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Tracing Trade Routes: Examining the Cargo of the 15th-Century Skaftö Wreck

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ABSTRACTS

The Skaftö wreck of c.1440, situated north of Gothenburg, Sweden, was investigated between the years 2005 and 2009. Investigations revealed a variety of cargoes, such as copper and speiss ingots, barrels with lime and tar, bricks and roof tiles, and oak timber in the form of planks and boards. In order to identify the different cargo types found on the wreck, and, possibly, establish their geographical origin, a variety of analytical methods have been utilized. The present study accounts for the archaeological investigations of the cargo and for the analyses that have been conducted to date. Results are compared to and discussed in relation to other contemporaneous source material, both historical and archaeological. Based on this examination, it is concluded that the vessel was heading from the southeastern corner of the Baltic Sea, most likely Danzig (Gdańsk), aiming for the Western European market, possibly Bruges.

KEYWORDS

Trade routes; bulk goods; copper *Reißeisbeiben*; timber trade; Northern Europe; Late Middle Ages

Rastreo de rutas comerciales: análisis de la carga del pecio Skaftö del siglo XV

El pecio Skaftö (c. 1440), localizado al norte de Gotemburgo, Suecia, fue investigado entre los años 2005 y 2009. Las investigaciones revelaron una carga variada, compuesta por lingotes de cobre y aleaciones de metales pesados; barriles con cal y alquitrán; ladrillos, tejas y tablas de roble. Con el propósito de identificar los diferentes tipos de carga hallados en el pecio y establecer su posible origen geográfico, se aplicaron diferentes métodos analíticos. El presente estudio presenta la investigación arqueológica de la carga y los análisis que se han llevado a cabo hasta la fecha. Los resultados se comparan y discuten en relación con otros materiales arqueológicos e históricos contemporáneos de las fuentes de procedencia. Con base en los análisis, se concluye que la nave viajaba del sureste del Mar Báltico, posiblemente desde Danzig (Gdańsk) – actual territorio polaco –, con el propósito de comerciar en Europa Occidental, posiblemente en Brujas – actual territorio belga.

追寻贸易路线: 15世纪斯卡夫特沉船船货研究

2005年至2009年对瑞典哥德堡北部的c.1440斯卡夫特沉船的调查发现各式船货,例如铜锭和黄渣锭、装有石灰和焦油的桶、砖与屋瓦,以及木板和橡木板。多种分析方法被用于鉴别沉船上发现的不同类型的货物及确定它们可能的地理来源上。本研究说明了对船货的考古调查及到目前为止所做进行的分析,并将结果与其他同时代的历史和考古资料进行比较和探讨。基于此研究,可以得出结论,即该船是从波罗的海东南角出发,极有可能是但泽(格但斯克),其目标是前往西欧市场,可能的目的地是布鲁日。

追尋貿易路線: 15世紀斯卡夫特沉船船貨研究

2005年至2009年對瑞典哥德堡北部的c.1440斯卡夫特沉船的調查發現了各式船貨,例如銅錠和黃渣錠、裝有石灰和焦油的桶、磚與屋瓦,以及木板和橡木板。多種分析方法被用於鑒別沈船上發現的不同類型的貨物及確定它們可能的地理來源上。本研究說明了對船貨的考古調查及到目前為止所做進行的分析,並將結果與其他同時代的歷史和考古資料進行比較和探討。基於此研究,可以得出結論,即該船是從波羅的海東南角出發,極有可能是但澤(格但斯克),其目標是前往西歐市場,可能的目的地是布魯日。

إقتفاء أثر طرق التجارة: فحص حمولة حطام سفينة القرن الخامس عشر سكاftو

في الفترة بين عامي ٢٠٠٥ و ٢٠٠٩ تمت أعمال البحث والتحقيق في حطام سفينة سكاftو الواقعة شمال جوتنبرج بالسويد والتي تعود إلى عام ١٤٤٠. ولقد كشفت أعمال البحث والتحقيق عن بضائع متنوعة من حمولة السفينة مثل سبائك النحاس والسيبوس وبراميل الجير والقطران والطوب وبلاط الأسقف وخشب البلوط الذي كان على شكل ألواح. تم استخدام مجموعة متنوعة من الأساليب التحليلية وذلك من أجل تحديد أنواع البضائع المختلفة المتواجدة في حمولة حطام السفينة وربما تحديد منشأها الجغرافي أيضاً. تتناول الدراسة الحالية التحقيقات الأثرية للبضائع والتحليلات التي تم إجراؤها حتى الآن. وتمت مقارنة النتائج ومناقشتها فيما يتعلق بمصادر أخرى معاصرة تاريخية وأثرية على حد سواء. وبناء على هذا الفحص تم التوصل إلى استنتاج يفيد بأن السفينة كانت متجهة من الركن الجنوبي الشرقي لبحر البلطيق الذي من المرجح أن يكون دانزيغ (غدانسك) هادفة إلى الوصول إلى سوق أوروبا الغربي وربما بروج.

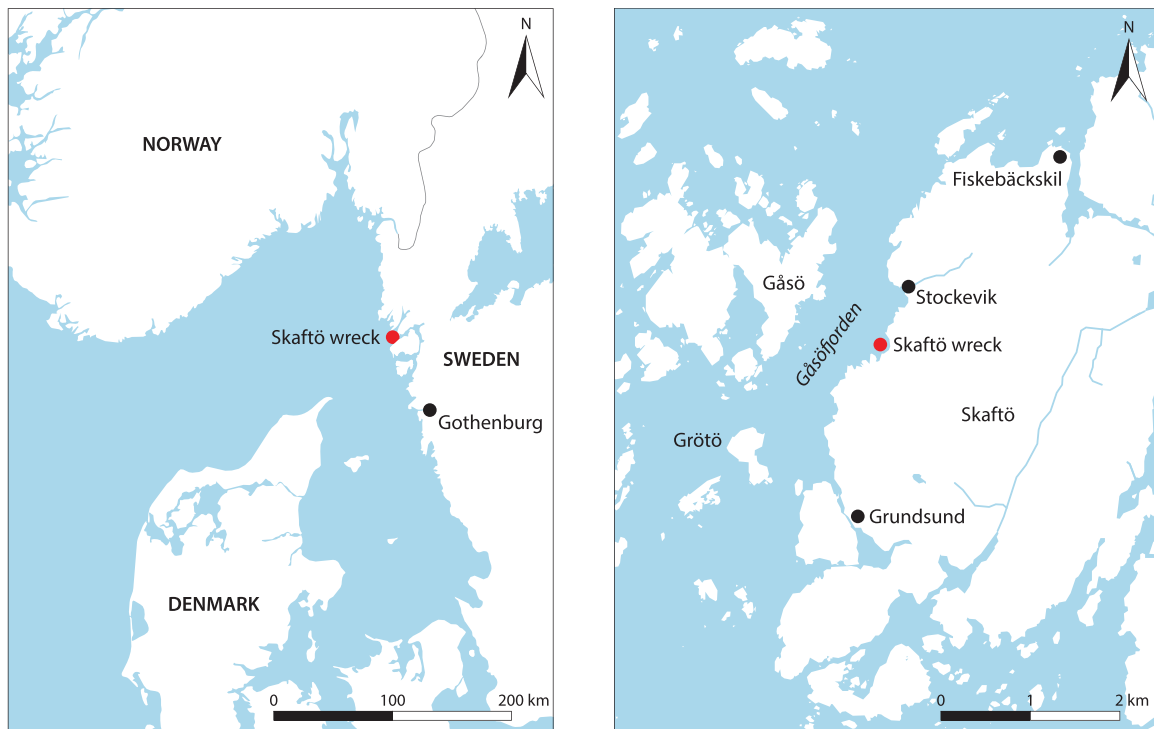


Figure 1. A: Map showing the location of the Skaftö wreck. B: The wreck site in relation to the island Skaftö and other geographical features mentioned (Anders Gutehall, Visuell Arkeologi).

Introduction

Nearly 600 years ago, a heavily loaded merchant ship foundered off the island of Skaftö, situated approximately 70 km north of present-day Gothenburg on the now-Swedish west coast, which at that time was part of Norway. The vessel came to rest in less than 10 m of water, close to the shore, in a relatively sheltered strait (Figure 1). It remained hidden until the summer of 2003, when it was accidentally discovered by a local skin diver. Later that year, maritime archaeologists from Bohusläns Museum in Uddevalla conducted a diving inspection of the wreck site. Among the most notable features observed were a large number of copper ingots in the form of round and oval slabs. Other cargoes noted during inspection were barrels containing what was thought to be lime and tar.

A suggested medieval date for the vessel was confirmed in 2004 by means of dendrochronology. Analysis concluded that the ship was likely built in the late 1430s of timber originating in present-day Poland (Linderson, 2004). Following a minor test excavation in 2005, a bigger research project was initiated in 2006 by the corresponding author. Further field campaigns were carried out in 2006, 2008 and, finally, in 2009 (von Arbin, 2010, 2014). Investigations revealed that the ship lies flat on the sea floor, resting on its starboard side, with substantial parts of the stem, sternpost, keel and rudder intact. Of the starboard side, approximately 70% survives. The port side has almost entirely vanished, with the exception of a smaller portion in the lower after section of the

vessel (Figure 2). The reason for the starboard side being so well preserved is the massive load of cargo, which has effectively prevented the access of different wood decaying organisms.

Despite the fact that only about 20 m² of the site, or less than 15%, has been subject to excavation, investigations have yielded a wealth of information regarding the technical features and general design of the vessel. With an estimated overall length of c.25 m, a height around 6 m, a beam of 8 m or more, and, possibly, two full decks, the ship must have been fairly big. In a number of previous articles, the corresponding author has suggested that it may be a representative of the so-called ‘hulk’ – a ship-type whose features have long been disputed by maritime archaeologists and historians (see discussions in von Arbin, 2012, 2013, 2014 with references). Moreover, parallels have been drawn to the wrecks of other big clinker-built vessels of similar construction, size, age and origin, in particular the Skjernøysund 3 (Auer & Maarleveld, 2013), Bøle (Daly & Nymoen, 2008) and Avaldsnes (Alopaeus & Elvestad, 2004) shipwrecks in Norway, and the so-called Copper Ship, also known as W-5, in Poland (Ossowski, 2014a).

The present study, however, does not primarily target constructional issues. Instead, the focus will be on the different cargoes, their likely origins and handling, with the ultimate aim to try to model the intended original sailing route of the vessel. The medieval shipwrecks that have been found and investigated in Northern Europe to this day often constitute



Figure 2. Skaftö wreck site plan (Anders Gutehall, Visuell Arkeologi).

discarded and partially dismantled vessels. Typically, they have been stripped of cargo, equipment and personal belongings (e.g. Åkerlund, 1951; Bill, 1997,

pp. 113–116; Hansson, 1960; Varenius, 1982). This is obviously not the case with the Skaftö wreck. Since the vessel sank fully loaded *en route* between two

ports, it offers a rare opportunity to obtain detailed information on the cargo by means of various analytical methods. While the study relies largely on the results of scientific analyses, written sources and contemporaneous archaeological evidence are equally important. We hope that this cross-disciplinary approach will contribute to a wider understanding of

the trading of bulk goods in Northern Europe during the late medieval period.

Cargo Types Identified on the Wreck

A number of different cargoes have been identified on the wreck, namely two different types of metal

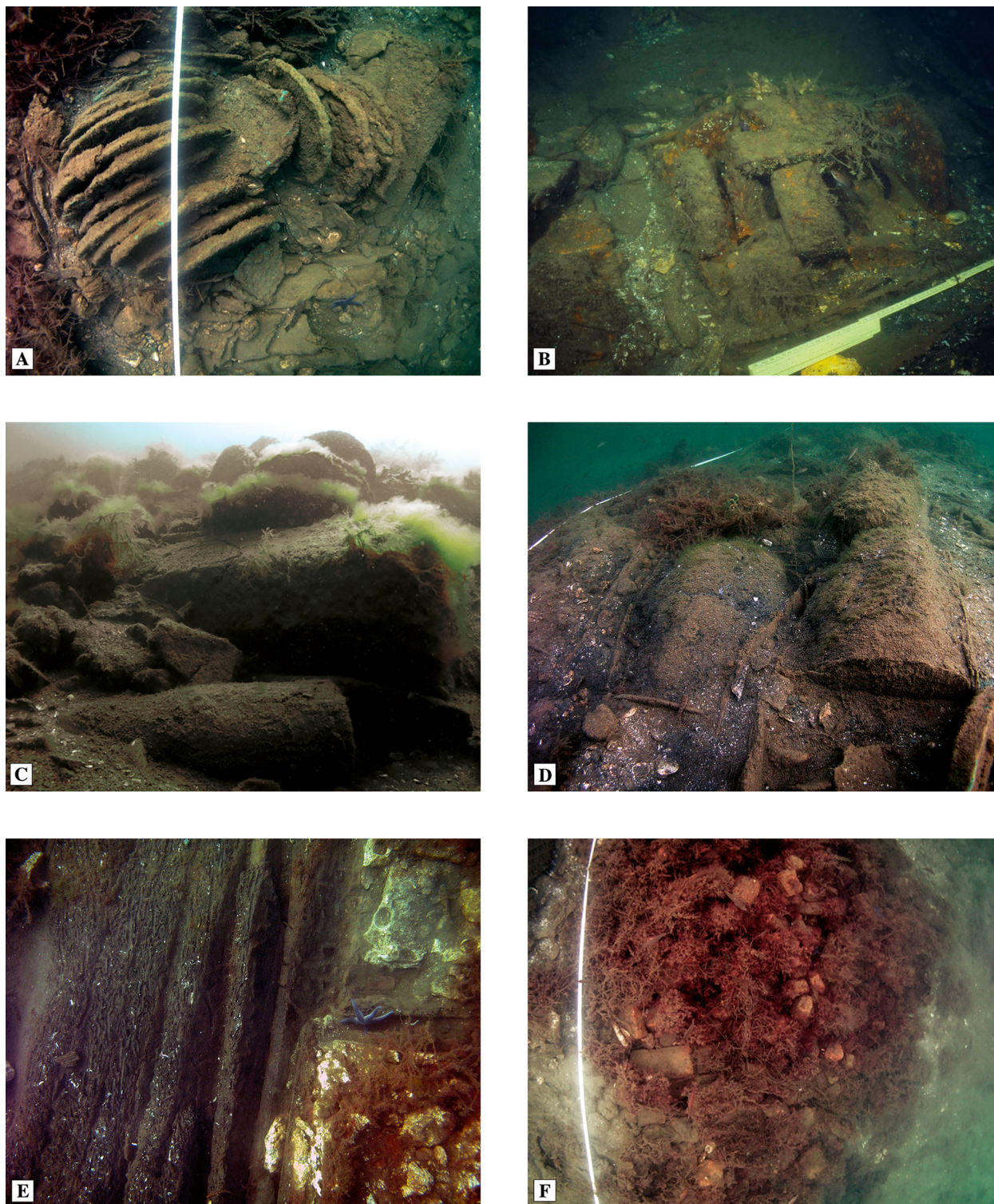


Figure 3. The different cargoes of the Skaftö wreck. A: The smaller assemblage of copper ingots. B: One of the assemblages of speiss ingots. C: One of the many lime barrels where the barrel has degraded while the content has remained more or less intact. D: Three exposed tar barrels. Behind them is a lime barrel, and in the foreground on the right hand side is a copper ingot. E: A portion of the timber cargo in test Trench 1. On the right hand side are two lime barrels. F: Brick and roof tile assemblage (A, C, D, E and F: Jens Lindström, Bohusläns Museum; B: Staffan von Arbin, Bohusläns Museum).

ingots, lime, tar, timber, bricks and roof tiles (Figures 2 and 3). To a diver, the many round and oval copper ingots, revealed by their bright green colour, probably constitute the most distinguishing feature of the wreck site (Figure 3a). Within the hull structure, ingots seem to be distributed in two major assemblages: a larger one deep in the hold of the stern area, consisting of approximately 70 fully or partially exposed ingots, and a smaller one amidships, containing at least 30 ingots that must have been stowed either on, or, perhaps more likely, immediately beneath the main deck. A further ingot, possibly deriving from the smaller assemblage, was found isolated on the seabed, just outside the hull. In the following account, the above ingots will be termed as *Type 1*-ingots.

The ingots vary significantly in size. The largest round ingot retrieved during fieldwork measured 45 cm in diameter. It had a thickness of between 1.5 and 4 cm and weighed just over 11 kg. The largest oval specimen measured 69×41×6.5 cm and weighed 56.6 kg. Based on visible ingots and recovered specimens, their total weight has been estimated to be somewhere between 1.5 and 3.5 tons, however most likely around 3 tons. This rough estimation should be treated with caution though, since more ingots may be buried deeper down in the sediment.

Apparently, ingots of approximately the same size and shape have been stacked together. The larger assemblage contains six or possibly seven discernible stacks, while the smaller one contains three. The number of visible ingots in each stack varies between approximately three and 12. No traces of containers of any sort have been observed, and neither are there any evidence of rope or wicker being used for keeping the stacks together. It is possible, though, that pine planks observed in the immediate vicinity of the largest assemblage were used as dunnage.

