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The calcified seaweed (maerl) deposits of the Falkland Islands

Report CR/03/148N

BRITISH GEOLOGICAL SURVEY

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The calcified seaweed (maerl) deposits of the Falkland Islands

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Contents

FIGURES

1 Introduction

Scattered across many foreshore areas around the Falkland Islands (Fig. 1) are fragments of white, limy material derived from carbonate-fixing, marine red algae. Locally, the limy detritus is sufficiently abundant to have built-up substantial beach deposits. In their report accompanying publication of the 1:250 000 scale geological maps of the islands, Aldiss and Edwards (1998) drew attention to the potential importance of these deposits as a source of agricultural lime, particularly in the absence of any other indigenous source of limestone. Very similar material has been exploited elsewhere in the world for both agricultural and horticultural use; for example, sub-tidal banks were extensively dredged in the English Channel off Cornwall and Brittanny. There, the limy, algal debris is referred to generically as *Lithothamion*, and commercially as *maerl*. The equivalent material in the Falkland Islands is known locally as *calcified seaweed*.

In all cases, the limy detritus is formed from the remains of marine red algae varieties that are characterised by cell walls impregnated with calcium carbonate. In the scientific literature these varieties are usually described as coralline algae, or corallines, and have been divided into two groups; articulated and encrusting. However, the division does not constitute a taxonomic grouping. The articulated corallines are branching, tree-like plants which are attached to the substrate by crustose or calcified, root-like holdfasts. The plants are made flexible by having non-calcified sections separating longer calcified sections. The encrusting corallines build up on rocks or shells as crusts ranging in thickness from a few microns to several centimetres. Crusts may be thin and leafy to thick and strongly adherent; many varieties produce knobbly, highly irregular crusts. Not all encrusting types are fixed on a host foundation. Some varieties form independent balls known as *rhodoliths* and these are well represented in the Falkllands. Most encrusting coralline types are very slow growing.

(Source and further information: www.botany.uwc.za/clines)

The most extensive historical account of Falkland Islands marine algae is that of Cotton (1915) based on collections by Mrs Elinor Vallentin made mainly around the north coast of West Falkland. Cotton’s paper lists least 7 species of encrusting red algae (described by Mme. P. Lemoine) and 1 species of articulated red algae. Recent observations from East Falkland, as part of the survey work reported here, suggest that at least 2 species of articulated corallines are present. All of these eight, nine or more species could contribute to the onshore deposits of calcified seaweed. Material collected from the near-shore seabed and held by the Falkland Islands Department of Fisheries, Stanley, confirms that the varieties of calcified seaweed collected from the beaches are the same as those found living offshore. A local source of live algae for most of the washed-up material is also indicated by the common retention of a red or purple tint by detritus newly-arrived on the beaches. The colour is not retained for long once the algae have died and the detritus is soon bleached white. This may not be entirely the result of subaereal weathering since white, dead material has also been collected from the seafloor.

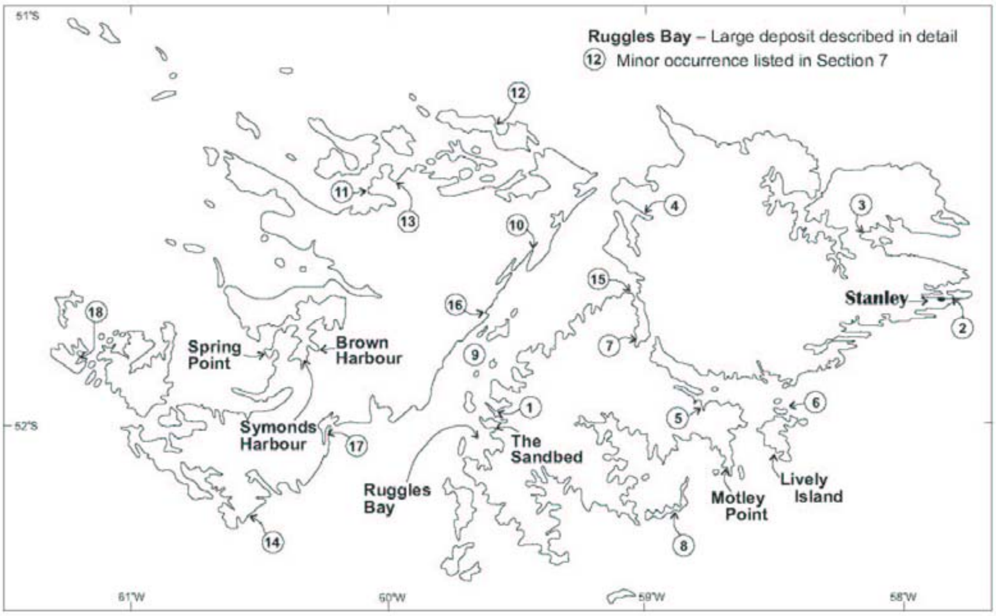

Figure 1 Location of the calcified seaweed deposits.

The widespread offshore occurrence of coralline algae is confirmed by comments on the Fisheries Department collections in the report *The First Shallow Marine Survey around the Falkland Islands* (1996). In the section on page 23 titled "Algae most Frequently Recorded in High Abundance" it is noted that:

- Crustose red algae: common throughout the Islands on all hard substrates. Likely to be multiple species.
- Foliose/filamentous red algae: observed on all substrates except mud. Multiple species.

Since there is clearly a wide distribution of the coralline red algae species, those areas where large deposits have built up (Fig. 1) must simply be particularly favourable habitats rather than unique environments. Those few, very large deposits have in common a south-west facing coastal aspect, but one protected by headlands or an offshore reef. There are three very large deposits on East Falkland, all in Lafonia; at Ruggles Bay (Falkland Sound coast), Motley Point (south from Walker Creek) and Prong Point (south coast of Lively Island). There are no deposits of comparable size on West Falkland. The largest deposit there is at Spring Point, with a scattering of relatively small deposits in the East Bay – Brown Harbour area. Small pockets and isolated fragments of calcified seaweed are common throughout the Falklands coastline.

In the following descriptions, latitude and longitude are cited in degrees, minutes and seconds. All of the descriptions are based on reconnaissance surveys and the estimates of volume and tonnage present are indicative only; they should not be taken verbatim as the basis for any economic evaluation. Illustrations of the principal deposits in the Falklands appear in Appendix 1.

2 The Ruggles Bay calcified seaweed deposits, East Falkland.

The area of interest is a bay on the west coast of Lafonia, part of the Ruggles camp, lying between Wreck Rincon and Ruggles Rincon. The bay is not formally named but forms the extreme north-east corner of the much larger Ruggles Bay. There are two separate deposits present though they are more-or-less in continuity: The Sandbed to the north, and an area known as Ruggles Arroyo Beach to the south.

The calcified seaweed deposits are situated in a bay open to the west but protected by rocky promontories to the north and south; further out to sea, a shallow reef area affords additional protection. Aerial photographs show that there are abundant submarine sand waves throughout the bay, up to 1 km from the beach complex. If these consist of calcified seaweed moving towards the beach, then the offshore resource could be considerable. The locality was first visited by one of the authors (PS) in the late morning and early afternoon of Monday, November 27, 2000, accompanied by Alex Blake (DMR) and Jason Morris (FIDC). At the time of the visit the tide was fairly high and the weather was bad, with a very strong, cold westerly wind driving sleet squalls. This limited the possible observation and measurement. GPS locations for the deposits are as follows:

The Sandbed, north end inshore of lagoon … 52 01 28 S, 59 35 43 W.

Ruggles Arroyo Beach, north end …………. 52 01 54 S, 59 35 22 W.

2.1 THE SANDBED

This is a very large, composite accumulation of calcified seaweed consisting of a beach bar, a lagoon area behind the bar with active beach deposits also present on the inshore side of the lagoon, and two extensive raised beach terrace areas each stepping up about a metre from the back of the active beach zone. The beach bar was assessed by Don Aldiss (British Geological Survey) in June 1997 (DMR files for 1999, OIL/Admin/17 – 36) and the dimensions that he recorded, approximately 600 m long by 25 m wide by an average of 1.5 m thick, seem quite reasonable. The subsequent Falklands Conservation Environmental Impact Statement (EIS) refers to only a 30-50 cm depth of calcified seaweed but since Aldiss's investigations involved hand augering the deposit his estimate is probably the more reliable. The EIS also refers to a greater width of 200 m for the southern end of the bar. This broadening of the bar was not evident under the relatively high tide conditions prevailing during the November 27 visit. The difference may well be caused by the exclusion from Aldiss's calculations of areas of calcified seaweed thought to be significantly less than 1 m thick. Alternatively, natural variation in the state of the bar may be responsible.

The bar is founded on rock oucrop at both ends and in the south the rock beds dip north at a low angle and can be seen running out to sea, forming shallow reefs curving under the bar. The presence of these reefs was probably important in determining the initial location of the bar. The lagoon area was described by Aldiss as being floored by lime sand and mud, i.e. very fine-grained calcified seaweed, but this was not considered exploitable since it was largely water-saturated and below low water. Aldiss did not consider the raised beach areas forming the extensive terrace greens behind the lagoon. The lower of these is composed of calcified seaweed, at least at its seaward edge, with up to 1 m proved at several points beneath a thin veneer of peat.

The higher raised beach area contains some fine-grained calcified seaweed (possibly wind blown) but has a high proportion of quartz sand and a relatively high peat content.

The estimate of 22 500 m^3 of calcified seaweed in the beach bar, made by Don Aldiss in 1997, seems entirely reasonable. The more recent Falklands Conservation Environmental Impact Statement did not disagree with these figures. There is also a large potential source of calcified seaweed in the lower of the raised beach deposits. To quantify this a systematic pitting programme would be required. Conversion of volume to weight is made uncertain by the clear differences in density between different parts of the deposit. The beach bar has fairly coarse material on its surface, particularly on the seaward side, with a few fragments in the 10-15 cm size range, many clasts several cm across and most of the material in the 1-3 mm range. Quite a few of the larger clasts have sandstone cores, establishing that the living reefs offshore are founded on rock and are being actively eroded. Since the tide was high it was not possible to confirm a further increase in grain size towards the low water mark. However, there is an apparent reduction in grain size (and hence a likely increase in density) landward and deeper in the bar. On the landward side of the lagoon, calcified seaweed exposed in the leading edge of the lower raised beach is significantly finer grained with the great majority of fragments being sub-mm in size. This raised beach material would have a higher density than that in the beach bar.

In his original assessment of the beach bar deposit Don Aldiss used a figure of 0.3 tonne/m^3. In view of the relative coarseness of the material this might well be appropriate, but even taking this likely minimum figure the Sandbed bar would contain almost 7000 tonnes of calcified seaweed, though not all of this would be practicably exploitable. It is not inconceivable that a similar tonnage is contained in the raised beach area behind the lagoon, but this remains unproven.

Samples of calcified seaweed were collected as follows:

1. North end of beach bar, coarse pebbly material from seaward side.
2. North end of beach bar, coarse material from crest of ridge.
3. North end, seaward side of raised beach area inshore from the lagoon.

In addition to the above, two large fragments of calcified seaweed, one with a rock core, were collected from the north end of the beach bar.

All of these samples are held for reference in the Department of Mineral Resources, Stanley.

2.2 RUGGLES ARROYO BEACH

This deposit has the same general form as The Sandbed but is on a much smaller scale. The beach bar is about 150 m long, about 20 m wide, with about 1 m depth of calcified seaweed over that area. The Falklands Conservation Environmental Impact Statement refers to only a 30-50 cm depth of calcified seaweed but since Aldiss's investigations involved hand augering the deposit his estimate is probably the more reliable. The lagoon area behind the bar and the raised beach area landward of the lagoon are proportionately smaller than their counterparts at The Sandbed. In his 1997 assessment, Don Aldiss estimated 2 000 m^3 for the Ruggles Arroyo Beach bar. The fine grained calcified seaweed flooring the lagoon area was not considered an exploitable resource. The raised beach area behind the lagoon was not assessed but is likely to contain a significant quantity of calcified seaweed, perhaps equivalent to the volume in the beach bar. The material forming the bar was fairly coarse, in the 1-2 mm range, on the seaward side of the bar but for the most part was relatively fine, sub-mm down to coarse sand grade. This means that the weight estimate of Aldiss, based on an assumed density of 0.3 tonnes/m^3, may be on the low side. His estimate of 600 tonnes of exploitable calcified seaweed in the beach bar should therefore be regarded as a minimum. A similar quantity could be present in the raised beach area but this remains unproven.

