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ON THE INTENT TO MAKE CRAMP: AN INTERPRETATION OF VITREOUS SEAWEED CREMATION 'WASTE' FROM PREHISTORIC BURIAL SITES IN ORKNEY, SCOTLAND

Summary. *Vitreous slag-like material, known as 'cramp', from prehistoric cremation burial sites in Orkney is, apart from cremated bone, one of the recurrent remains found within or around Bronze Age burials. Although the suggestion that cramp was formed by the fusing of sand attached to dry seaweed while it was being burnt was first proposed in the 1930s, there has never been a consideration of seaweed's contribution to cremation other than as a potential fuel. Scientific analyses presented in this paper corroborate the use of seaweed. It is suggested that cramp may have been deliberately produced to act as an efficient collector of shattered bone which otherwise could have been lost during the cremation. Far from being a 'waste', cramp could well have been another form of 'human-remains' in its own right.*

INTRODUCTION

During the later Neolithic and the beginning of the Bronze Age on the Orkney Isles in northern Britain (Fig. 1), as in other areas of Europe, a change in treatment of the dead began to take place. Whether this was due to changing beliefs or social factors is largely beyond the scope of this paper but it suffices to say that there was a shift away from inhumations and communal monumental tomb building to cremation and graves for one or two individuals. The processes of change may have been complex as some sites provide evidence of several forms of burial or disposal of the dead (Ballin Smith forthcoming). In general, the construction of conspicuous and formulaic stone tombs was replaced by ever more discrete stone boxes or cists, constructed below ground, sometimes marked by a mound, other times not, and with inhumations being replaced by funerary pyres and cremations. Perpetuation of older traditions is noted in the grouping of some cists and in multiple burials, but this gradually gave way to one cist for one individual. The cremation might or might not have been contained within a funerary urn made of either clay or stone (steatite). In addition to the cremated bones, the most noticeable remains within these burials are perhaps the cramp.

Cramp, an Orkney dialect word, first appeared in the etymological dictionary of Edmonston (1866) and was defined as 'small heaps of vitrified glass and stones found in ancient tumuli'. In 1871, Petrie (1871, 348) added to the characterization that it was 'vitrified matter to

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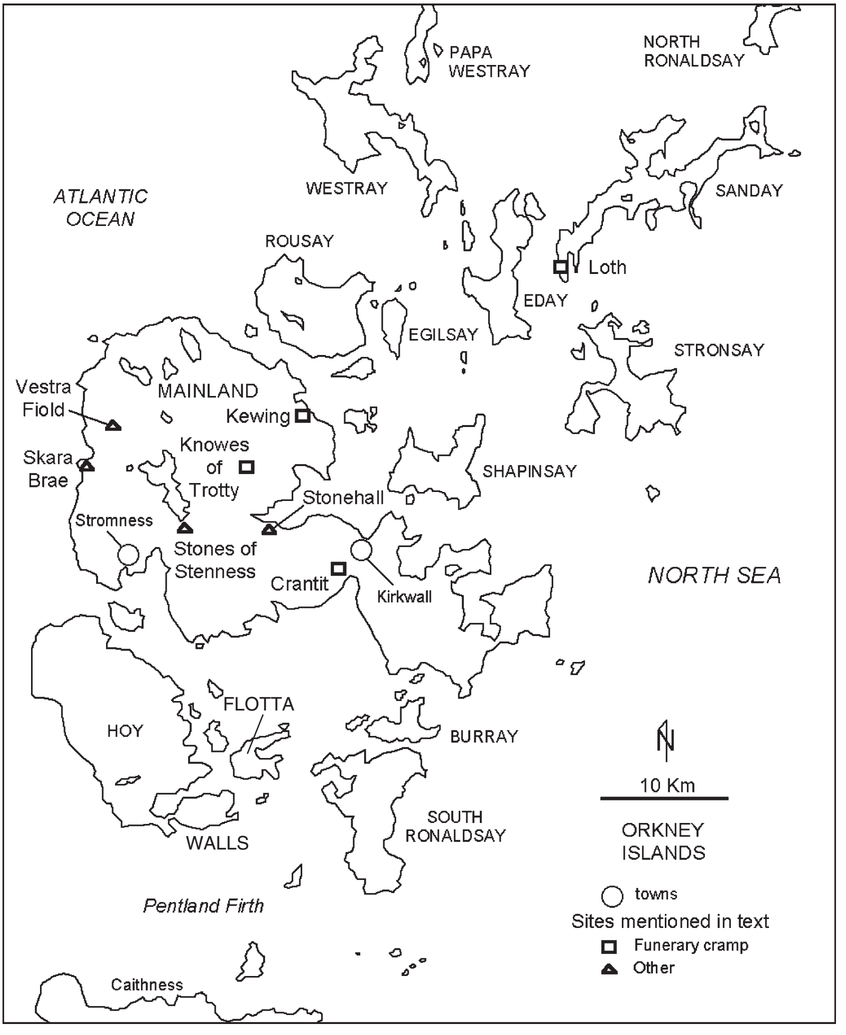

Figure 1
Map of Orkney showing the locations of sites mentioned in the text and also Skara Brae for reference.

which bits of bones adhered'. Many Orcadian sites were excavated and recorded in the nineteenth to the early part of the twentieth century. Between the 1930s and the 1990s cramp was frequently found in cists or cists associated with barrows, small earthen mounds on top of cists, urns or inhumations, but usually in small amounts. It was Callander (1935–36a) who first recognized and described cramp, its quantities (often large amounts) and its distribution. He was also the first to associate the formation of cramp with the cremation process even indicating that 'on Orkney it is a common idea that cramp was formed by the fusing of sand attached to dry seaweed while it was being burnt' and going as far as to suggest that 'may it not be that dried seaweed was the fuel used for cremating human bodies in Orkney and Shetland during the Bronze Age. . . .' (Callander 1935–36a, 447).

A register in summary form of published occurrences of cramp with presence/absence of cists, type of urns, additional materials like pottery and bone together with published dates is presented in Table 1. The sources of the cramp forming the basis of the present paper are similarly included in Table 1.

Although there are only a few radiocarbon dates which date burials with cramp, it is evident that the occurrence of cramp spans the Late Neolithic period through possibly the whole of the Middle of the Bronze Age from *c*.3500 to 2500 BC (see Table 1 and Ballin Smith forthcoming). However, for the majority of sites dating is problematic since cists in which cramp has been found often produce no datable organic material, and datable cists often have no cramp. Furthermore, some burial sites have been used repeatedly over a long period of time. There is clearly a need for more direct dating of cramp samples, for example by the radiocarbon dating of inclusions of bone and charcoal fragments.

As regards the nature of the locality of the cremated remains, they appear within cists with or without urns in single or multiple burial mounds (and without cists), and in pits in the shape of urns (without cists or mounds). It is difficult to draw conclusions regarding the choice of burial. What was the reason behind one's cremated bones being contained in a cist or simply placed in a pit in the ground? Was it a case of 'status begot status', or merely a case of sudden death which did not allow for full burial preparations? There are also questions arising about the choice of material for the urns: clay and steatite. Once shaped, the latter was ready to carry the ashes. The clay urn, rather than being conventionally fired in a bonfire before use, may have been shaped and then fired in the pyre. This view receives some support from the instance discussed below of cramp apparently being attached to the body of the vessel. In any case, pottery firing experiments in a bonfire on Orkney have shown that seaweed was a satisfactory fuel, giving temperatures up to 850°C (Jones and Brown 2000).

