Introduction

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Aims

The aim of the survey was to describe the various components which make up the coastal morphology and to identify and categorise sections of the coastline into erosion classes. Additional notes referring to drift type, soils, drainage and land-use were made because, although marine erosion presents the most important threat, it is not the sole eroding agent. Subaerial erosion by water and wind play key roles; especially within areas of softer drift deposits which contain the majority of archaeological information. Present land use is also of importance, in that erosion of drift deposits can be instigated or aggravated by land use, e.g. cultivation on steeply sloping land or sand extraction from foreshore or hinterland.

Geology

Geologically, the Orkney Islands are similar to the flags and sandstones of Caithness. This is reflected in the subdued topography of all islands except Western Hoy, West Mainland, Rousay and parts of Westray. Old Red Sandstones are the major underlying geological unit for all the surveyed areas.

The Old Red Sandstones are a laminated succession of hard and soft layers which repeat as cyclic units (cyclothems) and have been grouped into chronological groups. The three main groups found in the survey areas are (oldest first):-

- **Stromness Flags:** these tend to be grey siltstone and sandstones.
- **Rousay Flags:** these are very similar to Stromness Flags but have, in some cases, more pronounced weathering and a few purplish, soft limestone, fishbed layers.
- **Eday Beds:** these are yellow or red sandstones and marls, some derived from volcanic sediments.

The Eday beds are more readily eroded than the Stromness and Rousay Flags, as some of the intervening deposits are soft and so erosion can undermine upper tougher layers.

The differing laminates of the Stromness and Rousay Flags within the survey area are generally uniform as regards susceptibility to erosion. Most of the beds are generally close to the horizontal or have shallow angles of dip, although where a syncline or anticline is evident the beds can dip by as much as 40° or more.

Geomorphology

The topography has been softened in many places by the deposition of till, predominantly during and towards the end of the last ice age. Apart from till, the other main drift deposits are blown sand and peat. During this last glaciation, there was probably only one local glacier on northwest Hoy, with the major glaciation dominated by the westerly flowing Scandinavian ice sheet. Further gelifluction or colluvial deposits have also accumulated down slope since the last glacial retreat. There are relatively few places where deep layers of till are evident in section over the survey area.

The islands have been submerging since the last ice age due to an isostatic uplift of mainland Scotland, the loss of ice and a consequent down warping of peripheral land masses such as Orkney.

Added to this, there have been eustatic changes, that is global rises, in sea level. A post glacial shoreline of -4m for south Orkney, to -6m for north Orkney, approximately 6,500 BP has been derived by Smith et al (1996). A 20m rise in mean sea level change since 7,000 BP has been approximated by Lambeck (1995), based on a mathematical model.

If the submergence was consistent over time, which is unlikely, this would equate approximately to between a 0.92mm and 2.9mm/year change in sea level. Emmery and Aubrey (1985) have estimated that, at present, there is a 2mm to 4mm/year change in sea level at specific locations within the Southern Isles of Orkney, on Burray at Enloch Bay and Links, and on South Ronaldsay at Herston Head, Widewall Bay, Newark and Manse Bay.

Within the survey area, evidence of submergence can be seen where peat layers are found at or below the high water mark. This occurs especially along the eastern side of Westray within Bay of Skaill and at Bay of Brough. Within the survey area, and especially on Westray, blown sand is much more widespread than pure peat along the coast edge.

Soils and Land Use

The natural soils tend to be peaty gleys or peaty podzols, however cultivation has modified the soils into more uniform, mixed horizons. The more freely draining and improved soils are cultivable: they could be cultivated by mechanical means, although most are down to grass. A few of the less exposed areas are under cultivation, with barley forming the dominant arable crop. In most places the fields are fenced to the edge of the coastline. In the areas which are more vulnerable to erosion, fence lines have had to be relocated further back from the coast as erosion advances.

Susceptibility to Erosion

The coastlines most susceptible to erosion are those which are low-lying, generally below 5m, and have edges composed of soft drift materials, which lie close to, or below, the high water mark.