A sample of relatively fine-grained calcified seaweed was collected from the north end of the beach bar close to its termination. This sample is held for reference in the Department of Mineral Resources, Stanley.

2.3 SUPPLEMENTARY COMMENTS FROM REVISIT, 27.2.02

A second visit to Ruggles Bay was made by PS on Wednesday, February 27, 2002, accompanied by Director, DMR and Co. Richard Cockwell. At the time of the visit the tide was low but rising; the weather was fine and mild. An impressive and well-organised stockpile of calcified seaweed has now been established beside the North Arm road. No extraction was in progress on the day of the visit and it was not immediately obvious which part of the beach was being worked. Vehicle tracks were the only clear signs of activity and so far the extraction programme seems to have had very little effect on the overall appearance of the beach. The following points were noted and are supplementary to the above report of the visit made on November 27 2000.

A large quantity of coarse (1-3 cm) fragments of coralline calcified seaweed had been recently washed up onto the beach bar at The Sandbed. Much of this material was still pink suggesting a recent derivation from the living reef. In amongst the encrusting coralline forms were examples of at least two different varieties (species?) of articulated forms. The latter was not noted as being present at the time of the earlier visit. However, similar recent accumulations of pink coralline forms and articulated fragments have been seen subsequently at other sites, e.g. Motley Point (Walker Creek) and Prong Point (Lively Island), and there seems no reason to suppose that any abnormal erosion has occurred recently offshore at Ruggles Bay.

At the northern end of The Sandbed, behind the bar and lagoon area, a thin veneer of fine-grained (perhaps wind-blown?) calcified seaweed (<20 cm) covers the peat on the extensive back-beach green. The peat extends down well below high water mark, a phenomenon widely noted at other sites investigated in connection with sea-level change. The contact between peat and calcified seaweed is sharp, with no trace of the latter in the underlying peat sequence. It would seem that the first arrival of calcified seaweed was an abrupt event, although higher in the profile, towards the ground surface there is some alternation of thin (<1 cm) peat and calcified seaweed layers.

Pits were dug randomly across the green area of raised beach terraces behind the lagoon, and proved that the thickness of calcified seaweed present was even more variable than had been previously noted. Depths noted ranged from 5 cm to 80 cm, and the grain size was consistently small. In addition, the substrate to the calcified seaweed also varied. At the seaward side of the green peat commonly underlies the calcified seaweed but in a few places was replaced by stiff grey clay. Further inland, rock was encountered beneath alternating thin layers of calcified seaweed and peat. Although there is probably a large volume of calcified seaweed in the “green” area behind The Sandbed beach bar and lagoon, its variability would preclude exploitation on anything other than a small, localised scale.

South of The Sandbed, at Ruggles Arroyo Beach, there is an area of green behind the beach where up to 90 cm of fine-grained calcified seaweed has a thin turf capping and overlies rock. About 200 m^2 of this green does probably represent an exploitable source of calcified seaweed. The lowest layers of this deposit are likely to contain the oldest calcified seaweed in the Ruggles Bay deposits. A sample was collected for further study and a duplicate has been added to the collection in the Department of Mineral Resources, Stanley, as Ruggles Arroyo Beach 2.

2.4 SUPPLEMENTARY COMMENTS FROM REVISIT, 18.2.03

A third visit to the Ruggles Bay localities was made from mid-morning to mid-afternoon on Saturday, 18 February 2003, accompanied by Dr. Louise Phillips, an Australian specialist in marine algae based at Monash and LaTrobe Universities, Melborne, who was visiting the Falklands on an independent research project. At the time of the visit a spring tide was falling and was fully low by the time that we left; the weather was good but with a freshening breeze during the afternoon. The following points were noted and are supplementary to the reports arising from previous visits.

Extraction of calcified seaweed was in progress from Ruggles Arroyo Beach, from an area below high water. The excavated material was being loaded into 1 m^3 (approximately) sacks which were lined-up above high water ready for removal to the stockpile at North Arm. A similar exercise had been completed at the southern end of The Sandbed where calcified seaweed had been extracted from the same general area as had been targeted in the previous year. About 700 sacks were lined-up behind The Sandbed, with probably more than that behind Ruggles Arroyo Beach where work was still in progress, though apparently due to be completed within a few days. A minimum total extraction of 1500 m^3 seems likely.

There had been one significant geomorphological change at The Sandbed since the site was visited in 2002. The spit of calcified seaweed that extends south from the northern shore of the bay had curved inwards at its southern end to join with the main beach. The lagoon area behind the spit was hence completely enclosed and appeared to be drying out at its northern end. A large area of the intertidal, desiccated peat flat noted on previous visits was exposed across what had been the floor of the lagoon and the opportunity was taken to dig a series of trial pits across it. These proved that up to 80 cm of peat, extending down to about 50 cm below approximate high water mark, covered a lower layer of calcified seaweed. It proved impossible to dig through this lower layer since the saturated calcified seaweed flowed laterally into the hole which promptly collapsed; at least 30 cm of calcified seaweed was proved but its substrate remains unknown. The lower layer of calcified seaweed was traced inshore at the northern end of the bay and is certainly present beneath peat at the eroded front of the flat, green area behind and slightly above the present high water mark. However, 5 m behind the eroded edge only a few centimetres of calcified seaweed intervenes between peat and a basal mixture of clay and shingle; 10 m behind the eroded edge 50 cm of peat rests directly on shingle. Samples of the base-of-peat / calcified-seaweed interface were taken for further study.

Whilst digging was in progress Dr. Phillips donned a wet-suit and swam out to examine the red algal communities living in the bay. She confirms that several different species are involved (probably more than 5) and that whilst definite identification is difficult, the commonly assumed designation of *Lithothamion* species is almost certainly incorrect. She also noted that the majority of the living algae were not anchored to any substrate but instead formed free-living balls known as rhodoliths. At mid to low tide the water depth rarely exceeded 2 m. A different situation was observed in the zone just below low water (spring tide) on the rocky north side of the bay. There, another species of encrusting red algae is firmly attached to the rock and has a very different morphology to the deeper-water rhodoliths.

The recent geomorphological changes at The Sandbed should not be assumed to result directly or solely from the calcified seaweed extraction. Coastal changes of this sort are common and are more likely to arise from severe storm conditions or unusually long periods of consistent winds. However, it must be recognised that the main change is in precisely the area from which extraction has taken place and that extraction is likely to have had some contributory effect. Regular monitoring of the site would be advisable.

As was noted on previous visits, much of the calcified seaweed debris on the lower part of the beach retained its pink and purple, living colour. Similarly coloured, living material was collected from the seabed and spread out in a Stanley garden to check the rate of colour loss. After only 3 days all of the exposed surfaces had become bleached, with a pink colouration only retained on the underside of the larger fragments. Hence it can be safely assumed that all of the coloured material on the beaches is newly arrived. This will have implications for any assessment of recharge rates.

3 The Motley Point (Seal Cove) calcified seaweed deposit, East Falkland

The area of interest spans two bays on the west side of the Motley Point promontory, Seal Cove camp (Walker Creek). Neither bay is formally named. There are two separate deposits, one in each bay, with the smaller of the two occupying the northern bay and the larger deposit occupying the southern bay. The calcified seaweed deposits are principally active beach and storm ridge accumulations in west-facing bays afforded a degree of protection by offshore rock reefs. Aerial photographs show localised offshore sand waves, apparently developing in the lee of a rock reef.

The locality was visited in the late morning and afternoon of November 30, 2000, by PS accompanied by Alex Blake (DMR), John Willie Jaffray and Brian Aldridge (Walker Creek). At the time of the visit the tide was falling and was fully low when the site was left. The weather was fine and mild with only a light wind, allowing for extensive observation and measurement. GPS locations for the deposits are as follows:

North end of northern (smaller) bay …………. 52 05 44 S, 58 40 29 W.

North end of southern (larger) bay …………... 52 06 00 S, 58 40 42 W.

South end of southern (larger) bay …………... 52 06 23 S, 58 41 00 W.

3.1 THE NORTHERN DEPOSIT

The northern end of this small bay is formed by a low rocky headland, much of which is inter-tidal. The calcified seaweed at the extreme northern end of the bay forms a thin surface veneer over coarse platy shingle, thickening shoreward to about 30 cm depth in a low storm ridge. The beach deposit broadens and thickens slightly southwards. The calcified seaweed at this northern end of the beach is fairly coarse grained, with fragments ranging up to 2 cm. Some of the material is remarkably delicate in structure, with fine, coral-like multiple branches and rarer, very delicate fragments of branching tracery. Although this material is mixed with much rounded and broken debris it strongly suggests a very local source for at least some of the calcified seaweed. It seems very unlikely that the delicately structured material would have withstood much attrition during current-driven transport.

Southwards, through the middle part of the bay, the calcified seaweed deposit on the beach broadens to about 20 m across. At the seaward side a feather edge overlies coarse platy shingle and a rock platform at about the low water mark. Rounded fragments of calcified seaweed up to about golf-ball-size are scattered across the rock platform. The inshore side of the beach terminates in a storm ridge in which the calcified seaweed thickness increases to about 50 cm. There is an overall increase in grain size from the seaward side, where many fragments are sub-mm, into the storm ridge where many of the fragments are in the 1-2 cm range. However, sorting is not that good and there is a fair mixture of grain size throughout. Behind the beach and storm ridge there is an area of green formed by a raised beach about 0.5 m above the back of the active beach. Pits dug into this area showed that the seaward side of the raised beach contained between 30 cm and 50 cm depth of relatively fine grained calcified seaweed, beneath a thin layer of peat and overlying coarse platy shingle. This does not apparently continue far inland since only 10 m back from its seaward edge the green is immediately underlain by peat, although this does contain a scattering of possibly wind-blown calcified seaweed grains. At its southern end the beach terminates against a rocky promontory that extends north-west into the sea for about 100m.

The total beach length over which calcified seaweed has been deposited is about 200 m. A rough assessment of the volume of calcified seaweed present would be about 1000 m^3. The overall coarseness of the deposit suggests that a fairly low density value would apply. Even so, there could be up to 500 tonnes present in the active beach with a small additional resource in the front edge of the raised beach. One problem with any assessment of quantities on this beach is the anecdotal evidence that much of the calcified seaweed on the lower part of the beach is removed by big storms. This can be interpreted in two ways: either the calcified seaweed is swept back out to sea, or all of the lower part of the beach accumulation is swept up onto the storm ridge. The potential recharge rate of the deposit will be significantly affected by the correct interpretation of this phenomenon.

A sample of calcified seaweed – Motley Point / Seal Cove 1 – illustrates the delicate fraction from the coarse, storm beach accumulation of calcified seaweed; it was collected from the north end of the beach. This sample is not representative of the deposit as a whole but illustrates an unusual feature. It is held for reference in the Department of Mineral Resources, Stanley.

3.2 THE SOUTHERN DEPOSIT

This accumulation of calcified seaweed occupies a bay about 800 m long, significantly larger than the northern deposit, from which it is separated by the rocky promontory mentioned above. The northern end of this larger deposit consists of the active beach zone and storm ridge; at the time of the first visit the latter was developed several metres forward from the back of the beach deposits. At the back of the beach, just inland from the storm ridge, digging proved calcified seaweed up to 1.5 m deep, hence beneath the ridge there could be as much as 2 m depth. There was a tendency for the grain size to decrease with depth. From about 30 cm downwards, most of the calcified seaweed is in the sub-mm to coarse sand grade, whereas on the crest of the storm ridge grain size is mostly in the 2 mm to 1 cm range. The beach deposits thin seawards for about 15 m and, towards the low water mark, overlie coarse, platy shingle and a wave-cut rock platform that extends offshore for perhaps as much as 100 m. Average grain-size appears to increase seawards. At the margin of the beach and in pockets across the adjacent rock platform there are accumulations of calcified seaweed pebbles 1-5 cm across, many of which were strikingly pink and/or maroon in colour. These pebbles were presumably derived fairly recently from the living offshore reef.

