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Cleaving White Oak (Quercus Petraea & Q.Robur) for shipboards used in viking-ship reconstruction in Scandinavia.

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Contents

1. Acknowledgements:

I would like to extend my gratitude to a whole score of people.
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The volunteers, I am sorry I cannot state each and every name from among your number, but you all know, through our shared laughs, shared sweat, shared clothing and discussions about the logs, the importance of drinking water for gut-health and pine-needle extracts, that we had a lot of fun. It is through your muscle, grit and spirits that all projects are possible. It is so easy to think of the “architect” or the head of a project when looking at a ship. But you, the workmen, the cooks, the myriad perspectives when looking at a log, are the reason building ships is at all possible.

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2. Samandrag / Abstract

Norrøne vikingskipsskrog blei bygd med kløyvd eik. Me veit om dette gjennom kunst og tekster frå seinare tidspunkt, såvel som frå arkeologiske funn. Me veit tilfallande lite om kløyving I seg sjølve.

I denne artikkelen spør eg:

- Korleis kunne dei norrøne ha kløyvd?
- Kva eigenskaper i tre påverkar eit kløyveresultat?

- Kvak an me seie overordna om kløyving, finnes det ein beste retning å kløyve frå I eik?

Dette gjeres ved å vise fram forskjellar i klyving fra toppen, sida og botnen av ein serie eikestokker. For å vise kvifor klyving fra kvar retning mislykkes.

For å oppsummera, Klyving frå toppen eignar seg der det er avsmaling gjennom stokken.

Klyving frå sida kan fungera risikoavvirkande ved tilfeller der det er kvist I veden, eller for å penetrere direkte gjennom kvisten.

Klyving frå top og botn er meir naturfallande når man har ei merg utav sentrum.

I stokker med langkrok fell det seg meir naturleg å klyve frå sida.

Klyving burde tenkast mindres om some in sanning å halde seg til, og meir som eit verktøy I kassen å bruka vidare.

I tilfeller der det var gode vilkår for kløyving, var det lett frå alle sidar, I tilfeller der det var vanskelege vilkår, var det vanskeleg frå alle sider.

English:

The Norse built their hulls from oak boards hewn from cleaved or '*rived*' logs. We know this through artworks and texts as well as archaeological finds describing the ships as well as their construction from the latter half of the early-medieval period. However, we know summarily little when it comes to the pre-production of hewn boards.

I ask,

- how could the Norse have possibly cleaved?
- Which properties in white oak affect cleaving?
- Which simple truths can be found of cleaving. Which direction of cleaving is best for oak?

This is done by showcasing the differences in cleaving from the top, side, and bottom of a series of white oak logs. Namely why cleaving from each direction fails.

To summarize the results. Cleaving from the top shines in cases where there is a large difference in the diameter at the top and bottom of the log.

Cleaving from the side can act as a mitigator in the case of knots or to pierce directly through a knot or burl.

Cleaving from the top *or* bottom falls more naturally in the cases where the pith is off-centre.

With a log bent like an arch, cleaving from the side fell more naturally. The direction of the cleave ought to be thought of less as an immutable truth and more of as another tool to extract as many boards from a log as possible.

We found that no direction of cleaving was inherently better in all scenarios. It is a case of risk-mitigation, which benefits from taking a thorough look at the log and making an informed choice.

In cases where the angle of the twisting fibres of a log is significant, all cleaving directions struggle and fail, in cases where there are few natural faults, cleaving from all sides succeed.

3. Introduction:

Ships are absolute wonders of wood-technology, requiring advanced knowledge of the material, how to process it, treat it, join it and maintain it. The Norse were master ship builders of their time, their advanced ships enabling exploration, trade and famously raiding. Ships of various sizes, but in the general shape of *Gokstad* were built locally in Scandinavia. The hulls were constructed with hewed boards of white oak (*Quercus Petraea* and *Q. Robur*) wherever it grew. We know from tool marks left on the finished boards, and preserved residues, a lot about their later stages of production. We know little about the early stages, pre-production and namely the processing steps associated with transforming a round log into pre-hewed pieces. One such method, namely the oldest, is “cleaving” or “riving”. To cleave an oak log, the current understanding is that the log is “initiated”, opening a “split-crack”. The split-crack is then expanded by driving wedges, of wood, stone or metal, into it with manpower. Once the split-crack has completely penetrated through the length of the log, you have got two halves of a log that can be further processed by hewing, into two wide boards or thick beams. To produce more boards from a single length of a log, you can cleave the two halves into quarters, and those further still into 1/8ths et cetera. This is what Finderup describes as a series of “mirror-cleaves” (Finderup T.S. 2022).

The high medieval period sees the spreading of water-power through continental central Europe (Shulman, 2022). The long-ship, would continue to see limited military use slightly past this point through levied freemen, called ‘Leidang’. Documented in law-texts produced by King Magnus VI Håkonsson (Rindal, 2024). People eventually adopted the water-powered saw in the 1500s here in Norway, earlier in Sweden and Denmark (Sandvig, 1931). This marks the end of the period in which cleaving oak was considered for larger production. Its use as feed for livestock, and other construction kept it relevant in the minds of the common folk, however (Friis, 1632). Cleaving of other trees for other purposes continues in areas less densely populated and further from rivers. Examples of use-cases for cleaved pieces, would include fence-posts, barrels, roof-spans in feed-sheds, structural components in hunters-lodges and other various small and large constructions whose sourced raw material, processing and construction would happen on-site see Godal & Renmælmo. It is through the continued tradition of cleaving other kinds of wood for these various purposes that we know much of what we do about the craftsmanship of *general* cleaving.

With *no* contemporary descriptions of cleaving, their tools and their preferences in raw material, we can still infer some knowledge from later descriptions, given that cleaving changed little from the early medieval period, until the late medieval period. Thankfully, the archaeological record informs us on the shape, size and angles of the hafts of their various tools. Archaeology is also able to supply us with finds which can give an insight into their preferred materials. As a result of the remarkable state of some of the original finds, simply looking at the end-face of any board, will help you place it in the cross-section of a log. Which can tell us something about ‘the how’ of its extraction. Looking at their side-faces we can see a preference for knot-free material. Also looking at the surviving tool-marks, can tell us about how it was hewed.

As there is no surviving continuous tradition of splitting oak for ship-boards, to gain a deeper level of understanding, a helpful source is the practice of experimental archaeology, and craft-science in general. Planke points to and discusses the necessity of creating a common language between craftsmen and researchers, see Planke & Lorentzen. Practical experiments, tempered with critical analysis, and communicated understandably to both parties is one such step. Experimental archaeology seeks to recreate methods of the past by experimentation and documentation. Craft-science seeks to document craftsmanship, documenting surviving structures, rediscovering their creation-story and their management over the course of history, to try to understand connections between the material, the physical forces and construction interlink. Craftsmen have, for over a century, created replicas in various scales and degrees of authenticity, based on ship finds from the turn of the millennium to the end of the early medieval period. These reconstructions were initially carried out by craftsmen in a time of nation-focused pride. A desire to preserve the knowledge of the craft of their ancestors, seemed foremost. However, some could not help but marvel at practical grounded wonders of the ships, as well as appreciate the historical value. For example, during an Atlantic crossing. On their way to the world-fair, the crew of 'Viking' noted that her hull, constructed in Sandefjord during the late 1800s, would bend and twist together with the roiling sea. The rim of the hull was written to have gone 150mm out of position and returned at the most. Like a spring, returning to position (Rasmussen, 1894). Viking, notably had a deeper keel than the original it was based on, and together with other differences, it makes for an interesting anecdote, though unsuitable to derive absolute truths about the original finds. As the field has matured from then, the newest reconstruction efforts have also sought to be done with tools based on contemporary finds and methods thought to have been used. The priority lies, of course, to use near-to contemporary tools and methods of production, where it is believed to influence the final result (Finderup T.S. 2022). One such believed meaningful method is cleaving and hewing to produce boards. Much can be learned during the course of these efforts and the testing afterwards, and work is continually done in both Sandefjord and Tønsberg in Norway and in Roskilde in Denmark.

The splitting of a round log into a group of boards appropriate for use in a ship-hull is an arduous expensive process. Splitting tens and hundreds of logs requires a lot of man-hours, attention to detail and knowledge of the material. A large diameter, straightness, low slope of the spiral-grain and lack of branching and knotting are all wanted properties by the professional cleavers. As these properties are seen in the original finds and are known to allow for the extraction of the most boards for the least effort and time, per length of log. Unfortunately, such logs, though in high demand by craftsmen, are hard to come by nowadays in Scandinavia. White oak is generally considered non-economically viable in Scandinavia. Many attribute a comparatively slow growth to Oak, when the alternative is Spruce. To attain the wanted characteristics, white oak has a relatively intense silvicultural need. There is also little knowledge on the specific impact each property has on the yield. Without knowing which controllable properties hold the most impact for cleavers, the silvicultural practices are further diffused. As such, little is planted, and natural stands are not intensively cultivated in Norway. During the early parts of the 1800s oak was planted on Visingö in Sweden and North-Zealand in Denmark , as well as planted all over in less organized fashion, to secure the respective crowns access to fleet-oaks. (Cameron, 2021). These oaks are of limited number, and suitably expensive to procure.

Due to this inherent lack of suitable material, and the suitable material having many years of invested effort, costs of procuring logs with wanted characteristics are quite high. This high cost puts strain on foundations and museums providing funding, and may even cause projects to be cancelled, or high-quality material to be out of reach for some reconstructors. Ways to lower overall costs, but still retain historical and educationally valuable results are therefore in demand. Methods to lower costs could include increasing supply. The timescales we are looking at, and the economic incentives needed, places this idea firmly in the camp of the infeasible, if we look to perfect logs. However, the supply can certainly be increased by 'lowering our standards', as imperfect logs are in far greater quantity, and cheaper. Methods to cleave less suitable logs more easily is therefore of interest, given that the resulting boards still retain an acceptable quality. On the efficiency-side, increasing the yield from a successful split log, increasing the chance of a successful split per attempted cleave, and time- and effort-saving measures during splitting, are all theoretically feasible. It is possible to intuit, that the way we currently cleave, due to being unrooted in longstanding traditions, will still have significant time and effort-saving steps yet to be found. As such, a deeper look into the methodology for cleaving is of significant interest in the eyes of the men who look to improve their craft. Knowing the effects on yield when cleaving using different methods, and identifying unknown links between yield, and characteristics is therefore of interest to museums and foundations alike. In this paper yield is defined as the volume of raw boards produced by a length of log, and the quality is analogous to the strength of the boards produced.

The paper is structured as a resource to provide an overview of the methods of cleaving in use and possible to use, and could as such act as a guide, read front-to-back. However, the appendix contains a collection of terms that are useful to know before reading, (See appendix item 1). First, I will outline the underlying philosophies of cleaving and theory regarding general cleaving, firstly the half-cleave, then the quarter-cleave and further. I will then follow up by illustrating the cleaving methods used by different professional cleavers. Then I will outline the registered variables on whole logs and how I crafted indicators of suitability for cleaving. I then, will provide cases to outline the methods I have used in this study specifically. I will do this by showing the cleaving of three logs, cleaved from different directions and using differing methods and going step-by-step. After showcasing the cleaving, I will outline the variables I registered, and how they were registered on half-logs, and quarter-pieces. Then I will illustrate how I crafted indicators of success using those cleaved-piece variables. Followed by an explanation of the analysis done. The results will be ordered by direction of cleaving. I will showcase the yielded planks, then going by most meaningful correlations between variables. The discussion will cover the outliers and veers, the limitations found in the data, methods and tools, what areas this study doesn't touch upon, what could have been done differently and which results are worthwhile and valuable.

Finally, the goals of this article are threefold.

- To help the archaeologists and craft-scientists, to try to answer how the Norse could have feasibly cleaved by experimentally testing cleaving from all sides using simple hand-tools.
- To help the wood-scientists, silviculturists and forest-owners to try to discover links between the properties found in logs, and their effects on the production of boards from a cleaved piece.
- To help craftsmen and hobbyists, to try to find overarching simple truths regarding how to cleave difficult logs using simple hand-tools. And possibly create a system for assessment of a white oak log in a universally applicable manner.

4. Methods:

In this part of the study, I will firstly detail what a cleave is, which underlying philosophies drive a cleave, what differs from a half-cleave to a quarter-cleave and beyond and which direction you can cleave from. Along the way giving indications for how to initiate. This section is known as "What is cleaving or splitting"

I will then outline the registrations done on whole logs and how to craft indicators of suitability. Providing ample figures and schematic drawings to provide context and explanation along the way. This section is known as the "Pre-cleave registrations".

I will then showcase actual cleaves done with differing directions of attack or 'DoA' and methodologies, to provide the context necessary to understand the limits of specific methods used in this study, and the difficulties that become apparent when the theoretical methods meet practical reality.

Then I will explain how I registered properties found in the cleave itself and on the pieces produced, and construct some 'Indicators of success'. I will also explain the lab-tests I did with taken samples, before finally closing off with a simple explanation of how I looked for correlations and analysed them. This section is known as the "Post-cleave registrations".

4.1. What is cleaving?

Roughly speaking, cleaving, splitting or riving is a combination of three factors. A philosophy, a step and a direction. In addition to these three factors there are a number of properties that further differentiate all cleaves from one another, there is no single pair of cleaves that are identical, though there are certainly similarities.

Splitting a log can follow two philosophies. Allowing the split-crack to develop independently or attempting to control the development. Respectively relenting control and assuming control. Further detailed in their respective sub-chapters.

The step of a cleave, is asking the question of "what am I cleaving?" Are you cleaving a round-log into halves, a half-log into quarters or a quarter-log into eights. This is detailed in two subchapters, one for cleaving out halves, one for cleaving out quarters and beyond.

The direction of a cleave is divided into three main directions. From the top, from the bottom and from the side. The side can be further divided into 'from the sapwood' and 'from the pith' when speaking about cleaving anything other than a round-log. This is detailed in the subchapter titled 'Direction of Attack'.

Many cleavers will attest to the remarkable quality of a split-crack in oak to follow along the pith in most cases. It is thought that this may be the characteristically large rays of *Quercus Petraea and Q.Robur* acting as a guide. Guiding a split-crack towards the pith, regardless of your wishes. The cleavers in Roskilde, who have for a number of years created replicas of the skuldelev-ships, utilize a method of cleaving with focus on providing pressure from the root-end of the logs. This is in contrast to the living traditions of cleaving softwoods, almost exclusively done from the top as attested during conversations with craftsman, researcher and author Jon Bojer Godal. In conversations with craftsmen and looking at the physiology of white-oak, you notice another opportunity however, taking advantage of the guiding rays of oak, that are so prominent, providing pressure from the side, along the length of the log, could be just as feasible to produce boards of good quality. But keeping with the simple and theoretical let's start with exploring the philosophies which might influence your choice of tools and approach. Starting with abandoning control of the split crack almost entirely to the log.

4.1.1. Relenting control

Philosophy number one, almost Taoist in its approach, is about abandoning control of the split, to the physical characteristics and limitations found in the log. This philosophy is most at home when the twist of a given log is ideal for the use case of the finished boards and the knots and disturbances are few. Abandoning control will leave you with intact fibres throughout the core of the board, providing a strength advantage. It starts by identifying the initial-crack, branching and bend in the log. After a subjective evaluation of the effect of the identified variables on the route a given split-crack will take and its effect on the intensity of labour you need to employ to split it, you specify a given 'direction of attack', where you initiate the cleave from. This direction of attack can be, from the top, from the bottom or from one or both sides. 'top' and 'bottom' is in relation to the direction when the log was still standing as a living tree, 'from the crown' and 'from the root' being another way of putting it. On half-logs and smaller divisions,

‘from the side’ can be further specified as ‘from the bark’ or ‘from the pith’. The direction of attack is the side from which the pressure is driven into. If a log is good quality, the pressure from one end is enough to split the entire log, but this is most often not the case. You will often notice that a split-crack, when initiated from an end, will almost certainly stop expanding, or start shearing off to the side as soon as the split-crack hits the first knot. To act preventatively, pressure must in some cases be mounted from the sides in addition to the end. Such a way of cleaving has been called a “hybrid”-solution in this specific paper. Initiating and cleaving exclusively from either the crown-end or the stump-end requires fewer wedges overall than initiating and cleaving from a side. ‘Initiation’ may be skipped entirely if the ends of the logs are particularly cracked, as it might be possible to simply expand existing cracks without creating a groove.
A way to predict the path of the split-crack, when starting from the ends, is to look at the initial-cracks twist through the length of the log. The initial-crack is always visible on either end of the log. The initial-crack will have twisted naturally through the length of it, and the centre of the split-crack will often twist by the same amount when going through the log. The initial-crack may therefore be used as an aid in splitting, it is already there and will guide your split to follow the natural twist of the log.
Another easy way to get a feel for the angle of the spiral-grain in the log, is to debark a length and to draw a knife, letting it slide alongside the length of the fibres, and seeing how far off-centre from an axially parallel line it goes, beware, the angle will certainly vary through the length of the log, and may in fact be a lot more than what you initially suspect in the areas you don’t inspect. If you’re worried about going through the middle of a particular branch or knot in the wood, it is advisable to establish your split-crack in such a way that the developing crack circumvents them, taking spiral-grain angle into account. If initiating from the side, it could be advisable to initiate through the middle of the branch or knot at the very beginning, to get it ‘out of the way’ in a manner of speaking. As it therefore cannot later ruin an otherwise good cleave.

