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ORIGINAL PAPER

Sailing Rock Art Boats

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Abstract Amongst the thousands of Bronze Age rock art images that are found along the paleogeographic coast lines of southern Scandinavia the most ubiquitous is the boat. A few are furnished with what look like a mast or sail. These attributes have largely been ignored or explained away as features or objects other than rig because it is widely accepted that the sail was not used in Scandinavia until the 8th century AD. But what if after all they really are depictions of rig? Might this suggest that the sail was not only known but perhaps used here over a 1,000 years earlier than previously accepted? Starting from the bases of the images and the environment in which they are found, this paper asks whether vessels of the types we believe belonged to the Scandinavian Bronze Age could have been sailed? These evaluations led to a series of sail trials in a canoe undertaken in the archipelago of the Swedish west coast in the late summer and autumn of 2005. The successful results of these trials were later transferred to the *Tilia*, a full-scale reconstruction of the Hjortspring boat, a vessel dated to 350 BC but believed to belong to a long-established boatbuilding tradition stretching back into the Bronze Age. This is the report of the hypothesis behind these trials as well as their planning, execution and immediate results.

Keywords Bronze age · Rock art · Boat · Sail · Scandinavia · Experimental archaeology

Background

That boats played an important role in Scandinavian BA society is hardly controversial. Along the heavily indented coastline large numbers of graves and rock art sites are found near the paleogeographic coast or along inland waterways (Burenhult 1980:34; Coles 1994, 2000:99, 108; Eskeröd 1970:14; Ling 2008), and in the rock art, the boat image is the dominant motif throughout the entire period. In the county of Bohuslän on the Swedish west coast alone some 10,000 boat images are known to exist. The importance of the boat is further emphasised both by the fact that the bronze trade depended upon waterborne

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transportation and by the increasing archaeological evidence for direct contacts across open water during this period (Kristiansen 1998, 2002, 2004; Kvalø 2000; Østmo 2005:63). Nor can there be any doubt that seagoing vessels capable of such journeys were available (Crumlin-Pedersen 2003:220). This leads us to the question of how these boats were propelled. Were they solely paddled or is it possible that the sail could already have been used as a complementary means for propulsion during this period.

The Rock Art

The possibility that the sail was already known and used in southern Scandinavia in the Bronze Age arises when contemplating some of the contemporary rock art boat images, where features that resemble masts and sails have been recognized by several scholars in the past (Artursson 1987; Burenhult 1973a:157; Eskeröd 1970:207; Fett and Fett 1941:83–84; Halldin 1952:66; Humbla and von Post 1937:72–73; Malmer 1981:51, 53; Rausing 1994:71, 79; Sognnes 2001:51; Stölting 1996, 1999). Examples of this are two rock art boat images in the county of Blekinge in southern Sweden, depicting boats with mast-like attributes furnished with what appear to be yards (Fig. 1). Sail-like depictions can also be found at sites at Himmelstalund in Norrköping and at the parishes of Askum and Tanum in Bohuslän (Fig. 2). There are also depictions of a few boats furnished with what looks like a straight central pole like a mast. At the site of Järrestad in the county of Scania, three of these mast-like lines are also braced by what look like stays (Fig. 3: G).

It is often argued that these latter images were copied onto rocks from similar images depicted on contemporary portable objects brought to Scandinavia from the Mediterranean region—such as the Nivilara steele or the Pylos vase from Peloponnesia (Althin 1945; Halldin 1952; Burenhult 1973a; Malmer 1971, 1981). Many other explanations have been offered to explain away resemblance to rig and these range from mere coincidence (Kaul pers. comm. 2005); that the higher central mast-like features simply represent a standing crew member or someone of chiefly status (Fredsjö 1948:72–73); that lines resembling a mast and stays are some sort of tent (Althin 1945:80) or 'net' figure (Nordén 1925:98). These and many other things are all possible but the explanation that is the most obvious has been studiously ignored by all but a few including those named above.

Instead it has become received opinion that the sail was not used in Scandinavia until around the 8th century AD (see for example Westerdahl 1995), yet these facts remain: in Scandinavian rock art there are many images of boats with a straight line positioned close to the centre line where a mast would normally be expected to be positioned. In some instances such central lines are furnished with what appear to be yards or stays, both of which suggest masts designed for the purpose of carrying a sail. In addition, boats actually appearing to be carrying a square sails can be found in at least two different sites. This imagery is found all across the region in most of the major rock carving areas (Fig. 3), and

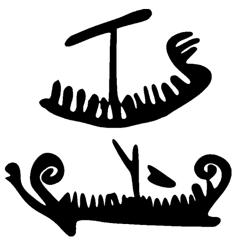

Fig. 1 Boat with mast and yard-like attributes from the county of Blekinge, Sweden. From the *top*: boat depiction from Torshamn and the *bottom* one from Lösen (after Burenhult 1973b)

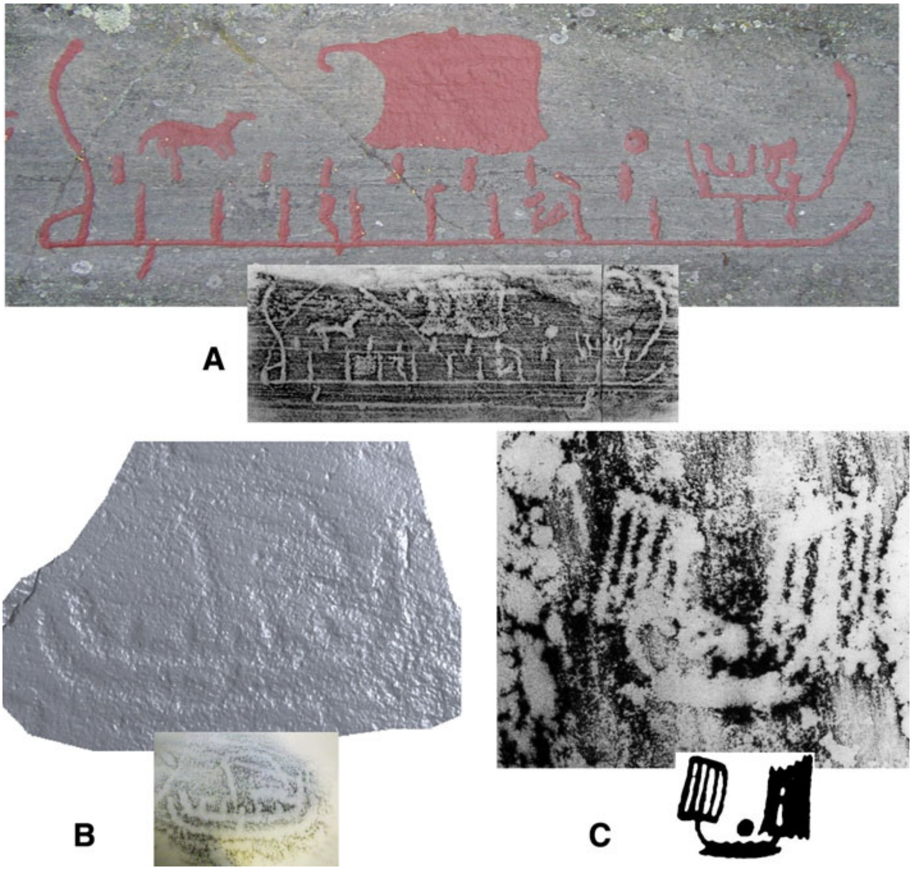

Fig. 2 Sail-like attributes on rock art boats. **a** Himmelstalund 1, photo (B.Bengtsson) and rubbing (Stölting 1996:31), **b** Askum 44, scan (Metimur 2005) and rubbing (B. Bengtsson), **c** Tanum 833, rubbing (Högberg unpublished, Vitlycke museum), interpretation by Bengtsson and Olsson 2000:77

appear to span the entire Bronze Age extending well into pre-Roman Iron Age and early Iron Age. This makes it hard to argue that they are either coincidences or imports. As a comparison, the number of images in southern Scandinavia that appear to depict boats being paddled are equally as scarce (Halldin 1952:76) (for example no such imagery at all is found in the south of Sweden and only one or two can be found on the Swedish east coast) and yet we know from archaeological finds from earlier periods that paddles were used here to propel boats (McGrail 2001:176).

This of course raises questions. Accepting that the concept of the sail was unknown, especially given its use in adjacent seas, is problematic. Alternatively, the sail might have been known but not used. But if these images are representing elements of rig why furnish what are clearly depictions of local Scandinavian boats with such attributes? If the concept was known, is it not possible that the sail began to be experimented with and slowly adopted on local types of boats? A strange idea? Perhaps not if one considers that this was a society that was clearly dependent upon boats, and that many of the rock art boat images are found in the palaeogeographic archipelago with its sheltered and relatively shallow waters which would have served as ideal nursing grounds for such early experimentation