In addition to copper, there is a smaller number of irregularly shaped ingots, which initially were believed to consist of iron (Figure 3b). A simple check with a regular magnet, however, showed that they are only slightly magnetic. In the following, these ingots will be referred to as *Type 2*-ingots. Like the copper ingots, they are distributed in more or less well-defined assemblages. One such assemblage is located in the bottom of the hold, just before the large assemblage of *Type 1*-ingots. Another one is located amidships. Here, ingots appear to have been stored either on, or more probably, just beneath the main deck. A third assemblage was discovered in the foremost trench (Trench 1, Squares R1–R2), close to the bow. These ingots range in size from c.10×10×5 cm up to c.45×30×5 cm, but there are also much smaller, pebble-sized lumps. Barrel parts found in conjunction with ingots indicate that they were originally packed in barrels that subsequently disintegrated.

In terms of volume, the main cargo of the vessel was most certainly lime, as evidenced by the significant number of lime-filled barrels. Such barrels have been recorded in most of the hold (Figure 3c). Since many of them have partially disintegrated, scattered lumps of lime are distributed over an even larger area. There seem to be several different barrel sizes, but due to degradation, measurements are generally very unsure. However, recovered barrel staves and barrel heads from Trench 2, located in the after part of the vessel, suggest that the largest and most common type of barrel may have held just over 90 l. When filled, each of these barrels must have weighed more than 300 kg. Tar also likely constituted a significant part of the cargo. Tar barrels seem to be mainly distributed in the after section of the vessel (Figure 3d). They are estimated to have contained approximately 80 l each. As can be seen on the site plan (Figure 2), barrels were mainly placed horizontally, with their ends facing towards the ends of the ship.

Oak timber, in the form of planks and boards, was mainly carried in the bottom of the hold, stacked lengthwise on top of the mast-step buttresses. Spaces between buttresses were filled with shorter boards, placed crosswise. The preserved timber stock measures approximately 1 m in height. In addition there is what appears to be a smaller concentration of crosswise stacked boards higher up in the hold, just before amidships. These boards are placed on top of the lime barrels, in close conjunction with one of the cross-beams. Altogether, it appears as if the volume of timber carried on board must have been quite substantial (Figure 3e). Partially exposed timbers are heavily degraded due to wood borer attack. Still, two distinct groups of timber can be identified in this material. *Group 1* consists of boards with a presumed original length of around 85 cm. Widths vary from c.15 to c.17 cm and maximum thickness is 2 cm. *Group 2* consists of planks with presumed lengths exceeding 1.37 m. Here, widths vary between 23 and c.30 cm, and thicknesses between 3 and 6 cm.

Bricks and roof tiles are assembled in the northwestern part of the wreck, that is, abaft the centre of the vessel (Figure 3f). The total number of bricks could be estimated to perhaps a few hundred, whereas tiles occur more sporadically. From their location on the site, one gets the impression that they must have been stored, if not on the main deck, high up in the hold. Bricks typically measure around 29.5 × 14 × 7.5 cm and recovered specimens weigh approximately 5 kg each. Some of them are broken, or, possibly, cut, in halves. Roof tiles are of the 'Monk and Nun' type. None of the tiles observed on the wreck are preserved for their entire length. The best preserved retrieved specimen is 31.5 cm long. It is slightly tapering towards one end, and widths thus vary between 11.5 and 13.7 cm. Bricks and tiles are all made of red-burning clays.

Analysis Results

Metal Ingots

Introduction

Already in 2007, analysis of three ingots of each type were carried out using scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy, abbreviated SEM-EDS (Grandin, 2009). While SEM metallographic analysis can provide information regarding the production process, EDS-analysis is restricted to point analysis. This might result in a chemical composition that is not representative for the whole ingot. Another problem is the low penetration depth of the electron beam, which may result in a composition that is more representative of the surface than the interior of the ingot.

For this reason, inductively coupled plasma mass spectrometry (ICP-MS) was carried out as part of the present study. High resolution ICP-MS has the advantage of being able to measure the relevant elements down to 1 part per million (ppm). Nearly all elements of the periodic table can be analysed, although silver, tin, antimony, tellurium, lead, bismuth, phosphor, sulphur, iron, cobalt, nickel, zinc, arsenic and selenium are particularly useful in this

case. ICP-MS is thus currently the best choice for determining chemical composition. Additionally, it can be used to determine lead isotope ratios, which can provide provenance information for the ore. In this case, trace elemental data were obtained at the Laboratory for material sciences of the German Mining Museum, Bochum, while isotopes were measured at the Frankfurt Isotope and Element Research Center (FIERCE), Goethe University, Frankfurt am Main.

Type 1-Ingots

Type of Metal. Judging by their physical appearance, especially their discoid form and blistered surface, Type 1-ingots can be identified as so called *Reißscheiben*. This type of ingots – *Reißscheiben* literary meaning ‘ripped-out discs’, referring to the production technique (Figure 4), represent late medieval to early modern standard copper smelting operations (Weisgerber, 1999, p. 296; Zedler, 1742, p. 95). They have been found on a number of Northern European sites, dating from the early 15th to the late 17th century/early 18th century (for overviews, see Ossowski, 2014b, pp. 246–247; Werson, 2015, pp. 84–89; cf. Martín-Torres et al., 2020).

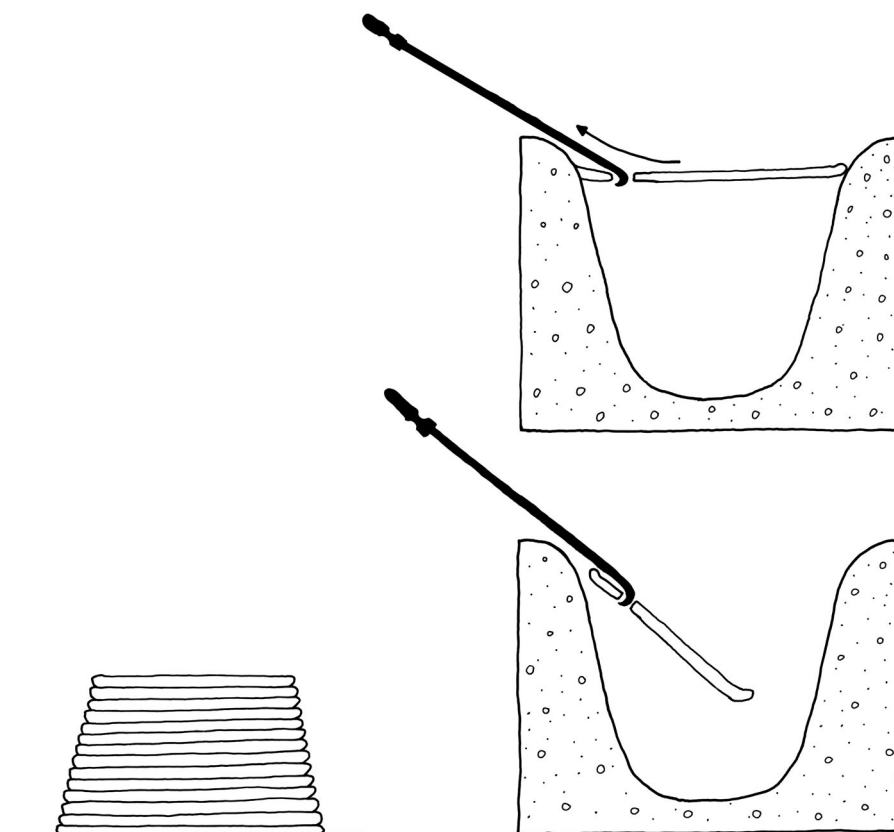


Figure 4. The process of producing *Reißscheiben*, as described by Georgius Agricola in 1556 (Agricola, 1556/1950). Melted copper is poured in a crucible or, which is likely the case with the Skaftö ingots, a dug out hole in the ground. Water is then sprayed on the surface of the molten copper in order to solidify the metal. Immediately afterwards, the copper ingots are being pulled out using an iron hook. This is repeated until there is no liquid metal left. Depending on the shape of the crucible/hole, the *Reißscheiben* will get gradually smaller in diameter during the process (Anette Olsson, Bohusläns Museum).

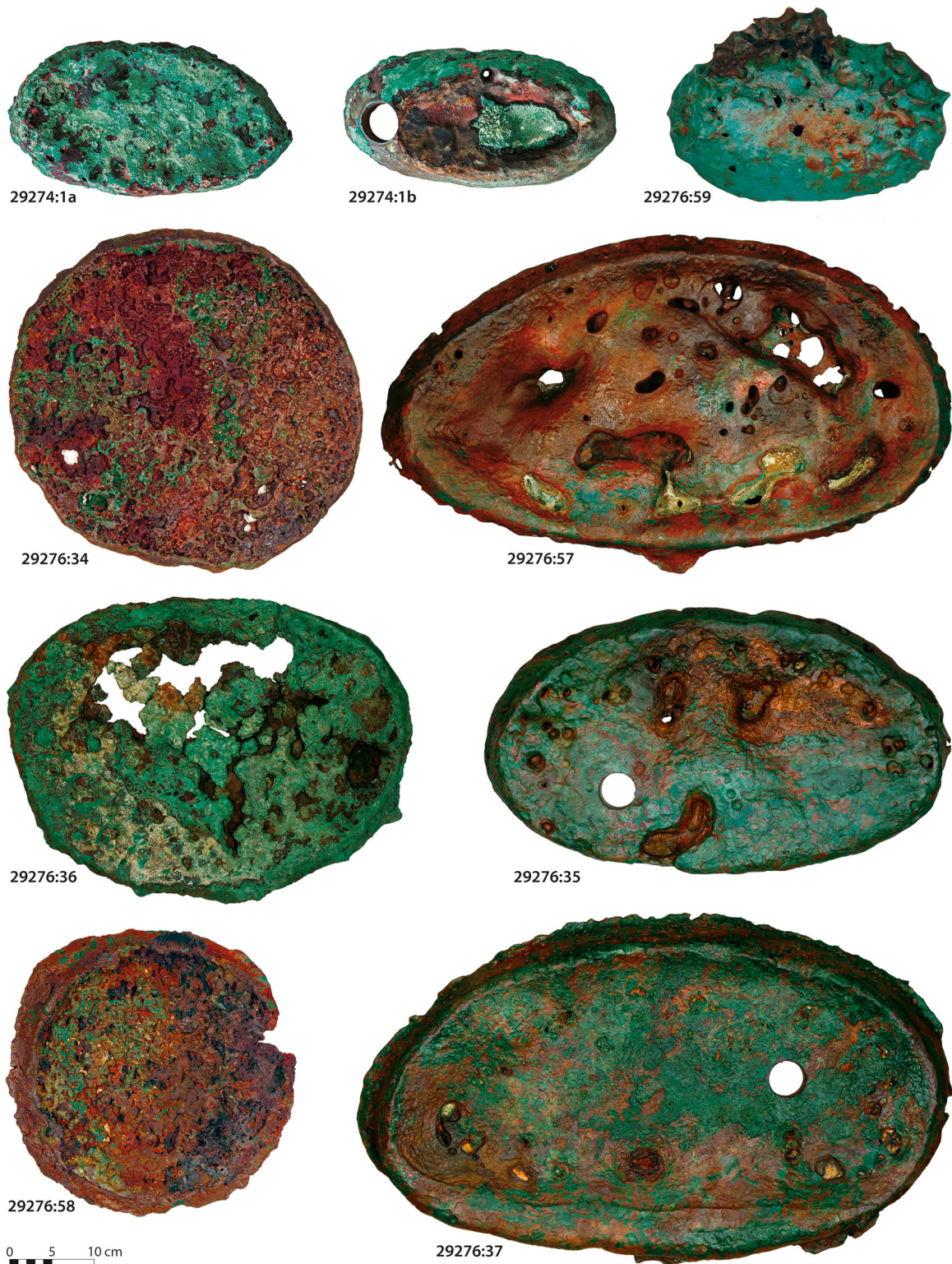


Figure 5. All of the recovered copper (Type 1) ingots from the Skaftö wreck. Samples from all ingots have been analysed as part of the present study. The round holes that can be seen in inventory Nos. 29274:1b, 29276:35 and 29276:37 are from previous sampling in 2007 (Cecilia Ahlsén, Bohusläns Museum).

All the Type 1-ingots retrieved from the wreck, nine specimens in total, were sampled and analysed (Figure 5). The results reveal those nine ingots to be chemically inhomogeneous, as five of them have significantly different trace elemental composition than the other four. These two groups will hereafter be referred to as *Type 1a* and *Type 1b*, respectively. Type 1a has noticeable higher amounts of impurities

like tin, sulphur, zinc and selenium, while being significantly lower in nickel, antimony and arsenic. Antimony ranges up to unusually high amounts in Type 1b-ingots (Table 1, Figure 6).

The existence of two chemically distinct groups of *Reißscheiben* could also be recognized on the contemporary Mönchgut 92 shipwreck, discovered in the proximity of Rügen, Germany (Werson, 2015), but

Table 1. Chemical composition of the analysed ingots as measured by means of ICP-MS.

Inventory No.	Type	Cu weight-%	ppm Ag	ppm Sn	ppm Sb	ppm Te	ppm Pb	ppm Bi	ppm P	ppm S	ppm Fe	ppm Co	ppm Ni	ppm Zn	ppm As	ppm Se
29276.57	1a	98	900	200	2640	4.3	9200	220	14	1640	480	200	320	910	3600	18
29276.58	1a	97	790	45	2050	3.3	1300	280	2.3	1000	64	15	220	32	3900	25
29276.36	1a	98	760	38	5410	3.3	1300	300	3.9	870	72	14	270	30	4800	21
29276.34	1a	99	570	23	6050	14	700	470	11	640	75	13	290	37	3500	13
29274.1a	1b	96	900	9	41000	5.1	150	440	5.0	530	100	<0.5	930	12	8600	<5
29274.1b	1b	97	1200	10	50500	5.3	700	110	1.7	260	80	1.1	760	18	12400	<5
29286.35	1b	95	820	12	69600	7.8	250	550	1.4	120	31	<0.5	860	25	8700	<5
29276.37	1b	96	640	10	76000	6.0	890	46	3.0	120	31	<0.5	1300	31	16300	<5
29276.59	1b	96	920	9	45100	3.3	2700	180	5.4	350	170	1.3	760	16	15300	<5
29276.39	2	29	140	560	30700	4.9	71900	20	160	29000	328000	15500	54100	33	144000	<5
29276.38	2	25	400	1350	39400	5.8	70800	110	110	20300	253000	27500	17600	150	124000	<5
29276.1	2	22	160	610	39200	3.9	61100	31	47	75800	246000	26800	128000	36	187000	<5

All values are given in parts per million (ppm) except for copper, which is given in weight percent (wt%).

was not fully understood at the time. Interestingly, two types of *Reißscheiben* were also present in the Copper Ship, which foundered in Gdańsk Bay, according to recent analyses (Garbacz-Klemka et al., 2014). It remains uncertain if chemical patterns observed in the Skaftö material resemble those derived from the Copper Ship *Reißscheiben*, as it appears as only semi-quantitative methods (SEM-EDS) were applied in the latter case. At present, however, it seems as the Skaftö copper does not compare chemically with any other known 15th century *Reißscheiben* finds (cf. Skowronek et al., 2021).

The process of producing copper out of sulfidic ores during this period, as described by Suhling (1990, pp. 50–56), required different stages of roasting, smelting and refining with the major goal of separating sulphides from the copper. As a final step, copper ingots were refined in an open oven called a *Garherd* (Rößler, 1700/1980, p. 147). Here, two types of ingots were fabricated: one sort for casting (*Garkupfer*), and another one for forging (*Hammergarkupfer*) (Suhling, 1990, p. 55). On the Venetian market, these two copper sorts occur already in the 14th century as *rame duro* (hard copper) and *rame dolce* (sweet [malleable] copper), respectively (Braunstein, 1977, p. 79).

In order to be malleable, the copper has to be as pure as possible. Therefore, the copper intended as *rame dolce* was kept much longer in the oven (Suhling, 1990, p. 55). However, it appears that the smelters of the Skaftö *Reißscheiben* did not have much experience with this production. While they managed to reduce sulphur, tin and zinc, the amounts of arsenic and antimony rose to a point where the copper would have been unsuitable for any forging, as it would get brittle and too hard (cf. Gowland, 1914, p. 53). Probably they neglected the roasting process of the ore, which is especially important if arsenic and antimony bearing Fahlores are present. Once alloyed with copper, arsenic and antimony are difficult to remove (McKerrell & Tylecote, 1972) and thus require roasting prior to smelting.

Therefore, Type 1b-ingots likely represent a failed attempt to produce a purified copper sort out of Type 1a-ingots. The proper process, later to be named ‘Deutscher Kupferprozess’ (German copper process) (Suhling, 1990, p. 53), does not seem to have been mastered at the time. In the mid-16th century Georgius Agricola (1556/1950, p. 538) points out that ‘If the copper is not perfectly smelted the cakes will be too thick, and cannot be taken out of the crucible easily’. Compared to other *Reißscheiben* finds, such as the ones from Heligoland (Stühmer et al., 1978, p. 16), Wiltshire (Martinón-Torres et al., 2020, p. 39) or the Elbe (Althoff, 1995, pp. 41–42), the Skaftö *Reißscheiben* appear to be much thicker, which further supports the conclusion regarding improper smelting operations.