Following the philosophy of relenting control, as you cleave, you let the split-crack develop as it will, providing as few corrections as possible to the path of it, only expanding the crack as it goes. This results in the fewest breaks in the fibres of the wood. Sometimes though, you will have to cut fibres if you wish to end up with two even halves at the end. There will almost certainly be bundles of fibres crossing the split-crack, regardless of how little you try to force a split-crack to develop. Theoretically, pieces cleaved using this method will be twisted identically to the spiral-grain of the sourced log, though further drying will affect this twist, as is well known to be the case by any who has ever dried lumber.

4.1.2. Assuming control

The second philosophy, is much more authoritative, it seeks to control the shape of the final board by cutting fibres and bundles throughout the development of the cleave. If seeking to control, you must be prepared to, in the worst case, fight the natural twist of the log every cm of the way by cutting bundles of fibres going astray from your ideal imagined splitting-line. You may be wondering what the difference is from just sawing the two halves from one another, as the fibres are cut no matter what. The difference is of course the tool-marks left behind and the resulting effect this has on the fibres either being ripped open by a saw-blade, cut over and crushed together with an axe or split apart using wedges, if the face you cut, ends up being the face of a board.

There are a number of reasons assuming control can be viable, common among them is a lack of 'suitable' logs. You may have a desire for a specific shape, but not a log with that shape. It is important to note, you must have access to time and workers, and intact fibres throughout the length are not that important to you. In Norwegian "*asking og vekking*" literally ashing and awakening (see appendix, item 1 for terms), is one part of such a method of initiating and controlling the split-crack in pine, presented to me and several others by Jon Bojer Godal in person at one occasion in Dovre and described on other occasions by several works, briefly in 'Skuldelevskibene - Vikingernes værktøjskasse' p.142 as "the Norwegian method", and detailed more thoroughly in a text by Renmælmo 'Kløyving av Tømmer med Konrad Stenvold' in a larger work by Godal. To describe it in my own words. You start by first debarking two 10cm wide strips opposite another along the length of the log. You then draw two parallel lines on each debarked area, between-which you cut out a v-shaped groove. The 'v-groove' must go through the sapwood and into the heartwood, to the edge of the imagined cross-section of your wanted board. According to how you want the final boards to look, the drawn lines along the length of the log may have a bend or arch to them, beware of the lowered strength as you *cross* instead of *run along* with the fibres. After you finish cutting the V-grooves out along both sides of the log following the drawn lines, you can start initiating the split-crack by hitting an axe or other sharp tool with a striking-tool along the entire length of the v-grooves. The initiated split crack is then further opened by driving wedges into one or both groves, if you do it from one side, drive the wedges evenly across the entire length of the log, if you do it from both sides, you can start mounting pressure from mainly one end, in most cases traditionally cleaving of all logs, save juniper was done from the top-end (Godal, 2023) presumably because of the extra elasticity of the crown-end, and branches and other disturbances guiding the crack towards, rather than away from the pith as it develops from the top. As the split-crack opens, cut fibres and bundles of fibres spanning the two halves as you are able, either with a dedicated tool like a fibre-cutter, an axe or a sharp iron of any kind.

Alternatively, stepping away from the strict method, trying to merely initiate the split-crack without first creating a V-groove has led to successful cleaves in this experiment. However, the ability to control the development of the split-crack was subjectively experienced as diminished, and the amount of work during cleaving was felt to have increased. This could be explained simply as an effect of the sap-wood representing more fibres wanting to drag the split-crack off-line from your imagined splitting-line. Keep in mind though, this is not experimentally proven, and as such must be taken with a grain of salt.

4.1.3. The half-cleave

Long before we had saws or even metal, presumably before we even had learned to ignite fire ourselves, one observant fellow saw that the broken branches they would come across sometimes were split by the ripping forces of gravity, or that reedy plants, when twisted, would split. And intelligent person that they were, they saw and understood the structure that was fibres, and considered what would happen if they wedged a rock into an already made crack. An unbroken tradition of 250 thousand years is then borne, of cleaving out from the end of a piece of wood, two pieces of semi-processed wood. They have with this innovation, from the same raw material greatly increased the speed at which their fires could grow and be controlled, and later this split would enable the extraction of two tool-handles from a single length of material. What a quantum leap!

A half cleave is simply the splitting of a single whole, into two halves. And can be done regardless of your philosophical approach to cleaving. The simplest and oldest method is most definitively cleaving from the ends abandoning control, as it requires no specialized tools beyond wedges of any kind and striking-tools. Assuming control would require a sharp instrument of some kind, patience and a mind prepared to the reality of having to cut fibres. The two produced half-logs, would then be used as is, or processed into “huggenbord” in Norwegian, or “hewed boards/beams” in English. The orientation of the beam seen in figure 1, below.

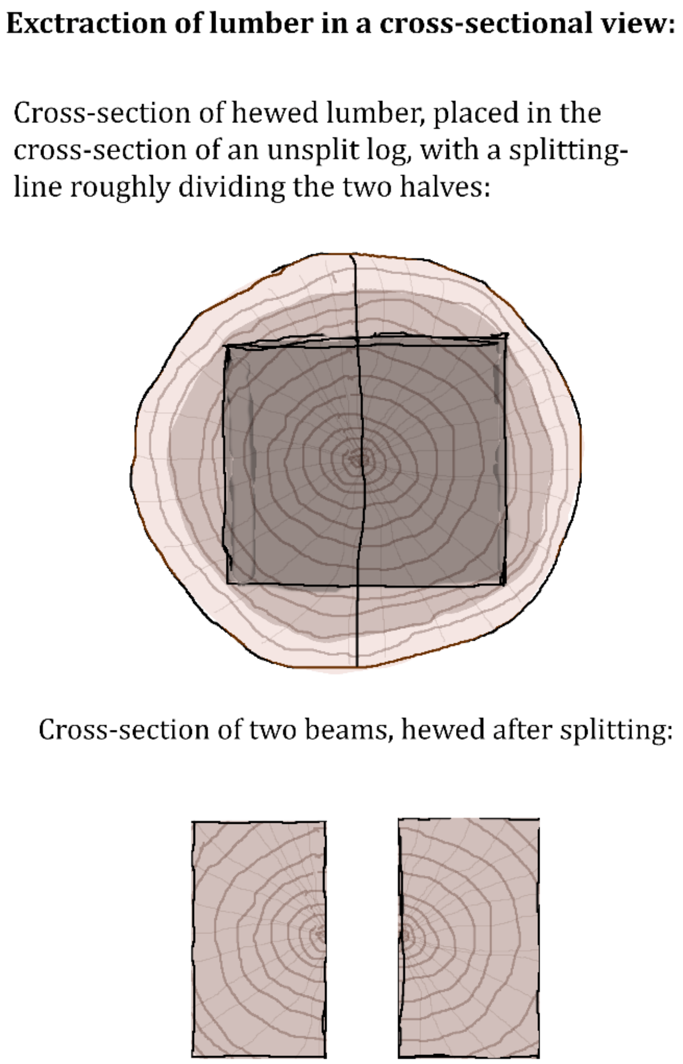

Figure 1, The extraction of two hewn beams from a log. Illustrated by the Author.

Note the location of the pith, centred on one face of the beam along its length, and the orientation of the growth-rings throughout the cross-section, the axis of thickness runs perpendicular to the growth-rings in the middle-portion of the beam. This orientation will inform the type of shrinkage-induced bend in the beam as a result of drying.

Hewing at this stage will of course leave you with some freedom to decide the thickness of the board. The maximum width of any given board is entirely dependent upon the diameter of the heartwood of the log.

4.1.4. The quarter-cleave, a step beyond.

If you desire to extract even more boards from a single log, you may cleave each half-log into two quarter logs each, and even further by cleaving to eights or sixteenth pieces.

The step from the half-cleave to the quarter-cleave, could summarily be called a half-step, in the sense that it is a rather short leap of logic to deduce that you can split a log more than once. However, it requires a distinct desire for structural components of a significantly smaller cross-section that are squared, or at the least, edged. For those areas of use without such a requirement, for example smaller roof-spans meant to tie straw to, it simply would have been easier to source smaller stems, branches and logs, rather than split and hew them out of a larger log, which requires much more felling- and processing time for little, to no benefit.

In the areas we do prefer hewed boards, mostly large structural components, or fine exact components, there are numerous advantages to having a square. It is easier to stack, for transport and trade, and saves a lot of dead weight that would provide unneeded structural strength. It is easier to physically handle when constructing, and will, generally speaking, not roll away or over you. Finally, in the case of ship-boards, it allows for water-proofing by layering various water-resistant materials like sheeps-wool between two relatively flat surfaces, as the boards swell the gap closes further and waterproofed hulls are born. Therefore enabling the construction of wooden hulls as we well know them. Where boats used to be sown and greased skin over bone or branch skeletons, they now become primarily structured around a flexible hull.

Mirroring the ease of the conception of the *idea* of splitting a half-log into a quarter, the actual *effort* required to cleave a half-log into a quarter-log could, in many ways, be considered lesser than a round log into two halves. There are numerous factors that ease the work, you have already produced a somewhat flat face, the previous split, which can serve as a steady surface to touch ground and prevent rolling. When initiating from the side, you have a defined middle-line of the remaining half-circumference. When approaching from above or below, you're only required to develop the split-crack in a piece that is now a radius wide, as opposed to a diameter wide. Finally, you have all the tools necessary for the job, regardless of your philosophical leanings, considering you just cleaved a whole log presumably following your subscribed philosophy.

If you decide to hew forth boards from lesser pieces the cross-sections of the boards will fall as seen in figure 2 below. Take note of the location of the pith being outside the boards completely, an unusable centre, as opposed to how it was placed in the previous illustration. Also take notice of the very distinct reduction of the overall size of the produced boards, in comparison to the previous illustration. Please also note the orientation of the growth-rings running parallel to the axis denoting the thickness of the board, as well as the rays running parallel to the axis of width.

Exctraction of lumber in a cross-sectional view:

Cross-section of numerous hewed boards placed in the cross-section of an unsplit log, with denoted splitting lines shown.

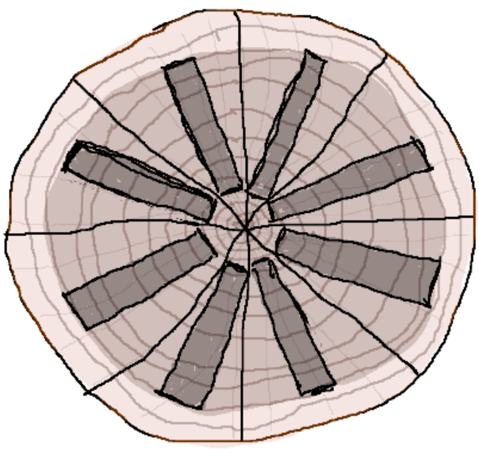

Figure 2, Cross-sectional view of hullboards layered on a whole log. Illustration by Author

The iterative nature of cleaving half-logs into quarters, quarters into eights, eights into sixteenths etc. means that an explanation of the cleaving of the previously mentioned pieces would be redundant. Suffice to say, past the quarter-cleave the methods don't change, save the consideration for the structural integrity of the piece during the cleave. You are simply much more worried, when splitting out a sixteenth piece, that it will have a check that enables a shift following along a growth-ring, or that the split crack will shear off to the side, than when cleaving forth a quarter-piece.

4.1.5. Direction of attack

The Direction of Attack, or 'DoA' is defined as the direction the log is initiated from, force is mainly applied from, and wedges are mainly driven. It is the source of much discussion and has been sought understood for a long time. In reality, the direction of attack is very fluid, as pressure is usually mounted from multiple directions to deal with a number of problems arising during cleaving. Cleaving is no simple mathematical operation, it is a series of methodical choices to best meet the questions a log asks of you. Seen in figure 3 below is view of a half-log and a quarter-log suspended dramatically in the air to illustrate the different directions that could have spawned them. The last cleaved surface is shaded. Please note that the letters correspond to a direction, 'T' for Top, 'B' for Bottom, 'S' for side, 'Ss' for Sapwood-side and 'Sp' for pithside.

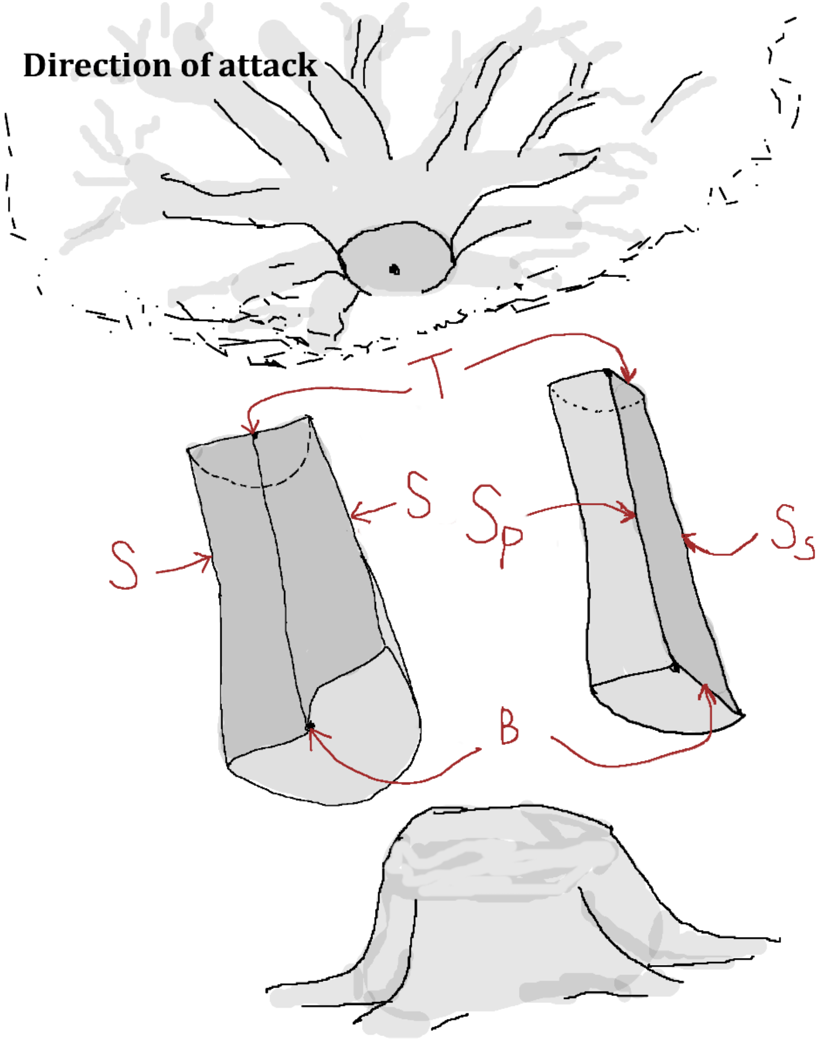

Figure 3, Directions of attack to produce a half-log and a quarter-log.

As an extra notice, cleaving from the pith-side was not conducted during the course of this study. This was after we conducted a short preliminary experiment and found the method difficult and time consuming compared to the three other sides. Thus pithside will not be mentioned outside of sporadic comments to its potential from here on out.

4.2. Pre-cleave Registration and Indicators of suitability

Data was collected in several groups over the course of the spring of 2023 and the spring of 2024. The data collected over the course of the spring of 2023 is referred to as 'subset 1' and consisted of 6 logs of 30-50 cm diameter at 5 meters length. Cleaved using a philosophy of relenting control to quarter-pieces, using a randomized drawing of the direction of attack. Data collected over the course of the spring of 2024 is referred to as 'subset 2' and consisted of 5 logs of between 40-60 cm diameter at between 3-5 meters length cleaved to halves using a philosophy of relenting control, using a randomized drawing of the direction of attack. A single other log, referred to as the 'Meginhufr' log at 70cm under bark and 15,5 meters in length, was cleaved using a philosophy of assuming control and specifically using cleaving from the side, but otherwise registered in the same manner as the rest of the logs.