The same situation noted at the northern end of the beach continues southwards for some 200 m, with the width of the beach zone broadening to 20 m. Over the same distance a thin layer of calcified seaweed, up to about 30 cm thick, was seen to develop on the surface of the raised beach green behind, and about a metre above, the active beach. The calcified seaweed layer was covered by a thin veneer of peat but also overlay about 20 cm of peat developed above a grey-brown clay. The near-surface layer of calcified seaweed in the raised beach only extended for about 10 m inland. Beyond that distance, although the ground surface continued at the same level and with the same appearance, at least 50 cm of peat was present.

Towards the central part of the bay the calcified seaweed deposit appears to thin a little, although the active beach width of about 20 m is maintained. The overall appearance of the deposit at surface remains the same but pits dug into the landward side of the beach showed that the calcified seaweed was interbedded with thin layers (up to about 5 cm thick) of fine quartz sand or small rock pebbles. These layers comprised up to 25% of the 1 –1.5 m depth exposed in several pits. A decrease in the grain size of the calcified seaweed with depth was again noted. The low-water rock platform in the central part of the bay was scattered with abundant large lumps of calcified seaweed, all of which showed some signs of rounding and abrasion and many of which had a rock component. This demonstrates the likely growth environment of the offshore reef, based on an exposed rock substrate. The largest fragment of calcified seaweed observed measured 20x15x7 cm. There was no rock attached although one flat side was presumably the original base of the growth on a submerged rock slab.

Along the southern part of the bay the calcified seaweed deposit becomes more variable in thickness and breadth but both dimensions probably decrease southwards overall. The layers of sand and pebbles within the deposit also continue, as does the trend towards finer grained calcified seaweed with depth. The deposit terminates in the south at a point where the low water rock platform extends out towards the north-west, merging with a rocky promontory which continues north as a mostly submerged reef. This affords the bay some protection from the prevailing wind and waves and may be a significant factor in the colonisation of this area by the coralline algae that produces the calcified seaweed.

The deposit can be best assessed in two parts, with and without interbedded sand and pebble layers. The northernmost half of the beach deposit, about 400 m long, seems to contain little except calcified seaweed. About 4 000 m^3 are probably present. There will be a considerable density variation between the coarse, storm ridge material and the fine-grained calcified seaweed deeper in the beach. As a fairly conservative estimate, there are probably 2 000 tonnes of calcified seaweed in this northern part of the beach but not all of this will be practicably exploitable. A smaller, additional resource is present in the seaward part of the raised beach green. The southern sector of the deposit appears to be more variable, and is generally thinner and narrower, than the northern part. It is unlikely that there are more than 3 000 m^3 present but, whilst this might still yield a theoretical 1 500 tonnes of calcified seaweed, the interbeds of sand and pebbles (possibly as much as 25%) would make this part of the deposit very difficult to exploit. A more extensive programme of pitting would be needed to fully assess the extent of this problem.

Samples of calcified seaweed were collected as follows:

Motley Point / Seal Cove

1. Northern end of bay. Relatively fine grained material from about 30 cm depth at the back of the beach, behind the crest of the storm ridge.
2. Northern end of bay. Coarse material from the crest of the active storm ridge.

3. Centre of bay. Beach surface material, mid-way between the storm ridge and the low water mark.

In addition to the above, three large fragments of calcified seaweed, one with a rock core, were collected from the wave cut platform at the low tide level.

All of these samples are held for reference in the Department of Mineral Resources, Stanley.

3.3 SUPPLEMENTARY NOTE ON THE MOTLEY POINT DEPOSIT AFTER A REVISIT IN NOVEMBER 2001

The locality was revisited in the late morning and afternoon of November 13, 2001, by PS accompanied by Brian Aldridge (at that time manager at Walker Creek). At the time of the visit the tide was rising and was fully high when the site was left. The weather was fine and mild but with a moderate wind which was fanning a nearby grass fire. Smoke from this occasionally blew across the beach areas but did not interfere with observation and measurement of the deposit.

The smaller, northern beach and the northern part of the larger, southern beach were very much the same as seen the previous year. In the central part of the southern beach more very coarse material, irregularly rounded pebbles in the 2–5 cm range, had come ashore and was forming ridges superimposed on the previous beach profile. At the southern end of the deposit, in November 2000, a large pond lay immediately behind the calcified seaweed beach deposit. By November 2001 this had completely dried out and digging in the exposed pond bed revealed that it was underlain by a layer of calcified seaweed. Several trial pits showed that at least 60 cm of fine grained material, overlain by about 10 cm of peaty turf, extended over an approximately 20 m by 25 m area. The full depth of the calcified seaweed could not be established because beneath 60 cm depth the holes became waterlogged and collapsed. Nevertheless, this accumulation adds at least 300 m^3 of calcified seaweed to the Motley Point total. The quality is good, with a fine grained, crumbly texture and only a very small component of tiny, rounded granules of rock.

A sample of the calcified seaweed from beneath the dried-out pond was collected at 52 06 23 S, 58 41 00 W, and is held for reference in the Department of Mineral Resources, Stanley.

Throughout the length of the main Motley Point deposit the seaward side of the calcified seaweed beach accumulations thins out as it rests on an inter-tidal rock platform. At the extreme southern end of the beach, beyond the dried-out pond described above, the rock platform is overlain first by a thin layer of clay and then by about 1-1.5 m of peat. The clay and peat form a low cliff that is actively being eroded by the sea; significant erosion had taken place since the November 2000 visit with more of the seal bones noted then at the base of the old wallowed area having been exposed. The same peat layer continues as a low bank around the inland side of the dried-out pond, and is presumably part of the same peat layer detected beneath the central part of the calcified seaweed deposit in November 2000. The sequence of events would seem to be:

1. Erosion of rock platform by wave action.
2. Fall in sea level allowing accumulation of clay layer and then growth of peat.
3. Rise in sea level so that areas of the newly formed peat are eroded.
4. Accumulation of calcified seaweed in some places (dried-out pond) whilst wave erosion of peat and exhumation of the pre-existing rock platform continues in others.

To help quantify this sequence of events, peat samples from the Motley Point section have been radiocarbon dated. Results are discussed and integrated with other data in section 8, below.

4 The Lively Island calcified seaweed deposits, East Falkland

The principal area of interest spans three beaches on the north and east sides of the enclosed inner part of a bay opening from the west side of the Prong Point camp, the southernmost part of Lively Island. The largest accumulation of calcified seaweed occupies the middle of the three beaches, which are separated by rocky promontories. Calcified seaweed forms the active beach and storm ridge in all three deposits; the northernmost and central deposits also have areas of raised beach green, underlain by calcified seaweed, behind the active beach zone. The Prong Point inner bay area is almost completely enclosed with only a narrow entrance in the south-east corner leading to an outer bay. Aerial photographs show the inner bay to be almost completely filled with submarine sand waves giving the impression of a dominantly clockwise water flow; there is a particularly marked shallow area off the main, central beach. Calcified seaweed is confined to the inner bay, with quartz sand forming the beaches around the outer bay.

The locality was visited by PS in the morning and early afternoon of February 1, 2001, accompanied by Alex Blake (DMR) and Alec Jaffray (Lively Island). The three beaches were visited in sequence from north to south. At the time the tide was falling and was fairly low by the time that the largest, central beach was examined. The weather was fine for inspection of the northern and central beaches, allowing ample opportunity for assessment. The sudden onset of very heavy rain curtailed examination of the southernmost beach. GPS localities for the deposits are as follows:

West end of northern beach ……………… 52 04 28 S, 58 27 12 W.

East end of northern beach ………………. 52 04 29 S, 58 27 04 W.

North end of the main, central beach …….. 52 04 33 S, 58 26 45 W.

South end of the main, central beach …….. 52 04 45 S, 58 26 41 W.

4.1 THE NORTHERN BEACH

This beach runs for 150 m, approximately NW-SE along the most northerly shore of the Prong Point inner bay. It is constrained at the western end by an abrupt change in direction of the shoreline and the appearance of a rocky foreshore. At its eastern end, the northern beach is separated from the main, central beach by a low, rocky promontory. Behind the active beach there is a narrow, green area of raised beach.

At its western end, the active zone of the northern beach is about 12 m wide, sloping up from a leading edge apparently overlying a low rock platform (this relationship could not be firmly established under the prevailing, relatively high, tide conditions) to a storm ridge. Behind the storm ridge the raised beach terrace continued back at about the same level for a further 8 m. Fairly coarse calcified seaweed, mostly with a 2-3 mm grain size, formed the active beach surface, with slightly coarser material concentrated at the top of the storm ridge. Scattered larger pebbles of calcified seaweed, up to about 15 mm across, occurred throughout the deposit but were concentrated at the extreme western end of the beach and appear to become less abundant eastwards. Pits dug across the active and raised beaches showed that the calcified seaweed layer increased in thickness away from the sea to a maximum of 90 cm beneath the storm ridge and the front edge of the raised beach. The deposit then thinned towards the back of the raised beach, over all of which the calcified seaweed was covered by a thin veneer of peat containing scattered, probably wind-blown calcified seaweed grains. In both the active and raised beach zones the calcified seaweed becomes finer grained with depth so that below about 50 cm most of the material is sub-millimetre in size.

The beach extends for about 150 m in length and, whereas the active zone increases eastwards to about 20 m in width, the raised beach, green area narrows considerably in the same direction. The thickness of the calcified seaweed layer also decreased eastwards so that at the eastern end of the active beach the maximum encountered in a series of pits was 50 cm, beneath the highest point of the beach profile and directly overlying rock. There was also an overall trend of decreasing grain size eastwards along the beach, until an abrupt increase at the extreme eastern end where most fragments were in the 5 – 15 mm range. There, the coarser fragments preserved quite delicate "flaky" structure and did not appear to have been transported far from source. The eastern half of the active beach contained noticeably more sand, pebbles and organic detritus mixed in with the calcified seaweed. These included materials were both scattered randomly through the calcified seaweed and concentrated into thin layers alternating with calcified seaweed layers. In one of the pits dug into the eastern end of the beach about 30% of the thickness exposed consisted of sand and pebble layers.

As a rough estimate, about 800 m^3 of calcified seaweed are present on the northern beach at Prong Point bay. This includes both that forming the active beach zone and that underlying the raised beach, green area behind the active beach. The density of the deposit will increase both downwards and eastwards as the grain size decreases and this introduces much uncertainty into any conversion from volume to weight. About 400 tonnes is probably a realistic figure, but the presence of the sand and pebble layers towards the eastern end of the beach is a detrimental and complicating factor in the assessment.

Samples of calcified seaweed were collected as follows:

Lively Island / Prong Point 1. Western end of beach, surface sample from slight hollow between crest of active storm ridge and eroded front of raised beach.

Lively Island / Prong Point 2. Eastern end of beach, surface sample illustrating preservation of delicate "flaky" structure.

These samples are held for reference in the Department of Mineral Resources, Stanley.

4.2 THE CENTRAL BEACH

This beach runs for 400 m, approximately NNW-SSE, along the most easterly extension of the Prong Point inner bay. It is separated from the northern beach by a low-lying, rocky promontory, and from the southern beach by a more substantial low headland. Behind the active beach there is an extensive green area of raised beach.

At its northern end, the active beach is about 30 m broad with a weakly-defined storm ridge about 10 m forward of the back of the beach. The surface layer of calcified seaweed is fairly coarse grained with fragments in the 1-5 mm range but decreasing with depth. Pits dug along and across the beach showed that in general the calcified seaweed layer thickened away from the water's edge to a maximum thickness of about 1m (overlying rock or shingle) in the central part of the beach cross-section. It thence thinned inland to about 60 cm at the back of the beach where, in two pits, the calcified seaweed was seen to overlie a 10 cm thick organic layer that in turn overlay stiff grey clay. Elsewhere, a scattering of rock pebbles and sand lenses were noted within the calcified seaweed deposit, and these appeared to increase in abundance seawards until distinct layers of pebbles and sand were seen to alternate with the calcified seaweed. Thin layers of organic material were also noted within the seaward third of the calcified seaweed accumulation.

Farther south, in its central part, the active beach zone broadens to about 50 m. The maximum depth of calcified seaweed was 80 cm, and this thickness was fairly consistent between a number of pits. Grain-size at the surface is in the 1-4 mm range but decreases with depth as seen elsewhere. Inter-bedded layers of sand or pebbles are less common than in the beach sector to the north, but there was a marked increase in the abundance of disseminated peat grains which in places were sufficiently concentrated to produce dark laminae running through the calcified seaweed. It seems most likely that this peat comprises wind-eroded grains blown out onto the beach from inland areas. The same overall conditions continue to the southern end of the beach with a reduction in maximum depth to 70 cm and an overall narrowing of the active beach to about 20 m.