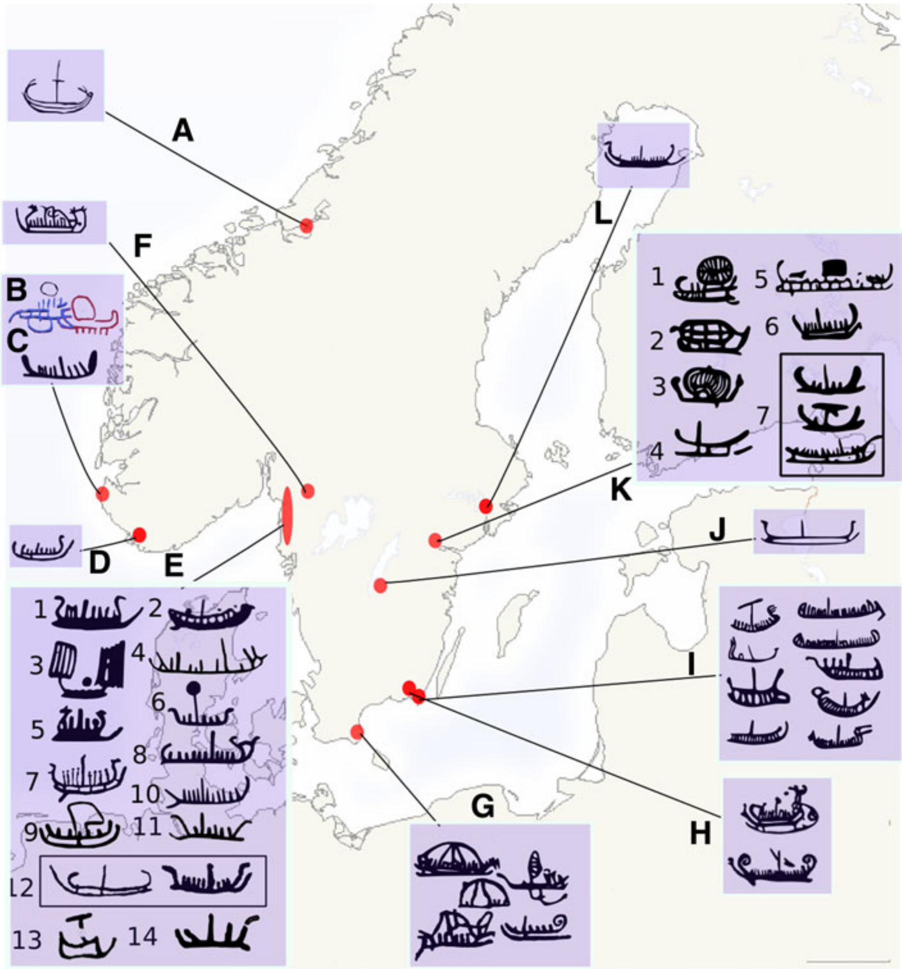

Fig. 3 An *overview* of boat renderings with attributes resembling mast, rig and/or sail in the southern Scandinavian rock art. (Additional mast–like renderings are described in the *text*) (*A*) Stuberg I (Sognnes 2001:166); (*B*) Harvaland–26 (Fett and Fett 1941, pl. 40); (*C*) Sør–Sunde–40 (Fett and Fett 1941, pl 33b); (*D*) Penne–44 (Fett and Fett 1941, pl 44); (*E1*) Onsøy–014801 (Vogt 2000); (*E2*) Bottna–80 (Fredsjö et al. 1975:16); (*E3*) Tanum–833 (Bengtsson and Olsson 2000); (*E4*) Tossene–10, (unpublished, Vitlycke museum); (*E5*) Tanum–406 (Högberg 1997, unpublished); (*E6*) Svarteborg–3 (Broström and Ihrestam 2000); (*E7*) Svenneby–17:1 (Fredsjö et al. 1971:39); (*E8*) Bro–26:1 (Baltzer 1881, I, pl 14); (*E9*) Askum–44; (*E10*) Tossene–23 (unpublished, Vitlycke museum); (*E11*) Tossene–49 (unpublished, Vitlycke museum); (*E12*) Svenneby 11:1–2 (Fredsjö et al. 1971:24); (*E13*) Kville–212 (Fredsjö et al. 1981:276); E14) Bottna–45 (Fredsjö et al. 1975:131; L) (*F*) Ronarudden–15 (Rex Svensson 1982:38); (*G*) Järrestad–13 (Burenhult 1973b:24–25); (*H*) Lösen–26 (Burenhult 1973b:76–77); (*I*) Torshamn–11 (Burenhult 1973b:67); (*I*) Hästholmen–5 (Burenhult 1973b:101); (*K1*) Herrebro–59 (Burenhult 1973b:159); (*K2*) Skälv–18 (Burenhult 1973b:171); (*K3*) Skälv–41 (Burenhult 1973b:171; (*K4*) Leonardsberg–84 (Burenhult 1973b:149); (*K5*) Himmelstalund–1 (Burenhult 1973b: 104–106); (*K6*) Skälv–31 (Burenhult 1973b:164–165); (*K7*) Ekenberg–23 (Burenhult 1973b:138–140); (*L*) Trosa–Vagnhärad–434 (unpublished, Broström 2004, RAÄ)

and development of the sail. This in fact would pre-date the current estimation of the introduction of the sail by more than a 1,000 years (Bengtsson 2003:47, 77).

Let us therefore consider how the type of boat we believe belongs to the Scandinavian Bronze Age could have been sailed, starting with the boat itself.

The Scandinavian Bronze Age Boat

We know very little about what Bronze Age Scandinavian boats looked like, but the recent dating of a piece of boat plank from Norway to the late Bronze Age provides us with a glimpse (Sylvester 2006:97). Other than this, there are only various forms of indirect evidence to rely on, which aside from the rock art include images on bronze artefacts and a few ship settings. The rock art tells us that many different types of boats existed for a variety of activities, possibly alongside each other, and that some of these might have been of considerable size (Capelle 1995:71,75; Goldhahn 1997:12; Sognnes 2001:47).

The only real indicator as to the shape or form of these vessels comes with one important find; the Hjortspring boat, found on the island of Als in southern Denmark in 1885 and excavated in 1921–1922. This 18m long symmetrical sewn canoe was found in a bog along with 16 paddles and a steering oar positioned at each end of the boat (Rosenberg 1937:70–71, 86–89). The boat has been dated to 350 BC, but despite postdating the end of the Bronze Age by about 150 years, its astounding similarity with many of the boats found in rock art, which share the same shape of the sheer line as well as the distinct "beaks" or "horns" in each end of the boat, makes it clear that the Hjortspring boat belongs to a boatbuilding tradition that must reach back into the Bronze Age—indeed a tradition which can be traced back to the Rørby sword dating from the early Bronze Age, about 1700 BC (Fig. 4) (McGrail 2001:191; Kastholm 2008:166; Kaul 1995:88,1998:73–74; Rieck 1994:49; Stölting 1999:277).

Skin or Wood?

In the past, there has been a vivid debate as to whether the Scandinavian Bronze Age boats were made of skin or wood, and therefore, whether the Scandinavian boatbuilding tradition had its origin in the umiak or the logboat (Crumlin-Pedersen 1972:112; Eskeröd 1970:23; Hale 1980:119; Marstrander 1963:150, 450; Zedig 1998:22–25). Of these two schools the latter has gained prominence today, supported not only by the piece of planking described earlier but also by the invaluable knowledge gained by the Hjortspring Guild while making the *Tilia*, a full-scale reconstruction of the Hjortspring boat, which suggests that the skills

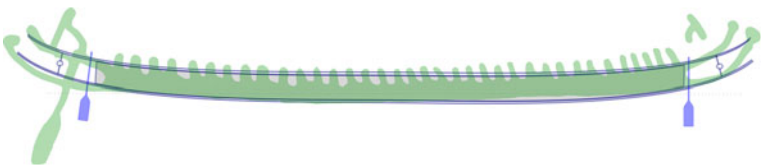

Fig. 4 The Rixö rock carving from Brastad parish, Bohuslän, showing a possible late BA or early Iron Age type of boat overlaying the outline of the Hjortspring boat as interpreted by Rosenberg (1937). The boat depicts two people steering, one in each end of the boat, although the actual steering oar is only *outlined* in one end (after Halldbäck 1944:57)

required and craftsmanship involved in building such a vessel are those of specialists with a long experience to build upon. It has been proposed that the original was most likely made in a boatyard as one in a long line of similar vessels (Valbjørn 1999:59).

Whether one can say that such boatyards might have been present in the Bronze or early Iron Ages or not, the skilled craftsmanship displayed by the Hjortspring boat certainly provides additional strength to the argument for a boatbuilding tradition incorporating some skills in common with those required to construct and repair logboats. Evidence that this type of boat was in more widespread use is further suggested by a pine plank, in shape similar to a Hjortspring upper crossbeam from Västernorrland in Sweden and dated to c.220 BC (Jansson 1994; McGrail 2001:191).

Capabilities of the Hjortspring Boat

The Hjortspring boat is estimated to have weighed around 530 kg, and has an underwater hull shape designed to minimise friction with the water, which indicates that already at this time some Scandinavian boats were made for lightness and speed. Sea trials under paddles, the records of which were published in 1999 (Valbjørn) and 2003 (Crumlin-Pedersen and Trakadas), have shown the reconstruction of the Hjortspring boat to be far more seaworthy than previously believed, coping with winds of up to 12–14 m/s and waves of up to 1 m (Vinner 2003:112–113). With a capacity of about three tons, including ballast of about 600 kg and a crew of 20–25, the boat could manage a speed of 5 knots for short periods of time and an average of 4 knots over longer distances (Valbjørn 1999:56). During long-distance trials in 2001 with a crew of 18 professional dragon race paddlers (as opposed to the amateur crew the Guild used during previous trials), but without the ballast, a cruising speed of 4.7 knots was achieved in dead calm conditions, and in 6 h the boat covered some 24.5 nautical miles. Thus, on a calm day the boat is estimated to have had a radius of travel of some 40 nautical miles (Vinner 2003:117–119).

Sensitivity to Wind

Early on during these trials it was noted that the boat was very sensitive to wind, which when blowing from behind the boat increased its speed by almost one knot, and the question was raised as to whether the advantage of using this extra force, for example by raising a few spears and spreading a cloak to catch it, would have been apparent to its original crew (Valbjørn 1999:56). It is clear not only that this type of vessel would have been sensitive to wind, but also that any person standing up in it, or raising a pole, be it for ceremonial purposes or not, would have gained an understanding of the impact of the wind and its effect on the boat. This obvious speed difference coupled with the rock art imagery of boats with possible sails raises the question whether a concept of a temporary rigging device with some sort of wind catcher was employed to take advantage of this, especially if the boat was travelling over longer distances.

Developing a Concept for Sailing a Bronze Age Type Boat

The typical Scandinavian BA vessel was most probably a symmetrical round hulled sewn canoe built in wood, with double extensions or “horns”. It had no keel and being a canoe, was less stable than the average boat we are used to today. How then, can such a vessel be sailed and what possible solutions are there for sail and rig?

