Chapter 3

THE ÅLAND CHURCHES PROJECT AND THE NECESSITY OF INTERDISCIPLINARY RESEARCH

ABOUT THE ÅLAND CHURCHES PROJECT

An important aim of the project was to put an end to all speculation about the age of these significant churches. New approaches are needed this time. It is not enough to use traditional humanistic methods, instead the churches themselves should provide the historical sources. Archaeological artifacts and coins do not necessarily date stone churches, as they can derive from older buildings on the site, and they may also belong to later periods. The lack of written sources must be compensated by all available methods. All experts should be consulted.

Now was finally the time to establish the true dates of the churches. To reach an objective chronology, I was prepared to employ systematic implementation of scientific methods of analysis on a large scale. This priority of the natural sciences has come as a surprise to many art historians. Scholars have even expressed concern that such an approach might overshadow humanistic aspects such as architecture, art history, and style. Yet interdisciplinarity and the implementation of scientific methods in fact often provide the very basis for archaeological, architectural and art historical analyses. Only with reliable results is it possible to draw conclusions concerning the medieval history of the Åland Islands, about the building activity, and about the art of the churches.

▲ **Fig. 167. Peter Klein analyzing a wooden sculpture in Finström church, July 2005.**

Ideally this chapter should function as a guide through the large numbers of complicated scientific processes. Above all through the different steps of developing mortar dating, which have been taken within the Åland Churches project. Other methods used are also described, as is the interdisciplinary collaboration and the result of this approach.

Dendrochronology

To begin with, everything seemed straightforward and easy. Dendrochronology was the method to solve all problems. It was to be implemented on all the churches, on all building stages. Of all scientific dating methods dendrochronology is the most reliable. The sample is drilled from the sapwood to the inner core, if possible with all annual rings included. When comparing the pattern of the annual rings with the pattern of the master curve individually developed for different geographical regions, it is in principle possible to establish the exact year when the timber was felled. So far the method has primarily been used for oak and pine.

Thus dendrochronology was the first scientific method implemented by the project, and all available timber in the Åland churches was tested. The analyses were performed in 1991-1992 by Thomas Bartholin, from the National Museum of Copenhagen and the University of Lund. Of a total of 283 samples 159 yielded results, and out of these 107 were of medieval origin. This material was to form the basis for an Åland master curve. However, a large part of the samples were of spruce, a timber which is not easily dated by this method. Often, it would also show that the annual rings were too few for a determination of the age.

It was also demonstrated that well preserved timber mainly derived from secondary building stages, or from later repairs. Due to rot and fire, many parts of the roof constructions had been renewed. Dendrochronology can provide an exact date for the wood in question, but not necessarily for the original building stage. Therefore, the initial results were somewhat disappointing.

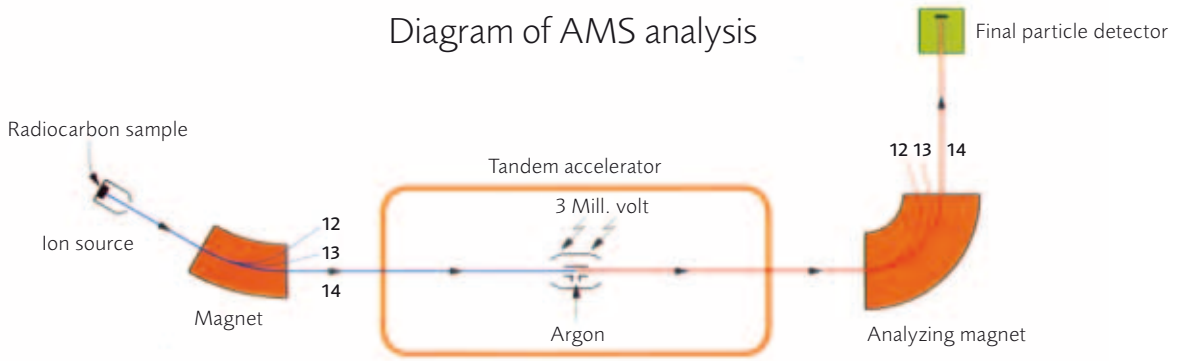
Although dendrochronological analysis could not always determine the date for the first building stage of the construction, the benefits of the implementation were soon evident. Dendrochronology could determine the ages for secondary building stages, such as towers, vaults, porches, and sacristies, which meant that we had valuable material for comparative analysis, and for the interpretation of an internal building history of the churches.

Peter Tångeberg, the Swedish conservator and art historian, was consulted about the wooden sculptures in Åland; he suggested that I should contact Peter Klein from the University of Hamburg, in order to complement stylistic analysis with dendrochronological dating of the sculptures. Klein has developed an important non-destructive method for wooden sculptures, where a nailbrush and a loop replace the drilling into the wood. The analysis of individual wooden sculptures is described in their respective contexts.

^{14}C analysis of fragmentarily preserved wood

Less well preserved wood, not datable through dendrochronology, such as fragments from wooden scaffolding or organic fragments embedded in the mortar, has systematically gone through radiocarbon analysis. Together with the results from dendrochronology, this material has provided an important databank with age control for comparative research.

Diagram of AMS analysis



Radiocarbon dating

As a method radiocarbon dating (^{14}C analysis) was developed at the end of the 1940s by Willard F. Libby, who received the Nobel Prize for this discovery in 1960. In the atmosphere of the earth, carbon exists primarily as carbon dioxide (CO_2). In the inner circulation of the carbon, carbon dioxide is bound to the earth through the photosynthesis of plants. From the plants it is further spread to animals and to different living organisms in the food chain.

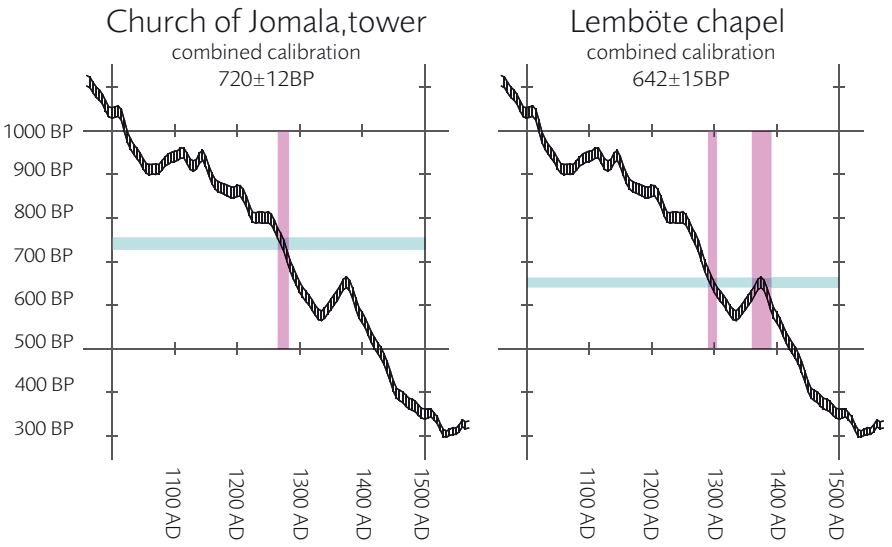
The amount of ^{14}C stored in plants and animals, in the oceans and in the global carbon reserves, remains rather constant through the ages, which means that the ^{14}C contents of living organisms is largely the same as in the atmosphere. Radiocarbon dating is based on the ratio between radioactive ^{14}C and the stable isotope ^{12}C, a relation that mirrors the atmospheric concentration of the isotope in living organisms. Isotopes of an element stand for atoms with the same number of protons (6 for carbon), but with different numbers of neutrons in the nucleus. There are three different naturally occurring carbon isotopes: the ^{12}C isotope, which in addition to 6 protones includes 6 neutrons (a total of 12 nuclear particles), the ^{13}C isotope with 7 neutrons, and finally the ^{14}C isotope which has 8 neutrons. By far the most common is the stable isotope ^{12}C which represents 98,9% of all carbon isotopes. The ^{13}C isotope, equally stable, amounts to 1.1%. Thus, together the two stable isotopes form about 100% of all carbon isotopes. Unlike the other carbon isotopes, however, the ^{14}C isotope is unstable, and is only a minimal part of the entire whole. That is, only one of a million millions carbon atoms is a ^{14}C isotope. It is radioactive, and therefore characterized by radioactive decay, which starts when the living organism dies. The decay has a half life of 5730 years, which means that after less than 6000 years the organism contains only half of the original amount of ^{14}C isotopes. Furthermore, a Beta particle is triggered for each decaying atom.

At the beginning, the measurements were done conventionally, by Beta counting, or measuring and detecting of Beta emissions from ^{14}C atoms over a period of time. Conventional dating requires large samples. One kilogram raw-material (mortar) is needed to get the necessary amount of 1-2 grams of pure carbon. Since only isotopes decaying during the period of analysis are measured, the conventional method is less precise and the statistical uncertainty becomes larger for small samples.

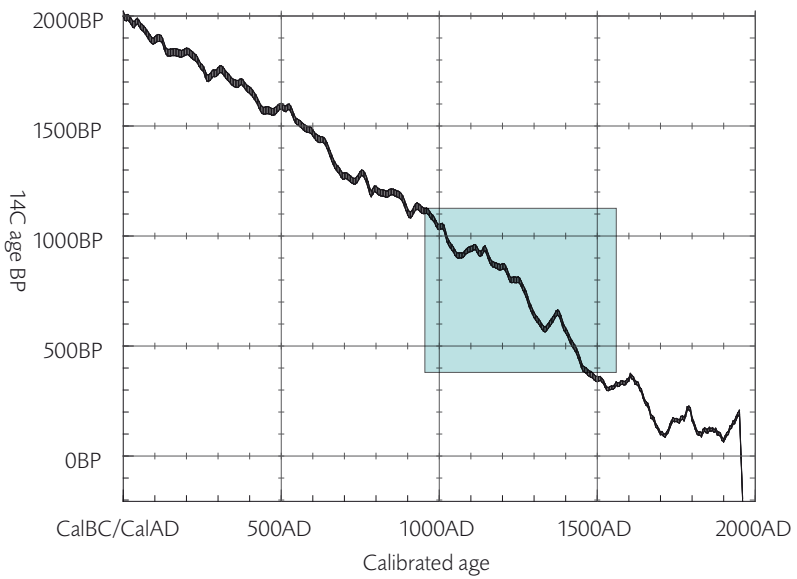
For radiocarbon dating the introduction of accelerator mass spectrometry (AMS) in 1977 meant considerable improvement. The system requires a tandem accelerator, which includes two separate phases of acceleration. The diagram demonstrates the process: the prepared graphite sample is placed in an ion source, after which the ionized carbon isotopes pass through two angled magnets on each side of the accelerator. Already by the first magnet a number of ^{12}C and ^{13}C isotopes are thrown out of their course. The remaining isotopes (^{14}C) reach the tandem accelerator, which they pass with accelerated (hence the name) speed, only to force the remaining ^{12}C and ^{13}C isotopes off course at the next magnet. Thus only the ^{14}C isotopes reach the final detector, where every single ^{14}C isotope is counted: the fewer the ^{14}C isotopes that reach the final particle detector, the older the sample. Radiocarbon dating is a statistical method, with built in error margins presented as ± values.

Calibration

A basic fact concerning all ^{14}C dated materials, not only mortar, is that the result is presented as a BP ("Before Present") age. Paradoxically "present" in this case is identical to the year 1950, since after that the amount of carbon dioxide was disturbed by repeated atomic tests and nuclear power stations. Since the ratio of the isotopes in the carbonate of the sample reflects the carbon dioxide at the time when the mortar hardened, this BP age is converted to calendar years using a calibration curve. This calibration curve is based on ^{14}C dating of annual rings in trees of known age, and it observes the continuing changes in the concentration of atmospheric ^{14}C. Therefore the curve falls irregularly, which affects the precision of the results. Where the curve is falling steeply, the margin of error is only a few years, but where the curve is largely horizontal, or when it wiggles and turns upwards, the measurement becomes less precise. For medieval Scandinavia in general, and for medieval Åland especially, the irregularity during the 14th century is a greatly disturbing factor. Where the chronology has been a matter of disagreement, however, it is still very valuable to be able to place individual buildings within the right century.



