JOURNAL NAME

Journal of Maritime Archaeology

NAME OF AUTHOR

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TITLE

Marine Mammal Train Oil Production Methods:

Experimental Reconstructions of Norwegian Iron Age Slab-Lined Pits

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ABSTRACT

Seal hunting and whaling have played an important part of people's livelihoods throughout prehistory as evidenced by rock carvings, remains of bones, artifacts from aquatic animals and hunting tools. This paper focuses on one of the more elusive resources relating to such activities: marine mammal blubber. Although marine blubber easily decomposes, the organic material has been documented from the Mesolithic Period onwards. Of particular interest in this article are the many structures in Northern Norway from the Iron Age and in Finland on Kökar, Åland from both the Bronze and Early Iron Ages in which these periods exhibited traits interpreted as being related to oil rendering from marine mammal blubber. The article discusses methods used in this oil production activity based on historical sources, archaeological investigations and experimental reconstruction of Iron Age slab-lined pits from Northern Norway.

KEYWORDS

Marine Mammal Oil – Slab-Lined Pits - Northern Scandinavia – Experimental Archaeology

ACKOWLEDGEMENTS

The experimental reconstructions in Kvænangen and on Vestvågøy were funded by The University of Tromsø - The Arctic University of Norway. Practical assistance was provided by North Troms Museum and Lofotr Vikingmusem. A special thanks to Captain Jan Bjørn Olav Kristiansen who provided the minke whale blubber, his boat Jan Bjørn and Flid 1 for transportation of blubber to Tromsø. The reconstructions on Iceland are thanks to the efforts of Bergsveinn Birgisson and the financial support from Menningarráð Vestfjarða and Menningarráð Vesturlands. Thanks to Lars Erik Narmo, Camilla Nordby and Bergsveinn Brigisson who participated in the fat-rendering experiments. Also a special thanks to Karin Fareth and Henric Agnè at Nordic Pharma for analyzing the fat content of the experimentally produced seal and whale oil.

MARINE MAMMAL TRAIN OIL PRODUCTION METHODS:

EXPERIMENTAL RECONSTRUCTIONS OF NORWEGIAN IRON AGE SLAB-LINED PITS

INTRODUCTION

The utilization of marine resources has great significance from the Mesolithic Period onwards as reflected in archaeological finds; e.g. kitchen middens, artifacts and personal adornments made from shells and the bones from fish and aquatic mammals. Isotopic analysis confirmed a substantial element of marine nutrition in Mesolithic diets in coastal areas (Fischer et al. 2007, Milner et al. 2004, Richards et al. 2003, Tauber 1981). There is additional significance associated with whale hunting scenes depicted on rock carvings, for example at Novaya Zalavrunga, Russia (Gjerde 2010:20).

During the Mesolithic Period onwards in which the meat, bones, hides and baleens were used from aquatic animals (e.g seals, walruses and whales), their blubber was also found to be very useful for fueling hearths as well as for rendering into oil. A substantial local train oil production is well documented on Åland in the Bronze Age (ca. 1500-400 BC) and Early Iron Age (ca. 400 BC-500 AD) and in Northern Norway in the Iron Age (ca. AD 0-1000) and Early (ca. AD 1000-1350) and High Medieval Periods (AD 1130-1350) (Henriksen 1996, Gustavsson 1980, G. Nilsen forthcoming).

The first to extract train oil in great quantities following the Northern Norwegian endeavors were the Basques who hunted whales in the Bay of Biscay from the 12th century, later moving on to the waters around Iceland and Labrador. From the beginning of the 17th century, commercial whaling also took place off the coast of Northern Norway parallel with the exploitation of the resources in the waters around Svalbard. The Basque were later followed by the British, Dutch, French and Danish-Norwegian peoples bringing the train oil production to a highly industrialized scale (see for example Dalsgård 1962, Hacquebord 1984, Jenkins 1921, Jørgensen 1994, Ross 1993, Schokkenbroek 2008).

There are obvious differences between the early Scandinavian train oil production and the later industry introduced by the Basques. The Scandinavian efforts were local and set in a context predating the establishment of national states. In contrast, the Basque were, after the initial phase, not confined to a local setting, but expanded overseas. National states had now also been formed, making it possible for kings to grant special privileges to groups to exploit certain resources. Boat technology obviously also changed through time. The Scandinavian types probably involved skin boats in the Bronze Age, open, clinker-built boats similar to the Viking ships in the Iron Age, whereas the Basque industry involved the use of *naos* and *galéons*. These differences are closely related to the actual time period the activity took place in and were under the influence of the general social organization mode and technological repertoire available.

This article will focus on the local train oil production in Scandinavia preceding the Basque train oil production, with a special focus on the Northern Norwegian Iron Age slab-lined pits. Based on the archaeological investigations, historical sources and experimental reconstructions of Norwegian slab-lined pits, the article will also discuss the methods used in this local train oil production activity.

MARINE FAT-RENDERING METHODS

Figure 1. Map of general area and sites discussed.

Marine mammal fat can be rendered into oil by employing several different methods, some of which leave few detectable archaeological traces.

One such method that is difficult to retrace in an archaeological context is the low temperature, slow-going rendering process in a seal poke (i.e. a prepared seal hide that has been sewn together in the shape of a bag) which functions as a container that can be filled with blubber. In the Inuit cultures, such as the Nunavik, filled pokes are known to hang in the sun or buried in beach gravel from weeks up to months to allow the blubber to slowly decompose and thereby rendering it into oil (Schmitt 2013: 119, Schmitt et al. 2009:14). In the *Greenland Annals* it is noted that similar pokes were used for distilling the marine mammal oil. The Norse settlers of Greenland produced "seal tar" by pouring melted seal blubber into skin sacks that were hung on drying racks in the wind, resulting in a thickening of the oil (Birgisson 2013: 348: footnote). The wear/usage studies on 12,000-year-old Hensbacka awl bits and flake axes have also been discussed as indirect evidence of the use of seal pokes (Schmitt 1998; Schmitt et al. 2009:13-14).

Other train oil production strategies are only documented on a handful of sites. There are a few examples of oil production found in clay-lined ovens, one of which was excavated at Giske, Giske Municipality, Møre og Romsdal County, Norway. The structure, dated to AD 900-1200 and AD 1050-1200, consisted of a clay-lined depression measuring 1.8 x 1.9 m. Inside the oven, layers of clay, humus, sand, charcoal, and hazelnut shells were uncovered (Halting 2012: 14-15, 22). In addition, burnt and unburnt seal bones of common and grey seal were unearthed (Bratbak & Hufthammer 2012:5).

An additional example, recorded at only three sites, is the two room/cistern method documented at Bær and Gröf in Öræfi and one structure at Kúabót, Iceland (Einarsson 2008). High levels of omega 3 fatty acids (EPA (eicosapentaenoic acid) and DHA (docosapentaenoic acid)) were found at the pre-1362 farm Bær. The elevated levels were associated with a structure consisting of a cistern and a square room connected by a narrow channel. Similar structures at Gröf and Kúabót had previously been interpreted as a sofnhus; i.e. a house used to dry grain and a sár; i.e. a large container for storing food in lactic acid. The close resemblance between the two sites and Bær led Bjarni I. Einarsson (2008) to interpret all three sites as representing local train oil production.

