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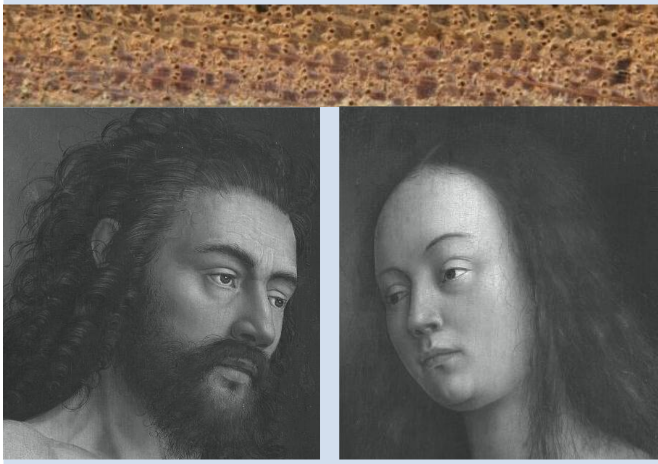
# Report of Dendrochronological Analysis

## **Panel paintings**

# Hubert and Jan van Eyck
## *Ghent Altarpiece: Adam* and *Eve*
Ghent, St Bavo Cathedral



Dr Pascale FRAITURE

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| Sampling | **23 April 2013** |
| Report | **21 Octobre 2013** |

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Cover
*Ghent Altarpiece, Adam* and *Eve*, details. Hubert and Jan van Eyck.
http://closertovaneyck.kikirpa.be

# 1. Analysis protocol

## 1.1. Sampling

The feasibility of a dendrochronological dating of a painted support is limited by diverse constraints. Firstly the wooden elements have to be from a species that is compatible with dendrochronology. In our regions this is the case for oak (*Quercus robur* or *petraea*; the principal species used for painted panels in the ancient Netherlands), beech (*Fagus sylvatica*), Scots pine (*Pinus sylvestris*), spruce (*Picea*), larch (*Larix*), etc., but not poplar (*Poupulus*), birch (*Betula*), hazel (*Corylus*), walnut tree (*Juglans*), etc.

Subsequently, the planks have to be analyzable without having to resort to destructive sampling. During dendrochronological analysis of a work of art, as opposed to studies of buildings or archaeological vestiges, the dendrochronologist does not remove a sample since the object is too precious. The tree rings have to be measured without destructive sampling. Direct access to end grain, i.e. the surface of the transverse cut of the tree (Fig. 1), is therefore necessary. It concerns lateral sides of the planks if the wood grain of the support is horizontal, or horizontal sides if the wood grain is vertical. When possible, two series of tree rings are measured for each plank, on the opposite sides. This precaution aims, firstly, to get round eventual deformations in the growth of the oak that could blur the dendrochronological signal, like the proximity of knots (Fig. 2a) or the presence of distorted rings (Fig. 2b)[1], secondly to remedy lacunae due to damaged parts of the wood (Fig. 2c), and lastly to dispose of the most recent tree ring present on the support.

Finally the elements to be dated have to be from a good dendrochronological quality. This mostly follows from the strength of the climatic signal the tree contains. This aspect cannot be controlled during sampling; it depends as much from the genetic potential of the tree as from its biotic and abiotic growth environment. The dendrochronological quality of the samples also largely depends on the number of visible tree rings on the objects to be dated. As such, a series of around thirty rings is statistically too short for a reliable dating: the risk of obtaining several plausible proposals prevents to consider any date as absolutely certain. Sequences of around fifty rings can lead to a certain result, on the condition that a large number of analyzable wood elements is available. We generally consider that at least seventy to eighty rings are required; the higher the number of tree rings, the more the dating is certain. For panel paintings this number primarily depends on two parameters:

- the general grow rhythm of the tree, which characterizes the quantity of wood produced per year: narrow rings represent a slow growth while wide rings represent a rapid growth (Fig. 3a et 3b). Hence, the slower the growth, the higher the number of tree rings;
- the initial position of the plank in the timber. The cutting of the log by splitting or by sawing produces four main qualities of planks (Fig. 1 et 4). *Full quarter* (or *full radial*) cutting provides planks of which the medullary rays run parallel to the panel edges; tree rings are perpendicular to the rays and thus to the panel edges and the plank therefore contains a maximum number of rings (Fig. 4a). *Quarter* (or *radial*) cutting leads to slightly oblique medullary rays in relation to the panel edges; the tree rings, which are also slightly oblique, are slightly less numerous (Fig. 4b). Concerning *semi-radial* cutting, the rays and rings are very oblique (45°); the number of visible rings is significantly reduced, that much that it may not suffice (Fig. 4c). *Tangential* cutting, finally, limits the number of rings present, which are generally not enough for dating (Fig. 4d).

