Seaweed, Swords and Smoke

Assessing the practical significance of seaweed in a metalworking context during the Viking Age

By

Matilda Sebire

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Declaration

I declare that this dissertation has been composed by myself and that the work of which it is a record was performed by myself. The dissertation has not been admitted in any previous application for a degree at this or any other university. All sources of information have been specifically acknowledged.

Signed

Date

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Abstract

This dissertation aimed to answer the question of whether seaweed could have had a practical significance in a metalworking context during the Viking Age. At the Viking Age site of Vatnsfjörður in Iceland, excavations of a longhouse and smithy revealed the presence of charred seaweed remains of the species *Ascophyllum nodosum* alongside the remains of birch wood charcoal. While the presence of wood charcoal is a common occurrence in archaeological sites, the question remains: Why was seaweed being burnt at this site? One hypothesis, which is researched through this dissertation, is that seaweed was being used in a metalworking context at Vatnsfjörður. Several metalworking experiments were performed in order to test this hypothesis: the first used seaweed as a fuel when forging, the second used seaweed ash as a flux when welding, and the third created a 'seaweed tar' as a by-product of the process of producing seaweed charcoal. The results of these experiments revealed that, while seaweed burns at too low a temperature to have been used as an independent fuel in a metalworking context, its ash could have been used as a flux when welding and the tar-like substance produced when seaweed is burnt under reducing conditions could have had other applications around the site. As well as its potential to be used as a supplementary domestic fuel, several properties of burning seaweed, such as the colour and intensity of the flame and the odour of the smoke produced, also suggest that the choice of seaweed as a fuel in the house and smithy could have had more symbolic meanings.

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1. Introduction: Background and Context of the Research

When Scandinavians settled Iceland in the late ninth century, they encountered an island rich in resources, particularly in regards to wood fuel (Vésteinsson 1998). Previous belief that the settlers soon depleted these woodland resources through overuse has been proven to be false by examining the palynological records from the island, which reveal that woodland management was in place (Mooney 2013). However, very little research has been conducted in regards to the use of other more obscure resources in Iceland, such as seaweed. Recent excavations at the site of Vatnsfjörður in Iceland have revealed the presence of charred seaweed remains, thus implying that seaweed was being used at the site. The aim of this dissertation is to clarify the reason for why seaweed was being used at the Viking Age site of Vatnsfjörður in Iceland. This introduction provides contextual information on the Vatnsfjörður site, Viking Age Iceland, and seaweed use, and concludes with an overview of the research design of this project and the structure of the dissertation.

1. 1. Vatnsfjörður Site

The site of Vatnsfjörður lies on the northwest coast of Iceland and includes the remains of a Viking Age settlement dating to the first half of the tenth century (Edvardsson 2005). The Viking Age area of the site consists of a longhouse, or *skáli*, (structure 1 in Figure 1 and 2) a smithy (structure 3 in Figure 1 and 2), and several smaller outbuildings (Milek 2007).

Further examination of the floor layers within and the midden deposits surrounding both the longhouse and smithy structures revealed the presence of wood charcoal and, more unusually, charred seaweed (Milek 2006). The greater majority of the wood charcoal fragments were identified as birch and the charred seaweed remains as *Ascophyllum nodosm* (Mooney 2013). Charred seaweed remains have also been discovered at other sites, including Papa Stour in Shetland (Brady and Batey 2008), Alpingistreiturinn in Iceland (Mooney 2013), and Monte Verde in Chile (Dillehay *et al* 2008). However, its presence at these sites has never been fully explained, and so the question explored throughout this dissertation asks why seaweed remains were discovered at Vatnsfjörður.

Figure 1. Layout of structures in the Viking Age area of Vatnsfjörður (Milek 2007)

In order to gain a better understanding of the charred fuel remains at Vatnsfjörður, samples from the hearth, floor and surrounding midden of both structures were collected (as shown in figure 2) and archaeobotanical analysis was undertaken by Dawn Mooney (2013). When comparing the relative amounts of charred seaweed in the two structures in this analysis, the results were as follows:

Hearths: Virtually no charred seaweed was present in the hearths of either structure, although it is important to consider that hearths are normally cleared after use, and so the samples taken from the surviving layer are not necessarily representative of every material ever burnt as fuel in the hearth.

Floors: The floor layers of the smithy contained a higher level of seaweed than the floor of the longhouse.
Middens: The midden surrounding the longhouse contained a much higher amount than the midden surrounding the smithy, in relation to the floor and hearth layers.

It has therefore been hypothesised that seaweed could have been used at the site for some industrial purpose, due to the larger amount of charred seaweed remains on the floor of the smithy compared to the floor of the longhouse, perhaps in the form of a fuel or other substance that could be used in a metalworking context (Mooney 2007). Another interpretation, formed when considering the different amounts of seaweed remains in the middens of the two structures combined with the low level discovered in the hearths, is that seaweed was being burned elsewhere on the site and then the waste deposited in the middens, particularly that of the longhouse (*ibid*).

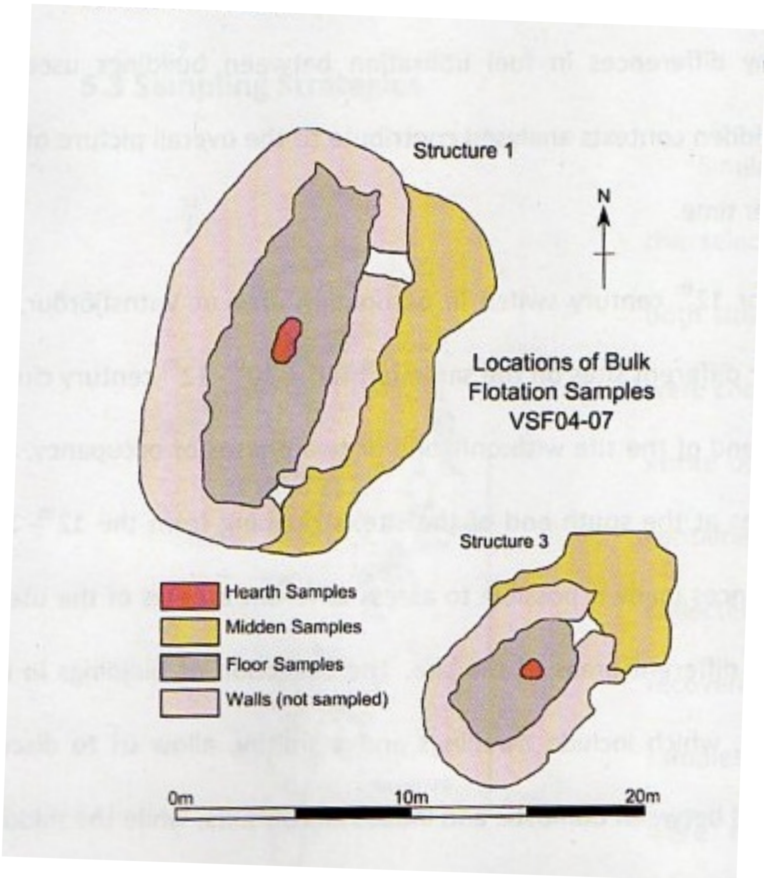

Figure 2. Sampling areas from the longhouse and smithy (Mooney 2013)

The aim of the current research project was to clarify the reasons why charred seaweed was present at the Vatnsfjörður site. This research was undertaken through a series of practical experiments concerning the potential use of seaweed and / or seaweed ash, especially in a metalworking context. As mentioned above, the relatively high level of charred seaweed remains discovered on the floor of the smithy compared to the floor of the longhouse suggests that seaweed was used for some practical industrial purpose in metalworking, for example as a fuel, or that seaweed ash of some other by-product of seaweed burning was use din some way. This hypothesis was tested experimentally through practical research that explored the following:

1. Whether or not dried seaweed could be used as a fuel when metalworking.
2. Whether or not seaweed ash could be used in a metalworking context.
3. Whether or not there are further products or by-products formed through the burning of seaweed that could have been useful to Viking Age Icelandic society.

During the course of the experiments, any potential domestic uses and practicalities were also noted, such as the use of dried seaweed as a domestic fuel and the practicality of using seaweed ash in a domestic context. However, due to the higher concentration of charred seaweed remains in the smithy structure at Vatnsfjörður, the main part of my research concerned the practicalities of seaweed use in a metalworking context during the Viking Age.

1. 2. Viking Age Iceland

In order to gain a greater understanding of the context of the site, it is important to examine Viking Age Iceland in further detail. The only written accounts of the original settlement of Iceland and the first few centuries of Viking life on the island are present in the form of the Sagas of Icelanders (Byock 2001). However, as these sagas were only physically written down in the thirteenth to fourteenth century (Ogilvie *et al* 2000), they have little reliability when reconstructing the exact events of Viking Age Icelandic society. However, when used in conjunction with archaeological methods it is sometimes possible to link certain events described in the Sagas with archaeological remains, as shown in examples below.