Registrations were done on logs before cleaving, as well as after. The properties registered before cleaving will all be outlined in the appropriate sections. The registration of properties before cleaving are illustrated in accompanying figures 4-6, as the properties are discussed.

In addition to registering variables which describe the log in a simple manner, I will outline indicators of suitability in this section, which together with indicators of success, which I'll outline in the section covering the post-cleave registrations, form the basis of the analysis-portion of the paper. The indicators of suitability build upon registrations done on whole logs, the indicators of success build upon the registrations done on cleaved pieces.

4.2.1. Whole log/Pre cleave registration

Whole log or Pre cleave registration was carried out using mainly a tape measure and a knife. Though a piece of string or twine will be of aid in certain scenarios. It takes some inspiration from the Norwegian measurement standard used by sawmills in the assessment of roundwood degradation and features, see EN-1309. Visual strength-grading was also considered, however concern over the reliability of using standards devised for boards spruce and pine of a certain thickness being used on quarter-logs and half-logs of oak, meant this was not conducted. These measurements are done in this paper to produce 'indicator' variables, that could theoretically be evaluated before the log is bought. Whole log registration also includes the determination of the direction of attack from which the cleave proceeds.

The length of the log is measured equivalent to the standard for length-measurements done under document “B1 Målereglement for Sagtømmer” from Norsk Virkesmåling. Figure 4 below outlies the common cases.

1. A regular log with non-angled cuts.

2. In the case of an uneven cut, or a cut at a steep angle, you measure from any point on the imagined circumferential line going through the highest point at the stump end cut, to the equivalent point on the imagined circumferential line going through the lowest point at the crown end cut.

3. When measuring the length of an arched log, the length is, in this instance, measured along the side-face of the arch. Laying the arched log on its side, so that it is arching parallel to the ground, we measure the length following the topmost-part of the edge of the log, as best we are able. In this endeavour it is easier to use a piece of string, laid on top along the length, and later measure its length outstretched, than to bend the measuring tape in a perfect replica of the natural arch of the log.

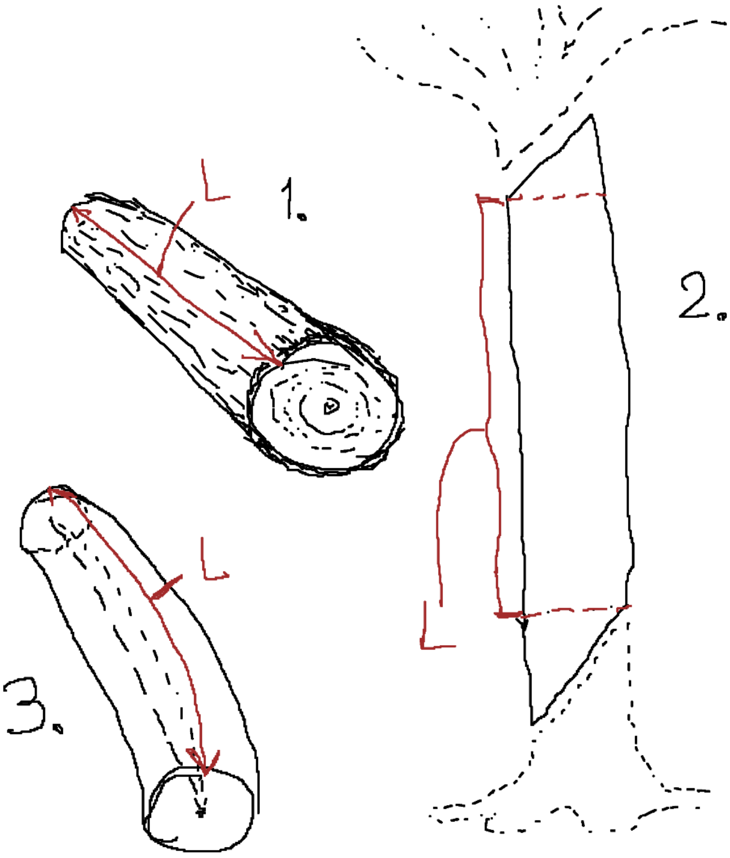

Figure 4, An illustration by the author of how to measure length on a log, in different circumstances.

The diameter of the log is measured at the cut-faces at the top and bottom. Both diameter under bark (D_UB) and the diameter of the heartwood (D_HW), see figure 5 below. Each type of diameter is measured twice, with a 90 degree angle between them, and both measures for each diameter-type are written down.

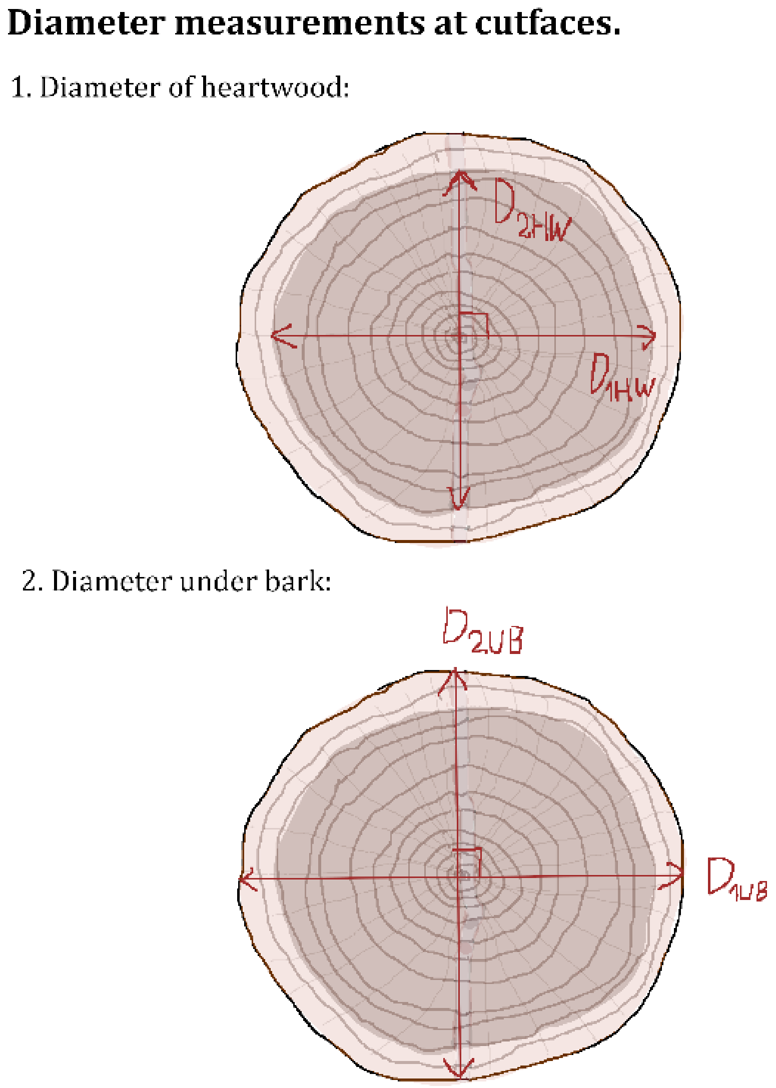

Figure 5, Illustration by the author. Diameter measurements taken at the cut-faces.

The angle of the spiral-grain, or 'twist' of a log is measured according to the standards set by NS-INSTA 142. By debarking a strip along the length of the log at least a meter long. Starting at the highest point of the circumference at one of the ends, draw a line to the highest point of the circumference at the other end, when the log is laid flat on the ground. Take a knife or other sharp implement and drag it along, following the slope of the grain along the log. Note the deviation from the drawn line, to the scored line at the 1-meter mark in centimeters, and whether it is positive or negative, when deviation to the righthand side of the drawn line is defined as positive. Where the log has a notable difference in twist at its root and crown end, do the test twice, once at the top, another at the bottom, and note both deviations from the straight line, see figure 6 below.

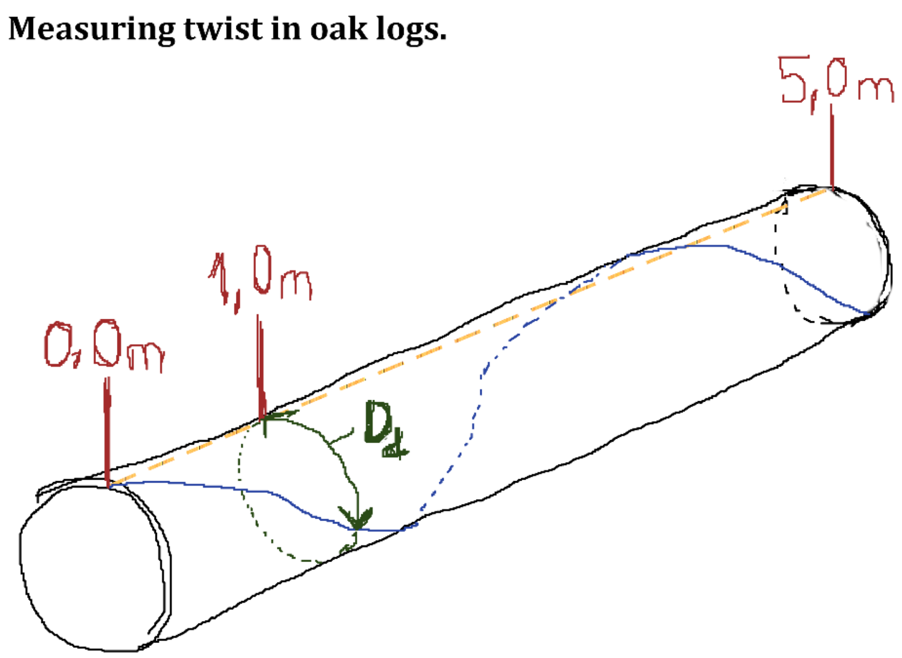

Figure 6, Measuring the distance of deviation (Dd) (green) between a straight line (yellow dotted line), and the actual twisted fibre (blue curve) on a log. Illustration by the author.

The direction of attack was registered as the final variable in pre-cleaving in the field. And was randomly drawn for all logs save the 'Meginhufr'. The direction refers to from which end or side pressure was initially mounted from and, when possible, *only* mounted from. When possible, no other sources of pressure should be utilized. Though if cleaving is impossible to accomplish without applying force from another direction, additional wedges can be driven from another direction. In the case of initially providing pressure from the top or bottom, extra pressure can be mounted along one of the sides, if this proves impossible still, the pressure can be mounted from the other side, though all cases of additional wedges along one or more sides, must be documented as 'hybrid'-cleaves. In the case of initially mounting pressure from the sides, pressure can additionally be mounted from either the top, or bottom end. Though this must also be noted as a 'hybrid' cleave in the post-cleave registration. The initial direction is specified as either, from the 'Top', 'Bottom', or 'Side'.

When we cleaved two sister-pieces, produced from a previous cleave e.g. a half into a quarter, we randomly drew a pair of different angles of attack (e.g. top-bottom, top-side, bottom-side) and then began the cleaving process once more. Cleaving the two according to the directions drawn. Once they had been split in half again, we repeated the paired drawing process and cleaved iteratively down to the smallest step we could conceivably cleave and still hew out a usable hull-board, due to the small diameters of Subset 1, this was down to quarters. Due to limited time, this was down to halves for subset 2. Due to the intended pieces being extracted from halves, this was down to halves for the 'Meginhufr'-log.

Alongside dimensional registrations, systematic sampling for the purposes of dry-density determination was conducted by gathering cut-offs of various sizes from logs of subset 2. The sampled pieces would be from the top-ends and bottom-ends. The samples would be dried and weighed, and wetted and weighed to gather information on the dry-density and wet-density, taking inspirations from the standards of NS EN 13183-1, for the drying, and from 'Treteknisk håndbok' to measure density at various moisture-levels. As the different logs had an unknown time of felling, unknown time of decay, various degrees of infection by fungus rotting away at the sap-wood and cleaving took place over a period of time that enabled the seasons to do their work. Measuring 'basic' density was not done. As the pieces would not be able to be measured in the field for a 'raw' measurement, and thus would be meaningless.

The samples were only collected from subset 2. They were dried slowly at first over the course of the spring of 2024, with a final 2 weeks in a climate-controlled lab and 3 days in a drying-kiln. For the samples that had sap-wood attached, I removed the sap-wood by cleaving it off. I then measured the dry weight and -volume by first placing the individual samples on a scale, before wetting the surface of the samples, drying this off and then submersing the sampled pieces into a container of water on a scale, to measure the weight of the displaced water when the sample was fully submersed and suspended in the liquid. I then fully submersed the samples for a week before remeasuring the weight and volume. Some samples were so resistant to moisturizing by submersion, that I extended the submersion by another week.

Indicators of suitability

After I've gathered data on the log-level, I can start to create 'indicators of suitability', specifically for cleaving. Indicators of suitability are the ways in which the log itself looks, which can easily be seen, but which traditionally have been difficult to quantify. Parameters such as diameter at the top, might give some indication of suitability of cleaving and is easy enough to gather once the tree has been felled. But any craftsman will tell you that it is the whole of the log that speaks to you, and not any one single parameter. The indicators are thus crafted to be easily recognizable by craftsmen, and easily quantifiable for research-purposes, thus bridging the gap between the real experiences and gathered knowledge of craftsmen and the rigorous demands on methodology of research. In this section I will therefore aim to showcase the different indicators which logically would have some real connection to the results of a cleave, and how to get to these indicators from the specific variables we have gathered.

Diameter in the top-end can, as stated, by itself give some indication of suitability. After all, it is usually the smallest diameter found along the length of the log and can thus serve its purpose in providing a 'restriction' at the lower end of the scale. It will therefore be tested alongside other indicators of suitability. Defined as the average of the two sampled diameters at the top-end.

$$D_{topavg} = \frac{D_{1top} + D_{2top}}{2}$$

The 'Stoutness' of a log, or better put, the diameter in relation to the length, is a simple, easy to measure and perhaps 'good enough' indicator of suitability, given that you exclude the obvious faults found in a set of prospective logs.

$$Stoutness = D_x/L$$

Top-diameter is, as stated previously, naturally more indicative of a restriction, than the bottom-diameter. As such, top diameter divided by the length can be thought to be the better indicator among the choice of the *many kinds* of diameters D_x. To be safe however, both 'bottom-diameter divided by length' and the 'average of the root- and crown-diameters divided by length' are tested alongside the crown-diameter.

The 'Narrowing' is the reduction in relative diameter per meter, and is defined as the difference in diameter in relation to the root-end-diameter, divided by the length up-to that initial diameter. It is most easily calculated using the top-end diameter and the length of the log.

$$Narrowing = \frac{1 - \frac{D_{topavg}}{D_{bottomavg}}}{L}$$

This type of form-factor is definitively expected to have an implication upon the ways we cleave. A very narrow-tipped log will more often have the split-crack veer-off, is the implied knowledge gathered from the cleavers. The crafted indicator provides a mathematical way of expressing the narrowing of the cross-section in logs of any size.

The 'ovality' of a log is also implicitly believed to have an impact upon the cleave. I find it pertinent to arrive at an indicator that is applicable to a wide array of logs, as such it needs to be relative. To reduce the amount of head-scratching that will naturally come from a series of indicators I find it equally pertinent to arrive at a single indicator for each phenomena. To test for the simplest forms of the ovality in the top-end (1) and the ovality in the bottom-end (2), you simply take the absolute value of the difference.

1. $O._{top} = |D_{1top} - D_{2top}|$
2. $O._{bottom} = |D_{1bottom} - D_{2bottom}|$

To make it a relative measure, the ovality needs to be in relation to the average diameter at the given cross-section (1 & 2).

1. $Rel.O._{top} = \frac{O._{top}}{D_{topavg}}$
2. $Rel.O._{bottom} = \frac{O._{bottom}}{D_{bottomavg}}$

We then take the average of the two, to get a single indicator. Which I'll take the liberty of addressing as simply 'ovality' from here on.

$$Ovality = \frac{Rel.O._{bottom} + Rel.O._{top}}{2}$$

The 'distance of deviation' from a straight line of the grain of the wood, measured the same way as 'twist' through INSTA-142 (Standard Norge, 2009), as previously defined, works as a good indicator of twist in logs of comparable diameters. If the dataset contains varying diameters however, a relative indicator of twist works better. This requires the least amount of math by measuring the circumference at the 1-meter mark. However, due to limited time, and due to us already having collected diameter-data, we have no need to measure it directly.

Assume a linear decrease in diameter along the length of the log, and a perfectly circular log, and we can easily estimate the circumference at any point along the length of the log. We find the circumference at the ends of the log, if we multiply the average diameter at the bottom-end (1), and at the top-end (2).