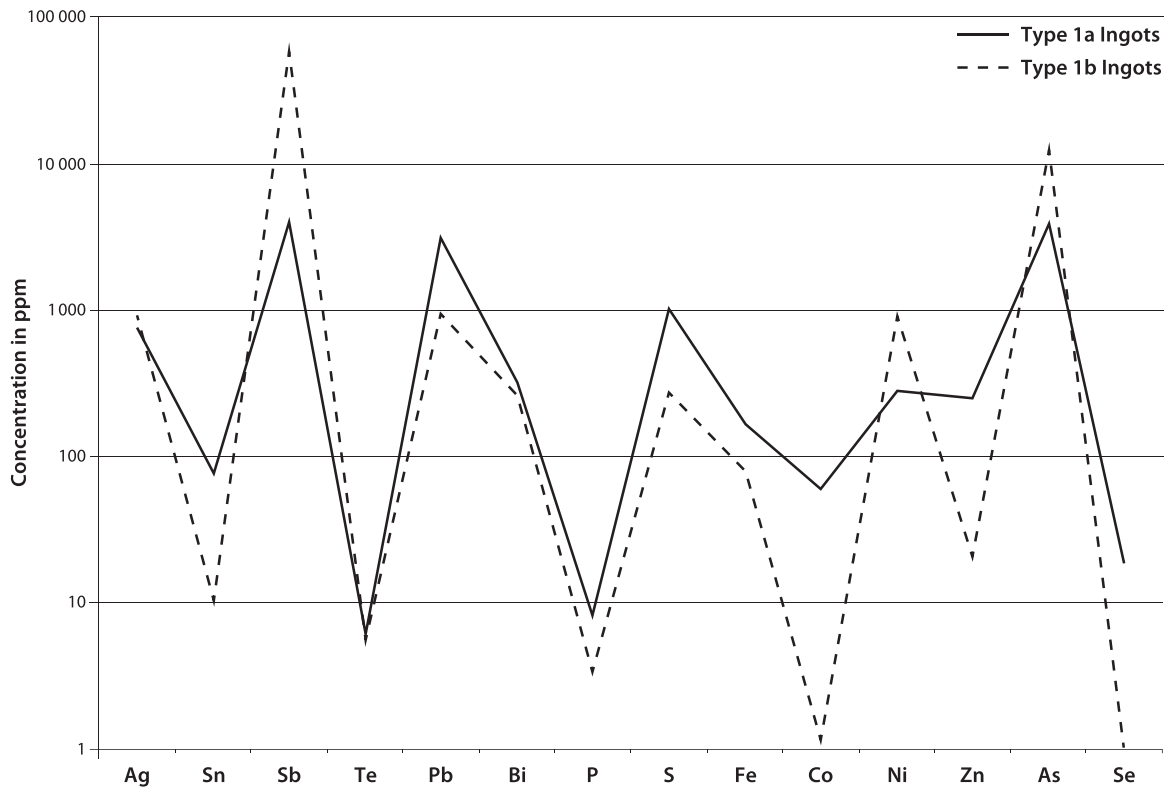


Figure 6. Mean trace elemental composition of the two types of copper ingots, with Type 1a $n = 4$ and Type 1b $n = 5$. While Type 1a ingots have higher amounts of impurities like tin (Sn), lead (Pb), sulphur (S) and zinc (Zn), amounts of arsenic (As), nickel (Ni) and antimony (Sb) are notably lower. It seems that some sort of refinement process lowered the amounts of rather volatile elements on the one hand but enriched those elements that are difficult to remove after smelting on the other hand. The high amounts of As and Sb in both types of copper ingots indicates the use of Fahlores (Tobias Skowronek).

From analysis, it appears that the Type 1a-ingots are mainly from the smaller assemblage, located amidships, while all of the analysed Type 1b-ingots derive from the large copper assemblage, which is located in the stern area (Figure 2). At first glance, it would thus seem that the two copper qualities were kept separated during transport. There is, however, one exception from this pattern. One of the analysed ingots, inventory No. 29276:57, which, according to the analysis, could be identified as a Type 1a-ingot (Table 1, Figure 5), was found in the larger assemblage, together with ingots similar in size and shape. For two of the other ingots, inventory Nos. 29274:1a and 29274:1b (both Type 1-ingots), their original positions are not known

since they were salvaged without prior documentation in conjunction with the discovery of the shipwreck in 2003.

Provenance. The lead isotope ratios are presented in Table 2. Type 1-ingots show some data spreading, as they range from $^{206}\text{Pb}/^{204}\text{Pb} = 18.07\text{--}18.41$ and $^{207}\text{Pb}/^{204}\text{Pb} = 15.645\text{--}15.656$, respectively. The isotope ratios form significant cluster groups. All the Type 1a- and one of the Type 1b-ingots (inventory S6:59) derive from ore deposits older than 400 Ma, indicating pre-Variscan orogeny. The remaining four Type 1b-ingots exhibit significant higher lead isotope ratios, thus deriving from genetically younger ores formed during Variscan orogeny (Figure 7).

Table 2. Lead isotope ratios of the analysed ingots as measured by means of ICP-MS.

Inventory No.	Type	$^{206}\text{Pb}/^{204}\text{Pb}$	2SD	$^{207}\text{Pb}/^{204}\text{Pb}$	2SD	$^{208}\text{Pb}/^{204}\text{Pb}$	2SD	$^{207}\text{Pb}/^{206}\text{Pb}$	2SD	$^{208}\text{Pb}/^{206}\text{Pb}$	2SD	$^{204}\text{Pb}/^{206}\text{Pb}$
29276.57	1a	18.149	0.012	15.650	0.01	38.29	0.03	0.862	0.0001	2.110	0.0004	0.055
29276.58	1a	18.068	0.016	15.656	0.016	38.26	0.04	0.866	0.0001	2.117	0.0005	0.055
29276.36	1a	18.144	0.013	15.647	0.011	38.28	0.03	0.862	0.0001	2.110	0.0004	0.055
29276.34	1a	18.146	0.014	15.649	0.013	38.30	0.03	0.862	0.0001	2.111	0.0003	0.055
29274.1a	1b	18.392	0.027	15.652	0.025	38.47	0.06	0.851	0.0002	2.092	0.0005	0.054
29274.1b	1b	18.410	0.016	15.645	0.015	38.46	0.04	0.850	0.0001	2.089	0.0004	0.054
29286.35	1b	18.379	0.016	15.653	0.015	38.46	0.04	0.852	0.0001	2.093	0.0008	0.054
29276.37	1b	18.386	0.014	15.649	0.013	38.46	0.03	0.851	0.0002	2.092	0.0003	0.054
29276.59	1b	18.182	0.014	15.649	0.012	38.32	0.03	0.861	0.0001	2.108	0.0003	0.055
29276.39	2	18.412	0.012	15.636	0.012	38.43	0.03	0.849	0.0001	2.087	0.0002	0.054
29276.38	2	18.385	0.014	15.655	0.012	38.48	0.03	0.851	0.0001	2.093	0.0002	0.054
29276.1	2	18.387	0.012	15.650	0.013	38.47	0.03	0.851	0.0001	2.092	0.0002	0.054

Analytical error is generally lower than 0.02 (2 σ).

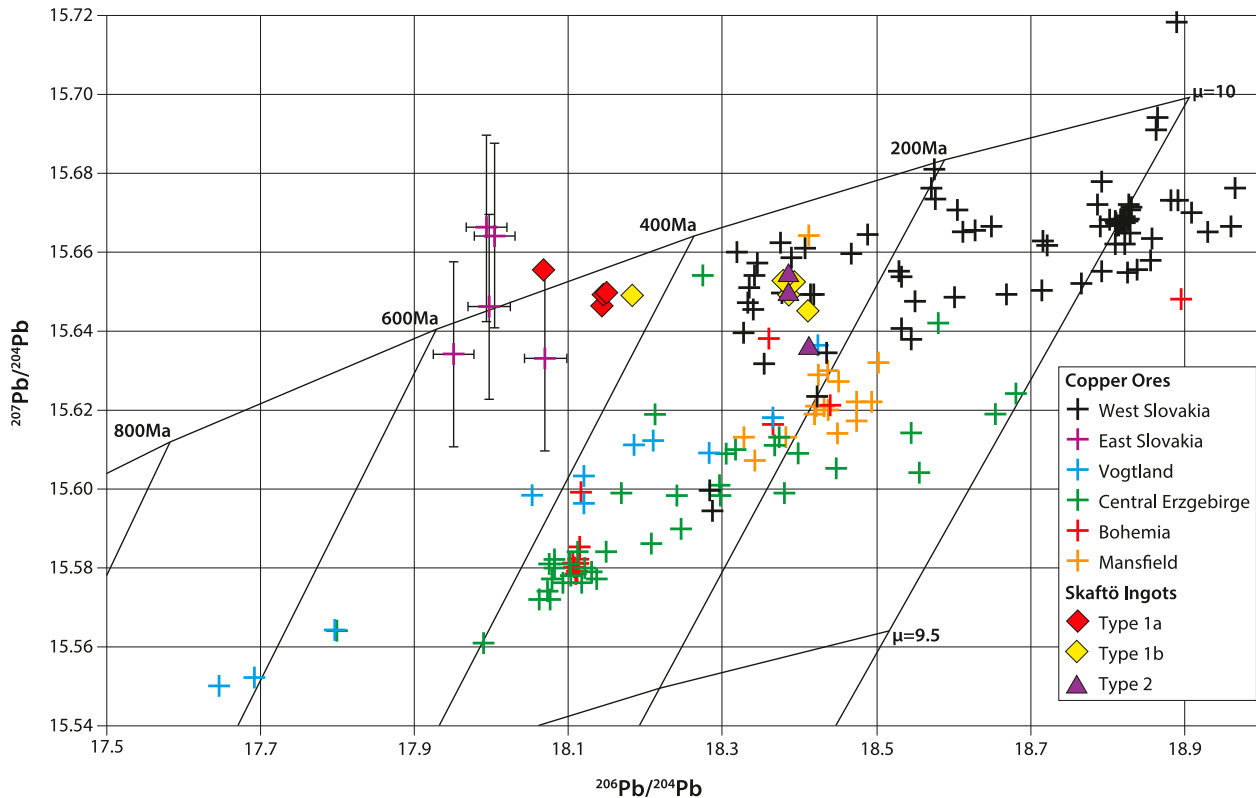


Figure 7. Lead isotope ratios of the Skaftö ingots in relation to those of copper ores worked during the 15th century. The copper ingots form significant groups, where some have older and other younger geologic ages well defined by the dividing 400 Ma line. All Type 2 (speiss) ingots plot with the younger group, indicating their similar origin. While the group deriving from younger geologic ages matches best with central Slovakian copper ores, the older group is likely to derive from eastern Slovakian ores. The crosses show the analytical error. Also, note the different μ -lines, as they indicate different ore chemistry. Data sources: central Slovakia: Schreiner (2007, pp. 218–221); eastern Slovakia: Cernysev et al. (1984, p. 316); Vogtland, Erzgebirge and Bohemia: Niederschlag et al. (2003, pp. 79–81); Mansfeld: Niederschlag et al. (2003, p. 81; Frotzschner, 2012, pp. 126–131). Lead evolution after Stacey & Kramers (1975, p. 216) (Tobias Skowronek).

While Variscan copper ore deposits are very common in Central Europe, pre-Variscan copper is rather rare. In both Bohemia and the Bohemian-Saxon Ore Mountains (Erzgebirge), copper deposits of the latter age can be found, but their chemical composition is inconsistent with the one that produced the Skaftö copper ingots, as expressed by their data plotting on different μ -lines (Figure 7). The St. Briccius Mine in the Erzgebirge is the only known deposit with similar chemical composition and age, but as only one lead isotope ratio is available it remains unclear if the data is reliable.

The copper deposits of eastern Slovakia in the Spišsko-Gemerské area of Gelnica and Smolník appear to be a much better match. Those deposits have both Lower Palaeozoic model ages (400–600 Ma) and the matching ore-chemistry expressed by the 10 μ -line. Their sulfidic polymetallic character (Cernysev et al., 1984, p. 312) would produce copper *Reißscheiben* similar to those studied here.

For the remaining Type 1b-ingots, the copper deposits around Banská Bystrica (the former Neusohl) in central Slovakia – namely Špania Dolina (former Herrengrund), Poniky and Richtrova (Schreiner, 2007, pp. 25–27) – show the best correlation. They too have the Fahlore characteristic that would produce

copper with high amounts of antimony and arsenic equivalent to the Skaftö *Reißscheiben* (Hauptmann et al., 2016, p. 17).

Type 2-Ingots

Type of Metal. Three of the Type 2-ingots were analysed (Figure 8), one from each of the mapped assemblages. Judging from their chemical composition (Table 1), they can be identified as *speiss*. *Speiss* constitutes a mixture of elements such as iron, copper, nickel and cobalt, with major amounts of arsenic and/or antimony. It has to be further differentiated between *ferrous speiss*, containing mainly iron and arsenic or antimony, and *base-metal speiss*, containing copper, nickel, iron, antimony, arsenic, cobalt, and often also sulphur and lead (Thornton et al., 2009, p. 308), which is the type present in the Skaftö wreck.

Base-metal *speiss* forms when complex arsenic and antimony bearing ores are smelted (Bachmann, 1982, p. 29). It was regarded as an unwanted by-product, especially in medieval times, since copper can become trapped inside the *speiss* (Rehren et al., 1999, p. 77). *Speiss* can, on the other hand, act as a collector of precious metals, but its possible de-silvering during

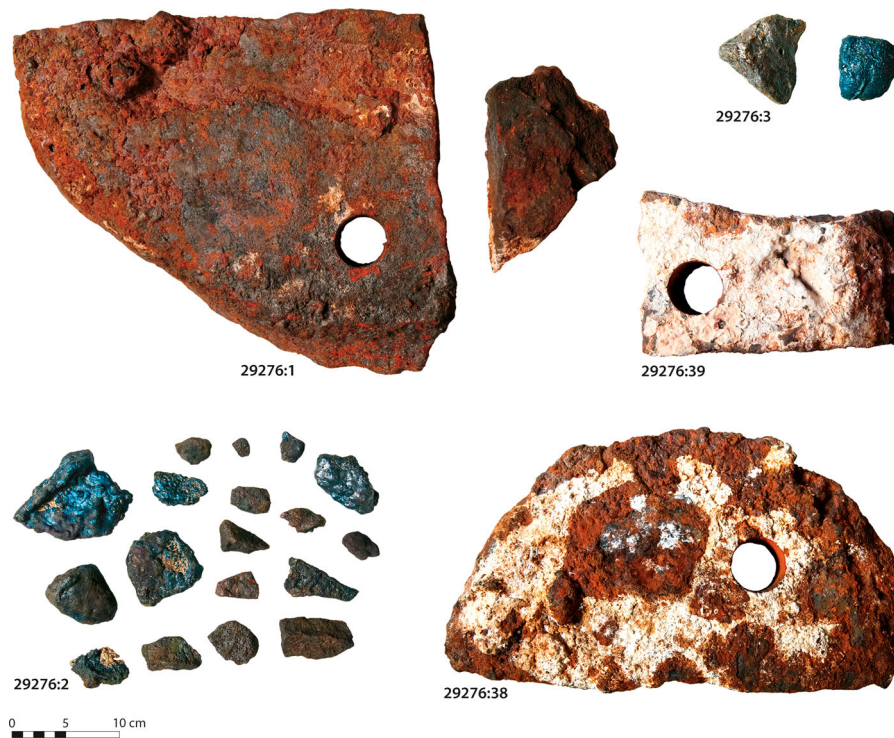


Figure 8. All of the recovered speiss (Type 2) ingots from the Skaftö wreck. Samples from inventory Nos 29276:1, 29276:28 and 29276:39 have been analysed as part of the present study. The round holes that can be seen in inventory Nos 29276:32, 29276:33 and 29276:34 are from previous sampling in 2007 (Cecilia Ahlsén, Bohusläns Museum).

earlier periods is open to debate (Kassianidou, 1998). Here, however, the silver content is quite low and comparable to the amount in de-silvered copper ingots dating slightly later (Hauptmann et al., 2016, p. 15). It might well be the case that these ingots were formed unintentionally – as a by-product – in the fabrication of the Type 1 or *Reißscheiben* ingots since both products are the result of the smelting of sulfidic (Fahl)ores.

Provenance. The lead isotope ratios for the analysed Type 2-ingots are presented in Table 2. The three analysed ingots have lead isotope ratios of $^{206}\text{Pb}/^{204}\text{Pb} = 18.39\text{--}18.41$ and $^{207}\text{Pb}/^{204}\text{Pb} = 15.64\text{--}15.65$, respectively, and are thus rather homogenous. They have the same lead isotopic characteristic as the majority of the Type 1b-ingots (Figure 7), underlining the assumption of them being a by-product (see above). Thus, it is likely that they too derive from central Slovakia.

