coastal sections from car, appeared to be bedrock and glacial and not promising for suitable peat sections.

Figure 83 View south over north Ay Wick, note the pastureland absence of peat and rocky coast

Otters Wick (HU525856, WP 651) (Location Fig. 77). Looked at coastal sections from car, appeared to be storm beach with bedrock and glacial deposits and not promising for suitable peat sections.

Wick of Gossbrough (approx. HU530833) (Location Fig. 77). Looked at coastal sections, where there is an extensive area of cliffs of laminated wind-blown sands showing cross cutting dunes. These extend along several hundred metres of the beach. Below the sands are bedrock and glacial deposits.

Burra Voe, near Hamnavoe (approx. HU494802 WPs 652) (Location Fig. 77). Checked peats at the top of the beach at the ayre. Here there are large blocks / rafts of peat up to 1.5m high. They show a sequence of peats including layers of Colluna (heather) within smoother sphagnum moss peat.

Checked site near fish farm at mouth of Aris Dale (river. approx. HU486808. WPs 653 and 654) (Location Fig. 77). Peat 1-2m high sits on top of sands and gravels (Fig 78). There are a few wisps of sand within the peat in the basal few centimetres of the sequence. At one location there is a curious horizon of large schistose boulders about 60cm above the base of the peat (Figs 841 and 85). Armouring of peat on Yell by beach boulders is report by Flinn (1994), who considered these to reflect storm events that allow preservation of peat during marine transgressions.

Figure 84 Peat at the fish farm at Burra Voe

Figure 85 Peat section at the fish farm with boulders at base

3.2.11 **Fetlar**

A day was spent on Fetlar (Fig. 86) conducting a reconnaissance survey for tsunami sediments. Fetlar is mainly composed of obducted oceanic crust, predominantly ophiolites, so soils are thin, peat is not well developed on the island. The land is mainly pasture

Figure 86 Locations visited on Fetlar.

On the southwest coast we visited the Wick of Triesta and Papil Water (WPs 686-688), here the coastal sand dunes directly overlie bedrock (Figs. 87 and 88).

Figure 87 Beach and dunes fronting Papil Water, Fetlar

Figure 88 Heh Jimmy! No peat here Eh!

On the southeast coast at Funzie Bay (Fig. 86) there is a storm beach composed of cobbles and boulders (Fig. 89).

Figure 89 Storm Beach at FunzieBay, east Fetlar

Figure 90 The rocks of Fetlar (inset board with geological description)

3.2.12 **Unst**

We carried out a reconnaissance visit to Unst to survey potential coastal sites (see locations on Figs 91 and 92) where tsunami sands might be preserved. Previous visits to the island (Smith, 1993b) had not found sands in the coastal peats, but deposits in cores had been found and dated at Norwick, Burragarth and Snarravoe (Fig. 91). Like Fetlar, the south eastern part of Unst is oceanic crust and composed of Ophiolite and gabbro, so peat is not present here, but seems to be well developed elsewhere, where the tsunami sands were cored.

Figure 91 Unst locations visited (red text locations where tsunami sands have been sampled

Figure 92 Unst locations visited - WPs

At Norwick the peat is 8 m thick and two sand units were sampled at about 4 m depth beneath ground and dated 6840±40 years ^{14}C (Smith et al., 2004). At Site 2, the lower part of the Burn of Norwick valley landward of coastal dunes is widely occupied by peat (Smith, 1993; Smith et al., 1995). In the centre of the valley at its seaward end, the peat rests upon a thin (ca 10–20 cm) layer of grey, micaceous, sand with angular clasts and organic fragments, beneath which is a laminated, grey-green, silty clay. The top of the silty clay is relatively uniform, lying at -3.38m (-4.70 m) to -4.17m (-5.49 m), with the top ca 25 cm not laminated, and contains a scatter of angular clasts (the largest 4 cm in its greatest dimension). Above these basal deposits, the peat is woody at its base and above this contains silty horizons. The sand continues up-valley forming a tapering wedge in the peat. Throughout, the sand contains peat intraclasts as well as many organic fragments. In the sand, the pollen includes *Chenopodiaceae* and *Plantago maritima*,, which may indicate a marine origin, given that the sites probably lay a considerable distance from the shore at time of deposition. There are exceptionally high percentages of corroded pollen and spores in the sand and at the top of the underlying grey-green, silty clay. A ^{14}C (AMS) date of 6840±40 (7748–7589) was obtained for the base of peat overlying the sand layer at borehole 140.