Other materials associated with cramp include calcined human bones and occasionally animal bones, charcoal and/or ashes (see Table 1). What constitutes 'ash' is unclear since the term seems to feature more commonly in the early reports of cramp occurrence than in the more recent ones. And could the ashes be deliberately ground up cramp? In 1998, cramp and a large mass of cremated bone, with woven fibres from a basket thought to have carried the cremated bones from the funerary pyre to their final resting place, were recovered from within a large cist which was closely associated with a small chambered tomb at Crantit Farm (Ballin Smith 1999; forthcoming). In the summer of 2001 a cist was excavated at Kewing, Rendall, Orkney (Robertson 2001; Ballin Smith forthcoming). As well as cremated bones and a large single mass of cramp weighing over 8 kg, remnants of fibres were recovered. What was unusual about this cramp was that it was moulded to the cist side and therefore could have been very hot when placed in the ground.

Among the cists and barrows excavated over the last decade only small amounts of cramp have been found or none at all (Card and Downes 2002, 4; Downes unpublished; Moore and Wilson 1995; Will forthcoming). However, a notable exception was at an underground chamber at Sandwick where 58 kg of cramp (called fuel ash slag) had been deposited between the wall of the cist and the chamber before the closure of the tomb (Dalland 1999, 382, 401).

Beyond Orkney, there are only few studies into cremation-related rituals which appear to be relevant in the sense that they discuss cramp-like materials. Henderson *et al*. (1987a, b) analysed cremation slag in funerary urns in eastern England and confirmed that it was a high-temperature siliceous slag or clinker that was unlikely to represent fused human hair, as had previously been suggested (Wells 1960 in Henderson *et al*. 1987a, b); instead it represented fused

TABLE 1

Selected sites related to understanding cramp occurrences on Orkney (HS-DB = Historic Scotland C14 dating database)

Site locality by Orkney Parish/Island	General context	Urn type	Cramp (*of PRESENT STUDY)	Other materials and notes	References	Radiocarbon dates
Deerness, Mainland (east)						
Blows, Deerness (Howen Blo mound area)	Cist with urn	Steatite urn	None	Blackened steatite urn burial in cist; thin soil in the Blows area	Marwick (1928–9)	None
Blows, Deerness (Howen Blo mound area)	Buried urn. No cist	Baked clay urn	None	Charred bones and pottery sherds representing a small vessel. Urn was very fragile. Pottery, described by Callander (1932–3, 345–53), interpreted as remains of a smaller urn within the larger urn. The first discovery of clay urns on Orkney (Callander 1932–3, 346)	Grant (1932–3); Callander (1932–3)	
Blows, Deerness (Howen Blo mound area)	Pit (urn-shaped) under a flat stone	No urn	None	'dark grey matter' assumed to be human remains. The three sites at Blows are within an area of a few square yards (Grant 1932–3, 351)	Grant (1932–3)	
Deerness	Urn	13″ high clay urn	Ashes correspond to cramp	$^{3}/_{4}$ full of bone and ashes (Callander 1932–3, 346)	Callander (1932–3)	None
Stenness, Mainland (west)						
Ring of Brodgar	Cist with urn	5″ high baked clay urn	None	No human remains recorded	Grant (1932–3, 347)	None
Ring of Brodgar	Nearby cist with urn	Steatite urn	None	Calcined bones		
Stones of Stenness	West ditch of terminal		Slaggy material – fused sandy material; seaweed ash suspected as flux. High Ca and P	Diverse animal bone. Burnt bone. Small calcareous crustaceans suggested probably contamination. No indication that there is human bone	Ritchie (1976); for geo-analysis, Fleet in Ritchie (1976, 46–8); for bone, Clutton-Brock in Ritchie (1976, 34–7)	Bones in ditch *c.*3000 BC – 7 dates (HS-DB)
Ring of Brodgar	Central setting: square area bordered by large stones	No urn	Fist-sized pieces of cramp in packed layer. Fleet does not give exact locality of analysed samples	Indications of cremation: bone, charcoal, pottery, reddened soil	Ritchie (1976); for geo-analysis, Fleet in Ritchie (1976, 46–8)	Charcoal: 3100–2450 BC (Ritchie 1976, 50)
Barnhouse	Various non-funerary settings	No urn	Slaggy material sometimes with high Ca and P and some bone	Material described as 'cramp' but from non-funerary contexts and although bone in some samples, no indication of human bone	Stapleton and Bowman (2005)	13 dates *c.*BC 3000 – occupation of settlement (HS-DB: Jones *et al.* 2005)
Birsay, Mainland (north-east)						
Broch of Okstrow, Broadhouse, Birsay	Mound with burials	Stone urn	Ashes – could be cramp?	Large number of structures; cists above the broch in the mound with burnt bones and ashes. A bronze ring and a story of an eagle carving on a cover stone (Petrie 1890)	Petrie (1890, fig. 4, 76); Grant (1932–3, 352)	None

Ophir, Mainland (south, central)						
Groundwater Hill, Ophir	Group of cists		Ashes may correspond to cramp	1928 discovery. Cist with bone fragments; cist with ashes; cist with ash and burnt bones; cist with bones (inhumation burial). Probably BA	Marwick (1928–9, 383); Low (1928, 383)	None
Firth, Mainland (north, central)						
Grimbister, Firth	Urn burial with small mound on top. No cist	18″ high clay urn. Inverted	Lumps of cramp (containing bone) with stone in clay surrounding the urn	Discovered in 1859 and account recorded by Petrie in unpublished notebook	Callander (1935–6a)	None
Sandwick, Mainland (west)						
Sandwick Parish	More than 100 burial mounds; commonly short cists	?	Much cramp		Callander (1935–6a, 448)	None
Cist at Sandwick (2860–2500 BC)	Cist	Food vessel urn lined with basketry with cremation	58 kg of cramp or pyre debris deposited before closure of tomb. FSA 2900–2500 cal BC (in Dalland 1999)	Several unburnt bone inhumations and cremations. Dates *c*.2900–800 BC	Dalland (1999)	None
Vestrafiold, Sandwick	No info on possible burial site	No information	Cramp; very general petrography and chemical analysis by Davidson (1936, 450)	Cramp on surface and in walls (Callander 1935–6, 445)	Callander (1935–6a); Davidson (1936, 448)	None
Linga Fiold, Sandwick	Cist from mound 9 in area of 13 mounds visible in 1946	No urn	0.3 g cramp; brief account of cramp given by Newton (1995, 244–5)	633.11 g bones (human – young adult probably – Williams in Moore and Wilson 1995, 246). Small amount of charcoal. No pottery	Moore and Wilson (1995); Newton (1995)	None
Linga Fiold, Sandwick	Mound 2 : 6 cists and a pit cremation				Clouston (1845)	None
Linga Fiold (Lyking)	Mound with cists	Urns	Pyre remains; cramp. Cramp petrography and microprobe analyses (Carter forthcoming)	Burnt bone	Downes (forthcoming)	Various materials: *c*.2000–1400 BC (Downes forthcoming)
Sandwick: 500 yds NW of Ring of Brodgar	Mound	No information	Cramp lying about	No information	Callander (1935–6a, 445)	None
Harray, Mainland (northwest)						
Knowes of Trotty, Harray	Series of mounds. BA cemetery	??	*Samples from trenches F and G of Card and Downes (2002) from burnt areas with cramp	Cremation likely here on soil and slabs	Photos-Jones (2003b); Card and Downes (2002)	