For much of its length the central, active beach is backed by an extensive green, raised beach area that was also investigated by a series of pits. The seaward edge of the raised beach, a strip at least 5 m across, is underlain by calcified seaweed forming a layer with a fairly uniform thickness of 60 cm. The calcified seaweed overlies peat and is covered by a thin veneer of peat. Farther back from the sea the proportion of peat increases abruptly. The grain size of the calcified seaweed beneath the raised beach was the finest seen at Prong Point, with all fragments sub-millimetre in size and most forming a coarse sand. It is thought that the widely-observed reduction in grain size with depth (= increase in age) arises from the progressive degradation of the calcified seaweed fragments.

As a rough estimate, a maximum of 4 000 m^3 of calcified seaweed are present on the central beach, inner Prong Point bay. The green area of raised beach behind the active beach contains at least another 1 500 m^3 although in this case the complex relationship with overlying, underlying and inter-fingering peat layers makes assessment difficult. A similar, though less acute, problem is caused by the sand, pebble and organic layers within the active beach deposit. The finely disseminated peat grains are irrelevant in any volume calculations but could be important in any future assessment of compositional purity. Bearing in mind the uncertain and variable density, the active beach probably contains about 2 000 tonnes of calcified seaweed. The finer grained (and therefore denser) raised beach deposit could contain a further 1000 tonnes. In neither case would these full amounts be practicably exploitable.

Samples of calcified seaweed were collected as follows:

Lively Island / Prong Point 3. Middle area of beach, towards the back. Sample from 60 cm depth immediately overlying an organic layer on grey clay.

Lively Island / Prong Point 4. Middle area of raised beach, about 5 m back from the seaward edge. Sample from 60 cm depth above peat.

Lively Island / Prong Point 5. South end of beach, surface specimen from slight hollow between crest of active storm ridge and eroded front of raised beach.

These samples are held for reference in the Department of Mineral Resources, Stanley.

4.3 THE SOUTHERN BEACH

This beach runs north-south for about 250 m in the south-east corner of the inner Prong Point bay. It is separated from the central beach by a low rocky headland. There is a narrow strip of green, raised beach behind the active beach. Examination of this beach was brought to a premature conclusion by a dramatic deterioration in the weather, and only the northern end was visited. Aerial photographs suggests that sand dunes encroach onto the southern end of the bay and so, in that case, a high proportion of blown sand might be expected in the southern part of the calcified seaweed accumulation.

The active beach width was in the 10-15 m range. Calcified seaweed at the surface was fairly coarse, in the 2-4 m range, but with a scattering of larger, rounded pebbles (rhodoliths) up to tennis-ball-size. As usual, the grain size decreased with depth, but this was only 30 – 40 cm in the two pits that were dug; on this basis the southern beach may have a substantially thinner calcified seaweed accumulation than the two bays to the north. The narrow raised beach area did not seem to contain any significant thickness of calcified seaweed.

From the limited information available, the southern beach at Prong Point bay seems unlikely to contain much more than 750 m^3 of calcified seaweed. The relatively small depth range would favour an average coarse grain size and therefore a low density. About 350 tonnes of calcified seaweed would seem a realistic estimate.

4.4 ADDITIONAL NOTES ON LIVELY ISLAND OCCURRENCES

In the Prong Point area, Alec Jaffray reports that small quantities of calcified seaweed come up on the south-west side of the inner bay, opposite the major beach deposits described above. None is known to occur outside the inner bay. This would suggest that the source of the calcified seaweed, a living algal reef, is actually situated inside the inner part of the Prong Point bay.

The north-east shores of Useless Water are scattered with small pockets and isolated, large pebbles of calcified seaweed. A noteworthy locality lies at the southern end of the sand dune promontory extending south-west from the House Rocks area. There, rounded lumps of calcified seaweed up to the size of a tennis ball are strewn across an extensive foreshore of quartz and shell sand. There is no trace of fine-grained calcified seaweed at this locality. Small pockets and strand lines of calcified seaweed in the 0.5 to 3 mm size range, together with isolated larger pebbles, are seen at intervals along the northern coast of Useless Water, the southern shore of the Sand Hills. A source within Useless Water seems likely and, as the name suggests, aerial photographs confirm abundant shoals and sandbanks.

The northern coast of Lively Island, west from the settlement, is scattered with isolated pebbles, small pockets and strand lines of calcified seaweed. There is a particular (though still very small) concentration on a tombola building out from a promontory on Lively Island towards Cow Island. Aerial photographs show sand banks drifting from this tombola along the southern side of Cow Island. The south-east corner of Cow Island is reported to have a small accumulation. More substantial, though probably still fairly small, accumulations are reported from two (possibly three) small bays on the south-west side of Philimore Island, opposite Reef Island. Aerial photographs show that the central of these three bays contains many shallow sandbanks and is protected by an offshore rock reef. This bay would seem the most promising site for a significant accumulation

Shell sand was noted at a number of localities around the east coast of Lively Island. A significant accumulation occurs on the east side of Shallow Harbour (western coastline of the Sand Hills promontory) forming about 500 m of beach. A reference sample was collected at the southern end of the beach and is held in the Department of Mineral Resources, Stanley.

Sample locality: 51 59 33 S, 58 25 35 W.

5 The Spring Point calcified seaweed deposit, West Falkland.

The calcified seaweed deposit is situated in a small bay at Peatbog Paddock. The bay is open to the south-west but protected in that direction by Spring Point Island and a promontory from Fox Island. Aerial photographs show many offshore sandbanks in the vicinity but local reports suggest that most of these consist of quartz sand rather than calcified seaweed. This locality was visited by PS on the afternoon of Thursday November 23, 2000, accompanied by Ron Rozee of Spring Point Farm. The tide was fairly low and the weather was good enough for observation and measurement. GPS data for the locality are as follows:

North end of beach, primary deposit …. 51 50 40 S, 60 27 08 W.

South end of beach, primary deposit …. 51 50 44 S, 60 27 07 W.

The primary deposit consists of the active beach zone, about 10 m wide, and a raised beach, green area about 0.5 m above the current beach and extending back from it for about 10 m. The lengths of the beach and raised beach are both about 110 m. Pits dug into both of these areas proved calcified seaweed, with only small quantities of included organic matter. The pits also established a depth of about 0.8 to 1 m for most of the raised beach deposit, and a similar thickness for the inshore part of the active beach, which thence thinned seawards. An extensive inter-tidal rock platform extends seawards from the beach. The dimensions cited are in close agreement with those given in the Environmental Impact Statement produced by Falklands Conservation.

There are two areas adjacent to the primary deposit which could provide an additional source of calcified seaweed. Firstly, a higher raised beach level, about 2 m above the active beach, is about 100 m long and extends back for about 20 m. The top 20-30 cm of this area consists mainly of fine-grained calcified seaweed which has possibly been blown inland from the beach deposits; below this level the calcified seaweed is mixed with an increasing proportion of peat. Secondly, in the next small bay 50 m south-east from the southern margin of the primary deposit, an accumulation of calcified seaweed occupies an area of about 30 x 20 m, spanning the active and raised beach zones, and is up to 1 m thick.

A layer of calcified seaweed up to 30 cm thick was also noted beneath a thin peat cover in the small bay immediately north of the primary deposit. This accumulation is probably too thin and restricted to represent an additional resource.

The likely volume of calcified seaweed present in the Spring Point primary deposit is approximately 2000 m^3. This figure is in close agreement with the conclusion of the Falklands Conservation Environmental Impact Statement. There is some uncertainty in converting this volume into a weight since the density of the calcified seaweed is clearly very variable. The active beach deposits are relatively coarse with most of the individual grains between 1 and 3 mm across, mixed with a small component of molluscan debris of similar size. The coarsest material was found at the seaward side of the beach, towards low water, where fragments up to 20 mm across were common with sporadic larger fragments. Larger fragments up to about tennis-ball-size were scattered across the inter-tidal rock platform. In contrast, the calcified seaweed detritus forming the raised beach deposits was finer grained overall with a range of particle size from 2 mm down to a fine sand grade. Several pits were dug into this component of the primary deposit and proved a fairly uniform composition (and depth). The finest grained material was noted in the potential additional sources of calcified seaweed adjacent to the primary deposit; these may contain a higher proportion of windblown detritus.

Density values (dry) previously cited for the calcified seaweed range from as low as 0.3 tonne/m^3 (Report by Don Aldiss on Ruggles Bay deposit, DMR files for 1999, OIL/Admin/17 – 36) up to about 0.6 tonne/m^3. A crude experiment with material from the Spring Point raised beach material (relatively fine grained), involving filling several sacks, weighing them, estimating volume and scaling up, suggested that a higher figure might be appropriate in that case, perhaps as much as 0.8 tonne/m^3. The density figure used has a significant effect on the tonnage calculated to be in the deposit but it is unlikely that the Spring Point primary deposit exceeds 1500 tonnes, and not all of that would be practicably exploitable.

Samples of calcified seaweed were collected as follows:

1. Active beach, highest point at north end of primary deposit.
2. Coarse material from the seaward side of the active beach zone, south end of primary deposit.
3. Raised beach component of the primary deposit, from a depth of about 50 cm in a pit dug in the approximate centre of the area.
4. Finer grained material from the smaller accumulation to the south-east of the primary deposit.

All of these samples are held for reference in the Department of Mineral Resources, Stanley.

6 The East Bay - Brown Harbour calcified seaweed deposits, West Falkland.

The area of interest spans the eastern side of Symonds Harbour (Brown Harbour camp) and the eastern side of Brown Harbour (East Bay camp). The shore is predominantly rocky, with only a few small beaches developed, usually inshore of inter-tidal rock platforms. There are numerous localities along these coastlines where small pockets of calcified seaweed have accumulated but in only a few places have significant deposits built up. Even then, the amounts of calcified seaweed present are relatively small.

The area was visited by PS in the late morning and early afternoon of February 6, 2001, accompanied by Alex Blake (DMR) and Mark Gleadell (East Bay). The Symonds Harbour section was visited first, traversing from north to south; the Brown Harbour section was visited second, again traversing from north to south. At Symonds Harbour the tide was fairly high but falling. By the time Brown Harbour was reached the tide was fairly low. During the morning the weather was cloudy with occasional light rain and the usual strong wind, the afternoon showed a marked improvement. These conditions did not cause any problems for the assessments.

6.1 THE SYMONDS HARBOUR SECTION

Four localities are described below from the Symonds Harbour shore of the Brown Harbour camp. Between them the coast is strewn with small pockets and isolated pebbles of calcified seaweed, but the quantities of material involved are very small.

- GPS locality data for the northern end of the section: 51 51 03 S, 60 20 25 W.

From here south there is a scattering of fairly coarse-grained (up to 3 mm) calcified seaweed across restricted areas of beach shingle and low rocky outcrops. Locally the calcified seaweed accumulates into pockets up to 10 m^2 in area and up to 15 cm deep. These are trivial amounts and do not represent a viable resource.

- GPS locality data for the northern end of a small bay: 51 51 09 S, 60 20 28 W.

This small bay contains a beach about 60 m long and with a maximum width of about 25 m in its central part. The surface of the beach consists of poorly sorted calcified seaweed fragments ranging in size from grains of less than 1 mm, up to larger pebbles 2 cm across. The larger pebbles (rhodoliths?) are very variable in shape. Some are rounded whereas others retain a delicately branching, coral-like structure. Pits dug across the beach showed that the depth of the calcified seaweed layer increased to a maximum of 50 cm towards the back of the beach in its central part, with the grain size decreasing downwards. The calcified seaweed layer overlay large pebbles and probably areas of bedrock. In most of the pits, the calcified seaweed was inter-bedded with thin (1-3 cm) layers of fine-grained quartz sand that made up perhaps 25% of the total material present. The small area of green, raised beach behind the active beach does not appear to contain any calcified seaweed. As a rough estimate, about 600 m^3 of calcified seaweed is present on the active beach. In view of the variable, but generally coarse grain size this probably represents no more than 250 tonnes of calcified seaweed.