At Burragarth the northwestward-facing bay (Lunda Wick) is backed by dunes, landward of which a peat moss occupies the lower end of Vinstrick valley. At the base of the sequence lies a sand and gravel surface, overlain to seaward by a grey, silty clay which forms a gently sloping surface and thins out landward, reaching a maximum observed altitude of –3.65m (-4.88 m). Above the silty clay is a widespread layer of grey micaceous sand, up to 0.75 m thick, containing fragments of vegetation (roots, stems and twigs). Above the sand, peat with horizons of organic silt and sand extends to the surface. Towards the head of the valley, the sand layer attains an altitude of at least 4.11 m (2.88m) (Burragarth E., Table 4). The sand shows high values for corroded pollen and spores and at the top contains Chenopodiaceae (see Fig. 10, below). There are no diatoms in the fine sand, but the silty clay contains a few broken and eroded pennate forms, mainly *Pinnularia viridis.* Pinnularia occurs widely in Storegga tsunami deposits in eastern Scotland, incorporated into the tsunami sand as the tsunami moved across underlying freshwater sediments. The presence of Pinnularia fragments in the silty clay at this site could indicate re-working of the upper layers of that deposit as freshwater (possibly peaty) sediments either down valley or towards the valley sides were reworked. A radiocarbon date of 7215±60 (8165–7878) was obtained for the base of the peat at 4 m depth, overlying the fine sand in borehole 108 (Smith, 1993).

Coring at Snarravoe sampled sands at about one metre depth dated at 7785–7974 cal yr BP, and correlated with the Storegga event (Bondevik et al., 2005).

Nor Wick Beach (WPs 691-692) (Fig. 93). Very boulder, storm beach, no peat, with pastureland over rock cliffs that descend to the sea.

Figure 93 Nor Wick Beach

Burra Firth (WP 693) (Fig. 94). Mainly rock cliffs at the coast with a sandy beach at the head of the loch.

Figure 94 Burra Firth. West side of Loch looking south

Quoys (WP 694) (Fig. 95). Above Loch of Cliff, mainly pasture land, no peat.

Figure 95 Quoys. East side of Loch looking west

Houland (WP 696) (Fig. 96). Pasture land, no peat.

Figure 96 Houland. South end of Loch looking west.

Ham of Muness (WP 697) (Fig. 97). Pastureland, gravel/cobble beach, thin peat.

Figure 97 Ham of Muness looking east

Sand Wick (WP 698) (Fig. 98). Pasture overlying till on bedrock, no peat.

Figure 98 Sand Wick. Looking north.

Lunda Wick Bay (WP 699-700) (Figs. 99, 100). Pasture on till overlying bedrock; Sand and rocky (storm) beach.

Figure 99 Lunda Wick Bay. Looking east from St Olaf's church.

Figure 100 Lundwick Bay with St Olaf's Church showing a cliff of till

3.2.12.1 COMMENTS – UNST

No peat was observed along the coast, and no evidence of tsunami sands, that contrasts with the peat sections and tsunami sands recovered in the coastal valleys at Nor Wick and Burragarth, and in the lake cores at Snarravoe.

3.3 SUMMATION, GENERAL DISCUSSION

All of the main coastal exposures on Yell visited in 2013 where possible tsunami sediments had been identified previously were visited and all sediments present, examined. Tsunami sediments were confirmed at Basta Voe, Mid Yell Voe and Whale Firth. At Kirkabister more work is required to validate the sediments origin and at Burra Ness the sediments are probably not from a tsunami. The one site at Sullom Voe, Scatsta where tsunami sediments are proven provided a context to the Yell sediments, allowing the identification of both similarities and differences in the sediments at the different locations (Sullom Voe and Yell). The observations made during the fieldwork reveal a number of significant aspects of the different sands observed and their relationships to the peat which may be further developed to establish improved discriminating criteria for identifying their origin and (possible) different ages.

3.3.1 Relationships between the tsunami sands and the peat

The field work confirmed preservation of tsunami sands in coastal peat at the Yell locations noted above. A significant aspect of the preservation of the sands (or lack of them) is that they were deposited, and are now preserved, in thick coastal peats. Preservation of the tsunami sediments is thus dependent on peat accumulation which is primarily controlled by the underlying rock type. Significant peat accumulations are found on till or siliceous rocks such as Old Red Sandstones and metamorphic schists and gneisses. It is these rocks which form the bedrock of Yell, much of northern Mainland and northeast (Nor Wick) and southwest (Barragarth) Unst. This explains in large part why the potential for finding tsunami sediments along coastal exposures at these locations is so high. The large areas of serpentine in Unst and Fetlar produce a very poor soil able to support few plants but not significant accumulation of hill peat; again explaining why tsunami sediments are not found there.

The fieldwork identified significant features of the peat/tsunami sand relationships. The first is that, at Whale Firth, Mid Yell and around Sullom Voe, where the tsunami sands are definitely identified, they lie towards the base of the peat sequence, resting on a significant underlying peat thickness (of at least 0.5m) usually with a greater peat thickness above. The second feature is that, at all these locations (Whale Firth, Mid Yell, and around Sullom Voe) the peat within which sand is preserved tends to be very ‘woody’, with a significant proportion of large birch roots and branches.

At Whale Firth, the single sand bed is preserved towards the base of the peat; it is up to 12 cm thick and very similar in lithology (except for an absence of large rip-up clasts), thickness and extent to the sands at Sullom Voe. The sand was traced inland to an elevation of 8-9 m above sea level (Milne et al. (2014); all evidence that supports a tsunami origin.