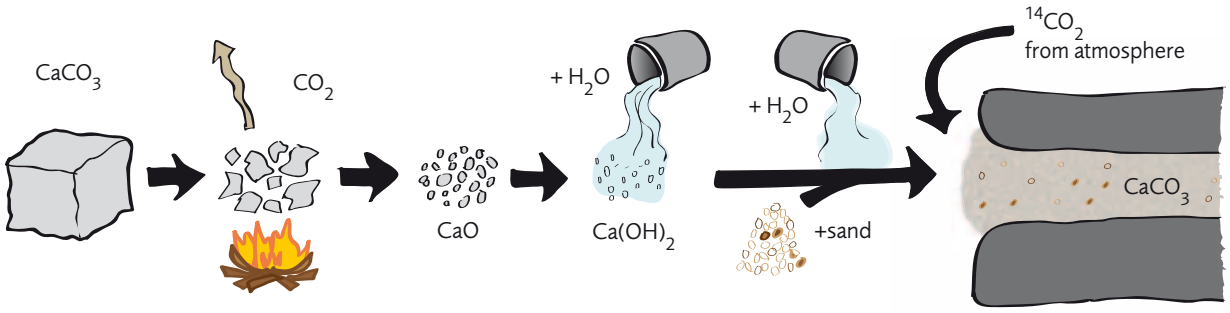
▲ **Example of calibration uncertainties during the 14th century.**



▲ **The calibration curve between the birth of Christ, and 2000 AD. Oxcal.**

The irrationality of the calibration curve

Two Åland examples are presented to demonstrate the effects of calibration on dating: to the left, the tower in Jomala, with the BP age of 720±12, to the right, Lemböte chapel BP 642±15. In both cases the margin of error is relatively small. The BP age is marked horizontally in blue. The vertical line in mauve marks the calendar age defined when a BP age cuts the calibration curve. In Jomala the BP age hits the calibration curve in a position where it is falling steeply. In this case the cutting is sharp and obvious and results in an exact age, 1270-1285AD. When it comes to Lemböte chapel, the BP age cuts the calibration curve when it is irregular and occasionally turning upwards, which means that the BP age cuts the calibration curve in two different places. Regardless of the error margin in the BP age being relatively small, the dating result is broad and uncertain. This time the calibration results in two different ages, that is, 1295-1310 and 1360-1387.



▲ **Fig. 168. The chemical process of mortar (Pia Sonck-Koota, modified version of Hale et al. 2003).**

^{14}C ANALYSIS (AMS) OF MORTAR

Mortar – unlike other materials– is the only one to be found in large quantities and from every stage of construction in its original composition. Therefore mortar dating has a great potential for archaeology. The first time I heard of the method was in 1989, when Högne Jungner, head of *the Laboratory for Radioactive Dating* at Helsinki University, presented the results from conventional ^{14}C dating at a Franciscan conference at Källskär, Kökar, in the outer Åland archipelago. I immediately realized the great potentials of the method, and the need to distance myself from all earlier theories and speculations. From now on mortar dating was to be implemented on a large scale. It would, of course, be done parallel with other methods, both archaeological and scientific. In August 1989 an interdisciplinary group was immediately formed, consisting of the physicist Högne Jungner, the archaeologists Kenneth Gustavsson and Milton Nuñez, and me, an art historian and archaeologist.

Mortar is not an organic material. Yet the chemical process in the hardening in principle makes it into an ideal matrix for ^{14}C dating (Fig. 168). To make mortar, limestone has to be heated up to at least 900°C. After the carbon dioxide has been released in the process, calcium oxide (unslaked lime) remains. Later, when this calcium oxide is slaked with water, slaked lime occurs. In the next stage, slaked lime is mixed with water and aggregate, usually sand. In the hardening process the slaked lime reacts with atmospheric carbon dioxide, and calcium carbonate is produced. Thus the mortar absorbs the carbon dioxide from the atmosphere and thereafter behaves as if it were organic.

The principle behind mortar dating was known as early as the 1960s, but it involved well-known risks, with a negative effect for the development of the method: The mortar could contain unburned limestone, due either to insufficient burning, or contaminating carbonate in the sand. These yield ages that are too ancient. Mortar can also result in ages that are too recent, which happens if the lime has gone through re-crystallization. If the mortar sample is taken deep within the construction, a delayed hardening occurs, with equally rejuvenating effects.

New procedures, new collaboration in 1994

Mark Van Strydonck, at the ^{14}C Dating Laboratory, Royal Institute for Cultural Heritage, Brussels, has been one of the pioneers in dating mortar. He abandoned the method in 1993, believing it was too complicated. Before that, however, he declared that ^{14}C analysis of mortar could be developed as a method, provided that AMS-analysis was implemented. He based this on experiments of his own. Some of the first experiments with AMS analysis of mortar were done already in 1990 by L.E. Tubbs and T.N. Kinder. They, however, only analyzed small fragments of charcoal within the mortar, not the mortar itself.

In 1994 Högne Jungner and Jan Heinemeier (from the AMS ^{14}C Laboratory at the University of Aarhus, Denmark) received promising results from implementing ^{14}C AMS analysis on mortar from the so-called Viking Tower in Newport Rhode Island, in the United States. After some sleepless nights, I decided that the Åland Churches project should also transfer to ^{14}C AMS analysis of mortar. From now on, all earlier results from conventional ^{14}C analysis were to be disregarded, and the entire process was to start all over. Hereafter, only AMS analysis of mortar would be considered. The samples were analyzed at the AMS ^{14}C Dating Centre at Aarhus (Fig. 169), which meant that the project became more interdisciplinary and international in character.

▲ **Fig. 169. The tandem accelerator at the University of Aarhus, Denmark.**

A great advantage of AMS analysis, compared to conventional analysis of mortar, is that smaller samples are required. For the AMS-analysis a handful of mortar per sample is sufficient, and as little as one milligram

of the prepared sample will be enough for the analysis (Fig. 170). In addition to the material analyzed, the remaining part of the sample is collected for any possible re-dating, and for different types of chemical and geological analyses.

The results from the transition to AMS analysis meant that such Åland mortars as had earlier been analyzed conventionally were now corrected. Within individual building units the results were more coherent and more recent, with the margins of error diminishing.

▲ **Fig. 170. Jan Heinemeier and Alf Lindroos sampling mortar in the church of Kumlinge in 2007.**

The geologist Alf Lindroos joined the project in 1994, marking another important step forward for the project. Since then he has been the central figure of the team, in charge of the scientific development of the method. To solve problems with contamination and re-crystallization, he focused on preparatory procedures. Since then the Åland Churches project has been the only team to systematically develop the method internationally.

International cooperation and challenges in 1997

In the autumn of 1996, I was invited to be a guest professor in architectural history at the University of Louisville (UofL), in Kentucky, with far reaching consequences for our project. In 1997 Stephanie Maloney, professor of Art History at UofL, invited me to join their excavations at Torre de Palma, Portugal, the largest Roman Villa on the Iberian peninsula. Thus the project expanded to include also Classical Archaeology. Help was needed to establish the chronology of the site. At Torre de Palma, the mortar is like Åland mortars in principle - it is a matter of non hydraulic lime mortar. With the aid of mortar analysis a chronology could be established for the site, from the first century AD until ca 639 AD. At the same time preliminary experiments were done on Spanish mortars from Merida and Barcelona. John R. Hale, classical archaeologist from UofL, became an active member of the international research team. He suggested that we should try the method in Rome, to see how it worked on well-known buildings, firmly dated by historical sources.

Sampling Roman pozzolana concrete in Rome thus began in 1998, which meant a real challenge for the development of the method. Chemically, hydraulic Roman pozzolana mortar is entirely different from lime mortars in Åland and in Portugal. "Hydraulic" in this case means that the mortar includes volcanic ash, which makes it possible to harden under water. Roman pozzolana mortar is stronger than other concrete-like materials, and so it became one of the prerequisites for the architectural revolution, when the Romans could liberate themselves from old rules of masonry and create freely. Even if we have had remarkable successes in testing AMS analysis on pozzolana mortar from well known buildings of firmly documented ages, such as the Colosseum and Trajan's Market, and buildings in Ostia, harbor and holiday retreat for the Romans, we already now know that pozzolana mortar is much more complicated to date than non hydraulic lime mortars. Lynne Lancaster, from Ohio University in Athens, Ohio, an expert on Roman building technique, has been our guide in Rome.

So far, all dating analyses connected to Åland have been done at Aarhus, as have many samples from our international projects. Other dating laboratories involved in our international collaboration are since 2005 the Oxford Radiocarbon Accelerator Unit, England and, since 2006 the NSF (Natural Science Faculty) - Arizona Accelerator Mass Spectrometry (AMS) Laboratory, Tucson, United States.

Development of the mechanical and chemical separation

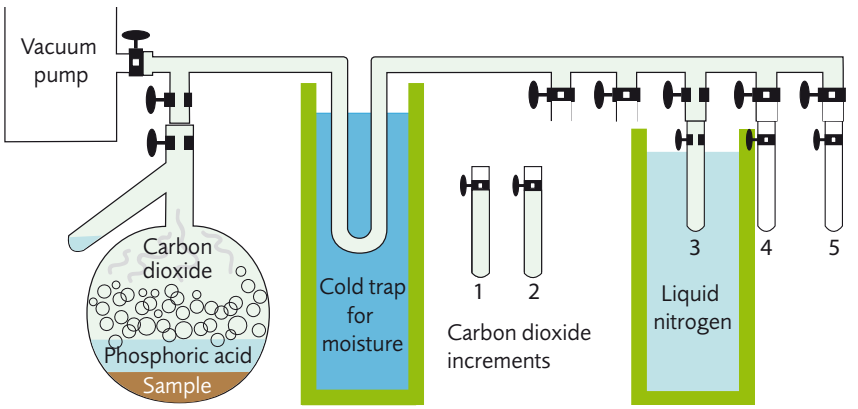
To avoid risks from contamination of unburned lime-stone and from the effects of re-crystallized calcite, the mortar samples have to go through different types of preparatory processes, including both mechanical and chemical separation.

Mechanical separation: For an optimal collection and enrichment of the datable, soft and porous mortar carbonate, every single sample is carefully crushed in a mechanical separation. The process aims at excluding or at least minimizing the hard and unburned limestone, which contains old carbonates and therefore can yield ages too ancient in the analysis. Then the samples are sifted in a sieving system that varies in grain size from 20 to 500 microns (1 micron is 1/1000mm). The finer grains of the mortar pass through the rougher sieves, where they are separated from the larger grains of the aggregate, which can include both calcite crystals from re-crystallizations and contaminating, unburned limestone. For the final AMS analysis we normally choose a grain size window of 39/46-75 microns. The prepared powder is then subjected to cathodo-luminescense microscopy, which reveals any possible remains of unburned limestone.

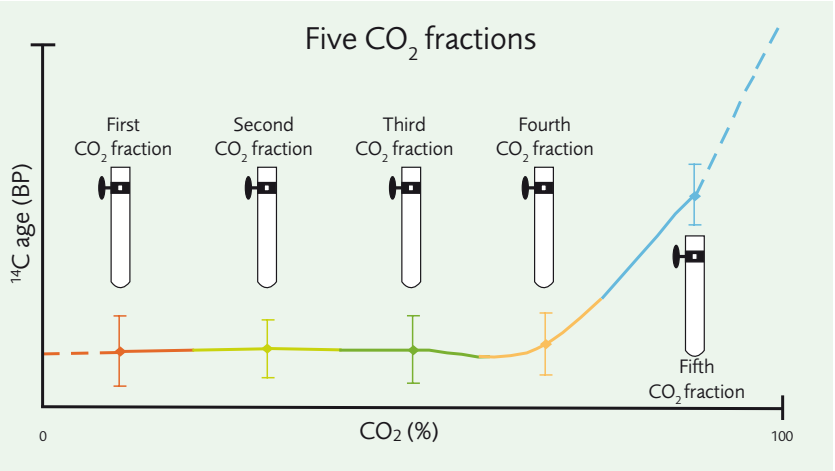
▲ **Fig. 171. Chemical preparation using phosphoric acid in two carbon dioxide fractions. On the left the phosphoric acid is still isolated, on the right it reacts with the mortar carbonate.**

Chemical separation: In the subsequent chemical separation an 85% solution of phosphoric acid is poured under vacuum over the mechanically separated mortar, at this stage a fine powder of approximately one mg. A chemical reaction occurs, which begins very fast. The mechanically separated sample is still isolated from the phosphoric acid in the side arm of the vial (to the left in Fig. 171). To the right in Fig. 171 it bubbles in the vial when the phosphoric acid reacts with the binding carbonate. Thus, the carbon dioxide is liberated from the sample in the form of gas. The carbon dioxide from this first reaction is identical to the first carbon dioxide fraction, a term frequently used in this text. This gas is collected in vials at different stages of the dissolution process. The first carbon dioxide fractions are isolated within seconds, whereas the second takes a few minutes. The next fractions are isolated during the subsequent hours. Since the mortar carbonate dissolves so much faster than unburned limestone, the carbonates from the mortar dominate the beginning of the dissolution process. The first carbon dioxide fraction is therefore expected to be less influenced by slowly dissolving unburned limestone, and thus these first carbon dioxide fractions are supposed to come closer to the hardening of the mortar than the later ones. Until 2002, the mortar samples were separated and analyzed in two carbon dioxide fractions.