TABLE 1
continued

Site locality by Orkney Parish/Island	General context	Urn type	Cramp (*of PRESENT STUDY)	Other materials and notes	References	Radiocarbon dates
St Ola, Mainland (central)						
Crantit, St. Ola	Cist	No	Ashes may correspond to cramp	5 pints of calcined bones and a smaller pile and a small pile of ashes. 'Nothing else to be seen.' A 1924 find	Marwick (1924)	None
Crantit, St. Ola	2-storey cist	No	Ashes may correspond to cramp	Some calcined bones; various colours; carbonate of lime precipitate. Skeleton on the ashes. Deer-horn probable hammer-head. 1909 find	Ref. in Marwick (1924) to Curister (1910)	None
Crantit Farm, St Ola	Western cist of two BA cists excavated in 1998 and 1999		*Cramp of context 78 of Ballin Smith (1998a-d)	Bone, plant remains (Miller 1998), white calcareous residue	Photos-Jones (2001); Ballin Smith (1998a-d, 1999, forthcoming)	Cremated bone 3420 and 3460 BP (Ballin Smith in Ashmore (2003))
Rendall, Mainland (north)						
Kewing, Rendall	Context 004, cist (Robertson 2001)		*One large sample of cramp		Photos-Jones (2003a); Robertson 2001	Cremated bone 3520 BC (Ballin Smith in Ashmore (2003))
Ferndale, Rendall	Burial mound with cists	No	Cramp (largest amount *c*.1 kg) in each of 3 cists (Duffy 2005, 13)	Fragments of human bone (Duffy 2005, 7–8). Lithic fragments – arrowhead and debitage (Pollard in Duffy 2005, 10). Charcoal and plant remains (Miller and Ramsay in Duffy 2005, 9). Decorated stone slab (MacGregor in Duffy 2005, 11–12)	Duffy (2005)	Cremated bone. Two samples. *c*.1900 BC (Duffy 2005, 14)
Rousay (island in north)						
The Knowe of Ramsay, Blotchnie Fiold, Hullion, Rousay	Long burial chamber mound	None	Cramp; very general petrography (Davidson 1936)	Excavated 1935. Extensive stone robbing. 14 cells in long chamber. Poor scarce human remains and sherds. No cremation	Callander (1935–6b); Davidson (1936, 448)	None
Steatite urn, Rousay	In museum from 1860	Steatite urn	20 pieces of cramp; very general petrography (Davidson 1936)	Bones	Callander (1935–6a); Davidson (1936, 448–52)	None
Mount Pleasant, Frotoft	Stone slab structure		Barrowful of cramp close to a stone slab structure (Callander 1935–6a, 446); cramp – very general petrography (Davidson 1936)	Fire-fractured stones	Callander (1935–6a)	None
Quandale	Cists	Not recorded	Cramp in 10 of 12 cists excavated; cramp stuck to bone noted	Excavations by Grant in 1936	Callander (1935–6a, 447)	None

Sanday (island in north-east)						
South end of Els Ness peninsula, Sanday	Group of burial mounds		Mounds 'covered with it' (cramp)		Callander (1935–6a, 445)	None
Loth Road, Sanday	A disturbed BA mortuary site (mound with pits and cists)		*Cramp from various contexts		Photos-Jones (2003c)	Tree charcoal from cist: 1500 BC; 5 samples charcoal ~same age as cremation: 1135–1500 BC (Card in Ashmore 2004)
Stronsay (island in north-east)						
Orem's Fancy, Stronsay	Cist with urn buried under a mound	Steatite urn	Cramp present	Fragmented bones. Burnt bones. Probable Iron Age	Petrie (1871)	None
Egilsay (island in north)						
Midskaill, Egilsay	BA cist of Ellibister type (p. 247) of Hedges (1980)	No urn	Cramp (81.3 g). Cramp stuck to a sherd (Moore and Wilson 1995, 243)	Coarse pottery sherds. Some charcoal. No bone. Oat, barley and chickweed grains. Cramp stuck to a sherd and other features indicate pottery had been in pyre (Moore and Wilson 1995, 243)	Moore and Wilson (1995)	None
South Ronaldsay (island in south-east)						
Isbister, Rendall Parish	Cists	No	No	Mentions Orcadian cists often have good drainage (Petrie 1864–6, 414)	Petrie (1864–6)	None
North Ronaldsay (island in extreme north-west)						
Cists at Atnabreck, N Ronaldsay	Two cists	No urn	On 2nd cist: 'half calcined human bones and teeth were found among the ashes. The entire mass of burnt material appears to have been laid upon coarse cloth or interlaced rushes . . . ' (Trail 1874, 310). No mention of cramp	One cist with portions of two skeletons. Second cist better made and with heap of ashes	Trail (1874)	None

sandy material, from the substrate of the pyre, with human and fuel ash. It is noteworthy that the amounts recovered from the urns were small (less than 100 g). With a broader view in mind McKinley (1997) considers the archaeological evidence for cremation-related activities at Bronze Age barrows. It is on account of the minimal information available regarding this material in contemporary sites across Europe that the present report is presented. Is cramp a unique 'Orcadian' man-made material? Is it related to areas with low tree growth and availability of seaweed?

THE TECHNICAL CHARACTERIZATION OF CRAMP

The first published technical examination of cramp was by Low (1928) of material found in a cist from Groundwater Hill, Orphir. This was followed by petrological and chemical analysis on cramp from Rousay and the Bay of Skaill (Davidson 1936 in Callander 1935–36a), Midskaill, Egilsay and Linga Fiold, Sandwick (Newton 1995, 244–5) and Linga Fiold, Lyking (Carter forthcoming). The detailed petrographic examination and microprobe analyses of cramp by Carter (forthcoming) provide a similar picture to that presented below but with no indication of the use of seaweed. Frequently cited is the petrological and chemical analysis of 'cramp' found at the Stones of Stenness (Ritchie 1976, 46–8), which has been assumed to be non-funerary in origin since it was found within or around a mound or a cist. However the possibility that it may have been 'scattered' over the site as some part of ritual cannot be dismissed. Nevertheless no bone inclusions were reported. Similarly the 'cramp' described in detail by Stapleton and Bowman (2005) from Barnhouse is not funerary in origin.

The most recent technical characterization of cramp and similar materials from diverse archaeological contexts in Orkney has been undertaken by one of the present authors as part of a post-excavation examination and reporting process (Photos-Jones 2001; 2003a, b, c). Furthermore, a Historic Scotland-funded project into the technical characterization of cramp from four sites in Orkney became the impetus for the re-evaluation of the existing evidence regarding its composition and properties and the role of natural materials such as soil, fuel and bone as the main 'ingredients' in cramp formation. The project also included experimental work on cramp formation. Underlying the re-evaluation was the necessity to consider the sequence of events that took place during Orcadian funerary rituals, particularly those which might not be visible in the archaeological record. Sites investigated and included in the present report (Table 1) are Crantit Farm, Kewing, Rendall, and Knowes of Trotty on Mainland and Loth Road on the island of Sanday.