[1] A *distortion* is a deformation of the tree rings characterized by offsetting of the vessels from one side of a medullary ray to the other (Fig. 2b).

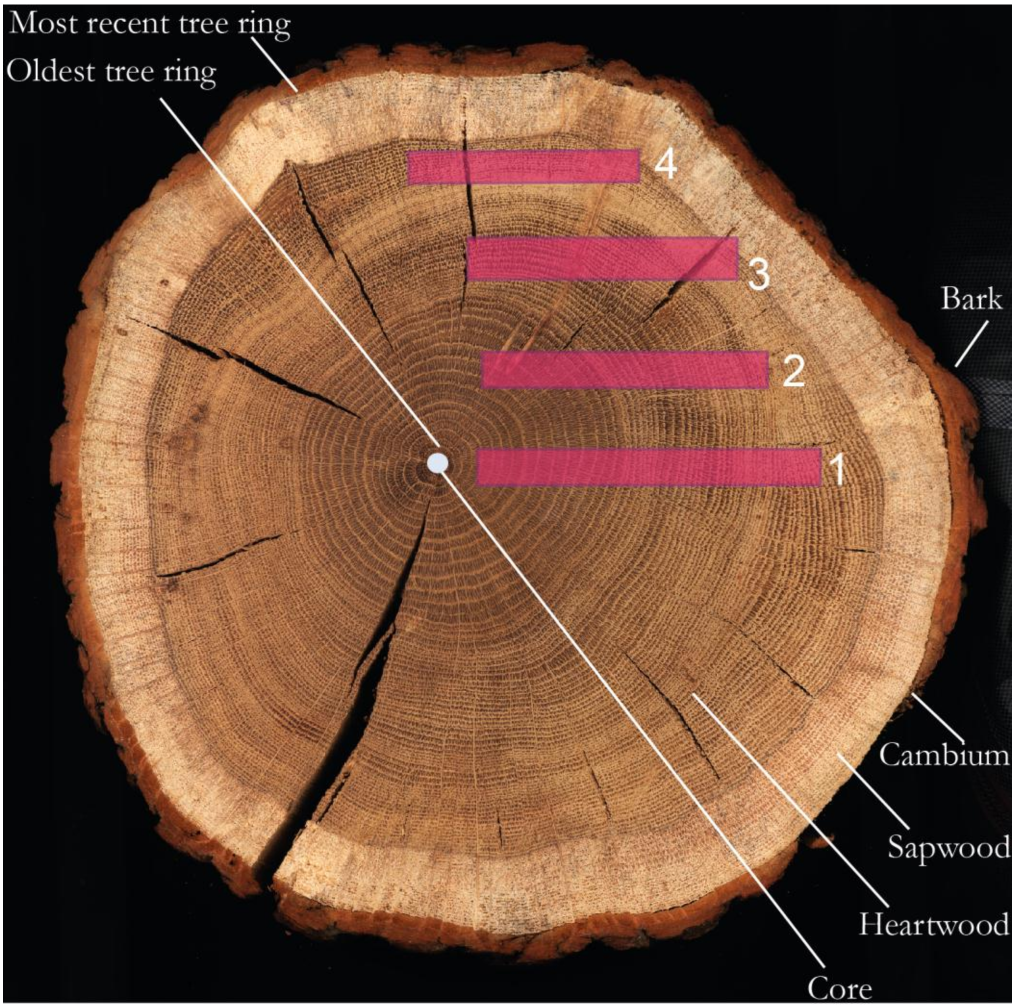


**Fig. 1.** Schema of the transversal section of an oak trunk showing:

- the different parts of the tree: core, heartwood, sapwood and medullary rays (and bark covering the trunk);
- the succession of annual growth rings, the oldest surrounding the core and the most recent formed on the periphery of the trunk, just below the bark;
- the different orientations for cutting planks (in red): full radial (1), radial (2), semi-radial (3), and tangential (4).