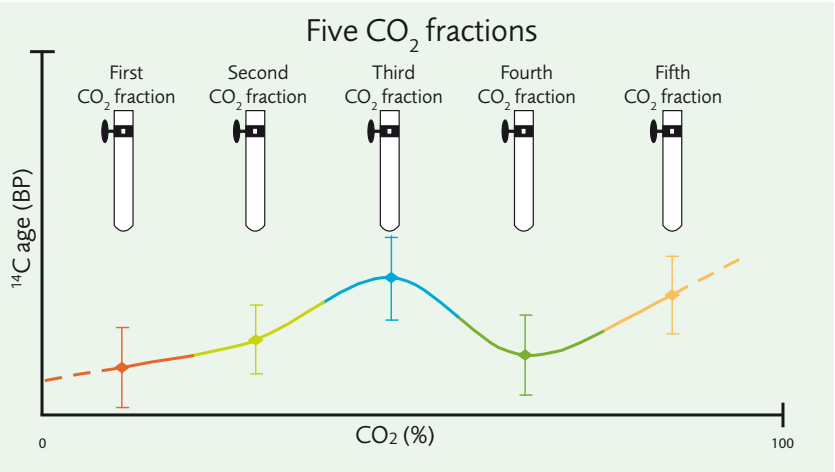
One big step forward in the chemical separation was taken in 2002, when our experiences from Roman pozzolana mortar had demonstrated the importance of following the dissolution process in the interpretation of the results. To maximize this information, all samples from then on went through a chemical separation in five successive fractions (Fig. 172). The process results in age profiles that illustrate all stages of the dissolution process. For Åland in general, the first CO_2 fractions reveal the correct age (cf. Fig. 180a). Exceptionally, as with mortars that have been damaged by fire, the conclusive age is revealed later in the age profile.



▲ **Fig. 172. Chemical separation in five successive carbon dioxide fractions. In this case the process has lasted a few minutes and two CO_2 fractions have already been isolated. The third fraction is being chilled by fluent nitrogen, while the two last ones, which take hours, have not yet been isolated.**



▲ **Fig. 173. Example of an age profile with the individual CO_2 fractions marked. In this case the correct age is identified in the horizontal plateau at the beginning of the profile. (CO_2 fractions 1-4). The contamination does not affect the result until the last fraction.**



▲ **Fig. 174. Example of an age profile where the first CO_2 fraction reveals the right age, while a slight contamination can be traced already in the second CO_2 fraction.**

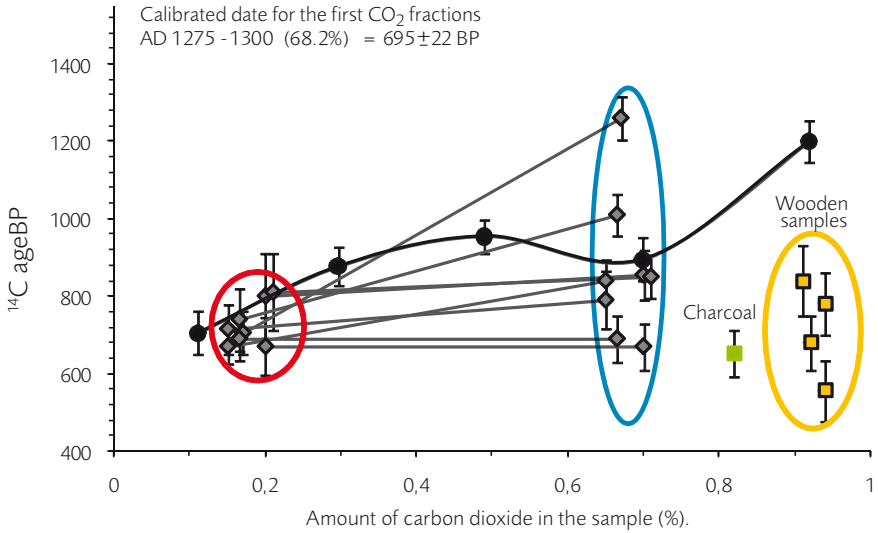
SCIENTIFIC DATING AND THE ÅLAND CHURCHES

Eckerö

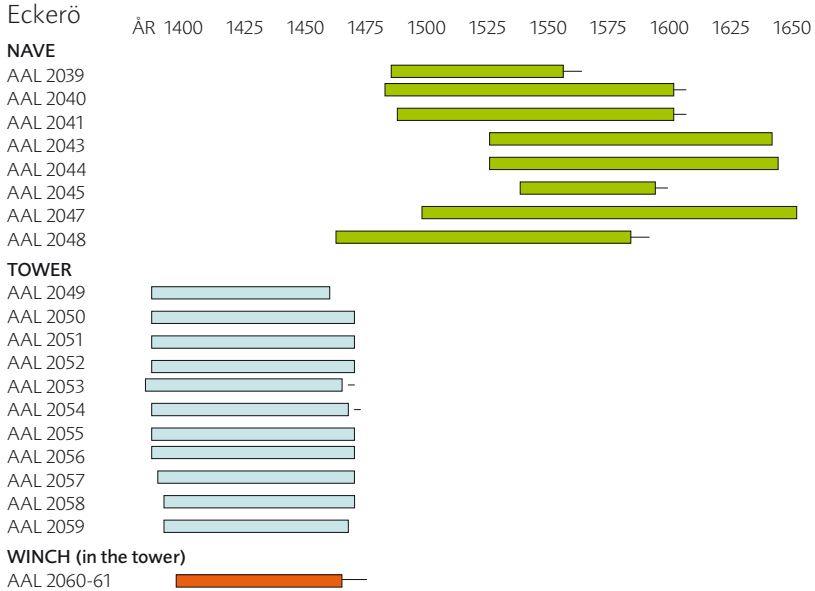
Dendrochronological analysis from the church of Eckerö presents results typical of the Åland churches – rather than revealing the age of the first nave, we see a large spread of results varying from around 1554 and 1650 (Fig. 175).

Obvious marks of secondary repairs, partly confirmed in the archives, can be seen. In this case the real age of the nave is based on scientific dating methods of different materials, such as mortar, charcoal, and wood (Fig. 176a).

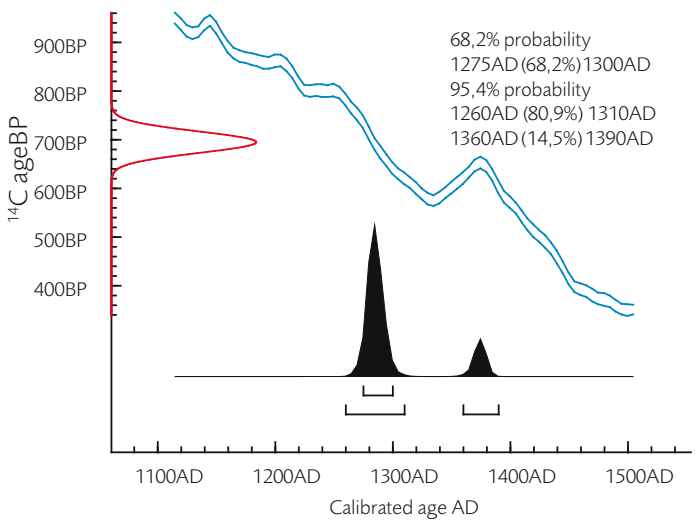
Combined calibration of eight mortar samples from the nave yields the age 1275-1300AD, which agrees with the ^{14}C analysis of the fragmentarily preserved scaffolding and the northern wall plate. This time the results coincide with the ^{14}C analysis of a charcoal particle embedded in the mortar. A fourth wooden sample, partly outside the margins of error for the other samples, may depend on a secondary replacement of the wood. The other uniform samples were later confirmed in a renewed analysis in a complete age profile of Eka 030 (cf. 176a).



▲ **Fig. 176a. Results of scientific dating of the nave at Eckerö: mortar dating in two carbon dioxide fractions and ^{14}C analysis of poorly preserved wooden constructions. The first carbon dioxide fractions of eight mortar samples are inscribed in a red circle, the second fractions in a blue circle. One of the samples has further been analyzed in five fractions to form a full age profile.**



▲ **Fig. 175. Dendrochronological analysis from the church of Eckerö.**



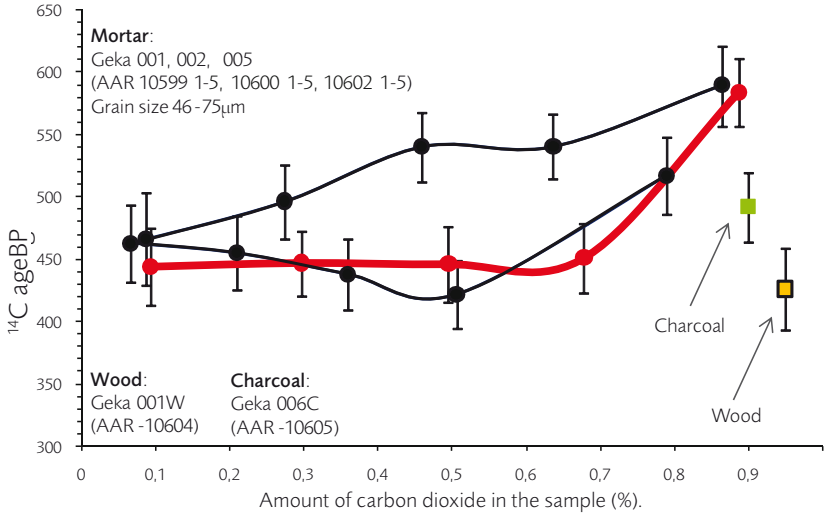
▲ **Fig. 176b. Combined calibration of all first carbon dioxide fractions (encircled in red) yields the age 1275-1300AD, at a probability of 68,2%.**

Geta

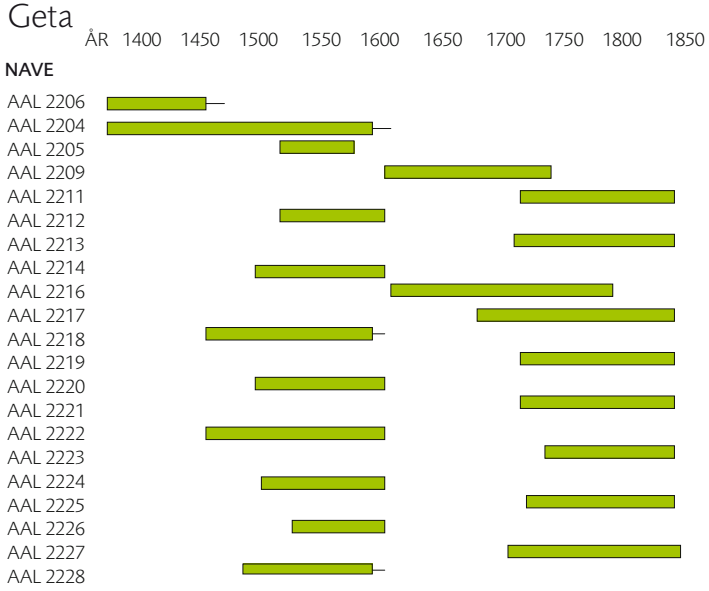
In Geta church, the results from dendrochonological analysis were confusing. Every second roof truss seemed to belong to the 1590s, whereas the rest of the timber was felled in the 1820s (Fig. 177).

Only one timber, the northern wall plate, suggests a medieval origin, sometime after 1450. This was a case which only mortar dating could solve.

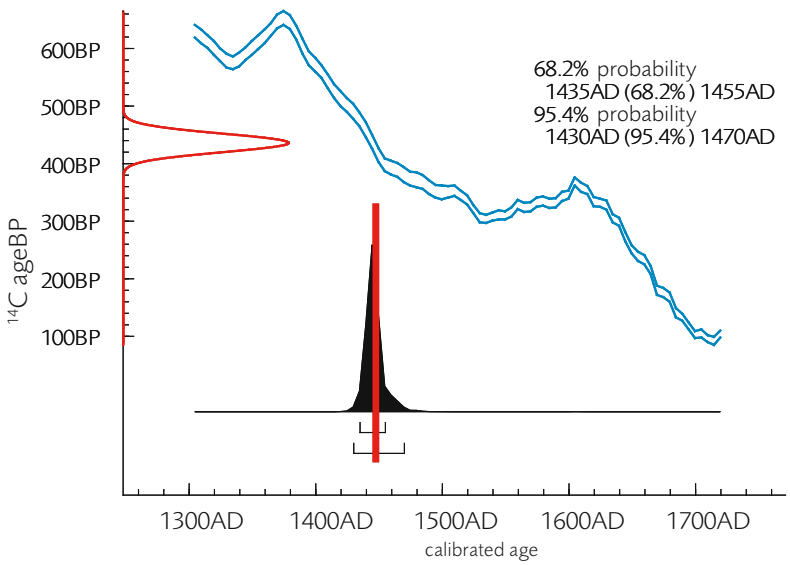
In this case the three age profiles are unusually convincing (Fig. 178a). All first carbon dioxide fractions converge within the range of the same error margins. In addition all four introductory fractions in one of the age profiles (Geka 002) form a horizontal line. We see an almost ideal profile, without contamination from either ageing or rejuvenating effects. A combined calibration from all first fractions yields the age 1435-1455 AD. The result is additionally supported by a wooden splint, embedded in one of the samples, falling within the same error margins. Thus, in the church of Geta mortar dating confirmed that the only dendrochronologically established sample from the Middle Ages really belongs to the original construction. In this case the implementation of different methods and different materials yields uniform results.