1. $C_{bottom} \approx D_{bottomavg} * \pi$
2. $C_{top} \approx D_{topavg} * \pi$

We can then find the circumference at any point by taking the difference in circumference at the bottom-end and the top-end, dividing by the length, and finding the increase or decrease per meter. Our circumference at 1 meter from the ends, by (1) 1 meter from the bottom-end, and (2) 1 meter from the top-end is:

1. $C_{1m \leftrightarrow bottom} = C_{bottom} - \frac{C_{bottom} - C_{top}}{L} * 1m$
2. $C_{1m \leftrightarrow top} = C_{top} + \frac{C_{bottom} - C_{top}}{L} * 1m$

An indicator of twist, enabling comparison across diameter classes, which I'll simply call 'twist' is then calculated by simply dividing the 'distance of deviation', D_d at one meter, as measured in subsection 4.2.1., by the now calculated circumference at the one-meter mark C_{1m}:

$$Twist = D_d / C_{1m}$$

This indicator is notably a relative measure, which describes a portion of a circumference. Notably this indicator can therefore easily be converted to degrees or radians by respectively multiplying by 360 or 2π.

4.2.2. Other registerable sources of trouble during cleaving.

There are a number of other properties that are simple to observe, which are known by cleavers to have a large impact upon the cleave. Knots, Branches, off-centre-piths, root-legs, rot and checks to name some that were registered when found and counted when applicable. Burls and bumps in the surface of the sapwood also provide a source of disturbance which can drive the split-crack to either veer, or require cutting fibres to correct. These variables are easy to spot, and thus a cleaver of any worth will avoid these with a passion. However, there is a value in observing which variable is primarily responsible for a cleave failing, as such any time a split-crack veers an explanation is naturally sought and some kind of reason can usually be attributed to either twist itself or one of these stated variables. In the subsection regarding registrations post-cleave I will also detail which sources of trouble lead to certain issues in the split itself.

4.3. Examples of cleaving

To collect data for this study, a series of cleaves were conducted. These cleaves consisted of collecting data in three stages. On whole logs, on half-logs and on quarter-logs. And it consisted of collecting data before a cleave, during a cleave and after a cleave. In this section I will detail the ways in which specific logs were cleaved according to a philosophy of relenting control and cleaving from the top and side, Titled DoA: Top and DoA: Side, followed by their respective log and subset-numbers. Included in this section I will also detail a walkthrough of the cleaving of a log for the production of two "Meginhufr" or "the thick long board", by a cleave from the side under a philosophy of asserting control, Titled DoA: Side Meginhufr.

4.3.1. DoA: Top, Subset 1, Log nr 1

Log nr. 1 was a small log, though the largest of subset 1, and a fine log. It had been stored outside for a number of years estimated to between 6-9 years by the craftsmen, as the sapwood had clearly begun to rot. As the log was inspected it was clear to see that it had a low to no degree of twist <1cm/m, no branching and few if any knots. In other words, a good log, if a bit on the small side for producing good-sized boards. When splitting from the top, we began by identifying the initial-crack, at the top and bottom end. Discovering that the initial-crack had a similar slope on both ends, we preliminarily concluded that the internal twist of the log was as uneventfully straight as the twist in the outer portions of the log. That in mind, we decided that expanding the split-crack of said log was as good of a strategy as initiating at any other angle, if not better, as we then needn't worry about a crack running through our split portions.

Initiation from the top

As the reality of this split was very much tied to expanding the initial-crack, a line was drawn on the cross-section of the crown-end. Suffice to say, it was no different from any other initiation from the ends. By scoring an opening no deeper than 5cm, with an axe and hammer in a straight line, through the pith.

Cleaving from the top

Cleaving was done by striking initially metal wedges into the initial crack, then iteratively larger and larger wooden wedges finally culminating when the opening got so large, so as to fit spacer-blocks to further drive from the top, see figure 7 to the right. The log had a satisfying hollow thunk with each strike as we neared the completion of the split. The final split happening after the log is allowed to rest. Tension placed by the spacers and wedges finding its release by gradually splitting autonomously at this point. This particular log was remarkably easy to cleave, needing no intervention, no fibres to be cut, no extra pressure from the sides and otherwise presenting as a textbook example of a cleave. It really was a perfectly satisfactory log in all regards but dimension. This log represents the very real possibility of encountering a log that could be said to "want" to be split.

Figure 7, Log nr 1 of subset 1 is allowed to rest after being pressured, the sound of crackling tension being released is continual as it nears the completed split by itself. No further strikes are necessary before this log splits open on its own. Picture taken by Author.

4.3.2. DoA: Side, Subset 2, Log nr 4

Log nr. 4 laid on supports raised from the ground, enabling easy visual inspection of the entire log. Subset 2 consisted of logs of medium to a large diameter with a lot of faults, namely branching, checks, knots, large degrees of twist and arching and bend.

During the inspection of Log nr. 4, as we had drawn the side as our direction of attack, enabling a large degree of initial control as to where the split-crack will originate, we noticed that we had an opportunity. As the log had a medium degree of twist >5 cm/m <10 cm/m, and most knots and branches were concentrated in one half. We could theoretically produce a half-log without branching. We therefore opted to try to "sacrifice" one half of the log, so as to produce another that could yield a full length beam or board.

Initiation from the sides

Because we opted to try to separate the half with branching and knots from the half without, we needed to lay the imagined split-crack so as to circumvent several branches. We identified the critical points at which we *needed* to lay the split beyond, or critical points, for the split-crack to pass successfully, specifically nearby the branches and knots which would be closest to the split-crack. Then we aided one another in the assessment of its feasibility, as one held at the critical points, another went to the end of the log, to gain vantage. After a visual assessment we found points that were at approximately opposite ends of the log circumference, and still outside the boundaries of the critical points. We then started initiating at those points. As we follow a philosophy of primarily relenting control of the split-crack to the log, we initiated by scoring a shallow groove around 4 cm deep, using a hand axe and hammer, along the natural twist of the fibres following the length of the log. This was done by first laying the edge of the axe parallel to the fibres natural inclination, the through-line of the axe-head oriented towards the pith. Secondly you strike the axe-head into the wood with a striking-tool. Each strike will separate the fibres present in the sapwood from one another approximately one cm in front, and behind, of the axe-head. This opened groove would set the angle and direction that would inform the next strikes after loosening the axe-head from the sapwood. This step was time-consuming, and the position was awkward to work in, as the initiation was done horizontally along the length of the log, rather than the classical vertical initiation. This awkwardness could probably be avoided by simply turning the log so that the initiation is done in a vertical fashion. The task was made slightly less awkward by having the log laid on a raised bed. To draw a cautionary tale from this anecdote, we noticed a bit later along one of the scored grooves, that the axe had been too angled away from the centre. This introduced more problems with spanning bundles of wood-fibres, that could have been mitigated. This issue can partially be explained as a combination of the awkward working-angle and the pith being off-centre. But foremost, the larger the log is, the more difficult it is to angle the axe-head perfectly. Below in figure 8, you will notice a finished initiated log nr. 4.

Figure 8 Log nr 4 of Subset 2. Laying initiated and ready for cleaving, metal wedges have already been struck into the points along the initiated line from which the cleave will proceed. Namely at the most critical points from which failure or success is achieved. Note the clear proximity to the broken branch. Picture taken by Author.

Cleaving from the sides

After initiating a line, metal wedges were driven into the line at points closest to the most prominent branches. An ounce of prevention is worth a pound of a cure, as they say. Starting at the points most likely to cause problems if the split-crack were to run into it at a later point, works as a preventative measure. We then let the split-crack develop as it would from those points. As larger wooden wedges are able to be placed next to the metal wedges, we naturally reposition the metal wedges further out along the split-crack, and drive both metal and wood. As always, cutting fibres that hinder the expansion of the crack. As we continued eagerly along the one side, the split-crack penetrated deeper than the pith and started wanting to exit the other side. Quite naturally for the log, and inconveniently for us, not along where we had previously initiated. As such, we turned the log, and started cleaving from the other side, correcting it. And trying to prevent a crooked cleave. See figure 9 below to view the situation before and see figure 10, to view the situation after starting the cleave from the other side. Note that the log is turned roughly 60 degrees clockwise between the taking of the photographs.

Figure 9, Log nr 4 of subset 2. A split-crack gone past the pith into an already extant crack that was presumably created from the handling of the log.

Figure 10, Log nr 4 of subset 2 Wedges are starting to be driven from the other side to prevent this development from spreading further down the length of the log. A handaxe at the end of the initiation process is seen having produced the pre-cursor to the wanted

In a way, cleaving from the sides is much like a waiter balancing trays of half-filled cups and jugs. Just as the waiter must be conscious of the amount of weight placed on either side of his palm and grounding forearm, regardless of the amount of earthenware, we as cleavers must be conscious of the expansive force exerted by the wedges on either side of the pith. Otherwise, like a tray clattering to the ground, and shards laying on the floor, a split-crack will penetrate across the pith and leave you with a jagged “shattered”, or “pie-slice-like” split-crack, when seen from the ends. Seen below in figure 11 is the split-crack penetrating past the pith. Probably due to a combination of lacking counter-pressure, the off-centre pith, some twist and pre-existing cracks and a number of other fibre-disturbances invisible to the human eye.

Figure 11 Log nr 4 of subset 2, The split-crack is exending as far as it is able, Without a group of wedges on the other side to act as a guide, the split-crack opens ‘willy nilly’, even forking and “shattering” the cross-section. A palpable dissatisfaction is voiced by the team of amateur cleavers, me included, at this result.

4.3.3. DoA: Side, Meginhufr.

In the forests near Tønsberg a specific tree was chosen on the private property of the Wedel Jarlsberg family, to serve to become what is known as two “Meginhufr” in the efforts to make “Saga Gokstad”. Saga Gokstad is the latest in a line of historic reconstructions modelled after the historic find at Gokstad. The Meginhufr are the thickest boards found in the hull, placed mid-ways up the hull and are meant to serve as the chief reinforcers only second to the prow. They are necessarily thick and strong, and quite long. And are hewed from half-logs, like beams, instead of being hewed from a 1/8th or lesser piece.

Selection and felling

The specified wanted measurements of the finished Meginhufr, were 15 m length 30 cm width at the mid-point and 15cm width at the ends. The thickness aimed for during rough-hewing was approximately 5 cm at the ends and 10 cm at the middle. Requirements for the log which the Meginhufr would be hewed from, were therefore accordingly at least 15m in length, and a comfortable 30 cm in top diameter, as well as for little to no twist, no branching that would weaken the boards and few knots. Because of the requirements posited, the standing tree marked with a band, as seen in the middle of figure 12 to the right, was chosen. Work had to be done to ready the felling-site for the log. First finding where would be most appropriate to lay the log down, after seeing an area with no large trees for the log to snap against. A rope was then looped a good ways into the crown to provide tension to prevent back-fall. Brush was cleared, smaller trees that could complicate matters removed and half-rotted logs in the way rolled to the side.

Figure 12, The felling-direction is being evaluated for the selected tree to produce the Meginhufr, behind the man with the off-white jacket. Note the lack of branching for a portion of the stem, straight growth and and satisfactory dimensions. Photograph by Author.

The tree fell into the cleared area after an hour of labour. After the tree was felled, the crown-end of the log was cut, by chopping off a fork in the stem, and a large branch a meter and a half below the fork. In all, 15,5 meters of length from the cut at the root, to the cut at the crown. Enough for some leeway in regards to faults at the ends. A felling crack at the root-end, as well as the split piths of the fork at the crown-end both going approximately 20-30 cm along the length into each end.

Inspection, debarking, grooving and initiation.

The log presented a few issues, despite looking very promising from the ground before felling. The twist was practically near zero at the root-end, but the last 3 meters or so of the log had a twist of 10 cm->/m. Along with this, we quickly discovered knotting and some bend in the upper end of the log. Due to the special circumstances and requirements of the Meginhufr, the success of the cleave was most important. It's not just any day you find even a somewhat suitable log, and it's certainly not cheap when you do. Together with the fact that the Meginhufr would be hewed from two halves, so the loss in strength from fibres unaligned with the non-intact fibres would be offset somewhat by the thickness of the board, meant that a philosophy of assuming control was followed for the cleave. By such a philosophy, the method previously described in that specific subsection of this paper and known by the cleavers in question would serve as the baseline for this cleave.

Figure 13, The Meginhufr log is left at 15,5 meters after felling and rotated to be viewed from all angles. Before setting a splitting-line, mumbles and discussion are broken by timely orders to turn every once in a while. Photo by Author.

We would rotate the log, back and forth as seen in figure 13, for viewing from all angles, to make an informed decision about the orientation of the splitting-line, and subsequent location of the v-grooves from which to initiate and cleave, as seen in figure 14. To circumvent the worst of it, we planned to cleave in a manner that minimized the problems, and started to debark strips, away from the biggest knots. The debarked area was

Figure 14, A strip of bark is being removed, to enable the marking of the splitting line along its length. At the same time the cut-face at the root-end is cleaned up. A choir of scraping and small knocks is heard when the work is ongoing. Photo by Author.

about 15-20cm wide, to accommodate adjustments during ashing to the splitting-line, and was made using a combination of axe, peeling-bars and drawknife, by a mass of workers.

Using a piece of soot-powdered string, two parallel lines were drawn upon the first debarked area, in segments, due to the length of the log. The cutting of the v-groove was started upon and finished within one hour of labour with axes. The workday ended as such. The next day arrived, and to save the labour and time needed to turn the log over more than necessary, we started by initiating the already finished v-groove, as seen in figure 15 to the right. Initiation was done with a heavy wooden club and an axe with a long handle. The axe was struck with a well-placed strike to its back-end, enough for it to bite 4-5 cm into the wood. Then it was loosened, before being moved along length of the bottom of the groove and struck again, this was repeated until completion. After initiation, along the groove, a noticeable crack-had started to form at the top-end, the crack was noticeably departing away from the pith, which could present to be an issue later.

Figure 15, The log is initiated along the bottom of the first v-groove. The early birds do the work, as the rest of the work-team prepare their tools and start fires for the day. Photo by Author.

After finishing the initiation on one side, we turned the log and started debarking a 15-20cm wide strip on the opposing side. During this round of debarking, new knots, previously hid by the bark, emerged. They were summarily discussed and ignored, because their imagined effect would be small in comparison to the larger effects of the branching and knotting in the crown-end. We ashed, once more, drawing two parallel lines using sooted string and unceremoniously started cutting the v-groove, which took

45 minutes to cut out. After cutting out the second v-groove, we of course initiated the crack at its bottom, same as with the opposing side.

Cleaving

Going back in time a bit, after initiating the first of the v-grooves, we immediately struck a metal wedge into the very end of the groove at the root-end of the log. The split-crack formed immediately, as seen in figure 16 to the right, penetrating to the pith. Satisfied that the initiation served its purpose, we postponed driving more wedges, until after we had finished initiating on the other side. After the initiation on both sides finished, we turned the log 90 degrees, so that the split-crack was horizontally aligned, and we began striking metal wedges into the initiated v-grooves at the root-end.

Figure 16, The first strike on the first wedge produces a straight split-crack to the pith. The log is turned and initiated from the other side, before any more are driven. Photo by Author.

The split-crack opened through the pith from groove to groove in a straight line from the first strikes. This was a good sign, that informed our next choice. Unlike the traditions associated with pine, where axes are employed, to ensure the split-crack goes straight through to the pith and beyond to the other side, we relied on the rays emanating from the pith to do most of the work, seen in figure 17 to the right. Cutting only, where the twist of the grain

Figure 17, Cleaving has begun in earnest, workers stepwise introduce larger wedges, before they're brought further and further forwards, notice the root-end of the log has no wedges, as they have all been moved. Photo by Author.

disallowed this method from being sufficient to produce a straight product. We gradually worked our way through the length of the log by driving wedges into the sides, starting from the root-end. We led with metal wedges, introducing larger and larger wooden ones as we were able.

As the split-crack opened a sufficient amount, we started cutting spanning fibres and bundles using a woodworking chisel. Working our way along the 15 meters, as the crack progressed, we removed the wedges from the root-end of the v-groove, allowing the top-half of the log to act as the beam in a lever configuration, the group of wedges acting as a fulcrum, exerting additional ripping force to aid in the splitting ahead of the metal wedges. The work was very quickly done, with a work-team of 7 or so workmen, 5 as wedge drivers, one on metal wedges with a hammer, two on small wooden wedges with hammers small mallets and clubs and two on the large wooden wedges with clubs and one workman as a fibre cutter, seen in figure 18 to the right.