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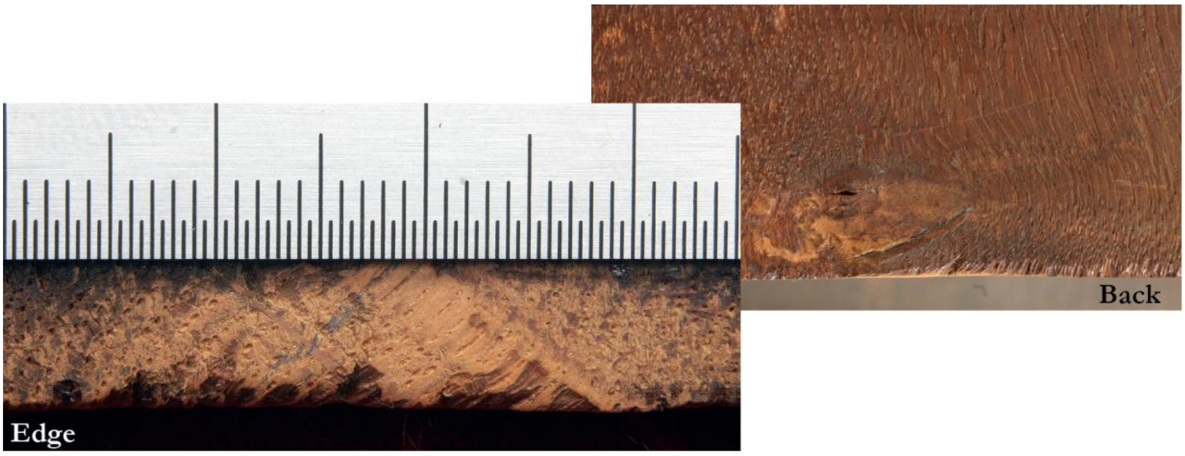