The above example illustrates that some train oil production methods are difficult to detect in archaeological material, while other methods seem to have a relatively small dissemination. These train oil production methods will not be discussed further. Instead, the focus will be on the methods that experienced widespread use and that are easily detectable in archaeological material due to the use of fire. The two such fat-rendering methods that seem to have had widespread use involved the following: a metal cauldron set in an oven and preheated stones added to a blubber-filled pit or chamber.

Metal cauldrons

The use of metal cauldrons, which were placed in some form of an oven, is a well- known and documented train oil production technique. As the Basque expanded further and further northwards during the 16th century they initially carried out their train oil production on land. However, the heavy hunting pressures near land pushed the hunt into open waters which resulted in moving the train oil production to the ship (Jørgensen 1994: 50, Schokkenbroek 2008:31). The land-based production took place in so-called tryworks;

> "(…) which consisted of circular ovens or fireboxes arranged in a row. The clay-lined stone tryworks formed a long rectangular structure. They were generally located parallel to the shore with the open end facing the water. Copper cauldrons of varying sizes were positioned on the fireboxes. A wooden platform used as a work area was set up behind the ovens. The tryworks were often protected from the elements by a wooden structure with a roof made of "Roman" or half-round tiles" (Lalande 1989:11).

The rendering of oil from marine mammal fat was a complicated endeavor. The Basques were considered experts and for a long period of time were hired by other North Atlantic whaling nations to perform and direct the cooking process (Jørgensen 1994:50).

Metal cauldrons (or pots) were also used by local marine-oil renderers in Scandinavia, though the vessels were smaller. The fireplace or oven used for heating the pot was less elaborate than the Basque tryworks. This method has been used in moderns times (see Figure 2) and is well-documented in historical sources. One example is Johannes Tengström's ([1747] 1989) thesis *De arte dipem phocarum coquendi in Ostrobotnia* (i.e. *The art of cooking seal oil in Ostrobothnia*) delivered at the Åbo Academy, Finland in 1747. Tengström ([1747] 1989:29) based his thesis on observations in Mustasaari, Malax and Närpes, Ostrobothnia, Finland.

Figure 2.Remains of iron pot used to melt seal blubber in the 20th century, Breiðafjörður, Iceland (photo: Gørill Nilsen).

Tengström ([1747] 1989:37-38) explained that after the hunt the blubber was cut up in very long thin slices which was done to facilitate the oil-rendering process. The next step involved pouring the sliced-up blubber into barrels to prevent fermentation but also to promote the partition of the oil from the waste products. This part of the process was called the outflow. The blubber was later put in a copper pot with water covering the bottom. Afterwards the copper pot was placed on top of a circular tile oven located at the beach. The oven had two openings, one used to feed wood to the fire, the other to let the smoke escape. It was important to make sure that there were no openings between the copper pot and the tiles so that flames could not reach the rim of the vessel.

When the fat was finished cooking, the oil was filtered into cooling vessels that were covered with boards to prevent unwanted objects from getting into the oil. The vessels were then left for one or two days to allow the oil to settle.

During this time the impurities fell to the bottom and the clear oil flooded upwards. The pure oil was then poured into a new vessel. The black, sticky residue at the bottom of the vessel, the trainfoot, was also collected and sold to tanners in the nearest town or Stockholm (Tengström ([1747] 1989:40).

Tengström ([1747] 1989:40) reported that other train oil producers used a slightly different method with less success. The seal hunters at Åland and Åbo did not cut up the blubber in small parts, but instead they used wooden sticks to beat the seal skin (which still had the blubber attached). They also used higher temperatures forcing the blubber to release the oil faster and did not cover the bottom of the vessel with water. These factors increased the fire-hazard (Tengström ([1747] 1989:41).

The techniques described by Tengström do not differ much from the procedures reported from Kökar Municipality, Åland in modern times. Kenneth Gustavsson (1980:107-108) described how the blubber was separated from the meat and skin and then cut up in decimeter-size pieces. These parts were then placed in a large iron pot. Before and after both the First and Second World Wars, the pots were often made from half of a naval mine (i.e. a self-contained explosive device placed in the water to damage or destroy ships). The pots and ovens were always located at the beach for various reasons: the blubber was difficult to handle and transport, driftwood was plentiful, and water was easily accessible if the blubber and oil caught fire.

A fire was then made underneath the pot using large amounts of wood to achieve the right temperature. The seal hunters spent time and effort maintaining the necessary temperature to keep the cooking process going. When the oil first started to ooze out, the process moved quickly as the oil rose to the surface and then was scooped out. Unrendered pieces were pushed down into the pot again. The process continued until there was no blubber left. After the cooking was completed, the unmelted remains were often discarded. The first cooking produced a raw oil that was then further distilled to achieve a better quality (Gustavsson 1980:108).

This train oil production method involving a metal cauldron (or pot) is a well-documented technique. The approach was used by the Basque and subsequent overseas whalers as well as local train oil seal producers. The method involving the use of preheated stones added to a blubber-filled basin has on the other hand been more neglected by researchers. Combining the knowledge of the train oil production method in metal cauldrons (or pots), with knowledge of the oldest technique from archaeological investigations, historical accounts and experimental reconstruction of slab-lined pits, creates a foundation for understanding the train oil production method using preheated stones.

Preheated stones in pits or production chambers

The widespread use of metal cauldrons (or pots) in oil rendering could not have been achieved before such pots were readily available. Although large metal cauldrons are known from both the Bronze and Iron Age in Scandinavia, these vessels were highly-esteemed and often involved in prestigious or religious events.

The train oil production in the Bronze and Iron Age was quite different from the later endeavours. Instead of placing the blubber in a metal vessel and heating the container from the outside, this older production technique consisted of creating a pit or chamber where blubber and heated stones were mixed. Such structures are particularly numerous in Northern Norway and Kökar municipality, Åland (Gustavsson 1980, Henriksen 1996, G. Nilsen forthcoming).

One testament to this technique are the 731 Iron Age slab-lined pits from Troms and Finnmark County, Norway that are documented in the national heritage database Askeladden. The slab-lined pits are on average 2-4 m long, 1-2 m wide and 0.3-1 m deep. The pits are sometimes marked by an outer wall while the inner walls may be lined with flat stone slabs. Zooarchaeological as well as fatty acid analysis confirms their use as marine train oil production facilities. The C14 dates reveal that the pits were in use from ca. 0 until AD 1200, with a climax at AD 600-900 (Aspenes 1996, Henriksen 1996, 2000, Henriksen & Valen 2013, Heron et al. 2010, Myrvoll 2011).

On Kökar, Åland, over 150 fire-cracked stone heaps, predominantly from the Bronze Age, are recorded. These stone packings, often having a horseshoe shape and varying from ca. 3 m to over 20 m in diameter, were located on gently sloping outcrops surrounding a natural depression in the rock. A frame of unburned larger stones were placed between the fire-cracked stone heaps and the natural depression (Gustavsson 1980, 1997:13). The structures, which date from the period 1300 BC-AD 450 (Gustavsson 1980:53-54, 84), were associated with societies with a high dependency on seals and remains of fat-rich organic material confirms that they were used to render oil from seal blubber (Gustavsson 1980, 1997:14).