At Basta Voe the sediments were as described previously, with three sands present, but only the uppermost sand traced significantly far inland and up the stream slope, which supports a tsunami origin. The peat/tsunami sand relationship at Basta Voe is different to the locations at Whale Firth, Mid Yell and around Sullom Voe. The sand is preserved in the upper part of the peat section, the peat is a ‘blanket’ deposit, and not ‘woody’.

3.3.2 Age dating of the tsunami sands

There are no established ‘unique’ sedimentological criteria for identifying tsunami sediments, for example, that allow their discrimination from other high energy processes such as storms, although work is progressing on this (Costa et al., 2015; Costa et al., 2012). For the most part, recent tsunami deposits are identified from their immediately recorded source mechanisms, such earthquakes in the instances of the Indian Ocean, 2004 and Japan, 2011. Palaeotsunami deposits are also recognised from their relationship to an identified source mechanism, with the relationship usually established from a positive correlation between the age of the source mechanism and the age of the deposit; an excellent example is of course the correlation in ages of the coeval tsunami sand deposits in Scotland with the Storegga landslide off Norway.

Until recently most tsunami sands in Scotland have been identified or been assumed to result from the Storegga landslide off Norway; because no other submarine landslides, either off Norway, or off Scotland, have associated coeval sediments that indicate a tsunami was generated. This does not mean, however, that these landslides did not generate tsunamis, it is just the preservation potential of these sediments is very low. It is also now apparent that on Shetland age dating of the peat in which the tsunami sediments are preserved may be subject to contamination that compromises what should be straightforward correlations with putative sources.

Thus, when the most likely origin of the 1,500 cal yr BP sediments at Basta Voe was identified as from a tsunami, it was somewhat contradictory that, conversely based on the foregoing, no immediate source was identified. Subsequent dates of 5-6,000BP from Yell in 2013 were further confusing because, although there were submarine landslides of approximately this age off Norway (e.g. Traenadjupet), identifying these sources was compromised by the limited extent of the deposits (none being found anywhere else) that indicates the source to be local. Thus from Shetland, there was the possibility of two local tsunamis, but no source mechanism.

Based on the evidence from Basta Voe (with additional confirmation of an event of this age from farther south at Dury Voe on Mainland), both sedimentological and ^{14}C dating, although there is no obvious source mechanism, it seems most probable the sediments here are from a locally generated tsunami; yet to be found.

The dating evidence from Mid-Yell and Whale Firth for a mid-Holocene tsunami requires further and careful consideration. There is strong evidence for a mid-Holocene (~5,000 year) event from lake cores farther south on Mainland where two events are recorded within two stratigraphical sequences at two very close locations; sedimentological and age dating evidence is strong; as with Basta Voe however, there is no obvious source mechanism.

The evidence on the tsunami source from Yell at this stage, is inconclusive. The sand at Whale Firth is remarkably similar to the sands at Sullom Voe (except for the absence of large rip-up clasts); it lies within a woody peat, so a Storegga source seems to be most likely, except the one date here is mid-Holocene (4760±30 cal yr BP). There is no sequence, similar to those cored at Loch Benston and Garth Loch, which would provide a firmer context (two sand layers at one site with different ages). Thus the identification in 2013 of three sand layers within one stratigraphic sequence at Mid Yell promised to provide a firmer basis for a mid-Holocene event. It is thus unfortunate that the results from our 2014 visit do not confirm the presence of more than one tsunami sand at this location. The thick sand at the base of the peat, because of its' thickness and stratigraphic position (at the base of the peat) where it overlies till or bedrock (not within it as seen elsewhere at Whale Forth and Sullom Voe), is probably not a tsunami deposit. We suggest it is weathered bedrock, mineralogenic sand laid down before the peat formed (as described by Flinn, 1994), a lacustrine sediment (Fraser Milne, *Pers. Comm*.) or a combination of all three processes. Only one tsunami sand therefore is confirmed at Mid Yell, its origin interpreted as such because it is preserved fully within the peat and because of its lateral extent along the section; its variable elevation, high in the east, but below ground level in the west supporting a tsunami origin.

Our interpretation of a single, laterally extensive mid-peat sand is hard to reconcile with the logs of the Mid Yell 7a and 7b logs reproduced in Dawson et al. (2013). The sequence we identify most resembles Mid Yell 7b with an upper sand preserved in woody peat and overlain by fibrous peat. The lithology of the sand we describe within the woody peat is different to the sand at Whale Firth (and hence Sullom Voe) in that it is thinner, muddier, the upper and lower peat contacts are not as sharp, and in places it is contorted. Not being able to relate our results to ^{14}C dates of Mid Yell 7a compromises our interpretation of the age dating from this section. If we are correct that the basal sand in Mid Yell 7a is not from a tsunami, then the lower of the overlying two sands should be Storegga and the upper a mid-Holocene event based on the peat age of 8120±40 cal yr BP for the lowest peat and the 5800±40BP age from the peat immediately below the upper sand. From a similar location, Milne et al. (2014) identify in a gouge core two 5-6 cm intra-peat sands above the basal sand in Mid-Yell Log 7 (contorted sands location).