Lime

Introduction

Chemical analysis of the content of one of the lime barrels was conducted already in 2005 in order to define the type of lime present. Analysis showed that the sample consisted of calcium in the form of calcium carbonate (CaCO_3). However, due to budget constraints, it was not possible at that point to determine

if the original content of the barrel had in fact been chalk (calcium carbonate, CaCO_3), slaked lime (calcium hydroxide, $\text{Ca}(\text{OH})_2$) or burnt lime (calcium oxide, CaO) which was slaked by seawater in conjunction with the foundering of the ship and thereafter carbonated (Wranne et al., 2005).

In order to further clarify this, samples from three different barrels, situated in the after, amidship and bow sections of the wreck and collected during the 2006 field campaign, were provided to Torben Seir at SEIR-materialeanalyse A/S in Denmark for microscopic thin-section analysis (Seir Hansen, 2006). The objective of this analysis was to define the composition and structure of the material, in order to be able to determine the type of lime and, ultimately, also the provenance of the limestone.

Type of Lime

The analysed material could be described as an inhomogeneous and partially porous mass of lime, which contains unevenly distributed solitary sand grains measuring up to 0.7 mm, as well as grey-black lumps of aggregated sand grains measuring up to 10 mm. Microscopically, the lime appears to consist of an aggregation of small lime crystals (calcite, CaCO_3). Diffuse, irregular to rounded structures are frequently occurring in the samples but are unfortunately not possible to interpret further at this stage.

As limestone fragments show evidence of being heated, it is possible to conclude that the content of

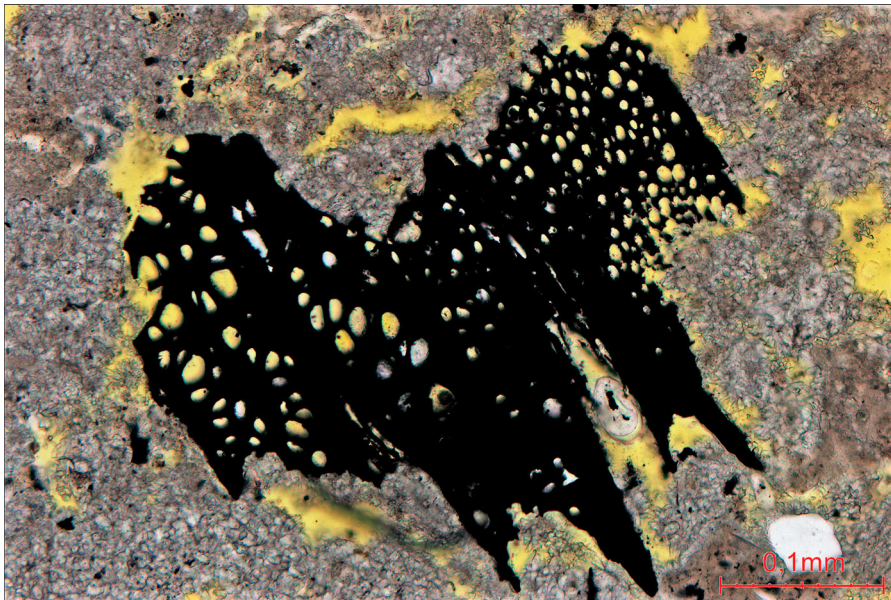


Figure 9. Thin section photo (parallel polarizers) of lime, showing a fragment of charred wood (charcoal) surrounded by the carbonated lime. The charcoal is believed to originate from the wood used for the burning of the limestone. Sample 19 from a degraded lime barrel in Trench 1, Square R2 (Torben Seir).

the barrels was calcium oxide, that is, burnt lime – a composition also commonly known as *quicklime*. The presence of large, well-developed crystals of calcium hydroxide (portlandite) points in a similar direction, as portlandite is a mineral that appears in products containing burnt limestone, which has been in contact with water. Small pieces of charcoal are possibly residues of the firewood used in the burning process (Figure 9). Sand grains and pieces of sandstone has given the lime slightly hydraulic properties.

Burnt lime is transformed into calcium hydroxide in contact with water; a process known as *slaking*. This process results in a highly exothermic reaction

and expansion of the material. As the water intrusion of the Skaftö lime barrels has been a slow process, lengthwise channels have gradually evolved into the lime mass. The presence of several generations of such channels indicate that slaking has occurred *after* the lime was packed in barrels. If the lime had been slaked before packing, signs of expansion would have been little or none.

In contact with atmospheric air, slaked lime will react with the carbon dioxide and transform into calcium carbonate. Similarly, calcium carbonate will form if slaked lime is exposed to bicarbonate from carbon dioxide dissolved in seawater. In the Skaftö case,

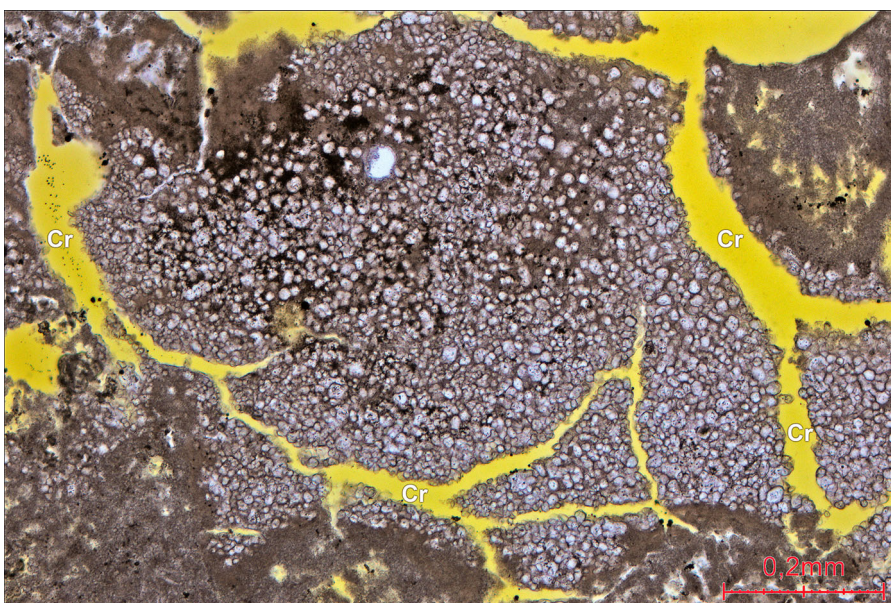


Figure 10. Thin section photo (parallel polarizers) of lime, showing a fragment of underburned limestone that has been partly transformed to quicklime by burning. The fragment and the surrounding carbonated lime is intersected by desiccation cracks (Cr). Sample 20 from an exposed lime barrel in the aft section of the wreck (Torben Seir).

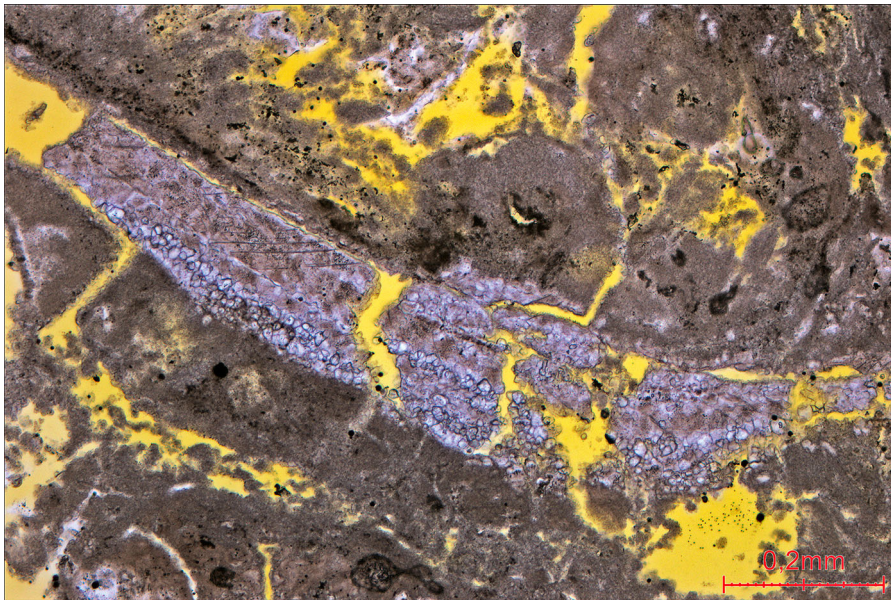


Figure 11. Thin section photo (parallel polarizers) of lime, showing a shell fragment, which is probably from the animal group Brachiopoda. The fragment originates from the limestone used for lime burning. Sample 20 from an exposed lime barrel in the aft section of the wreck (Torben Seir).

this carbonation process has been ongoing since the day the barrels were deposited on the seafloor. Presently, the lime is almost fully transformed into calcium carbonate.

Provenance

It is possible to determine the provenance of the limestone used for the lime burning due to the presence of sand grains and small pieces of sandstone, together with residues of underburned limestone (Figure 10). Sand grains mainly consists of quartz and feldspar and occur as 0.2–1 mm nodules. Similar grains also occur intercalated, together with mica minerals and opaque minerals interpreted as iron sulphide (pyrite), in up to 10 mm pieces of what is believed to be a fine-grained, slightly clayey sandstone. Both sand grains and sandstone are interpreted as being part of the original limestone. Sand grains are generally heavily affected by heat from the lime burning, as well as by the subsequent etching processes caused by the strongly basic slaked lime. Residues of underburned limestone occur as small pieces of texture-less, fine-grained limestone and up to 3 mm long shell fragments of the animal group *Brachiopoda* (Figure 11).

The composition of the limestone shows that it is of sedimentary origin with content of grains of sand and, in some layers, calcareous siltstone or fine-grained sandstone. This type of limestone is formed in relatively nearshore environments, which would exclude the possibility of a Mesozoic or Tertiary age (e.g. chalk and so-called Danian limestone). Coastal occurrences of similar limestone can be found on isolated locations in Scania (Ignaberga and Hannaskog). Proper sandstone, however, is not present here.

Similarly, limestone of Cambrian-Ordovician age can be excluded (e.g. Orthoceratite limestone). What remains is Silurian limestone, which is exposed in Scania and on Gotland (Lindström et al., 1991, pp. 267–272), in the Oslo Fjord area (Berthelsen & Sundvoll, 1996) and in Estonia (the islands of Saaremaa and Hiiumaa) (Männik, 2014, p. 124).

Over the years, SEIR-materialeanalyse A/S has conducted a large number of lime and limestone analyses. Compared to this material, the Skaftö lime appear to show a particularly high resemblance to limestone derived from a retaining wall from the 16th or 17th century, located in the bastion Grå Munken at Varberg Fortress, Sweden. The lime from Grå Munken has a similar structure and composition as the analysed lime from the Skaftö wreck. The size of the sand grains, as well as their distribution and frequency, are in fact almost identical. Since the preservation of the original limestone was considerably better in the Varberg case, it was possible to fix provenance to Gotland – more specifically the area of Halla, on the central part of the island, or Burgsvik on the southernmost tip (Seir Hansen, 2005). Based on the conducted analysis and comparative material, Gotland is thus considered to be the most likely origin of the analysed Skaftö lime. It should however be noted that this determination is to be considered preliminary, since limestone occurrences in present-day Estonia have currently not been evaluated.

Tar

Introduction

Already in 2005, analysis by means of thin layer chromatography (TLC) was performed on tar-like

material from one of the barrels at the wreck site (Barrel W). This analysis confirmed that the content is indeed a tar, and tentatively a wood derived product – or a mixture of a wood derived product with one or more other substances (Wranne et al., 2005). In order to improve this chemical determination, further analysis was conducted by Sven Isaksson at Stockholm University's Archaeological Research Laboratory (Isaksson, 2009). This time analysis comprised samples from two barrels: Barrel E and the aforementioned Barrel W.

Analysis of tars and pitches found on shipwrecks have been performed on several previous occasions (Bailly et al., 2016; Connan & Nissenbaum, 2003; Lange, 1983; Reunanen et al., 1989, 1990; Robinson et al., 1987; Stern et al., 2006, 2008) in attempts to identify the wood species from which it was produced,

Table 3. Distribution of main components (>0.5%) in the two tar samples, expressed as a percentage.

PeakNo.	Ret. time	Component(s)	Relative abundance %	
			Barrel W	Barrel E
1	14.2	Pimarine	0.58	0.0
2	14.6	Norabietane 1	0.58	0.61
3	14.9	18-Norabieta-8. 11. 13-triene	0.85	1.99
4	15.3	Simonellite	0.81	0.61
5	15.7	Norabietane 2	12.6	14.9
6	16.7	Pimaric ac. homologue 1	2.88	3.29
7	16.8	Retene	3.74	2.55
8	17.0	Isopimaric acid	5.56	8.19
9	17.2	Pimaric acid	4.67	2.49
10	17.5	Pimaric ac. homologue 2	2.61	2.01
11	17.6	Dihydroabietic acid? (M^+ , m/z 376), co-elute steroidal comp.	27.6	24.8
–	17.7	Methyl dehydroabietate	0.59	0.56
12	17.8	Methyl-6. 8. 11. 13-abietetraene-18-oate	3.16	3.25
13	18.0	Dehydroabietinsyra	18.8	19.3
14	18.2	Abietic acid	14.8	15.2
15	18.8	Abietic ac. homologue 1	0.78	0.81
Resin acids			80.8	79.3
Neutral components			19.2	20.7
Acids/neutral			4.21	3.83

Some identifications are somewhat uncertain, as highlighted in the table.

to shed light on the manufacturing technique used, and to determine its geographical origin. For the latter, bulk stable light isotope (δD , $\delta^{13}C$ and $\delta^{18}O$) analyses have been proven successful in separating birch bark pitches from Northern and Southern Europe, while there was no clear difference detected between samples from England, Norway, Denmark or Sweden (Stern et al., 2006). Most studies of components of these materials are instead based on molecular analysis using gas chromatography mass spectrometry (GCMS), and this was also the method chosen for the samples from the Skaftö wreck.

Composition

The results of the analysis are summarized in Table 3, and a chromatogram is exemplified in Figure 12. The analysis shows that the main components of the residues from both barrels are tricyclic diterpenoids of the abietane and pimarane series. These are characteristic components of resins, pitches and tars from spruce or pine, that is, of trees of the *Pinaceae* family. In Northern Europe, pine trees were the main source for tar production in historical times. Even though it is possible to distillate tar also from spruce, the comparatively low content of resin makes it less worthwhile (Svensson, 2007, p. 619). Thus, the tar transported on board the Skaftö vessel most likely constitutes pine tar.

In earlier investigations of archaeological remains of prehistoric tar production facilities (Hjulström et al., 2006), the distribution of four main components were shown to be diagnostic, namely, retene, abietic acid, methyl dehydroabietate and dehydroabietic acid. Retene is a neutral diterpene formed by the reduction of the corresponding resin acids. The content of retene in both samples (Figure 13) is in par with what has been previously reported for both tar and prehistoric tar production facilities. Methyl dehydroabietate is present in low concentrations in resins

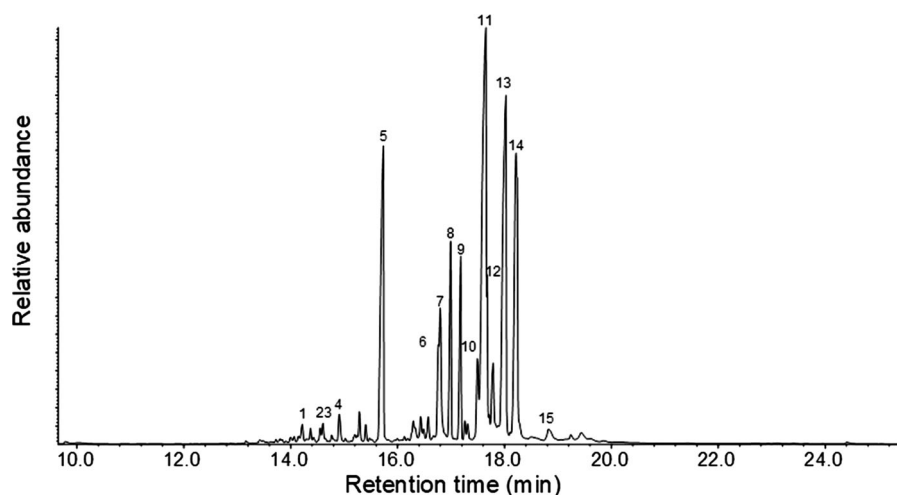


Figure 12. Example of chromatogram recorded from the sample from Barrel W. Component numbers are found in Table 3 (Sven Isaksson).