▲ **Fig. 178a. Three age profiles of mortar analysis in the church of Geta. Especially important is the horizontal age profile of Geka 002, enhanced in red. Within the same error margins also fits a wooden splint embedded in the mortar.**



▲ **Fig. 177. Dendrochronological analysis from the church of Geta.**



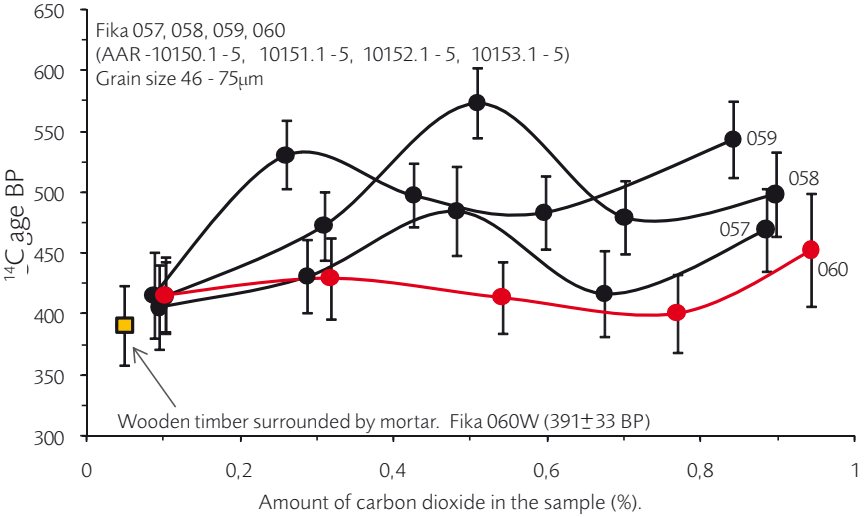
▲ **Fig. 178b. Combined calibration of the first carbon dioxide fractions from individual age profiles, 436 ±16 BP, yield the age 1435-1455AD, which is in complete agreement with the dendrochronology (vertical in red).**

Finström

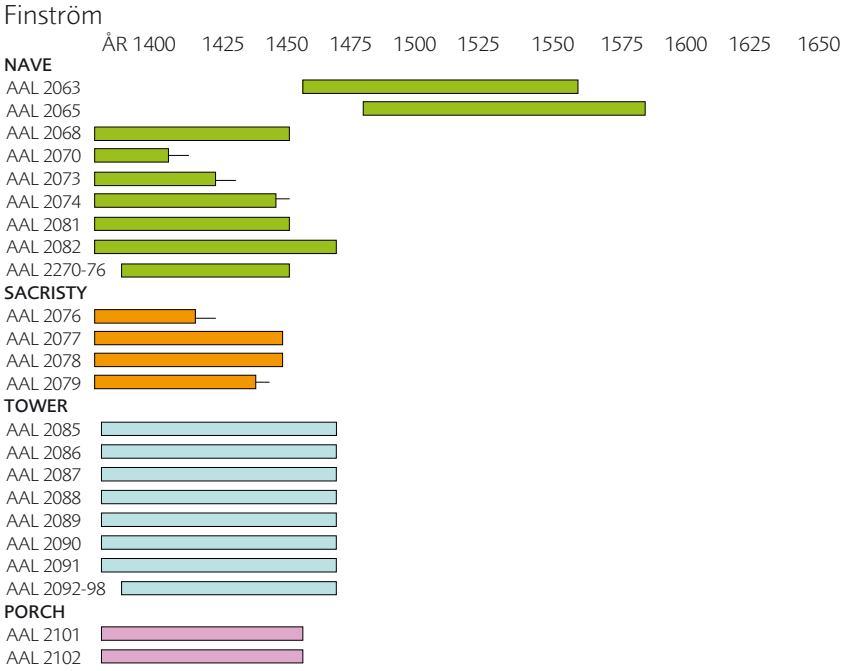
The church of Finström is one of the best preserved medieval buildings in entire Finland, but the building history of the church is confusing.

Dendrochronology seems to provide explicit results from different building units. The sacristy from the 1440s is oldest, closely followed by the nave around 1450, the porch from the 1450s, and finally the tower, which was erected in 1467 (Fig. 179). Such a late date for the entire building is surprising. Therefore a number of mortar samples were taken from the walls of the nave. It was important to test the dendrochronology.

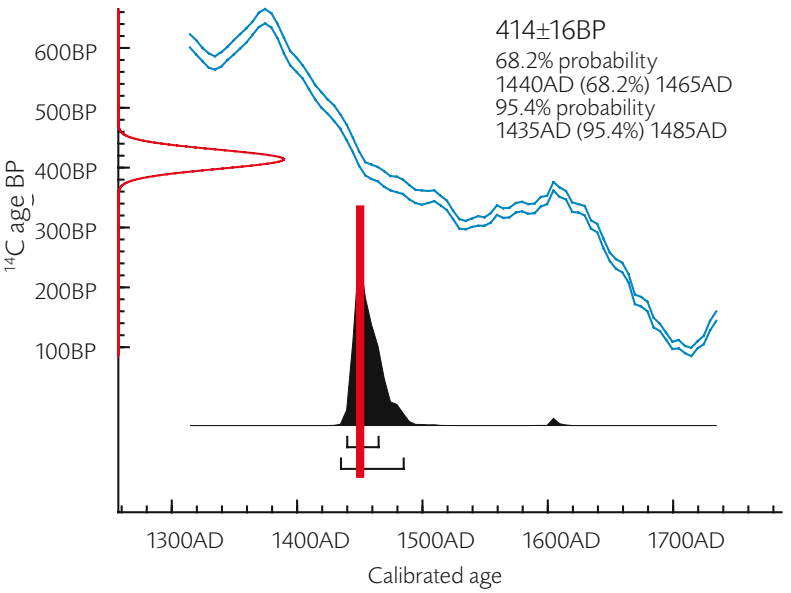
Four of the samples were analyzed in complete age profiles (Fig. 180a). From a technical point of view the results were extremely well disciplined, all of them reaching identical results at the first carbon dioxide fractions. The results are in complete agreement with the dendrochronology of the nave.



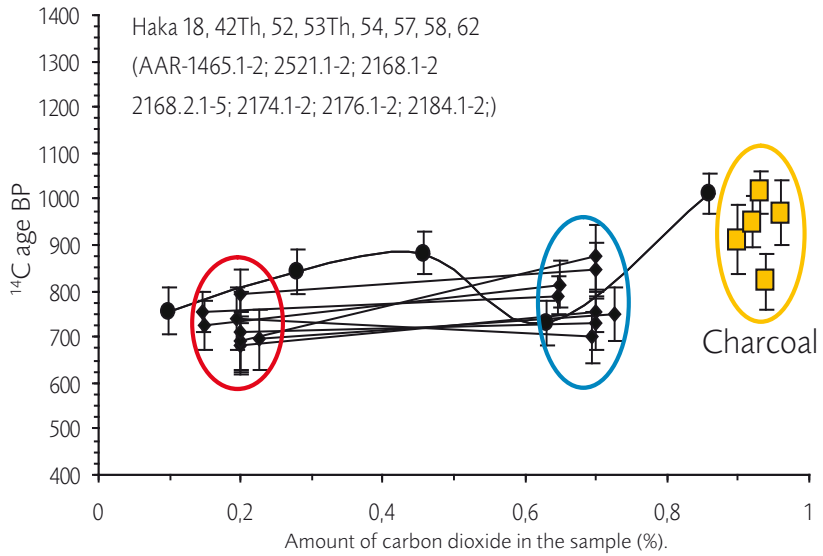
▲ **Fig. 180a. The first carbon dioxide fractions in four age profiles converge at the 414±16 BP age. Yet once more, one of the age profiles, Fika 060, is almost horizontal and completely free from contamination. The embedded wooden fragment, Fika 060W, fits well into the picture with the age 391±33 BP.**



▲ **Fig. 179. Dendrochronological analysis from Finström.**



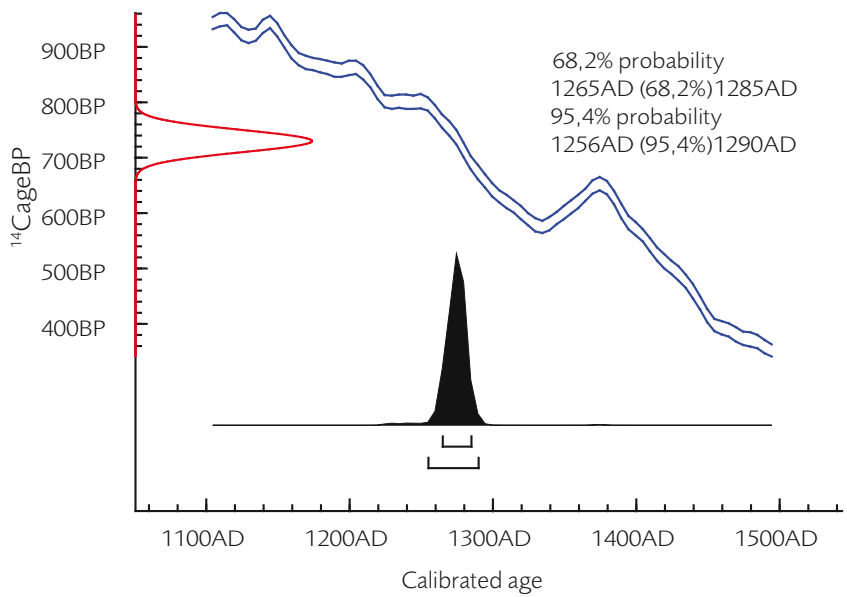
▲ **Fig. 180b. Combined calibration of the first fractions yields 1440-1465AD, at a probability of 68,2%, which is in agreement with the dendrochronology, 1450AD.**



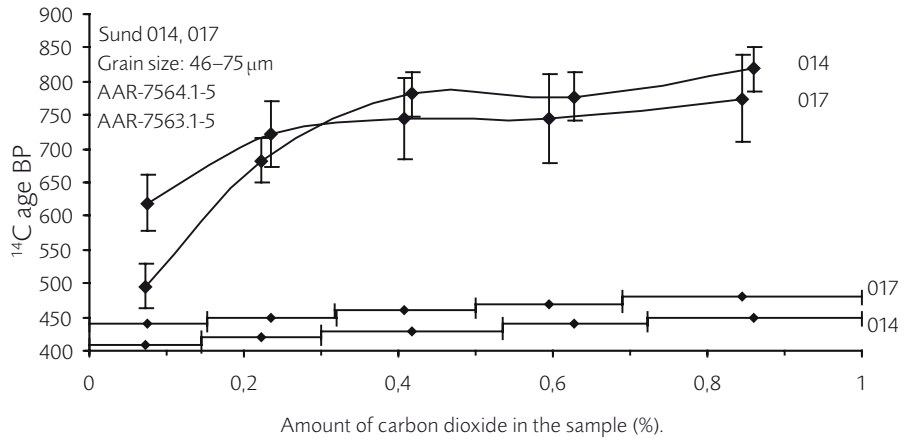
▲ Fig. 181a. The church of Hammarland. The results from mortar dating from the first building stage of the nave, analyzed in two carbon dioxide fractions. One of the samples was later analyzed in five successive fractions. The first fraction of the age profile confirms the earlier results.

Hammarland

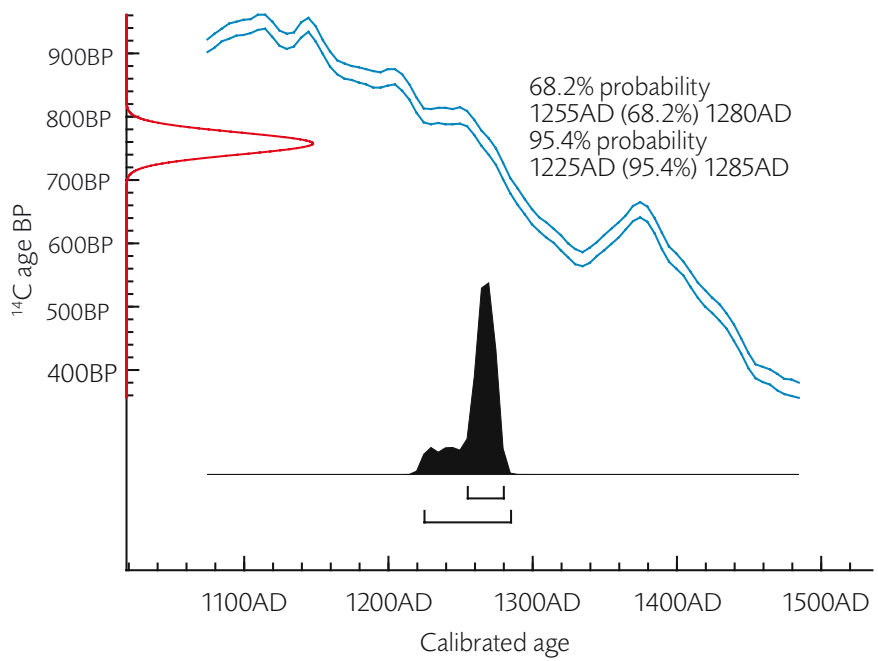
In Volume I of the *Åland Churches*, covering Hammarland and Eckerö, four different ages were presented for the nave in Hammarland, based on mortar analysis and ^{14}C dated wooden samples, depending on the age difference between the individual results being uncomfortably large. It is now obvious, however, that eight mortar samples from the nave, all of them representing CI, differ from the others in a remarkable way (cf. Fig. 181a). It has gradually become clear that the results actually represent two different stages – the nave and a later secondary stage, which among other things includes the vaulting of the nave. The first stage of the nave was erected 1265-1285, while the following stage belongs to the 14th century.