Scandinavians originally settled Iceland in the late ninth century, in the years immediately before or after 870 AD (Ogilvie *et al* 2000). When looking at archaeological remains from Iceland, it is possible to see a correlation between this date and the emergence of early settlements, as all inhabitable regions of the island were occupied by the first half of the tenth century (Vésteinsson 1998). Palynological records from Iceland also show a decline in the amount of birch pollen and a rise in dominant grass and weed pollen following the settlement in 870, which suggests that birch forests were being cleared to make way for grazing fields and other areas of agricultural and horticultural practice (Smith 1995). However, while it is true that significant areas of birch forest were cleared on initial settlement of Iceland, historical sources suggest that the pockets of woodland between farms were closely managed and intensively used as late as the eighteenth century (Vésteinsson and Simpson 2004), and regional archaeological studies have revealed that complete depletion of the island's woodland resources did not occur (Mooney 2013).

This latter point is particularly important regarding the aims of this dissertation. If woodland management was in place, this then implies that fuel such as the birch charcoal discovered at Vatnsfjörður was not a rare commodity. If seaweed was used as a fuel, it must therefore have been used for a particular reason, either due to its superior nature as a fuel or else due to some other particular property. The use of seaweed as a fuel will be discussed later in this chapter. Other fuels that were known to have been used in Iceland, according to the seventeenth century land register for Þingeyjarsýslur, include birch and willow wood, peat, turf, animal dung, driftwood, and fish-bones (Simpson *et al* 2003).

One additional reason why Vatnsfjörður was an important site on which to base this dissertation is its continued use from the tenth century up until the present day (Mooney 2013). Normally, such successful sites cause a build-up of archaeological layers as new structures and settlements are rebuilt on top of previous ones, which prevents discovery of the earliest archaeological layers, or at least makes them harder to locate (Vésteinsson *et al* 2002). However, the Viking Age area of the Vatnsfjörður site lies approximately 100 metres northwest of the main modern farm buildings (Edvardsson 2005), and so was reasonably accessible for an archaeological excavation. Because most such accessible sites are usually those that were abandoned due to being unsuccessful (Vésteinsson *et al* 2002), the excavation of Vatnsfjörður provides a valuable opportunity to increase our understanding of early, successful, Viking Age settlements in Iceland.

1. 3. Seaweed Use

One question that is vital when understanding the presence of charred seaweed at Vatnsfjörður, is what potential uses of seaweed could have resulted in its presence at an archaeological site.

Examining written ethnographies, historiographies and experiments concerning seaweed use are vital for developing an understanding its significance in the past, as it is unlikely to be discovered amongst archaeological remains under normal preservation conditions. The few remains that are discovered are normally burnt, as was the case at Vatnsfjörður and the other sites mentioned previously in this chapter. Another possible method of identifying the presence of seaweed in the past is to examine the remains of marine molluscs and barnacles at archaeological sites, which often latched themselves on to seaweed and so would signify that seaweed had been at that site. In the same way, a case study from Guidhall in Exeter revealed the remains of the fly *Leptocara zosterae* (which is generally associated with rotting seaweed) amongst the material from the bottom of a sixteenth century pit, thus suggesting that seaweed could have been stored there (Bell 1981). The presence of mussels in midden deposits at Mývatn in Northern Iceland is also believed to be due to their inclusion in seaweed balls that were used at the site (McGovern *et al* 2006). This method of past seaweed identification is particularly important when considering the midden surrounding Structure 6 at Vatnsfjörður, the nearest structure to that of the smithy (see Figure 1). In soil samples taken from the midden, two staphylinids specimens from the genus *Omalium* (Rove beetles) were discovered, which are often associated with decaying materials such as piles of seaweed (Forbes 2006), thus suggesting that large amounts of seaweed could have been stored there.

The use of seaweed as a source of human nutrition is well known in the modern world, particularly in regards to Asian foods. However, whether or not it was used as a component of the human diet in the past is still uncertain. Scientific studies on the nutritional value of seaweed have shown that it could be possible, as it contains important vitamins and a relatively high level of protein (MacArtain *et al* 2007). One of the earliest records of humans eating seaweed can be found in the saga of Egil Skalla-Grimsson who lived around 961 AD, when he was tricked into eating seaweed while threatening to starve himself (Bell 1981; Scudder (translator) 1997). This form of edible seaweed was known as s*oll*, or *söl* (or scientifically *Rhodymenia Palmata*), in Old Norse and is also mentioned officially in Iceland's oldest lawbook, *Grágás*, dating to the early twelfth century, in a law concerning the 'right to collect *soll*' (Hallsson 1961; Dennis *et al* (translators) 2007).

The greatest use of seaweed for nutrition concerns the feeding of animals (Byock 2001). One of the earliest written records of seaweed use as an animal fodder can be found in 45 BC in *Bellum Africanum*, which states that "In times of scarcity, [the Greeks] collected seaweed from the shore and, having washed it in fresh water, gave it to their cattle and thus prolonged their lives" (Inergaard & Monsaas 1991, 21). In Orkney, on the island of North Ronaldsey, there exists a population of sheep who feed exclusively on seaweed, and have even made specialised physiological adaptations to avoid any lethal side effects of this diet (Balasse *et al* 2006). While not being fed on such an exclusive diet, other domestic breeds are also fed on fresh seaweed and are encouraged to graze throughout most of the year (Chapman & Chapman 1980). An alternative to fresh seaweed is seaweed meal. This meal, made normally from the genus *Ascophyllum nodosum*, first emerged officially in Norway in 1937 and has shown varying results regarding contrasts with terrestrial fodder (Inergaard & Monsaas 1991). Scientifically, it is believed that a good quality meal made from *A. nodosum* has a composition equal to that of good hay and oats (Chapman & Chapman 1980), and has certainly provided some positive results which may show a general superiority over land-based food. Ewes fed the meal maintained their body weight better and had greater wool production, improved fertility, and a higher growth rate in their lambs than those who were not fed seaweed meal (Inergaard & Monsaas 1991). When fed to chickens there was also an improvement in the colour of the egg yolks and the egg iodine content (Chapman & Chapman 1980).

Another popular use of seaweed, both in the past and present day, is as a natural fertilizer, particularly *A. nodosum*, which has a high level of alginate and also improves the quality of grass by reducing the compaction of the ground (Blunden 1991). When contrasted with terrestrial fertilizers, it has been shown that seaweed increases crop yields, the resistance of plants to frost, the uptake of inorganic constituents from the soil and the resistance of plants to stress conditions (Blunden 1991). It is also known to enhance seed germination, to prevent or cure fungal diseases, and to make plants less prone to infestation from pests such as aphids (Booth 1966). The most extensive use of seaweed as a fertilizer is in the north west of France along the Ceinture d'ore, where an area of 400 miles along the coastline, from the sea to 500 metres inland, is annually applied with 30-40 m^3 of seaweed per hectare (Chapman and Chapman 1980).

One of the more modern uses of seaweed is as a renewable fuel, where seaweed is farmed, both inshore and now increasingly offshore, to produce a biomass that can be used for biofuel production (Ross *et al* 2008). However, there is also evidence that it was used as a fuel in the past up until the middle of the twentieth century, particularly when other fuels such as wood and peat were scarce (Hallsson 1961; Trbojevic *et al* 2011). This is an important point to note when considering the charred seaweed remains at Vatnsfjörður, particularly in the longhouse, because it raises the possibility that seaweed could have been used as a supplementary fuel at the site. However, it does not explain the presence of higher levels of charred seaweed remains on the floor of the smithy, the question of which will be explored throughout the practical research outlined in Chapter 2.

There are also several other possible uses that have been attributed to the presence of burnt seaweed at archaeological sites. The first is in an ash form to create a salt-rich lye that could be used to dye cloth (Hallsson 1961; Mooney 2013). Seaweed can also be used in the production of soap and glass (Brady and Batey 2008). Seaweed was also burnt in order to create sea salt in Viking Age Iceland, which could then have been used as a preservative (Milek & Roberts 2013).

All of these uses of seaweed could explain charred seaweed remains were discovered at Vatnsfjörður. However aside from a few instances such as its use as a fuel, the examples stated above do not require the seaweed to be burnt, as it was at the site. I believe that in order for it to be present in the archaeological record in its burnt form it is more likely that the seaweed was used as a fuel or for another purpose in a metalworking context, for example as an ash or other unknown by-product.

1. 4. Metalworking Context

The process of working metal requires a high level of skill and experience in order to produce objects of high quality, such as the famous Viking pattern-welded swords (Moilanen 2009). The presence of metalworking activities in the past can be determined by examining the metallurgical remains at an archaeological site, which are usually the waste products of metalworking activities. For example the presence of hammerscale (small iron oxide flakes) is often used to identify the presence of smithing activities such as forging and welding (Jouttijärvi 2009). Smelting activities and other methods of iron production are identified in a similar way through the presence of slag at a site (Stenvik 2003).