Figure 18, The spanning fibres are cut in the open portion of the split-crack. Here the practiced hand of Jan Vogt Knutsen works swiftly and helps tension be further focused on the remainder of the connective fibres, While Tore Forsberg, facing away, being filmed, deftly and rhythmically drive wedges together with the volunteer workers. Photo by Author.

The work was swift and smooth, mostly limited by the additional care needed in the crown-end of the log. As we neared disturbances and a strong degree of twist, the drivers had to slow their pace, so that the cutter could shine. Having loosened the connection between the fibres with wedges, the cutter was needed to, logically, cut the fibres that would otherwise cause the split-crack to twist along with them, or in the worst case, veer off to the side. If care was not taken, all would be for naught.

With a sharp crack and the hollow sounding echo of the two halves striking against each-other on the rebound, the two halves are separated, whether it was an exact strike on a wedge, a precise cut of a woodworking chisel, or time enough for the material fatigue to provide ground for a break. Who can say which exact straw broke the camel's back, as they all provide weight together. Thankfully, the cleave was a success, the time of the splitting itself was slightly under one hour. The total amount spent on what I would consider "cleaving" as a broader statement, from the inspection of the ready log to the inspection of the two separated halves, was 6 hours, which included a lunch-break. In addition to the cleaving, work was also done, in situ, to rough-hew the boards. A piece of work that took another hour of work, per half-log by a varying amount of workmen.

4.4. Post-cleave registrations and Indicators of success.

Registration of variables after cleaving, was done on all produced pieces iteratively, when a log was half-cleaved each half log would be measured, following a quarter-cleave each quarter log, and so on. All quarter-pieces as part of subset 1 and all half-pieces as part of subset 2, were assessed as if they were the final cleave. to be hewed into squared lumber immediately. Whether beams or wide boards for half-logs, or regular boards for lesser pieces.

After a cleave is conducted I would go along the length of the cleaved pieces and assess the surface and pieces together with the other workmen, I would, as well, hear their assessment of the ease of work. To get an indication of whether the log was difficult to work with and whether the result is comparatively good or bad for the given log. I would, after the oral data-gathering, then solitarily go with my measuring tape and register data for the cut-faces, as well as the length of usable heartwood.

After registering all pieces of information, I created or systemized certain indicators of success. Indicators of success were built upon a series of properties that are easy enough to gather in a relatively short timeframe, but also might provide an insight into the specific reasons for a failure. The variables gathered as well as the indicators of success are all specified below, with accompanying figures.

In addition to registrations of variables intended to create indicators of success, certain cleaves were considered failures due a number of faults being present during, or as a result of, cleaving. These faults were registered as annotations during the cleaving process and their suspected reason for failure was noted alongside it as well. The registrations were verified post-cleave using images taken during cleaving.

4.4.1. Piece registration

Before any other variable was collected, the variable 'veer' as a boolean, was collected. The 'veer' variable asserts whether the split-crack veered at all during the cleave. A veer is a departure from the expected axial split, when the split-crack goes across the grain, rather than along it.

The oral data-gathering on the pieces consisted of three parameters that had to be assessed. For all registrations, a consensus would be reached and a score of between 1-10 noted, given the cleave succeeded.

Firstly the ease of work would be discussed between the workmen. The question the workmen were tasked to consider was “How easy was it to produce a ‘good result’ with this log, on a scale of 1-10 where 1 is the hardest, and 10 is the easiest?”. The variable is to serve as an indicator of the ‘general ease’ of a given log for cleaving. A ‘10’ is a “perfect” cleave, with no issues, simple work and the total amount of workload low. A ‘1’ would be a cleave which could not be accomplished using the method prescribed for it. If the cleave failed, we were incapable of splitting the log at all. I would note down a 0 on both orally gathered parameters.

Secondly the cleaved surface was looked upon with a critical eye, the less fibres that had to be cut between the two halves, the better. A ‘1’ would indicate a surface with more cut fibres than intact fibres, a ‘10’ would be a completely smooth surface with little to no cut fibres. The evaluation often took less than a minute to accomplish. As with a build-up of experience with the scale, allowed for a rapid assertion of the specific class the given pieces belonged to.

Finally the ‘Mass-balance’ was considered. The experienced cleavers pointed to the even-ness of the distribution of mass between the produced pieces of a given cleave as a variable that indicated a good log, not just the surface-produced. The mass balance is a subjective evaluation of that pecific distribution, again on a scale of 1-10. With ‘10’ being considered perfectly evenly distributed mass between the two halves. And ‘1’ being the case where you have a distribution of 1 part to one of the two halves and 9 parts to the other.

The length capable of producing a board with the minimum required proportions would be measured on the produced pieces. Given no faults, the length would be equal to the length of the log. A branch, a top-break, rot or other such things which affect the centre of the log would diminish the Length-measure. On the occasions, when the split-crack veered, the length of the potential board in the piece that would be veered into would be considerably reduced as a result. The length of usable heartwood would also naturally be limited by our constraints of a minimum width of our boards of 100 mm.

This minimum width means, that whenever the usable heart-wood of a piece in the top-end is less than 100 mm, we have to shorten the piece until the top-end usable heartwood becomes 100 mm. In this manner the usable length of the heartwood is dependant upon the width of the usable heartwood minimum criteria being met.

In the axial plane, the width of the usable heartwood, is measured in a straight line along the edge that has just been produced by a splitting-action. The radial measure is done, as far as able from the pith to the underbark, in the cases where the split has veered, the radial measure will read as 0 if the split-crack veered so much as to not reach the cut-face. In the cases where the split-crack veered slightly, and the pith doesn't extend to the cut-face, the radial measure would extend from the middle-point of the remaining circumference in a line towards the point where the pith would be found. The circumferential measure was done under bark, to and from the edge where the split-crack meets the bast. These measures are taken to describe the result of the cleave as a reduction in the surface-area of the cut-face and subsequently volume, together with the length, and can be seen with indications of their measurements and limits denoted with red in figure 19 below.

Measurements taken at cut-faces after cleaving:

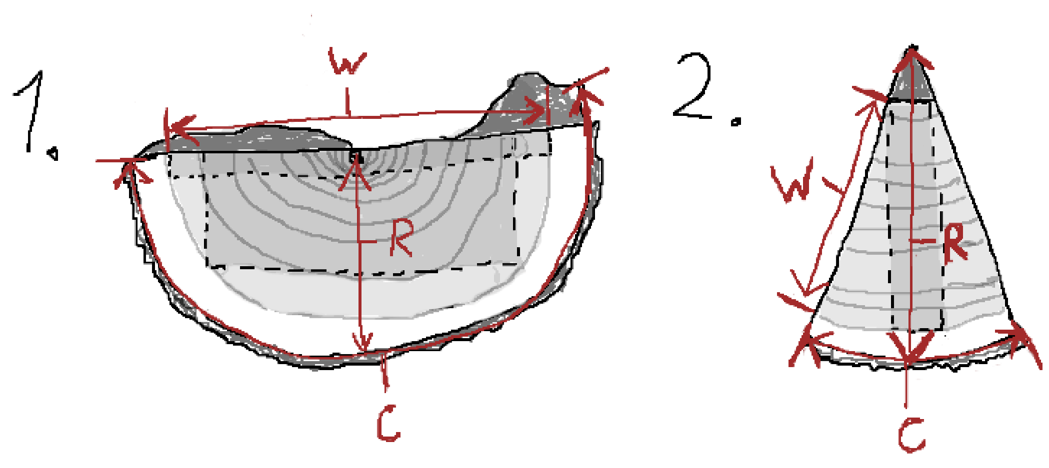

Figure 19, Measurements taken at the cut-faces after cleaving. Width of usable heartwood 'W', radius 'R' and the remainder of the circumference 'C'.

The variables 'Time of work, excluding lunch-breaks', or 'work-hours' and 'number of workmen' were gathered to understand the link between the stated ease of the work and the actual time spent on the given piece per worker.

4.4.2. Indicators of success

An indicator of success is a construction, or a systemized variable that seeks to answer certain questions in regards to the success of the given cleave. Whether the method was correct, whether the log was possible to cleave at all, whether the log could have produced more, whether the cleave was easily done and so on and so forth. As was the case with the indications of suitability, certain simple variables can themselves work as a direct indications of success, all orally gathered variables, the 'ease of the work', the surface-evaluation and the 'mass-balance' evaluation are such cases, as they are tasked with directly answering certain questions we have in regards to the 'successfulness' of the cleave.

The 'Toughness' of a log, is the number of work-hours per meter length per workman. It serves as an inverse to the 'ease of work'. To corroborate the subjective evaluation of the work-experience. It is constructed by taking the sum of the work-hours dividing by the length of the log to get the 'hours per meter' measure, and dividing once more by the number of workmen, to correct for discrepancies.

$$Toughness = \frac{\frac{H_w}{L}}{N_{wm}}$$

The 'board-volume' is an indicator that seeks to answer the question of the actual production from a log. It is constructed by calculating the cross-section of the board-produced at the end which is more restrictive in the 'width of usable heartwood', previously illustrated as simply 'W' in figure 19, by multiplying with the board-thickness 't', (t=2 for all boards, save the 'Meginhufr') Then multiplying that area with the 'length of usable heartwood' variable.

$$Vol_b = W_{u.h.w.} * t * L_{u.h.w.}$$

It is further possible to enable comparisons across diameters and lengths by looking at the extracted volume in comparison to the theoretical maximum board-volume. Or whether the cleave had succeeded to the highest degree. The theoretical maximum volume produced is defined as the diameter of the heartwood at the top-end, subtracted the variable unusable centre 'd_c', (dependant in size upon the stage of cleaving, becoming stepwise bigger) multiplied by the board-thickness 't', (t=2 for all boards, save 'Meginhufr') before multiplying again by the entire length of the log, for half logs (1) and for quarter-logs and below (2)

1. $Vol_{max} = (D_{top} - d_c) * t * L$

2. $Vol_{max} = \frac{(D_{top} - d_c)}{2} * t * L$

The indicator ‘relative board-volume’ takes the board-volume divided by the theoretical maximum board-volume for each piece.

$$Relative\ board\ volume = \frac{Vol_b}{Vol_{max}}$$

4.4.3. Faults in cleaving

Any property of the split-crack itself, which would reduce the volume, or the strength of a board, produced by the cleave, is considered a fault in the cleave. These faults were registered as annotations during the cleaving process and their suspected reason for failure was noted alongside it as well. The registrations were verified post-cleave using images taken during cleaving. The failures were divided into categories of severity as well. It is important to distinguish faults and failures of cleaving, from properties that lie inherent in logs. Cleaves that failed to lay the groundworks to produce a single full length board, were considered total failures. A number of cleaves produced 1 board, semi-failures, and some cleaves had small faults in the cleave, but which didn’t impact the production of a board directly, known as minimal failures.

The veering of a split-crack is the most severe of the various ways in which a cleave could fail. It happens when the path of least resistance departs from the pith, usually due to a disturbance in the fibre-structure. A total failure as a result of a veer would be when the split-crack departs enough from the pith to exit the log along one of its side-faces. A semi-failure as a result from a veer would be when the split-crack departs enough to shorten the length of the resulting board of one of the produced pieces. A minimal failure due to veer would be when the split-crack departs only slightly from the pith, but still enables the production of a full length of a board, given no other faults in the cleave or in the log.

During splitting from the side, there is the risk of the split-crack penetrating through the pith at an obtuse angle, rather than in a straight line in half-logs, such a fault may lead to further faults if it is handled incorrectly, the worst among them is “shattering” the cross-section. As detailed by experience in Log nr 4 subset 2. In cases where the shattering is a total failure, the shattered split-crack has ruined any usable length of the one half of the log. In cases where it is a semi-failure the shattering was in larger more coherent pieces that enabled the extraction of some lengths. In pieces where it is a minimal failure, shattering remains as an obtuse angled split-crack.

Splitting will oftentimes produce spanning fibres. This is a fault of the split-crack that appears as the path of least resistance runs counter to the direction the fibres are running. In the cases where there is a total failure of the cleave due to spanning fibres, you have failed to separate the two halves and no boards may be produced. This may present as a series of parallel split-cracks. In cases where it is a semi-failure, the spanning fibres had to be cut at such an amount, that the strength of the produced boards will be compromised, in comparison with boards that would be produced without cutting fibres. In boards with minimal failure, the amount of spanning fibres that had to be cut to separate the halves was such that there is no noticeable decrease in the strength of the produced boards.

4.5. Analysis

Division into strata?

During the course of the study, it has been brought up whether the data ought to be divided into strata during the analysis, because of several differences. In the case of subset 2 the entirety of the cleaves were half-cleaves done on low-quality logs. Subset 1 was gathered with the help of experienced cleavers, which would no doubt have a different account of what constituted an easy and a hard log to cleave, as well as have a greater understanding of their tools to ease cleaving. As the dataset is very much limited in size, due to the nature of the way in which gathering logs of cleavable dimension, together with a busy schedule, limits the amount of days I can spare to gather data, I have chosen to treat the set as a whole. In order to compensate for inherent differences in these two subsets of the data, I have developed my indicators to be as neutral in regards to dimension as possible.

The analysis done is simple enough, averages of the results of the half-logs and the quarter-pieces, further divided into classes of split from the top, bottom and side had their indicators of suitability compared to indicators of success. In cases where the averages appeared to give a correlation, the unstratified indicators and variables were plotted against each-other and the correlation visibly assessed, and the findings interpreted with the experiences in the field in mind. It will do no good to be too caught up in the minutiae of statistical analysis to not see the over-arching themes and problems that lie in the specific logs in question.

5. Results

Bear in mind when reading the results, that the logs tested are by no means what a cleaver would consider a group of good logs. Therefore read the results, not as a general statement of how to cleave successfully, rather read it for what it is, a limited experiment with limited size, done half-and-half by cleavers of experience, and inexperience. In other words, be careful when extrapolating beyond the scope of the dataset. Use the results and the questions posed by the paper as a guide for further experimentation with larger and more apt logs if you wish to speak with any degree of certainty on cleaving in oak in general. With all that stated, this papers results can inform us about the logs we cleaved.

5.1. Registered faulty cleaves

In table 1 the registered faults in cleaves and their suspected reason for failure is summarized. Note that this table only covers failures *in cleaving*, not in extracting usable boards. The cleaves which technically had no faults, but which still did not produce boards, due other factors during evaluation are thus not covered. The main reason for shorting the usable length of heartwood was due to knots, the effect of knots on extraction is thus compounded with the effects found on the cleave. The degrees of failure are described in sub-chapter 4.4.3. 'faults in cleaving'

Table 1, Registered cleave-failures, their degree of failure and their suspected reason for failure.

Subset nr. - log nr.	DoA	Type of cleave	Failure type	Failure degree	Suspected reason
1 - 2	B	Half	Spanning fibres	Minimal	Twist / Knots
1 - 2	T	Quarter	Veer	Total	Twist / Knots
1 - 2	S	Quarter	Veer	Semi	Twist / Knots
1 - 3	B	Quarter	Veer	Total	Twist
1 - 3	T	Quarter	Veer	Total	Twist
1 - 4	S	Half	Shattered split-crack	Minimal	Uneven side-pressure
1 - 4	B	Quarter	Veer	Total	Knots / Burls
1 - 5	T	Quarter	Veer	Semi	Knots / Bends
1 - 5	B	Quarter	Veer	Total	Knots / Bends
2 - 2	B	Half	Spanning fibres	Semi	Twist / Knots
2 - 3	T	Half	Veer	Semi	Knots / Centre-rot
2 - 4	S	Half	Spanning fibres	Minimal	Twist / Knots
2 - 4	S	Half	Shattered split-crack	Semi	Off-centre pith / Uneven side-

					pressure.
2 - 5	S	Half	Spanning fibres	Semi	Knots / Centre-rot

5.2. Board-production by direction of attack

Logs were split according to different directions of attack a different number of times in total and produced in total a different number of hull-boards, see table 2 below. A portion of the splits which produced acceptable hull-boards are also 'hybrid'-splits. Meaning the given cleave was impossible to accomplish without providing pressure from an additional face of the log. These hybrid-splits were responsible for a portion of the production of boards, seen as column 4 of table 2 below, 'Hybrid-boards'. All splits which were productive as hybrids, also veered. In addition to the four total hybrid-splits, there were 4 more splits which veered, see column 5 of table 2, 'Veered boards'. Column 5 of table 2 below, 'Hull-Board production per split' is a simple relationship between the number of hullboards produced in total per direction of attack, divided by the number of splits total per direction of attack.

Table 2, A summary of the splits done, the number of boards produced, boards from hybrid-splits, boards from veered splits, and per-split production of hull-boards, by direction of attack.