▲ Fig. 181b. A combined calibration from the first fractions (encircled in red Fig. 181a) yields the age 730±20 BP, or 1265-1285AD, at a probability of 68,2%.



▲ **Fig 182a. Two age profiles from fire damaged mortars from the nave coincide within the same error margins on the horizontal platfoms formed later in the profile.**



▲ **Fig. 182b. Combined calibration of the platforms yield 758±17 BP, or 1255-1280AD, at a probability of 68,2%.**

Sund

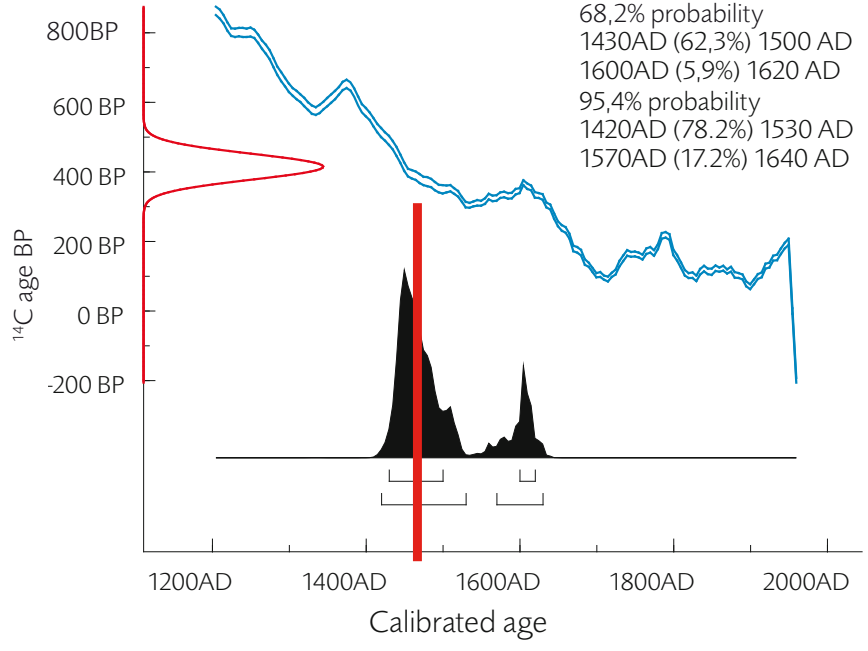
There are, unfortunately, no results from dendrochronology at Sund. All available wood from the nave has repeatedly been damaged by fire. The only wooden material left was a couple of charred fragments of the moulding forms from the tower staircase. These were also ^{14}C analyzed.

Thus the only remaining way to ascertain the age of the nave was by analysis of mortar badly damaged by fire. From the nave, including the vault, there are a total of five age profiles, all of them radically different from other Åland samples. Two of the profiles remind us of the profiles from hydraulic Roman pozzolana mortar, where the horizontal platform of the age profile often reflects the known age. A combined calibration yields 1255-1280AD at the highest probability (Fig. 182a-b).

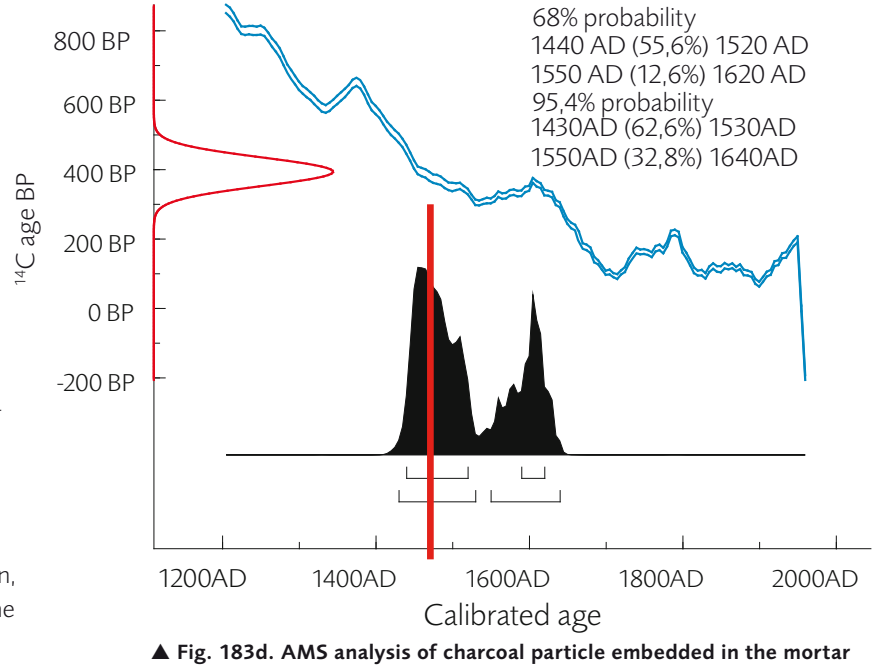
These atypical age profiles have to be interpreted critically and carefully, since real age control is lacking. Still, our experiences from other fire damaged constructions where age control is available have supported our hypothesis that the correct age in case of fire, is reached later in the profile. Our experiences from Sund have given important insights into the identification, interpretation and dating of buildings damaged by fire.

▲ **Fig. 183a. Vårdö church, the exterior.**

▲ **Fig. 183b. Vårdö 005, mortar sample taken from the original east gable of the nave.**



▲ **Fig. 183c. AMS analysis of mortar (Vårdö 005) yields 415±37BP, that is, after calibration 1430-1500 at the highest level of probability, in agreement with the dendrochronological analysis (vertical in red).**

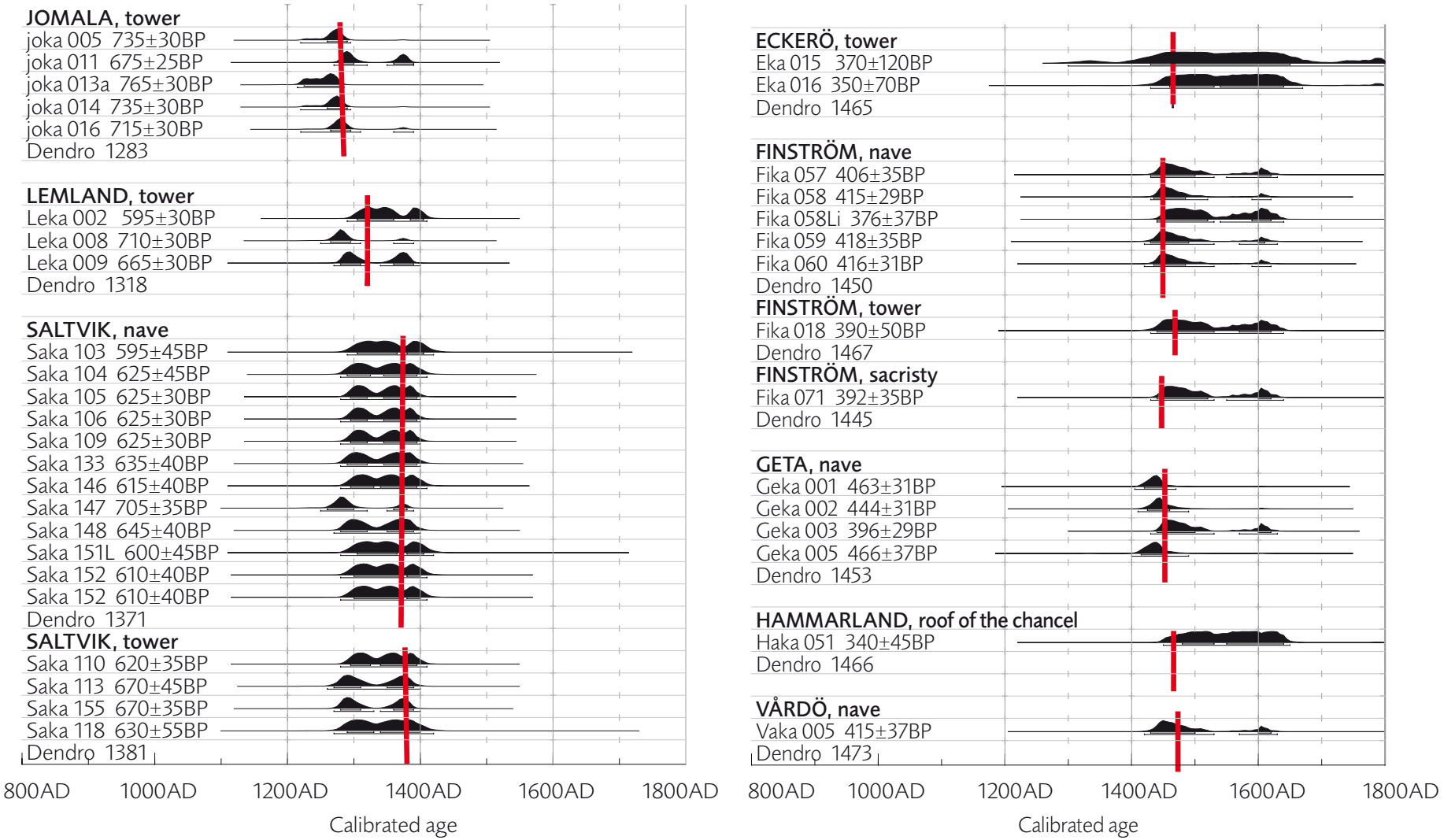


▲ **Fig. 183d. AMS analysis of charcoal particle embedded in the mortar (Vårdö 005). This is a rare case where the charcoal, 394±41BP, yields the same age as the dendrochronology.**

VÅRDÖ

Fig. 183b above, shows an interior from the attic of the nave at of the church at Vårdö, where the original east gable has been preserved. The red square indicates the sampling of Vaka 005, a mortar sample which also included an embedded particle of charcoal. The calibrated age in Fig. 183c represents Vaka 005, a mortar sample where the first fraction (415±37BP) after calibration coincides with the dendrochronological analysis of the northern wall plate. Exceptionally, in this case the embedded charcoal particle of Fig. 183d, (394±41) yields the same result as the mortar. Usually, as is well known, the charcoal particles are older than the mortar, but in no case could they be younger.

COMPARISON BETWEEN MORTAR ANALYSIS AND OTHER SCIENTIFIC DATING METHODS



▲ **Fig. 184. Mortar samples from Åland (calibrated dates from the first CO_2 fractions marked horizontally in black) confirmed by dendrochronologically dated wooden structures (vertical in red).**

The time has come to submit the samples from mortar dating to comparative analysis. Constructions which have been firmly established by dendrochronology of course have the highest priority. Of all Åland mortar results, 38 can be weighed against dendrochronology, of these 36 mortar samples agree with dendrochronology (Fig. 184).

RELIABILITY CRITERIA

Our experiences from Åland lime mortar, so far covering 150 samples analyzed, has made it possible to formulate four criteria of validity. Simultaneously they serve as criteria for different degrees of reliability and as auxiliary tools in the interpretation of cases where age control from other methods and other materials are lacking, in short – when mortar dating is the only option. To avoid misinterpretations the criteria have been kept as strict as possible on purpose.

Valid for independent mortar analysis, without age control:

Criterion I (CI)

When the first two carbon dioxide fractions in the analysis coincide (in this case one single sample per building unit is sufficient). In principle Criterion I is thus void of disturbing contamination, and shows only a minimal gradient between the first two CO_2 fractions. In cases where the samples have been analyzed in full age profiles, a horizontal platform at the beginning of the profile is expected to show the same minimal gradient, if at all.

A subdivision of Critierion I is made up of age profiles where the correct age is revealed by a horizontal platform later in the profile. This can occur when hydraulic pozzolana mortar is analyzed, and when the mortar is damaged by fire.

Criterion II (CII)

When the first CO_2 fractions coincide in a series of three or more samples from the same building unit.

Not valid for independent mortar analysis, requires age control:

Criterion III (CIII)

When the first CO_2 fractions coincide in two samples from the same building unit.