One interesting aspect in this respect is the sail depictions (if this is what they are) from Himmelstalund and Askum (Fig. 2), both of which are wider than they are high, i.e. having a low aspect ratio. Similarly, many of the mast like attributes on some of the rock art boats appear to be relatively low, such as for example Svenneby-11 and Trosa Vagnhärad-434 (see E12 and L in Fig. 3). The same sail shape is found on the much later Gotlandic picture stones from the 6th or 7th centuries AD (Nylén and Lamm 2003; Varenius 1992). These shapes would be a better solution for putting a sail on a relatively narrow and unstable boat, providing a lower centre of effort than a sail with a high aspect ratio, i.e. higher than they are wide. A similar origin might lie behind the foldable rig solution of the boats of the Viking Era, the earliest rigs we know of in Scandinavia. The need to quickly take the rig down before the arrival of a squall, when approaching land or when navigating in coastal areas with sudden wind changes (as is common on mountainous coasts), would have been advantageous in a narrow boat. In such conditions the ability to take the mast as well as the sail down would have been vital for reducing wind resistance and facilitating paddling or rowing.

Given the lightness of the vessels used and the relatively small forces a low sail and moveable rig would impose on them, this might be why so few of the few boat finds so far discovered have shown signs of having been sailed. A telling example is the 10th century AD Ladby ship. This was interpreted as a sailing vessel solely on account of four heavy iron rings that were positioned on each side of the boat along the washstrake close to the middle of the boat. The only explanation for them was that they were used as shroud rings for the support of a rig (Thorvildsen 1975:22). In addition, the Skuldelev boats which, like the Ladby ship were discovered in Denmark, were found stripped of their masts and rigs, indicating that when a boat was discarded, this equipment was thought worth reclaiming to be used again (Vinner pers. comm. 2006). Given the fact that only two boat finds pre-date the 820 AD Oseberg ship (so far the earliest ship discovered that shows irrefutable evidence of having been sailed), the Hjortspring and the Nydam boats, the odds of finding traces of a rig on archaeological boat finds are very small. In addition there is also uncertainty as to what traces of wear we need to look for, and where in the boats one could except to find such traces, given our lack of knowledge about these early forms of rig.

This leads on to another aspect of a sailed vessel, that of a keel and a stable steering device. The presence of a keel has sometimes been cited as a pre-requisite for the ability of a vessel to carry a sail (Haasum 1989:12), but, and this is an important but, there are other alternatives to a keel such as leeboards for example or the use of double steering oars, one attached to each end of a vessel. Such an arrangement will actually make a keel superfluous as the means to prevent leeway. This concept has even been adopted for use on America's Cup boats, a famous example being US-61 in the 1987 challenge in Perth (USA-61). It seems that the Hjortspring boat also may have been equipped with a steering oar at each end—and if so shows that this concept was known and used already in the Pre-Roman Iron Age if not earlier (Rosenberg 1937:86–89).

Several rock art boats are equipped with steering oars[1] at each end of the vessel, all of which Kaul (2003:199) has placed in the Pre-Roman Iron Age. According to Kaul (*ibid.*) this indicates that double steering oars were not used before this period. Østmo (1992:38) on the other hand, argues the possibility that double steering oars were already in use at the very

[1] Steering oar is the commonly used term but as these are not oars *srictu sensu*, 'steering paddle' would be more correct.

beginning of the Bronze Age. The sea trials of the reconstruction of the Hjortspring boat under Max Vinner (2003:104–105), also strongly suggest the double steering oars to be fundamental for a boat of this type to be practically manoeuvred and steered in a straight line with the wind across the hull, as it would be unrealistic to believe that this type of boat only went out in dead calm conditions. Thus, Østmo's hypothesis appears to be the most likely one.

Based on the above it is possible to set up the following criteria for undertaking valid experimental sail trials in order to try and assess how boats we believe belong to a Bronze Age boatbuilding tradition might have been sailed.

Type of boat

- round hulled canoe-like vessel with no keel

Means of steering

- steering oars in each end

Type of rig

- simple, easy to take down in response to changeable winds and to ease paddling
- leaving few or no marks on the vessel

Type of sail

- low aspect ratio, low centre of effort, reducing the heeling moment

In addition to these criteria, it is necessary that the boat be sailed by someone used to this type of unstable boat such as for example a dinghy sailor. The reason for this is easy enough to explain. The full potential of a boat can only be deduced by someone for whom a canoe is more of a norm as opposed to a more stable Viking Age boat. In short, someone who understands how to use the "instability" of a boat as an advantage just as the Bronze Age people probably did, for whom this type of boat was the norm.

Putting the Concept into Practice

Experimental archaeology with regard to ancient seafaring and its relevance has been matter of much discussion in the past (Coates et al. 1995; Crumlin-Pedersen 1995, 2006; Crumlin-Pedersen and McGrail 2006; Edberg 1995; Goodburn 1993; McGrail 1992, 2006; Weski 2006; Westerdahl 1996). Although such discussions have generally focused on the authenticity of reconstructions of excavated boat finds, a comprehensive paper on principles and methods of experimental boat archaeology by Coates et al. (1995:294) argues that if the aim of a project is limited to certain aspects of performance of a boat, a suitably ballasted plastic hull of the authentic shape would do for carrying out tests. Such an argument might successfully be applied not only to the vessel but also its equipment so long as it can be argued not to affect the overall relevance of such trials. With this in mind, the aims of these experiments are three-fold;

(1) to test the validity of the concept of sailing a BA type vessel as outlined in the criteria above, using the simplest possible methods and technology that can be argued might have existed in the Scandinavian Bronze Age
(2) if the concept is proven valid, test the practical use of such a concept in an authentic environment,

(3) transfer and carry out similar tests on the reconstruction of the Hjortspring boat to see how well this boat responds, given the fact that Bronze Age boatbuilding technique resulted in flexible hulls that might not cope with the additional stresses of a sail.

Boat and Equipment

The first on-water experiments to test the concept were carried out in 2005. Originally, the idea had been to try and assess the whole spectra of sail types and mast positions that some of the rock art imagery seem to indicate. However, this was abandoned quite early on as it would have been too time consuming but also because it does not really provide any additional "evidence" as to whether or not the boat could actually sail—how a boat is rigged and what type of sail is used are secondary issues to whether it can sail at all.

The Boat: A Canoe

As an alternative to the more expensive and time-consuming construction of a purpose-built hull, a survey was conducted to identify a boat with a hull form similar enough to that of the Hjortspring boat for the purposes of experiment. After considering several alternatives, a half fabricated Canadian canoe was chosen, a type of vessel which had incidentally been cited in the past as probably being very similar in both shape and dimensions to the Scandinavian rock art boats (Strömberg 1989:15). This particular boat however, was made of glass fibre reinforced plastic (GRP) and came straight from the mould, making it easy to configure to our requirements.

Although the hull shape of the canoe in question was slightly more U-shaped than that of the *Tilia*, thus perhaps a little more stable, the L/W-ratio (Table 1) and the slight V-shape in the bow and stern ends, perhaps the most important determining factors for assessing static stability, were similar enough to make a valid comparison (certainly in view of the inevitable variability there must have been in Bronze Age watercraft). The stability of a vessel under sail can be likened to a person's stability when riding a bicycle. Although due to different mechanisms a narrow boat is similarly less stable when paddled or rowed at slow speed but more stable as speed is increased (Hudson pers. comm.).

The 'Steering Oars'

In order to be able to attach steering oars in a manner similar to how the oars might have been secured on the Hjortspring boat (tied onto the side of the "horns"), the canoe was equipped with "horns" cut out of plywood to imitate the upper horn and small retaining hooks just above the waterline to correspond with the lower horn.

For the steering oars, standard wooden paddles of pine that can be bought in most boat chandleries in Northern Europe were used. The forward oar was tied in order to be kept completely straight and was not used for active steering during the trials whereas the aft steering oar was. The only position for the helmsman was sitting on the floor in the stern of the boat so the oar was equipped with a tiller, extended with a naturally curved stick which also avoided interference with the stay.

Table 1 A comparison between the canoe used for initial sail trials and the Tilia, a full-scale replica of the Hjortspring boat

Data	Canoe	The *Tilia*	The Hjortspring boat (Johannessen)	Sources
Length of the hull	5.05 m (p to p)	15.5 m (from paddle to paddle -p to p)	13.61/18.6—19.6 (horns included)	Crumlin-Pedersen 2003:36; McGrail 2001:192; Rosenberg 1937:92, part III
Length of waterline (L)	4.7 m	9.5 m (empty), 14 m (crew-1,400 kg + 600 ballast)	12.5/14.5	Crumlin-Pedersen 2003:36; Rosenberg 1937:92, part III; Vinner 2003:105
Width (W)	0.85 m	1.9 m (wash strakes not included)	2.04 (including wash strakes)	McGrail 2001:192; Rosenberg 1937:92, part III
Depth (D)	0.313 m	0.7 m	0.71	McGrail 2001:192; Rosenberg 1937:92, part III
L/W-ratio	5.56	5 (empty)/7.37 (with crew + ballast)	7.1	
L/D-ratio	15	13.6 (empty)/20 (with crew + ballast)	20.4	
Weight (hull)	40 kg	c. 530 kg (it has never been weighed)	c. 530 kg	Vinner 2003:105

Johannessen's original measurements are also included

Rig

The parameters for the rig dictated something lightweight that would be easy to raise and secure without leaving marks on the hull and which could be easily taken down and folded away (Figs. 5, 6). This in addition to being able to quickly move the mast position in order to find the proper balance between sail and steering during sail trials, made the use of a bipod mast the simplest choice. This would also reduce the need to attach extra fittings to the boat, or shrouds to support the mast athwart. For material, several woods could have been used but bamboo (c. 2 cm in diameter) was chosen as it was easily cut to the right size and shape and secured with twine, thus vastly reducing preparation time. The same material was used for the yard.