The structures from Åland and Northern Norway share a set of common denominators as follows: a basin that was either constructed as a slab-lined pit dug into the sub-surface or an elevated frame constructed with large stones that functioned as a production chamber. They are associated with remains of fire-cracked stones, charcoal and remains of marine fat and mammal bones. The structures were placed on contemporaneous shorelines, and are often found in groups of several dozen structures (Gustavsson 1980, Henriksen 1996, G. Nilsen forthcoming).

These archaeological remains give indications on how the marine mammal blubber was rendered into oil. The method of using preheated stones was faster compared to the low temperature process using seal skin pokes. The presence of charcoal and charred wood indicate the use of an open fire and the large amounts of fire-cracked stones indicate that the marine mammal fat was indirectly exposed to heat by using hot stones. Analysis of organic material from Northern Norwegian slab-lined pits has also detected the presence of w-(o-alkylphenyl) alkanoic acids that are produced through prolonged heating of tri-, di- and/or monounsaturated fatty acids at 270 °C or above (Heron et al. 2010). These facts support the hypothesis that the fat was transformed to oil in a hot and rapid process.

Dr. Giles Fletcher's (1591) account from the Divina area, Russia in 1588 is a frequently sited historical account used to explain how the rendering of oil in a basin using hot stones was undertaken (see for example Äikäs 2009:152, Broadbent 2010:157, Gustavsson 1980: 74-75, Henriksen 1996: 63-64). Although the Divina area structures are much younger than those in Northern Norway and Åland, the interesting aspect with Fletcher's account is that it describes marine mammal oil production in a pit using hot stones, rather than some form of metallic cauldron, which represents a later technological step.

Fletcher (1591:9) described the activities succeeding the seal hunt on the ice in the following manner:

> "After the slaughter, when they haue killed what they can they fall to sharing euery boate his part in equall portions: and so they slay them taking from the body the skin, and the lard or fat withall that cleaueth to the skin. This they take with them, lauing the bodies behind, and so goe to shore. Where they digge pits in the ground of a fadome and an halfe deepe, or there about, and so taking the fat or larde off from the skinne they throw into the pit, and cast in among it hoat burning stones to melt it withal. The vppermost and purest is solde & vsed to oyle wooll for cloth, the grosser (that is of a red colour) they sell to make sope."

The account is quite sketchy, and especially one piece of information that may be considered to be less plausible is the size of the pit. A depth of 1.5 fathoms equals ca. 2.74 m which is a size that does not equal any known structures and may be an exaggeration (Jørgensen 1994:29, Henriksen 1996:64). However, the account describes that clean blubber, without skin, was thrown into a pit where stones with high "burning" temperature were added. As the blubber heated, it seemingly melted and boiled out in different qualities and was scooped out of the pit.

The archaeological investigations and Fletcher's account give some indications on how marine mammal oil was produced in pits or basins using preheated stones, and also indicates a technique that differed from the later technological stage involving metal pots or cauldrons. But the question remains, was the later use of metal cauldrons a development of the older techniques, or does it represent an altogether different "industry"?

TRAIN OIL PRODUCTION TECHNIQUE STAGES

Even though the use of preheated stones in a pit was used as late as 1588 in the Dvina area, and therefore contemporaneous with the Basque use of copper cauldrons in the Atlantic, there does not seem to be any relationship between the two production methods. There were no Basque whaling stations in the Bothnian Sea, however the local metal pot tradition described by Tengström ([1747] 1989) seems to resemble the earlier Basque technique (that was not in line with the older local pit/basin tradition). The stone-heaps at Kökar do not postdate ca. AD 450, so as a result there is no time overlap between the two methods used in the Bothnian Sea.

The use of preheated stones in slab-lined pits also predates the Basque and Dutch endeavours along the coasts of Northern Norway. As previously mentioned the slab-lined pits seem to date no later than AD 1200 as the latest one is documented in Vesterpollen, Nordkapp Municipality, Finnmark County, C14 dated to AD 1160-1270 (Henriksen 1996:132). Roger Jørgensen (1994:3) lists 17 commercial whaling stations between Andøya and Varanger in Northern Norway based on written evidence. At Sandholmen in Karlsøy Municipality, Troms County, archaeological remains are also documented and associated with a station built after the permission was granted by Fredrik III in 1663 (Jørgensen 1994:57, 71). According to Jørgensen (1994:36), it's unclear when the commercial whaling along the coasts of Northern Norway actually started. There are no indications of Basque endeavors in these waters before the whaling around Svalbard started in 1611, but French commercial whaling was documented in written sources from Troms as of 1614 (Jørgensen 1994:38). There is therefore a time gap between the use of the slab-lined pits and the later commercial activities.

As previously mentioned, there are obvious differences between the local pit/frame tradition and the later Basque approach. Consequently, we know little about the actual pit or fame technique. The Fletcher account gives some indication of the actual procedure, but due to its sketchy character, many problems remain unsolved.

The pits or frames did not involve metal containers, so why wouldn't the oil just simply seep into the subsurface? The risk of fire when adding red-hot stones into a blubber mass must have been a major problem. Ulla Odgaard (2001) points out that blubber may burn violently when exposed to high temperatures. If that was the case, then why wouldn't the mass of blubber and red-hot stones just create a big, hot-burning fire? Was the quality of the oil produced in pits or frames any good? Did blubber from different marine animals effect the actual train oil production methods and the quality of the train oil produced? The archaeological evidence and historical account provide significant background information, but experimental reconstructions of slab-lined pits may give new insights to the technique involved.

EXPERIMENTAL RECONSTRUCTIONS OF SLAB-LINED PITS

Information from archaeological investigations and historical sources, especially the "recipe" from Fletcher (1591), formed the knowledge base a series of experimental reconstructions were built upon. Supplemental information was also gathered from high-tech seal and copepod oil nutrient supplement producers. In these modern production lines, enzymes are used to ease the splitting of the blubber or copepod into its different components. However, the process also involves heating of the raw material to temperatures between 80-95 °C. Temperatures over 100 °C are not recommended as the oil then rapidly oxidizes and turns rancid, an undesirable outcome in the food industry. High temperatures were also stressed as a potential fire-hazard.

Based on this information, as well as the fire risk described by Odgaard (2011), the first reconstructed pit was downscaled to approximately 1/3 of an average slab-lined pit, a strategy chosen to control any involuntary combustion. The first series of train oil rendering trials was performed in a pit 1 m long, 0.5 m wide and 0.4 m deep. The depression was lined with slabs along all four walls and the bottom then stacked with birch wood.

After the wood caught fire, stones (measured at 15-20 cm in diameter) were placed on top of the fire. When the wood had burnt down, the red-hot stones and remains of charcoal were shoveled out of the pit. In the first test only 80% of the bottom of the pit was covered with a seal skin with the fur side placed in contact with the hot slabs. The remaining 20% was covered with pure blubber (without skin) to evaluate if a barrier was needed to contain the rendered oil inside the production basin. A layer of pure blubber from a full-grown harp seal was then placed inside the pit, covered with a layer of preheated stones. This layer of stones was then covered with yet another layer of pure blubber.