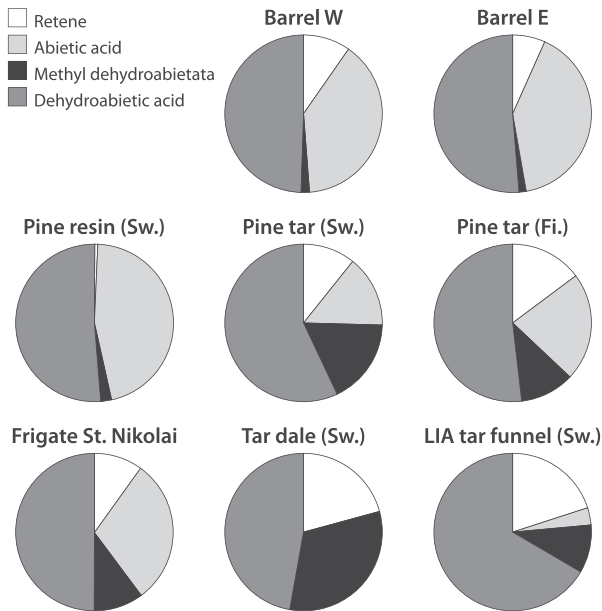


Figure 13. The relative abundance of the four components retene, abietic acid, methyl dehydroabietate, and dehydroabietic acid in the two samples (Barrel W and Barrel E), compared to the composition in samples of contemporary pine resin and pine tar (traditionally produced in a tar dale) from Sweden (Hjulström et al., 2006, p. 291), a contemporary pine tar from Finland, a sample from a tar barrel from the 18th century Russian frigate *St. Nikolai* found at Svenskund (Reunanen et al., 1989, p. 37), and pine tar residues from a tar dale (historic time) and a Late Iron Age funnel shaped tar pit, all from eastern central Sweden (Hjulström et al., 2006, p. 291) (Sven Isaksson).

from pine and spruce, but is also formed by reaction between methanol and the resin acid in connection with dry distillation (tar production).

The relative content of methyl dehydroabietate is lower in both of the samples than in reference samples and in the prehistoric tar production facilities previously analysed (Figure 13), indicating either a different process or effects from deviating deposition conditions. The ratio of resin acids per neutral diterpenes is also relatively low, which indicates a high temperature in connection with tar burning (cf. Egenberg & Glastrup, 1999). This in itself points towards a different manufacturing process, with higher temperatures in comparison with previously analysed samples from prehistoric tar production sites (cf. Hjulström et al., 2006).

Even though the outer surface was discarded during sampling, the marine environment seems to have affected the composition slightly. One such process that has been suggested is the degradation and modification of abietic-type resin acids, mainly through microbial hydrogenation, resulting in the formation of tetrahydroabietic acid and 18-norabieta-8, 11, 13-triene (Reunanen et al., 1990). 18-norabieta-8, 11, 13-triene is identified in both samples at low levels (peak number 3 in Table 3 and Figure 12), but there are only traces of

tetrahydroabietic acid found when extracting characteristic ion chromatograms.

From the molecular ion m/z 376, and other ion fragments, peak number 11 in Table 3 and Figure 12 is suggested to contain the trimethylsilyl derivative of dihydroabietic acid. It is however co-eluting with other components, the most prominent of which most probably is a steroidal component as suggested by characteristic ion fragments, and the secure identification of both compounds is thus indecisive.

Timber

Introduction

As part of the present study, a dendrochronological analysis of a total of seven samples from the timber cargo was carried out by one of the authors (Daly), who in 2012 did a similar analysis of barrels containing lime from the wreck (Daly, 2014a). Before this, dendrochronological analysis had been conducted by other researchers: of structural timbers from the ship itself (Linderson, 2004; reanalyzed by Krąpiec in 2006), of some barrel remains (Krąpiec, 2006), and of planks and boards from the cargo (Linderson, 2007). So far, all dendrochronologically analysed timbers from the wreck and cargo have been of oak (*Quercus* sp.). It should be mentioned, though, that a timber found in conjunction with the big plank stack and sampled for U_{max} analysis in 2005 proved to be of ash tree (*Fraxinus excelsior*). It is however uncertain whether this heavily degraded timber was actually part of the timber cargo (von Arbin, 2010, p. 20; Wranne et al., 2010).

The present analysis used the same seven timbers that Linderson analysed in 2007 and was undertaken in the context of the research project TIMBER, which is directed by Daly at the Saxo Institute, University of Copenhagen. The project deals with the material and historical evidence for trade of timber in Northern Europe c.AD 1200–1700. Preserved timber cargoes in shipwrecks are extremely rare, and the cargo of the Skaftö wreck is thus of great importance for this research. Analysis of three samples from the boards (Group 1; samples P1, P3 and P5) and four from the planks (Group 2; samples P2, P6, P7 and P8) was performed on duplicate samples retained at Bohusläns Museum.

Linderson (2007) suggested that the cargo and the ship timbers of the Skaftö wreck have a very similar dating: the trees for the ship's hull were felled c.AD 1437–39, while trees for the timber cargo were felled c.AD 1437–41. The analysis of the lime barrels reaches a similar conclusion (Daly, 2014a). In his analysis of the timber cargo, Linderson identified two provenances: northern and southeastern Poland respectively. He furthermore suggested that the ship timbers are from a more eastern area than the cargo. However, neither Linderson (2004, 2007) nor Krąpiec

Skaftö wreck, plank cargo, dendrochronological dating

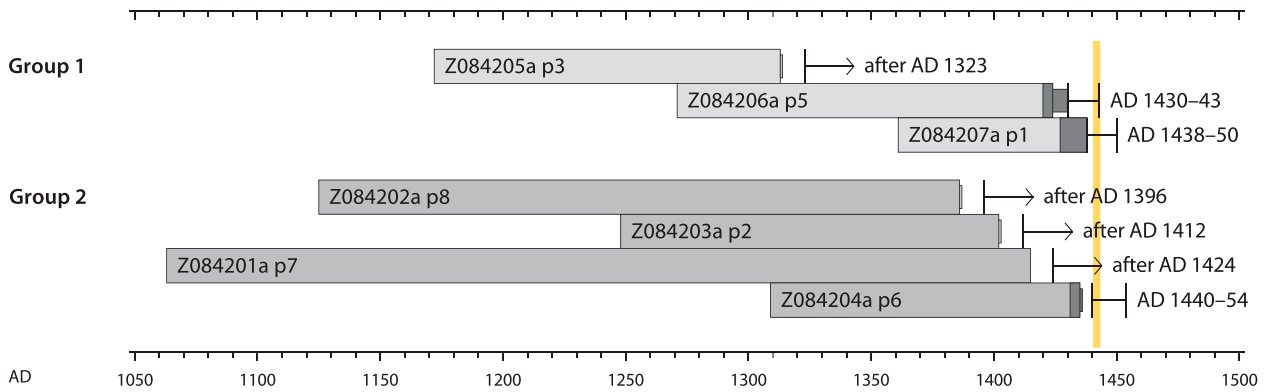


Figure 14. The results of the dendrochronological dating of the timber cargo from the Skaftö wreck. The grey bars represent the chronological position of each sample. The dark grey ends represent the sapwood. The line symbols represent the probable date for the felling of each tree, using a sapwood statistic for northern Poland (Wazny, 1990). The orange line represents the combined results of all seven samples, suggesting felling took place c.AD 1440–43 (Aoife Daly).

(2006) provided any correlation statistics to corroborate their conclusions.

Dating

The result of the dating analysis is illustrated in the diagram in Figure 14. All seven analysed samples are from radially cleft planks and boards. Two of the three boards belonging to Group 1 have sapwood preserved: Sample P5 had four sapwood rings that could be measured and six unmeasured outermost on the sample. This is from a tree that was felled c.AD 1430–43. Sample P1 has 11 sapwood rings and is from a tree that was felled in c.AD 1438–50. One of the plank samples belonging to Group 2, P6, has four sapwood rings preserved and, allowing for missing sapwood, is from a tree felled c.AD 1440–54.

There are slight discrepancies between the tree-ring count and the dated position of the respective timbers, between Linderson's (2007) analysis and the current analysis. Possibly, this is due to the slight difference in how many rings that are present at different positions along the length of the planks and boards. There is one exception to this. The current analysis provides a different dating position for P3, a sample with only heartwood. It is unclear whether this is because the duplicate sample contains fewer rings than the sample analysed by Linderson, or whether he identified a different position for this series.

If we make an assumption that the timber cargo is from trees felled at the same time, then we can combine the results of all seven analysed samples and suggest that this felling took place c.AD 1440–43, which allows for a slightly later date than that proposed by Linderson (2007). This is marked in the diagram with an orange vertical line (Figure 14). The dating of the three samples that have sapwood preserved does not allow greater dating precision to determine whether they are from a single felling phase or not, however, and the heterogeneity of Group 1 might suggest in fact that the felling took place in separate occasions. Considering the homogeneity of the barrel material analysed previously (Daly, 2014a), the felling of oaks for the barrels might have taken place in spring or summer 1439. Taking the dating of the vessel itself into consideration, it seems quite clear from the dendrochronological results that the Skaftö vessel sank while it was very new.

Provenance

A matrix of internal correlation is presented in Table 4. This shows the correlation, *t*-value (Baillie & Pilcher, 1973), between the tree-ring curve from each plank with each other. Those that display highest similarity are grouped together. The timbers display a rather heterogeneous dataset. Four timbers form a small group, which was observed also by Linderson

Table 4. Table showing the correlation (*t*-value) between the tree-ring curve from every dated sample from the Skaftö timber cargo with every other.

		Sample No.s	Z084201a	Z084202a	Z084203a	Z084204a	Z084206a	Z084205a	Z084207a
Average Z084M003	Group 2	P7 Z084201a	*	6.75	2.82	2.98	4.06	1.97	0.3
		P8 Z084202a	6.75	*	3.93	4.24	1.07	3.5	\
		P2 Z084203a	2.82	3.93	*	5.09	1.54	1.79	1.28
		P6 Z084204a	2.98	4.24	5.09	*	\	2.42	
	Group 1	P5 Z084206a	4.06	1.07	1.54	3.3	*	3.01	2.11
P3 Z084205a		1.97	3.5	1.79	\	3.01	*	\	
P1 Z084207a		0.3	\	1.28	2.42	2.11	\	*	

The grey tones highlight the *t*-values achieved.

Table 5. Table showing the correlation (*t*-value) between the average of four planks from the cargo (Group 2, Z084M003) and a range of site and master chronologies for Northern Europe.

Filenames	-		Planks Group 2	
	-	-	Z084M003	
-	start	dates	AD 1063	
-	dates	end	AD 1435	
Master and site chronologies				
BALTIC2	AD 1257	AD 1615	10.95	Baltic 2 , 40 timbers (Hillam & Tyers, 1995)
PP106M01	AD 1110	AD 1399	8.31	Poland, Gdańsk Parc. 6, 14 timbers (T. Wazny, pers. comm.; revised Daly, 2007)
P823001m	AD 1236	AD 1447	7.40	Poland, Ruziec (T. Wazny, pers. comm.)
PUCKM002	AD 1134	AD 1329	7.25	Poland, Puck, 3 timbers (T. Wazny, pers. comm.)
P671001m	AD 980	AD 1347	7.19	Poland, Elbląg (T. Wazny, pers. comm.)
PM670108	AD 725	AD 1985	7.10	Poland, Gdańsk (T. Wazny, pers. comm.)
DM200005	AD 915	AD 1873	6.82	Germany, Niedersachsen Nord (Göttingen University)
PP116M01	AD 1174	AD 1358	6.68	Poland, Gdańsk, Kobziarz, 11 timbers (T. Wazny, pers. comm.; revised Daly, 2007)
PP111M01	AD 1136	AD 1399	6.59	Poland, Gdańsk, St Nikolaus, 11 timbers (T. Wazny, pers. comm.; revised Daly, 2007)
DM200004	30 BC	AD 1960	6.56	Germany, Weser (Göttingen University)
DM100006start	AD 851	AD 1293	6.24	Germany, Lübeck (Hamburg University)
PP124M01	AD 982	AD 1356	6.21	Poland, Elbląg, 120 timbers (T. Wazny, pers. comm.; revised Daly, 2007)
DM200006	AD 914	AD 1873	6.20	Germany, Lüneburger Heide (Göttingen University)
PP118M01	AD 1112	AD 1399	6.19	Poland, Gdańsk, various, 31 timbers (T. Wazny, pers. comm.; revised Daly, 2007)
DM100007	AD 1080	AD 1967	6.07	Germany, Hamburg (Hamburg University)
P676001m	AD 1084	AD 1393	6.04	Poland, Kołobrzeg (T. Wazny, pers. comm.)
BALTIC1	AD 1156	AD 1597	6.01	Baltic 1 , 64 timbers (Hillam & Tyers, 1995)
GD98010A	AD 1250	AD 1338	5.96	Poland, Gdańsk, Wyspa Spichrzów (T. Wazny, pers. comm.)
PM000004	AD 996	AD 1985	5.93	Poland, Gdańsk-Pomerania (T. Wazny, pers. comm.)
0680001S	AD 1121	AD 1398	5.89	Poland, Gdańsk, St Nikolaus (T. Wazny, pers. comm.)
G350PZ01	AD 967	AD 1381	5.87	Germany, Truhen, 46 timbers (Göttingen University; revised Daly, 2007)
POL_TOQ1	AD1225	AD1584	5.78	Poland, Toruń, architektura (A. Zielski, pers. comm.)
POL_WIEL	AD1197	AD1606	5.71	West Central Poland, Wielkopolska (M. Krąpiec, pers. comm.)
POL_PULT	AD1192	AD1452	5.55	Central Poland, Pułtusk (M. Krąpiec, pers. comm.)
POL_VIST	AD1100	AD1529	5.41	Southern Poland, Vistula (M. Krąpiec, pers. comm.)
Chronologies from ships, barrels, furniture etc.				
Z076m001	AD 1097	AD 1393	11.16	Norway, Skjernøysund, Wreck 3, strong group, 14 timbers (Daly, 2011a)
CLS2000	AD 1110	AD 1393	10.95	England, Hull, Yorkshire, Chapel Lane, 11 boat planks (I. Tyers, pers. comm.)
Z223M001	AD 1126	AD 1411	10.62	Germany, Peenemündung, Fpl. 105, planks, 4 timbers (Daly, 2019a)
GAS_SHIP	AD 1052	AD 1370	10.54	England, London, Southwark GAS88, 10 timbers (I. Tyers, pers. comm.)
HMC_T165	AD 1078	AD 1369	9.35	England, Hull, Yorkshire, boards from 37 coffins (I. Tyers, pers. comm.)
00751M03	AD 1221	AD 1456	8.63	Denmark, Vejdyb ship, 4 trees (Daly, 1997)
2129M001	AD 1125	AD 1399	8.31	Denmark, Copenhagen, Niels Hemmingsensgade, barrel, 3 timbers (Daly, 2000)
02071M01	AD 1126	AD 1414	7.89	Denmark, Copenhagen, Dokøen, Wreck 2 (O.H. Eriksen, 2001)
os160_t7	AD 1138	AD 1382	7.69	England, York, Vicars Choral, Large table, 7 boards (I. Tyers, pers. comm.)
D0132M02	AD 1096	AD 1336	7.20	Denmark, Odense, Thomas B. Thriges Gade, staves, 7 timbers (Daly, 2016c)
staves				
se629m01	AD 1118	AD 1386	7.13	England, York Minster, Zouche, 4 timbers (Sheffield University; revised Daly, 2007)
0045M002	AD 1109	AD 1370	6.80	Denmark, Vejby ship, 18 timbers (Bonde & Jensen, 1995)
PERTHM6	AD 1225	AD 1499	6.75	Scotland, Perth Museum, panels: Baltic (A. Crone, pers. comm.)
StCrux27	AD 1144	AD 1388	6.59	England, York, St Crux church, decorative bosses (I. Tyers, pers. comm.)
P0011009	AD 1103	AD 1403	6.43	Poland, Copper Ship, wainscots (T. Wazny, pers. comm.)
se617M01	AD 1100	AD 1396	6.42	England, Grimsby, New Baxtergate, boat planks, 5 timbers (Sheffield University; revised Daly, 2007)
GNT.PPS.M3	AD 1247	AD 1362	6.29	Belgium, Gent, Peperstraat, barrel, 5 timbers (K. Haneca, pers. comm.)
Z140st01_CT	AD 1364	AD 1492	6.25	Norway, Røldal church, doors, same tree, CT (Daly, 2016b)
0056M001	AD 1174	AD 1335	6.15	Scotland, Aberdeen, barrel (A. Crone, pers. comm.)
Z034m001	AD 1188	AD 1371	5.95	Denmark, Bovet, Læsø, wreck, 2 timbers (Daly, 2009)
Z219M001	AD 1103	AD 1351	5.89	Denmark, Vordingborg boat, 3 timbers (Daly, 2018b; Daly et al., 2021)
GB00M001	AD 1165	AD 1386	5.75	England, London, ABB87 door (I. Tyers, pers. comm.)
Z0952M01	AD 1190	AD 1345	5.71	Norway, Barcode ship 17 (BC17), 2 timbers (Daly, 2016a)

The grey tones highlight the *t*-values achieved.

(2007). These are the larger planks, Group 2. An average of these is made (Z084M003). The remaining three boards, Group 1, are dating independently of the material from the Skaftö cargo.

When we look at the correlations between planks belonging to Group 2 and tree-ring datasets for Northern Europe (Table 5), we see very high *t*-values with material from the southern or southeastern Baltic region, chiefly with datasets from around Gdańsk Bay. There is also very high agreement with the so-called Baltic 2 chronology, a chronology built with tree-ring datasets from oak panels used as supports for fine arts (Hillam & Tyers, 1995). We also see very

high correlation with a range of shipwrecks and other materials made from southern Baltic oak. In Linderson's (2007) study, he states that this material is from southeastern Poland but, as mentioned above, no correlation values are presented in his report. It is clear from Table 5 that lower correlation with chronologies from the southern regions of modern-day Poland argue for a more northerly source for this timber.