Samples of calcified seaweed were collected as follows:

Symonds Harbour (Brown Harbour camp) 1. Surface sample from centre of beach showing variable grain size.

Symonds Harbour (Brown Harbour camp) 2. Sample from 50 cm depth (base of calcified seaweed layer) overlying shingle and immediately beneath sample 1.

These samples are held for reference in the Department of Mineral Resources, Stanley.

- GPS locality data for a small patch of raised beach: 51 51 25 S, 60 20 06 W.

A small green area of raised beach lies behind a narrow and restricted active beach zone. Small patches and ridges of calcified seaweed are banked up against the eroded front of the raised beach, the surface of which is about 1 m above the high water mark. The quantity of calcified seaweed present on the active beach is trivial, but the eroded front of the raised beach provides an interesting cross-section. The surface peat is about 15 cm thick and overlies a 25 cm thick layer formed by rounded granules of calcified seaweed with diameters ranging from 1 to 4 cm and all stained brown by the peat. There is no finer grained material present and the granule layer overlies more peat. It appears that calcified seaweed has accumulated here over a long period during which time sea level has fluctuated (see section 8 for further discussion).

A sample of calcified seaweed was collected as follows:

Symonds Harbour (Brown Harbour camp) 3. Front of raised beach area, 25 –35 cm depth, rounded granules of calcified seaweed.

This sample is held for reference in the Department of Mineral Resources, Stanley.

- GPS data for small headland at southern end of section: 51 51 31 S, 60 20 02W.

A small headland marks the southernmost point on the Symonds Harbour shore from which significant calcified seaweed accumulations have been reported. A triangular area of beach has built out from the headland with dimensions of about 20 m. This beach area consists of fairly coarse-grained calcified seaweed in the 0.5 to 3 mm size range at surface but, as usual, the grain size decreases with depth. The accumulation here only amounts to about 200 m^3, probably no more than 100 tonnes.

6.2 THE BROWN HARBOUR SECTION

Two localities are described below from the Brown Harbour shore of the East Bay camp. Between them the coast is strewn with small pockets and isolated pebbles of calcified seaweed, but the quantities of material involved are very small.

- GPS locality data for the northern end of a small beach: 51 49 07 S, 60 17 58 W.

This beach runs NNE-SSW for approximately 100 m; for most of its length it is about 15 m wide. The seaward side of the active beach rests on a rock platform that continues seawards at a level just above low water. Behind the active beach there is an irregular development of green, raised beach about 0.5-1 m above high water, but this area does not appear to contain any calcified seaweed. The active beach is composed of calcified seaweed forming a series of ridges rising away from the water's edge to give a depth of about 40-50 cm at the back of the beach. The calcified seaweed is mostly in the 1-3 mm grain size range, with the average grain size decreasing downwards to become less than 0.5 mm at the base of the deposit. There is a fair amount of fine shingle mixed in with surface layer of calcified seaweed, as much as 10% in places, but this also decreases in abundance downwards. Randomly mixed with the surface layer of calcified seaweed grains are rounded pebbles (rhodoliths) of the same material up to about tennis-ball-size. Similar sized rhodoliths are also strewn across the low-water rock platform. Overall, this beach accumulation probably contains about 500 m^3 of calcified seaweed. The average grain size appears to be fairly low but even so it is unlikely that more than 250 tonnes are present.

A sample of calcified seaweed was collected as follows:

Brown Harbour (East Bay camp) 1. Centre of beach, towards the back, 20 cm depth.

This sample is held for reference in the Department of Mineral Resources, Stanley.

- GPS data for small beach at southern end of the section: 51 49 20 S, 60 17 56 W.

This small beach occupies an area between two low, rocky headlands. It is about 10 m wide for most of its length. The calcified seaweed forming the surface of the beach is fairly mixed in grain size, with a background of fragments in the 0.5 mm to 4 mm range containing sporadic larger, and usually rounded pebbles several centimetres across. Digging proved up to 60 cm of calcified seaweed beneath the back of the beach with a much reduced grain size and very few pebbles in the lower half of the deposit; the lowest part of the calcified seaweed layer was a water-logged calcareous mud. No firm base was encountered and so the 60 cm depth is a minimum figure. Over most of the back half of the beach, pits revealed an unusually coarse granular layer about 20 cm beneath the surface and about 10 cm thick. This layer consisted of rounded pebbles of calcified seaweed all in the 1-3 cm diameter range and with no finer grained matrix material. The fine-grained calcified seaweed beneath this layer contained several thin (1-2 cm) beds of fine-grained quartz sand. The volume of calcified seaweed present in this accumulation is probably no more than 120 m^3. The variable grain size, including some quite coarse material, would suggest that this equates to no more than 50 tonnes. The adjacent rocky areas are littered with rounded pebbles and cobbles (rhodoliths) of calcified seaweed up to 15 cm in diameter. In places these are concentrated at the high water line but the overall quantity of material involved is very small.

A sample of calcified seaweed was collected as follows:

Brown Harbour (East Bay camp) 2. Centre of beach, towards the back, rounded granules of calcified seaweed from distinctive layer at 25 cm depth.

This sample is held for reference in the Department of Mineral Resources, Stanley.

6.3 ADDITIONAL NOTES FOR THE EAST BAY AREA

Small pockets and isolated pebbles of calcified seaweed are reported to occur sporadically around the north side of the East Bay camp, i.e. the shores of Rees Harbour, East Bay itself, and the bay between East Bay House and Half Tide Island. All of these accumulations, as reported, are trivial and do not represent an additional resource.

7 Notes on minor calcified seaweed occurrences

Small accumulations or isolated fragments of calcified seaweed are common all along the Falkland Islands coastline. The occurrences listed below are characteristic of these minor deposits. The list is by no means exhaustive.

1. Chico Point, on the north side of Findlay Harbour, East Falkland. This relatively large deposit lies to the north of Ruggles Bay, but in a similar topographical position to that locality, on the east side of Falkland Sound. The Chico Point deposit was also assessed by Don Aldiss (British Geological Survey) in June 1997 (DMR files for 1999, OIL/Admin/17 – 36) who further commented (Aldiss and Edwards, 1999) that drifts of calcified seaweed sand extended offshore for about 100 m.
2. The Canache, Stanley Harbour, East Falkland. Coarse, spiky fragments of calcified seaweed are scattered across the rocky foreshore, particularly so to the north-east of Boxer Bridge, but also more sparsely on the southern shore. When observed on 4 December, 2000, the fragments present ranged up to about 5 cm across; by the time of a second visit on 11 February, 2001, larger fragments up to about 8 cm across had appeared and the overall quantity present had also increased. Local reports indicate that this area has long been a source of "hen grit" but that for the past few years none has been present, only recently has the material begun to reappear. A long history of arrival in this area is confirmed by thin layers of calcified seaweed grains in the peat at the back of the beach. Very little calcified seaweed is seen to the west of Boxer Bridge, and none was noted outside the narrow entrance to The Canache. The conclusion must be that the *lithothamion* algae grow in The Canache.
3. Port Louis Harbour, East Falkland. Widely scattered fragments of calcified seaweed were present on the extreme western shore, Jack's Point camp. When observed (10 February, 2001) all of the fragments were rounded and weathered but still ranged up to about 6 cm in diameter.
4. Port San Carlos, East Falkland. Sporadic fragments up to 10 cm across seen (25 February, 2002) on the shoreline west from the settlement.

5. Walker Creek, East Falkland. Sporadic fragments up to 2 cm seen (14 Novenber 2001) on the shoreline in the vicinity of the settlement.
6. Philimore Island, East Falkland. Substantial beach accumulations have been reported from the south coast, facing Reef and Cow Islands. These deposits have been viewed (1 February 2001) from the opposite, Lively Island shore, and do not appear large enough to represent a significant resource.
7. Salinas Beaches, Brenton Loch, East Falkland. Fragments up to 5 cm diameter were observed sparsely but widely scattered across the foreshore (19 February, 2002).
8. Bleaker Island, East Falkland. Fine grained material mixed in with fine rock shingle seen (19 November, 2001) on the north-west coast, south from the Settlement in "First Island bay".
9. Sandy Tyssen Island, Falkland Sound. A substantial, thick beach accumulation has been reported. No further information is available.
10. Bold Cove, West Falkland. A scattering of coarse fragments was present across the rocky foreshore in the north-east corner of the bay (51-35-09 S, 59-26-23 W). Fragments range up to about 5 cm across and are highly angular, with irregular and spiky, coral-like growths preserved. A very local source seems likely. The quantity present at the time of the visit (7 February, 2001) was trivial but Jimmy Forster (Bold Cove) reports that larger quantities are sometimes present.
11. Sound Point, West Falkland. The beach at the western end of the West Lagoons camp, south of Sound Point, was reported to contain some calcified seaweed but none was present at the time of the visit (5 February, 2001). Some calcified seaweed was found on the rocky foreshore to the south of the headland forming the southern limit of the beach. This was in the form of rounded pebbles up to about 8 cm across, and heavy encrustation on loose, angular rock fragments. The latter appeared to have been derived locally. At low tide, pinkish growths were noted on still-submerged rocks that had the same general appearance as the more "flaky" fragments of calcified seaweed seen elsewhere.
12. Pebble Island, West Falkland. Fragments up to 10 cm across seen (9-12 February, 2001) widely along the south side, with rarer and smaller fragments on the north coast.
13. Shallow Bay, West Falkland. Beach deposit reported to extend for about 100 m. No further information available.
14. Albermarle, West Falkland. Beach deposit reported to extend for about 300 m in the vicinity of Eagle rocks. No further information available.
15. Saladero, East Falkland. Beach deposit reported. No further information available.
16. Shag Cove, West Falkland. "Several trailer loads" reported to lie on beach. No further information available.
17. Port Edgar, West Falkland. Beach deposit reported to extend for 300 - 400 m on the settlement spit. No further information available.
18. Beaver Island, West Falkland. Large deposit reported from the south side of Beaver Harbour. No further information available.

8 Age of the calcified seaweed deposits

Live algal detritus is currently arriving on Falkland Islands beaches, but for how long this has been occurring is unclear. The presence of calcified seaweed beneath the green areas of apparently raised beach, behind and up to about 1 m above the current beach, would suggest a long history of arrival, initially with a slightly higher sea level. At Ruggles Bay (Ruggles Arroyo Beach) up to 1 m of calcified seaweed forms the front edge of the raised beach green and lies directly on a flat bedrock surface. Elsewhere, thinner layers of calcified seaweed form the upper parts of the raised beach terraces and in several localities these layers overlie peat. This is an important relationship since radiocarbon dating of the peat will give a maximum age for the arrival of the overlying calcified seaweed. Three localities were examined in detail and peat from beneath the calcified seaweed was dated: the radiocarbon dating certificates follow as Appendix 1.

8.1 MOTLEY POINT, WALKER CREEK

In the central part of the southern deposit a thin layer of calcified seaweed, up to about 30 cm thick, forms the surface layer of the raised beach green behind, and about a metre above, the active beach. The calcified seaweed layer is covered by a thin veneer of peat, but also overlies about 20 cm of peat that in turn rests on grey-brown clay. The near-surface layer of calcified seaweed in the raised beach only extends for about 10 m inland. A sample of peat immediately underlying the calcified seaweed was collected at 52 06 00 South, 58 40 42 West, and was dated at the Scottish Universities Research and Reactor Centre. A radiocarbon age of 1000±50 years BP (before 1950 AD) was obtained. This gives a calibrated date of formation of about 1000-1100 AD. Hence, the first arrival of calcified seaweed occurred no more than about 1000 years ago.

At the southern end of the southern deposit the base of the peat was independently dated where it can be seen to directly overlie an old wave-cut rock platform that is currently being exhumed by marine erosion of the peat. The peat samples were collected at 52 06 21 S, 58 41 04 W. Ages of about 5 000 years and 10 000 years were obtained, the latter being in broad agreement with the oldest dates previously recorded for Falklands peat (Clapperton and Roberts 1986). There is no sign of any calcified seaweed interbedded with these older peat deposits.