There are many different ways that metal can be worked. The basic shape and size of the metal is obtained by heating it in a forge and then hammering it into shape (Carlisle 2013), a method that will be utilized in the forging experiments of this dissertation. Another common metalworking process that will be applied in the practical research of this dissertation is piling, or forge welding, which allows several pieces of metal to be combined into one purer object (*ibid*).

1. 5. Dissertation Layout

This dissertation will explore whether seaweed could have potentially been used as a fuel in metalworking, and whether there are any practical uses for seaweed ash in a metalworking context. Chapter 2 of this dissertation will outline the methodology for the practical experimental research, including the preparation for and facilitation of these experiments. Chapter 3 will describe the results of the three main experiments performed, which will then be discussed in further detail in the Chapter 4 and summarised in the conclusion in Chapter 5.

2. Methodology: Explanation of the Practical Experimental Design

The question of seaweed use in a metalworking context was answered in this research using experimental archaeology: "the physical modelling of ancient production technologies and functional determinations of things, artefacts, and features, and a simulation of various economic and social processes of the past" (Malina 1983, 73). By using experimental methods, all aspects of the study were not only monitored but also experienced, thus adding an extra level of understanding to the potential use of seaweed in a metalworking context in the past.

2. 1. Preparation for Practical Research

The first step in this research was to collect the seaweed that would be used in the experiments. As this dissertation is based at the University of Aberdeen in Scotland, it was considered impractical to ship over a large amount of seaweed from the Vatnsfjörður coast. Instead, Scottish seaweed of the same species (*Ascophyllum nodosum*) was used. While the level of physical and chemical similarity between the Icelandic and Scottish regions of the species is as yet untested (future analysis will be performed to determine their level of similarity; see Chapter 5), they are the same species and so it is hypothesised that any difference between them would not be so great that it would effect the results of this research. Another sample of the same species was collected from the north coast of Brittany, France, to provide further regional comparisons, in case the chemistry of the coastal waters has a significant effect on the elements taken up by the seaweed.

The seaweed for this study was collected from a beach just south of Stonehaven, as this is a relatively non-industrialised area of the north-east Scottish coast and so contains less pollution that could contaminate the seaweed sample. The identification of the genus *Ascophyllum nodosum* was carried out using Wells' (unknown date) *A Field Guide to the British Seaweeds*. The amount of seaweed required for burning in order to raise enough heat to work metal was unknown at the time of collection, and so as much seaweed as could be carried was collected and transported back to Aberdeen. The seaweed was then laid out to dry using the traditional sun-drying method, which used to make use of cliffs or hay-drying frames well into the twentieth century (Inergaard & Monsaas 1991).

The practical experiments were carried out in Dartmoor under the supervision of David Budd, a professional blacksmith who holds a Master's degree in experimental archaeology from Exeter University. As well as introducing me to the basic techniques of blacksmithing and allowing me to use his open-air Viking-style forge (Figure 3) for my experiments, he also provided me with charcoal and iron.

Figure 3. Open air Viking-style forge used for the practical experiments

2. 2. Experiment on the use of Dried Seaweed as a Fuel when Forging

As explained in Chapter 1, the original hypothesis concerning the presence of charred seaweed remains in such abundance at Viking Age Vatnsfjörður was that seaweed must have been used for some industrial purpose at the site. Due to the known use of seaweed as a supplementary domestic fuel up until the middle of the twentieth century (Hallsson 1961: Trbojevic *et al* 2011), the following experiments were designed to test the hypothesis that dried seaweed could also have been used as a fuel in a metalworking context.

Five forging experiments were conducted to determine the efficacy of seaweed as a fuel. In each experiment, a round rod of mild steel (0.2 – 0.3% carbon) with a diameter of 15mm was flattened to a strap approximately 60mm long and 7mm thick. Mild steel was used in the place of pure wrought iron, as the latter is more expensive and also a lot easier to work in a forge (Rajput 2005, 36) making it more difficult to determine the effect of the seaweed on the forging process. Five forging experiments were conducted with the following fuels:

1. Initial control forging experiment using 100% wood charcoal.
2. 75% wood charcoal and 25% dried seaweed by weight (3:1 ratio of wood charcoal to dried seaweed).
3. 50% wood charcoal and 50% dried seaweed by weight (1:1 ratio).
4. 25% wood charcoal and 75% dried seaweed by weight (1:3 ratio of wood charcoal to dried seaweed).
5. 100% dried seaweed.

The fuel ratios/percentages in the second, third and fourth experiments were approximate due to the natural flow of the forging process, which required continuous fuel application throughout the experiment, ensuring that both the wood charcoal and dried seaweed are added at the same time. The exact measurements of the weight of both fuel types were taken following each experiment, by determining the difference in weight of each fuel bag at the end of the experiment compared to the beginning.

An additional part of each experiment was to see whether the mild steel rod could be brought up to 'welding point'; the point at which the metal is heated to a high enough temperature to fold and join together in a fire-weld. This is usually around 1200-1400 °C depending on the materials used (Moilanen 2009). The welding point can be visually determined by the bright yellow-white colour of the metal and the high number of white sparks produced as it is removed from the fire (pers. comm. Budd 2013). Welding was an important aspect of Viking Age blacksmithing, as blades were often made using a 'pattern-welded' technique, which displayed the skill and beauty of the blacksmith's work (Moilanen 2009), therefore if seaweed were used as a fuel it would have to be able to provide enough heat to bring the metal being worked in the forge up to welding point.

As well as using the 'raw' dried seaweed, an experiment was performed using seaweed charcoal, which was produced by burning dried seaweed in a sealed airtight container. This seaweed charcoal was then applied to an already burning fire in order to determine its efficiency as a fuel. The results from these experiments are outlined in Chapter 3.

2. 3. Experiment on the use of Seaweed Ash as a Flux when Welding

An additional technique used by blacksmiths is to perform what is referred to as a forge-weld (Williams 2003). This is a welding method whereby the two pieces of iron to be welded together are brought up to welding point in the forge and then hammered together to form a solid join between the two separate pieces. In order to create the most complete join possible blacksmiths normally use a flux when welding. A flux is a powdery substance which melts on application to hot metal and creates a vapour barrier, which then prevents iron oxide from forming in the join and also assists in the exclusion of impurities that could hinder the welding process (Moilanen 2009).

As it has been suggested that salt may have been used as a flux in the past (Gustafsson 2005), it was hypothesised that a relatively salty material such as dried seaweed could also have been used as a flux in its ash form. The production of seaweed ash requires seaweed to be burnt, which could account for the charred seaweed remains discovered at Vatnsfjörður if it were being used as a flux at the site. The efficiency of seaweed ash as a flux was tested by comparing it with three other welding techniques:

1. A 'dry weld' experiment using no flux.
2. A welding experiment using a traditional fine sand flux (Moilanen 2009)
3. A welding experiment using a modern borax (sodium tetraborate) flux

There were two different seaweed ashes used in these experiments. Both were produced by burning the dried seaweed in a crucible on an open forge. The first production of ash, which will be referred to as 'Ash 1', was formed over a newly lit wood charcoal forge, while 'Ash 2', was formed on the same forge but after the fire in the forge had been constantly burning for longer, and so emitted a higher temperature. This means that Ash 1 was formed using a slightly cooler temperature than Ash 2, making it possible to determine whether the temperature at which an ash flux was formed resulted in any significant variation in its efficiency during the welding experiments.

During the production of these ashes, the dried seaweed in the crucibles broke down in volume to form a bubbling liquid which eventually formed a hard crust on the inside of the crucible, which was then crushed with a pestle to form an ashy, grainy powder that could be used as a flux (Figure 4).

4.1. Seaweed was burned in a crucible

4.2. Small localised flames

4.3. Gradual breakdown of burning seaweed

4.4. A hard crust forms on the crucible sides

Figure 4. The Production Process of Seaweed Ash

In the welding experiments, a round rod of mild steel was flattened out and then folded so that the two flat planes lay side by side. Mild steel was again used in the place of pure iron, as the naturally occurring slag in the latter acts as a flux itself (Rajput 2005; Williams 2003) and so it would have been more difficult to determine the efficacy of the seaweed ash. The join was sprinkled with flux and the steel was then placed in the forge until it reached welding point. Once this point was reached, the steel had to be quickly removed from the forge before it burned and then hammered swiftly together while the metal was still bright hot. Once the metal started to fade in colour to a bright orange, more flux was sprinkled on the join and the steel put in the forge once more to reach welding point. This process was repeated as many times as necessary until the join between the two planes was complete; normally only one repeat was sufficient to form a solid join.

This experiment was repeated seven times to produce seven welded bars. These welded bars and the fluxes used in their formation are provided below:

Bar I: First welding experiment using Ash 1 as a flux
Bar II: First welding experiment using Ash 2 as a flux
Bar III: Repeat welding experiment using Ash 1 ash as a flux (by David Budd)
Bar IV: Repeat welding experiment using Ash 2 ash as a flux (by David Budd)
Bar V: Welding experiment of a 'dry weld' using no flux (by David Budd)
Bar VI: Welding experiment using modern borax flux (by David Budd)
Bar VII: Welding experiment using traditional fine sand flux (by David Budd)

Details of the results from the welding experiments are outlined in Chapter 3.