Some of the rock platforms within bays, such as the Bay of Tuquoy and Bay of Ireland, are quite wide and shallow. This is also the case in sounds, such as those between Westray, Papa Westray and Holm of Papa Westray. Such long shallow platforms are more capable of dissipating wave energy than coastlines facing the open seas, where coastlines tend to have a steep intertidal rock platform, forming narrower beaches.

Another main factor to be taken account of is the exposure of the coast to the long reaches of storm waves. There is little long-term information on wind speeds and direction, two factors which affect wave size. Wright (1976) reviewed meteorological data and found that between 1920 and 1974 there was an increase in northwesterly and northerly winds, at the expense of westerly and southwesterly winds. However, the winds are still predominantly westerly or southerly (Borne 1997). Wave height exceeds 1.5m for 10% of the year and 0.5m for 75% of the year on the south and western facing coasts (Draper 1991).

Currents are also likely to affect erosion. This would be more pronounced within narrow sounds, where a venturi effect is likely to increase the velocity of the current.

Types of Erosion

The sea is the main agent of erosion within the survey area. Landslip can occur after mechanical undercutting of the cliff face or scouring of the coast edge. The sea is also directly responsible for erosion through the cutting of geos and coves into the coastal edge. This can instigate a consequent separation of landmass, creating sea arches and stacks. If the wave height, speed and direction are constant along the coast, then the rate of erosion is moderated by the rock platform gradient and the depth of the cove. A deeper cove and a longer, more shallow rock platform tends to dissipate wave energy before it hits the coast edge; a forward breaking wave is the dominant form.

Marine erosion is also manifested in storm beaches which gradually migrate landwards. This type of erosion is not always obvious and a cursory look, or a snap-shot in time, may lead one to assume an accretion of shingle, since one cannot discern the gradual landward migration of the coast. If a storm beach lies on a steeply rising foreshore then the waves are more likely to throw the cobbles against the base of the cliff or coastal edge, so increasing the erosive power of the waves.

Marine erosion also takes place along the hinterland of exposed coastal edges and headlands, where wave throw and splash followed by water run-off causes some denudation of soil and drift deposits. This is especially evident along the northwestern coast of Westray at The Nev, but is also found in localised areas mainly along the western facing coasts

Chemical erosion by salt spray is a rather more protracted process. It has not been alluded to in this survey other than in combination with observable weathering processes of rocks and the denudation of stabilising vegetation.

Subaerial erosion, caused by rain water and wind, is the second main eroding agent. With rain water, the affects are seen as soil creep, peat flow, land slip and water erosion, i.e. rill and gully formation, or stream erosion caused by run-off. No active gully erosion was seen in the survey. It is primarily surface water run-off which is most destructive. If infiltration of water into the soil or drainage is impeded, then the surface run-off increases. Cattle poaching and smearing of the soil decreases infiltration, whereas vegetation increases infiltration and also slows down the water run-off velocity. Subaerial erosion tends to be locally confined, yet aids or instigates localised sea erosion. In some areas, such as along the west facing coast in the Bay of Noup on Westray, this is the primary cause of soil and drift erosion.

Wind erosion is usually manifested in soft drift deposits, mainly sand in this case, where wind blow can lead to deflation troughs and scouring of sand dunes as is apparent at Grobust and Mae Sand, Westray.

Other agents of erosion are biological. In the survey area, the agents are limited to animal (mainly sheep, cattle, rabbit) and human disturbance, all of which can be controlled by management policies. Land use practices and management tend to aggravate or alleviate subaerial erosion but appear to have little effect on sea erosion.

Accretion

Within the survey area accretion was found to be limited and localised. Sand is the major accreting material, due to strong variable winds and the particle size. If sands are deposited on the foreshore by the sea they can be easily blown onto the hinterland and subsequently stabilised by vegetation. Although coastal edge erosion may contribute to some sandy sediments, the major proportion of source material comes from deeper sea bottom sediments. Under rainy temperate to rainy marine climatic zones sand makes up almost a half to two thirds of sea bottom sediments respectively (Hanson, 1988). Large areas of sea bottom sand sediments have been located to the west of Orkney (I.G.S.1977).