8.2 PRONG POINT, LIVELY ISLAND

Peat was discovered to underlie the calcified seaweed deposits in two different circumstances in the central part of the central beach at Prong Point. At the back of the active beach, in two pits dug behind the contemporary storm ridge, about 60 cm of calcified seaweed was seen to overlie a 10 cm thick organic layer that in turn overlay stiff grey clay. Behind the active beach, for most of its length, is an extensive green, raised beach area that was also investigated by a series of pits. The seaward edge of the raised beach, a strip at least 5 m across, is underlain by calcified seaweed forming a layer with a fairly uniform thickness of 60 cm. The calcified seaweed is covered by a thin veneer of peat but also overlies peat, with a thickness exceeding 50 cm.

Peat immediately underlying the calcified seaweed was collected from both environments as follows:

Active beach – 52 04 36 South, 58 26 41 West

Raised beach – 52 04 39 South, 58 26 38 West

Both samples were dated at the Scottish Universities Research and Reactor Centre and radiocarbon ages (in years BP) of 690±50 and 530±50 were obtained for the active and raised beach peats respectively. The implication here is that calcified seaweed was first emplaced onto an eroded peat surface no more than about 550 years ago.

8.3 SYMONDS HARBOUR (BROWN HARBOUR CAMP)

At one locality in Symonds Harbour, small patches and ridges of calcified seaweed are banked up against the eroded front of the raised beach, the surface of which is about 1 m above the high water mark. The quantity of calcified seaweed present on the active beach is trivial, but the eroded front of the raised beach provides a cross-section that shows surface peat, about 15 cm thick, overlying a 25 cm thick layer formed by rounded granules of calcified seaweed with diameters ranging from 1 to 4 cm and all stained brown by the peat. There is no finer grained material present and the granule layer overlies more peat with a depth exceeding 50 cm.

The peat immediately underlying the calcified seaweed granule layer was sampled at 51 51 25 South, 60 20 06 West and was dated at the Scottish Universities Research and Reactor Centre. A radiocarbon age of 590±50 years was obtained, indicating that the first arrival of calcified seaweed at this locality was no more than about 600 years ago.

8.4 DISCUSSION

The maximum possible age established for any of the calcified seaweed deposits is the 1000 years obtained from Motley Point. However, of more significance may be the approximately coincident ages of about 550-600 years that span East and West Falkland from the Prong Point and Symonds Harbour deposits. These ages are younger than might have been expected from the association of the calcified seaweed with raised beaches that have a likely age of several thousand years at least. It seems highly improbable that well-defined raised beaches are little more than 500 years old. This apparent anomaly raises the possibility that the calcified seaweed was emplaced on the raised beaches, at some time after their formation, by wind or an unusually severe storm. Alternatively, the interpretation of the terraced green areas behind and above the active beach is incorrect, and their formation should perhaps be viewed in terms of storm-ridge progradation or some other mechanism. The history of sea-level change around the Falklands is not well understood and this part of the interpretation of the calcified seaweed deposits will need to be reconsidered as more data becomes available. In particular, the recent discovery of a lower layer of calcified seaweed, beneath peat that itself extends for about 50 cm below high water mark, is a complicating feature worthy of further study. Whatever the precise timing, it seems probable that the first arrival of calcified seaweed is an indicator of environmental change, dating when Falklands' coastal waters became amenable to colonisation by red, coralline algae.

The radiocarbon dating certificates are included in this report as appendix 1.

9 Mineralogy and microtextures of the calcified seaweed.

A sample of calcified seaweed from Motley Point was analysed by X-ray diffraction (XRD) to determine its mineralogy and also examined by scanning electron microscopy (SEM) to record grain size, morphology and microtextures.

9.1 X-RAY DIFFRACTION ANALYSIS

For XRD analysis, a portion of the calcified seaweed was subsampled, hammer-milled to <0.12 mm, micronised under acetone for 5 minutes and then dried at 55˚C. The dried material was then disaggregated and back-loaded into a standard aluminium sample holder. Analysis was carried out using a Philips PW1700 series diffractometer using Co-Kα radiation and operating at 45kV and 40mA. Diffraction data were analysed using Philips X'Pert software coupled to an

International Centre for Diffraction Data (ICDD) database running on two Gateway personal computers. The powder mount was scanned from 3-50 °2θ at a scanning speed of 0.55°2θ/minute.

XRD analysis indicates that the calcified seaweed is principally composed of calcite ($CaCO_3$, ICDD pattern 43-0697) with minor aragonite ($CaCO_3$, 41-1475) and quartz (SiO_2, 46-1045). The position of the calcite XRD peaks suggests that it is a high-Mg species containing *c.*11% $MgCO_3$ according to the calibration curve of Roselle (1982) and typical of red algae. A labelled XRD trace is shown in Figure x.

9.2 SCANNING ELECTRON MICROSCOPY

For SEM analysis, a portion of the coralline material was removed and mounted on aluminium stubs using carbon-based Leit-C cement. Once dry, the stubs were coated with a layer of carbon approximately 25 nm thick in an Edwards 306A carbon evaporation coater. The stub was then examined in a Leo 435VP Scanning Electron Microscope operated in Secondary Electron Imaging mode at 20 KV. Semi-quantitative chemical analysis was performed on individual mineral grains using a Link Analytical Energy-Dispersive Spectrometer (EDS).

The grains of coralline material range from 2-3 mm down to less than 100µm in diameter, and most are rounded or subangular in shape (Figure Y, A, B). A variety of surface features were imaged on the grains. The most common comprises a honeycomb texture of cells each about 7-10 µm across, with cell walls 1-1.5 µm thick. (Fig. YC). Individual cells are partially or completely filled with carbonate grains 1-5 µm across. These grains appear to be texturally distinct from the carbonate forming the cell walls, which in a few cases appears to be fibrous with a radial arrangement. Other surface textures show cells arranged along ribs with a semi-radial structure (Fig. YD). Some grains lack the cellular structure and show smooth coatings of scaly carbonate crystals1-2 µm across (Fig. YE).

Together, the microtextures and mineralogy suggest that the cellular structure was formed by early growth of the algae, precipitating aragonite as perhaps radial fibres. The early aragonite has been overgrown by Mg-calcite, either as part of an ‘encrusting’ phase of biogenic carbonate formation, or during posthumous early diagenesis when aragonite inverted to Mg-calcite.

Appendix 1

Figure 2 Ruggles Bay. Calcified seaweed extraction in progress (18th January 2003)

Figure 3 Motley Point

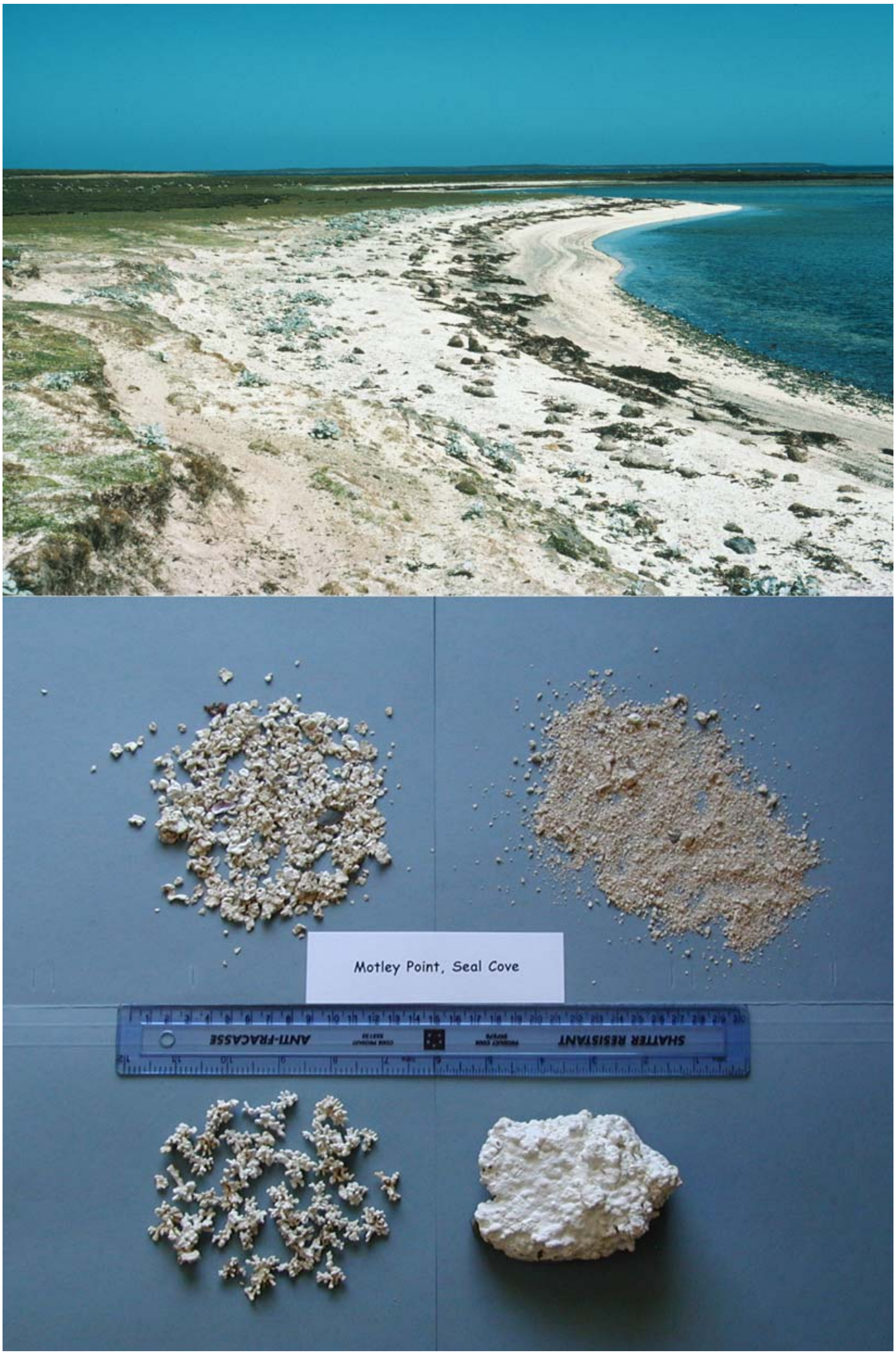

Figure 4 Lively Island

Figure 5 Spring Point

Figure 6 Brown Harbour

Figure 7 Brown Harbour. Rhodoliths accumulated at high water mark.

Appendix 2

Radiocarbon Dating Certificates

SURRC

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Rankine Avenue
Scottish Enterprise Technology Park
East Kilbride Scotland UK G75 OQF

E-mail: g.cook@surrc.gla.ac.uk
Telephone: 01355 223332
Direct Dial: 01355 270136
Fax: 01355 229898

RADIOCARBON DATING CERTIFICATE

28 August 2001

Sample	GU-9395
Submitter	Dr. Phil Stone British Geological Survey Murchison House West Mains Road Edinburgh EH9 3LA
Material	Peat : Humic Acid Dated
Sample Reference	Motley Point, East Falkland : PS/F01
Delta ^{13}C rel. PDB	-24.8‰
Radiocarbon Age BP	1000 ± 50
Calibrated Age Ranges	**1σ** cal AD 997-1148, cal BP 953-802 **2σ** cal AD 904-1160, cal BP 1046-790

N.B. 1. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error is expressed at the one sigma level of confidence.

2. The calibrated age ranges are determined from the University of Washington, Quaternary Isotope Laboratory, Radiocarbon Dating Program, Rev. 4.0 1998. The decadal atmospheric calibration curve is used throughout and the calendar age ranges, obtained from the intercepts (Method A), are expressed at both the one and two sigma levels of confidence. In the case of marine shell samples derived from around the U.K. coastline, an apparent age (reservoir effect) of 405 ± 40 years (Harkness, 1983) is subtracted from the conventional ^{14}C age prior to calibration using the decadal atmospheric curve.

3. Samples with an AA coding are measured at the University of Arizona AMS Facility and should be quoted as such in any reports within the scientific literature. Any questions directed to SURRC should also quote the GU coding that is given in parentheses after the AA code.

Reference

Harkness, D.D. (1983) The extent of natural ^{14}C deficiency in the coastal environment of the United Kingdom. In *^{14}C and Archaeology*, Groningen August 1981, 351-364.