2. 4. Experiment to Determine Potential By-products of Burning Seaweed

The final practical experiment was conducted in order to determine if burning seaweed could produce other useful substances. This was done in order to test the hypothesis that the charred seaweed remains discovered at Vatnsfjörður were formed while processing seaweed for another purpose altogether. During a preliminary experiment to produce seaweed charcoal, in which an airtight tin container full of dried seaweed was buried under a fire, it was observed that the charcoal produced was very greasy and had a pungent, tar-like odour. On this basis it was hypothesised that a tar-like substance could be extracted from seaweed in the same manner as tar made from wood bark (Lucquin *et al* 2007).

Two experiments were performed to determine whether seaweed tar could be produced by burning seaweed under reducing conditions. As mentioned in the first section of this chapter, the seaweed collected for the practical experiments was the species *Ascophyllum nodosum*. While the forging and welding experiments were both performed using the Scottish seaweed, the tar-making experiment made use of both the Scottish and the French seaweed in order to provide a regional comparison.

190 grams of seaweed were sealed in a tin container. This container had a hole drilled in one corner to allow any tar produced to drip into another tin container placed beneath that corner (Figure 5). Both containers were placed in this manner into a pit and buried just below the ground surface. A fire was then lit on the ground surface and was kept burning for 50 minutes before being left to dwindle and cool, at which point the two containers were uncovered and the products within examined. The results of both tar-making experiments, as well as the forging and welding experiments, are outlined in the following chapter.

Figure 5. The layout of the containers in order to produce seaweed charcoal and tar

3. Results of the Practical Experiments

Described below are the results of the experiments as well as additional observations that were made during the practical research, particularly regarding the smoke produced when burning seaweed.

3. 1. Results of the Experiment on the use of Seaweed as a Fuel

The first hypothesis concerning the presence of charred seaweed at Vatnsfjörður, particularly on the floor layer of the Viking Age smithy, was that dried seaweed had been used as a fuel in metalworking. The results from the five experiments performed to determine the validity of this hypothesis are provided below.

In order to facilitate the presentation and interpretation of these results, a numerical scale was used to measure the following elements:

1. The amount and character of smoke produced in each forging experiment.
2. The intensity of the flame produced in each forging experiment, including the brightness and height of the flame.

The numerical scale designed to measure the level of smoke present in each forging experiment runs from 1 to 6, as shown in Table 1.

Table 1. Numerical scale describing the quantity and thickness of smoke produced

Numerical Scale	Thickness of Quantity of Smoke
1	Very thin and translucent, wisps
2	Partly translucent
3	Partly translucent, partly opaque,
4	Partly opaque, steady streaming cloud
5	Completely opaque, thick, continuous spreading clouds

The numerical scale designed to measure the intensity of the flame in each forging experiment runs from 1 to 5, as shown in Table 2.

Table 2. Numerical scale describing the intensity of the flames produced

Numerical Scale	Intensity of Flames
1	Bright but pale orange colour, gently burning, low level of sparks
2	Bright orange-yellow colour, gently burning, low level of sparks
3	Bright, thick orange colour, 'roar' while burning, sparks and popping
4	Bright, thick orange colour, intense roar, high flames, higher level of sparks and popping
5	Bright, thick orange colour, intense roar, very high flames, large amount of sparks and popping

Further observable elements such as the smoke colour, flame colour, ash and ember remains, sparks produced, and whether the metal rod being forged was able to reach welding point are also described in the text and are summarised in Table 3

The first forging experiment was a control experiment using fuel comprising 100% wood charcoal. It required approximately 0.7kg of wood charcoal to work the metal rod down to the 60mm long and 7mm thick strap required in the experimental design. Initial burning of the wood charcoal produced thin white wisps of smoke (level 1), which quickly disappeared in the place of thin, bright orange flames (level 1). Application of air to the fire from the bellows caused the flames to turn blue around their base (i.e. the flame became hotter). There were few and occasional sparks. On completion of the experiment, the wood charcoal burnt down to form glowing white-orange embers. Welding point was achieved.

The second forging experiment used fuel comprising approximately 75% wood charcoal and 25% dried seaweed by weight (3:1 ratio of wood charcoal to dried seaweed). In the entire duration of the experiment, approximately 0.7kg wood charcoal and 0.25kg dried seaweed were required. Initial addition of the wood charcoal to the fire produced the same thin white wisps of smoke as in the first experiment, while addition of the dried seaweed to the fire produced a thicker, white, sweet-smelling smoke (level 2 / 3). This smoke decreased in quantity once the fuel caught fire, to form bright, thick orange flames, which burned with what can only be described as “ferocity” (level 3). These flames lowered in intensity in under a minute of burning time to a bright yellow colour with a green tinge, which on application of air from the bellows turned to purple around the base. There were few and occasional sparks, caused by the explosion of the seaweed bulbs. On completion of the experiment, the wood charcoal burnt down to glowing white-orange embers, and the seaweed decreased significantly in volume to leave very few white ashy remains. Welding point was achieved.

The third experiment used fuel comprising approximately 50% wood charcoal and 50% dried seaweed (1:1 ratio). The amount of fuel required to work the metal rod to appropriate dimensions was approximately 0.7kg wood charcoal and 0.6kg dried seaweed. Initial addition of the fuel produced thick white-green, sweet-smelling smoke (level 3), which thinned to wisps once the fuel caught fire, however the sweet odour remained for the duration of the experiment. An extremely thick, bright, and high orange flame was produced on burning of the fuel, accompanied by a lot of popping and sparking (level 5). On completion of the experiment, once the wood charcoal had burnt down to glowing white-orange embers and the seaweed had decreased in volume down to white ash, the remaining flames turned a bright green colour. Welding point was achieved.

The fourth forging experiment used fuel comprising approximately 25% wood charcoal and 75% dried seaweed (1:3 ratio of wood charcoal to dried seaweed). It required approximately 0.4kg wood charcoal and 0.7kg dried seaweed to work the metal rod down to the appropriate dimensions. A lot of thick, pungent, white-green smoke was produced on initial application of the fuel (level 4 / 5). On burning, the fuel produced a bright, thick, orange-yellow flame, which burned with equal intensity to the third forging experiment, although the flames did not reach as high (level 4). However there was considerably more popping and sparking. On completion, the fuel decreased in volume at a quicker rate than in the previous three experiments to glowing white-orange embers and a large amount of white seaweed ash. Welding point was achieved, but required a longer duration of application of air from the bellows than in the previous three forges.

The fifth and final forging experiment used fuel comprising of 100% dried seaweed. After using approximately 0.7kg dried seaweed the experiment was abandoned. Burning of the seaweed produced a very large amount of thick, pungent, grey-green smoke (level 5), and bright orange flames that were not hot enough to more than warm the metal rod (level 3). The seaweed burned down in volume to a white ash too quickly to contain and maintain sufficient heat.

The burning ability of seaweed charcoal was also tested. On the Viking-style charcoal forge on which the five experiments concerning the use of seaweed as a fuel were performed, the seaweed charcoal did not burn. On a modern coke forge, where a higher temperature can be achieved, the seaweed charcoal did eventually catch fire, however it required a very high temperature to ignite, and once lit was unable to retain its heat and the flames died almost instantly.

Table 3

3. 2. Results of the Experiment on the use of Seaweed Ash as a Flux

Another possible use of seaweed in a metalworking context that could account for the presence of charred seaweed remains at Vatnsfjörður is the use of seaweed ash as a fluxing agent when welding. This hypothesis was tested by comparing the efficiency of seaweed ash as a flux with modern borax, fine sand, and a dry weld using no flux. The observations made during these welding experiments are presented below.

In order to provide a further level of detail to observations of the welding experiments and the exploration of the efficiency of seaweed ash as a flux, the welded metal rods were cut into sections (displayed in Figures 6 and 7) These sections showed a clearer picture of the welded joins, especially when examined in closer detail under an optical microscope using oblique incident light. The images of these sectioned welded samples are provided in figures 8-13, along with detailed descriptions and tables (5 and 6) summarising the comparisons of the quality of the joins produced using the different varieties of flux in tables.