Cobble and shingle storm beaches may or may not be accreting; in nearly all cases there appears to be erosion coexisting with the accretion. Generally, it is suggested that the storm beaches are eroding the shoreline by migrating landwards. In most cases there is evidence to support this view, such as the presence of dead or decaying vegetation beneath an advancing front of cobbles.

There were very few ayres encountered within the survey area. The most significant lies within the Bay of Tuquoy. This shows no definite signs of accretion, although there is evidence that rushes are stabilising the landward area behind the ayre. Overall, the ayres are probably stable or accreting at a very slow rate.

Survey

Hinterland Geology and Coastal Geomorphology: Gazetteer Entries

The gazetteer entries comprise a set of characteristics for each coastal unit. The categories are as follows:

CATEGORY	EXAMPLE
Label - Placename	**1 Waulkmill Bay**
Grid Reference (to centre of area)	HY 380 055
Length of unit	1.0 km
Foreshore Type	Rock platform with 60-80% cobble or shingle....
Coast Edge Type	Coast edge is > 5m.
Hinterland Type	The drift/rock interface is visible.
Description	The rock platform has 60-80% cobble.....

Erosion Class: Gazetteer Entries

The gazetteer entries comprise a set of characteristics for each coastal unit. The categories are as follows:

CATEGORY	EXAMPLE
Label - Placename	**1 Waulkmill Bay**
Grid Reference (to centre of area)	HY 380 054
Length of Unit	1.40 km
Erosion Class at time of visit	Stable
Description	The coast edge is over 5m to the east....

Erosion Classes

The following definitions have been used:

- Eroding: Where more than 70% of the coastline is actively eroding.

- Eroding to Stable: Where there is both active erosion and stable areas, with 30-70% of either one.

- Stable: A section which is more than 70% stable. Usually any erosion is limited and local; any variation is specified in the accompanying text.

- Accreting to Stable: Where there are both accreting and stable areas, with 30-70% of either one

- Accreting: A section with accretion over more than 70% of its length.

- Accreting/Eroding: There are both accreting and eroding processes taking place and may vary from 20% to 80% of each process. The erosion and accretion may not be arranged in a linear fashion along the coastline; there may be erosion of the coastal edge and deposition of sands along the foreshore.

Results

The majority of the coasts surveyed have a foreshore made up of rock platform with a clear distinctive coastal edge. There appears to be no single, main direction in which storm beaches may face, although on Westray the high energy storm beaches lie to the north and face northwest and northeastwards. On Papa Westray they face northeast and there is a well sorted storm beach to the southwest. Within the Mainland survey area, storm beaches are of much lower energy than those encountered on the Northern Isles. This is as could be expected given that most of this coastline faces into Scapa Flow.

There are a number of sandy beaches within each of the areas surveyed. There are more hinterland dune and links areas, resulting from wind blow, on the exposed Northern Isles of Westray and Papa Westray than there are on the Mainland area, however.

Cobbles are fairly widespread throughout the survey areas, tending to lie as a narrow band along the upper foreshore. The exposed western and northern facing coasts of the Northern Isles with steep rock platforms are generally devoid of cobbles.

Westray: Geology and Geomorphology

Westray can be divided into two broad land forms. To the south and east, the hills are low and gently rolling with predominantly shallow slopes and cultivable fields. The majority of the northeastern side is also partially sheltered from westerly winds because of the hills to the west. Along the northwest of the island, the land form is dominated by a ridge of hills with steep slopes and little cultivation. Here, high cliffs dominate much of the coast edge. Two smaller peninsulas which are exposed and less well cultivated lie to the extreme north at Aikerness and the extreme south west along the west side of Rapness. The underlying geology of the island comprises of Rousay Flags, which are part of the laminated Middle Old Red Sandstone series. Generally, the soils are in good condition, with exposure presenting the limiting factor to crop growth.