Criterion IV (CIV)

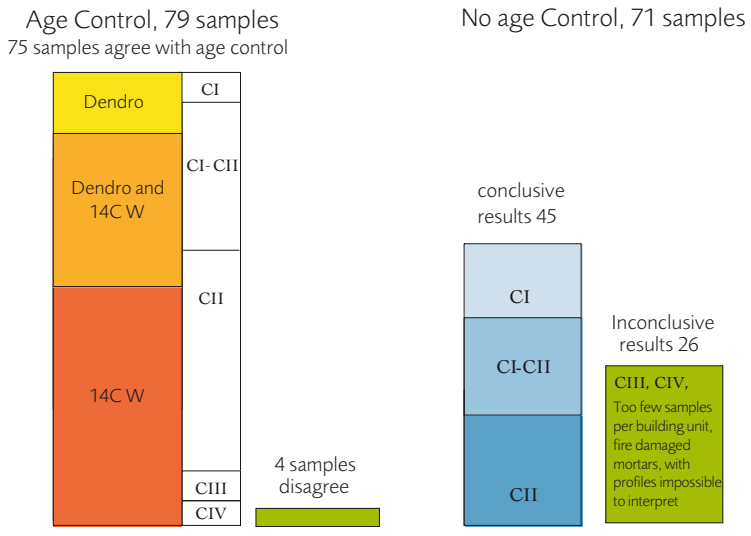
When the first CO_2 fraction in one single sample from a building unit results in an age which is acceptable compared to other building units within the same construction.

The Åland mortar samples with age control versus no age control are divided 52% to 48% (Fig. 185). 75 out of 79 samples with age control agree with the known age, which means that they have to be regarded as conclusive. Thus 95% of all samples with age control are in agreement with the known age. The requirements for Criterion I have been so strictly formulated that they only match 33% of all conclusive samples with age control. Only four samples deviate from the age control. So far we don't know why.

Of the remaining 71 samples without age control, the majority, or 45 samples, follow the strict requirements for Criterion I and II. The results in the blue staple are therefore conclusive, which means that the total percentage of conclusive results amounts to 80%, regardless of age control.

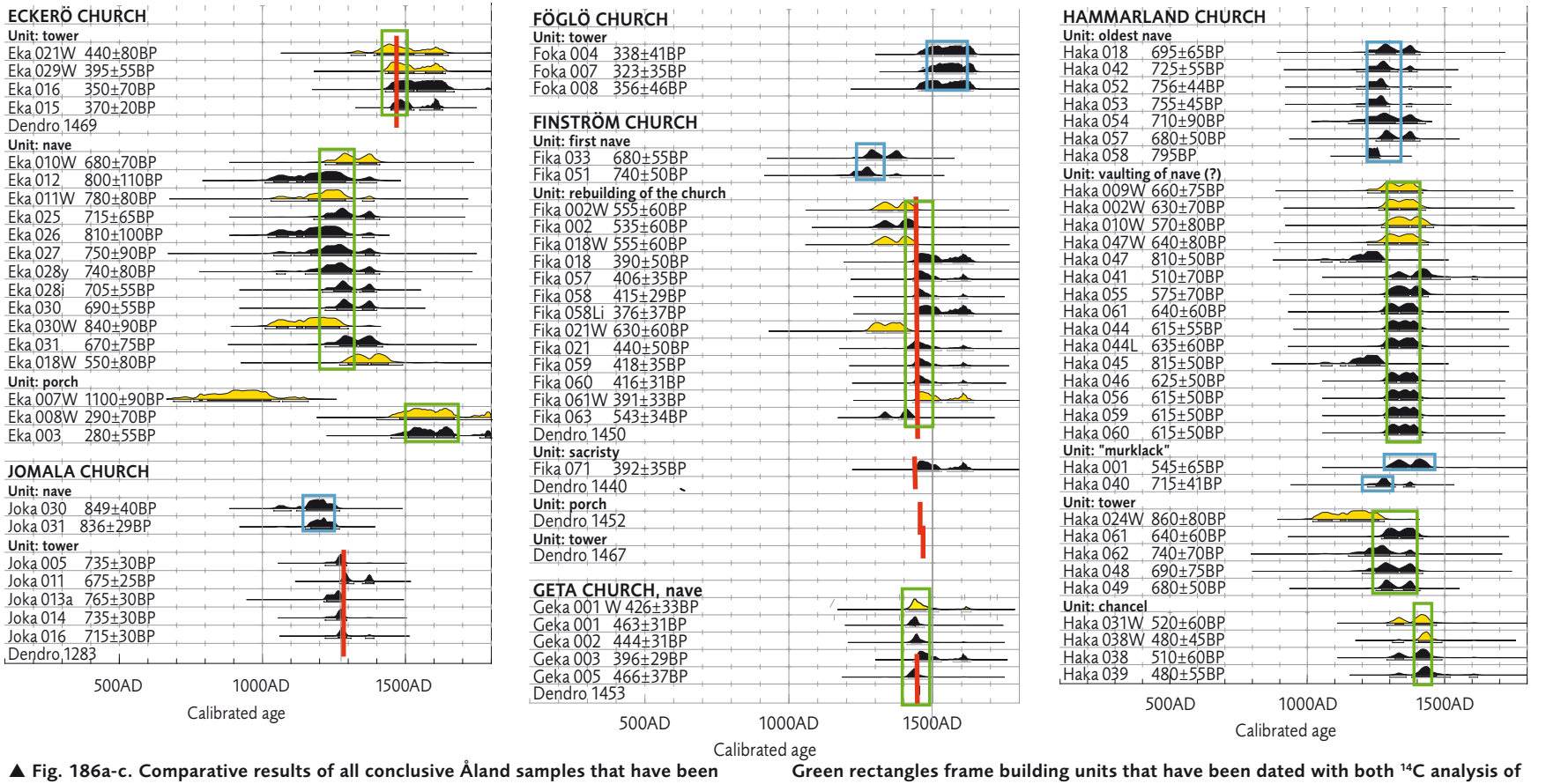
In regard to non-hydraulic Åland mortars, we generally find that only 57 samples meet with the strictest of all criteria, Criterion I, which means 38% of all conclusive results. Criterion II represents the majority of the conclusive results. 92 samples, or 62% of all samples, belong to series where three or more samples from the same building unit reach identical results with the first CO2 fractions. In this case we have contamination from unburned limestone, but it has been successfully eliminated with the aid of mechanical and chemical separations. 42 samples (28%), which represent both Criterion I and Criterion II simultaneously, must be seen as especially reliable.

The staple to the far right represents 26 inconclusive results. These results are not uniform, but we normally know the reason why. They often represent Criteria III and IV, which means that too few samples have been analyzed per building unit. Even if several of the results indicate a certain age, it is not conclusive enough without age control. This category also includes fire damaged samples from the church in Sund, samples which result in age profiles without horizontal plateaus, and therefore impossible to interpret.



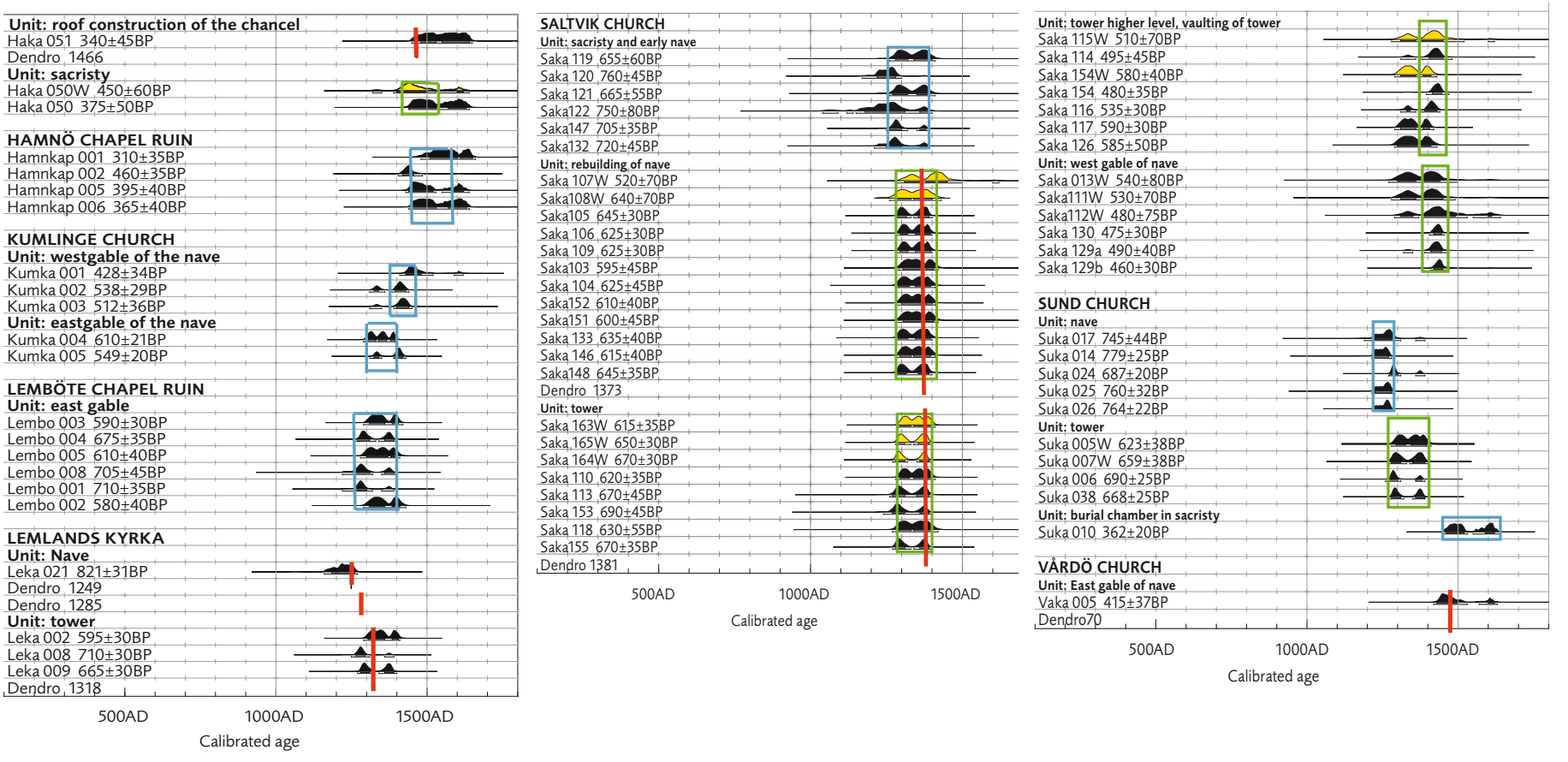
▲ Fig.185. Classification of results from Åland mortars. The staple in red and yellow to the far left represents samples with age control, based on dendrochronology and/or ^{14}C dated wooden structures. 75 samples out of a total of 79 agree with the known age. The adjoining narrow white staple reveals the proportions of the different validity criteria. Four samples in green deviate from the known age. In the staple with different shades of blue represents 45 mortar samples without age control. They can still be considered conclusive, since they represent only Criterion I and Criterion II. Another staple in green to the far right represents 26 inconclusive results.

COMPARISON BETWEEN ÅLAND MORTAR SAMPLES, ^{14}C SAMPLES OF WOOD AND DENDROCHRONOLOGY



▲ Fig. 186a-c. Comparative results of all conclusive Åland samples that have been scientifically analyzed. Calibrated results of ^{14}C analysis of wood is marked horizontally in yellow, mortar horizontally in black, and dendrochronology vertically in red. Green rectangles frame building units that have been dated with both ^{14}C analysis of wood and mortar. Rectangles in blue mark building units where mortar dating has been the only option.

Results of different scientific dating methods implemented in the Åland churches are presented in Fig. 186a-f. With the exception of the fire-damaged church in Sund, and the fire-damaged east gable in Kumlinge, it is always the result of the first CO_2 fractions that counts. Note that where age control is available, i.e., either dendrochronology or ^{14}C analysis of fragmentarily preserved wooden constructions and wooden fragments embedded in the mortar, the results from mortar and wood agree with one another. In some rare cases the wooden fragments deviate. They can be considerably older (Eka 007W, Haka 024W) or just a little older (Fika 018W, Fika 21W and Fika 063W). Where the odd wooden sample, in an otherwise homogeneous series, exceptionally is more recent (Eka 18W) secondary repairs can be suspected. In two cases, the mortar samples show considerably older results (Haka 047 and Haka 045) in an otherwise very uniform line. They are therefore included in the 5% that deviates from age control. Further, note that results of dendrochronology, when available, coincide with both mortar and ^{14}C analysis of wood. Results from dendrochronology for the nave at



▲ **Fig. 186d-f. Comparative results from all conclusive Åland samples analyzed scientifically (continuation from previous page).**