The other dates from Mid Yell of 6060±40 cal yr BP at Mid Yell 1 (by the road) and 780±30 cal yr BP from Mid Yell 3 (at the west end) do not really provide any further confirmatory evidence on the likelihood of additional tsunami events, except that at these locations there is only one sand within the peat, that perhaps confirms a single laterally extensive event.

3.3.3 Tsunami sands at other locations?

At Kirkabister, on the south side of the headland, a complex series of peat/clay/sand/gravel interbeds at the foot of a low coastal peat cliff are of uncertain origin. One clay bed is similar to the Storegga sediment at Maryton on the east coast of Scotland. The absence of a significant thickness of peat beneath the sediments together with no evidence of woody peat above or below the sand compromises the interpretation of their origin from a tsunami of 5,000 or 8,200 years BP. The clastics could be from a younger tsunami - ?1,500BP, but their lithology is completely different.

No further convincing evidence of tsunami sands was found at any other location visited on Unst, Fetla, Yell or Mainland.

3.3.4 The 'laminated' sands

Other sand layers and lamina we discovered at Whale Firth, Mid Yell Voe, Vatsetter and Basta Voe are probably not tsunami deposits. The two lower sand laminae at Basta Voe are probably storm deposits because of their limited extent (Dawson et al., 2006). At Whale Firth, Mid Yell and Vatsetter the laminated (cm) sands in the peat are of uncertain origin, although several observations suggest they are not from a tsunami; at both Whale Forth and Yell the sands are at a similar elevation to the tsunami sands identified at these locations. Differences between the laminated and tsunami sands include; i) their laminations within the peat and ii) their limited lateral extent both along the coast and inland. At Vatsetter, tsunami sands are absent, but here the laminated sands are preserved in displaced blocks (seaward of hummocky peat morphology) at the mouth of a series of small streams. The laminated sands at Whale Firth were also associated with streams and an, inland, hummocky peat topography. There are no streams at Mid Yell, but the sands here are also preserved in displaced blocks. At all three locations the laminated sands were not preserved in woody peat, although the sands in the displaced blocks at Vatsetter were overlying woody peat with large birch logs that were well exposed in the coastal cliff just to the west. The 'overthrust' relationship of the blocks to the woody peat at Vatsetter demonstrates lateral movement towards the coast.

Alternative origins of the laminated sands (discounting tsunami) include deposition from streams or some form of peat block displacement, such as from bog bursts (see Appendix 2), both of which would account for their limited lateral coastal extents and local associations with streams and translated blocks; but a lack of landward extent of sand in the gouge coring (which might be expected) does not support either of these interpretations (see Appendix 2 for further discussion). A marine or wind-blown origin is also possible, but if this was the explanation, why are the sands not more common along the coast? Further research is required to determine the origin of these sands, but in the context of this report, the most important conclusion is that they were not deposited from a tsunami.

3.4 CONCLUSIONS

There is undoubtedly strong evidence for tsunami sands within the coastal peat exposures on Yell resulting from the May 2014 fieldwork, that confirms some, but not all, of the conclusions of field visit results from 2013. The evidence is supportive for tsunami sands at both Whale Forth and Mid Yell, but the age of these deposits and hence their source mechanism, requires further investigation. At Mid Yell there is good evidence for one laterally extensive deposit that drapes a previously existing undulating peat surface. The basal sand, on the basis of the peat stratigraphy is considered either to be weathered bedrock or monomineralic sands (lacustrine?? Pers. comm. Fraser Milne) laid down before the peat development.

The preliminary ^{14}C dating suggests that in Shetland there might be three tsunami events, but only 8,150 BP Storegga has a positively identified source, confirmed by coeval deposits on mainland Scotland. The absence of coeval deposits on mainland Scotland for the younger events compromises somewhat the tsunami interpretation for the two younger events as it is more usual that there is a tsunami source mechanism, but no corroborating sedimentary evidence, rather than *vice versa* with sedimentary evidence but no source.

A mid-Holocene tsunami is indicated by the lake core data from Mainland Shetland and preliminary age dating available from the sediments on Mid Yell supports the presence here of this event., However the deposits on Mid Yell are very similar to those in coast sections around Sullom Voe which are interpreted as sourced from Storegga; these deposits (as Sullom Voe) were also initially dated as mid-Holocene in age, with dates similar to those recovered from Mid Yell and Whale Firth, so does contamination also explain the younger dates at these locations? Further work is required.

The sands and dating at Basta and Dury Voes support another (younger) tsunami event; unfortunately only the first location was visited. The young age dating and the blanket peat in which the sand is preserved that is not 'woody' compared to coastal sections at Whale Firth, Mid Yell (and at Sullom Voe) suggest that the deposit seems most likely from a tsunami much younger then Storegga, and with a local source, as yet unidentified.