The Hjortspring boat is equipped with a series of four integral cleats located on the upper part of each of the stern and fore ends, each with a rectangular hole about 25 × 10 mm running through it, and large enough for holding more than one rope (shown below) (Rosenberg 1937:75; Valbjørn 2003a:74–75). The exact purpose of these cleats is not known but according to one hypothesis they could have served as attachment points for a trussing rope or hogging truss, used to increase lengthwise stability. This is what they were used for during the initial sea trials in the *Tilia* (Valbjørn 2003a:74). However, the hypothesis has not been convincing as the trussing rope, which is tightened through twisting with the end of a stick, consistently became slack by the end of each day on the water (Valbjørn 2003a:82) and also proved a hindrance for the crew in moving from side to side in the vessel, although it was found to ease movement forwards and backwards as something to hold on to for less experienced passengers. However, an alternative use for these cleats, and for which they appear to be perfectly positioned, is as attachment points for stays, holding up a temporary mast. Therefore, the canoe was equipped with similar attachment points.

Fig. 5 The canoe with the bipod mast up. (Photo: Boel Bengtsson)

Fig. 6 Canoe with rig folded. (Photo: Boel Bengtsson)

As for ropes and fastenings, the criteria was to use something that in terms of handling would have been similar to what would have been available in the Bronze Age; examples of possible materials would have been yew, linden bast (bark fibres of the small-leaved lime *tilia cordata*) and nettle. Linden bast is excellent rope material in a wet environment and actually shrinks a little when wet, making it more resilient than most modern ropes, although its breaking load is considerably smaller. This does not seem to have been a problem as it was used on Viking rigs (Magnus 2006:28–29). Samples of ropes made of bast were also found with the Hjortspring find and, although only imprints were preserved of the rope used to sow the boat together, two-ply rope of linden bast has since been used to great effect for sowing the *Tilia's* hull together (Valbjørn and Rasmussen 2003:64–65; Fenger and Valbjørn 2003:95). Indications such as these show that the ropes available in the Bronze or early Iron Ages with all probability would have been strong enough to be used for a rig or for tuning a sail. Furthermore, tests made by Southampton university show that withies of yew are equal to modern 8-plait pre-stretched polyester ropes both in terms of strength and elasticity (Gifford et al. 2006:59). Therefore, the use of modern substitutes for ropes appear to be of little significance for the outcome of the sail trials described here, especially given the relatively small dimension of the rigs and sail in question and hence the relatively small forces involved.

The Sail

There is no doubt that suitable materials to make sails were available to Bronze Age Scandinavian society—if it is possible to make clothes it is also possible to make sails. Considerable research has gone into the materials of early sails, mainly at the Viking ship museum in Roskilde, where for example it has been proved that wool impregnated with the right amount of sheep-tallow or horse-fat together with a mixture of birch bark, can be made as efficient and durable as sail cloth made of cotton or duradon (Andersen 1995:255–256, 258; 1997:210–211; Vinner 1997:256–257). Therefore, for the purpose of the initial sail trials in the canoe, a square shape from a well used dinghy sail was cut out, resulting in a completely flat and shapeless sail.

The shape of a sail makes a fundamental difference to its effectiveness. Anyone who has sailed a dinghy with a sail trimmed the wrong way can testify to this. A flat sail will not allow the wind to flow around it and, instead of creating a force that can be used to propel the boat forwards, has a tendency to create turbulence, which will slow the boat down as well as making it hard to trim (Walker 1985). A cloth that is softer and more elastic than the modern fabric we used might actually be more effective in this respect as it would automatically assume a shape from the pressure of the wind. Thus, it can be argued that the choice of fabric had little significance on the outcome of the experiment described here.

In order to attach the forward clew of the sail without having to drill any holes (thus leaving marks) a stick, very similar to a beitáss, was used, which could be secured by holding it down against the sheer line (Åkerlund 1956). At the end of this stick, a notch was made into which the rope, where it was attached to the clew, was placed. This proved to be a perhaps overly simple way of securing the clew, but it worked. However, once the right position for the clew was identified it became easier to attach a simple hook onto the sheer strake for the same purpose. One has to bear in mind that a similar solution on the Hjortspring boat would be much easier as it has so many natural attachment points with its many integral cleats and thwarts Table 2.

Sailing the Canoe

The sail trials in the canoe were carried out in the archipelago on the Swedish west coast, just north of Gothenburg. This landscape is very similar to that in which the rock art was carved and the stone cairns and barrows were built in the Bronze Age, and the shallow and sheltered waters, with a tidal range of only 20 cm and relatively small currents, create an

Table 2 Data for rig and sail

	Length of mast (m).	Length of yard (m).	Weight of mast (kg)	Weight of yard (kg)	Sail Area (m^2)	Width of sail (m)	Height of sail (m)
Canoe	1.58, ¤1.38	2.57	0.8	0.4	3.25	2.5	1.3
The ***Tilia***	4.35	7.5, *5	24	8	20, *15	5	4

¤ The initial height of the mast used for sail trials in the canoe

* Indicates what was used during the trials in the Tilia. The weight of the rig used for the canoe was insignificant

ideal nursery for early experimentation with sail. In fact, several large stone cairns can still be found at the highest points of the peninsula from where the picture in Fig. 7 was taken. In the Bronze Age, when water levels in this area were some ten metres higher than today, these cairns were situated on small islands so it would have been an environment through which early Bronze Age seafarers certainly travelled by boat.

During the very first on-water trial the configuration of the canoe was found to be usable, whereupon the aim shifted towards getting a feel for balance, boat handling and manoeuvring, and then to assess its performance on different tacks. For this purpose a series of short sailing trips of 10–20 min were made. This is a very efficient way in which to carry out sail trials as each trip can be evaluated and the necessary changes made before beginning the next trial and so on. Once the boat became more familiar, a longer 4 h sailing trip was made further out in the archipelago to assess the practicality of the set up, the changing from sailing to paddling and vice versa. For recording purposes, a GPS handset was carried on-board to record the course taken.

Balance

Trying to balance a canoe with a total depth of 30 cm and a sheer line that is only some 15 cm above the sea level is hard to appreciate before having actually experienced it. However, despite limited space, and no halyard, the act of hoisting the sail proved not to be

Fig. 7 View to the west across the archipelago just north of Gothenburg where the canoe sail trials took place. The canoe can be see at the *lower right* in the picture. (Photo: Björn Bengtsson)

as difficult as anticipated (Fig. 8). Once the wind filled the sail, the canoe became very steady and on a set course never felt unstable. Throughout the trials the crew sat on the bottom of the boat trying to keep the bodyweight low, but never had to lean their bodies sideways more than vertically to compensate for any heeling, not even in winds of 10–14 m/s which was quite a surprise.

Performance and Manoeuvrability

An important aspect of the rig is that it is so low, with a centre of effort a mere 1.4 m above sea level. The closer the wind is to the water, the more friction it will be subject to, which explains why modern sails are made increasingly high to catch the stronger and more stable wind higher up. This means that the actual force on the sail used here is relatively smaller than that on a sail of higher aspect ratio or one that is hoisted higher on a mast. Despite this, the performance of the canoe under sail was far from bad, although, given the fact that there is generally less wind closer to the water, a much larger sail area could probably have been carried which potentially would have increased the boat speed considerably. For example, in near ideal paddling conditions, with a light breeze of about 3–4 m/s, the speed achieved under paddles was 3.7 knots. For how long this speed could have been maintained is uncertain as we are no paddling specialists, but by hoisting the sail a speed of 2.5 knots could be maintained with ease for as long as the wind prevailed.

With a larger sail, this speed difference could easily have been made much smaller without the risk of the boat being over powered. For most other wind conditions, unless of course the wind comes from around the very direction in which you wish to travel, using a sail will bring you there more quickly and without the need for protracted physical exertion.

During the test runs recorded in Table 3, a shorter, 1.38 m high mast was used, but when the wind increased to above 8 m/s the sail was found to be harder to control, and the boat had a tendency to slide sideways rather than accelerate in the gusts. Therefore, the mast was lengthened by 20 cm. This new set up enabled a tighter forward leach and better control of the sail, a difference that was especially noticeable when it was windy, enabling sailing in winds of up to 12–14 m/s without losing control (Fig. 9). Unfortunately, the GPS was not operational during this last test run, but it is very likely that the boat would have

Fig. 8 Setting the sail without using a halyard. (Photo Vivian Leke)

Table 3 Data for three of the test runs made in the canoe

Test run	Wind strength (m/s)	Max. Speed beat/run (knots)	Tacking angle (°)	Paddling speed (max) (knots)
1	3–4	2.5	52.5	3.7
2	5–6	2.8–3.5/4.9	45–50	–
3	8–10	2.8–3.8/6.3	–	–

Fig. 9 The canoe in winds of 12–14 m/s. Notice the tilt of the yard towards the fore end of the vessel. (Photo: Vivian Leke)

had an even higher maximum speed than the 6 knots plus previously recorded. The difference in the set up of the rig is apparent when comparing Figs. 9 and 10.