Direction of Attack	Number of splits total	Hull-boards total	Hybrid-boards	Veered boards	Hull-Board production per split.
Bottom	8	4	1	2	0,5
Side	9	12	0	2	1,33
Top	7	5	3	4	0,71~

5.3. Distribution of certain properties and indicators of suitability

You could be forgiven for jumping to conclusions about the foolishness of cleaving from the root-end and the superiority of cleaving from the side. Bear of course in mind the natural distribution of the type of log that was cleaved at each stage.

5.3.1. Density

Table 12 below details the measurements of dry density at the top and bottom. The dry density appeared consistent across the length of a log.

Table 3, Dry density-measurements taken at the top and bottom of whole logs.

Dry density bottom	Dry density top
0,65	0,66
0,60	0,55
0,68	0,66
0,72	0,74
0,80	0,78

Table 13 below details the measurements of wet densities at the top and bottom. The wet-density appeared much more variable across the length of a log.

Table 4, Wet density-measurements taken at the top and bottom of whole logs.

Wet Density bottom	Wet density top
1,02	1,05
1,07	0,95
1,00	1,01
1,10	1,13
1,07	1,03

The measured densities were found to have no correlation to any other measured variable or property. Figure 20, below shows dry densities at the top and bottom plotted against each-other, as well as wet densities at the top and bottom plotted against eachother, illustrating the clear correlation of dry densities and lack of correlation in wet densities. Possible causes for this lack of correlation will be discussed later.

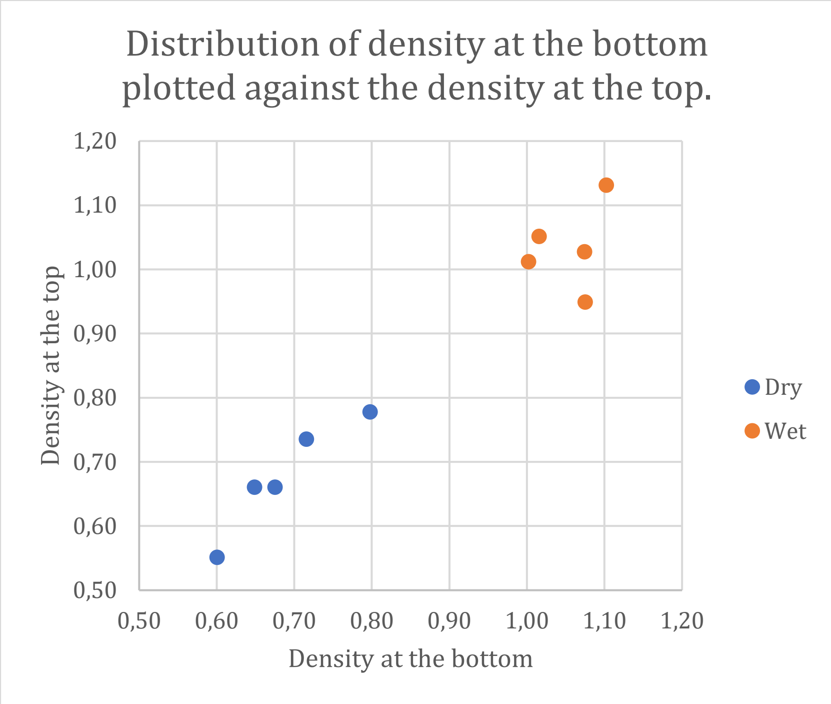

Figure 20, Densities at the bottom plotted against densities at the top.

5.3.2. Narrowing

The narrowing of the mother-log was distributed unevenly throughout the cleaving-directions. If you direct your eyes to the distribution below in table 3, you will notice an overweight of logs with a low degree of narrowing in the logs randomly drawn to be cleaved from the side.

Table 5, Average narrowing of the mother-log of quarters and halves by direction of attack, Q. for Quarter pieces and H. for Half-logs.

DoA	Narrowing Q.	Narrowing H.
B	4,25 %	5,94 %
S	3,76 %	3,95 %
T	5,71 %	3,81 %

5.3.3. Twist

As seen in table 4 below, ‘twist’ was unevenly distributed as well. This has once more favoured cleaving from the side to produce quarters.

Table 6, Average twist of the mother-log of quarters and halves by direction of attack, Q. for Quarter pieces and H. for Half-logs.

DoA	Twist Q.	Twist H.
B	3,32 %	6,70 %
S	0,98 %	1,84 %
T	4,30 %	1,46 %

Notably, this incredible difference in twist-distribution in quarter-pieces can be attributed almost entirely to log nr. 3 of subset 1, with a twist of 13,27% being counted multiple times due to the multiple pieces produced. In table 5 below, we see what happens if we exclude this log. The overall distribution still disfavours the logs that would be cleaved from the top into halves, though not by as much. And it tells the tale of logs being distributed rather evenly, when measured using the metric of twist.

Table 7, Average twist of the mother-log of quarters and halves by direction of attack, if we exclude log number 3 of subset 1, Q. for Quarter pieces and H. for Half-logs.

DoA	Twist Q.	Twist H.
B	0,00 %	4,51 %
S	0,98 %	1,84 %
T	1,31 %	1,46 %

5.3.4. Diameter of the Top-end

The average diameter at the top-end of the mother log appears unevenly distributed across the cleaving-directions, favouring cleaving from the side into quarter-pieces. Seen distributed in table 6 below The overall difference in diameter from the quarter-pieces to the half-logs is because the logs of subset 2, and the Mehinhufr-log weren't cleaved to quarters, and thus only count towards the diameter-average as a mother log for the half-logs.

Table 8, Average diameter at the top-end of the mother log of quarters and halves by direction of attack. Q. for quarter-pieces and H. for Half-logs.

DoA	Diameter top Q.	Diameter top H.
B	30,30	37,40
S	33,13	35,01
T	28,55	36,33

5.3.5. Ovality

Ovality is distributed in another manner than the other variables. As it largely favours the pieces cleaved from the top and bottom. The strange distribution is seen in table 7 below.

Table 9, Average ovality of the mother log of quarters and halves by direction of attack. Q. for quarter-pieces and H. for Half-logs.

DoA	Rel. Ovality Q.	Rel. Ovality H.
B	0,13	0,06

S	0,11	0,14
T	0,08	0,09

5.4. Distribution of indicators of success, by direction of attack

The indicators of success show a distribution which can be compared to the distribution of indicators of suitability. The distribution was overall not even, and far less even in the production of quarter-pieces for quarter boards, than in the distribution of half-pieces for half-boards.

5.4.1. Relative board-volume

The distribution of the average relative board-volume can be seen in table 8 below. Note that the average of the quarter-pieces is of the production believed to stem from that piece, whereas the average of half-logs does not consists of the aggregated average of all pieces stemming from that half-log, as that would confer the results of the quarters unto the halves, even in cases where the direction of attack was changed, due to the random draw. As such, it is corrected by only carrying the logs of subset 2 into the column of volume production for half-logs, as they were actually assessed for production at that stage, unlike the logs of subset 1, which had that assessment at the quarter-stage only. The distribution is uneven. This difference is notably largest in quarter-boards.

Table 10, The average relative board-volume evaluated as extracted by direction of cleaving, separating boards extracted from quarters (Q.B.) and from halves (H.B.).

DoA	Rel.Volume Q.B.	Rel.Volume H.B.
B	37 %	48 %
S	86 %	72 %
T	41 %	59 %

5.4.2. Surface-evaluation

Notably the surface was evaluated as best in logs cleaved from the *side into quarters*. Otherwise cleaving from the *top* appears to provide the cleanest cleaving-surface in surfaces cleaved *into halves*, as seen in table 9 below.

Table 11,Average surface-evaluation of quarter-pieces Q. and half-logs H. by cleaving-direction.

DoA	Surface-eval. Q.	Surface-eval. H.

B	4,75	4,75
S	9,75	4,90
T	5,38	6,33

5.4.3. Mass balance

The mass was most balanced between sister-pieces when their creationary cleave was from the *side into quarter-pieces*. Here the pieces were in fact more prone to be balanced if they were cleaved from the *top into halves*, as seen in table 10 below.

Table 12, Average mass-balance in quarter-pieces Q. and half-logs H. by direction of attack

DoA	Mass-balance Q.	Mass-balance H.
B	4,50	8,50
S	8,75	7,60
T	3,00	8,67

5.4.4. Ease of work & Toughness

The work was reported as most easy when producing quarter-logs split from the side. Otherwise splitting from the top was reportedly most easy. The objective indicator of toughness supports the self-reported accounts of cleavers, as seen in table 11 below.

Table 13, The average of self-reported ease of work to produce quarter-pieces Q. and half-logs H. and the calculated toughness-factor for producing half-logs H. split by direction of attack.

DoA	Ease of Work Q.	Ease of Work H.	Toughness H.
B	4,75	4,00	0,20
S	8,75	5,60	0,10
T	3,00	8,33	0,04

5.5. Indicators of success and their connection to indicators of suitability

Some indicators of suitability could be perceived to have a connection to the indicators of success, when looking at just the averages, others had tenuous, if any connection. Looking at the raw-data instead of the averages, some indicators of suitability and success appear further linked.

Below is a series of figures associated with the average relative volume of boards extracted from quarterlogs in the case of subset 1 and half-logs in the case of subset 2. The indicator with the clearest correlation to the relative board-volume is the indicator 'narrowing' seen in figure 21 below.

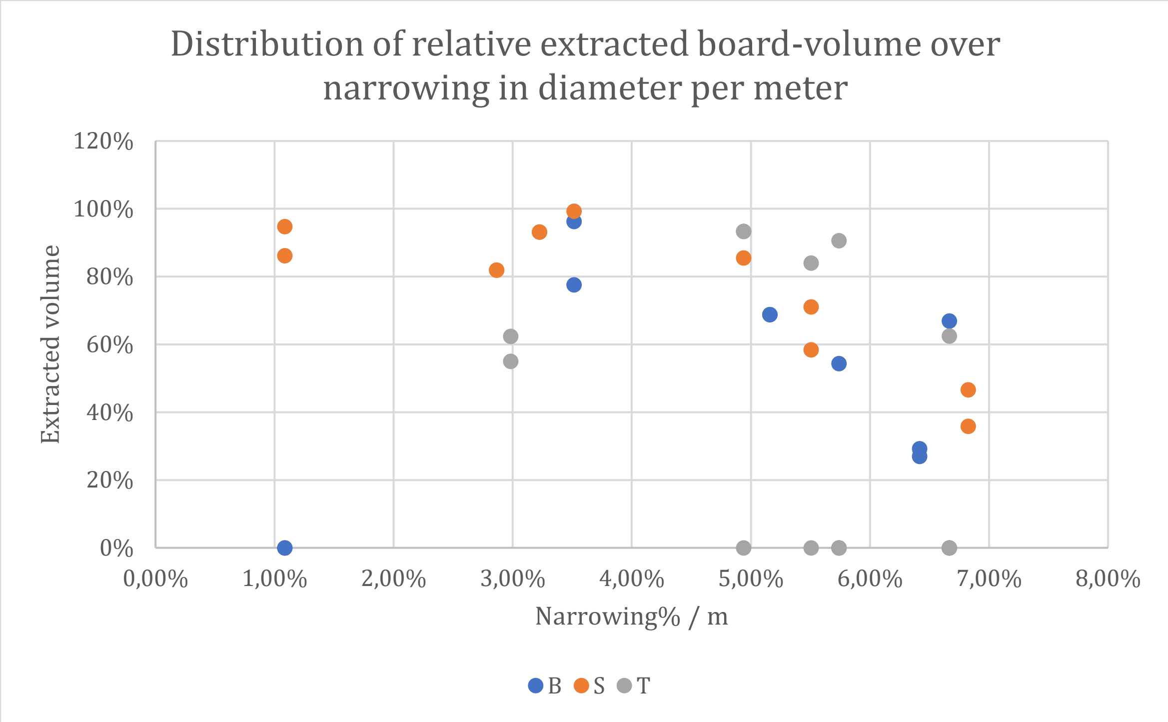

Figure 21, A scatterplot of relative extracted board-volume against the indicator of suitability 'narrowing'.

It can be gleaned that the higher the narrowing, the less volume is able to be extracted. And that somewhere above 5% per meter of length, the volume extraction is drastically reduced in this experiment. We can also see the distribution of narrowing appears much more even, than at first glance. And that cleaving does seem to have an effect. Every point from subset 1 has a partner, which if the cleave veered drastically leaves the partner near or at 0% extraction. This would qualify as a semi-failed cleave.

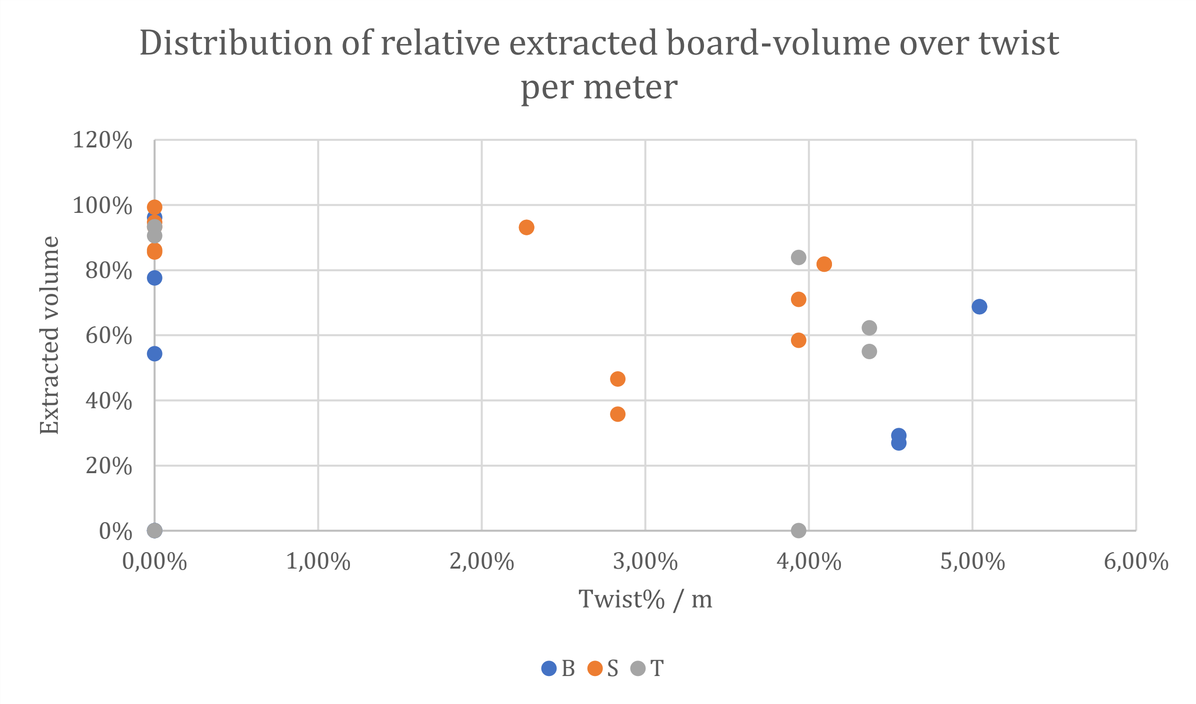

Figure 22, A scatterplot covering the relative extracted board-volume against the indicator of suitability 'twist'.

Figure 22 above, shows the extracted board-volume against twist in the same manner, and removing the outliers at 13% twist, we spot some of the same tendencies. That cleaving from the side appears to lie in the upmost part of the plot, and that cleaving from the top and bottom appears to lie at the least, lower. Here we see that despite the average twist was higher in the pieces cleaved from the bottom, the average was being pulled by a concentration of points over 4,5% twist. Though it is not made clear from the figure, cleaving from the bottom has 4 points of 0% extraction laying at the point of origin, which constitutes failed cleaves, thus the figure paints a rather rosy picture of the usefulness of cleaving from the bottom in comparison to the reality.