This first attempt was unsuccessful. The preheated stones did not raise the temperature of the blubber high enough to start the rendering process. The highest degree measured was 79 °C, which declined rapidly. The frontal flippers had been removed from the skin and blubber, creating "air vents" channeling oxygen into the mid layer which caused a blow up of the top blubber layer. Open fire also flared up, which charred the blubber surface and created a crust that prevented the oil from boiling out into the basin. The slabs along the side walls were uneven, creating small "chimneys" and fires.

The results revealed only 2 dl of oil were rendered from the 44 kg of harp seal blubber. The second test was a repetition of the first with small adjustments. The "chimneys" between the slabs and the subsurface were filled with sand and gravel so a fire could not be generated in the space between the outer walls and stone slabs. Greasy charcoal from the first test was also used to ignite the wood so that a new fire was easily started. The left-over charcoal from the first test was used as fuel to reduce the need for wood, which might also explain the reason for the greasy character of the archaeological remains. Although this fuel enabled the second test to be easily ignited, only 2.3 l of oil were rendered from 72 kg of harp seal blubber. The blubber was left in the pit overnight to see if anything would happen to it at low temperatures. No oil was registered the next day, but the blubber had attracted large quantities of flies.

The unsuccessful nature of the first two tests provided insight on how to adjust the subsequent experiment. First, covering the bottom of the pit with seal skin with the fur side facing the slabs created a good barrier between the content of the pit and the subsurface. When only pure blubber covered the bottom, it was evident that the fat had penetrated the subsurface, whereas the bottom was almost dry in the areas covered by skin. Second, the use of large pieces of blubber prevented the preheated stones to elevate the blubber temperature to levels needed to start the rendering process. Third, high temperatures were needed to get the process running.

The third test was done by lighting a fire in the pit in the same manner as in the first two runs. However, the blubber was now cut into 10 cm wide strips and two seal skins were then placed over the bottom of the pit fur side down. Even though the inside of the pit was a very hot 700 °C after the fur came in contact with the slabs, the skins could be reused three to four times before becoming too charred and stiff so that they no longer functioned as a membrane between the ground and the content of the pit.

Using strips instead of large pieces of blubber meant that the hot preheated stones rapidly sunk into the blubber mass. As a result a solid contact zone between the blubber and preheated stones was created transferring the heat from the stones to the blubber efficiently (see Figure 3). This made a critical difference from the two prior unsuccessful tests. At 80 °C, the rendering process started and when the blubber temperature rose to 130 °C the oil boiled out rapidly. As the stones cooled down, the process also slowed. When the temperature was below 70 °C the process came to a complete stop, and it was necessary to reheat the stones. Later tests confirmed that even higher blubber temperatures, 170-200 °C, resulted in a rapid, yet steady rendering process that allowed the oil to be easily scooped out of the pit (see Figure 4).

Figure 3. Strips of blubber and preheated stones in slab-lined pit reconstruction (photo: Gørill Nilsen).

Figure 4. Scooping out seal oil from pit (photo: Gørill Nilsen).

These tests also revealed an interesting factor concerning the use of hot stones. Even though a high blubber temperature is favorable, overheated red-hot stones are not advantageous, since the intense temperatures cause the blubber to catch fire. Self-combustion of the blubber seems to take place when the stones are red-hot and maintaining a temperature over 500 °C. If the stones are cooled down to under 400 °C and exhibit a white surface, then the temperature is still high enough to generate the heat for the rendering process but not hot enough to create any serious fire risk. This observation was confirmed in all the tests using seal blubber.

In the past, the oil procurers did not have temperature-reading equipment, however, as noted the shift in color of the stones became an indicator for achieving the right temperatures, an indicator that could have been used in the past. The blubber itself also gave telltale signs of optimal rendering temperatures. If a lot of steam escaped the pit; i.e. the water component in the blubber vaporizing, the temperature was high enough to have a good steady rendering process. If there was less steam, and more sound, i.e. squeaking noises, the temperature was too low. This unique element of a “talking pit” emitting high squeaks, hisses and gurgles as the temperature cooled down under 80 °C, was observed a number of times during experimental reconstructions.

The fact that the stones did not need to be heated to the maximum also meant that the stones did not crack as much as initially believed. After 35 kg of stones were heated three times, there were only a few signs to reflect this fact once the stones had cooled down. There were 12 kg that exhibited a few cracks and alligatoring, but they were still in one piece while 21 kg of the stones showed more cracking. In the archaeological material however, there are often stones cracked into small bits. This fractured condition of the archaeological material indicated that the stones had been heated and cooled down a great many times and also implied reuse of the same structure for several rendering events.

This oil-rendering technique resulted in good yields. In one test, 18 l of oil were rendered from 30 kg of harp seal blubber. In another test, 21.2 l of oil were rendered from 37.5 kg of common seal blubber. An additional 3.3 l were pressed out of the remains of common seal blubber and skin left from the initial boiling.

After successfully rendering oil in down-scaled pits, one attempt was also made in a pit close to a full-scale size, measuring 1.8 x 0.65 m and 0.2 m deep. It proved to be more difficult to produce any quantities in a larger pit due to the fact that it was harder to achieve a high enough temperature to get the rendering process going. This factor may indicate that large pits, up to 10 m in diameter documented in both Sweden and Finland interpreted as seal blubber rendering pits, may have been used for purposes other than oil production (see Äikäs 2009, Broadbent 2010:72-91, 157-159).

The blubber used in the test pits came from harp and common seals and also grey seal. The blubber from the grey seal originated from a male measuring 2 m in length and 1.8 m around the chest before butchering. The adult grey seal’s fiber-rich blubber, which was dense and compact, made it more difficult to render into oil compared to the common and harp seals’ homogenous and “loose” blubber, the grey seal’s was more dense and compact. For the first test the grey seal blubber was divided into 10-15x 20 cm-large pieces. However, because there were not enough stones in the pit, which were also too cold, it was difficult to elevate the blubber temperature above 80 °C. In the next test, the size of the blubber pieces were reduced to 2-3 x 5 cm-large pieces. In addition, both the number of stones and temperatures were both increased which resulted in a better rendering process.

The amount and character of the protein fibers in the blubber seemed to effect the rendering process. This was evident when using grey versus common and harp seal blubber and still even more pronounced when trying to render oil from minke whale blubber.

All marine blubber consists of essentially fat, protein, water and minerals, however the balance and structure differs. While harp and common seal blubber appears homogenous with no fibers and a loose quality (i.e. fat that's easy to cut with a knife), the blubber from an adult minke whale appears solid, dry and compact making it much harder to cut. The outer skin (i.e. epidermis) of the minke whale is also paper thin in contrast to the thick and fury skin of the seals used in the tests. Although both species have a very fat-rich hypodermis, the blubber from the right whale family generally has a lower blubber density, so if this species was used then the oil rendering would probably have been more similar to that of seal blubber than the minke whale blubber. It is however important to note that the thickness of the skin and fat layers differs between the species, sex and also varies on different places on the body and changes through the feeding seasons (Lockyer et al. 1984, Parry 1949).