The highest speeds were achieved on a broad reach (see maximum speed in Table 3) which was no surprise but interestingly, after the initial familiarisation, the boat was found

Fig. 10 Trials using the earlier and lower rig with the yard tilting towards the aft of the vessel. (Photo: Britt Bengtsson)

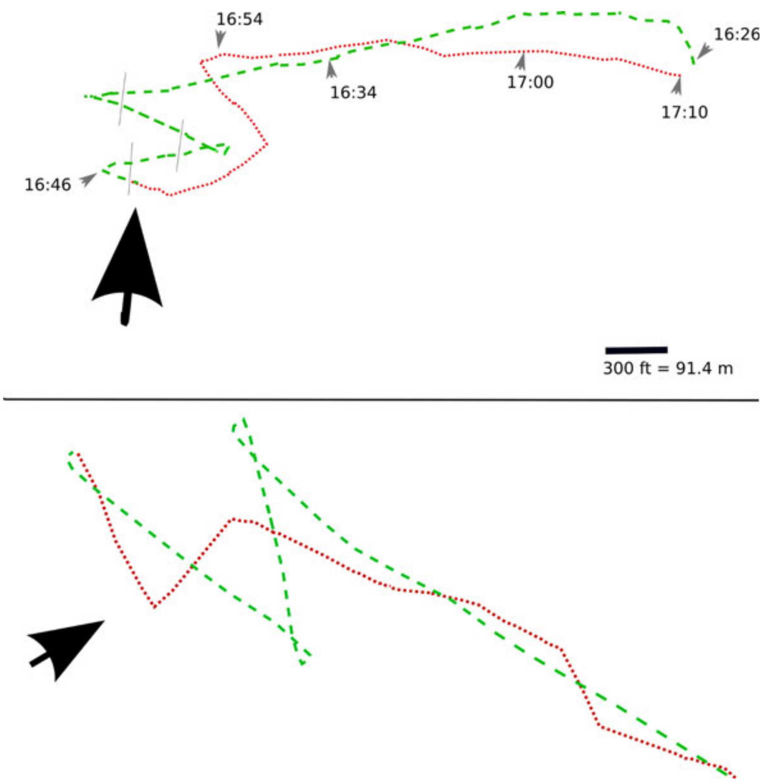

Fig. 11 The GPS data for two of the test runs. *Dashed line* indicate the passage towards the wind, *dotted line* going away from the wind. *Arrows* indicate the wind direction. North is the *top* of the page. (Diagram: author)

to be able to sail with an angle of 60°–63° to the wind. This is evident from the GPS readings of the two test runs in Fig. 11.

Once the rudders were firmly attached, steering became very easy, but it was apparent that double steering oars were necessary, even for steering on a dead run as otherwise the canoe would simply slide sideways when trying to steer any other direction than with the wind. Sometimes in the gusts, the aft steering oar lost its 'grip' or steering ability. This did not happen very often and only for a second or two, and steering was always regained without any accidents. A possible explanation for this phenomenon is the shape of the paddles which, from a hydrodynamic perspective, were far from ideal.

Initially, a lot of ground (up to 14 m) and speed was lost in the tacks, but with better timing and by using a paddle to help the bow through the eye of the wind, this was greatly improved (as can be seen on the GPS data in Fig. 11). Generally, less speed and ground was lost tacking through the wind than when 'gybe tacking', i.e. bearing away from the wind, gybing, and coming up again on a new tack.

As part of the evaluation, a longer sailing trip was made to the outer part of the archipelago and back, with a simple goal; to get back to the starting point without having to paddle more than absolutely necessary in a wind of about 3–4 m/s. The voyage out was easy, with the wind coming from the south east (see the green/light line in Fig. 12). Coming back, the rig was taken down in order to paddle through a narrow gap between two

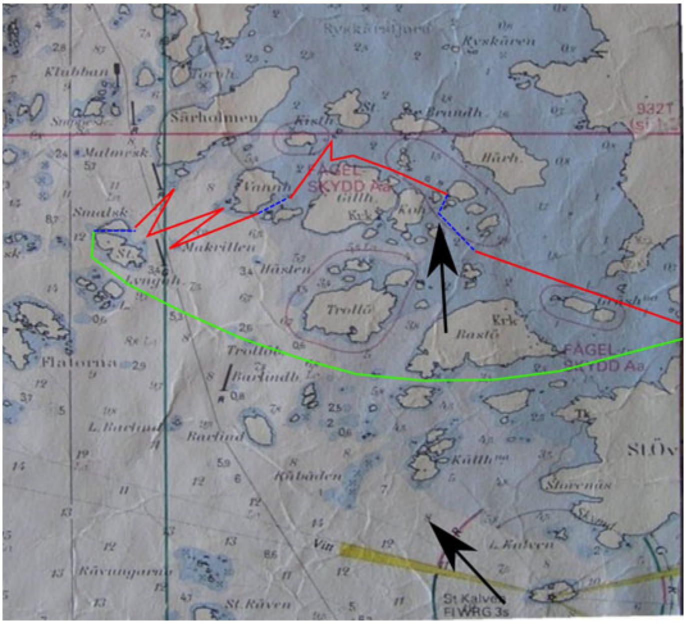

Fig. 12 Map showing the longer sailing tour in the canoe. During the day the wind (indicated with *black arrows*) veered from south-east to south, thus the *bottom arrow* represents the wind in the morning and the top arrow the wind in the afternoon. *Green/light grey line* represents the course going out, *dotted lines* where the rig was taken down to paddle and *red/dark lines*, the journey back. (Diagram: author) (Color figure online)

islands and then quickly raised again to continue on a starboard tack. During this beat (sailing upwind), the wind veered slightly to the south, which was noticeable on the following tack back on port. Approaching the islands around Gillholmen (upper centre in Fig. 12), the wind became very light and gusty and finally disappeared completely behind the islands. This made it necessary to recommence the paddling until the wind returned, when the sail was set anew. By this time, the wind had continued to veer to the south and paddling had to be resumed in order to get through some further narrow gaps between the islands. From here, the canoe was paddled until a point was reached from where it was possible to sail all the way to the point of departure some 4 h earlier.

Sometimes it felt almost unreal to sail past the type of smooth sloping rocks that on higher ground are adorned with rock art boats (Fig. 13). However, for two 21st century sailors the temptation to keep the sail up for as long as possible was obvious and on at least one occasion we stubbornly tried to keep on beating instead of taking the sail down and beginning to paddle. This was one of the greatest insights of this trip—the need to think in a manner that was unusual for sailors used to modern equipment and modern methods of sailing in order to use the available technology to its full potential.[2]

When it was time to land, both steering oars had to be loosened so as to avoid running aground, and therefore it became necessary first to take the rig down. Perhaps this is the reason why we so seldom see boats with the sail up on the rock carvings, or why the few boat images where we can see the steering oars almost without exception show them in a position where they are ready for landing or departing.

[2] The authors have 15 and over 20 years respectively of sailing at international and Olympic level.

Fig. 13 Sailing along the glacially smoothened cliffs of the modern day coastline. (Photo: Britt Bengtsson)

Applying the Results to a Bronze-Age-Type Boat

The conclusion from these preliminary sail trials is that the concept to be tested proved viable in that, using only very basic technology and equipment, it is possible to travel long distances by sail with relative ease within the sheltered waters of an archipelago. The next step was to transfer the same concept to a full-scale copy of a ‘Bronze Age type boat’. With this in mind, the Viking Ship Museum in Roskilde was contacted, who in turn made the introduction to the Hjortspring guild who had built the *Tilia,* a reconstruction of the Hjortspring boat. After an introductory meeting in December 2005, the guild agreed to help and preparations began for the ‘*Tilia* for Sail’, project. An initial date for on water trails was set for August 2006 on the primary condition that the safety of the *Tilia* was in no way to be compromised, a matter which the guild was to have full control of.

The data from the trials in the canoe were transferred by simply projecting the canoe over the Hjortspring boat, which provided the equivalent lengths for the rig and an approximate size of the sail (Table 1; Fig. 14). These data were analysed and discussed whereupon modifications were decided jointly. Apart from these aspects, we agreed to provide a sail, ropes, documentation material along with three experienced dinghy sailors to lead the actual sail trials, whilst the guild were to build the mast and yard, as well as provide a crew and a boat to act as a tender.

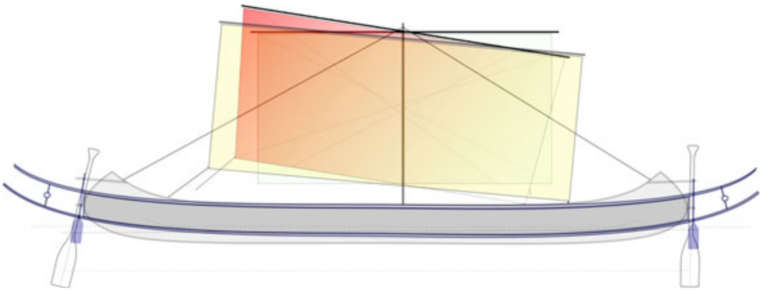

Fig. 14 Johannessen’s drawing of the Hjortspring boat projected over the canoe. The larger steering oars represent the ones used during the sailing trials in the canoe, whereas the smaller represent the oars used on the *Tilia*. Also notice the difference in the size of the sails, where the two smaller represent the smaller sail used on the *Tilia*, whereas the larger sail represent the size of the sail used on the Canoe

Main Differences

The main differences between the Hjortspring boat as Johannessen sketched it and the *Tilia* is that the latter has a much more curved profile (Fenger 2003:91). This means that the *Tilia* has a much shorter water line and that less of its v-shaped hull sections at the stern and bow are below the water line where they could act as a 'keel'. Therefore, the sailing ability of the *Tilia* might potentially be worse than that of a reconstruction of Johannessen's boat or the canoe, both of which have a straighter sheer line.

Another important difference concerns the size of the steering oars in relation to the overall size of the two vessels, where the steering oars used on the canoe are proportionally much deeper and wider (Fig. 14). The steering oars made by the guild are based on Johannessen's drawing which depicts them with shafts that are 3.4 cm in diameter, and blades that are 23 cm wide and 53 cm deep, but only 36 cm from the widest points down (Rosenberg 1937:86–88). The guild has made theirs with slightly deeper blades, 53 cm from the widest point down, 75 cm in total, but with the same thickness. Of the original steering oars, four pieces were found, including a 10 × 10 cm piece that has not been able to be joined with any of the other pieces (Crumlin-Pedersen 2003:33, Fig. 2.16; Rosenberg 1937:86–88). This leaves some room for interpretation, in particular regarding the overall length of the blades. Thus, overall size of the steering oars used for the sail trials are within the margin of error, but could be regarded as small for the task at hand.

Working with a Model

In order to determine the positioning of rig and crew in relation to the practical aspects of hoisting and tuning a sail, a 1:10 scale model of the proposed rig was built (Fig. 15). This enabled the testing of sails and manoeuvres through all wind directions by means of an electric fan. It was found that in order to sail the boat without prior experience, a minimum of seven people would be needed: two for the steering oars, one for hoisting the sail and taking it down quickly in an emergency situation, two to secure the clew of the sail in the forward part of the boat (the heaviest job on-board) and one person on the yard.