If cramp is indeed the product of fusion of seaweed with sand, the focus of the investigation shifts to the seaweed and how it was used and perceived by the Orcadian Neolithic/BA community. The link between seaweed and cramp or in other words the vitrification of seaweed is an important one and the process a familiar one. The kelp burning industry was prominent in the eighteenth and nineteenth centuries in Scotland as the basis of potash and soda production (Clow and Clow 1952) and Callander (1935–6a) would have been well aware of that. However, although peat, turf and driftwood have repeatedly been found in association with bone within cists (Ballin Smith forthcoming), thereby verifying the use of such resources as part of the cremation pyre, either as fuel or as funerary furniture, there has been no reported evidence for charred remains of seaweed in the cremation debris, either associated with cramp or bone.

This paper confirms the previously stated but tenuously supported relationship between vitrified seaweed and cramp. Given the terminology, cremation cramp can be considered to be vitrified fuel ash slag (VFAS), although this term does not account for the presence of bone and implies a waste material. We suspect that cremation burials with significant amounts of cramp are unlikely to be unique to Orkney, and we anticipate its presence in the archaeological record in prehistoric sites in mainland coastal sites or on islands elsewhere in northern Europe. This paper provides a descriptive and interpretive account of cramp suggesting its origin and its potential role in the ritual of cremation. It alerts the archaeological community to the need for evaluation of vitreous materials as potential human remains and highlights the importance of tracing similar materials in other regions outside Scotland. It examines the material evidence in the context of the other artefactual evidence found in the cist. Finally it calls into question our conventional notion of what constitutes 'waste'.

Methodology

A number of scientific techniques, summarized in Table 2, have been used to determine both the inorganic and organic components of cramp. It is the first time that an attempt has been made to establish the presence/absence of the organic component. Only the main outcomes relevant to the aims of this paper are summarized below. The purpose of the exercise is to ascertain the main ingredients necessary in cramp formation. Subsequent to that a series of

TABLE 2
Techniques of examination and analysis used in this study

Technique	Description/rationale
Petrography on polished thin sections and/or polished blocks mounted in resin	Observation of textures and identification of mineral and other inclusions within cramp using both transmitted and reflected-light microscopy. Polished surfaces, once carbon coated, can be used for SEM-EDAX.
SEM-EDAX (scanning electron microscopy with energy-dispersive X-ray analysis)	The usual secondary emission (SE) imaging on freshly fractured surfaces combines depth of field with high magnification. The backscattered electron (BSE) detector facility is well suited to viewing at high magnification the brightness variation due to small variations in chemical composition of the diverse micro-phases present. Energy dispersive X-ray analysis provides a rapid method of determining the major elements present in micro-phases.
XRD (X-ray diffraction)	Routine method for identification of major and minor crystalline phases, such as minerals, within powdered cramp. Sometimes of limited value for cramp because of multitude of glassy and semi-crystalline phases.
ICP-ES (inductively coupled plasma emission spectroscopy)	Bulk multi-element chemical analysis potentially suited to identifying those elements associated with each component. However, the same elements may have more than one source in a bulk sample.
GC (gas chromatography)	Identification of lipids and other organic components in cramp. The organic content was extracted from a crushed sample of cramp in hexane in a soxhlet extractor. The residue was derivatized in advance of GC, using the method described by Jones *et al*. (2005).

experiments were carried out in the laboratory to establish the conditions under which cramp formed.

Analyses and results

Cramp samples for the present study, all from funerary contexts (Table 1), consist of a lightweight, frothy, highly siliceous vesicular material with a predominantly glassy skin covering a porous and particulate under-surface of glassy and micro-crystalline components (Figs. 2 and 3). Pieces recovered are normally less than 10–20 mm in size. The size distribution of Kewing cist cramp showed that over 98 per cent of the pieces were less than 40 mm long, but sometimes they appeared as ‘cakes’ or welded aggregates of several smaller pieces *c*.60 mm long. It is important to note that the small size of most pieces of cramp reflects their original dimensions and is not the result of fragmentation prior to burial. An exceptionally large piece recovered from the Kewing cist is shown in Figure 2 but this reflects the coagulation of small pieces into a large one while still hot. Cramp is predominantly grey-coloured, but surface tints can vary from greenish to bluish to beige and light brown. The drop-like appearance indicative of flow of the vesicular material that is visible macroscopically

Figure 2
Unusually large lump of cramp from Kewing Cist. Scale bar 20 cm.

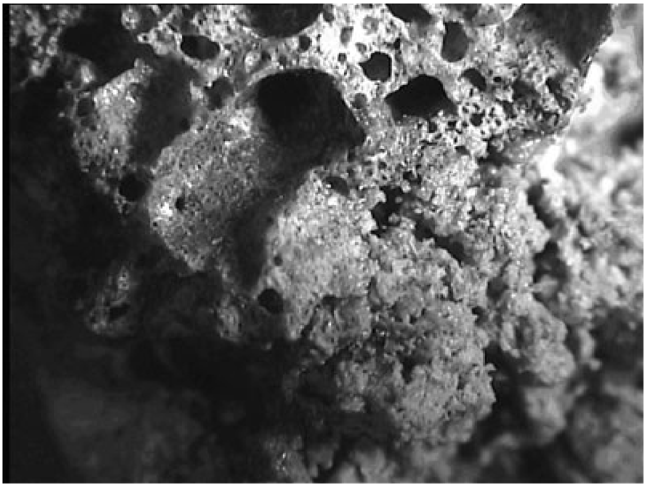

Figure 3
Stereo-binocular image of cramp from Crantit Cist: it is vesicular (frothy) with a multiplicity of colours (green, blue, beige, light brown). Field ~2 cm wide.

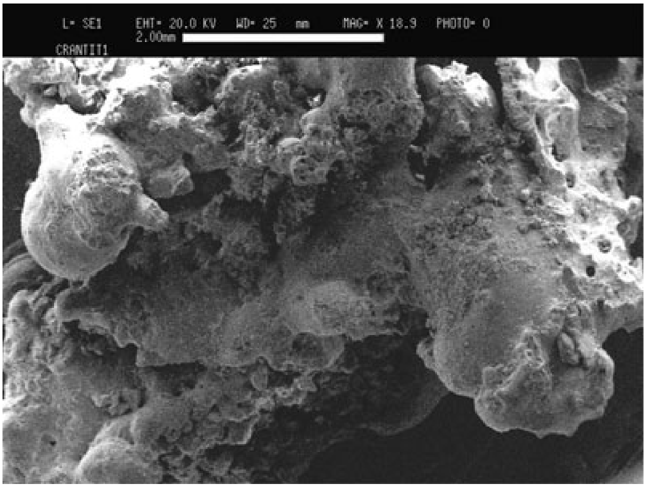

Figure 4
SEM-SE image of drip-like surface of cramp (Crantit) comprising variably vitrified material. Scale bar 2 mm.