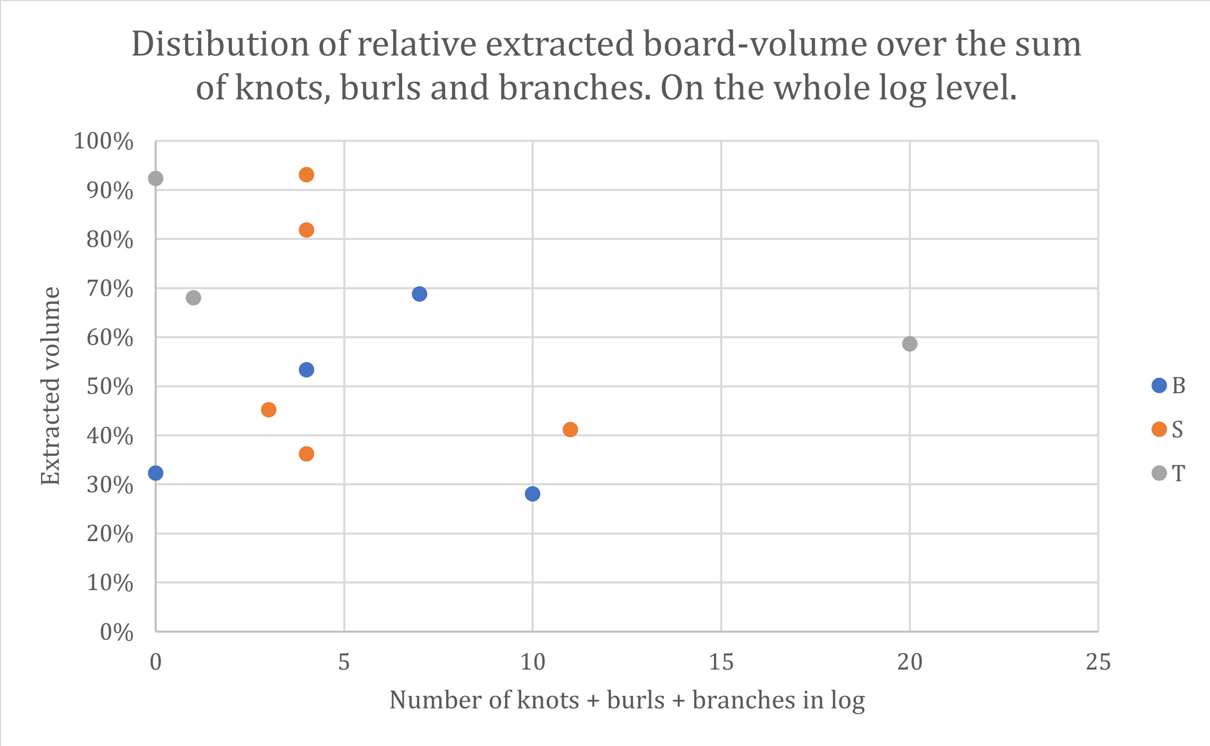

Figure 23, A scatterplot of the extracted board-volume in comparison to the sum of all knots, burls and branches in a whole log.

Figure 23 above shows the distribution of extracted volume from the average of the half-logs across subsets 1 and 2. We see what we expect. A decline in extracted volume as the number of registered knots, burls and branches increases. Though this plot understandably has fewer points of data, due to the aggregated nature of the averages being applied to whole logs.

6. Discussion:

6.1. Cleaved and Hewn, or Quartersawn?

As we have no surviving contemporary literature or art that mentions or illustrates the process of cleaving or sawing for the purpose of producing boards for longships. Nor do we have archaeological finds of a worksite abandoned with the tools mid-act, to inform us. Cleaving is what is defaulted to, and acts as the null-hypothesis. The alternative is quartersawn lumber, which has similar cross-sectional properties. However this is an alternate explanation which fails in several regards to hold up to scrutiny.

Looking at literature, water-powered mills were a known technology in antiquity. The mills were used for cutting marble into blocks. Later, water-powered mills for the purposes of sawing lumber are described in Byzanthium in Southern-Europe, and later still our earliest known sketch of a sawmill comes from Villard de Honnecourt between 1200 and 1300 in the Frankish realm (Shulman, 2022). Sandvig places the introduction of the water-powered sawmill in Norway at the beginning of the 1500s (Sandvig, 1931).

From this simple timeline alone, it seems unlikely that despite quarter-sawn lumber exhibiting the same cross-sectional profile as hewn boards and being more quick to produce, that it would be unlikely for the Norse of the early medieval period to have access to use quartersawn lumber in their work. Much can also be said of the toolmarks left behind on the side-faces of boards being from axes, being the subject of whole studies by dedicated craftsmen, see Finderup 2022.

6.2. Limitations

6.2.1. Initial registrations and dimensions

Data was initially gathered as part of a larger project between Osebergstiftelsen and NMBU, where the goal was to chart the link between variables able to be registered when a tree is seen undisturbed in a forest on-root, and the yield produced after cleaving. With the ultimate goal of producing a mapping-service where a tree could be registered in a non-damaging way on a map. Before cleaving, data was registered for each whole log, seen in the subchapter dealing with registrations on whole logs. Variables related to the cleaved pieces were registered for each resulting half- and quarter-log. Variables related to the cleaved pieces are outlined in the subchapter detailing registrations on cleaved pieces. A total of six logs were cleaved, all registrations from this group of logs is known as “subset 1”.

All logs in Subset 1 were varied in their qualities, some having a lot of branching, some having laid outside for a long while and started decomposition in the sap-wood, and some with large degrees of twist. However, all the logs were of the same similar dimensions, all logs were 5 meters in length and from 30-50 cm in diameter at the root-end. The dataset is therefore considerably limited by dimension. The experimental data in this study was therefore gathered with the express purpose of supplementing and contrasting the existing data. What I call subset 2, 5 logs found in Tofte at a local shipping-yard where the logs were slated to be turned to woodchips along with the ‘Meginhufr’-log. These logs had a distribution of 40-60 cm bottom diameter from tofte and 70cm bottom diameter at between 3-5 meters length in tofte and 15,5 meters length for the ‘Meginhufr’-log. In addition to this, the logs found at Tofte held other properties often denoted as “low quality”.

There is a distinct lack of logs *of large size with wanted properties*, this affects the dataset by heavily scewing the data to favour less desirable results, as in veers and hybrid-cleaves. And provides the dataset with few half-cleaves, some quarter-cleaves and no lesser cleaves. As the difficulty, increases and the usable heartwood decreases. Keep these points of limitation in mind when looking at the results, as in reality, any log a craftsman would have picked to cleave, will already be more likely to produce better results than what is seen in this paper.

6.2.2. Measuring success

Because this is an understudied part of wood-technology as well as history, no standardized methods exist for gathering data on the success of a cleave. All cleavers will tell you that a success is relative to what you’re trying to achieve, whether a thin board or a thick beam. A cleave that didn’t successfully produce pieces that can be processed into hull-boards, may still successfully be processed into shorter boards with other uses. Even if we are to include the caveat that all boards must be used in a hull, this still leaves a lot of flexibility, in that the lengths of the boards in a hull can vary a lot. And a cleave that was considered successful earlier in the process of the build, might be considered a failure now, because the shortest lengths have all already been successfully sourced. Nevertheless, for the purposes of this study, I consider a cleave whose *resulting* *pieces* can produce at least a single board 20mm in thickness 3 meters in length and 100 mm in width when hewed, to be a semi-successful cleave, and any cleave which produced two pieces which could be hewn into boards of such dimension a successful cleave. This can be considered *very* generous, when looking at the archaeological finds, as this is the absolute minimum of what could be considered a board suitable for a hull. Requiring many pieces to be joined at the ends, is asking for a less water-resistant hull. There is therefore little hope that cleaving logs of this quality will ever supplant cleaving better logs, rather, it can supplement it as a way to source *cheaper* lumber which still holds some value for teaching the craft and to save resources.

6.2.3. Density

Subset 1 and 2 are limited in different ways. The samples for density measurements were mainly gathered to try to see if there was a significant difference in density in the top-end, compared to the bottom-end of oak-logs and whether this difference could be a contributing factor to a successful cleave. As well as if there was a link between density and any easily measured properties. Subset 1 was gathered before density-variables were considered, and as such no data is available for any of those logs. Subset 2, on a whole-log level, is by itself, simply too small of a sample-size to provide any meaningful information in distribution, especially considering the relative homogeneity of their dimensional distribution. Even if we include the meginhufr-log, a single more log to a small pile, does not make for a convincing dataset.

Basic-density was not measured, nor would it be possible to measure correctly, in that most logs, save the log meant for the “Meginhufr” were felled, cut and had been stored for a variable amount of time before the events of this study, in very differing conditions. Some being affected by rot and degradation. As such, dry and soaked measures of density would serve as more comparable. During soaking, several pieces took significantly longer to stop absorbing water. This is possibly due to a surplus of anti-fungal residues or fungus itself stopping water from entering the pores of the wood. This is a likely explanation because the two logs which had the largest differences in wet-density between the top and bottom were logs 3 & 5 of subset 2, which both happened to be infected with fungus and were clearly rotting, log number 3 which had its heartwood also bear clear signs of fungal infection, was also the log with the highest difference in wet-density between the top and bottom.

Mostly out of curiosity, moisture was measured at the ends of a few of the logs. In line with the common understanding of moisture-content through the cross-section of a log, after cutting a section of 20 cm off the end of a few of the logs, the moisture was found to decline as we neared the pith. Interestingly however, the area with the least moisture was found to be 5-10 cm from the pith, this is possibly due to the role of the initial-crack drawing moisture into the log from the air.

Due to the destructive nature of sampling for density-tests, it was only possible to sample the ends of the logs. This might prove problematic in and of itself, as the density at the ends might not correlate fully to the density in the middle the log, especially if the log has properties known to affect the density, like knots and crooked growth. As such for future studies, where density results could prove to be more useful, I propose a series of samples taken from the bottom-end, the-top end and the centre of the log on a piece-level, rather than a whole-log level. The samples would in this ideal experiment be a collection of several hewed splinters and flakes collected during hewing. It was my hope to try to link a few visually distinguishable properties in the log, with density, in turn linking the sciences concerned with the mechanical properties of oak, to the sciences concerned with the morphology and behaviour of oak. Alas, the link could not be established in this paper, however I leave the methods I have described so far, for any who seek to continue the work, my final advice would be to set aside more than enough time for wetting.

6.2.4. Reliability of 'Ease of Work'

Ease of work is subjective and determined with a discussion with the workmen, As such, it might prove to be only as reliable as an indicator for actual ease of work, as the experiences of the workmen accumulate, inexperience at the start with the measuring scheme, and the lack of reference can perhaps increase uncertainty of the result, and upon a second passing, a log which was previously put into a category, might no longer seem to fit with the other logs later put there. As such, accumulation of experience is needed, before such variables become useful by themselves. To limit this effect, ease of work was determined by asking experienced cleavers in the case of subset 1, and from me and a couple of less experienced workers in subset 2 after having observed the cleaving and grading for subset 1. Despite subset 2 being gathered after subset 1, thus carrying some familiarity with the scheme and scale of things with us, the overall inexperience of the group might still influence the scale.

Those fears appear unfounded in this example. When referring to table 11, there is a clear link between the perceived difficulty and the actual measurable toughness. It can thus be stressed that people were largely able, at least on the average, to tell when a log was difficult. Which makes sense, as most people will have an intuitive understanding of the time spent on a log, in comparison to the rest of the experiences they've accumulated. Which speaks in favour of craftsmen and layfolk alike being able to recount their experiences reliably enough to lay the foundations for other kinds of research into the difficulty of cleaves in the future.

6.2.5. Whether to destructively test for strength

If destructive tests were to be carried out in addition to simple measurements, I had fears regarding the amount and quality of information that would realistically be transferable to the boards you could theoretically extract from the half-logs of subset 2, as well as the costs to transport the pieces, and the time needed to break them, to provide such information in the case of subset 1. Therefore destructive testing was not carried out on logs from subset 1 nor 2. This study is therefore very limited in its ability to say anything regarding the strength of pieces produced. If I were to design an experiment to determine the strength, I would go about collecting more information regarding the faults registered on whole logs typically associated with lowered strength, for the whole dataset and gather it post-cleaving for all pieces, so that each piece can be evaluated with its various properties, hew the pieces into boards, measure density from the chips hewed off at the top- and root-end of the board and document the faults once more on boards, before breaking the boards using a hydraulic press.

6.2.6. Other Properties and Faults in logs

Other information than method and dimensions could be gathered from subset 1 by interpreting photographs. Simple information, counting bends, arching and knots is possible to do after the experiment was finished, due to a series of images being taken during the cleaving. As such we still can do some ad-hoc testing in regards to simple variables regarding knots and other faults on a whole-log level to possibly discuss the effects of the sum of faults and sum of specific faults. However due to a limited amount of pictures taken during the cleaving out of quarter-pieces, such registrations are impossible to attribute on pieces, only on the whole-log level for logs in subset 1. Subset 2 had all their knots counted on the piece-level and bend and arching registered as they were cleaved, and as such simple assertions like the possibility of 'concentrating' faults and unwanted characteristics in one half of a log, could be tested on the individual log, and documented in the data.

Other denotations of properties in subset 1 can only be found in sporadic comments about what stood out to the cleavers. Measurements of twist were regrettably only carried out on logs in subset 1 when the twist was noticeably great, leaving a large gap of information with logs of comparatively low amounts of twist in subset 1. Explaining the concentration of twist at 0% found in figure 22 in the results.

6.3. Direction of Attack

6.3.1. Drawing the attack-direction

By choosing to randomly draw DoA, we limit bias. If we were to be given free reign to choose the way to cleave, and all cleaves succeeded, the results would be moot for answering our research-questions. As we would not be charting the effect of direction of attack on the result, but rather documenting the morphological differences between which logs we prefer to cleave from differing directions. Which itself could be interesting to study, but beyond the scope of this study. Instead, by drawing, we allow the faults and decidedly unpleasant-to-cleave scenarios play out as they will, documenting the results, providing us with the best possibility of capturing in data what specifically makes for a bad cleave, in contrast to a good cleave.

6.3.2. Mitigating risk

The theme when cleaving logs of lesser quality, is risk mitigation. When you have factors which put a cleave at risk, there are certain things you could try to mitigate risk such as a choice of direction, however there appears to be a unifying truth that certain logs simply go wrong for reasons most often tied to knotted wood or spiral-grain. The truth of the matter is that there is simply no "best" way to cleave in all scenarios, and I believe asking the question "which way did the Norse shipbuilders cleave" is framing the question in the wrong light, which limits our understanding. I believe cleaving could benefit from taking a small break to analyse a log and evaluate whether the log in front of you is a non-arbitrary case, rather than going about the process of selection of DoA completely subconsciously. What exactly is going to influence the split-crack, and what can be safely ignored? Below, you will find table 14 summarizing my experiences with how properties of a log interact when cleft from different directions. It has got no exact parameters, it is by no means exhaustive, and it is certainly not going to cover your exact log, however it can act as a guide for an internal or external dialogue to reflect upon the log you have before you:

Table 14, Results to expect when cleaving whole logs, in case the lefthand listed fault was the only fault of the log, using the overhead method, based on experiences with difficult logs of middling to low diameters, compared between faults and methods.

Direction of Attack	B	S	T
Knots/Burls (spread)	--	--	--
Knots/Burls (grouped)		+	
Knots/Burls (aligned)	+	++	+
Twist > 4%/m	--	--	--
Narrowing > 5%/m	-	+	+
Root-disturbances / Rootlegs	-	+	+
Crown-disturbances / Branching	-	-	--
Off-centre pith	+	--	+
Arched log	+	+	+
Bend/Top-break (singular)	-	+	-
Bend/Top-break (multiple)	--	-	--
Rot (sapwood)	+	-	+
Rot (centre)	--		-
Inexperience with the DoA	-	--	-

Key to remember, is that the parameters in this table suppose you know what you're doing to compensate for the given difficulties that accompany each type of cleaving, when meeting the properties on the left.

For instance, when going from the top or bottom, it sometimes is beneficial to go around a knot, and some other times the split-crack wants to go directly through it. What the different arrangements of knots tell us, is that the more concentrated a group of knots is in the cross-section, the less you as a cleaver have to worry about it, when trying to either isolate it in one half of your log, or when trying to penetrate it during cleaving from the side.

Twist cannot be compensated for.

Logs that grow narrower tend to do better when cleaved from the top and side rather than the bottom.

Logs with disturbances in either end tend to do poorly from that end, while crown-disturbances, often large branches, tend to complicate matters for all types of cleaving.

If a pith is off-centre the risk of “shattering” the log in the cross-section is increased as the risk of an obtuse split-crack is increased.

A single bend and an arch can be compensated for by rotating the log to have the bend or arch go into the air, and then cleaving perpendicularly. A single bend can also be cleaved from another orientation, however the risk of veering is increased. Multiple bends makes any cleaving method hard, the risk of veering is high.

Rot in the sapwood can be beneficial for cleaving from the ends, as the rot makes the split-crack follow more neatly along the wishes of the heartwood. This may mean increased amount of spanning fibres in the sap-wood, however the sap-wood is unimportant for the strength of the finished boards. Rot in the centre, means an easier time splitting from the sides, as the centre will easily part. However, splitting from either end runs an increased risk of veering.