We do not know, still, where the source of the trees that belong in the Baltic 2 art-historical group is (but see Daly & Tyers 2022). If it is from oak timber rafted along the river Vistula (Wisła), how far up-river was this resource exploited in this early phase of the

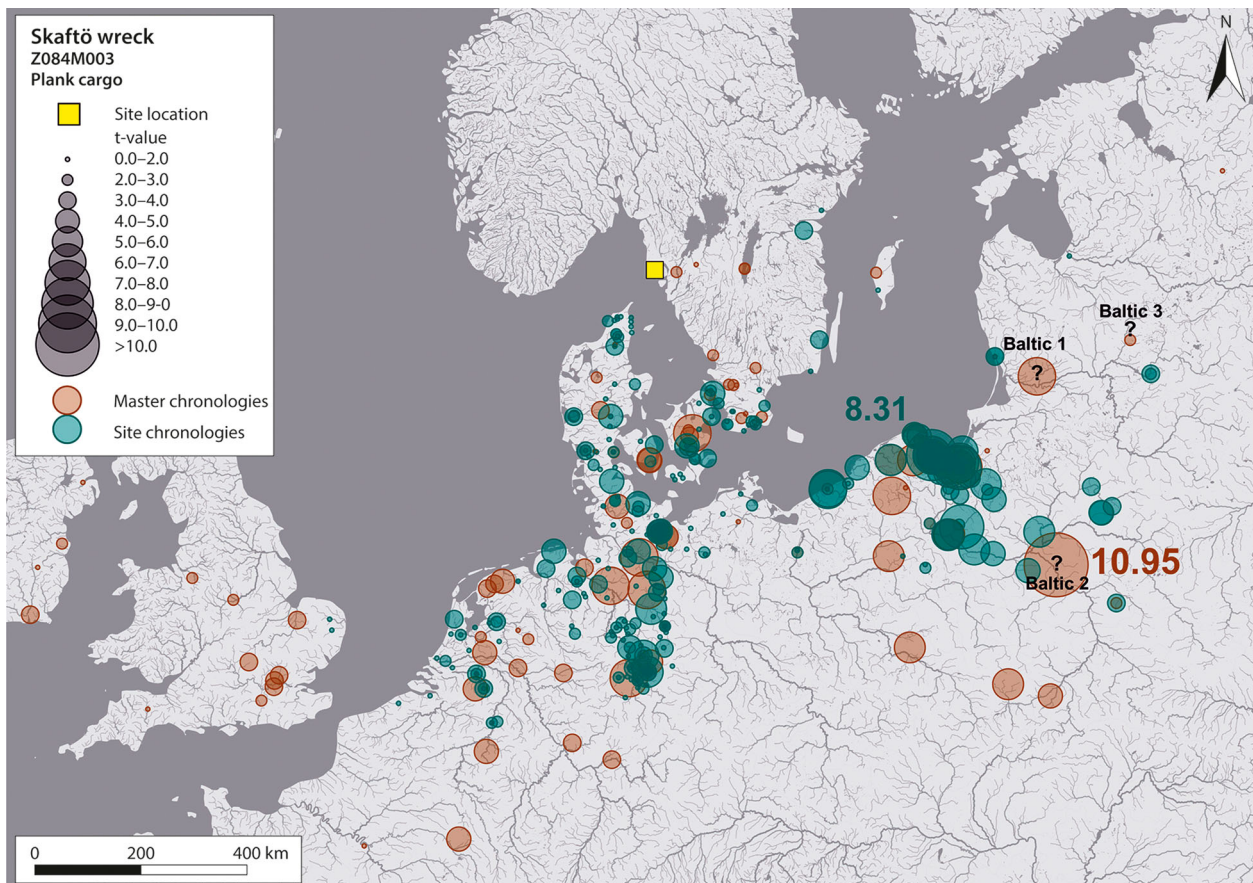


Figure 15. Map showing the distribution of the correlations (t -value) for the Group 2-planks from the Skaftö wreck plank cargo. The larger the dot, the higher the t -value. For details of the method, see e.g. Daly, 2007. The river data are from Lehner and Grill (2013, www.hydrosheds.org, accessed 3rd March 2020) (Aoife Daly).

trade and transport of oak panels and planks from the southern and southeastern Baltic? The map in Figure 15 shows the distribution of the correlations for the Group 2-planks. Positions for the three main art-historical chronologies are postulated, marked with '?'. Of the existing chronologies for terrestrial sites in current day Poland, the Baltic 2 chronology (Hillam & Tyers, 1995) correlates best with northeastern chronologies (Pułtusk) and with a large regional chronology from southeastern Poland, so in the map it is placed approximately between the Bug and Vistula Rivers in central Poland. The three boards belonging to Group 1 are also dating with southern Baltic material, but these correlations do not allow a clear suggestion of where, in this large region, these trees grew (Table 6). They might nevertheless come from a different region than the Group 2-planks.

In contrast, when the tree-ring curves from the sampled lime barrels from the Skaftö wreck were compared with a wide range of chronologies from northern Europe, they also achieved high correlation with both art-historical chronologies Baltic 1 and Baltic 2, but higher again with tree-ring datasets from Vilnius (Pukienė & Ožalas, 2007; R. Pukienė, personal communication, 2019) and Klaipėda (Vitas, 2020). It thus appears that the barrel material might come from further east in the southern Baltic region than

the Group 2-planks. Furthermore, the low correlation between the barrels and the planks and boards leads us to suggest that the oak trees for the two uses were felled in different locations. A total of 20 staves or heads from the lime barrels were analysed (Daly, 2014a), constituting a quite robust, well replicated dataset. Though the number of cargo planks and boards analysed are rather low, a clear separation can be seen, in terms of the tree-ring correlations between the two cargo types and in terms of the chronologies that each group matches best with, to suggest quite separate geographical sources within the wider southern Baltic region.

Bricks and Tiles

Introduction

In order to determine the geographical origin of the clays used in the production of the bricks and roof tiles found on the Skaftö wreck (Figure 16), inductively coupled plasma mass atomic emission spectrometry (ICP-MA/ES) analysis was performed on samples extracted from material retrieved during the 2005, 2006 and 2008 campaigns. For the present analysis, the amounts of twelve different elements were measured: aluminium, chromium, gallium, manganese, vanadium, calcium, magnesium, strontium,

Table 6. Table showing the correlation (*t*-value) between the three independently dated boards (Group 1) from the cargo and a range of site and master chronologies for Northern Europe.

FileNames	–	–	Cargo plank P3 Z084205a	Cargo plank P5 Z084206a	Cargo plank P1 Z084207a	
-	start	dates	AD 1172	AD 1271	AD 1361	
-	dates	end	AD 1313	AD 1424	AD 1438	
Master and site chronologies						
PP117M01	AD 1173	AD 1394	5.27	–	–	Poland, Gdańsk Lub. Okret, 9 timbers (T. Wazny, pers. comm.; revised Daly, 2007)
PP111M01	AD 1136	AD 1399	4.17	4.37	–	Poland, Gdańsk, St Nikolaus, 11 timbers (T. Wazny, pers. comm.; revised Daly, 2007)
P671001m	AD 980	AD 1347	3.29	4.45	\	Poland, Elbląg (T. Wazny, pers. comm.)
P815001m	AD 1262	AD 1503	–	6.65	–	Poland, Bielsk (T. Wazny, pers. comm.)
PP402M01	AD 1267	AD 1412	–	6.42	–	Poland, Brańsk, 11 timbers (T. Wazny, pers. comm.; revised Daly, 2007)
0628002m	AD 1225	AD 1445	–	5.75	–	Poland, Toruń (T. Wazny, pers. comm.)
BALTIC1	AD 1156	AD 1597	–	5.10	3.40	Baltic 1 , 64 timbers (Hillam & Tyers, 1995)
BALTIC2	AD 1257	AD 1615	–	4.00	4.21	Baltic 2 , 40 timbers (Hillam & Tyers, 1995)
Chronologies from ships, barrels, furniture etc.						
CLS2000	AD 1110	AD 1393	5.78	–	–	England, Hull, Yorkshire, Chapel Lane, 11 boat planks (I. Tyers, pers. comm.)
HMC_T165	AD 1078	AD 1369	5.74	–	\	England, Hull, Yorkshire, boards from 37 coffins (I. Tyers, pers. comm.)
S00940M01	AD 1099	AD 1354	5.23	–	\	Sweden, Gotland, Endre church, altarpiece, 9 timbers (Bartholin et al., 1999)
se629m01	AD 1118	AD 1386	4.86	4.90	\	England, York Minster Zouche chapel, 4 timbers (Sheffield University; revised Daly, 2007)
Z076m001	AD 1097	AD 1393	4.80	–	–	Norway, Skjernøysund, Wreck 3, 14 timbers (Daly, 2011a)
02071M01	AD 1126	AD 1414	4.53	4.04	–	Denmark, Copenhagen, Dokøen, Wreck 2 (Eriksen, 2001)
Z129M001	AD 1125	AD 1399	4.32	–	–	Denmark, Copenhagen, Niels Hemmingsens Gade, barrel, 3 timbers (Daly, 2000)
00751M01	AD 1113	AD 1463	3.45	4.24	3.15	Denmark, Vejdyb ship, 14 trees (Daly, 1997)
Z105M001	AD 1266	AD 1479	–	6.52	4.80	Norway, Berg tabernacle, 5 timbers (Daly, 2014b)
GAPCX7	AD 1283	AD 1450	–	5.97	–	Scotland, Guthrie Aisle panels, 7 timbers (A. Crone, pers. comm.)
0075M0042012	AD 1247	AD 1455	–	5.75	–	Denmark, Vejdyb wreck, 4 timbers (Daly, 1997)
Z102M006 gr1	AD 1262	AD 1490	–	5.46	–	Norway, Kvæfjord 2, altarpiece group 1, 11 timbers (Daly, 2014c)
0EQKTM001	AD 1295	AD 1549	\	5.35	–	Estonia, Tallinn, painted panel, 'Christ Driving the Money-lenders from the Temple', 3 timbers (Daly & Läänelaid, 2012)
Z256M001	AD 1239	AD 1479	–	4.95	–	Norway, Missale Nidrosiense, 5 timbers, CT (Daly, 2019b)
Z005M002	AD 1177	AD 1356	–	4.94	\	Norway, Bøle wreck, beams, 4 timbers (Daly & Nymoene, 2008)
MPD09VB6	AD 1283	AD 1509	–	4.94	–	Scotland, Stirling doors: Baltic (A. Crone, pers. comm.)
0012m002	AD 1155	AD 1353	–	4.91	\	Denmark, Lille Kregme ship (Eriksen, 1992)
HEADSx3	AD 1372	AD 1513	\	4.41	4.46	Scotland, Stirling heads: Baltic (A. Crone, pers. comm.)
Z2180018	AD 1384	AD 1543	\	3.23	5.72	Denmark, painted panel 'The Strife between Carnival and Lent' (Daly, 2018a)
Z103005a	AD 1395	AD 1477	\	–	5.25	Norway, Slagen altarpiece, right wing top relief 7 (Daly, 2013)
Z140st01_CT	AD 1364	AD 1492	\	–	5.06	Norway, Røldal church, doors, same tree, CT (Daly, 2016b)
BTV0M001_B3	AD 1342	AD 1616	\	–	4.55	Australia, Batavia wreck, Baltic 3 group, 20 timbers (Daly et al., 2021)
00751M03	AD 1221	AD 1456	–	–	4.75	Denmark, Vejdyb ship, 4 trees (Daly, 1997)

The grey tones highlight the *t*-values achieved.

cerium, lanthanum, sodium and cobalt. Samples were taken from three different bricks and three different roof tiles. Analysis was carried out at OMAC Laboratories Ltd., Ireland, whereas the comparative analysis, statistical processing and interpretation was conducted by Torbjörn Brorsson of the Swedish company Ceramic Studies (Brorsson, 2019). The results are presented in Table 7.

Provenance

To be able to determine geographical origin, results need to be compared with reference data from other analysed sites. These data were collected from Ceramic Studies' own extensive database, which currently contains information from almost 4000 unique sites in Northern Europe. In this case, comparisons were made with material from Sweden, Denmark,

Germany, the Netherlands, Great Britain, Belgium, Poland, Estonia and Norway.

As a first step, the six samples were analysed and compared to each other. This comparison shows that the brick samples Skaftö 1 and Skaftö 2 constitute a group of their own, and so do brick sample Skaftö 3 and tile sample Skaftö 6. These four samples are likely to belong to two different ceramic productions within the same geographical area. The sample Skaftö 5, however, forms a separate group. So does Skaftö 4 (Figure 17). Both constitute roof tile samples. They are likely to represent two separate productions, which may or may not belong in the same geographical area as the other four. Their similarities and differences are better highlighted, however, when compared to material of completely different origin.



Figure 16. A: Examples of bricks (inventory No. 29276:30) and 'Monk and Nun' roof tiles (inventory No. 29276:31) recovered from the Skaftö wreck. Recorded bricks fall within the size range that characterizes bricks from medieval Northern Europe (cf. Debonne, 2014, pp. 20–21) (Ebba Phillips, Studio Västsvensk Konservering).

Table 7. Results of the ICP-MA/ES analysis of the six brick and tile samples.

Sample	Al %	Ca %	Ce ppm	Co ppm	Cr ppm	Ga ppm	La ppm	Mg %	Mn ppm	Na %	Sr ppm	V ppm
Skaftö1	3.56	0.47	45.5	6.5	35	8.4	21.4	0.42	262	0.41	75.2	39
Skaftö2	3.44	0.48	57.7	8.9	37	8.44	30.3	0.4	274	0.4	68.3	44
Skaftö3	4.08	0.36	48.7	5.8	43	9.88	22.9	0.42	219	0.37	69.7	49
Skaftö4	4.97	0.43	63.1	7.7	52	12.15	31.5	0.43	194	0.53	76.6	58
Skaftö5	3.83	0.37	44.2	7.6	32	9.37	21.3	0.31	152	0.51	84.3	36
Skaftö6	4.32	0.36	51.9	8	41	10.7	24.5	0.37	220	0.54	70.3	47

These figures constitute the basis for the comparative analysis and interpretation.

Comparisons have been made with ceramics from a large number of sites in Denmark – from Zealand in the east to Jutland in the west – as well as with ceramics from Belgium, Holland, Norway and western, southern and eastern Sweden, including Gotland. The Skaftö samples do not match any of these sites. A comparison with ceramics from northern Germany gives a similarly negative correlation: the chemical composition of the analysed samples differs from ceramics from Lübeck, Wismar, Bremen, Hamburg, Rostock and Greifswald, which makes a provenance

in northern Germany unlikely. The analysis, however, indicates that bricks and tiles may have been produced in a geographically adjacent area.

Further comparisons with ceramics from the Baltic states and Poland were initially obstructed by the fact that there was very little analysed material to compare with. Available reference data concerned ceramics from a small number of sites in western Poland and Tallinn in present-day Estonia. For the sake of this study, ceramics from different excavations in Gdańsk were therefore analysed. Samples were kindly

Dendrogram using average linkage (between groups)

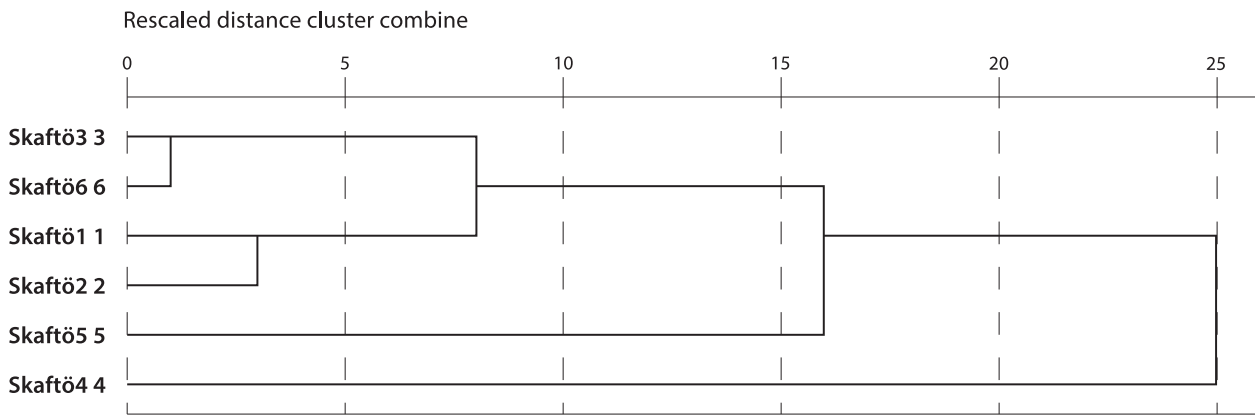


Figure 17. Dendrogram showing the internal correlation of the analysed brick and tile samples. Samples grouped to the left have a similar chemical composition, whereas those grouped to the right, at 20 and higher, are completely different. Samples Skaftö 4 and Skaftö 5 seem to differ somewhat from the other samples (Torbjörn Brorsson).