Fig. 2a

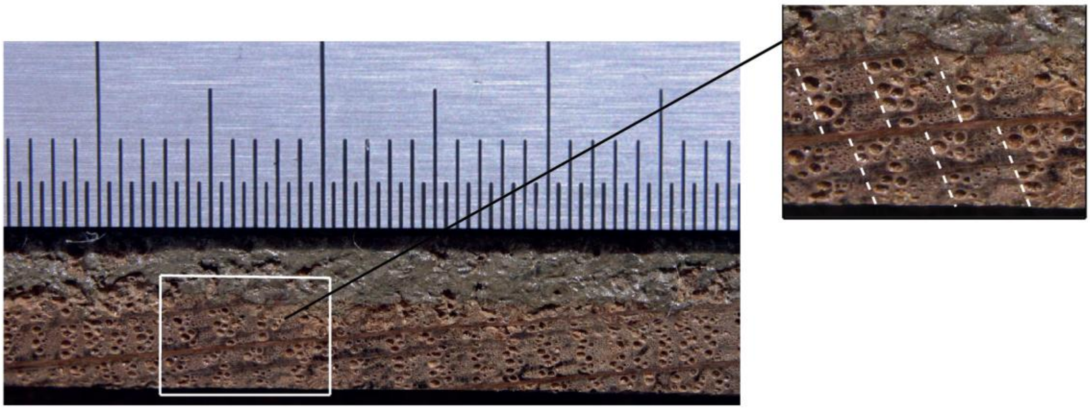

Fig. 2b

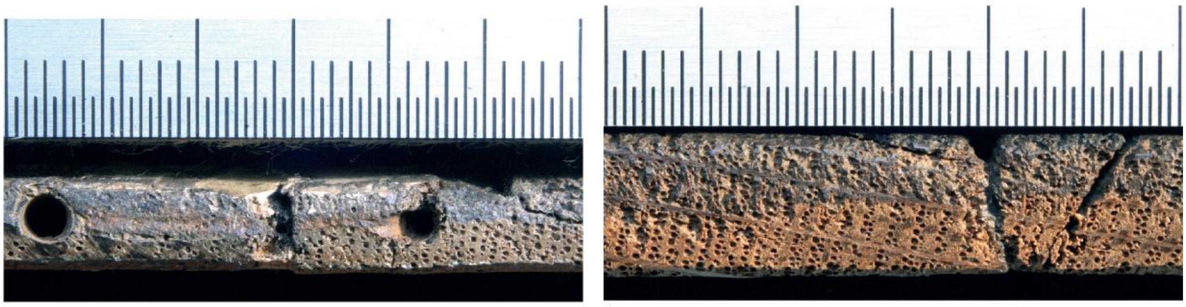

Fig. 2c

**Fig. 2.** Factors that complicate dendrochronological measurement and/or dating (oak planks):

- growth deformations such as knots close to the edge to be measured (Fig. 2a) affect the climatic signal of the dendrochronological series;
- other types of deformations, such as distortions of tree rings (offsetting of the vessels from one side of a medullary ray to the other; Fig. 2b), cause hesitations or even errors during dendrochronological measurement;
- degradations in the wood, even slight ones, can obstruct measurement since they interrupt the tree-ring sequences (Fig. 2c).

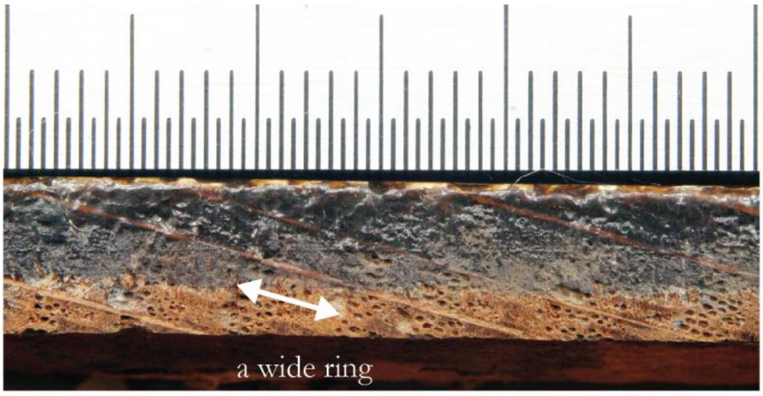


Fig. 3a

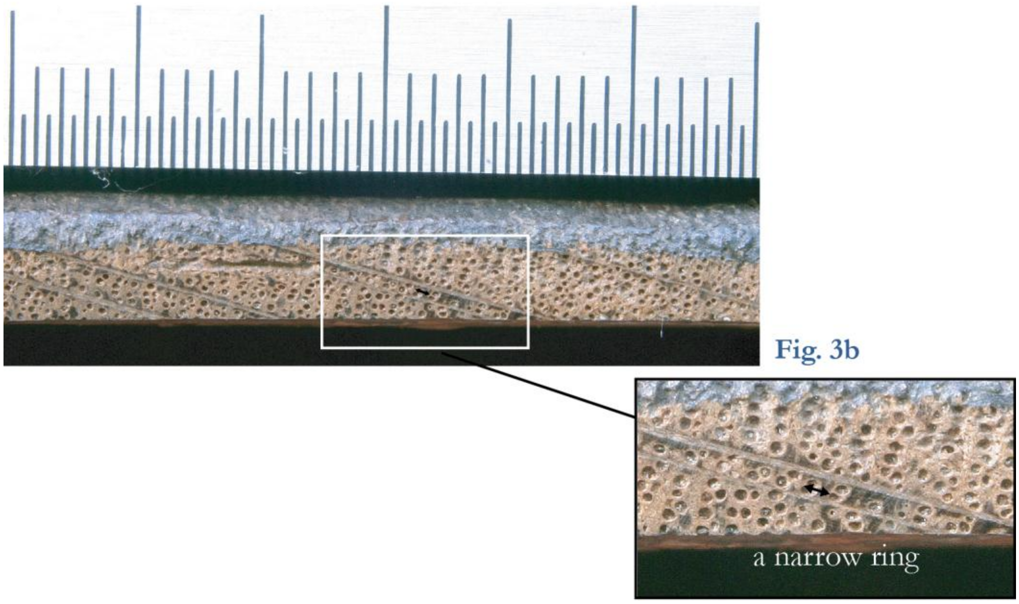


Fig. 3b

**Fig. 3.** Edges of oak planks illustrating different grow rhythms: rapid (wide rings) in Fig. 3a and very slow (very narrow rings) in Fig. 3b.