It is clear the quality of the minke whale blubber effected the train oil production method as evidenced by using the following same procedure on both seal and minke whale blubber. After igniting birch wood, preheating stones then emptying the hot pit, the 30 x 30 cm pieces of minke whale blubber were placed on the bottom of the pit, then a layer of hot stones and 10 x 30 cm strips of blubber were added on top. However, only 1.5 l of train oil were rendered from 26 kg of blubber. Although a crusted surfaced formed on the blubber nothing else seemed to happen. A new test reducing the pieces in size to 5 x 10 cm strips still only rendered 0.5 l of train oil from 26 kg of whale blubber. The reduction of the size of the blubber pieces, an effective technique used in rendering seal blubber, did not work with the minke whale blubber and was most likely a result of the different fat structure. The hard and solid whale fat did not come in contact with the hot stones the same way as was the case with the loose seal blubber, thereby preventing a good transmitting of heat from the stones to the blubber (see Figure 5).

Figure 5. Minke whale blubber and heated stones (photo: Gørill Nilsen).

In hindsight, part of the problem with producing minke whale oil was also related to the area of the body the blubber was harvested from. In the first test, the blubber came from the ventral grooves. In a fin whale blubber study C. H. Loyker, L. C. McConnell and T. D. Waters (1984:2554) reported:

> "A problem encountered throughout the analyses was the difficulty in homogenizing blubber tissue adequately to ensure complete detection of components. The blubber proved to be an extremely tough and intractable tissue, particularly in the region of the ventral grooves."

In the second minke whale trial the blubber was harvested from the abdomen, which was still much harder and compact than the seal blubber used in tests, but looser than the blubber from the ventral grooves. However, using blubber from the back may have offered an easier rendering process as blubber from this region of the body, at least on fin whales, has proved to be thick and of lower specific gravity (Lockyer et al. 1984:2561).

Although the minke whale fat structure hampered the rendering process, water proved to be the critical factor with successfully rendering oil from minke whale blubber. The fact that water in the blubber vaporizes when heated led to the next adjustment: closing the pit. After a fire was made inside the pit, the stones were added to magazine the heat. The hot stones were then removed, but charcoal was left in the bottom ensuring high temperatures inside the structure. Covering the pit with turf to shut off the oxygen meant that the hot charcoal mixed with blubber did not represent any fire hazard. For the next trial 30.5 kg of minke whale blubber was placed on top of the charcoal. One big piece covered the entire bottom, then a layer of hot stones covered the bottom blubber layer, followed by two more layers of blubber cut up in 5 x 5 cm large pieces. Then another layer of hot stones was placed on top before finishing off with another pit-sized blubber part weighing 30 kg. Turf then topped the many layers of blubber and hot stones.

The temperature inside the structure was monitored and was stable for several hours. At closing the blubber held a temperature of 130 °C, remaining at 100 °C after six hours (see Table 1).

Time elapsing	**Temperature**
At closing point	130 °C
20 min	130 °C
35 min	130 °C
50 min	120 °C
1 h 25 min	110 °C
2 h 40 min	110 °C
3 h 5 min	110 °C
3 h 45 min	100 °C
4 h 5 min	100 °C
5 h 5 min	100 °C
6 h 5 min	100 °C

Table 1. Temperature in closed minke whale blubber pit.

When the pit was opened after six hours, it was evident that the minke whale blubber released the oil in a different manner than the seal blubber. Initially the blubber did not appear to be transformed in any substantial manner. The blubber was still in the same shap**e** as when it was placed into the pit, and little oil was observed at first look. The bottom layer of blubber was charred and crusted after direct exposure to the charcoal while the upper layers of blubber exhibited no charring or crusting. When the blubber originating from the top of the pit was removed from the production chamber, it was evident that it now had a loose character, similar to the seal blubber consistency. The oil was however still trapped in the blubber, and did not seep out until the blubber was exposed to mechanical influence, e.g, stirring. The top piece alone, which weighed 30 kg, produced 11 l of train oil.

Closing the pit meant that more water remained in the oil produced (in contrast to the water that vaporized into the air in an open pit). This also meant that an oil of lesser quality was produced in a closed pit. This observation was confirmed by a fatty acid profile performed by Nordic Pharma in the seal and minke whale oil produced in pits (see table 2).

	EPA **(**eicosapentaenoic acid)	**DHA** **(**docosapentaenoic acid)	**Total omega 3**
Harp seal oil	6,6%	8,0 %	23,75
Minke whale oil	3,4%	4,6%	13,2%

Table 2. EPA and DHA in experimentally produced seal and whale oil.

Experience from using blubber from different animals offers a general rule of thumb: the larger the species and the older the animal, the smaller the blubber pieces are needed to render train oil. There are however certain exceptions to this rule. Blubber from young animals of larger species may have been used to render oil at low temperatures. Modern whale hunters have for example placed blubber from spekkhunder (i.e. blubberdogs, young minke whales still dependent on milk) in barrels on a ship deck to transform their blubber to oil by using the sun as a heating source (pers. comm. Jan Bjørn Olav Kristiansen 2008).

Other experimental reconstructions using seal blubber have documented the efficiency of using blubber as fuel. Odgaard (2001) performed experimental trials using seal blubber as fuel in reconstructed box-shaped fireplaces from Independence I (Odgaard 2001:110-128). These fireplaces were constructed using flat stone slabs to form a box, often 40 x 40 cm. in size. These boxes were then filled with fire-cracked stones, charcoal, bones and fat (Odgaard 2001:55-58). According to Odgaard the most efficient way to stack firewood was to place the wood down in a criss-cross pattern. Then when 2.5 l of seal blubber were added to this configuration, the hearth burnt so violently that made getting close to the fire difficult. By using marine-mammal-oil-dampened moss, and adding 50 grams of seal blubber the fire continued to burn for 20-25 minutes (Odgaard 2001:120-122). Based on these tests, Odgaard (2001:124) concluded that an elevated temperature was necessary if seal blubber was going to function as a good fuel source. This conclusion was also strengthened by unsuccessful test results when starting with a cold fireplace.

Odgaard's experiments demonstrate that pure blubber works well as fire fuel. The slab-lined pit tests also revealed that the mixture of blubber and charcoal left from a previous burn also formed a solid basis for a new fire. On average 120 l of birch wood was consumed in pits of 1 x 0.5 x 0.4 m size. However, the reuse of blubber remains from previous tests indicate there was dramatic reduction in the need for wood. It would have been quite labor intensive if the only fuel used to feed the fires in the slab-lined pits was wood (see Figure 6). If for example the oil renderers got hold of a larger whale, blubber would have been plentiful and would have also been easier to cut up than wood and there would not have been a need for any additional transportation to the production site.

Figure 6. Piece of minke whale blubber as fire fuel (photo: Gørill Nilsen).