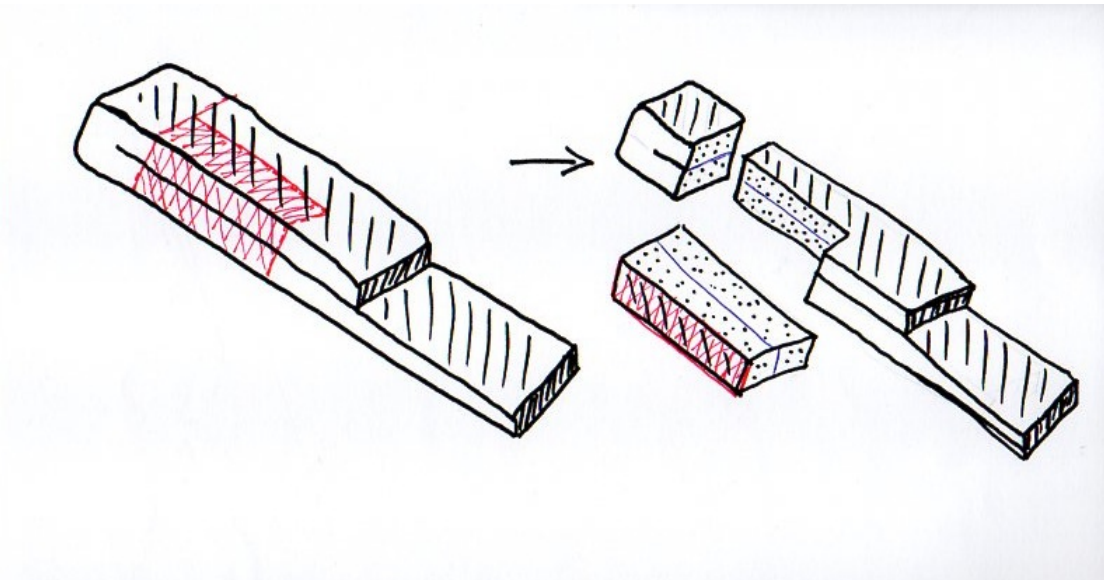

Figure 6. Sectioning method of the welded sample (red) from the welding experiments

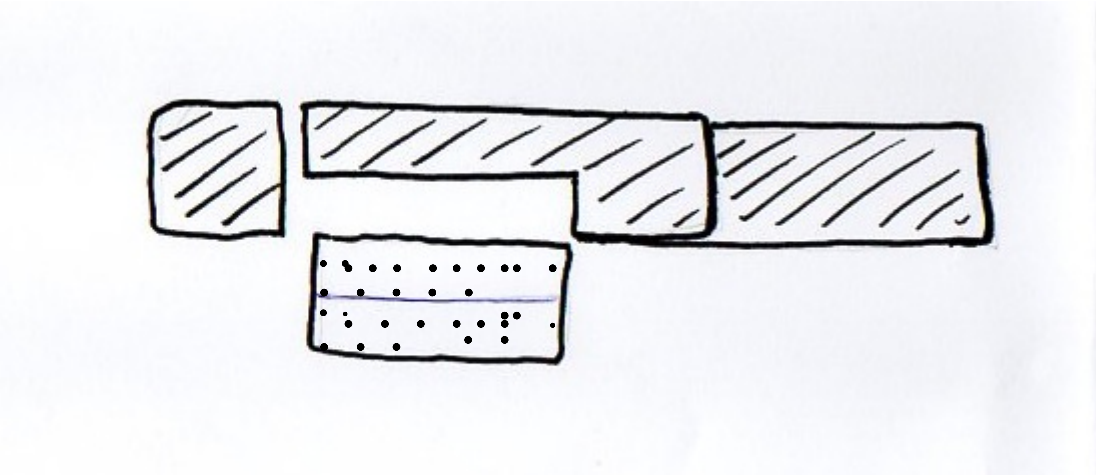

Figure 7. Orientation of section (dotted) examined to determine the join strength

The following descriptions will use the terms ‘left’, ‘middle’ and ‘right’ to describe the left, middle and right areas of the welded join as if the sectioned bar is orientated as displayed in Figure 7.

When burning seaweed in a crucible on a forge to form seaweed ash that could be used as a flux, sweet-smelling white smoke and localised orange flames were produced. Once the seaweed had burnt down in volume a thick, bubbling liquid was formed, which on cooling hardened to a crust As mentioned in Chapter 2, Ash 1 was formed on a charcoal fire that had been recently lit, while Ash 2 was formed on the same fire once it had built up strength and therefore produced more heat. When forming Ash 1, the seaweed took longer to light and required constant influx of air from the bellows in order to keep burning. When forming Ash 2 on the hotter fire, the seaweed remained lit and burning without the influx of air from the bellows, and there was a greater volume of bubbling liquid produced.

The first welding experiment used Ash 1. The weld was successful and produced Bar I. The middle of the welded join had no gap visible to the naked eye, however it was possible to see a faint join line on the left and right sections. Closer examination of the join under the optical microscope (Figure 8) confirmed that the join line could be seen on the left and right sections, but the join in the middle was complete.

The second welding experiment used Ash 2. The weld was successful and produced Bar II. The join line was less defined than that of Bar I, and it was only possible to see a line with the naked eye on the right side of the welded section. Closer examination under the optical microscope revealed no visible join in the left section, and an extremely faint line in the middle (Figure 10).

The third welding experiment used Ash 1 again. This repeat of the first welding experiment, and the following four experiments, were performed by the more experienced David Budd in an attempt to prevent any anomalies, which would lead to biased results concerning the efficiency of seaweed ash as a flux. The weld was successful, and produced Bar III. The join line was visible to the naked eye in the middle of the welded section, but was almost invisible on the right side and completely invisible on the left side. Closer examination using the optical microscope (Figure 9) showed that the whole join line was visible, although only very faintly on the left side. The middle and right sections showed a clear join line.

The fourth welding experiment was a repeat using Ash 2. The weld was successful and produced Bar IV. The join was very smooth and the line was only faintly visible to the naked eye on the right side of the welded section, and completely invisible in the middle and left sections. Closer examination using the optical microscope revealed a faint join line on the right, and an extremely faint line in the middle section, with no visible join line on the left (Figure 11).

The fifth welding experiment used no flux in a so-called ‘dry weld’. As expected, the weld was unsuccessful and a layer of oxidation product was clearly visible to the naked eye on the resulting Bar V. This bar was not examined further beneath the optical microscope, as there was no join.

The sixth welding experiment used borax (sodium tetraborate), which is a flux used by modern blacksmiths. This flux was used to provide a positive control against which to compare the efficiency of seaweed ash as a flux. The weld, as expected, was successful and produced Bar VI. The join line was almost invisible to the naked eye, although an extremely faint crack was discernable from the right of the welded section. Even when examined in closer detail under the optical microscope, this visible join line on the right was still very faint, and there was still no visible join line on the middle and left of the welded section (Figure 12).

The seventh and final welding experiment used fine sand as a flux. The weld was successful, and produced Bar VII. Unfortunately, the sample of sand used in this experiment contained a few impurities, which were visible to the naked eye on the right side of the welded section. There was however no visible join line in the middle and left sections. Closer examination under the optical microscope revealed a visible join line in the middle as well as the right of the welded section, and a very faint line on the left (Figure 13).

Table 4 displays a numerical scale used to describe the strength of the join in each welding experiment, as evident through the level of visibility of the join line. These numerical scales are used in Table 5 and Table 6 to assist in the formation of a scale of 'join strength', where 1 represents a weak join with the most visible join line and 7 represents a strong join with the least visible join line.

Table 4. Numerical scale of the strength of the join in each welding experiment

Numerical Scale	Description of join visibility
0	No visible join line
1	Almost invisible join line
2	Partially visible join line
3	Visible join line
4	Very clear visible join line

Table 5. Comparison of join strength, as suggested by the visibility of the join line by the naked eye

Bar	Visibility on the Left	Visibility in the Middle	Visibility on the Right	Total of Scale Values	Order of relative join strength (1-7)
I (Ash 1)	3	0	3	6	2
II (Ash 2)	0	0	3	3	4
III (Ash 1)	0	3	1	4	3
IV (Ash 2)	0	0	2	2	5 / 6
V (Dry Weld)	NA	NA	NA	NA	1
VI (Borax)	0	0	1	1	7
VII (Sand)	0	0	2	2	5 / 6

Table 6. Comparison of join strength, suggested by the visibility of join line under optical microscope

Bar	Visibility on the Left	Visibility in the Middle	Visibility on the Right	Total of Scale Values	Order of relative join strength (1-7)
I (Ash 1)	3	0	3	6	3
II (Ash 2)	0	1	4	5	4
III (Ash 1)	3	3	3	9	2
IV (Ash 2)	0	1	2	3	6
V (Dry Weld)	NA	NA	NA	NA	1
VI (Borax)	0	0	1	1	7
VII (Sand)	1	2	3	6	5

When combining the relative join strengths from both tables it is shown that modern borax was the most efficient flux, followed equally by Ash 2 and sand, with Ash 1 as the least efficient flux used.