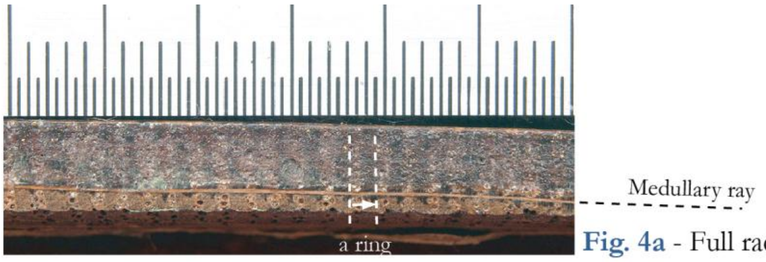


Fig. 4a - Full radial

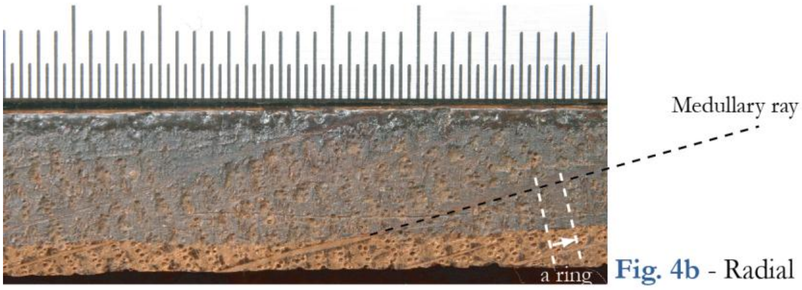


Fig. 4b - Radial

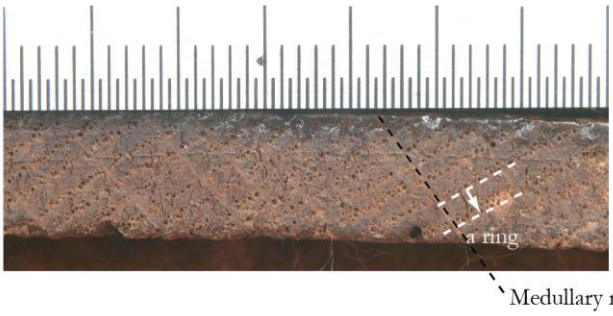


Fig. 4c - Semi radial

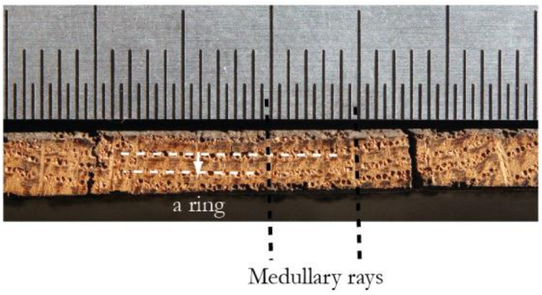


Fig. 4d - Tangential

Fig. 4. Edges of oak planks showing different possible orientations for cutting the planks:

- Fig. 4a. Full quarter (or full radial): the medullary rays run parallel to the panel's sides while the rings are perpendicular;
- Fig. 4b. Quarter (or radial): the rays are slightly oblique in relation to the panel's sides and the rings are perpendicular, while also slightly oblique;
- Fig. 4c. Semi-radial: the rays and the rings are 45° oblique;
- Fig. 4d. Tangential: the rays are perpendicular to the sides of the plank, while the rings run parallel.

## 1.2. Preparation and measurement of the ring sequences

Several techniques can be used to obtain dendrochronological data. The traditional method is to measure the width of the rings directly on the wood, using a magnifying glass or a microscope. Several years ago we developed an indirect measuring technique: a measurement of the tree-ring series on digital macro photos calibrated by a millimeter scale (Fig. 5)[2]. This procedure was facilitated thanks to the development of a computer procedure that allows for measuring the thickness of the rings directly on the computer screen[3]. The advantage of this method is that it provides the dendrochronologist with recorded measurements of tree rings to which he can refer at will, for example for verification (Fig. 2-4).