is even apparent on the electron microscope scale (Fig. 4) in small pieces of cramp. Vesicularity must have arisen from gas evolution, presumably either steam or carbon dioxide from inclusions in the melt, especially organic matter. Bone can often be seen enveloped by the glassy matrix of cramp and there are fragments of charcoal. Pieces have variable amounts of surface ‘contamination’, in particular fine soil as would be expected from such irregularly shaped and vesicular material recovered from a burial context. In some samples adhering patches of white material are indicative of more significant ‘contamination’ arising from a

TABLE 3
ICP-ES data for selected major elements expressed in weight percentage (wt.%) oxide, and the trace element strontium (Sr) which is in ppm. The analyses represent bulk samples. In most cases a number (given in brackets) of small sub-samples have been averaged. The CaO, P_2O_5 and Sr contents of sub-samples have been used in plots in this paper but only the mean data are provided here

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	Sr
Loth Road Cramp *mean (6)*	69.7	10.2	4.5	2.2	1.7	3.4	3.6	0.9	283
Knowes of Trotty Cramp *mean (4)*	69.2	13.5	3.4	1.1	0.5	3.4	3.8	0.4	112
Crantit Cist Cramp *mean (5)*	63.0	8.9	3.3	2.0	5.8	2.7	4.0	4.7	281
Kewing Cist Cramp *mean (5)*	63.9	10.7	3.7	2.9	6.7	2.9	3.3	1.4	433
Archaeological bone *mean (4)*	1.4	0.4	0.2	0.3	54.2	0.3	0.0	34.4	268
Modern animal bone *mean (2)*	0.7	0.1	0.1	1.1	47.9	1.0	0.6	31.2	65
Loth Road Soils *mean (9)*	64.6	11.2	3.5	0.7	0.4	2.3	2.9	0.3	*96*
C18B Vestra Fiold Turf *(1)*	14.8	3.2	1.3	0.8	2.7	0.7	1.2	0.5	173
Kelp ash 600°C/3 hours *(1)*	0.4	0.3	0.2	4.6	20.1	5.6	21.0	0.8	9068
Experimental seaweed ash *(1)*	12.3	3.0	1.6	8.3	11.1	9.5	8.4	0.9	1210

'mineralization' process in the burial environment and is attributed to calcium carbonate (calcite) precipitation from groundwater.

The bulk chemical compositions of small representative fragments of cramp and that of its main components, such as seaweed ash, bone and turf ash, are shown in Table 3 where major elements are expressed as oxides (weight per cent) and traces as elements (ppm). Major elements in cramp are silicon, aluminium, calcium, phosphorus and iron and, of course, oxygen. The potential origin of each of the main chemical constituents is considered below, bearing in mind that a given element may derive from more than one source; for this reason trace elements such as strontium (Sr) are also considered. Halogens were not analysed for using the techniques available for this study but their potential significance in confirming burnt seaweed has recently been emphasized by Stapleton and Bowman (2005).

Petrographic examination of thin sections of cramp from Kewing and Crantit cists (Figs. 5 and 6) reveals that cramp is a very impure glassy material, rich in vesicles and containing abundant detrital grains of quartz. The quartz shows signs of having been assimilated into the melt which has usually cooled rapidly to produce the flow-banded glass, but sometimes more slowly resulting in crystallization and the production of crystallites of up to tens of microns in size. Fragments of bone appear to have stuck to the melt but in places appear to have been partially assimilated into the melt. Devitrification of the glass to microcrystallites may also have taken place. Not unexpectedly, the white encrustation seen on macroscopic fragments of cramp is the calcium carbonate mineral, calcite.

Given the largely non-crystalline nature of cramp, X-ray diffraction (Table 2) of powdered fragments representing bulk composition revealed few major peaks, but there was often a 'hump' denoting a glassy siliceous matrix. Cramp from both Kewing and Crantit cists was confirmed to contain quartz, with minor calcite and hydroxyapatite (the calcium phosphate component of bone).

The glassy component of cramp is a complex material of variable appearance due to partial crystallization and probably to partial devitrification. This variation is because the original ingredients varied in abundance as well as composition over short distances, and they have been heated to various temperatures and cooled at various rates. Melting evidently occurred on a micro-level with all stages from simple fusion/sintering to advanced vitrification being

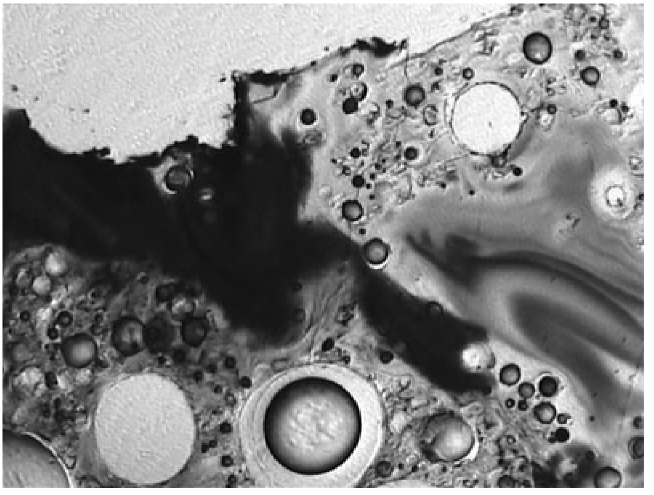

Figure 5
Photomicrograph of thin section of cramp from Kewing showing transparent to grey (light brown) and dark (brown) colour banding in glass on the right. The near opaque 'fuzzy' area from centre to left is probably rich in miniscule crystallites crystallized from the melt. Transmitted light. Field 1400 microns wide.

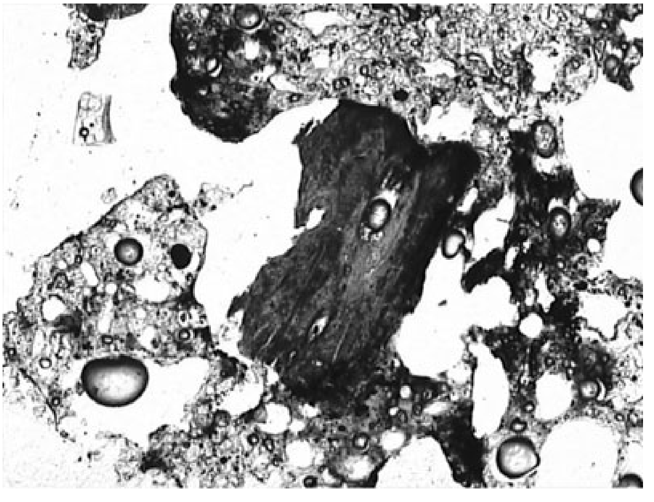

Figure 6
Photomicrograph of thin section of cramp from Crantit Cist, showing distinctive fragment of bone (dark greys) in large vesicle (white) in the vesicular glassy (mottled grey) matrix. Transmitted light. Field 1400 microns wide.

represented in the pieces of cramp. Any particular area of the glassy cramp therefore represents the physical make-up of a chemical process frozen on cooling. The variation in the physical appearance, even evident at the high magnification of the scanning electron microscope (Fig. 9), was reflected in the variation in the chemical composition determined on the micro-scale using