An important result of the 2014 fieldwork has been the identification of a possible relationship between the tsunami sands in the coastal peat exposures and the peat stratigraphy. Further examination of this relationship may provide a context to the age dating that will help in differentiating between the (mid and early Holocene) ^{14}C ages. The age period over which the tsunami sands were deposited experienced major climatic changes that are reflected in the vegetation (see Burnie, 1988), thus the peat palynology may provide an answer. The tsunami deposits at Whale Firth and Mid Yell were deposited in woody peat with a significant proportion of Birch. The youngest deposit at Basta Voe was deposited in blanket peat with no wood; the work by Birnie at Dury Loch suggests that this change is reflected in the palynology. The striking similarity between the Mid Yell/ Whale Firth deposits and those at Sullom Voe, both in sedimentology and stratigraphy suggests that they are the result of the same event. In isolation; ^{14}C dating may not solve this problem, but further research on peat stratigraphy just might.

With regard to the deposits at Kirkabister, their position at the base of the coastal peat sequence is at variance with the intra-peat tsunami deposits found elsewhere on Yell and on Mainland and suggests that may not be from the same tsunami source mechanism(s) as the sediments elsewhere on Shetland; further research is required.

The origin of the laminated sands found at Whale Firth, Mid Yell and Vatsetter is still uncertain, but they are probably not deposited from a tsunami, which is our primary interest here. Other mechanisms for emplacement include peat slides, flash floods, aeolian.

Postscript; Immediately after this report was finalised, age dating of peat sections at Whale Firth and Mid Yell Voe confirmed that the sands preserved in the woody peat here are of Storegga age, ~8,200 cal yr BP.

Appendix 1 Field Trip Diary

9th May 2015. Dave Tappin drives from Nottingham up to Edinburgh, stays overnight.
10th May 2015. Dave Tappin drives from Edinburgh to Aberdeen to catch the ferry to Lerwick in Shetland. The ferry stops at Kirkwall in Orkney where we pick up Dave Long. Overnight on the ferry (Watch the Eurovision Song Contest).
11th May 2015. **Visit Sullom Voe and the Scatsta Voe** site to introduce to the new visitors to Shetland the original Storegga tsunami deposit location. Small burn flows over the deposit forming a waterfall just down from new layby and information board. Tried to find the Dury Voe site of Burnie (1992) to the east, but this is now built over by the new road. Whilst on Mainland we examined the northernmost location, Isbister, for evidence of the Storegga event, bur unsuccessfully. The beach at Sand Voe is backed by thick till with no evidence for sand, and to landward is the Loch of Flugarth which might preserve the event (not previously sampled). DRT WPs 606-609.
12th May 2015. Visit Mid Yell Voe (DRT WPs 610-611). Observe a 3-4 m section of peat with one sand layer exposed and one at depth sampled in a gouge core; the sands are micaceous and organic rich, returning various ^{14}C dates ranging from 8120 to 730 cal ^{14}C BP. Birch wood is buried within peat above and below the sand layer. To the east, around a small headland is a second site with laminated sand and peat. Drive to the north end of Basta Voe to observe the thin (cm) sand bed dated at 1500BP (DRT WPs 612-615), then to Kirkibister (DRT WPs 616-618) to examine the section on the south side of the headland visited for the first time in 2013.
13th May 2015. Yell Island; visit the southern end Whale Firth to inspect the ?tsunami deposit discovered in 2013, then on to the north coast of Mid Yell Voe for further research on the sands there and then walk around the south coast of the Voe to visit the archaeological remains and a very thin sand in the peat cliff.
14th May 2015. Reconnaissance of Yell to search for tsunami sands on the coast (DRT WPs 616-654). At the north end of the island, at Gutcher, no evidence was found, even in coastal inlet (Loch of Gutcher) at the ferry terminal (HU549993, WPs 632-633). The coast along Bluemull Sound didn't show promise either. It was noted that this area had had improvements to the agriculture quality of the land such that the peat blanket common elsewhere on Yell, was rare and that worked fields extended to the coast. At Breakon the extensive dunes appear to sit directly onto bedrock (HP528051, WPS 635-6) with no evidence of peat in which tsunami deposits are usually preserved. The sands here seem richer in carbonate than on other beaches. At the mouth of the Gloup Voe, at Kirks of Gloup, there is an extensive storm beach of cobbles and larger clasts (HP507050, WPs 637-8) – Wick of Whallerie. Here there is a thin till overlying bedrock on either side of the beach but no peat at the coast to preserve any potential tsunami deposit. There possibly was peat behind the storm beach but the ground rises up quickly and here and almost certainly the peat has been cut to produce pasture land. At the southern end of Gloup Voe (HP506030, WPs 639-640) there is some peat here, but much wind-blown sand. It was noted that the Gloup inlet has several ayres (tombolo or sand bank) at the northern end and at low tide the water is very shallow. The position of tracks on either side of the loch suggests that it is easily fordable. The inner part of the Voe appears much deeper. If a tsunami wave entered this inlet it is likely to have become very broken up at the entrance and a wave reaching the southern end would be quite confused. On the return to Mid Yell an examination of the coastal peat sequences along the southern shore of Basta Voe south of the peat cuttings around the new jetty for the fish farms (HU512980, WPS 6553-654) found no sand layer. The coastal peat cliffs are over a metre high and overlie thin till upon bedrock. As well as no evidence of sand within the peat there is no tree material evident, that may imply that the peat here is younger than mid Holocene although there is no younger sand present as seen at the head of Basta Voe.
15th May 2015. Strong winds and rain. **Yell.** Visit Loch of Valsetter on the east coast of Mid Yell to look for sand in the coastal peat. In the area of tombolo (HU534896) the coastal cliffs are formed of glacial deposits. Walked around southern edge of the Loch to examine the peat cliffs which are best approached from eastern side to avoid the river.
At HU535889 (WPs 646-657) there is a peat cliff about 2m high which displays a sequence of:

1m of fibrous peat
70cm Peat with birch branches and logs up to 10cm diameter
20cm clayey peat,

but no sign of sand. Clays beneath the peat appear glacial. At approx. HU534889 (WP 648) between where two streams enter the Loch as marked on OS map there are laminated (<1cm) sands within the base of the peat. These are at the horizon in the peat with logs. The base of the interbedded laminated sediments is contorted, suggesting that they infill an irregular surface. Their upper surface is crosscut and overlain by darker, sand-free peat. This surface may represent a fallen or transported block of peat. Thin layers of micaceous sand can be seen towards the base of the peat cutting on eastern side of the western stream (of the two mentioned above). These are located within the peat with tree branches including pieces of Betula bark. At Salt Wick, approx. HU542891 (WP 650), there is a storm beach at the back of which there are a few patches of peat cliffs extending to the shoreline. There is no sign of old peat or sand, suggesting that cliff is rapidly eroding. Visited coastal sections at North Ay Wick (approx. HU537867, WP 651) and viewed from the car; these appeared to be composed of bedrock and glacial till, thus they are not promising for peat sections. Visited coastal sections at Otters Wick (approx. HU525856) and viewed from the car. The section appeared to comprise a storm beach overlying and backed by bedrock and glacial deposits, and thus not promising for peat preservation. Looked at coastal sections at Wick of Gossbrough (approx. HU530833) where there is an extensive area of cliffs of laminated, wind-blown sands showing cross cutting dunes. These extend along several hundred metres of the beach. Below the sands are bedrock and glacial deposits. Checked peats at top of beach at the ayre near Hamnavoe (approx. HU494802, WP 652), where there are large blocks/rafts of peat up to 1.5m high. The blocks have a sequence of peats including layers of *Colluna* (heather) within smoother sphagnum moss peat.

Checked site near fish farm at mouth of Aris Dale River (approx. HU486808, WPs 653 and 654), where a peat cliff is 1-2m high overlies sands and gravels. There are a few wisps of sand within the basal few centimetres of the pat sequence; at one location there is a curious horizon of large schistose boulders about 60cm above the base of the peat.

16th May 2015. Mainland. Examination of various inlets on the eastern side of Mainland where peat is notably absent; locations visited include Colla Firth, Swining Voe, Vidlin Firth, Dury Voe, Loch of Benston and Garth Loch. There are no coastal peat cliffs, but inland, peat sequences except at Dury Voe, but peat might be found through coring (as at Loch of Benston.

17th May 2015. Gareth Carter arrives, picked up at Sumburgh Airport. **Yell.** Visit the NW end of the Whale Firth site at the south end of the Loch where there is a separate laminated sand layer within the peat, located within the zone of peat wood fragments. The sand is located downslope of an area of hummocky peat, which appears to form the distal end of a debris flow.

18th May 2015. Dave Long departs – taken to Sumburgh Airport. Observe on route the dramatic landscape of the Channerwick peat slide. **Basta Voe**. Visit the site of the thin sand.

19th May 2015. Mid Yell. Work on the north side of the Voe, examining the peat and sand, gouge core inland of the main section above the ?archaeological site. Then carry out the gouge core traverse between Whale Firth and Mid Yell Voe; 9 sites cored, but no tsunami sand found.

20th May 2015. Visit **Fetlar** to investigate for tsunami sands; firstly to the south coast where a tombolo divides Papil Water from the Wick of Triesta; here we find a sandy beach at the rear of which is boulder storm beach. There is no peat in the 3-4 metres high coastal cliffs and Aeolian sand overlies bedrock of Old Red Volcanics. At Funzie Bay on the west coast, there is a storm beach of cobbles and boulders, with the bedrock geology here is of metamorphosed sediments of the ophiolite complex.