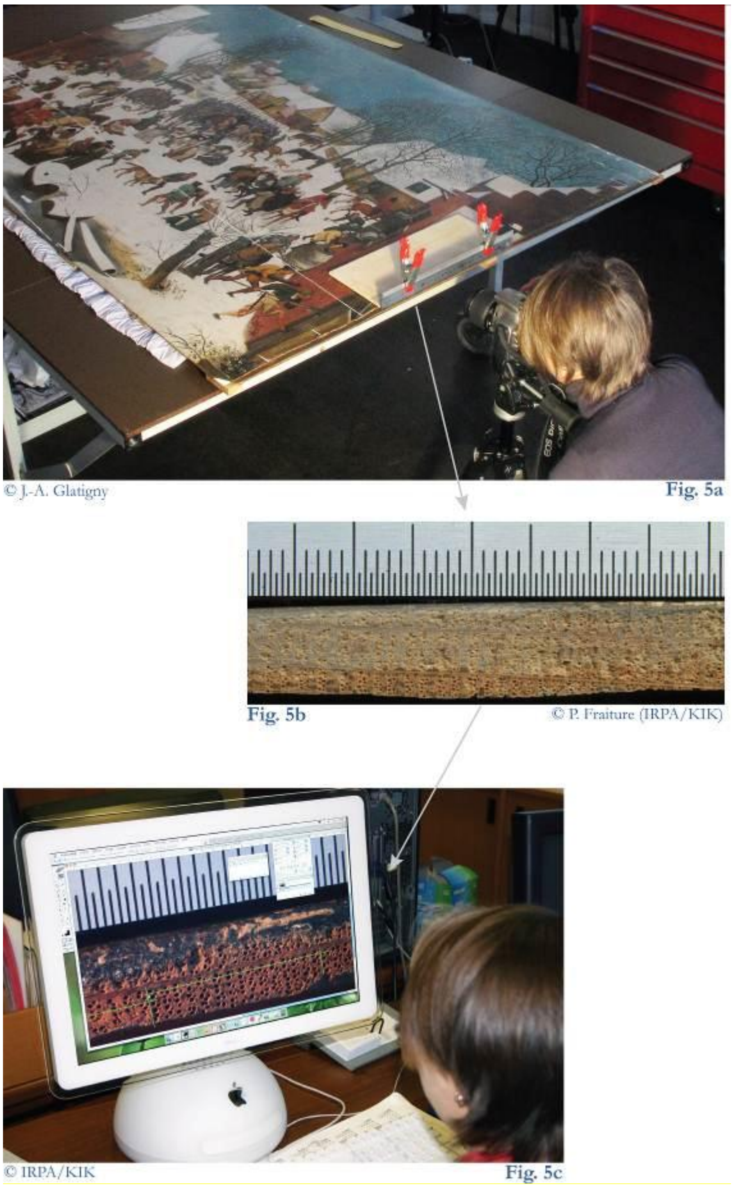


**Fig. 5.** Recording of a tree-ring sequence on the edge of a painted oak panel by digital macro photography (Fig. 5a). Each macro photo is calibrated by a millimeter scale (Fig. 5b), allowing precise onscreen measurements (up to 1/100 mm) of the ring widths (Fig. 5c). Measures are subsequently converted in a dendrochronological format using specific software.

[2] FRAITURE 2007.

[3] The measuring itself is carried out in *Adobe™ Photoshop™* using a specific procedure. The data are then reconstructed and converted in 'Besançon'-format by the software program *TakeMeasuresFromAdobePhotoshop*, version 20120113 (Lambert G.-N., ex-CNRS-Laboratoire de Chrono-Écologie de l'Université de Franche-Comté-UMR 6249; KIK-IRPA collaborator).

Before taking pictures of the edges of a panel, the wood generally has to be lightly cleaned in order to enhance the visual separation between the rings (Fig. 6). This "refreshing" is realized using a brush with semi-hard hairs and, if necessary, with supple and very sharp blades (of the type "cutter Stanley").