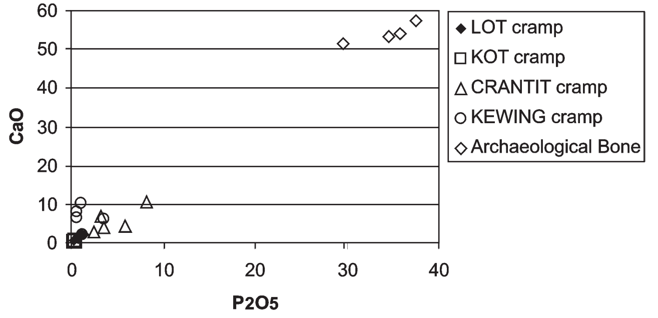

Figure 7
Plot of weight per cent calcium oxide (CaO) and phosphate (P_2O_5) in samples of cramp and bone. Note that most cramp samples lie close to the CaO/P_2O_5 ratio appropriate for bone, but some Crantit and Kewing samples have respectively, low and high CaO/P_2O_5 ratios indicating possible additional sources of calcium and phosphorus other than bone. LOT is Loth Road, KOT is Knowes of Trotty.

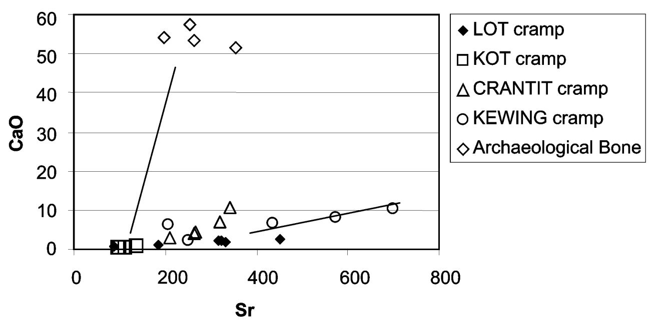

Figure 8
Plot of weight per cent calcium oxide (CaO) *vs* ppm strontium (Sr) in samples of cramp and bone. Some cramp samples are clearly enriched in strontium. There may be a source of strontium that is independent of calcium, but since there is a quite good correlation between CaO and Sr, albeit with slightly different ratios at Crantit, Kewing and Loth Road, the cramp from these sites could well have a source other than bone, of calcium (with associated very high strontium) such as seaweed ash. Gradient lines are inserted for guidance.

SEM-EDAX (Table 2). Cramp glass proved to be mainly silica with aluminium, potassium, sodium, and small amounts of iron and phosphorus.

The presence of bone in cramp is evident from the good correlation obtained when CaO is plotted against P_2O_5 as illustrated in Figure 7. However, while most samples lie close to the $CaO : P_2O_5$ ratio appropriate for bone, some Crantit and Kewing samples have a lower and higher ratio respectively, indicating probable additional sources of each of these elements from sources other than bone (see Fig. 7). This is reinforced by consideration of CaO *vs* Sr (Fig. 8). The strontium content of human bone (typically 50–300 ppm) is known to be influenced by environmental and dietary factors (Mays 1998; Burton 1994) being higher when there are marine influences (Montgomery *et al*. 2003). Our own analyses of Orcadian archaeological bone and seaweed, including kelp ash (Fig. 8), provide supporting evidence that the Sr-rich seaweed ash is the reason for the low CaO : Sr ratios in some cramp. However, the possible accidental or

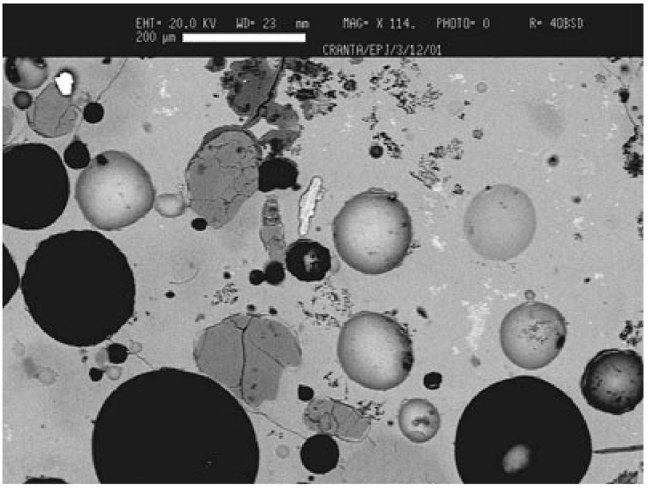

Figure 9
SEM-BS image of glassy matrix within cramp from Crantit with small irregular-shaped quartz/quartzite inclusions (grey). Round voids (black and zoned greys) originate from gas evolution. Bright inclusions are grains of titanium-rich iron oxides and zirconia. Scale bar 200 microns.

deliberate incorporation of sea shells in cramp as well as the variable redistribution of calcium on diagenesis are further complicating influences on CaO : Sr ratios that require investigation.

To summarize, we can now suggest that the *glassy component* of cramp was formed from four main components each with their characteristic overlapping elemental compositions:

a) Soil, silt and sand which together provide silica (SiO_2) for the siliceous glass and other elements such as aluminium, potassium and probably some calcium, sodium, manganese and iron.
b) Peat, turf and driftwood would contribute calcium, potassium and possibly some iron.
c) The seaweed ash which provides the reactive alkali oxides of potassium (K_2O), sodium (Na_2O) and calcium (CaO) which are key fluxes for producing a siliceous liquid.
d) Human bone would contribute the oxides of calcium (CaO) and phosphorus (P_2O_5) which may not be essential but once assimilated can act as a flux for the production of a siliceous melt.

Having established the origin of the main elements of cramp and how to trace them, it is now important to turn attention to the contribution of the two key components, namely the seaweed and bone. Seaweed is rarely mentioned as a source of fuel in the ethnographic record; rather, it has uses as a fertilizer or even as animal fodder (Fenton 1997), as well as a major role in the kelp/soda ash industry. No fragments of seaweed have been observed trapped within the glassy matrix of cramp, which suggests that, if present, the material was completely ashed. When a variety of seaweeds was heated in the laboratory in a crucible at 1100°C, it produced a form (Fig. 10) which is almost identical to that of pieces of cramp. A similar vitrified and vesicular product was obtained when seaweed was heated with turf at 650°C, thus demonstrating that a very high temperature, i.e. *c*.1200°C as indicated by the cramp-melting experiments of Kibble in Dalland (1999, 402), was not essential in cramp formation. However, as well as the alkali oxides

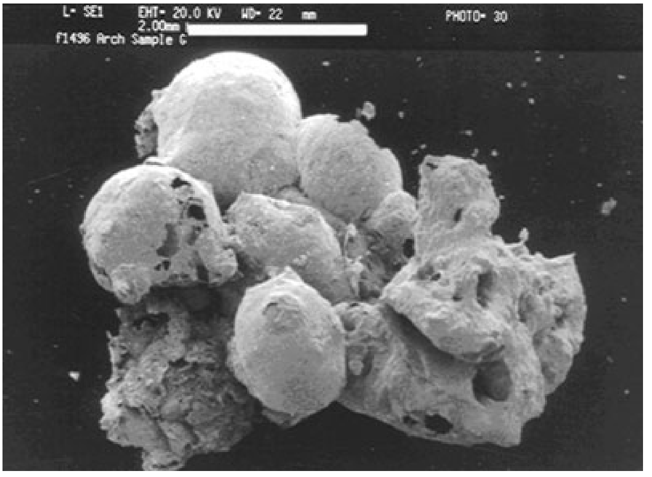

Figure 10
SEM-SE image of vesicular 'ash' from experimentally heated seaweed at 1100°C. Scale bar 2 mm.

in seaweed playing the role as 'glass formers' the vesicular nature of the cramp might point to a potential additional fluxing agent which, being volatile, would no longer impact on the melting temperature of reheated cramp. Thus it can be concluded that the main role of the seaweed is that of glass former, but the question remains why was it used in the first place?