Conventional age and calibration age ranges calculated by :- R. Anderson Date :- 28-8-01

Checked and signed off by :- Gordon T Cook Date :- 28-8-01

SURRC

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RADIOCARBON DATING CERTIFICATE

28 August 2001

Sample	GU-9396	
Submitter	Dr. Phil Stone British Geological Survey Murchison House West Mains Road Edinburgh EH9 3LA	
Material	Peat : Humic Acid Dated	
Sample Reference	Lively Island, East Falkland : PS/F02	
Delta ^{13}C rel. PDB	-21.3‰	
Radiocarbon Age BP	690 ± 50	
Calibrated Age Ranges	**1σ**	cal AD 1280-1382, cal BP 670-568
	2σ	cal AD 1258-1396, cal BP 692-554

N.B. 1. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error is expressed at the one sigma level of confidence.

2. The calibrated age ranges are determined from the University of Washington, Quaternary Isotope Laboratory, Radiocarbon Dating Program, Rev. 4.0 1998. The decadal atmospheric calibration curve is used throughout and the calendar age ranges, obtained from the intercepts (Method A), are expressed at both the one and two sigma levels of confidence. In the case of marine shell samples derived from around the U.K. coastline, an apparent age (reservoir effect) of 405 ± 40 years (Harkness, 1983) is subtracted from the conventional ^{14}C age prior to calibration using the decadal atmospheric curve.

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RADIOCARBON DATING CERTIFICATE

28 August 2001

Sample	GU-9397
Submitter	Dr. Phil Stone British Geological Survey Murchison House West Mains Road Edinburgh EH9 3LA
Material	Peat : Humic Acid Dated
Sample Reference	Lively Island, East Falkland : PS/F03
Delta ^{13}C rel. PDB	-25.1‰
Radiocarbon Age BP	530 ± 50
Calibrated Age Ranges	**1σ** cal AD 1331-1435, cal BP 619-515 **2σ** cal AD 1304-1446, cal BP 646-504

N.B. 1. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error is expressed at the one sigma level of confidence.

2. The calibrated age ranges are determined from the University of Washington, Quaternary Isotope Laboratory, Radiocarbon Dating Program, Rev. 4.0 1998. The decadal atmospheric calibration curve is used throughout and the calendar age ranges, obtained from the intercepts (Method A), are expressed at both the one and two sigma levels of confidence. In the case of marine shell samples derived from around the U.K. coastline, an apparent age (reservoir effect) of 405 ± 40 years (Harkness, 1983) is subtracted from the conventional ^{14}C age prior to calibration using the decadal atmospheric curve.

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RADIOCARBON DATING CERTIFICATE

28 August 2001

Sample	GU9398	
Submitter	Dr. Phil Stone British Geological Survey Murchison House West Mains Road Edinburgh EH9 3LA	
Material	Peat : Humic Acid Dated	
Sample Reference	Symond's Harbour : PS/F04	
Delta ^{13}C rel. PDB	-24.8‰	
Radiocarbon Age BP	590 ± 50	
Calibrated Age Ranges	1σ	cal AD 1302-1410, cal BP 648-540
	2σ	cal AD 1292-1432, cal BP 658-518

N.B. 1. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error is expressed at the one sigma level of confidence.

2. The calibrated age ranges are determined from the University of Washington, Quaternary Isotope Laboratory, Radiocarbon Dating Program, Rev. 4.0 1998. The decadal atmospheric calibration curve is used throughout and the calendar age ranges, obtained from the intercepts (Method A), are expressed at both the one and two sigma levels of confidence. In the case of marine shell samples derived from around the U.K. coastline, an apparent age (reservoir effect) of 405 ± 40 years (Harkness, 1983) is subtracted from the conventional ^{14}C age prior to calibration using the decadal atmospheric curve.

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Conventional age and calibration age ranges calculated by :- R. Anderson Date :- 28-8-01

Checked and signed off by :- Gordon T Cook Date :- 28.8.01

Dr. Antony Long

University of Durham

Report Date: 4/16/02

Material Received: 3/8/02

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 165790	9960 +/- 70 BP	-27.0 o/oo	9930 +/- 70 BP

SAMPLE : MOTLEY POINT 1
ANALYSIS : Radiometric-Standard delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 9620 to 9240 (Cal BP 11570 to 11200)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 165791	4780 +/- 60 BP	-24.9 o/oo	4780 +/- 60 BP

SAMPLE : MOTLEY POINT 2
ANALYSIS : Radiometric-Standard delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 3660 to 3500 (Cal BP 5610 to 5450)AND Cal BC 3460 to 3380 (Cal BP 5410 to 5330)

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-27:lab. mult=1)

Laboratory number: **Beta-165790**

Conventional radiocarbon age: **9930±70 BP**

2 Sigma calibrated result: **Cal BC 9620 to 9240 (Cal BP 11570 to 11200)**
(95% probability)

Intercept data

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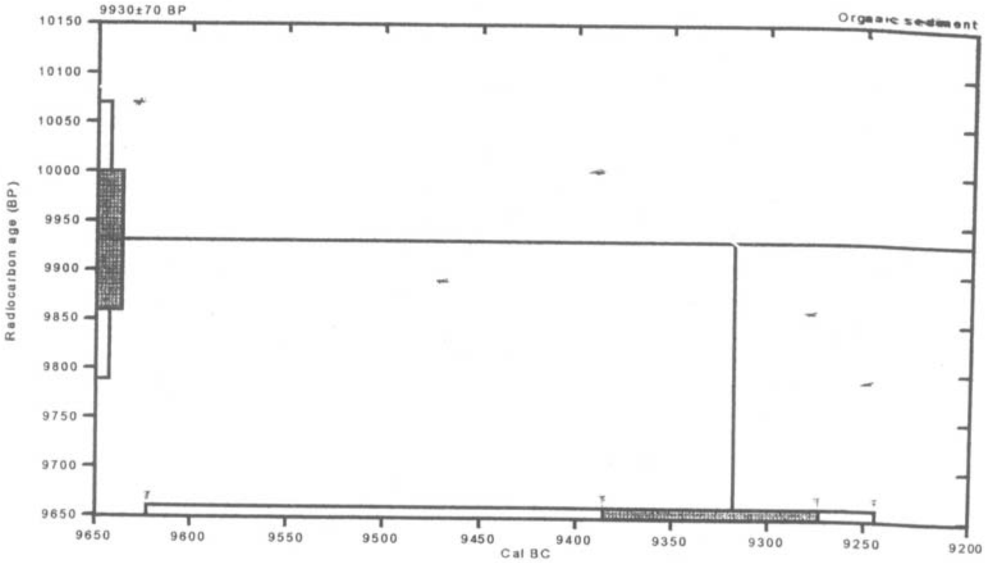
1 Sigma calibrated result: Cal BC 9390 to 9270 (Cal BP 11340 to 11220)
(68% probability)



References:

Database used

Calibration Database
Editorial Comment
Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii
INTCAL98 Radiocarbon Age Calibration
Stuiver, M., et. al., 1998, Radiocarbon 40(3), p1041-1083
Mathematics
A Simplified Approach to Calibrating C14 Dates
Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

Beta Analytic Inc.

4985 SW 74 Court, Miami, Florida 33155 USA • Tel: (305) 667 5167 • Fax: (305) 663 0964 • E-Mail: beta@radiocarbon.com

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.9:lab. mult=1)

Laboratory number: **Beta-165791**

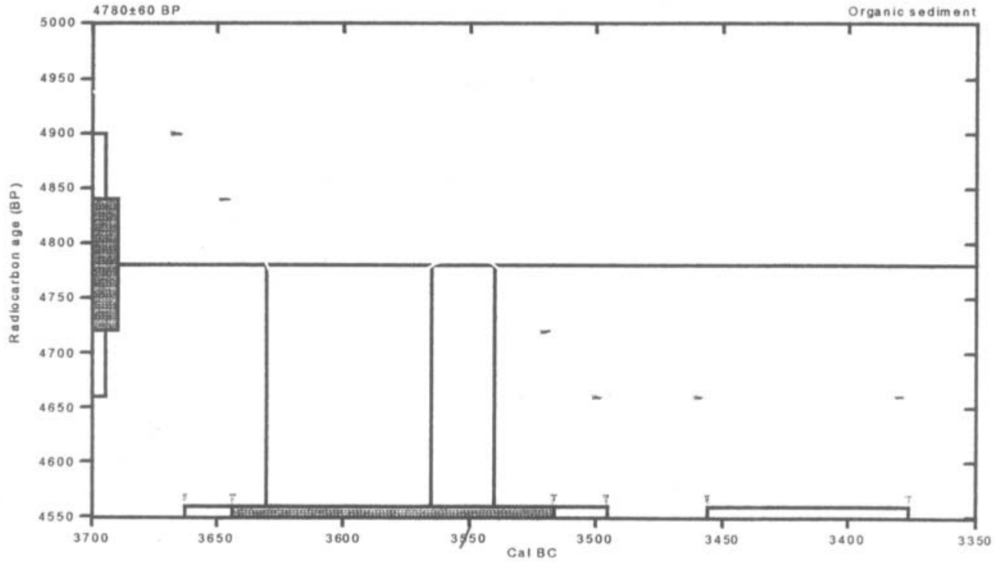
Conventional radiocarbon age: **4780±60 BP**

2 Sigma calibrated results: **Cal BC 3660 to 3500 (Cal BP 5610 to 5450) and**
(95% probability) **Cal BC 3460 to 3380 (Cal BP 5410 to 5330)**

Intercept data

Intercepts of radiocarbon age with calibration curve: Cal BC 3630 (Cal BP 5580) and
Cal BC 3560 (Cal BP 5520) and
Cal BC 3540 (Cal BP 5490)

1 Sigma calibrated result: Cal BC 3640 to 3520 (Cal BP 5590 to 5470)
(68% probability)



References:

Database used

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Editorial Comment
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INTCAL98 Radiocarbon Age Calibration
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Appendix 3

Mineralogy and microtextures of the calcified seaweed.