GOING FULL CIRCLE – INSIGHT FROM EXPERIMENTAL RECONSTRUCTIONS AS A BASIS FOR INTERPRETATION OF HOT-STONES RENDERING METHODS

The experimental reconstruction revealed a number of factors that influenced the understanding of the rendering process in pits or basins/frames, some of which may be attributed to the interpretation of the archaeological remains. Seal fat was rendered by adding strips of blubber and hot stones into an open pit where the bottom was covered by seal skin. Keeping the pit open allowed the possibility to reheat the stones and maintain the temperature needed to render blubber into oil. A closed pit proved to be the most efficient method when using minke whale blubber as a raw material, however, the water component in the whale blubber did not vaporize but became trapped in the closed-off structure, resulting in lower fat content in the produced oil. Although closing off the pit implied it was not possible to reheat the stones, the lid of turf and blubber contained the heat inside the production chamber, and as a result the stones did not need reheating. As a consequence, one should expect larger amounts of fire-cracked stones when dealing with an open pit.

The amount of fire-cracked stones associated with pits or frames may be an indicator of whether the blubber originated from a seal or whale. On Kökar, the societies involved in the train oil production were obviously dependent on seals (which was also substantiated by the heaps of large fire-cracked stones). The situation in Norway is more difficult to assess since both seals and whales were plentiful along the coast at the time the slab-lined pits were in use.

It is difficult to determine the exact blubber source using archaeological science for several reasons. Fatty acid analysis of material from slab-lined pits was not suitable for distinguishing species used in train oil production which makes it difficult to address this issue (Heron et al. 2010). Also DNA-analysis is probably not a useable method for assessing species in relation to a hot fat-rendering process as DNA degrades when exposed to temperatures above 50 °C which causes denaturation (Strickler et a. 2014:86).

There is however zooarchaeological material associated with slab-lined pits. Whale bones from a right whale species, most probably a North Atlantic right whale, have been found in slab-lined pits, structures S56, S5C and S9, in Fjellvika and Skjærvika, Hammerfest Municipality, Finnmark County and C14 dated to AD 650-780 and AD 680-890 (Amundsen 2009:46, Hufthammer 2013:478, Henriksen & Valen 2013:176, 195). A whale vertebra was also found in situ in a slab-lined pit at Mellaneset, Berlevåg Municipality, Finnmark County (Myrvoll 2011:89-90). Based on these findings is it possible to assess whether these probable whale blubber rendering pits display any particular features that distinguishes them from other pits, and whether the experimental reconstruction contributes to the interpretations?

An observation associated with the presence of whale bones is that the pits are all quite large. According to Jørn Henriksen (1996:51) the chambers in excavated slab-lined pits generally vary from 3.5 x 2-1.5 m down to 1.5 x 0.5 m with depths between 0.5-1 m. The largest pits in Skjærvika measured 3.6 x 2.7 x 0.65 m and 4.1 x 2.36 x 0.6 m (Henriksen & Valen 2013:191,197). The chamber at Mellaneset measured 3.8 x 1.8 m (Myrvoll 2011:90). Though these excavations only represent a few examples, they do indicate that large pits can be associated with blubber from larger animals.

Although the experimental reconstructions lead one to expect that the whale blubber pits had been closed off resulting in a lesser need for preheated stones, the archaeological remains are vague which makes the hypothesis difficult to evaluate. In Skjærvika and Fjellvika none of the excavated slab-lined pits; F3, S56, S5c, S7, S36, seem to be associated with large amounts of fire-cracked stones, though not described in any detail (Henriksen & Valen 2013:134, 176, 180, 188, 190, 197, see Figure 7). An exception seems to be S9 which was described as containing "large concentrations of charcoal, cemented blubber, ash and fire-cracked stones" (Henriksen & Valen 2013:193, my translation). The pit at Mellaneset on the other hand did contain large amounts of fire-cracked stones (see Figure 8).

Figure 7. Slab-lined pit in Skjærvika with whale bones in situ (photo: Gørill Nilsen).

Figure 8. Slab-lined pit at Mellaneset with large amounts of fire-cracked stones. The bottom of the chamber measures 3.8 x 1.8 m (Myrvoll 2011:90). (Photo: Gørill Nilsen).

There appears to be no final consensus on the use of large pits, less fire-cracked stones, possible closed pits and whale blubber rendering activities, though it seems possible that this could have been the case. The large amount of fire-cracked stones at Mellaneset supports an open pit interpretation, which indicates that whale blubber could have also been rendered into oil in open pits. Factors such as species of whale (e.g. right whale), the part of the body the blubber originated from (e.g. back) and the age of the animal (e.g. young) may have contributed to the possibility for whale fat-rendering without closing the pit.

The results from the experimental reconstructions may also shed light upon the fact that it is common to find several slab-lined pits close to one another at the same elevation above the sea. As observed during the reconstruction of the slab-lined pits, the blubber needed to be heated above 80 °C to release the oil which made it more efficient to use smaller than larger pits during the rendering process. Using residue blubber and charred wood remains also made it easier to fire up the next pit. As Odgaard (2001:124) also observed, using blubber as fuel functioned better in preheated rather than cold fireplaces. If dealing with a large amount of blubber at the same time (i.e. the result of having large animals or various-sized multiple animals) it appears that rather than increasing the size of one singular structure, the situation supported the construction of several pits placed close to one another, thereby creating a form of pre-historic production or assembly line.

If the "assembly line" interpretation has any validity, pits located close to one another must have been used synchronously. The national heritage database Askeladden has many entries describing two or more slab-lined pits being placed in a row on the same elevation above the sea. This supports an interpretation of them being of the same age, but it is not possible to determine if they represent one and the same rendering event. To support this hypothesis, there are three locations where several pits have been investigated: the six pits in Skjærvika, Hammerfest Municipality (Henriksen & Valen 2013), the ones at Tareneset, Skjervøy Municipality (Schanche 1992) and the four pits at Haugnesodden, Skjervøy Municipality (R. Nilsen 2006, 2014).

At the Skjærvika site, two pairs of slab-lined pits seem to have been in use at the same time. One pair, S36 and S9, was dated AD 150-400. The other pair, S5c and S56, was dated AD 500-900/1000 (see Figure 9). The 43 of the C14 dates made from these four structures, indicated that synchronous use of the structures at several points in time was possible (Henriksen & Valen 2013:382-387). Although only two pits were involved at the same time, based on the material from this excavation, it does imply that some form of production line process was possible.

Figure 9. Slab-lined pits at Skjærvika, S36, S 9, S7, S5c and S56. Norwegian text in figure translates to: Whalebones in grams. (Illustration: Tromsø Museum: Henriksen & Valen 2013:386).

The 11 of the 25 slab-lined pits excavated at Tareneset involved only single C14 dates from five of the pits (Schanche 1992:23-25). Pit 11 was dated to AD 230-420 and pit 13 to AD 560-660. Three of the pits, 7, 8 and 11 were dated to AD 660-780, AD 690-900 and AD 650-780 respectively. It should be noted that pits 7 and 8 were placed close to one another and their C14 dates overlapped (see Figure 10). This may also support an interpretation of a "prehistoric production line" being established at Tareneset, though not as well documented as the one in Skjærvika.