Dendrogram using average linkage (between groups)

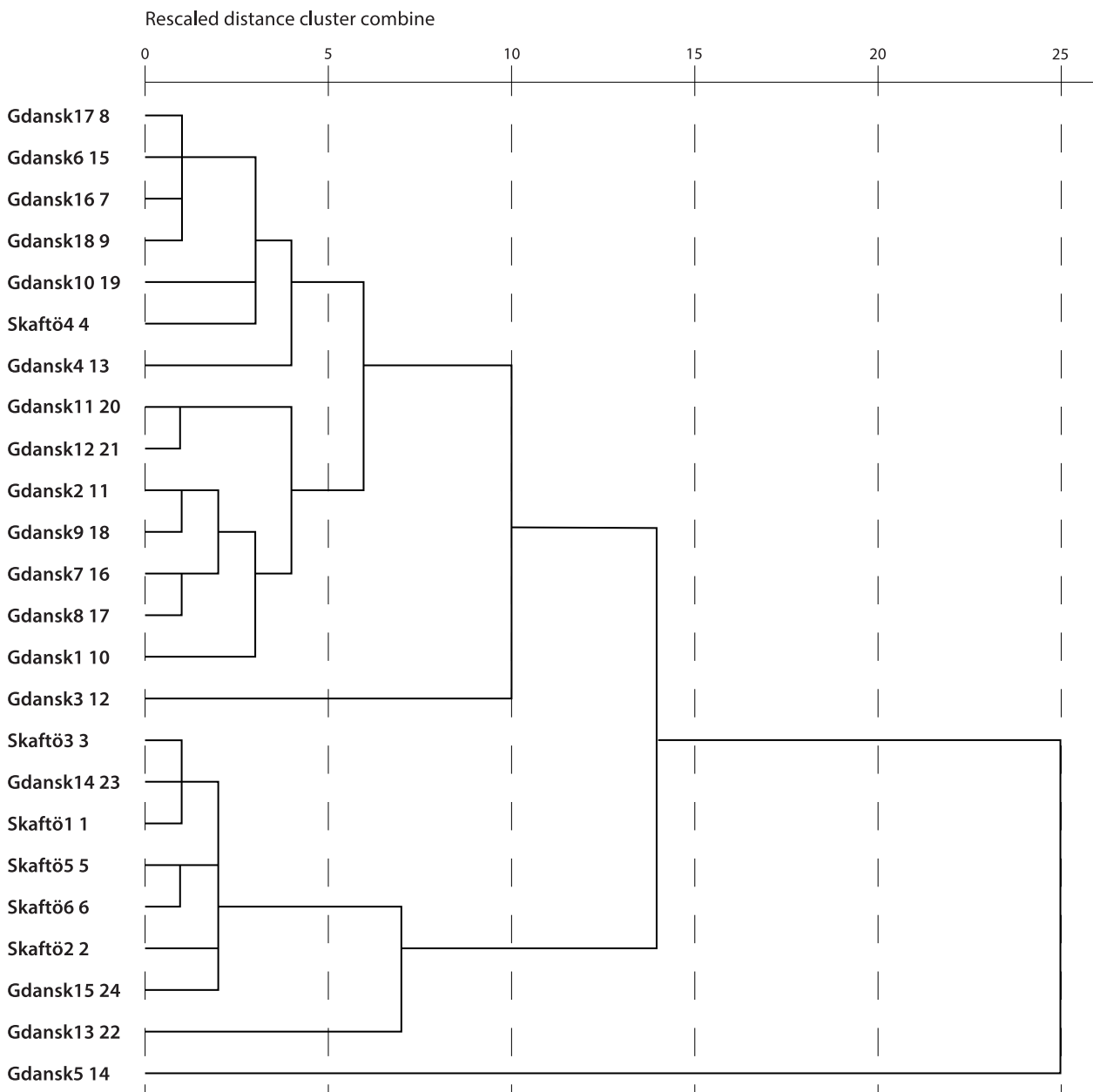


Figure 18. Dendrogram showing the correlation of analysed brick and tile samples with productions in Gdańsk (Torbjörn Brorsson).

provided by Bogdan Kościński at the Gdańsk Archaeological Museum. A total of 18 samples, representing ceramic vessels, production waste and bricks, found in different parts of the town, were analysed.

The comparison of the results reveals that samples Skaftö 1, Skaftö 2, Skaftö 3, Skaftö 5 and Skaftö 6 group perfectly with bricks from the 15th and 16th centuries found in Gdańsk. Possibly, they were even produced in the very same kilns. Sample Skaftö 4, which stem from a tile, group similarly well with ceramics from the Old Town of Gdańsk, but also with production waste found in conjunction with a ceramic kiln in the same town (Figure 18). Analysis thus clearly shows that all six samples from the Skaftö wreck derive from ceramic productions in central Gdańsk/Danzig.

Results in Relation to Contemporaneous Sources

Metal Ingots

Copper has long constituted one of the most appreciated, valuable and widely used metals, and this was also the case in medieval Europe. Due to its different properties, it was used as raw material in the production of a wide array of everyday and household objects, but also as building material, particularly for roofing. Other important areas of use were the minting of coins and the manufacturing of various church equipment, such as church bells, baptismal fonts, candleholders and liturgical vessels. In the late medieval period, copper was also increasingly used for weapon manufacturing, not least the casting of bronze cannons. The trade in copper thus grew increasingly important during the course of the Middle Ages (Garbacz-Klemka et al., 2014, p. 301; Irsigler, 1979, p. 15).

It has been shown here that the *Reißscheiben* retrieved from the Skaftö wreck most probably derive from two sources in the Carpathian Mountains, namely the area around Banská Bystrica in the central part of present-day Slovakia, and the Spišsko-Gemerské area of Gelnica and Smolník in the eastern part of the country. At that time, these two areas constituted the main mining districts in what was then part of the Kingdom of Hungary (Mozejko, 2014, pp. 65–66; Štefánik, 2018, p. 785). While the former area has received much attention from historians, not least due to the well-known exploitation of the Fugger-Thurzo company in the 16th century (Vlachović, 1977, pp. 148–150), eastern Slovakian copper has largely been overlooked. However, recent research by Martin Štefánik (2018) has shown that in the 15th century and earlier, the Spiš-Gemer region was one of the major providers of copper for the European market, and most recently, Miroslav Lacko (2016, 2019) has studied the trade networks and the different actors involved in this trade.

Copper from both areas is known to have been exported via Danzig. Ingots were shipped on rivers such as Poprad and Dunajec to the city of Kraków, from where they were transported further down the Vistula to Danzig, via the town of Thorn (Toruń) (Dollinger, 1970, p. 233; Lacko, 2016, p. 26; Mozejko, 2014, pp. 65–71; Štefánik, 2018, pp. 788–790). Most of the copper that ended up in Danzig seems to have been exported to the Western European market, mainly Flanders, Holland and England – either directly or via Lübeck (Dollinger, 1970, p. 222; Irsigler, 1979; Yrwing, 1966, p. 571). The main bulk, however, seems to have headed to Flanders, and Bruges in particular (Mozejko, 2014, p. 67; Štefánik, 2018, p. 791). At that time, Bruges, which was the location of one of the four *Hansekontore*, had become one of the main commercial centres in Northern Europe. It also served as a hub for the Mediterranean trade. From here, copper was distributed mainly to Venice, but also to other major ports along the Mediterranean coast (Elbl, 2007; Štefánik, 2018, pp. 786–787).

The Skaftö copper cargo has a close parallel in the Copper Ship, where at least three stacks of *Reißscheiben*, each containing approximately ten ingots, were recorded *in situ* within the coherent hull structure, in addition to the large number of ingots that were lying scattered on the seabed outside the wreck. Ingots appear to have been stacked in the same manner as in the Skaftö wreck. At least 226 ingots, with a total weight of approximately 1.4 tons, were recovered from the Copper Ship (Ossowski, 2014b, p. 243). Thus, the average weight of an ingot was 6 kg. This can be compared to the Skaftö wreck, where approximately 100 visible ingots, distributed in two major assemblages comprised of three and six or seven discernible stacks, respectively, have been recorded. Based on retrieved specimens, their total weight have been estimated to between 1.5 and 3.5 tons, which gives an average ingot weight in the range between 15 and 35 kg. This clearly shows that the Skaftö *Reißscheiben* in general are both larger and thicker than their counterparts from Gdańsk Bay.

Analysis reveals that speiss ingots are likely to derive from the same source as the Type 1b *Reißscheiben*, namely central Slovakia, and it may thus have been ferried along the same waterways together with the copper. As previously described, speiss was largely regarded as an unwanted by-product. As such, it is not known to have been traded on a regular basis. However, as shown by the Skaftö cargo, this material was apparently worth transporting for some reason. The question is if the Skaftö speiss represents an occasional transport, or if it is an indication of a trade not previously known from historical sources? Although the speiss in this case could be classified as rather poor (*cf.* Kleinheisterkamp, 1948), it is possible that the reason for trading the ingots

was their still reasonable copper content (c.30%). In the late medieval period, different technical and socio-economic factors severely affected the copper mining industry (Bartels & Klappauf, 2012, pp. 238–248), which could have made this rather unworkable material worth trading. Due to its low melting point, it is also possible that speiss could have been used in conjunction with soldering (Tylecote, 1976, p. 69).

Lime

As mentioned, lime is likely to have constituted the largest part of the cargo, at least in regards to volume. Analysis has revealed that it was so-called quicklime, or burnt lime. In the medieval period, burnt lime was mainly used for the production of mortar of different sorts. It had, however, a number of other applications as well. One such application was hide tanning (Granlund, 1963, p. 159). Due to its caustic properties, quicklime is also known to have been used as a defensive weapon, on land but possibly also in warfare between ships at sea (Sayers, 2006). Typically, it was transported in barrels due to the great risk associated with sea-transport (Munthe, 1945, p. 1, footnote 1; Granlund, 1963, p. 158). When exposed to water, a highly exothermic reaction is initiated which also leads to expansion of the material. For a ship at sea, this vigorous process could of course be disastrous. Possibly, this is also part of the explanation of why the vessel ultimately foundered.

Analysis of the lime points towards a likely Gotlandic provenance. As previously stated, however, an Estonian origin cannot be fully ruled out at this point. At present, very little is known about early lime export from Gotland. It has been argued that the burning of lime on the island was very limited in the medieval period and mostly served domestic needs (Sjöberg, 1972, p. 39; Steffen, 1940, p. 12). Moreover, it has been suggested that the export in the Middle Ages primarily concerned ‘raw’ lime, that is, unburnt limestone, and that it was not until the mid-17th century that the export of burnt lime really took off (Lisiński et al., 1987, p. 7; Sjöberg, 1972, p. 52). The supposed reason for this was a royal decree issued in 1649, which increased export fees on limestone in order to further the export of burnt lime (Steffen, 1940, p. 13).

It is worth noting that the main part of the Gotlandic lime produced before the Swedish takeover in 1645 seems to have headed for ports in the southeastern part of the Baltic Sea; among them Danzig and Königsberg (present-day Kaliningrad) (Sjöberg, 1972, p. 44; Yrwing, 1960, p. 395). One of the earliest written mentions of lime export from Gotland dates to the year 1318 and concerns trade with the Teutonic Order in the latter town. The Lübeck *Pfundzollisten* reveals a recurrent import of Gotlandic limestone to

Lübeck from the 1360s and onwards (Yrwing, 1960, p. 395). The first time export of burnt lime is mentioned is in 1460. This year, both limestone and burnt lime were shipped from Gotland to several ports in northern Germany, the eastern Baltic (among them Danzig), Denmark, Westphalia, the Rhine area, Holland and England (Granlund, 1963, p. 158; Munthe, 1945, p. 115). Sources, however, do not reveal if shipments consisted of quicklime or slaked lime.

According to the geologist Henrik Munthe, there was no substantial export of quicklime from Gotland before the mid-17th century. He based this opinion on the fact that the use of barrels in conjunction with lime export first occurs in written sources around that time (Munthe, 1945, p. 115). The lime cargo of the Skaftö wreck, however, could indicate that export of Gotlandic quicklime packed in barrels may have taken place already in the 1440s – that is, approximately 200 years before the written evidence. Of course, an isolated ship find like the Skaftö wreck does not automatically reveal the extent and nature of this export.

Markings, which could help in attributing lime barrels to particular merchants, either at the shipping port or at the port of delivery, have been recorded on two of the barrel staves recovered from the Skaftö wreck (Figure 19). The mark depicted in Figure 19 (inventory No. 29276:51) resembles merchant’s marks from the 14th–17th centuries that have been recorded in



Figure 19. Plaster castings of the two marks found on barrel staves (inventory Nos 29276:51 and 29276:52) (Ebba Phillips, Studio Västsvensk Konservering).

Rostock, Greifswald and Lübeck (Nordell, 2014). The stave is however quite heavily eroded, and it is thus not possible to determine whether the mark is preserved in its entirety. Since even small changes to the layout of the mark would alter its possible affiliations in crucial ways, it is probably wise for now to treat this evidence very cautiously.

Tar

Tar remains the most anonymous cargo of the Skaftö wreck. Historically, wood tar has primarily been used for the impregnation and preservation of wooden items, buildings, and other structures – not least boats and ships – but also of objects made from plant fibres (such as rope and fishing nets) and leather (e.g. shoes). Tar, and pitch, which is the further processed product, had numerous other applications as well. They were, for instance, used as sealants or adhesives. They could also be used for various medical purposes, such as treating psoriasis and other skin diseases (Granlund, 1974, pp. 417–418; Ossowski, 2014b, p. 269; Svensson, 2007, p. 613).

As shown, there are currently no reliable analytical methods available for determining the provenance of tar. In this respect, we are thus largely dependent on written sources. These sources tell us that tar from Sweden/Finland was exported already in the 14th century. The extent of this export, however, was probably relatively limited – at least compared to later centuries. It was not until the 17th century that Sweden/Finland became the major European supplier of tar (Villstrand, 1996, pp. 62–63). In medieval times, tar was produced also in Norway. The export of Norwegian tar, however, seems to have been very restricted during this period (Ropeid, 1974, p. 426).

Among the countries surrounding the Baltic Sea, it appears as if the major tar-producing region at the time was Poland (Villstrand, 1996, pp. 62–63). Apparently, large quantities of tar were also produced on Gotland. Surviving customs records from the late 15th century reveal that some of this tar was exported to Danzig (Lauffer, 1894, p. 17; Yrwing, 1974, pp. 421–422). Based on written sources alone, the Skaftö tar is thus more likely to originate in either of these two regions than in Sweden/Finland. This conclusion might actually also be supported by the results of the GCMS analysis. As mentioned, the difference in composition between the now analysed tars and the comparative materials presented in Figure 13, which are all of Swedish or Finnish origin, suggests a difference in the manufacturing technique, which possibly indicates a provenance outside of mainland Sweden/Finland.

Like the lime, tar was shipped in barrels. They appear to be of approximately the same size as tar barrels recovered from the Copper Ship in Poland. Here, capacities could be calculated to between 69 l and 99 l

(Litwin, 1985, p. 47; Ossowski, 2014b, p. 269), which can be compared to barrels on the Skaftö wreck, which likely held around 80 l.

Timber

Dendrochronological analysis shows that the planks and boards in the cargo are from different locations, possibly within present-day Poland. Major ports in this region at the time were Danzig (Gdańsk), Elbląg (Elbląg) and Königsberg (Kaliningrad). All three towns were major exporters of southern Baltic timber in the beginning of the 15th century. Danzig, however, soon became the paramount actor within this highly specialized trade (Bonde et al., 1997, p. 203; Dollinger, 1970, p. 221; Haneca et al., 2005, p. 262; Wazny, 2005, p. 117).

Towns were situated along Gdańsk Bay and Vistula Lagoon and received shipments from the interior of timber, brought to, and along the coast, via the inland waterways. The watershed of the Vistula has long been identified as the main transport route for this southern Baltic timber, but the large region that drains also from the east, with major rivers like the Pregolya, flowing to Königsberg, enabled wide exploitation of the forest resource also eastwards (Haneca et al., 2005, p. 262; Wazny, 2002, p. 316).

Southern Baltic oak was highly sought after by artists for painted panels, ecclesiastical furniture and woodcarvings (Daly & Streeton, 2017, p. 3; Haneca et al., 2005, pp. 262–263; Streeton & Wadum, 2012, p. 55) as the correlation tables presented here demonstrate. Another important area of use was the manufacturing of barrels (Daly, 2011b, pp. 112–113; Wazny, 2005, p. 119). We see it used also for shipbuilding, certainly locally, and it seems that by around 1400 timber for shipbuilding were also shipped elsewhere. It appears, however, that this trade was limited mainly to planking (Daly, 2007, pp. 217–230).

In the 15th century, most of the southern Baltic timber seems to have headed to ports in Western Europe. Among the major importers at the time were Holland, Flanders, England and Scotland (Dollinger, 1970, p. 221; Haneca et al., 2005, p. 262; Wazny, 2005, pp. 121–122). Of the Flemish towns, Bruges seems to have taken a particularly active part in this trade, later superseded by Antwerp (Dollinger, 1970, pp. 246–247; Haneca et al., 2005, p. 262). As shown by the dendroarchaeological record, this trade concerned almost without exception converted products from the parent tree, in the form of planks and boards of widely varying sizes. The Southern Baltic region was not the primary source for larger, bulky, structural timber, it seems (Daly, 2007, pp. 200–202; Wazny, 2005, p. 121).