Before assessing the need for a glass to form at the base of the pyre, it is important to establish the contribution of calcium and phosphorus oxides (as derived from bone) to cramp formation. At the early stages of cremation all soft tissue is combusted. The progressive combustion of the organic portion of skeletal bone takes place at temperatures up to 400°C. The final organic component to be lost is bone collagen leaving the mineral component, semi-crystalline hydroxyapatite, behind. Recrystallization of the bone mineral begins at ~600°C, fusion of crystals occurs by ~1000°C, and finally the bone mineral melts at ~1600°C. From the above it is clear that during the process of cremation the bone would have either shattered or fused and that essentially all intermediate stages should be manifested within the cramp.

Indeed the SEM-BS images (see Figs. 11, 12 and 13) of the glassy matrix of cramp from the Crantit cist depict the various stages of bone assimilation within the melt, recrystallization and final reaction with the glass. There are fragments of bone simply enveloped by the glassy matrix with little evidence for a reaction interface. There are in addition instances of the breakdown of bone, with subsequent recrystallization, as well as fusion following recrystallization and the formation of bone 'drops', suggesting heating to *c*.1000°C as shown in Figure 13. Therefore, in the course of cremation the most likely scenario is that the bone is enveloped or trapped by the melt, and furthermore, although there is some assimilation of bone chemicals into the glass of cramp, it does not appear to be a major flux for the formation of the siliceous glass.

The search for an organic component

The results of gas chromatography (GC) (Table 2) of seven archaeological samples of cramp are given in Table 4. Four of these, from Kewing, were from two pieces of cramp, the

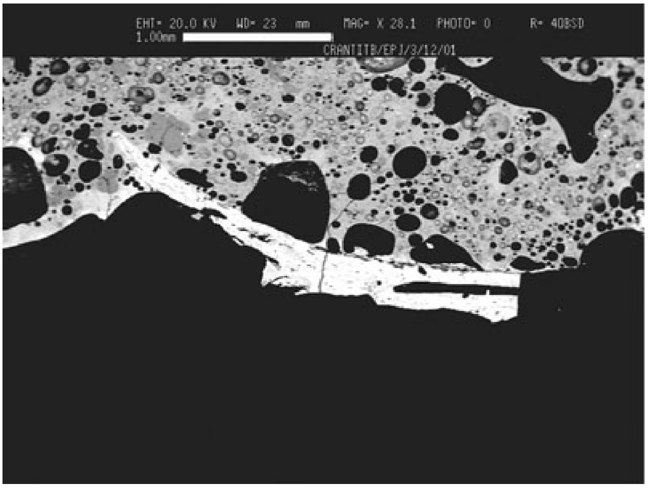

Figure 11
SEM-BS image of cramp from Crantit showing areas where bone (white) simply adheres on vesicular glass, and to the left where bone has begun to be assimilated into the glass. Scale bar 1 micron.

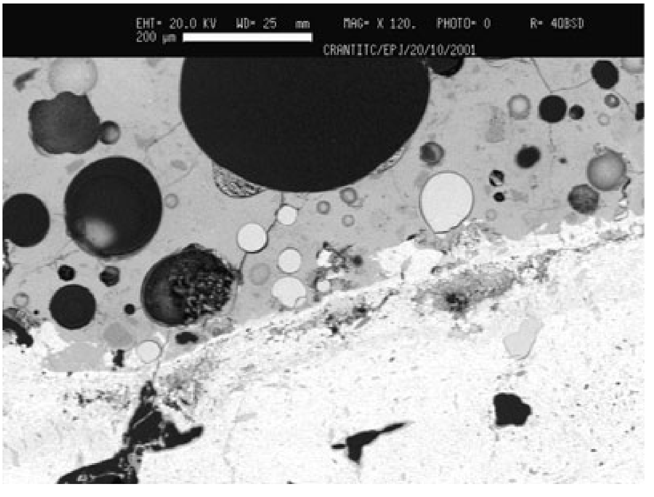

Figure 12
SEM-BS image of the interface zone between glass (greys) and bone (white) in Crantit cramp showing the formation of bone 'drops'. Scale bar 200 microns.

intention being to look at the variability of composition. Yields of organic residue were low, and in the case of the Kewing samples very low (*c*.1 mg from 15 g of starting material). In all samples there were a number of small unidentified peaks in the chromatograms. This exercise has shown that there is a small, variable organic component trapped within the glassy matrix of cramp, but there are apparently few, if any, diagnostic features in their compositions that could allow identification of the original material, whether human or otherwise.

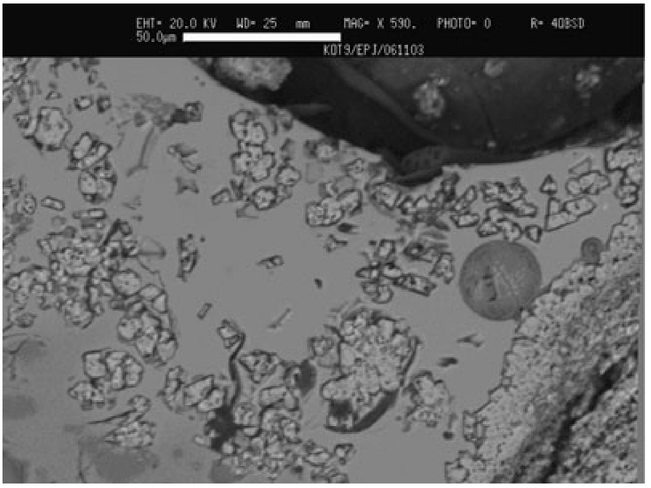

Figure 13
SEM-BS image of cramp from Knowes of Trotty showing small calcium phosphate (bone?) crystallites (about 10 microns) dispersed within the glassy matrix. Scale bar 50 microns.