Fig. 15 The rig model. (Photos: Boel Bengtsson)

Table 4 The coloured areas indicates the following: KEY: ■ The sail area should be safe to sail with and provide enough force for sailing towards the wind. ■ The sail area is getting a little harder to handle and requires a more skilled crew. ■ The sail area requires a coordinated crew for the given wind strength. The loads are high. ■ There are very small safety margins even for a skilled crew for the given wind force (Color table online)

	28m^2	24m^2	20m^2	16m^2
6m/s	**2566Nm** 885N×2,6+885×0,3	**2047Nm** 758N×2,4+758×0,3		
8m/s	**4375Nm**	**3491Nm**	**2695Nm** 1078N×2,2+1078×0,3	**2242Nm** 862N×2+862×0,3
10m/s			**4362Nm**	**3653Nm**
>10m/s				

Furthermore, one person would be needed for trimming the sail who would also give the orders on-board, a natural pairing of tasks as this person directly feels the power in the sail and quickly can relay this to the rest of the crew. The crew number needed for sailing compares well to the numbers needed for paddling as paddling trials had shown that a minimum of eight people would be needed to master it satisfactorily when carrying a ballast of 600 kg (Vinner 2003:108, table 3.4).

The Sail and Rig

In order to gain an appreciation of the kind of forces the wind would exert on different size sails rigged onto the *Tilia*, a sail maker as well as publicly accessible data on aerodynamics were consulted (NASA). The result is presented in Table 4, with given wind speeds on the left hand side and the size of the sail at the top. For the smaller sized sail the effect of a lower yard, i.e. a lower aspect ratio and centre of effort is included in the calculation. The formula is based on a crew of six people with a total weight of 420 kg and no ballast, and relies on an active crew for balancing the boat by moving all the way to the windward side when necessary, resulting in a righting moment of 4120Nm when so deployed. If then, the *Tilia* is allowed to heel up to 8°, the righting moment would increase to about 4920Nm (Fig. 16). Based on this the following criteria were set up as to how the *Tilia* should be sailed keeping maximum safety margins:

1. Always be sailed entirely upright, without any heeling.
2. When heeling occurs it should only be allowed for short durations—crew responding immediately.
3. Sideways lateral balance is sustained through;
(a) transferring the weight of the crew
(b) easing the sheet while trimming the sail
4. When the entire crew is positioned to windward and the sheet must be eased more than momentarily to maintain the balance, the sail should be reefed.
5. In unstable and gusty wind conditions the sail should be trimmed for the strongest gusts.

In the table, the calculation is based on the force at 90° onto a sail area of 16–28 m^2, with a depth of 13%, trimmed to provide maximum force i.e. just about over powered but never stalling (easing power from the sail by steering into the wind). The fact that some of the force is directed straight forward is not taken into consideration.

Due to safety concerns the size of the sail was reduced from the original estimated size of 28–20 m^2—in the hope that a larger sail might be used in further trials. In addition to this, reefs were sown into enable further reductions. In contrast to the sail used on the canoe which was entirely shapeless, a 13% depth was sown into the shape of the sail used on the *Tilia*, mainly because this would make the initial trials safer due to easier handling and trimming. The reefing system simply comprised of a row of two strings attached on each side of the cloth, parallel to the foot of the sail.

The mast, consisted of two pieces of larch, 8 cm in diameter and with a total weight of 24 kg. The yard was of slightly less diameter and tapered towards the ends with a total weight of 8 kg. This means that the mast in itself was quite over dimensioned as well as being heavy. Having so much weight high up in the rig might affect the stability and balance of the *Tilia* but it was decided to proceed rather than trying something that would prove too weak, especially for early trials. For the purpose of these early trials the bipod mast was bolted together to a rigid construction instead of the fully flexible mast as initially decided on (Fig. 17).

As already stated the *Tilia* offered many more natural attachment points for a rig than the canoe had. It was found to be quite easy to distribute the weight and potential forces incurred by a rig across several of the existing internal frames (Fig. 18), and, interestingly, the integral clamps that have also been mentioned, could fit not only the trussing rope that the guild was unwilling to remove, but also the stays (Fig. 19). The arrangement for the clew also proved relatively easy to secure (Fig. 20).

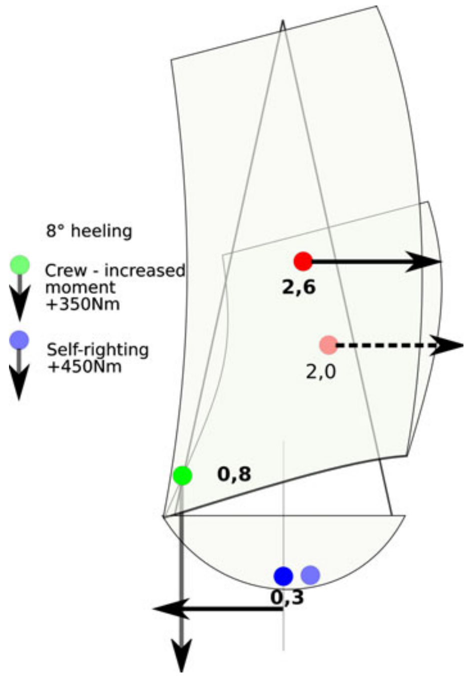

Fig. 16 The estimated forces applied to the *Tilia* under sail which serve as the basis for the calculations in Table 4. (Diagram: Björn Bengtsson)

The Rudders

Although many rock art depictions appear to show the person steering as actually sitting on the horns, it is very unlikely this would have been the case in reality as such a position in any kind of sea (other than dead calm) would be very unsafe. It is more likely that such depictions show that someone was in charge of them (steering) or climbing out to fasten or unfasten them in preparation for landing or departing. Earlier trials in the *Tilia* seem to verify such a theory (Vinner 2003:105). Therefore, tiller extensions were used in order to enable safe steering during the sail trials. The principle of this system is shown in Fig. 21. Apart from using extensions, the steering oars proved very easy to secure tightly to the horns using only a string and some leather to reduce any chafing.

Dry Sailing

In May, the newly manufactured rig and sail were put together and raised on land for the first time (Fig. 22). This provided an opportunity to ensure that every detail—from the hoisting and lowering of the sail and rig, the fitting for attaching the clew of the sail, to the lengths of the various ropes—worked. It also gave an opportunity to mentally prepare for new situations which might arise due to an untrained crew or unfamiliar equipment.

Fig. 17 The bolted version that was to be used during the sail trials. (Photo: Boel Bengtsson)

Fig. 18 The mast in its resting position. Note the *square planks* to which the foot of each mast is attached, which distribute the weight and force across two of the internal frames. Photo: Boel Bengtsson

Fig. 19 The *white trussing rope* and the *blue forestay* are both attached to the same four integral cleats that are located at each end of the *Tilia*. (Photo: Boel Bengtsson)

Fig. 20 The arrangement for fastening the forward clew of the sail. The stick which is attached to the log is inserted through the clew of the sail, and then held down and secured flush with the log with a looped string. This solution proved both simple and safe. (Photo: Boel Bengtsson)

Sailing the Tilia

The on-water trials took place during 2 days in August of 2006, at Dyvig on the island of Als (Vinner 2003:103, Fig. 3.95) (Fig. 23). This is the island where the Hjortspring boat was originally found and happens to be where the *Tilia* was built and tested during earlier on-water trials (Crumlin-Pedersen and Trakadas 2003). The aim of the sail trials was simply to ensure familiarisation with the boat and crew, and, once it proved able to sail, to learn some basic boat handling. Carried on-board, were a digital compass for taking accurate readings of the heading of the boat every 2 min, and a GPS to track the journey. Wind readings at regular intervals, photographs and towing assistance were provided by the accompanying tender boat.

The pre-conditions for the trials were as follows:

Wind on day one there was a fresh gusty north-easterly wind (4–9 m/s) with shifts of up to 40°, which on day two mellowed somewhat to a north–north–easterly (3–6 m/s) with shifts of 20°–30°. Thus, it is fair to say that the wind conditions were not the easiest for carrying out good sail trials and certainly not for familiarisation with a new type of boat.

Sail due to the unstable conditions and unfamiliar crew it was agreed that one reef was to be taken in, thus decreasing the sail area to about 15 m^2. This smaller sail area was used throughout the trials.

Crew Eleven crew members were used throughout the trials of which seven were actively involved in sailing the *Tilia*. The active crew had a very mixed sailing background, from

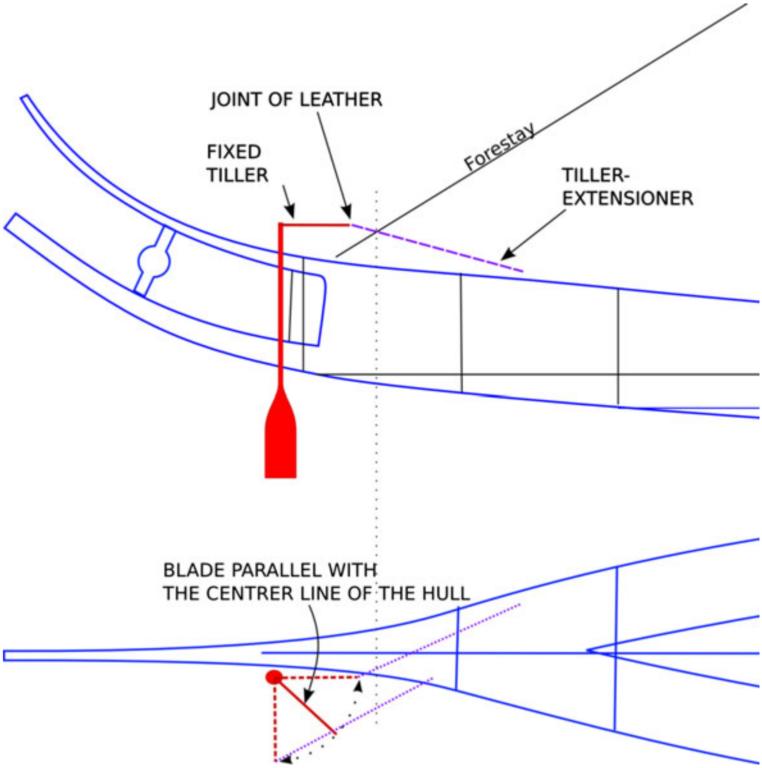

Fig. 21 The arrangement of the steering oars. Diagram: Björn Bengtsson

Olympic dinghy sailing to cruising and Viking boat experience, all of which ensured basic on-board sailing skills. It did however, lack any form of coordination prior to the trials.