During this period, it was common to distinguish between different timber varieties. In surviving

customs records and other contemporaneous sources, a number of varieties are mentioned, such as *Baumholz*, *Bogenholz*, *Bottichholz*, *Clappholz*, *Flossholz*, *Gudholz*, *Remenholz* and *Wagenschot* (Lauffer, 1894). A few of them are known only by name, whereas others are much better defined. Apparently, terms alternately refer to conversion techniques, shipping forms, timber qualities, and the intended use of the timbers. A problem, however, is that definitions often seem to have changed over time (Wazny, 2005, p. 119).

Both timber sorts that have been recorded in the Skaftö wreck have close parallels in the timber cargoes of the Copper Ship and Skjernøysund 3. These slightly older vessels carried timber of a similar geographical origin as the ship wrecked at Skaftö (Daly, 2011a, 2020; Krąpiec & Krąpiec, 2014). In both cases, boards resembling Group 1 have been interpreted as semi-finished barrel staves, possibly *Clappholz* or *Bottichholz*, while planks resembling Group 2 have been identified as *Wagenschot* (Eng. *wainscot*) (Auer & Maarleveld, 2013, p. 28, 46; Ossowski, 2014b, pp. 254–261; Zwick, 2019, pp. 194–195). It appears as if the latter term in this period was used for high quality planks extracted from straight-grown, fine-grained and knotless tree trunks (Haneca et al., 2005, p. 263; Wazny, 2005, p. 120). It is notable that all the analysed wainscot planks (Group 2) in the Skaftö wreck can be attributed to one distinct geographical region. Thus, it is possible that they represent one single production event. The origin of the boards (Group 1), on the other hand, may be a little more diverse.

Historical records show that timber was often prepared to semi-finished products on, or close to, the timber-felling sites (Haneca et al., 2005, p. 262; Wazny, 2005, pp. 119–121). Apparently, it is this practice that is being mirrored in the Skaftö material. An important reason for this was the difficulty of working oak after the wood had seasoned, which made it necessary to prepare the timbers as soon as possible after the trees were felled (Daly, 2007, p. 202). Besides, the handling and transport of semi-products was presumably more convenient than that of complete logs (Haneca et al., 2005, p. 262). More importantly, however, due to the relatively low value of wood in relation to the hold space it occupies, it must be carried as efficiently as possible to make trading economically viable. This means not shipping material that is only going to be waste, as, for instance, bark and sapwood, and converting the timber into forms that pack efficiently. The fact that the transport cost for southern Baltic timber sold in western markets in this period represented up to almost 80 percent of the retail price (Dollinger, 1970, p. 157) was obviously a big incentive to semi-finish at source.

Another interesting feature is the manner in which the timber cargo was stowed on board the ship, which have close parallels in both the Copper Ship (Litwin, 1985, pp. 46–47; Ossowski, 2014b, p. 259) and the Skjernøysund 3 shipwreck (Auer & Maarleveld, 2013, p. 27, 46). In all three cases, timber were stacked in the bottom of the hold, close to the keel, on top of the mast-step buttresses. In Skjernøysund 3, like in the Skaftö wreck, spaces between buttresses had been filled with shorter boards in order to make maximum use of the available storage space (Auer & Maarleveld, 2013, p. 27, 46). Similarly, some of the planks in the Copper Ship seem to have been deliberately cut in order to fit between the structural elements of the hull (Ossowski, 2014b, p. 254).

Placement of the timber cargo in the bottom of the hold, underneath much heavier cargo types, may seem strange from a stability point of view. However, since the curvature of the hull is less pronounced in this part of a ship, this was probably the most beneficial in terms of cargo efficiency. In addition, the placement of planks may also have served the purpose of protecting the hull interior from heavier cargo items (Ossowski, 2014b, p. 259).

Bricks and Tiles

ICP-MA/ES analysis reveals that all of the analysed brick and tile samples derive from ceramic productions in present-day Gdańsk. On the European continent, bricks became increasingly common as building material, particularly in urban contexts, during the High Middle Ages. This was largely a response to the intense economic and demographic growth, as it enabled standardization, and thus rationalization, of the building trade (Debonne, 2014). In the Nordic countries, its exclusivity remained up until the end of the 16th century. Here, it was reserved primarily for prestigious sacred and profane buildings, such as cathedrals, churches, monasteries, palaces and castles (Andersson & Hildebrand, 1988, pp. 51–52). This being said, a load of bricks and tiles on the wreck of a 15th century trading vessel is not particularly surprising, especially in view of the other building materials found on the wreck site. It seems, however, as if bricks and tiles mostly were transported only shorter distances (Spufford, 2000, p. 160).

Already at an early stage of investigation, the question arose whether the Skaftö bricks in fact could originate from a fireplace, rather than being part of the ship's cargo. At that time, there were, at least to the knowledge of the corresponding author, few, if any, published examples of large brick-built ship hearths from the first half of the 15th century or earlier in Northern Europe (there are examples, however, of simple 'fireboxes' filled with sand, clay, and/or bricks – see e.g. Vlierman, 1992). This, together with the

location of the bricks, which appeared somewhat odd in the context of food preparation; the occurrence of occasional roof tiles; and, most importantly, the lack of mortar on the surfaces of the bricks, eventually lead to the exclusion of this possibility (von Arbin, 2010, p. 16, 2012, p. 69). Since then, however, new and interesting comparative archaeological material has surfaced.

In 2009, the wreck of a big cargo vessel was located in the River IJssel, close to the historic centre of Kampen in present-day Netherlands. This vessel, termed the 'IJsselcog', is dated to around 1415–20 and was comparable in size to the Skaftö wreck. On its main deck, located to its starboard side, abaft the centre of the hull, the vessel had a large fireplace and a dome oven (Waldus et al., 2019). No evidence of a roof construction was found during excavation, which may indicate that cooking actually took place in open air. The hearth and oven was built from ordinary bricks, whereas the galley floor was made of glazed floor tiles. Interestingly, bricks did not display any traces of mortar (W. B. Waldus, personal communication, 2019).

This example shows that at least some of the larger vessels of the early 15th century were equipped with large brick-built fireplaces. Interestingly, the location of the IJsselcog galley seems to be almost identical

with the assumed original location of the brick assemblage on the Skaftö wreck. The IJsselcog has been interpreted as a vessel built and equipped mainly for military purposes, such as the convoying of merchant ships. This conclusion is partially due to the size of the vessel, and partially to the size of the galley, which is considered to be over-dimensioned for an ordinary ship's crew (Waldus et al., 2019, pp. 485–491). This explanation may be valid also for the Skaftö wreck, which, however, apparently carried cargo at the time of sinking. To summarize, it is currently not possible to say with any certainty whether bricks and tiles constituted cargo or not.

Discussion

Dendrochronological analysis of barrels containing lime, and, possibly, speiss, of planks and boards carried as cargo, and of timber from the ship itself, suggests that the vessel that foundered off Skaftö was fairly newly built when it set out on its final voyage – presumably sometime between the years 1440 and 1443. Judging from the archaeological and analytical data that have been accounted for here, it seems indisputable that the ship was heading from the Baltic Sea, when it for some reason foundered *en route*. Based on

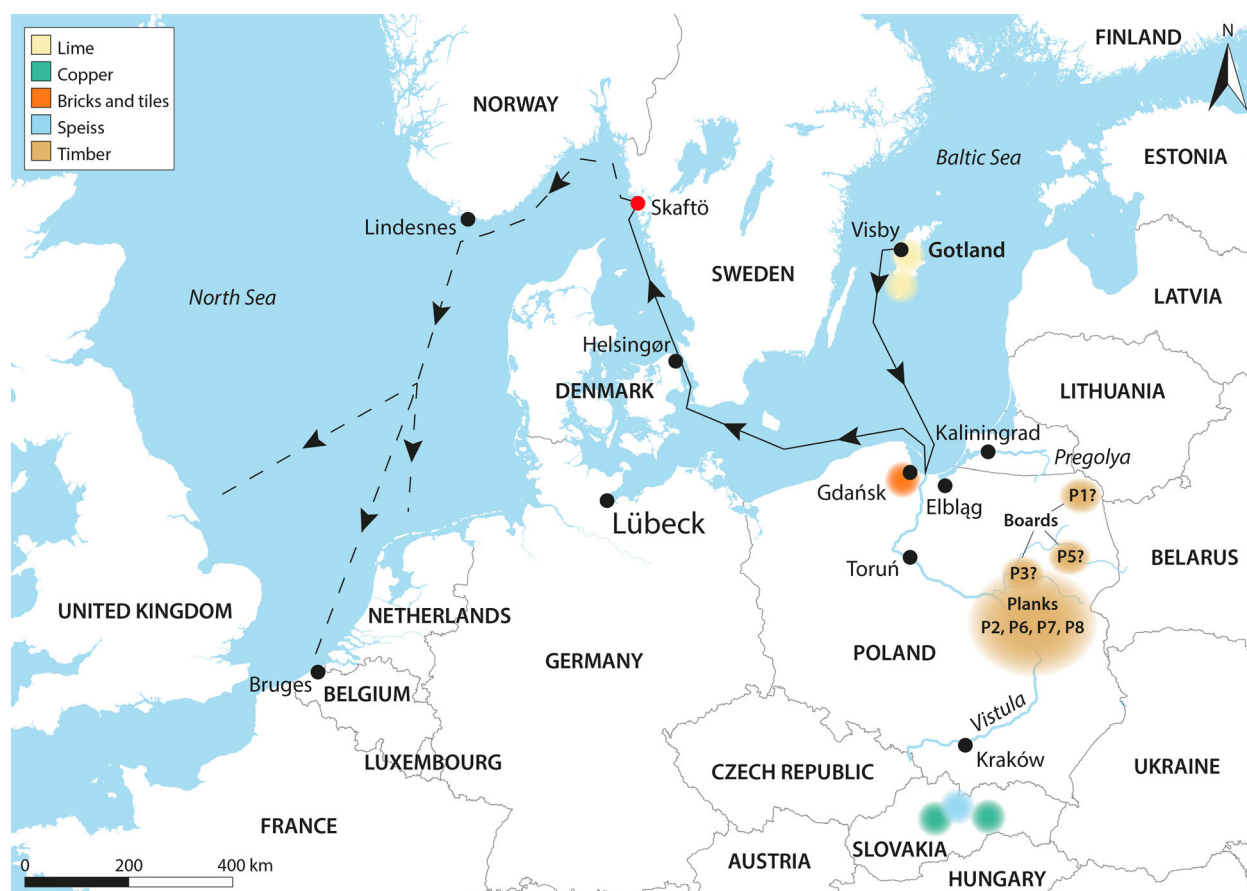


Figure 20. Map showing the origin of the various cargoes and the suggested planned route of the Skaftö vessel, based on investigations of the cargo and written sources. It should be noted that tar, which is likely to have originated either in Poland or in Gotland, has been omitted from the map. Borders and place names are modern-day (Anders Gutehall, Visuell Arkeologi).

current research, at least two presumptive shipping ports can be pinpointed within the Baltic Sea basin. One of them is Gotland, and possibly the town of Visby, from which lime was likely exported. The other is one of the Hanseatic towns of Danzig, Elbing and Königsberg, which were all situated along Gdańsk Bay (Figure 20).

Since Danzig, as previously stated, was the main shipping port for Hungarian copper and, in addition, had a dominant position in the southern Baltic timber trade at that time, it definitely stands out as the strongest candidate. As we have seen, Danzig also appears to be the origin of bricks and tiles found on the shipwreck, even though it can be disputed whether these actually constituted cargo. Tar may have arrived in Danzig either by sea from Gotland or from inland Poland, transported primarily on river routes, namely Vistula and its tributaries. In this period, and especially after the beginning decline of the Teutonic Order in the first decades of the 15th century, Danzig became the region's leading port in the transshipment of commodities between the east and the west (Dollinger, 1970, pp. 230–231). As such, it was certainly a place where goods from several different geographical sources may have been aggregated for a single shipload, like in the Skaftö case.

Probably, Danzig was also where the vessel had its homeport. Although long-distance trade in southern Baltic oak for shipbuilding purposes can be evidenced dendrochronologically from the beginning of the 15th century (Daly, 2007, pp. 217–230), the absence of 'foreign' constructional elements among the timbers suggests that the ship was built regionally, that is, in the Vistula estuary or its vicinity. This assumption is supported also by the use of *Drepanocladus* mosses for luting, which could be considered a distinct regional feature (Filipowiak, 1994, p. 93; Gos & Ossowski, 2009). From written sources it is known that, next to Lübeck, Danzig was the biggest shipbuilding centre among the Hanseatic towns, a position it maintained until about 1450 (Dollinger, 1970, p. 144). Another important shipbuilding centre at that time, however, was the town of Elbing, situated some 55 kilometres to the southeast (Litwin, 1989, pp. 154–155).

That the ship not only was built in this coastal region, but also operated from here is indicated by the small ceramic assemblage that have previously been recovered from the wreck site. This material consists largely of ceramic types characteristic for the southern Baltic region (von Arbin, 2010, p. 18). The vessel may well have belonged to merchants resident in Danzig. However, considering the Teutonic Order's involvement in Danzig shipbuilding at the time, and particularly in the construction of big 'hulks' (cf. Mozejko, 2014, p. 59), a Teutonic ownership – full or partial – cannot be ruled out, either.

Since the timber cargo was stowed in the bottom of the hold, and thus must have been the first cargo taken on board, the following two hypothetical scenarios for the vessel's last journey can currently be set up:

- (1) After having loaded timber, copper and speiss, and possibly also bricks and tar, in Danzig, the vessel set sail to Gotland, where lime and possibly tar were taken on board.
- (2) Lime, and possibly tar, were shipped separately to Danzig, where it was loaded onto the vessel together with the other cargoes.

Based on the distribution of the various cargoes within the remaining hull structure, and given that the cargo has not been restowed at any point during the journey, the last scenario is probably the most feasible.

To what extent distribution of the cargo actually corresponds to the original loading order of the vessel is of course difficult to tell. What we can observe at the wreck site today is at least partly due to the various site formation processes that have taken place during, and after, the foundering of the ship. For instance, some of the heavier cargo items, such as copper and speiss ingots, but also bricks and tiles, seem to have slid slightly towards the upper part of the starboard side as the vessel laid down on the sea floor. Other parts of the cargo, such as timber and lime and tar barrels, appear to have moved very little, if at all. However, if we accept that distribution is – essentially – correct, we must also assume that it is the result of deliberate considerations, made by the people who once loaded the vessel.

Considering the distribution of high-density goods relatively high up in the hold, it appears as if stability may not have been a decisive factor in the loading of the vessel. In other words, we need to look for other explanations as well. In the case of the Polish Copper Ship, it has been suggested that the division of *Reißscheiben* ingots into a number of well-defined assemblages could mirror different ownership, and thus possibly also different presumptive buyers (Ossowski, 2014b, p. 243). This might also be the case with the copper and speiss found in the Skaftö wreck. We should however also consider that division (although apparently not consistently executed, as shown by chemical analysis) might also have been a means of separating the two chemically different but visually similar copper sorts from each other.

From written sources, we also know that the distribution of goods on two or more ships, heading to the same destination, was common practice among medieval merchants in order to spread the economic risk connected with sea transport (Dollinger, 1970, pp. 155–156). Possibly, what we can observe today is

partially the result of this practice. An alternative interpretation, which of course does not necessarily contradict the former, would be that different assemblages were meant to be distributed in different ports along the proposed route. Sequencing, that is, the stowing of cargo in the presumed order of unloading, prevents the need for time and labour consuming restowing, which, ultimately, saves money in the transshipment process. Both interpretations, however, imply that cargo was intended for more than one purchaser.

The composition of the cargo suggests that the intended destination(s) for the ship was most probably none of the contemporaneous Norwegian ports. Instead, the ship was likely aiming for the Western European market. Ports of call may have been situated in, for instance, England, Holland and/or Flanders (Figure 20). For vessels, both native and foreign, that took on cargo in Danzig at that time, Bruges (or, rather, Sluis, which in practice served as the port of Bruges after the silting up of the Zwin channel from the late 13th century onward – see e.g. Charlier, 2011, pp. 747–748) appears to have been the most frequented port of call (Litwin, 2014, p. 24). Bruges was the location for one of the four *Kontore* of the Hanseatic League, and, as we have seen, it was also a major *entrepôt* for both Hungarian copper and southern Baltic timber at the time.

Coming from the Baltic Sea, the ship is likely to have headed through the Oresund where dues had to be paid at the Danish Sound Toll in Helsingør, established in 1429. Unfortunately for our case, there are no surviving customs records until the end of that century (Gøbel, 2010, pp. 305–306). From Oresund, the ship continued northwards, probably hugging the now-Swedish west coast, closely. Presumably, the initial plan was to follow the coast to the Agder side of Viken, most probably to the area of Cape Lindesnes on the southwestern tip of Norway, which for many centuries served as a crossroad for overseas traffic (Stylegar, 2004, pp. 145–147). Here, the course would have been set southwards – either to England or to the western European mainland via the Frisian Islands (Figure 20). However, for unknown reasons the journey instead ended abruptly off the island Skaftö.

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