TABLE 4
Organic molecules in archaeological and replica cramp determined using gas chromatography (GC). The C-number represents the number of carbon atoms in a molecule

Sample and findspot	Content	Comment
Cramp from Crantit (BA cist)	C14, C15, C16, C18:0, C20:0 and C22 fatty acids; C16–C25 n-alkanes	
Cramp from large fragment (see text) and one other fragment at Kewing (BA) – 2 samples each	C16 fatty acid; no n-alkanes	Variable organic composition even apparently within one sample
Replica cramp 1 (R1)	C16, C18:0, some triacylglycerols	Very low organic yield
Replica cramp 2 (R2)	C16, C18:0 fatty acids; some triacylglycerols	Some unidentified peaks in the GC, not associated with lamb meat/fat. Some similarity with one Kewing sample

To investigate the extent to which organic components could be incorporated into cramp, some simulation experiments were carried out. One lamb chop was divided in two: one part (meat/fat/bone) was mixed with typical Orkney Mainland turf from Vestra Fiold (see Fig. 1); the other had bone removed and was then mixed with the turf into a ball. Both samples were heated in a furnace for four hours at 900°C. The products were then crushed separately and each mixed with crushed dried Orcadian seaweed (2 : 1 ratio) and heated in a furnace for three hours at 950°C. In both cases (R1 and R2), the result was an ashy material. The organic extracts from R1 and R2 as well as samples of the turf, the dried seaweed and (commercially obtained) peat were analysed by GC for reference (see Jones *et al.* 2005). As shown in Table 4, the organic contents of the replica cramps, R1 and R2, are similar, but their concentrations are very low; at a basic level they resemble the Kewing archaeological cramp. The clear implication is that the fat and protein in lamb meat are effectively pyrolysed under the furnace conditions used here and very little fatty acid remains in the ash, rendering any organic component insignificant.

DISCUSSION

Cramp is a complex impure glassy siliceous material containing fragments of bone. It has a high content of potassium, sodium and calcium oxides which, in the presence of quartz and other silicate minerals, contributed as a flux to the formation of an alumino-silicate melt at relatively low temperatures (i.e. *c*.650°C). The melt produced the main glassy component of the cramp on cooling towards the end of the cremation process. Cramp normally formed small lumps up to *c*.20 mm in length. The rarity of large lumps is probably the result of insufficiently maintained high temperatures to allow for a more complete melt which would have the effect of joining the small lumps together into a cake. Fragments of bone were trapped by the siliceous melt but were also assimilated into it. The vesicularity of cramp is presumably due mainly to vaporization of moisture and organic components of the seaweed as it is combusted. The organic component, either from the body, fuel or seaweed, has limited preservation potential in cramp because of the high temperatures attained.

Having established the nature and conditions under which cramp formed, we now turn to the main question of the reason for its existence in the cist, namely the production of vitrified seaweed, whether deliberate or not. To that end, it is important to scrutinize the process of cremation. What took place at the cremation site in advance of the funerary pyre being lit and what steps may have been taken to ensure that cramp formed? It is clear that seaweed must have been laid on the ground *below* the funerary bier or wooden support on which the body may have rested (Fig. 14). It is also possible that a layer of seaweed may have covered the body as well. It is possible that the seaweed was spread in a thick layer over stone slabs, as in the case of Knowes of Trotty, where the eventual products of the cremation would have been easy to retrieve. At Crantit, where the scant remains of a small cremation survived, the seaweed layer may have been built on top of topsoil and close to a cist (Fig. 14).

All the potential fuels, peat, turf, seaweed and driftwood, would have had a dual function in the funeral pyre. They would have made up the bier on which the body rested and were also the fuel which ignited the body. Once the fire started, the body's own fat would have served as fuel. A high pyre with its elevated corpse would have allowed a draught to flow around and through the wooden construction. The sandy seaweed bed would probably have only begun to combust towards the end of the cremation process after the organic component of the body was well ignited and the bone had calcined and fractured. As the funerary platform disintegrated, whatever small bone fragments spattered would fall into a 'sizzling' part-molten and part-sintered 'bed' formed by the on-going reaction of the seaweed ash with the admixed sand and/or silty soil. This bed would have functioned as a collector of the fragmented bone from the burnt body, particularly the smaller pieces as in the case of Knowes of Trotty (see Fig. 13). The very small size of the fragmented bone clearly points to that effect, as does the way that they have been partly assimilated within the melt.

There is ample evidence that the remains of the funeral pyre were collected carefully: the larger fragments of bone were placed within a basket or cloth for transportation to, and deposition within, the cist or urn. The cramp with the smaller bone fraction was also collected and taken to the burial cist. Occasionally, this may have occurred while the cramp was quite warm and still partly fluid, as indicated by the large cramp lump from Kewing. The smaller

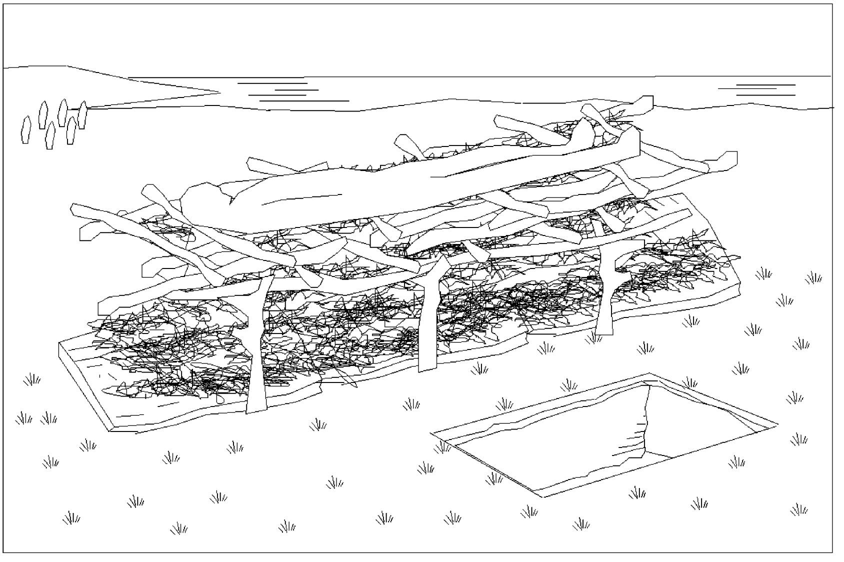

Figure 14
Reconstruction of funeral pyre close to the cist prepared as repository for the remains (bones and cramp) of the deceased.

pieces and those more difficult to retrieve would have been scooped up as a whole with the remaining ‘glassy bed’, small fragments of rock and other debris, and buried together with the bone. It is possible, as the evidence from both Knowes of Trotty and Crantit suggests, that the cremation site lay next to or very close to the cist so that transportation and handling of the remains were kept to a minimum. The method of collecting the cramp and the bone, and the order and arrangement of their disposal within cists are subjects requiring further research. It may be significant that the pieces of cramp were not broken up into smaller fragments before burial. The utilization of seaweed, not as fuel, but for the production of a molten ‘trap’, could have been a deliberate means of avoiding the loss of any precious remains of the deceased.

Cramp is intriguing because, despite appearing to be a waste material like vitrified fuel ash slag, it was considered important enough in Bronze Age burial customs to be buried with cremated human bone within a cist. But if cramp is found buried with bone is it indeed a waste or is it a product in its own right, intentionally produced? In the production of high-temperature materials, in particular the smelting of metals, product and waste are formed simultaneously, and the composition of the waste slag has to be controlled as much as that of the metal. However, the decision as to which to keep and which to throw away is unequivocal. In the context of cremation, the distinction between pyre product and waste is less clear. It is almost certain that the desire was to ‘convert’ the body to ‘ashes’ and small fragments of bone, and that the ritual of cremation would have been tailored for recovery and preservation of *both* products.

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