Figures 8-13 on the following page present the left, middle and right sections of each welded bar as they appear in the figures (ie; left to right)

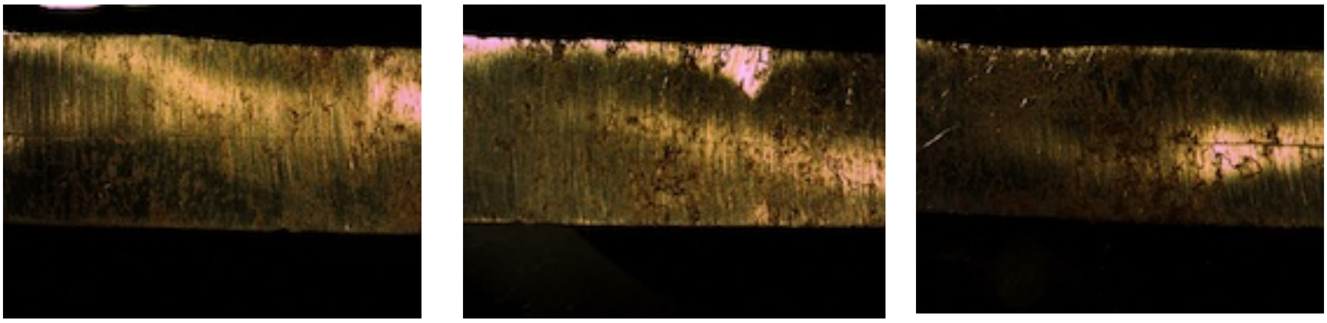

Figure 8. Observations of left, middle, and right sections of Bar I under an optical microscope (Ash 1)

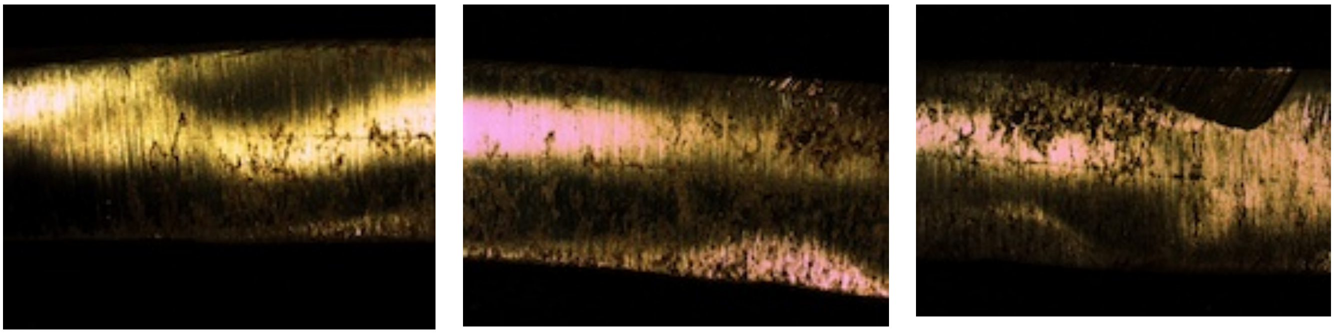

Figure 9. Observations of left, middle, and right sections of Bar III under an optical microscope (Ash 1)

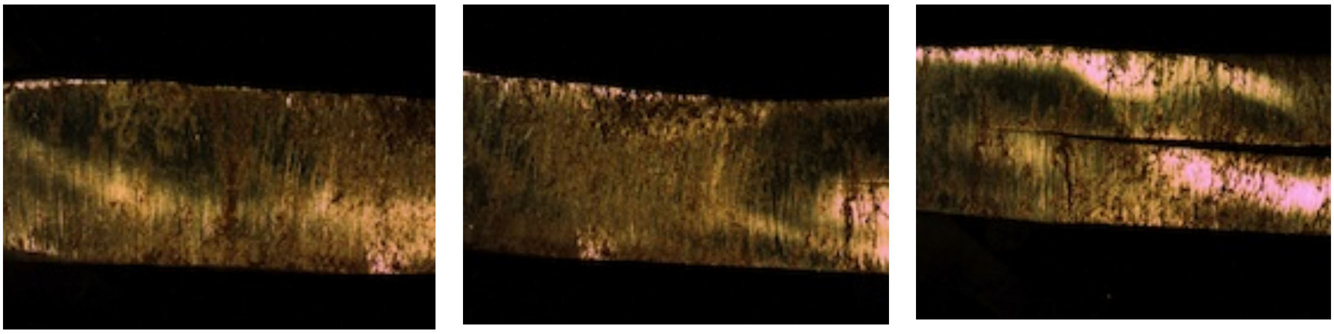

Figure 10. Observations of left, middle, and right sections of Bar II under an optical microscope (Ash 2)

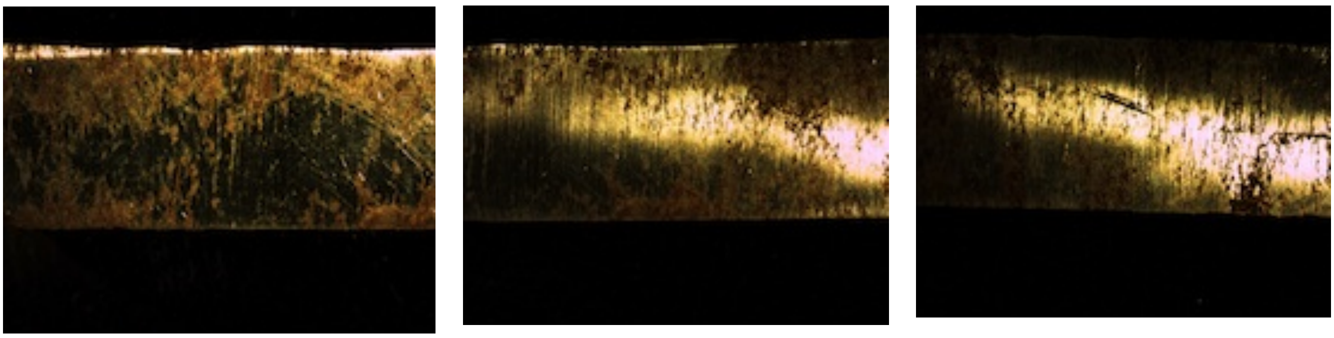

Figure 11. Observations of left, middle, and right sections of Bar IV under an optical microscope (Ash 2)

Figure 12. Observations of left, middle, and right sections of Bar VI under an optical microscope (Borax)

Figure 13. Observations of left, middle, and right sections of Bar VII under an optical microscope (Sand)

3. 3. Results of the Experiment on Production of Seaweed Tar

The experiment to determine whether seaweed tar could be produced as a by-product when producing seaweed charcoal seaweed was successful. Although further chemical analysis is required before the liquid produced can be absolutely identified as 'tar', the extremely pungent odour of the liquid extracted from seaweed under reducing conditions was suggestive of that usually produced by materials similar to tar, such as kerosene. The tar produced in both experiments was transparent and had extremely low viscosity.

Burning 190 grams of Scottish seaweed in a sealed and buried container for approximately 50 minutes produced 109 grams of seaweed charcoal (Figure 15) and 23 grams of seaweed 'tar' (Figure 14). Burning the same amount of French seaweed in the same way produced 85 grams of seaweed charcoal and 3 grams of seaweed 'tar'. These results are presented in Table 7.

Table 7. Amounts of seaweed charcoal and 'tar' produced

Regionality of Seaweed	Original Dried Seaweed (grams)	Seaweed Charcoal Produced (grams)	Seaweed tar Produced (grams)
Scottish	190	109	23
French	190	85	3

Figure 14. 'Seaweed tar' produced

Figure 15. Seaweed charcoal produced

3. 4. Additional Observations: Odour of Seaweed Smoke

During the practical experiments varying levels of smoke were produced while burning dried seaweed. This smoke was particularly noticeable during the experiment on the use of seaweed as a fuel for forging. The odour of this smoke was very powerful, regardless of the quantity of smoke produced: pungent and sweet smelling and noticeably similar to that caused when burning cannabis. The possible implications and significance of these observations in regards to Vatnsfjörður will be discussed in Chapter 4.

4. Discussion: Interpretation of Results and Observations

The results of the practical experiments suggest that, while seaweed burns at too low a temperature to have been used as an independent fuel in a metalworking context, seaweed ash was effective as a flux and the burning of seaweed under reducing conditions could produce a tar-like substance. It also has certain other properties that could be interpreted as having not only a practical but also a potentially symbolic or ritual significance, such as the flame colour and intensity and copious amounts of pungent smoke produced when burning seaweed.

4. 1. Practical Use of Seaweed as Fuel in a Metalworking Context

Due to the higher number of charred seaweed fragments found on the floor of the smithy compared to the floor of the longhouse at the Viking Age site of Vatnsfjörður (Mooney 2013), it was hypothesised that dried seaweed could potentially have been used as a fuel in the smithy. This hypothesis was also based on the other known uses of seaweed as a fuel. It was used as a domestic fuel in certain countries, including Iceland, up until the middle of the twentieth century (Hallsson 1961; Trbojevic *et al* 2011). There is also evidence through the presence of cramp, a material formed by the fusion of sand attached to dried seaweed while burning, that seaweed was being burnt in cremations as far back as the Late Neolithic Period in Scotland (Photos-Jones *et al* 2007). However, no experiments had previously been performed to determine whether seaweed could have been used as a fuel in a metalworking context.