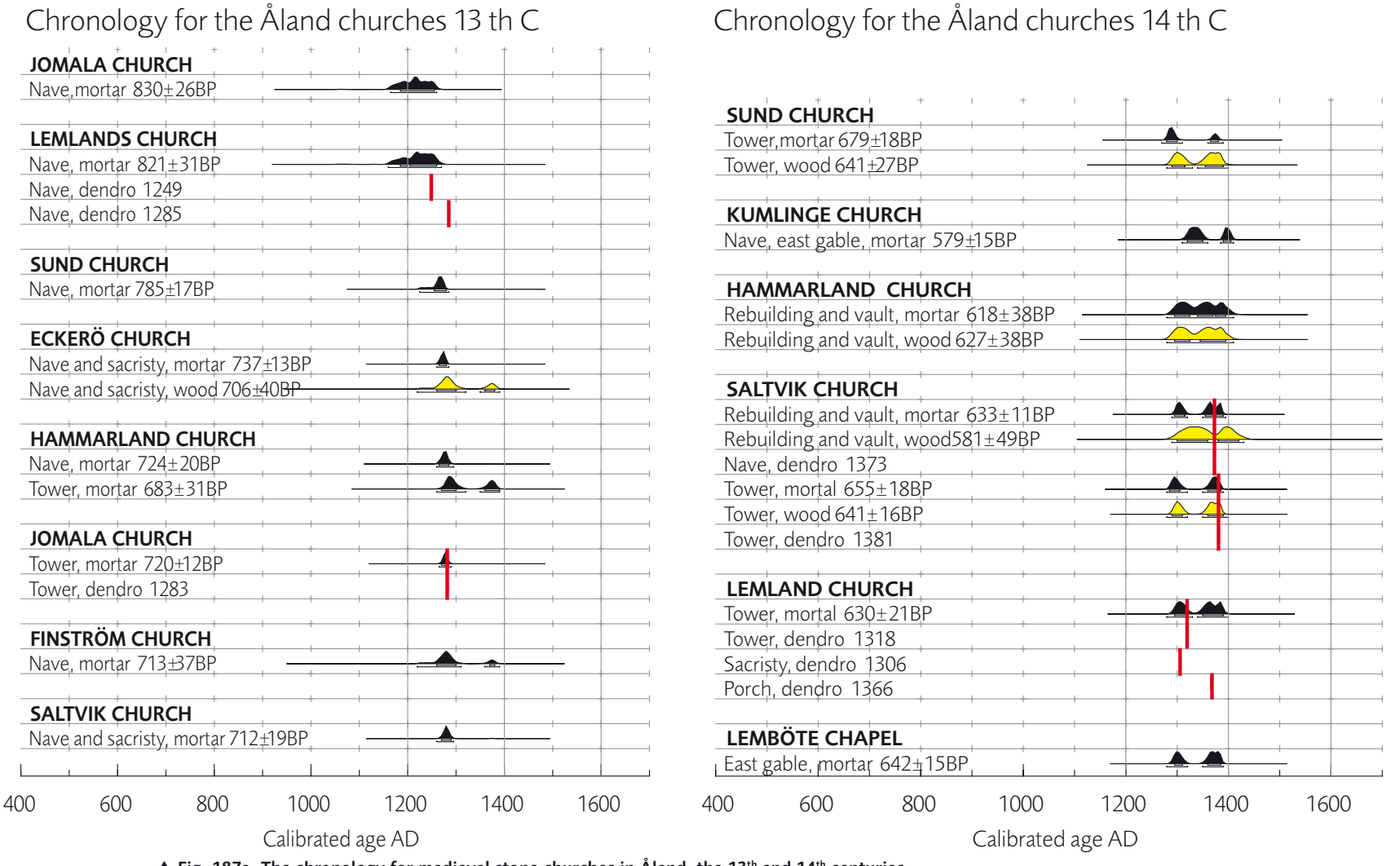
Hammarland, which represent repairs after a fire in the 1440s, are not included in the diagram.

Regarding mortar analysis and the first stone church in Finström, we still have to be cautious. The samples Fika 033 and Fika 051 indeed both meet the requirements of Criterion I, and therefore, in principle, they should be independently valid for the dating of the church. More samples, however, should be taken before a scientific analysis can show the existence of an early stone church in Finström. The same thing is true for the nave at Lemland.

Charcoal particles embedded in the mortar are missing in the survey. This is because they usually yield old and uneven results, depending on the old wood effect. Such an effect arises when only the inner core of a timber remains after the fire. Yet, for the sake of comparison charcoal particles are also analyzed. They can be contemporary with the mortar, but obviously they must not be more recent.

Green rectangles framing the results of individual building units mark the age indicated by mortar dating and age control from ^{14}C analysis of wood and dendrochronology. Rectangles in blue are especially important, since they date structures where mortar has been the only material available suitable for scientific dating.

A CHRONOLOGY TAKES SHAPE

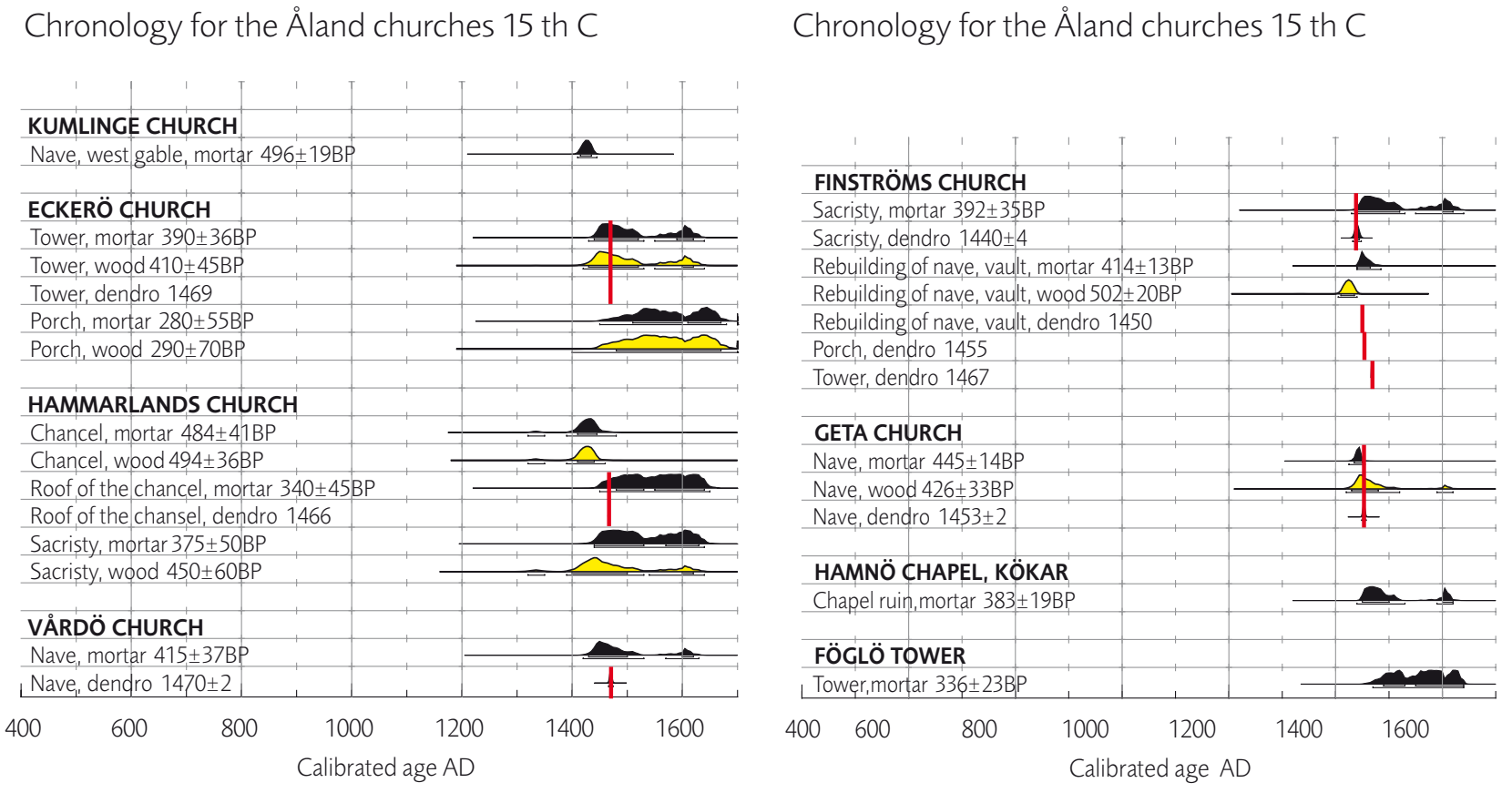


▲ **Fig. 187a. The chronology for medieval stone churches in Åland, the 13th and 14th centuries.**

The chronology of the Åland stone churches consists of a combined calibration, partly of mortar samples, partly of wooden samples (Figs. 187a-b). Note that the chronology remains the same, regardless of whether it is based on mortar dating or scientific dating of wood. In the analyses mortar and wood generally come close to one another.

Once more it has to be stressed that analysis of mortar often is the only way to reach the oldest building stages. We can further see how the building activity spreads relatively evenly from the 13th century onwards. Even if it is possible to find that building activity has been more intensive in some periods than in others, no hiatus in the building activity can be discerned.

The naves of the main churches, the so called mother churches, on the main island (Jomala, Lemland, Sund, Eckerö, Hammarland and Saltvik, probably also Finström) were erected more or less simultaneously during the 13th century. Of these Jomala and Lemland seem to be more ancient that the others, but as



▲ **Fig. 187b. The chronology for medieval stone churches in Åland, the 15th century.**

with Finström, these results so far rely on too few samples analysed.

Most early datings are based on mortar analysis alone. The results fulfil the strict demands of Criterion I and II, often in combination of the two. The nave of Lemland is so far the only one to be dated to the 13th century by dendrochronology, even though only few samples are available. The dating of the west tower in Jomala to the 1280s is very convincing with uniform series of both dendrochronology and mortar analysis. Further, the campanile in Jomala seems to be the only one dated from the 13th century, with the possible exception of the tower in Hammarland.

The chronology of the 14th century is not quite clear. As already mentioned, it is a century which cannot easily be established through ^{14}C analysis. We are still waiting for results from the archipelago churches in Föglö and Kökar. Therefore, they are not yet included in the different surveys (Figs. 186a-f; Figs. 187a-b). But other, non-scientific evidence such as coins and preliminary mortar results, indicate that Föglö also can belong to the 14th century. We still lack results from mortar dating in Kökar, but other materials that place the complex in the 14th century have been scientifically confirmed. The stone chapel of Lemböte, on the old sailing route between Denmark and Estonia, and described in the so-called Danish Itinerary, was either erected at the very end of the 13th century, or in the 14th century. In this case, the uncertainty depends on the wiggles in the calibration curve for the 14th century. But thanks to dendrochronology we now know that this century also was a dynamic period for Åland church building. That was the time for an intensive period of tower building, and many secondary building units such as

porches and sacristies take shape. At Saltvik radical rebuilding and vaulting takes place in the nave at the end of the 14th century.

The period 1450-70 means another intensive building period in Åland. We can now witness an almost total rebuilding of the church of Finström. In this case scientific dating indicates a more substantial rebuilding than just the vaulting of the nave and the erection of the west tower. It also involved the heightening of the nave and the sacristy. A porch was added to the nave, and the impressive new tower, surrounded by four turrets reflecting influence from the Turku Cathedral completes the rebuilding.

Three other towers were erected relatively late, at the end of the 15th century, i.e., in Eckerö, Föglö and probably also in Kumlinge. The west gable of Kumlinge church was built in 1410-30. The only completely new buildings from this century are the stone chapels in Geta and Vårdö, belonging to the mother churches of Finström and Sund respectively. Very surprising is the late date of "Kappalskatan", the little wooden chapel at Hamnö, Kökar. Here no wooden material remained, but mortar from the socle level indicates that it could, together with the tower at Föglö, belong to the very latest medieval ecclesiastic constructions in Åland, erected around 1500.

From the chronological survey (Figs. 187a-b) one might get the idea that the 15th century was the most dynamic period as far as activity in building churches in Åland is concerned. It is therefore important to complement the picture with a map focusing on the vital points, the naves (Fig. 188). With different centuries marked in different colors a clear pattern can be discerned.

It is quite obvious that the 13th century is the most intensive building period, with at least six mother churches, marked in orange, erected close to one another on the main island. Finström, which remains unclear, is marked with diagonal orange lines. The 14th century meant that stone church building reached the archipelago parishes, with naves marked in green. For Föglö and Kökar, the dating so far depends on analyzing other materials than mortar. On the main island the focus was on secondary additions to existing naves. The 15th century is dominated by the vast rebuilding of the church in Finström, marked in blue, in addition to secondary building units added to several of the naves. Completely new are the stone chapels of Geta and Vårdö, likewise marked in blue. Furthermore, wooden chapels of unknown age but most probably medieval, have been traced to Lumparland, Sottunga and Brändö.

Conclusion

A long time has passed since my longing to get an answer to the enigmatic and fascinating past of the Åland Islands was triggered. I had hoped that one day it might be possible to understand the larger context, and to take part in comprehensive interdisciplinary research– collaboration resulting in an objective and reliable chronology for the medieval stone churches in Åland. Developing new tools to compensate for the lack of written sources was to be of great importance. At an early stage it became clear that mortar dating, together with the implementation of all other possible scientific methods, would provide an important opening. In retrospect we can claim that it was more than fortunate that the big challenge - to develop an objective dating method for archeological questions – was initiated in the Åland Islands. Here mortar was very well behaved, and there is plenty of comparative material available from other methods. Regardless of whether Åland mortars are analyzed in two or five CO_2 fractions, it is generally the first fraction that counts. The results are easy to interpret and they generally yield distinct dates.

Exciting and enjoyable collaboration within our research team has had fruitful results. Even if details certainly will be refined, and results will become more precise, we have come close to our ultimate aim: a chronology for the medieval stone churches in Åland. We have seen that mortar dating is often the only way to reach the first building periods of the churches. Hopefully our experience from scientific dating in Åland can inspire future research. For us, such an interdisciplinary approach has provided the necessary basis for reliable results.