Ballast 500 kg water ballast was carried on-board as safety in an effort to increase stability.

Performance and Manoeuvrability

Due to the rather erratic wind conditions and the fact that most of the sail trials were made in Dyvig harbour where trials were confined to sailing only short legs whilst having to keep a close look out for passing boats and anchored yachts, the conditions for learning to sail the *Tilia* were difficult. Despite this, a satisfying level of sailing was achieved.

One of the main concerns before these trials was that of the stability of the *Tilia*. The anticipation of the *Tilia* was that it would be very similar to the canoe or an Olympic dinghy, that is, very unstable and easily tipped over. In comparison however, the *Tilia* felt quite stable and crew members could easily stand in the boat or sit on the thwarts rather than on the floor boards, which was a real surprise, especially considering the extra weight of the rig (Fig. 24). It was also found very convenient to climb onto the horns in order to adjust the steering oars (Fig. 25). As for finding the overall balance of the rig, this was

Fig. 22 Dry sailing the *Tilia* in May 2006. Here the full size of the sail can be appreciated. The reefing system can be seen as a *lateral line* across the lower end of the sail. (Photos: Boel Bengtsson)

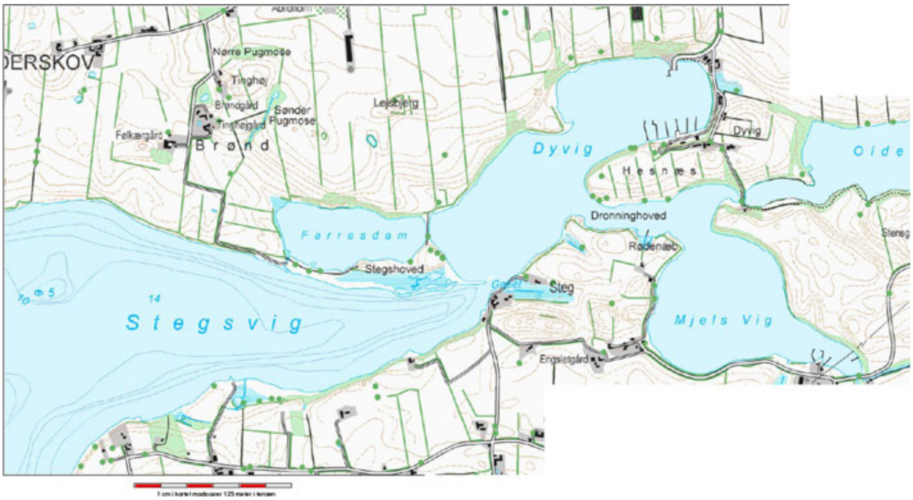

Fig. 23 The areas where the sail trials took place. During the first day we sailed around Dyvig harbour and even ventured out through Steg gap into Stegsvig

achieved through raking the mast forwards (and thus the centre of effort), by simply adjusting the length of the stays (Fig. 26). The very fact that the boat could lie in the water over night with the rig up, provides some sort of indication as to its stability.

In addition to the *Tilia* being far more stable than previously believed, the vessel heeled a lot less than anticipated when hit by a gust and, throughout the sail trials, it was sufficient to use one person alone to compensate for this. Furthermore, the vessel could heel a considerable amount without feeling unstable or close to a capsize and, in the lighter winds of the second day, the boat could be sailed much like a dinghy, slightly heeled in order to let the wind fill the sail more easily (Fig. 27).

The two steering oars proved a challenging new way of steering, which, given the length of the vessel and the fact that the two helmsmen could not communicate, would have required a lot more practice and time on the water to perfect. However, after some initial problems finding the right balance of the steering, this was much increased once the right

Fig. 24 Here we can see some of the active crew standing while controlling the sail, whereas some other members of the crew are comfortably seated on the thwarts. (Photo: Knut Valbjørn)

Fig. 25 Adjusting the forward steering oar. This shows the relative ease with which an agile crew member can climb the "horns" of the *Tilia*. (Photo: Knut Valbjørn)

balance of the rig was found and could also be controlled through active heeling of the boat. Once the steering was synchronised it worked very effectively and despite the small blades, the boat responded very well, and was subject to surprisingly little leeway. The few times when the rudders were not in harmony, turbulence occurred and hence sideways drifting. Once this happened, it was very hard for the helmsman to feel which way the blade of the steering oar was turned, forcing the aft helmsman to turn around and look rather than feel. Interestingly, had the shafts had a slightly squared shape just above the point at which the blade goes over into the shaft, which indeed the original steering oars found with the Hjortspring boat appear to have had, this would have been easier to avoid as the helmsman immediately could have felt when the blade was squared (Rosenberg 1937:88).

The basic handling of the rig and sail, such as hoisting and taking down the yard or gybing proved relatively easy and worked smoothly (Fig. 28). However, the fact that the crew was not very coordinated made any attempts for more advanced sailing hazardous. Thus, no tacks were attempted and no gybes were made in winds of 7 m/s and above. When the wind increased and the boat was sailing close to a dead downwind (with the wind

Fig. 26 *Tilia* on the second day of the sail trials in the light wind of Dyvig harbour. Notice the forward rake of the mast which is adjusted through lengthening or shortening the aft- and forestays. (Photo: Knut Valbjørn)

Fig. 27 Heeling the *Tilia* while attempting to fill the sail in the light winds of the second days trials. (Photo: Knut Valbjørn)

almost straight from behind), the sail started to move from side to side a couple of times, something which a more experienced crew would have been able to stem more quickly by tightening the sheets (ropes that control the sail) and perhaps by letting two people control the sheet. Pressing the course of the boat closer to the wind was another task that would have required better coordination and much more experience of *Tilia* under sail. An inexperienced crew, lack of time and unfavourable conditions makes it impossible to draw any definite conclusions regarding the overall performance of the boat. However, by studying some of the GPS sequences recorded during the sail trials and comparing them to the on-board compass readings as well as the wind readings from the tender, it is certain that considerably more would be possible.

Beginning with some of the early manoeuvring of practising gybes from the first day on the water, the *Tilia* was found to lose about 50 metres of height in each gybe (Figs. 29, 30). In between these gybes it appears that the vessel was able to sail at a 90° angle to the wind. This angle to the wind is further demonstrated by another sequence (Fig. 31), also from day one just after having paddled through the Steg gap into the more open waters of Stegsvig (where the wind shifts would still be significant but where longer legs could be sailed). Just before this sequence the top speed of 6.2 knots had been recorded, after which the *Tilia* proceeded on a starboard tack with a compass reading of between 270° and 288°. Meanwhile, the wind had a direction of about 330° but slowly veered about 20° to the right throughout the following 30 min.

The GPS track in Fig. 31 is marked as a dotted line and the on-board compass readings provided together with small black arrows. Surprisingly, there appears to be very little leeway, which some of the photographs taken during this sequence seem to verify (Fig. 32). There were times when, from the escort boat, it appeared that *Tilia* was sailing towards the wind but this is impossible to tell based on the GPS data, primarily because it was so hard to take accurate wind readings even from a stationary escort boat in the changeable conditions. However, as stated it is clear that the boat can sail without much effort at an angle of at least 90° to the wind and with a practised crew and with the reefs taken out of the sail might make some headway into the wind.

Discussion

Even though the sail trials in the *Tilia* left no conclusive information regarding her performance under sail, they leave little doubt as to whether she can sail or not. The size of the sail used was well within any safety margins and not at any time did more than one crew

Fig. 28 *Upper*: Sequence of taking the sail down on day two. Photo: Knut Valbjørn. *Lower*: Day one, paddling through the Steg gap and hoisting the sail. (Photo: Knut Valbjørn)

Fig. 29 GPS data for a sequence of gybes on the second day of the trials. During the sequence two instances were recorded (*A* and *C*) when the *Tilia* was sailing at an angle of 90° to the wind. The distance or height lost in each gybe (*B*) is about 50 m

member have to move his weight in order to keep the boat level. Furthermore, the technology of using integral cleats to spread forces from thwarts and internal frames appears to be useful also for spreading any additional strains from a mast and sail. The four integral cleats at the top of the end sections of the Hjortspring boat appear to have been strong enough to have been used not only for a trussing rope but also for attaching stays for the support of a temporary rig.