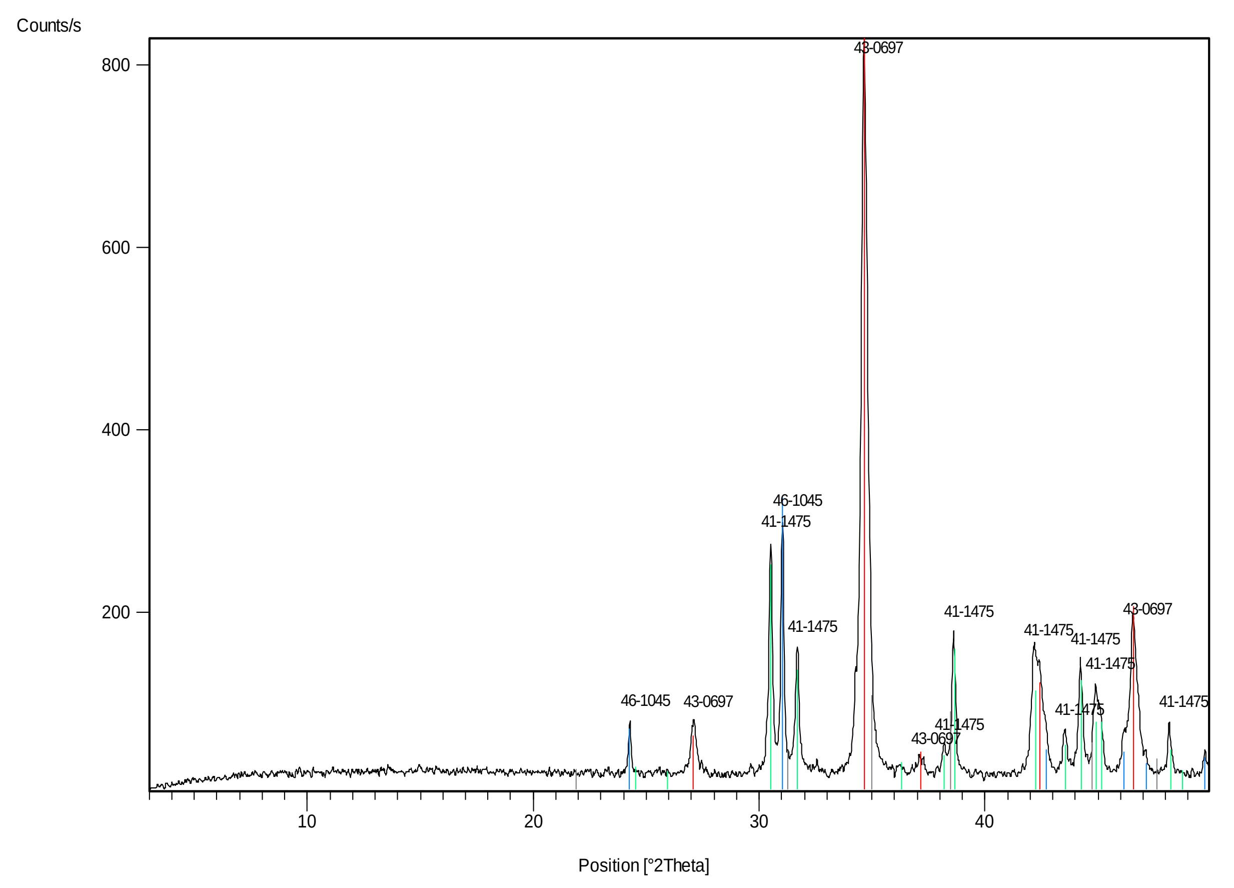
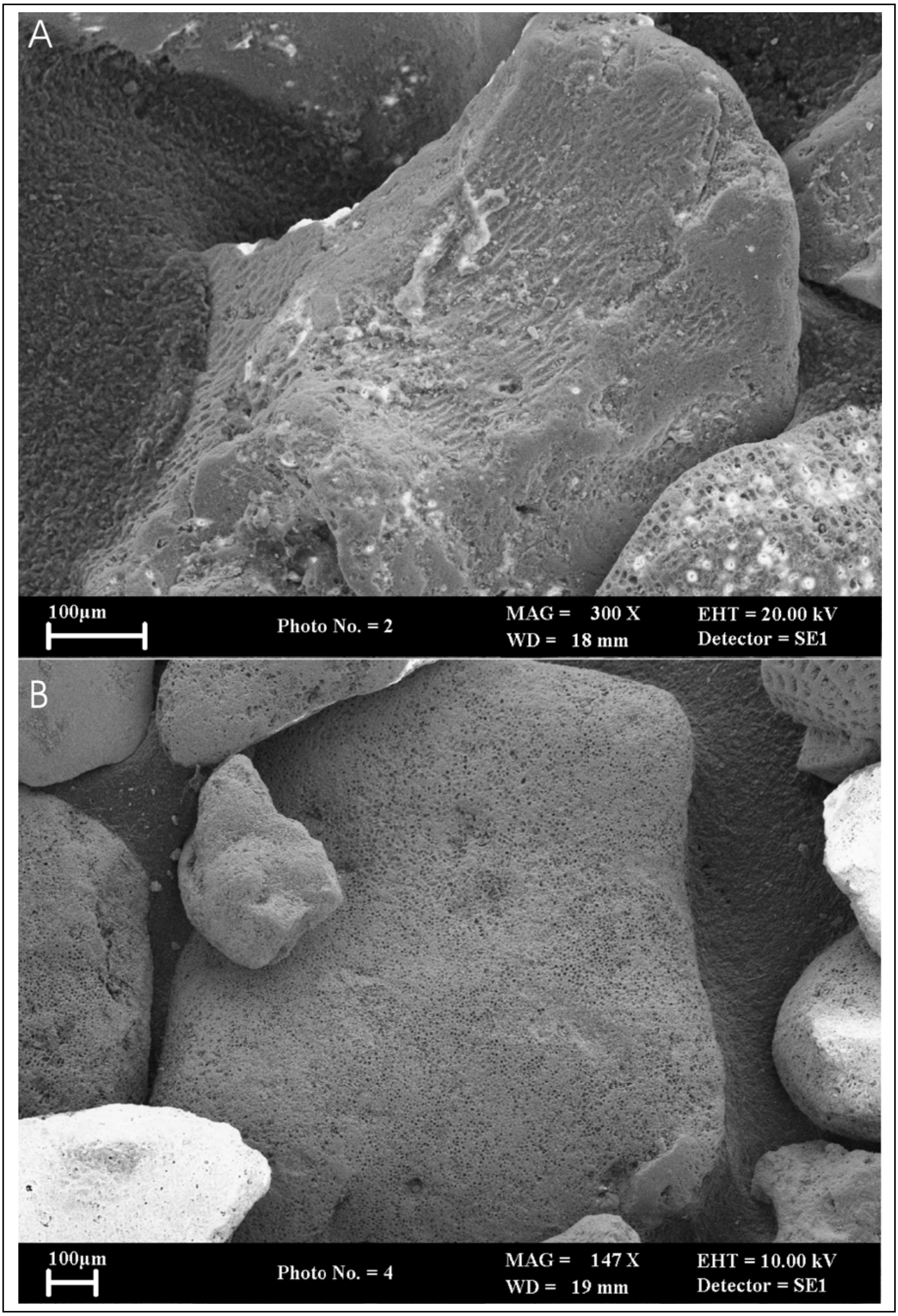
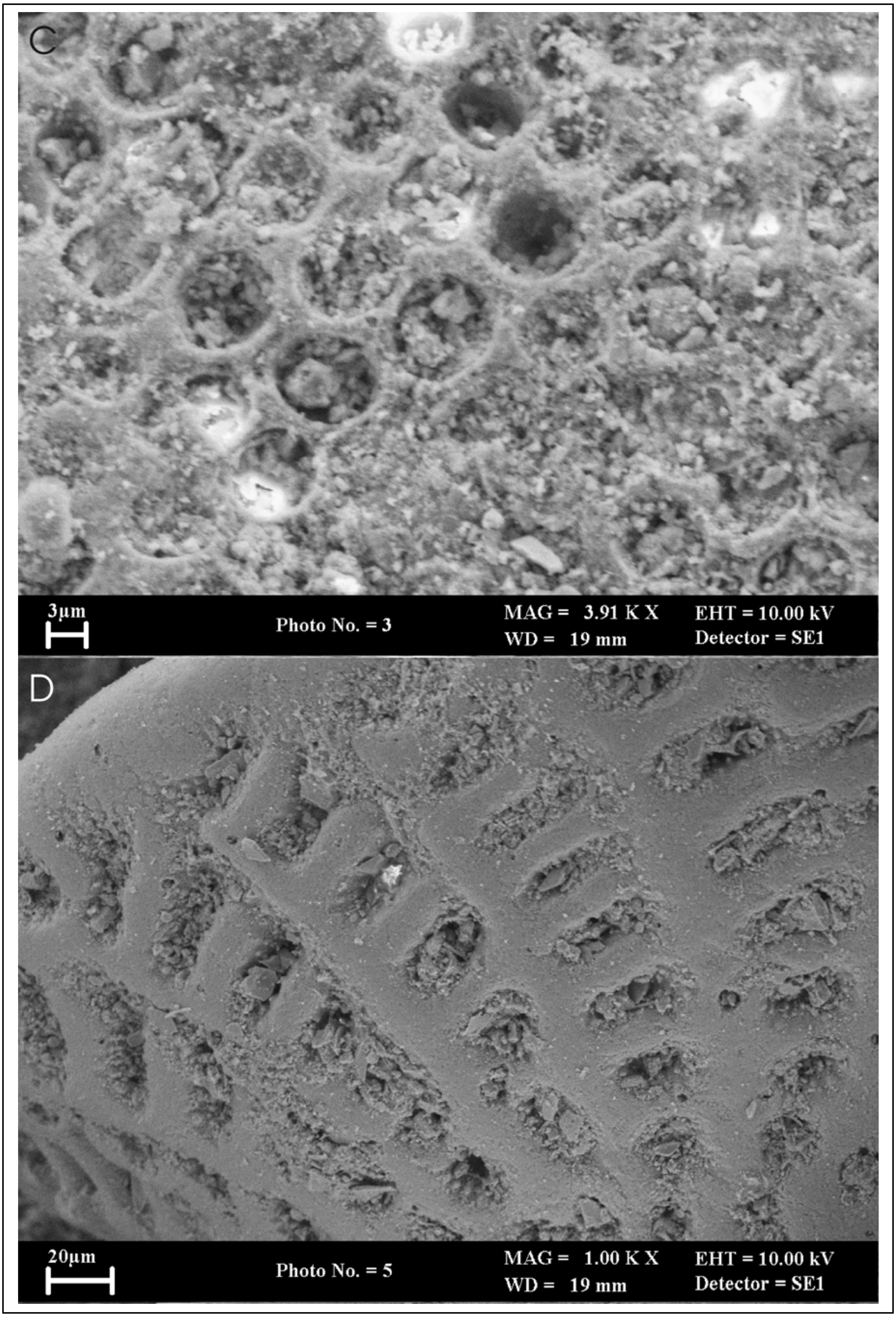


Figure 8 X-ray diffraction trace for the calcified seaweed from Motley Point. [Horizontal axis °2θ Co-Kα, vertical axis intensity in counts per second, red 'sticks' calcite 43-0697, blue 'sticks' quartz 46-1045, green 'sticks' aragonite 41-1475

Scanning electron microscope images.

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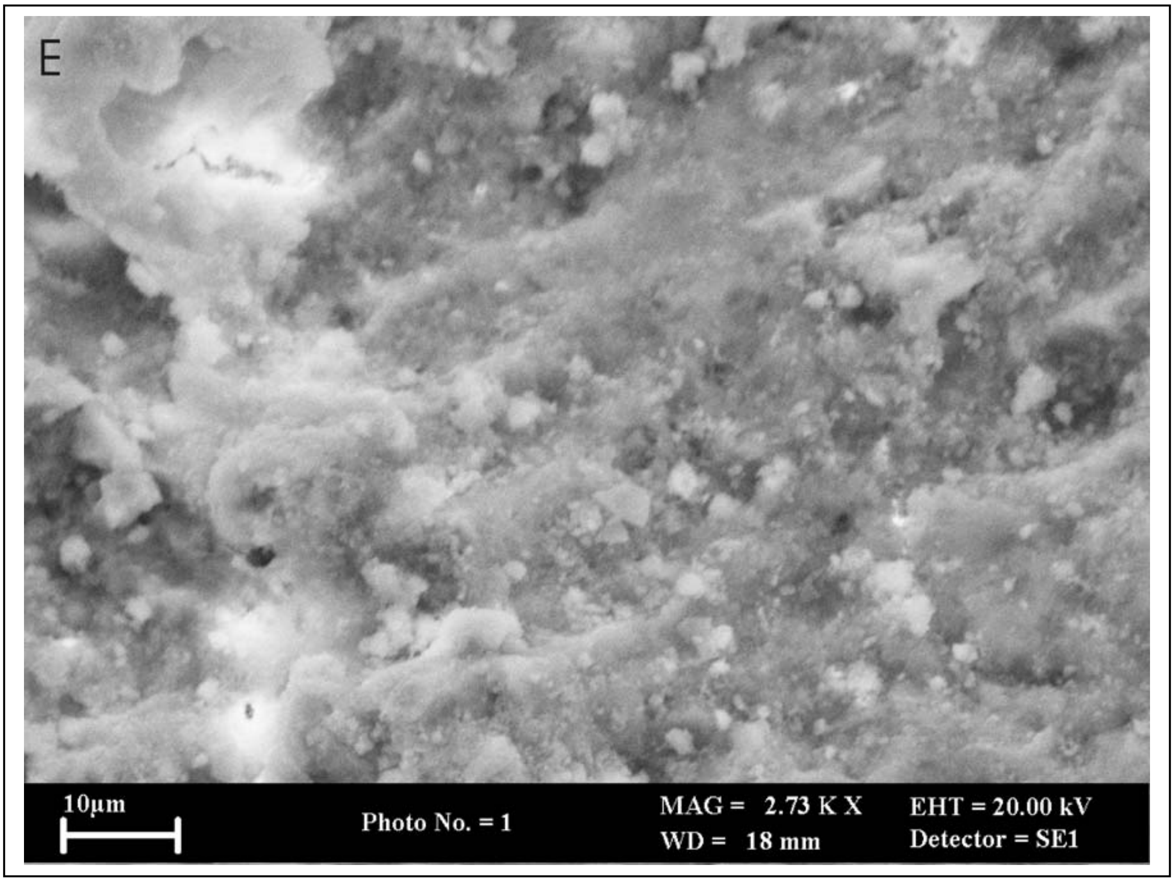
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Useful additional information can be found at the following website:

www.ukbap.org.uk/asp/UKPlans?UKListID=40