6.3.3. Assessing the faulty cleaves

Within the scope of this study, cleaving from the side, at least in logs of lesser quality, appears to be ‘as able’, if not ‘more able’ to split a log, and retain acceptable mass in both split parts to produce more than one board per split. In addition, a portion of the boards split from the top and bottom required providing pressure from the sides regardless to complete the cleave. So-called ‘hybrid’ splits. The consensus among the workmen was that side-pressure, is required in greater part to cleave logs of lesser quality.

Regarding such hybrid-splits. There were four splits starting from the bottom, which required intervention from the side to complete. However, there was only one board produced from these four splits. The three splits starting from the top, that required additional pressure from the sides, produced in total three boards. The consensus was that if these logs had continued to be pressured from only one end, the split would have ended in total failure. This difficulty when cleaving requiring the side-pressure indicates of course that the logs were of lower quality, which the data confirms to some extent. As these hybrid-cleaves in general produced less boards and boards of lower length, this could certainly skew the results in favour of cleaving from the side.

Regarding the veer, eight splits total veered, three from the top, one from the side and four from the bottom. All boards produced through hybrid-splits were also subject to veering. However there were a few boards which were produced despite a non-hybrid approach, when a piece veered. In total there were eight hull-boards produced from pieces which veered. four from the top, two from the sides and two from the bottom. The difference in production could be argued to be due the width-requirements of the boards being more dependant upon the split-crack going somewhat closer to the pith in the top, than in the bottom. This way, one could argue that, if you split from the top, you've already somewhat mitigated risk, by making sure that the most restrictive dimension of the log in regards to producing wide boards for a hull, the crown-diameter, has been secured. The difference could also possibly be explained by the physiological aspect of branches and twigs extending in an upward fashion from the pith acting as a line which the split-crack might follow. If you cleave from the bottom, this disturbance might lead the split-crack astray, whereas if you cleave from the top, the knot will guide the split-crack towards the pith.

6.3.4. Assessing the difficulty of a given direction.

Referring back to the discussion surrounding the ease of work, and table 11 specifically, I would like to specifically talk about the possible reasons for the differences in perceived difficulty, and whether they're a combined effect of the bias in our data, or whether they have to do with the cleaving-directions themselves.

From my own experience certain parameters show no correlation to difficulty, cleaving an oval log is not more difficult from the side, than from the top, at least I never noticed any such effect. What is most difficult to cleave remains the factors that are impossible to compensate for. Which there is no trick to overcome, namely twist and knots and other fibre-disturbances distributed evenly throughout the cross-section and length of the log.

It is precisely when looking at table 14 at the start of this sub-section, that you notice that cleaving from the side, happens to also account for many of the most common faults in the logs of this study. Yet despite that, on whole-logs, cleaving from the top, was what was considered most easy. Why?

I suppose it has something to do with inexperience with a new way of cleaving, which requires more labour, and something to do with precisely that, labour. Cleaving from the side is more labour-intensive than cleaving from the top or bottom, due to requiring more wedges, men and turns of the log. Naturally, if a method of cleaving requires more labour, it will be perceived as harder, and will take longer. Which is why it falls flat in the category of half-logs. When we look to quarter-piece production, the situation is flipped. The ease of which the work can be carried out when a half-log is laid flat and all you have to do is mark a line and strike perpendicularly along its side, is something to behold. A perpendicular strike with a club lets gravity do a lot of the job in bringing extra force into your strikes, and marking a splitting-line using a chalk-line is a non-intensive work-step.

I believe cleaving from the side is more apt in solving certain problems in half-logs. As there are clear trade-offs which need to be considered, the risk of "shattering" being prominent. However, when cleaving half-logs into quarters, cleaving from the side is particularly suited. The split-crack cannot possibly pass the pith, risking "shattering", so you get access to the specific ways in which a cleave from the side is well suited, with few of the trade-offs, and I believe this is what is being reflected in the distribution of the ease of work for quarters.

6.4. Limitations in the tools chosen

It is possible that the tools we used had a direct impact upon the ease of work. Lacking tools could cause a cleave that would otherwise succeed to fail to split open by only end-pressure, for instance when lacking tools to cut spanning fibres, releasing tension. The shape, size and weight of the clubs, as well as the wedges and available blocks for providing pressure are of great importance to the success of a cleave, together with the structure of the log. The tools we used for this study were of two sets:

Set number one consisted of professionally made and selected tools owned by Osebergstiftelsen and applied in cleaving on a regular basis. These tools were a mixture of wooden clubs, with end-grain at the striking-face reinforced with iron-rings, wedges made of beech of various sizes, iron-wedges the size of your hand, spacer-blocks made of various kinds of wood and a series of axes, fibre-cutters and peeling-irons and draw-knives for hewing, cutting spanning fibres and debarking.

Set number two, used in subset 2 was a series of wedges and clubs made using scrap-wood of various kinds. The clubs were made from glued elements, the heaviest were made from non-treated spruce, and were very prone to splintering when driving smaller wedges, whether metal or wood. However, they proved sufficient for the work when driving larger wedges. The smaller clubs were first made from spruce. However, as the join between the head and the hilt loosened continuously, we made a second club using glued oak-boards, the strike-face would then be the tangential plane. The club held up marvelously, the weakest link of the work, once-more being the joining of the head to the hilt. The wedges were made of scrap planks and cut at different angles and sizes. Some were profiled like right-angled triangles, this led to a series of problems with the application and direction of the force, either damaging the clubs by causing additional fraying of the fibres, or snapping the tips off of the wedges. The single other tool we had at our disposal in set 2, when cleaving, was a single hand-axe. Which held the sole responsibility of debarking, initiating and cutting spanning fibres. To wax poetic, one can begin to understand why the Norse preferred the axe over the saw, when one sees the versatility with which a single hand-axe can be wielded.

6.5. Limitations in scope

6.5.1. Geographic scope

The study only looked at a small number of trees felled in Norway, Sweden and Denmark. Due to the limited knowledge on the origin of the logs and known limitations of procuring logs of large diameters grown in Norway, it is not possible to know, whether locality of the sourced logs could have a significant effect on the results. This may of course be irrelevant for most, as few craftsmen can entirely source their logs from a given locality, but it would be interesting to compare with earlier sources. Friis states about oak at the end of the 1500s that oak growing at the top end of south-facing valleys in the sun, was brittle and floated in water, whereas the oak that grew in the wet spots or along the bottom of shadowy valleys was heavy, strong and sank, and made for the best construction-wood in Norway (Friis, 1632). Friis might not be the most reliable source however, as he was certainly no craftsman, and might have simply misunderstood heartwood and sapwood as being from different trees.

6.5.2. Research scope

There are always questions regarding how wide one should go, when discussing what events to cover in a text. How much should be included in the meat of the analysis, and how much should be left out, in order to streamline the product. I have opted to limit myself within this paper to looking at dimensional properties and visually distinguishable properties in regards to logs and cleaved pieces. This paper is wide enough as is. If I had had more time, I would have opted to gather cutoffs from more logs to test for density and tried to find quantifiable links to the properties presented in this paper. Which in turn, links it to other parts of the industry and papers done previously on the mechanical properties of oak. As of this moment, this paper stands isolated, though not far off-shore from the bounds of traditional research into the mechanical and morphological properties of oak. What it does do, which no paper previous, as to my knowledge, has done, is try to step unto the path of craft-science independently walking alongside wood-craftsmen, archaeological research and wood-science all at once, and try to find common ground and understanding between these sisters of knowledge. With an understanding that experimental research, grounded in the real experiences of craftsmen and documented rigorously using the language of maths, can reach a far wider audience and spread information regarding crafts to the archetypical researcher, and communicate methods of research to the archetypical craftsman. It is my hope that we can find common ground to communicate and systemize lived anecdotes of wood-behaviour, and on the other hand exemplify the results of research using large amounts of data.

6.6. Discrepancies with earlier works

As there are no other papers quite like this, there are therefore technically no discrepancies in the methods of gathering and interpreting data. However, a few points of data can be compared across genres. These are few and far between, but still can provide some grounds for reflection.

The tree chosen for the extraction of Mehinhufr-boards, measured at the root-end to 70 cm under the bark, was then felled in approximately one hour of continuous labour by four axes, the workmen were rotated out as fatigue accumulated, and axes promptly switched if heads loosened, handles broke or sharpening was needed. Thomas Søes Finderup anecdotally tells, in their work to recreate the Skuldelev 2 find, that four men required four hours to fell a tree of a meter in diameter, including time for breaks. (Finderup, 2022). Considering our surplus of workmen and tools allowed for replacements as needed, and the slightly more favourable diameter, the discrepancy in time isn't so far-fetched, and may be regarded as the difference between effective work without breaks, and reality.

The work done by the Cleavers and Boat-builders and volunteers in Sandefjord have been documented as the finished recreations of older finds. In viewing the older finds, there are certainly subtle discrepancies that we simply cannot avoid as we do our best. What we hope to accomplish as recreators and researchers, is to not let those discrepancies colour our perception of the very real constructions that existed, by remaining critical, continuing to question our methods and maintaining a healthy scientific skepticism. Becoming starry-eyed when you see a 'viking'-longship flow through water is natural after all the work is done, but a true craftsman and scientist alike always sees the potential to come all that much closer to the truth. It is by this principle that, when looking at earlier works cleaving came up as an unexplored part of the process. It is my hope that the future holds yet more nooks to continue to shed light into.

6.7. Usefulness of the results

There is a rather significant problem within general academia and craftsmanship, that instead of looking at the specific mechanics of what leads to a successful cleave or positive results, by destructively testing or looking for the negative results, we instead fall into the trap of simply repeating what has come before, imitating masters or verifying old results still apply in slightly different contexts. I hope to provide with this study the summarization of what not to do as a cleaver, by extensively looking at the ways to go wrong. By understanding where a cleave goes wrong, what the limits of a cleave are, you can better appreciate the level of wiggle-room you have to still get the specific result you want.

I have heard tale of certain logs being uncleavable or that it's infeasible to cleave in certain manners. I believe this to be a well-meaning exaggeration of the truth, to prevent apprentices from exhausting themselves and their tools upon inefficient pursuits. However, I believe in the pedagogic principle of letting people make their own mistakes. This of course requires a certain allowance for failure and an accompanying budget for resource-waste. They can then see and evaluate for themselves whether they would want to repeat the endeavour.

An innovative mind, is a rather new mindset. When we for most of history were taught a craft, and the correct way to do it, why would we choose to do anything incorrect? Most people saw perhaps one or two inventions spread during their lifetimes, if any. A craft was static, something you learned the proper way to do, and then taught your apprentice to do. When we instead are presented with 'alternate' ways to achieve the same result, we instead shape an innovative mind, one which looks for new ways to work, which can lead to efficiency-increases in the long run, by not letting us fall into the trap of a local optimum. For instance, the first saws were not more efficient than simply cleaving oak. Though it is by far more efficient today, at some point you had to drag a whole log out of the forest to a mill and produce lumber there, only to get two boards, same as cleaving and hewing. What those steps were, were a series of small step to the side, to gain another vantage, which some people at some later time, took another step forwards.

All this said, my study provides plenty of ways to cleave in a horrible fashion. And it is my belief that such a summary of different ways to cleave, what failures can and will occur and what things to expect, can help those who may need inspiration. To summarize, following a philosophy of relenting control, to cleave by providing pressure purely from the ends is possible if the material is free of knots and has little twist. To cleave from the sides is always possible and when doing a quarter-cleave and beyond, is preferrable, given it's from the sap-wood. But it is entirely possible to do from all sides, given the log specifically does not have any properties that hamper cleaving from a given direction.

7. Conclusion

The Norse could probably have cleaved from the top, bottom or side, depending on the properties of the log and their personal preferences. Cleaving from the side provided more yield in this paper with lower quality logs, despite a favourable distribution of properties it also seems to outperform the other directions in the areas where it does compare, distribution-wise.

The properties of Narrowing per meter, twist and number of knots/branches/burls had a clear correlation with production-levels. Twist and narrowing above 5% per meter tended to decrease production sharply. This decrease was steepest when cleaving from the bottom.

Cleaving can compensate for certain properties in logs. There is no single answer to which method is best all the time, nor is there a simple answer to the question of which direction does it best in logs of low quality, though it certainly appears that cleaving from the side can compensate for many of the properties that we typically associate with 'low quality', see table 14 for a summary. Whole logs were found to be easiest to cleave from the top, and half-logs were found to be easiest to cleave from the sapwood-side. After a thorough round of assessment, there is simply the answer to each log and each step of the iterative cleaving-process of that log.

In this paper I have provided the grounds for your own individual interpretation to take place within the framework of understanding cleaving as an informed choice built upon three components: A philosophy to inform, a step in the iterative process and a direction of attack.

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9. Appendix:

Item 1, Tool-terms:

“Wedge”, a pointed wooden or metal tool for cleaving.

“Through-line”, a theoretical line stretching through a wedge from the centre of the cleaving-edge to the centre of the striking-face.

“Club”, a large heavy wooden striking tool, requiring two hands.

“Mallet”, a small wooden, or metal, striking tool, requiring one hand.

“Sledge”, a large heavy metal striking tool, requiring two hands.

“Hammer”, a small metal striking tool, requiring one hand.

“Draw-knife”, an edged tool for removing strips of wood or bark, prototypically drawn towards yourself with two hands.

“Woodworking Chisel”, a chisel for cutting wood, a cutting tool with a narrow straight edge, at the end of a medium length piece of steel.

“Fibre-cutter”, a large cutting-tool reminiscent of a woodworking chisel, with a long handle typically requiring two hands.

“Peeling iron”, “bark-spud” or “bark-spade”, a long-hafted cutting-tool for debarking or ‘peeling’ a log, typically with a flat and wide cutting-edge.

Item 2, Method-terms:

“Establishing” or “Initiating”, the act of creating an opening usually 1-5 cm deep, by hitting a sharp hard object (metal wedge, axe-head, another sharp tool) into wood, with a striking tool.

“Driving”, “Cleaving”, “Splitting” or “Riving”, the act of expanding the size of an established opening, by placing a wedge in the opening and hitting it from behind with a striking tool. Wood is only cleaved when the expanded opening is borne due to expansive forces of the wedge overcoming the resistance of the material beyond the faces of direct contact. In other words, something is cleaved, when the created opening extends beyond the tip of your wedge.

“The split” or “the split-crack”, the cleaved opening.

“Veer” or “Veering”, from nautical terms ‘to veer off course’, here meaning a departure of the split-crack from the pith.

“Splitting-line”, a theoretical perfect line we could split the log along.

“Relenting control” can be summed up with the French words: c’est la vie, disallowing yourself from ‘correcting’ a split-crack on its path through the log, and instead working with what you get, afterwards. Hands off, aside from supplying driving force.

“Assuming control” is a term indicating a desire to direct control of the split-crack by corrective cutting of fibres throughout the entire length of the log, if necessary. The micro-management of cleaving.

“Ashing”, from the Norwegian “Asking” the act of physically marking the splitting-line, by stripping the bark and using a powdered length of string, also known as an ash-line, the term “asking” is also used in an expanded meaning, to refer to the entire process of creating a V-groove, from marking a line, to removing material.

“Awakening”, “Scaring” or ”Spooking”, from the Norwegian dialectical terms “Vekjing” and “Skræming”, the act of establishing an opening, along a determined path following the entire length of a log, to pre-release tension in the log, guiding the split in the heartwood.

Item 3, Structural terms:

“Whole-log” or “Round-log”, a log which has yet to be cleaved.

“Half-log” or “Half-piece”, a cleaved log whose remaining circumference is analogous to a half-circle.

“Quarter-log” or “quarter-piece”, a cleaved log whose remaining circumference is analogous to a quarter of a circle.

“Bottom-log” or “Root-log”, the roundwood previously connected to the root.

“Middle-log”, a length of roundwood neither previously connected to the crown, nor the root.

“Top-log” or “Crown-log”, the roundwood previously connected to the crown.

“Meginhufr” literally “The big strong board”, technically a plank and not a board it is what would join the upper and lower hull of a long-ship.

“Initial-crack”, the first crack always visible in the pith of a log right after felling, it will follow the pith along the entire length of the log.

“Drying-cracks” or “Checks”, cracking and separation of fibres in the log, as a result of drying.

“Piston-crack” or “cylinder-check” a circular crack found between two growth-rings, can be found in both standing trees, as well as occur because of drying in felled trees.

“Rays”, bands of connected living cells radially penetrating through wood from the pith, through the heartwood and sapwood to the vascular cambium. *Q. Petraea* and *Q. Robur* have characteristically large rays, their cross-section not uncommonly up to 20 cells high and 6 cells across.

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