As the most northwesterly island of the Orkney group, Westray is exposed to the long fetches of northerly and westerly storms. Most of the foreshore is gently sloping and fairly shallow with exceptions along the west coast from Noup Head to Inga Ness, the north west of Aikerness and the west side of Rapness where the rock platforms are narrow and steep. There are two

significant offshore shallow marine areas, The Bay of Tuquoy and the area between Aikerness and Papa Westray. The coast has many small sandy bays; larger expanses of sand are found within the Bay of Tuquoy, Bay of Tafts, The Ouse, Grobust and Mae Sand. Most have substantial areas of hinterland composed of sands. This is clearly seen at Mae Sand and Grobust. A links area extends across from the rear of Grobust Bay as far as Pierowall Bay. Smaller sandy beaches are mainly located along the south and east facing shores.

Westray: Erosion

The main points of erosion occur within the bays of the south and east of the island. This is as might be expected, given the presence of higher cliffs to the northwest with a lower coastal edge to the south and east, The softer drift sediments are most easily eroded where there is little protection afforded by solid geology, where there is a low coast edge or where an area faces open, exposed water. Marine action is the main agent of erosion although sub-aerial erosion by aeolian activity does constitute a large proportion of the dune and links erosion, particularly at Grobust and Mae Sands. There are only three localised areas where accretion is of note. Some accretion is occurring to the west side of the Rapness peninsula.

Papa Westray and Holm of Papa Westray: Geology and Geomorphology

Papa Westray lies to the northeast of Westray, just over 1km east of the Holm of Aikerness, from which it is separated by the shallow Papa Sound. The island is approximately 7km long by 2km wide. It is low lying, with most coast edges under 5m high. There are exceptions to this rule to the north and southeast. The highest inland point is North Hill, at 48m. As with Westray, the underlying geological unit is of the Rousay Flags, Middle Old Red Sandstone. Papa Sound is relatively shallow at 4m to 5m deep, (Admiralty 1993) and given that the islands have been submerging since the last ice age and that some depth of drift must have been eroded from this area it can be hypothesised that Papa Westray may have been linked with Westray at a point in the relatively recent past. The Holm of Papa Westray, a small island to the east of Papa Westray is separated by shallows which are less than 1m deep to the north. This island may also have been linked to Papa Westray in the past. In general, the coast edge tends to be well defined. even along the beach areas which are most prominent to the east.

Papa Westray and Holm of Papa Westray: Erosion

Generally, erosion is more prominent to the south of the island and along the middle and east shore. The most stable areas are to the north and southeast where high cliffs afford much more protection to the coast edge.

Mainland: Geology and Geomorphology

The underlying geology within the area to the south and east of Houton is composed of Eday Beds, with Stromness Flags to the north. The North Scapa Fault runs almost WSW to ENE and divides the two geological units. Most of the coast edge is under 5m in height with a wide rock platform. Some degree of cobble cover is present along the upper foreshore throughout the area. The hinterland has gentle to moderate slopes for the most part, with steeper slopes at Waulkmill and Houton Head. Further inland, the hills of Akla, Scorra Dale and Midland dominate the area. Some of Orkney's better agricultural land is situated around the sheltered Orphir area. Over the whole area the land is generally well farmed. There are two notable exceptions to this at Waulkmill Bay and Houton Head, where soils and topography place constraints on land usage. Soils tend to be poorly to imperfectly drained gleys on the whole with more peaty soils on the less intensively farmed areas.

Mainland: Erosion

Most of the active erosion is due to marine action and lies to the southwest of the survey area predominantly north of Houton Head to Norton. The main factors which account for such erosion are likely to be the low-lying coast edge with mainly soft drift deposits and the western facing coast line. Although the island of Graemsay partially protects the shores from the worst storm fetches, there is substantial exposure to the open sea through Hoy Sound. Other more localised areas of erosion lie within Swanbister Bay and Orphir Bay. These areas also have softer drift deposits over rock and low coastal edges.