When it comes to the question of whether a sewn vessel such as the Hjortspring boat could have withstood the additional load from a rig and sail, the very fact that the on-water trials were carried out over 2 days, one of which was very windy, and was left in the water over night, proves it can. However, 2 weeks after the trials, after having spent time back in a dry shelter, some pre-existing cracks in the stern section of the boat were found to have grown lengthwise, causing it to leak (Fig. 33a). These pre-existing cracks were caused when the tree from which the boat was made, was originally felled, and had been mended using the same technique found to have been used for a similar purpose on the Hjortspring boat (Valbjørn 2003b:52, 54–55). As such repairs show, wooden boats would have been regularly maintained. In this particular case however, the planks were already weakened making it hard to deduce whether the lengthening of the cracks occurred because of the sail trials or had been built up over time as indicated by the photo of them (Fig. 33b). Wood is an unstable material and wooden boats that are taken in and out of water, causing the wood to expand and shrink, will inevitably develop cracks. Given the relatively thin planks, a fall by a heavy crew member could easily cause similar cracks. Whichever is the case, these trials show that a sewn vessel such as the Hjortspring boat can take not only the additional

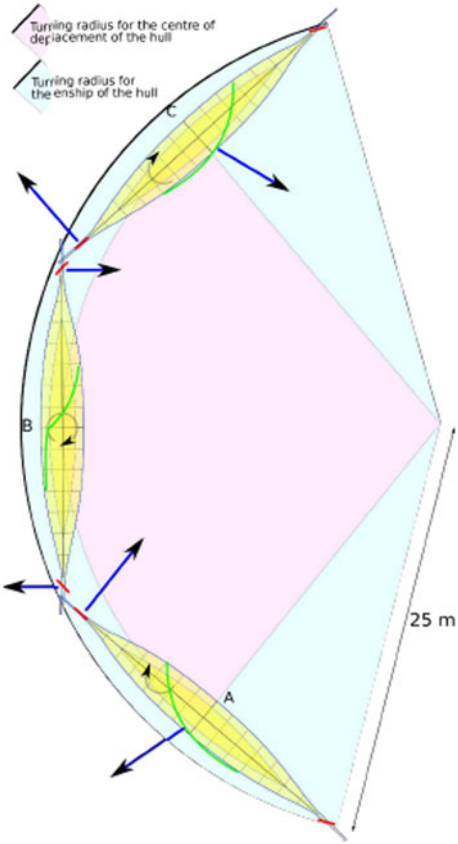

Fig. 30 A hypothetical drawing of the turning radius of the *Tilia* using two active steering oars. Even though it was made prior to the on water trials, it proved very accurate. Initially intended to illustrated the turning radius of a tack it can just as easily illustrate that of a gybe. *Position A*: initiating the turn. *Position B*: performing the turn, *Position C*: terminating the turn. (Diagram: Björn Bengtsson)

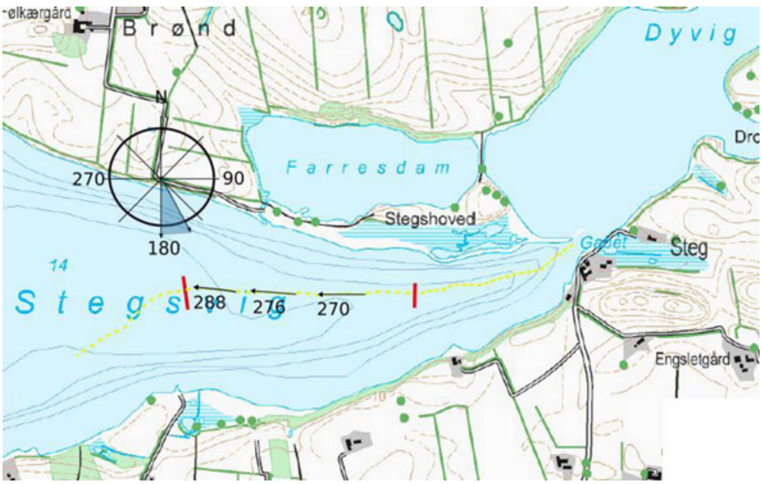

Fig. 31 The course of the *Tilia* is indicated with *black arrows* overlaying the *dotted line* of the GPS data. The wind direction, indicated by the *grey* area within the wind compass, slowly veered to the right (North) from about 330° to about 360°

Fig. 32 Outside the gap on day 1. A gust hits the boat in picture three of this sequence. Notice the *bubbles* in the water caused by the turbulence around the steering oars which can be used to detect leeway. (Photos: Knut Valbjørn)

load from a rig and sail, but also that a foldable rig can be handled with relative ease and without leaving easily detectable marks.

Perhaps the most intriguing result of the trials is the fact that steering oars with relatively small blades can be used successfully as a lateral plane (Brewer 1994:38–45) when sailing a long and narrow vessel. They would have functioned as an early type of keel which, when used correctly could have been very effective. It is also clear that fastening the steering oars onto the horns or beaks works satisfactorily when attached tightly (which can be done with a simple piece of rope), and that they are easy to detach. The ability to easily fasten and unfasten the steering oars would have been vital in preparation for landing or launching, which not least the trials in the canoe described above shows, something which is perhaps also depicted in some of the southern Scandinavian rock art. If attaching the steering oar on the horns as suggested here, the forces when sailing would be the largest where it is attached to the lower horn. A square form of the shaft such as indicated by one

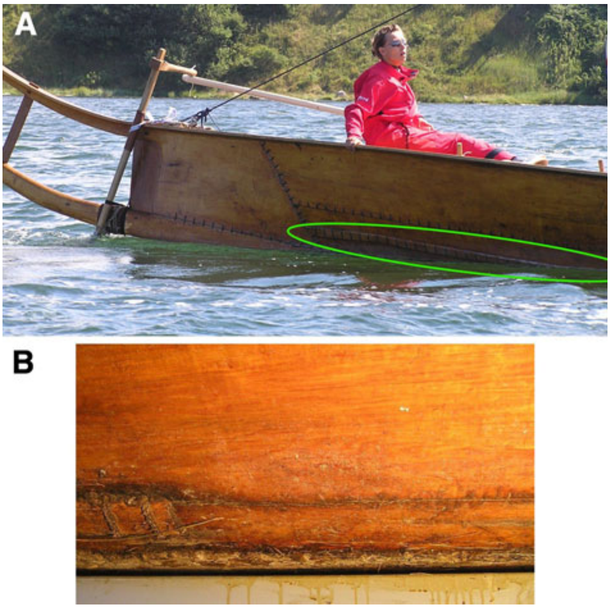

Fig. 33 **a** *Cracks* in the stern section of *Tilia* present in the tree from which the boat was made; **b** Close up of the crack which was found to have grown lengthwise, causing it to leak. (Photos: Knut Valbjørn)

of the steering oars found with the Hjortspring boat, would provide extra strength at this point and it is possible that a square form might also have made it easier to feel the direction of the blade when steering. It is likely that this was indeed the way in which the steering oars would originally have been fastened.

In addition to successfully demonstrating that it is possible to sail a Bronze Age type boat, these trials show that the concept can be transferred from a very small plastic vessel to a full scale reconstruction of a BA type vessel, in this case the *Tilia*. This despite the uncertainties regarding the curvature of the hull and size of the steering oars. The fact that the *Tilia* could be sailed without effort at an angle of 90° to the wind, an angle that might easily be improved upon if using a more experienced crew with more hours in the boat, indicates that the boat could have been sailed within a relatively large sector of a given wind direction facilitating the choice of route. Even if a more rudimentary sail had been used the same principle would have applied. If the wind changed in direction or speed, the rig could easily have been taken down and the boat could have been paddled, perhaps to a point from where it would be possible to continue by sail as was done during the longer canoe trip in the Gothenburg archipelago described above. In a similar manner, the masts of the Viking ships would have been taken down in favour of oars when the wind failed a 1,000 years later.

Conclusions

In view of the above it is not altogether strange to imagine that the sail might have been used and experimented within Scandinavia already in the Bronze Age, as indeed suggested by many rock art boat images. The imagery in question appears to peak around 1,300–900 B.C., coinciding with the peak of the rock carving tradition (Fig. 34) (Hygen and Bengtsson 2000:182; Kaul 1998:110; Nordbladh 1989:324). The sail at this time might not have been used all the time, but could certainly have been seen as an important complement to paddling, providing resting time for a fatigued crew, in particular over longer journeys across open waters. This suggests that the sail evolved on relatively small boats necessitating the use of low sails with a low centre of effort and low aspect ratio. Such a concept would have made early experimentation comparatively easy and it would have been a natural step to evolve rig and sail to any changes and developments in the technology of building boats and ships.

This article describes a series of experimental sail trials in Scandinavian Bronze Age type boats. The hypothesis behind these trials is primarily based on rock art boat depictions, experiences and evidence from the recent reconstruction of the Hjortspring boat, as well as reasonable assumptions concerning which fundamental factors would be needed to show whether a vessel could have been sailed or not. Based on these trials it is clear that sewn, round hulled vessels of the type we believe belong to the Scandinavian Bronze Age could have been sailed. This ability was achieved by the use of a steering oar in each end of the vessel, acting as a keel to minimize leeway, which surprisingly, could have had relatively small blades. When used together with a basic configuration of a low aspect ratio square sail on a simple foldable rig, the Bronze Age canoe could have been sailed in a very effective manner, possibly at an angle of 90° to the wind, if not more.

Of course, even if the rock art is depicting boats with sails, and even though we have demonstrated that boats of Bronze Age form could have been sailed, we still can not prove they were. However, instead of accepting the view that the sail only arrived a 1,000 years later we are surely justified in testing that assumption? Thus, the presence of masts and

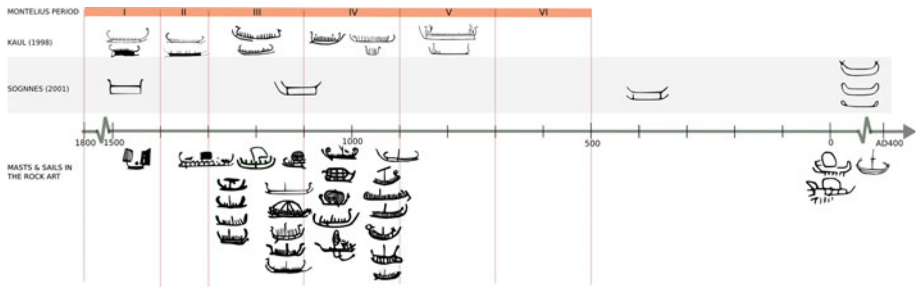

Fig. 34 Approximate time line for the rock art boats with mast- rig- and/or sail attributes. At the *top*, dated rock art boat imagery according to Kaul (1998:77), below which rock art boat depictions dated by Sognnes (2001:47) are inserted for comparison

sail-like features in Scandinavian rock art might not only indicate that the art of sailing was known at this time, but that it might also have been actively used.

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