The results of the practical research conducted for this dissertation were conclusive: seaweed is not efficient as a fuel in a metalworking context. While the forging experiments that used pure wood or mixtures of wood and seaweed fuels were successful in that the metal rod was worked down to the appropriate size and shape and welding point was achieved, the fifth experiment using 100% seaweed fuel was unsuccessful. Independently, burning seaweed does not provide a high enough temperature to work metal and it also breaks down in volume a lot more quickly than wood charcoal. This affects not only the efficiency of seaweed as a fuel but also its economic practicality. As birch wood was readily available to the inhabitants of

Vatnsfjörður (Mooney 2013), there was no practical reason to use a different source of fuel which not only provided insufficient heat for working metal but also broke down very quickly on burning and so would have required a larger initial volume. The white ashy remains of the seaweed following each experiment were also very different to the charred seaweed remains discovered at Vatnsfjörður, although it is possible that they were ejected from the flames before they were completely consumed.

The brightness and intensity of the flames produced when seaweed was used as a fuel, both independently and as a composite element of the fuel combined with wood charcoal, could have been a significant factor in the choice of seaweed as a fuel. The flames produced when burning seaweed were significantly brighter than those produced when burning wood charcoal, even if it only comprised a small percentage of the total fuel. Particularly in the dark winter months in Iceland, and in turf structures that may not have had any windows to permit the entry of natural light, a fuel that produced a more intense source of light may have been highly valued, particularly if it could also be combined with a fuel such as wood charcoal, which could produce sufficient heat. While this would not have been a particularly useful property of flames in a forge, because such bright flames are often blinding and in the few seconds it takes a blacksmith to regain his sight after removing metal form the fire the metal would have lost precious heat, it would have been useful in a domestic context. This could therefore explain the presence of charred seaweed remains in the longhouse as well as the smithy at Vatnsfjörður.

Further interpretations of the unique green and purple flame colours, the brightness and intensity of the flames, and the pungent odour of the smoke produced when burning seaweed suggest possible symbolic reasons behind the choice of seaweed as a fuel. This is especially possible when considering the symbolism and ritual roles of blacksmiths in different cultures and in Old Norse mythology. This potential symbolic aspect of seaweed use will be discussed at the end of this chapter in section 4.4.

4. 2. Practical Use of Seaweed Ash as a Flux in Welding Processes

Another possible explanation as to why charred seaweed remains were discovered at the site of Vatnsfjörður is that seaweed was being burnt in order to create an ash that could then be used as a flux in welding. Welding was a particularly important metalworking practice for a blacksmith to learn in Viking Age society, especially when considering the famous pattern-welded blades produced during this period. These pattern-welded blades were not only a symbol of high quality weaponry but also displayed the talent and skills of the individual blacksmith (Moilanen 2009).

The results of the welding experiments showed that seaweed ash was a successful flux. The dry weld showed that without a flux the mild steel bar could not be successfully welded. Because the metal did weld when seaweed ash was used, it is clear that it is an effective substance to use as a flux. The relative efficiency of seaweed ash compared to the other fluxes can be seen by examining Table 5 and Table 6 in further detail. This value of efficiency was constructed by comparing the visibility of the joins produced from each welding experiment. (An interesting point to note is that in almost every case the right section of the welded area had a more visible join (and therefore a less successful weld) than the rest of the sample. This trend is explained by understanding that the right hand side was the 'end' of the metal fold, and therefore was not the subject of as much hammering as the left and middle sections.) If we combine the relative join strengths from both tables 5 and 6 we arrive at the following order of efficiency, with 1 representing least efficient and 7 representing most efficient:

1. Dry Weld (no flux)
2. Ash 1
3. Ash 1
4. Ash 2
5. Ash 2 / sand
6. Ash 2 / sand
7. Borax

These results suggest several things. Firstly, the seaweed ash formed using a higher temperature forge was more efficient as a flux than that formed on a lower forge. This could relate to the higher volume of bubbling liquid formed on the hotter forge, which is suggested here to be liquid salt. It has been suggested that salt may have been used as a flux in the past (Gustafsson 2005), and so the salt content of the seaweed ash, extracted during the production process, could be the key to its efficiency as a flux. The chemical content of seaweed ash needs to be analysed to confirm this hypothesis (see Chapter 5).

The second inference that can be drawn by comparing the efficiency of the different fluxes is that the seaweed ash produced on a hot fire was as efficient as sand for welding. Fine quartz sand was known to have been used as a flux for welding during the Iron Age (Moilanen 2009) and silver sand is still used by modern blacksmiths (Williams 2003). When considering this latter point, given the availability of modern chemical fluxes such as borax, the fact that sand is still used identifies it as a practical and efficient flux to use when welding. Therefore, as the welding experiments using seaweed Ash 2 were equally successful to those using sand, this suggests that seaweed ash is an equally efficient flux, and could have been used as such at Vatnsfjörður. Leading on from this point, the beach at Vatnsfjörður has grey sand made from weathered basalt, which may not be as efficient as the sand used in the welding experiments, therefore seaweed ash would have been preferable when deciding on fluxes. Further exploration is however required on this point (see Chapter 5).

Another reason why seaweed could have been processed in this manner at the site relates to the production of the seaweed ash used in the experiments. This ash was very easy to make and, although only small amounts were required for these welding experiments as the flux was only applied to a small area being joined, it could have been made in greater quantities for larger scale welding projects. This could explain the presence of charred seaweed fragments at Vatnsfjörður, as opposed to ash: burning a larger amount of seaweed would have made it more likely that some pieces of seaweed were not fully combusted but were instead ejected from the fire, perhaps due to the popping and sparking observed in the forging experiments.

4. 3. Production of Other By-products when Burning Seaweed

The liquid that was produced as a by-product when making seaweed charcoal is believed to be some manner of 'seaweed tar'. Although the liquid is not as viscous as other types of tar, its smell is reminiscent of certain tar-like substances such as kerosene. The difference in the results of the Scottish and the French seaweed experiments could be explained in several ways. The first possibility is that the French seaweed was not dried out as well as the Scottish samples, and so the majority of the initial weight buried was water, which would then have evaporated. This explanation is a reasonable one; while the seaweed was dried out in both cases in the traditional sun-drying method, it was impossible to expel every last molecule of water from every seaweed strand. This would suggest that both the 58 grams lost from the Scottish sample and the 102 grams lost from the French sample were the weight of the water still trapped inside the seaweed. The large difference between the Scottish and French results could also suggest a regional variation in the chemistry of the seaweed, which will have to be confirmed through future research. If this does turn out to be the case, then the experimental research performed in this dissertation could be considered inconclusive regarding the specific site of Vatnsfjörður, where the seaweed would have originated locally and could be expected to have different chemical compositions from both the Scottish and the French examples. However, as stated in Chapter 2, all seaweed samples used in this practical research belonged to the same species (*Ascophyllum nodosum*) as the charred remains discovered at the Vatnsfjörður site, and so it was hypothesised that regional variation would not significantly affect the results.

If seaweed tar were being produced at Vatnsfjörður, it would not have been used in a metalworking context although the smithy may have been the main site of its production. For example, archaeological evidence from Scandinavia has discovered the use of tar pits in order to make pine tar (Hjulstöm *et al* 2006). Tar made from wood bark has frequently been used in the past. Birch bark tar was used as an adhesive and as a waterproofing agent for ceramics during the Neolithic period, and there is also evidence that it was used as a chewing tar (Lucquin *et al* 2007). Conifer tar was discovered smeared on the side of the Ma'agan Mikhael ship discovered off the coast of Israel, presumably as a protective layer for the timbers (Connan *et al*

2003). During the medieval period tar was smeared over doorways and beds, so that the pungent smell would deter evil spirits from entering a house or body (Lucquin *et al* 2007).

Further examination of the 'seaweed tar' produced through the practical experiments is necessary before any final conclusions are made. Even if the liquid extract produced by burning seaweed under reducing conditions cannot officially be classified as a tar, it may still hold other properties useful to the Viking Age people living at Vatnsfjörður.

4. 4. Further Interpretations of the Possible Symbolic Use of Seaweed

As mentioned briefly in section 4.1, certain observations made when burning seaweed such as the unique green and purple flame colours, the brightness and intensity of the flames, and the thick, pungent smoke produced suggest possible symbolic reasons behind the choice of seaweed as a fuel. It is worth noting in this context that the status of the blacksmith and the act of blacksmithing was endowed with ritual significance both in some modern societies and also in Old Norse mythology (Jørgensen 2012).