Analysis

The total length of the surveyed coastline is 121.5 km. (measured at a scale of 1:50 000). Overall, the main erosion class is *stable* with *eroding to stable* the next most common and *eroding* third. The main agent of erosion is due to marine action which dominates the *eroding* class. Subaerial erosion is associated with approximately half of the localised erosion in the *eroding to stable* class.

The survey results on erosion class have been grouped into the three main survey areas of **Westray**, **Papa Westray** and **Mainland**.

Erosion Class Distances (km)

	E	E/S	S	A/S	A	A/E	Area Totals
Westray	10.95	22.89	38.47	0.47	-	0.37	73.15
Papa Westray	3.93	8.18	8.76	0.24	-	-	21.11
Mainland	6.37	5.24	15.65	-	-	-	27.26
Total Survey	21.25	36.31	62.88	0.71	0.00	0.37	121.52

Erosion Class Proportions (%)

	E	E/S	S	A/S	A	A/E
Westray	14.97	31.29	52.59	0.64	-	0.51
Papa Westray	18.62	38.75	41.50	1.14	-	-
Mainland	23.37	19.22	57.41	-	-	-
Total Survey	17.49	29.88	51.74	0.58	0.00	0.30

E = Eroding E/S = Eroding to Stable S = Stable

A = Accreting A/S = Accreting to Stable A/E Accreting and Eroding

In total, 63km (52%) of the coastline surveyed is definitely stable, with 36km (30%) in the *eroding to stable* class. It has to be borne in mind that the *eroding to stable* class is made up of localised erosion with a combination of both stable and eroding areas, between 30-70%, an average of 50%, of either one. Also, much of the erosion of coastal edge is of a low rate,

especially where the coastal landmass volume is greater, i.e. high cliffs. Therefore one can estimate that probably 66% (80km) of the surveyed coastal edge is at present stable.
Given that a similar coastal survey, of the Southern Isles, carried out in 1997 (Stapf in Moore and Wilson 1998) demonstrated that almost 20% of the coastal edge was eroding it is not surprising to find that in this survey over 17% of coastal edge is eroding.

Westray has proportionally more coastal edge which is stable and Papa Westray the least however the Mainland area has more coastline which is definitely eroding.
There is very little coastal edge which appears to be gaining land by accretion, approximately only 1%, and this is occurring on each of the two Northern Isles. There is undoubtedly sand which is being blown onto the hinterland and which is being trapped by vegetation, but this has not been investigated.

Discussion

Overall, the geomorphological features concur with a mass of evidence that the sea level has been and still is rising due to the relative down-warping of the islands and global increases in sea level since the last glaciation. During this survey it was observed that small areas of peat are at present being eroded on the northwestern foreshore of Westray. There are other recordings of drowned peat deposits found around Orkney's coast (Mykura 1976, Stapf in Moore and Wilson 1998), in the latter work peat was noted at, or slightly below, high water mark. A complete absence of raised beaches may also be interpreted as a sign of a drowned landscape.

The predominant geology of flags and sandstones, where the bedding is largely horizontal, gives rise to straight edged cliffs where marine erosion is greater than subaerial erosion. Only in a few localised areas, such as the eastern side of Rapness, Westray, does subaerial erosion exceed sea erosion. In this area, talus accumulation below the cliffs has not yet been removed by the sea. However, this would appear to be a temporary state due to recent landslip.

The cyclothems of the various groups of flags makes predicting susceptibility to erosion uncertain, although, in the main, Eday Beds are most susceptible, followed by Rousay Flags and then by Stromness Flags.
The most easily eroded units are the soft drift deposits, made up mainly of tills or sand deposits, capped by soil. The deep tills, sometimes along with underlying saprolite, are generally found in low-lying areas. This results from past glacial erosion of higher ground followed by deposition within low troughs or basins. Therefore, the deeper tills tend to be found along the lower lying sections of coastline. The topography of such areas will have gentle slopes, as this type of medium is also susceptible to subaerial erosion.