21st May 2015. To **Unst,** to carry out a reconnaissance survey of the coast for peat; the weather is very wet and visibility low. We first visit the Heritage Centre at Haroldswick which provides a cup of coffee and some interesting insight into the history and development of the island, especially the relationship between the relationship between peat development and bedrock; peat forms mainly on till or on siliceous rocks such as Old Red Sandstones and metamorphic schists and gneisses. The large areas of serpentine of the ophiolite complex forming Unst and Fetlar produce a very poor soil able to support few plants and hill peat never formed on them. We then visited Nor Wick in the northeast, where we find no peat as the bedrock is ophiolite. At Burra Firth we find that there is bedrock at the coast and sand dunes. Inland at Quoys there is mainly pastureland; at the southern end of the Loch there is a similar landscape. Travelling south to the Ham of Muness we find a bolder beach and pastureland at the coast resting on a thin till, but again with no peat. At Sand Wick the till at the coast is thicker, the beach is sandier, but again no peat is present. On the southwest coast we visit Lunda Wick Bay by St Olafs Church where there is a sandy beach, with storm cobbles at the rear fronting low cliffs of thin till overlying Old Red Sandstone.

22nd May 2015. Yell. Back to Whale Firth for Russian Coring of the tsunamis and at the south end of the Firth. Then to the east end of the core traverse to Mid Yell Voe, to core at Site 9.

23rd May 2015. Packing up before heading off home.

24th May 2015. Depart Yell. Coffee at the Wee Haas, then onto the ferry to Mainland. Detour to Eshaness Headland to look at the storm deposits on the cliffs; then to Lerwick to catch the ferry to Aberdeen; overnight on the ferry (watch the European Champions Cup final).

25th May 2015. Drive Aberdeen to Edinburgh to drop Gareth Carter off, then Dave Tappin drives home to Nottingham.

Appendix 2 Sand Layers in Peat (Dave Long)

The peat cover on Yell is exceptional, even by Shetland standards with peat extending down to the shoreline where it forms small cliffs. These cliffs along with the abundant peat cuttings provide an opportunity to observe/trace mineragenic layers and using the adjacent organic material to date the event that emplaced them. Various ideas were discussed as to mechanisms to emplace continuous sand layers within the blanket bog at the coast. These mechanisms included: Storm surge, Tsunami deposition, Aeolian (wind blown), Peat slide.

The regional guide (Flinn, 1994) suggested that previously 97% of Yell had been peat covered and that currently 63% has more than half a metre of uncut peat. However he suggests that as this is mostly blanket type peat that based on data from Orkney and elsewhere on Shetland this peat started to accumulate about 3400BP. Radiocarbon dating since by Dundee University have disproved that, demonstrating that the peat has developed over a considerable longer time period. Flynn (1994) notes that in many places in Yell about 10cm above the base of the peat are to be found tree roots and branches up to several centimetres in thickness. In many cases they are of silver birch. He also notes that layers of sand and/or gravel, generally up to 10cm thick, are commonly visible in the peat along the banks of streams high up in the hills. Such occurrences extend down to the shores without change in character, and all appear to be the result of streams overflowing their banks as the result of heavy falls of rain.

POTENTIAL DEPOSITIONAL MECHANISMS

Storm surge
Shetland is subjected to strong waves. Deposits attributable to storms have been well reported from cliffs (e.g. Hall et al. 2006). The fact that the source material is potentially on a beach or in shallow water would support an inland thinning of a deposit resulting from winds or waves transporting the grains inland. However it is unlikely to transport cobbles or boulders.

Studies elsewhere suggest that tsunami and storm deposits can be distinguished (Tuttle et al., 2004).

Tsunami
The evidence is strong that Shetland has been struck by the tsunami wave triggered by the Holocene Storegga Slide .

Aeolian
Other than wind-blown sands during strong storms the other source of mineragenic layers within peat deposits are tephra-falls from volcanic eruptions. These events have been noted historically in Shetland (Thorarinsson, 1980) and the deposits found and studied in a variety of deposits (Bennett et al., 1992; Dugmore et al., 1995). The source of the tephra is Iceland. However many often events recorded within the peats are very thin (only a few mm) and often only noted during microscopic examination.

Airfall deposits are usually of even thickness and found at all altitudes, unless they are reworked by downslope waterflow. They therefore do not show the characteristic of the suggested tsunami deposits of thinning inland.

Peat Slides
Peat slides (aka bog-bursts) are well known in Shetland. They are a hazard that the local authority has to consider in many aspects of planning; development, infrastructure, civil contingencies. In August 2012 extensive flows of peat occurred following heavy rain at Uradale. These travelled downslope transporting a vehicle about 400m (Fig 101) (http://www.shetlandtimes.co.uk/2012/08/22/landslides-hit-central-mainland-including-uradale-farmhouse). These flows can transport sediment from the peat boulder clay / bedrock interface that may include sands and even gravel. In many cases the peat moves as a single mass or a series of blocks that extend the full thickness of the peat. Almost all the failure surfaces are at the base of the peat. The morphological features include large blocks, linear compression, thrust features resulting in hummocky terrain and unusual occurrences of mineral debris (Dykes and Warburton, 2008). Studies of peats on Yell have shown that the peat can reach 5m in thickness and these sliding events have been dated to the mid and late Holocene (Veyret and Coque-Delhuille, 1993).