Figure 10. Pits in "production line" at Tareneset (Illustration: Tromsø Museum: Schanche 1992:23).

At Haugnesodden, three of the investigated slab-lined pits lay ca. 10 m apart, 45173-3, 45173-4 and 45173-5 (R. Nilsen 2006:18). Two of these pits, 45173-4 and 45173-5, have been C14 dated to AD 615-655 and AD 535-655 (R. Nilsen 2014:195-196) which also indicates a possible contemporaneous use.

CONCLUSIONS

The production of train oil using preheated stones that occurred on Åland in the Bronze Age (ca. 1500-400 BC) and Early Iron Age (ca. 400 BC-500 AD) and in Northern Norway in the Iron Age (ca. AD 0-1000) and Early (ca. AD 1000-1350) and High Medieval Periods (AD 1130-1350) differed from the technique the Basque employed from the early 17th century in the areas surrounding the Norwegian Sea. These two different methods did not overlap in time, therefore the knowledge of the latter method cannot be projected back in time. The oldest production methods were carried out in a pit or frame where hot stones elevated the blubber temperatures. The blubber and the indirect heat were therefore contained inside the same chamber. The latter method involved a metal cauldron filled with blubber heated from the outside over an open fire. The Basque's later endeavors with train oil production are well-documented in both historical and archaeological material, making the actual method used well known. The older methods are well documented in archaeological material, but there are no significant descriptions of how the actual rendering process took place, except for the brief one described by Fletcher in 1588.

Experimental reconstructions of slab-lined pits combined with archaeological investigations contributed to the understanding of the methods used in the Bronze and Iron Age. The tests called attention to the need for employing somewhat different methods based on the blubber source. The protein structure in larger species and older animals made it necessary to close the pit, resulting in a less fat-rich oil. Processing blubber from a smaller species and younger animals was likely performed in an open pit, which enabled the actual rendering process to be fast and hot.

The open pit also allowed vaporized water to escape the production chamber which resulted in a more fat-rich oil. Except for these differences, the production methods were the same: a bonfire was made to preheat stones, then the hot stones and blubber were put in the production chamber (at the ideal blubber temperature range ca. 80-200 °C) to enable the rendering process. Temperatures above 400 °C resulted in the blubber catching fire, and when blubber temperatures fell below 80 °C, the rendering process slowed down, stopping all together below 70 °C. This need to attain certain temperatures for a successful rendering process favored smaller pits. To have several pits set in a row was therefore probably more efficient when dealing with large amounts of blubber, instead of creating one large chamber. Locations with high density of structures associated with marine animal blubber rendering, also gives the impression of a pre-historic "assembly line" indicating an activity producing high oil yields in an era that predated the commercial activities of the Basque.

DISCLOSURE OF POTENTIAL CONFLICT OF INTEREST

The author declares that she has no conflict of interest.

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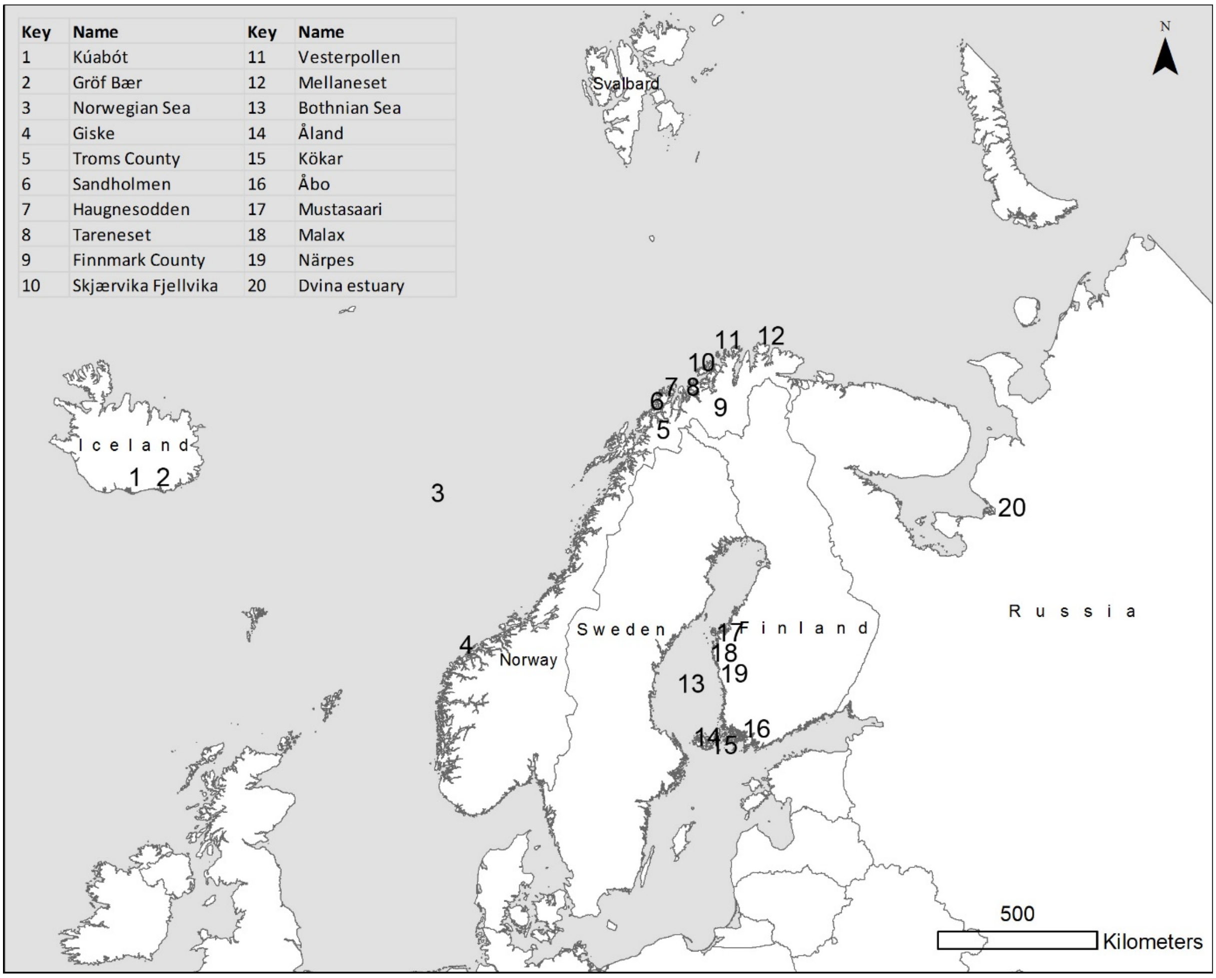

Figure 1. Map of general area and sites discussed.

Figure 2.Remains of iron pot used to melt seal blubber in the 20th century, Breiðafjörður, Iceland (photo: Gørill Nilsen).

Figure 3. Strips of blubber and preheated stones in slab-lined pit reconstruction (photo: Gørill Nilsen).

Figure 4. Scooping out seal oil from pit (photo: Gørill Nilsen).