The smoke produced when burning seaweed had a pungent odour very similar to that produced when burning cannabis. Internet research on the subject of smoking seaweed produced positive accounts from various anonymous individuals who described a strong "high" achieved when smoking seaweed. It is therefore suggested that seaweed could have been used at the site of Vatnsfjörður not only for its practicality as a flux in ash form and its possible use when producing seaweed tar, but also as a narcotic and hallucinogenic. Such substances were available and consumed in Viking Age society (Price 2002). For example, cannabis seeds were discovered in the Oseburg ship burial, and a grave excavated at the site of Fyrkat revealed a woman (thought to be a sorceress) with a pouch containing several hundred seeds of henbane; a plant with "mind altering properties" (*ibid*, 155). The fact that a sorceress was buried with these seeds suggests that mind altering substances producing altered states of awareness were used in magical or ritualistic events and activities. These types of activities and events have also been associated with blacksmiths and the practice of blacksmithing, as demonstrated in the following ethnographic examples.

In many African societies, the blacksmith is considered one of the most important members of the community and is associated with many mythical and ritual practices. For example in the Ovimbundu culture of Angola, a blacksmith's tools are so significant to ritual and belief that they cannot be sold until they are no longer being used (Hambly 1934). In some areas of Africa the practice of blacksmithing has achieved such high levels of ritual associations that it has grown into more of a cult than a mere profession (Edwards 1991). The process of iron production can also hold more meaning than that of a simple physical process. The idea of birth, and rebirth, has often been associated with the smelting process: the raw iron ore is inserted into the furnace and from it is produced a relatively pure iron bloom, which then requires further care (or working in the forge) in order to develop into a final workable object (Gansum 2004). Iron production can also hold some sexual connotations. In many African societies there are strict taboos in place concerning which part of the smithing process can be overseen by either men or women, and in Nepal the only person allowed to observe the smelting process is the smelter himself, who must also be completely naked throughout (Rijal 1998). In a Kpelle town in West Africa, a boy must master three general roles before he is recognised as a blacksmith: he must be a 'skilled worker', which comes with practical training, a 'big man', which relates to his ability to deal honestly and respectfully with customers outside his kinship group, and a 'medicine man', which concerns his importance in magical practices (Lancy 1980). Indeed, in many societies the working of metal is only one of many aspects of being a blacksmith. In Kpelle society, the blacksmith has an important role to play in rice cultivation, as he provides the iron tools required for this life-giving task, and he is also in charge of making animal sacrifices during 'mená', or the taking of oaths (Lancy 1980). Among the Verre, the blacksmith is considered to have supernatural abilities and so must be feared and respected, as they hold equal power to the mythical 'rainmaker' who controls all the natural elements (Edwards 1991).

Nordic Sagas and archaeological studies have revealed that a Viking blacksmith, or *smið*, would have worked with wood and bone as well as iron and was considered a position of high status within the community, both physically and symbolically (Jørgensen 2012). Iron itself is also considered to have magical properties: iron horseshoes are still considered good luck in many parts of the world, and up until very recently iron and steel knives were still placed in a baby's cradle in Norway to protect against evil (ibid). Scandinavian blacksmiths in the Viking Age were also associated with the mythical dwarves or black elves (Carlisle 2013), who were described as "the mythical representatives of a profession, paralleling the craftsmen of early society, who were, indeed, endowed with ritual importance" (Motz 1993, 84).

Taking these additional statuses of the blacksmith into account, it may be suggested that seaweed could have been a source of 'release', which would transport a blacksmith to an alternate state and would thus facilitate his magical practices, such as those described in the ethnographic studies above. The presence of charred seaweed remains in the longhouse could also suggest similar 'out of mind' experiences occurring in a domestic context.

5. Conclusion: Summary of Practical Experimental Research

The aim of this dissertation was to explore why seaweed was being used at the Viking Age site of Vatnsfjörður, in northwest Iceland, specifically focusing on the potential uses of seaweed in a metalworking context during the Viking Age. Iceland was settled by Scandinavians in the late ninth century AD (Ogilvie *et al* 2000), from which point palynological records show a decrease in the amount of birch woodland and an increase in the amount of open grassland, which suggests that birch forests were being cleared to make way for grazing and hay fields (Smith 1995). However, this does not mean that woodland resources were completely depleted, as archaeological evidence from Vatnsfjörður and other Viking Age and medieval sites shows that woodlands were managed (Mooney 2013), and historical sources suggest that pockets of woodland between farms were closely managed and intensively used as late as the eighteenth century (Vésteinsson & Simpson 2004). However, if there was a plentiful supply of high-quality fuel, why was seaweed being burnt at Vatnsfjörður?

Seaweed can enter into an archaeological site through several routes. It can be used as a source of human nutrition, as it is in the modern period (MacArtain *et al* 2007), and in the Viking seaweed known as *soll* or *söl* is known to have been part of a human diet (Bell 1981). It was also used as an animal fodder in both the past and present (Byock 2001; Inergaard & Monsaas 1991; Balasse *et al* 2006; Chapman & Chapman 1980), and as a fertiliser (Blunden 1991; Booth 1966). It was also used as a fuel in cremations (Photos-Jones *et al* 2007) and as a domestic fuel up until the middle of the twentieth century (Hallsson 1961; Trbojevic *et al* 2011).

The experiments conducted in this dissertation explored the previously unanswered question of whether seaweed could have been used in a metalworking context in the past. The experiments were successful, and demonstrated several possible routes by which charred seaweed fragments could be deposited at an archaeological site. Seaweed ash could have been used as a successful fluxing agent in welding. The creation of seaweed charcoal produced a pungent liquid by-product which could be 'seaweed tar', and as such could also be a useful substance for such purposes as waterproofing timbers at the site. The forging experiments showed that seaweed could not be used as an independent fuel in industrial processes such as working metal. However, the extremely bright flame created by burning seaweed means that it could well have been intentionally chosen as a supplementary fuel in the longhouse. While this area requires further investigation using a wider range of case studies, this research suggests that seaweed could indeed have had practical significance in a metalworking context at the Viking Age site of Vatnsfjörður.

One of the most interesting and unexpected results of these experiments was that, as well as the producing a much brighter flame when seaweed was added as a supplementary fuel compared to that produced by wood burning alone, the flame colour also became tinged with purple or green on application of air from the bellows, which could have had significance and meaning in both the domestic and the metalworking context. It may also be significant that the smoke produced on burning seaweed had a strong resemblance to the smell of burning cannabis. Cannabis and other hallucinogenic and mind-altering substances such as henbane were known to have been used in the Viking Age (Price 2002), and so it is not out of the question to suggest that seaweed may also have been burnt for this purpose. This suggestion is particularly relevant when considering the mythical associations of Viking Age blacksmiths (Jørgensen 2012; Carlisle 2013), and also the ritualistic and shamanistic roles of blacksmiths in many modern African societies (Gansum 2004; Lancy 1980; Edwards 1991). Seaweed smoke may have assisted the blacksmiths at Vatnsfjörður to reach an 'alternate state of mind' which may have been a component of their power and any magical or ritual practices they were involved with, and may also have been used for a similar purpose in a domestic context.

This research raised new questions and possible interpretations about the role of seaweed as a fuel, as a possible source of tar-like substances, and as a source of hallucinogenic smoke, but further research is required to answer these questions. Future research should include chemical analysis of not only the seaweed from the coasts of Scotland and France, but also seaweed from Iceland, in order to determine whether there are any major regional differences caused by localised differences in seawater chemistry. An analysis of the seaweed smoke is also necessary in order to determine whether it could be classified as a substance with mind-altering properties, and to compare it with other known hallucinogenic substances such as cannabis and henbane. The seaweed ash samples should be analysed in order to determine their relative salt content as well as other significant details of their chemical composition, and compared with that of the basalt sand present at the beach at Vatnsfjörður, to determine which would have been the more effective flux. The 'seaweed tar' should also be analysed to determine its exact chemical composition and whether it can in fact be classified as a 'tar'. Further experiments, which would have been conducted in this research if time and practicality had allowed, would involve repeating the experimental research using seaweed samples taken directly from the Vatnsfjörður beach, as well as iron smelted from Icelandic bog iron. A more detailed exploration of other remains discovered at the site with potentially symbolic or ritualistic associations, for example other burnt materials, would provide a broader understanding of the symbolic implications of fuel use during the Viking Age.

The experimental research conducted for this dissertation has contributed new and valuable information that has enhanced the interpretation of fuel choices and metalworking practices in Viking Age Vatnsfjörður and other Norse settlements in Iceland and the North Atlantic region. This study also has many broader implications for our understanding of past resource use, particularly in terms of the selection and management of different fuel types used in the past. From first-hand observations of seaweed used as a fuel, as well as the colour and intensity of the flames it produced and the quality of its smoke, this study has demonstrated that, while it had no use as an independent fuel in a metalworking context, as a supplementary fuel in both a metalworking and domestic context it could have been meaningful and significant. Fuel remains discovered at archaeological sites should therefore be interpreted not only in terms of their functionality but also in terms of any potential symbolic uses or associations. This research has broadened our understanding not only of the possible uses of seaweed during the Viking Age, but also the potentially wide set of factors behind fuel choice in both domestic and metalworking contexts in the past.

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