Figure 101 Urdal peat slide, August 2012

Images of a major peat slide (19th Sept 2003) at Channerwick in south Mainland show that it can comprise large intact blocks as well as extensive of fluid peat material on which the peat blocks are transported (Winter et al., 2005). The erosion extended down to bedrock where it was able to incorporate other material into the debris flow (Fig. 102). This event occurred following very heavy rain falling onto ground that had dried previously. Cracks within the peat provided conduits to the base of the peat where the impermeable bedrock caused the relatively light peat to lift off and flow down the hillside. Once moving the partially saturated peat moves rapidly as a debris slide with peat blocks breaking down into smaller sizes (Nettleton et al., 2005; Winter et al., 2005). These blocks can incorporate mineragenic layers from the bedrock interface and may even deposit them out of sequence through overturning (Fig. 103)(Dykes and Warburton, 2008).

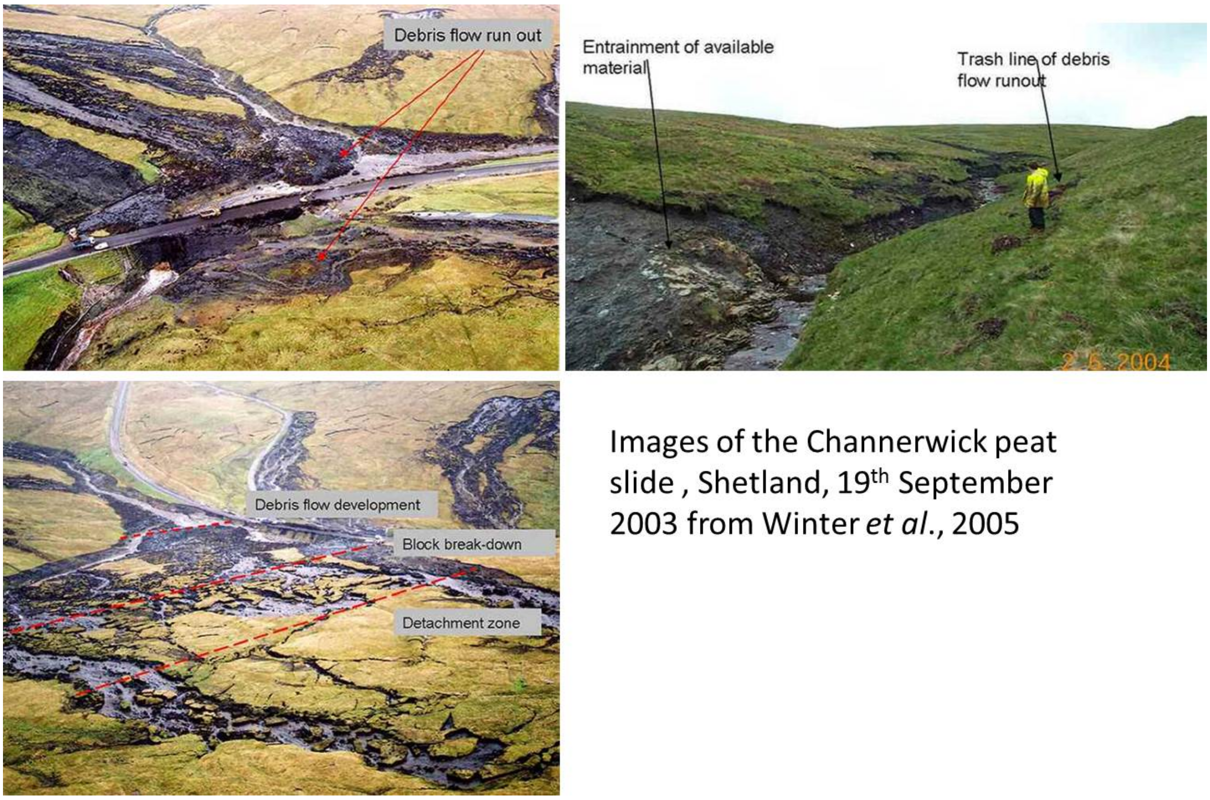

Figure 102 Images of the Channerwick peat slide

Figure 103 Channerwick peat slide showing how mineragenic material from peat / bedrock interface can become attached to transported peat blocks and can even become overturned. (from Dykes and Warburton 2008)

Both the sites examined at Mid-Yell and Vatsetter present coastal peat cliffs with a hummocky terrain landward. It is possible that the sections of sand layers exposed in the cliffs represent a cross-section through a relict peat slide that is now at sea level. The laminated sands and peats at the northern limit of the coastal section examined at Whale Firth are located seaward of very hummocky ground that is suggestive of a major peat slide.

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