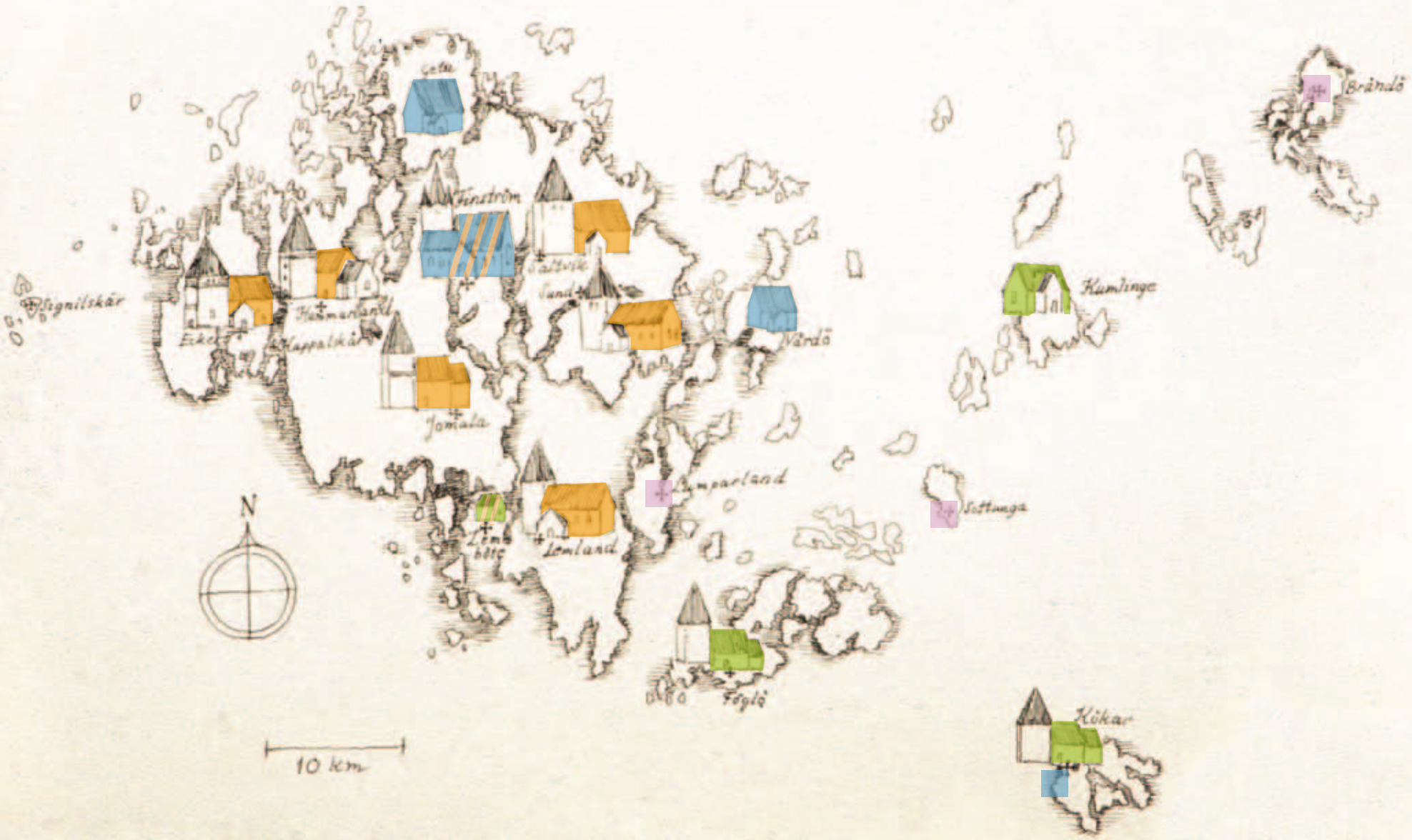
The scientific community has followed our research with great interest. Internationally, the response has been positive. The most prominent researchers and laboratories in the field are now actively participating in the development of our method.

In Finland, however, our work has been continuously criticized from the beginning by one researcher in the field of medieval stone churches, who has reached very different results in his estimation of a chronology for the Åland churches.

The project *International Mortar Dating* marks an important opening nationally, and as part of our international project, sponsored by the Academy of Finland since 2007, the method is being tested on Turku Cathedral and on a number of churches in the Åboland archipelago outside Turku.

The comparative research and the development of the method also continues on an international level, and here the corpus of Åland mortars is an important source of information. The discussion concerning the different credibility criteria, which has been of fundamental importance for the interpretation of the results, so far concerns Åland mortars especially. A complete table covering all Åland samples has recently been published (Heinemeier et. al. 2010, see also www.kyrkor.ax). We also know that the criteria work outside the Åland Islands, in Portugal and in Gotland in Sweden, where the lime mortar is non-hydraulic. We aim at a general refinement of the method, where we will define the limits for mortar dating and map areas where the method works.

The mortar dating study of the churches of the Åland Islands represents a significant development in medieval archaeology in recent years. And while much research remains to be done, it is hoped that this study will serve as a new basis for further development in the field.

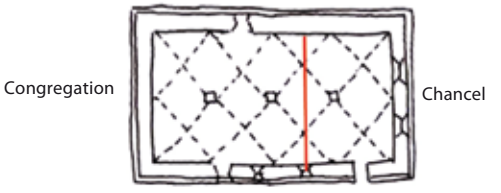


13th Century 14th Century 15th Century Medieval wooden chapels

▲ **Fig. 188. The Åland churches, the chronology of the naves marked on the map.**

GLOSSARY

Church with double naves, rectangular plan including chancel



Church with single nave, and a narrower chancel in the east, no apse

Aisles part of the church, passageways on either side of the nave, often lower than the nave

Ambo medieval pulpit

Apse semicircular addition to provide space for the high altar, usually placed at the eastern end of the nave, generally lower than the nave

Axis in architecture a straight line, along which elements of the plan are symmetrically or systematically disposed

Baldachin decoration in the form of a sheltering roof placed above wooden sculptures in an altarpiece, usually openwork, protruding and fastened on to the back wall of the altarpiece, see Fig. 66.

Barrel-vault barrel-like, formed as a half-cylinder with a semicircular cross-section

Bay regular and uniform structural subdivision of a church, the space enclosed by the two transverse arches and the two wall arches in a single nave, or by the transverse arches and longitudinal arches in a church with double naves, or a church with one nave and two aisles

Bracket projection from a wall with a carrying or supporting function, used as base for vaults and protruding building units

Calvary group a scene from Golgotha where Christ Crucified is flanked by Mary in mourning to the left and John, mourning apostle to the right, see Fig.15.

Chancel (often also called Choir) in a hall-church, without an apse, the space in the eastern part of the rectangular plan reserved for the clergy, with the high alter for the liturgy of the mass. Can also be a separate narrow building unit, either with a straight eastern wall or finished by an apse towards the east

Choir (often also called Chancel) in a hall-church, without an apse, the space in the eastern part of the rectangular plan reserved for the clergy, with the high alter for the liturgy of the mass. Can also be a separate narrow building unit, either with a straight eastern wall or finished by an apse towards the east

Choir-screen a screen wall or partition dividing the choir or chancel from the nave

Column freestanding vertical support, consisting of base, shaft and capital. The shaft usually has a circular cross section. Usually forming the division between the nave and the aisles in a church

Corpus central part of an altarpiece, flanked by wings which can be closed against the corpus for certain liturgical feasts, such as Lent, etc

Course horizontal level range of stones or bricks in the construction of the wall, laid evenly

Cross arm as the shorter parts of a cruciform plan

Cross vault intersecting barrel-vaults forming a groin-vault

Dendrochronology scientific dating method based on the master curve of the annual rings in the felled timber in building constructions or in wooden sculptures

Double nave church consisting of two parallel naves, divided by columns or pillars along the central axis. Can have a rectangular ground plan without an apse, or a rectangular ground plan with an apse

Eaves-board board fixed under the overhanging of the roof shingles

Groin sharp crease-like edge formed by the salient between two intersecting vaults, as in two barrel-vaults joined in right angles

Hall church 1. Church with aisles but without a clerestory, approximately uniform height throughout the interior (in German Hallenkirche). 2. A single nave church, where the interior forms a uniform space within the rectangular ground plan, with chancel or choir included in the rectangle not forming separate building units (in Swedish Salkyrka)

Iconography art historical terminology for the interpretation of images and symbols

Iconoclasm conscientious destruction of images, often connected to the Reformation

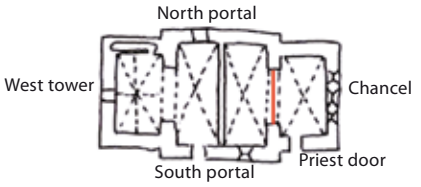
Jamb vertical support for an arch or a vault, carrying the weight of the arch or the vault

Joint meeting point of two building units. If bonded at the joint, they were probably built at the same time. A **vertical joint** without bonding may suggest different building stages

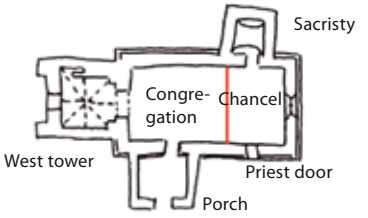
Man of Sorrows Christ rising from the dead, demonstrating all his wounds. Often with the arms of passion

Molding any continuous projecting or inset architectural member with a

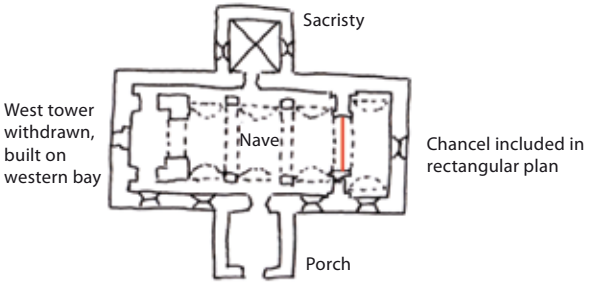
Church with short nave, two cross vaulted bays, a narrower chancel with a straight east wall



Hall church, rectangular nave including the chancel



Church with barrel vaulted nave and two narrow aisles



contoured profile defining and separating architectural details

Nave the main body of the church between western wall and chancel, whether aisled or not, used by laity or the congregation.

Ordovician geological term for limestone found in Åland, Öland (Sweden), and in Estonia

Palmette frieze ornamental dividing frieze, see Fig. 16.

Paten plate for the oblates, see Fig. 33.

Patron Saint a church is dedicated to a patron saint

Pillar vertical support with square section, with or without base and capital, dividing nave and aisles, or the parallel naves in double nave churches

Pietà presentation of Mary in mourning, holding her deceased son in her arms, see Fig. 43.

Predella horizontal and narrow lower part or base of an altarpiece, see Fig. 43.

Priest door separate entry from the south for priests directly into the chancel

Porch southern entrance hall to church, usually later addition in front of original main portal

Rapakivi easily split Åland red granite

Reliquary casket for or holder of relics, see Fig. 37.

Rib vault carried by a structural skeleton of ribs

Ridge turret little tower riding on the ridge of the roof, see Fig. 133.

Ring crucifix the cross-arms united by a ring, with the center of the circle in the intersection of the cross, see Fig.15.

Ring vault in a stellar-vault the intersection of the ribs are circumscribed by rings, see Fig. 120.

Rood beam cross beam between chancel and nave, or across the nave, for the carrying of the crucifix, synonym for trabes, see Fig. 15

Roof-beam horizontal beam in a roof truss uniting the rafters

Roof-truss triangular structure carrying the roof. Consisting of roof-beam and rafters, resting at regular intervals on the wall-plates

Sacristy separate space towards the north, for keeping vestry and church silver etc., also used as changing room for the clergy

Side-altar in addition to the high altar, medieval churches had at least two side-altars, one in north devoted to Mary and the other to the patron saint

Shell structure outer and inner shell of larger fieldstones, with the smoother side facing the exterior, filled with mortar and aggregate

Socle foundation wall, protruding from the wall

Spandrel wedge shaped downwards narrowing parts in the inner corners of the vault

Springing of vault the lowest course of a vault, supporting structure

Stellar vault late medieval development of rib-vaults, with the ribs arranged in the pattern of a star

Transverse arch placed at regular intervals across the nave, and the aisles, supporting the vaults

Triptych tripartite construction, for instance an altarpiece consisting of corpus, flanked by two wings

Triumphal arch between chancel and nave, to mark the separation between clergy and the congregation

Triumphal crucifix hanging in the triumphal arch

Transept in a cruciform church the transepts are the wings perpendicular to the nave that complete the cross form; a transept is often of the same section as the nave, and may have no aisles

Turrets miniature towers

Wall arch inside the wall, or parallel to a wall, anchoring for the vaults

Wall–pier pillar erected against the wall, often a later construction

Wall plate longitudinal timber set on top of a brick and masonry wall, on which roof trusses, joists and rafters are resting

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