At four points within the survey area, Admiralty charts show the marine floor to be very shallow at the Lowest Astronomical Tide:

- the sound between Westray and Papa Westray (depth 4m to 5m)
- the sound between Papa Westray and Holm of Papa Westray (depth <1m to 1m)
- the area within the Bay of Tuquoy (depth 1m to 3m)
- the area within the Bay of Ireland (depth 2m to 5m)

If it is assumed that since 6,500 BP there has been a submergence of the Northern Isles at a figure between 6m (Smith *et al*, 1996) and 20m (Lambeck, 1995), then it is probable that the islands of Westray, Papa Westray and Holm of Papa Westray were once joined. Similarly, the Bay of Tuquoy would have extended seawards by up to 1km and a bar of land would have run across the Bay of Ireland from Norton to Bu Point.

Erosion

Where the coastal edge is made up of rock standing 2m or more above the high water mark, there is very limited erosion. Conversely, where the coastal edge is low, or soft sediments lie within reach of high water, there is appreciable erosion. The depth of soft sediment does not appear to impede erosion, although the volume of material may slow down the rate at which this occurs.

Another point to be noted, particularly in reference to the Mainland survey area, is that although the area contains the greatest proportion of eroding coastal edge, it also has the greatest proportion of stable coastal edge. There is a very clear cut boundary between the *eroding* class, where soft sediments are close to high water mark, and the *stable* class, where rock lies above the high water mark.

Although subaerial erosion may only account for 5% to 10% of the erosion of the actual coastline, it probably accounts for perhaps as much as 25% of the total erosion if the hinterland areas are included. This is most obviously seen at Grobust and Mae Sand, Westray, where aeolian activity is eroding the dune hinterland and accounts for over 90% of the erosion at

these two locales. There is a strong possibility that there is a consequent build up of sand further inland, as sands can be seen trapped within field vegetation of the far hinterland.

There is very little accretion along the coastal edge within the surveyed area. The most significant areas lie on the Northern Isles, predominantly Westray. The source of the sand probably lies on the sea bottom to the west of Westray, where there are vast expanses of sand (I.G.S. 1977). The most notable areas of accretion lie to the southwest of Westray. To the north of Tafts Bay, at Taftend on Westray, a build up of sand along the upper foreshore is most likely due to longshore drift.

Recommendations

The lack of a national policy for coastal management gives rise to the potential for a conflict of interests between agriculture, mineral extraction, natural heritage, archaeology and recreation. One overall recommendation is that some form of coastal management policy be established and invoked. There is possibly more scope for instigating a holistic coastal management regime on islands, such as Orkney.

Subaerial erosion can be controlled to some extent through the implementation of changes in land management. With careful management of the hinterland and the implementation of good husbandry and farming practices subaerial erosion could be reduced by as much as 50%. Practical remedies which could be implemented include:

- a small grassed headland could be created between the coast and cultivated fields
- stocking levels could be decreased in particularly wet conditions.
- surface water run-off could be limited through the reduction of poaching and ground disturbance.
- infiltration and natural drainage could be increased by encouraging vegetation.
- cultivation could be reduced or judiciously timed to avoid leaving land denuded of vegetation

All of these measures are based on good management and husbandry techniques, necessary for sustainable agriculture and soil conservation. They should be actively promoted within any coastal management policy.

There is little that can be done to negate marine erosion, unless huge resources are committed to local problems. However, even roughly dumped deposits of concrete and rubble may slow down the rate of erosion, as was observed along the eastern facing coasts of Houton Bay and Bay of Myre, Mainland.

It would also be advisable to monitor the survey areas, perhaps every few years, in order to discern changes in erosion patterns and to increase the information on rates of erosion, for which there is very little data.