Figure 5. Minke whale blubber and heated stones (photo: Gørill Nilsen).

Figure 6. Piece of minke whale blubber as fire fuel (photo: Gørill Nilsen).

Figure 7. Slab-lined pit in Skjærvika with whale bones in situ (photo: Gørill Nilsen).

Figure 8. Slab-lined pit at Mellaneset with large amounts of fire-cracked stones. The bottom of the chamber measures 3.8 x 1.8 m (Myrvoll 2011:90). (Photo: Gørill Nilsen).

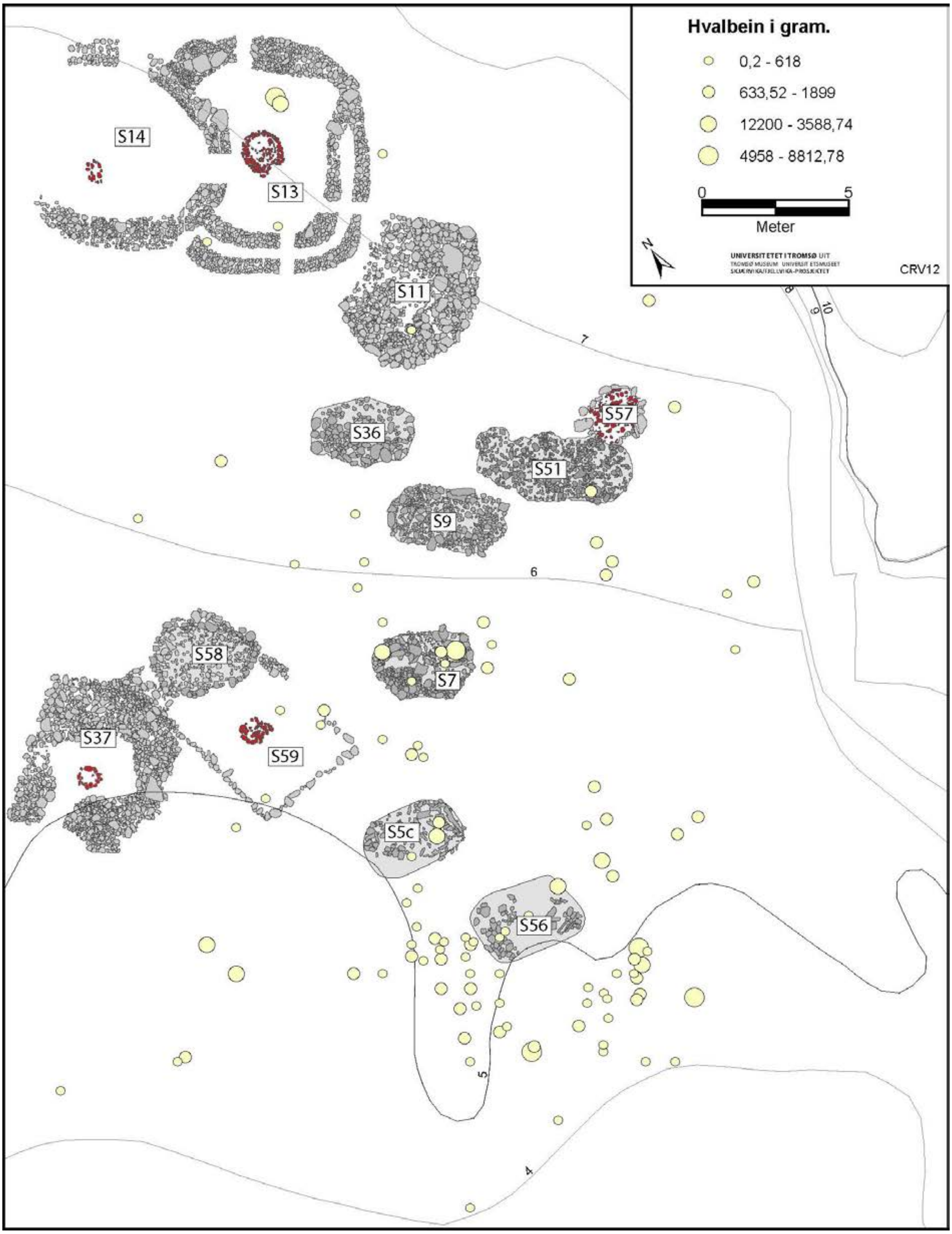

Figure 9. Slab-lined pits at Skjærvika, S36, S 9, S7, S5c and S56. Norwegian text in figure translate to: Whalebones in grams. (Illustration: Tromsø Museum: Henriksen & Valen 2013:386).

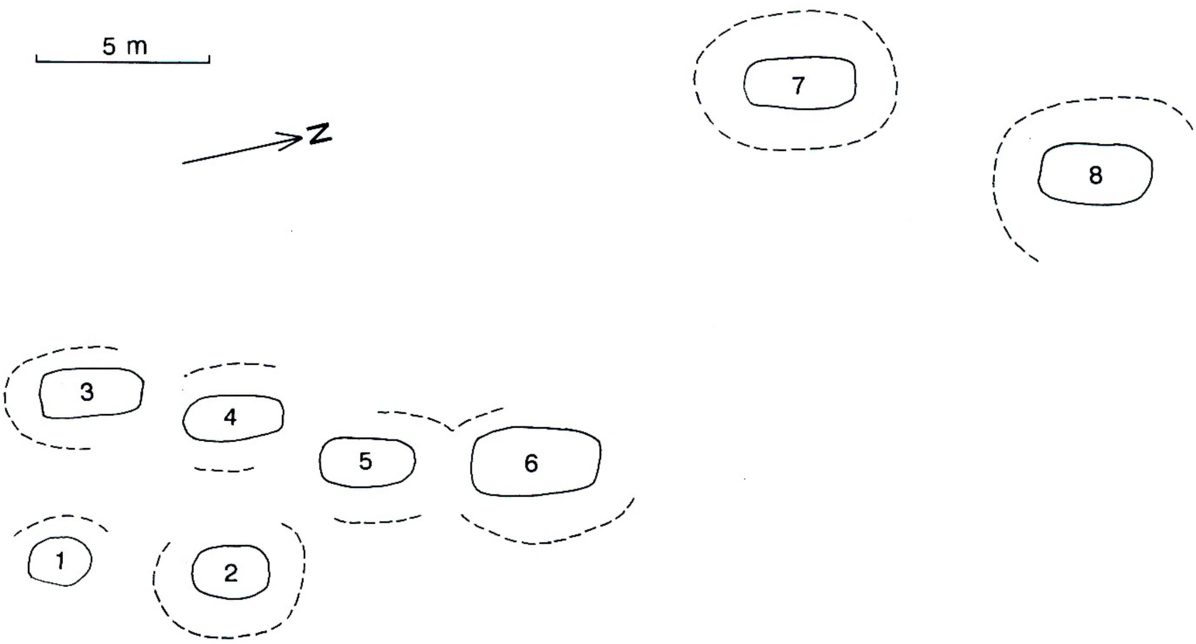

Figure 10. Pits in "production line" at Tareneset (Illustration: Tromsø Museum: Schanche 1992:23).