**Fig. 6a**

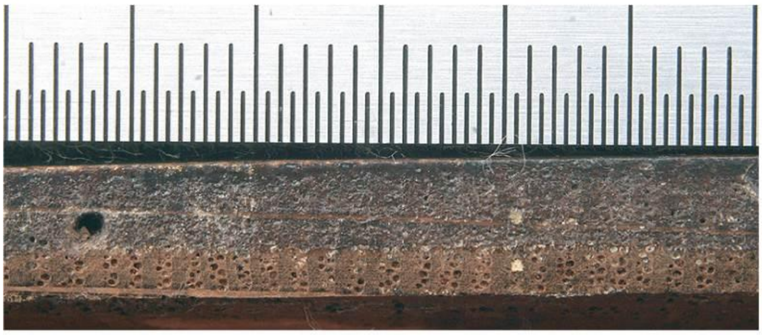

**Fig. 6b**

**Fig. 6a**

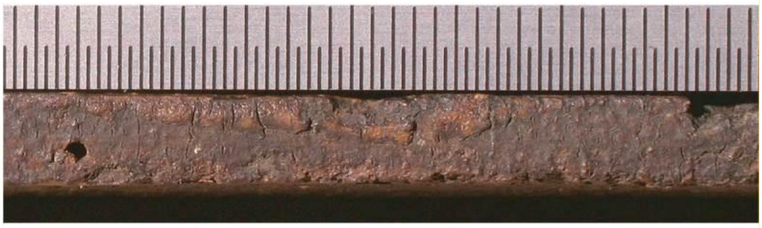

**Fig. 6b**

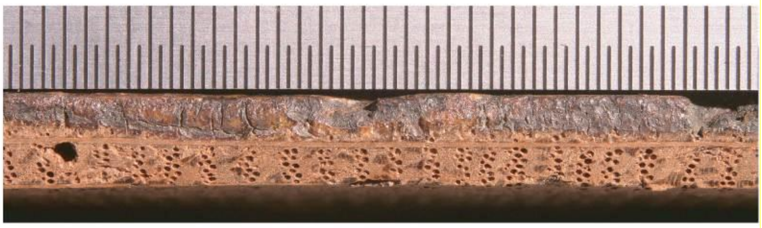

**Fig. 6.** Edges of oak planks before and after preparation of a dendrochronological measuring path: prior to cleaning the rings were not visible (Fig. 6a), afterwards they are perfectly differentiated (Fig. 6b).

## 1.3. Data processing by computer

A well-established collaboration between European dendrochronologists (e.g. G.-N. Lambert, Besançon ; P. Hoffsummer, Liège; I. Tyers, Sheffield; W. Tegel, Bohlingen; C. Perrault, Besançon; E. Jansma, Amersfoort[4]; S. van Daalen, Deventer; S. Wrobel, Hamburg; K. Haneca, Brussels; A. Daly, Copenhagen) ensures a constant exchange of databases between the different laboratories.

The *Dendron* program, developed and regularly updated by G.-N. Lambert[5], ensures the organization of these databases in which dendrochronological sequences can easily be compared and grouped in the form of regularly refined and updated repositories.

As such, the IRPA-KIK reference database comprises several categories of data, provided by these European laboratories. The *master* or *regional* chronologies are long dendrochronological sequences that combine hundreds or even thousands of wood samples, covering several centuries and each representative of a more or less extensive geographical zone. The *site* or *local* chronologies consist of contemporary wood samples that come from the same building phase or archaeological site. *Individual* chronologies, lastly, taken from different types of materials – archaeological, architectural, artistic – are dendrochronological sequences that each represent one single tree. Our reference database is particularly rich in chronologies taken from painted panels from the ancient Netherlands, dating from the 15th to the 17th century[6].

## 1.4. Synchronization and dendrochronological dating

### *1.4.1. Synchronization of the different dendrochronological series of a panel painting*

The different dendrochronological sequences recorded on a painting support are compared, on the one hand to verify the accuracy of the measurements, in particular when faced with reading difficulties (see point 1.1), and on the other to identify planks originating from the same tree when a panel is composed of several elements.

Methodologically speaking, there is no established approach that allows for the identification of planks from the same tree; the dendrochronologist reaches a conclusion on the basis of different criteria.[7] In practice, the strong similarity between dendrochronological graphs of ring series (Fig. 7a) and high correlation rates in dendrochronological tests provide convincing arguments. Added to these is the comparison of mean ring width and the contemporaneity of the sequences compared, which reflects the tree's growth (the growth rate and the age of the tree)[8]. Finally, observation of wood anatomy may contribute to the answer in part; such as when a growth irregularity is seen on two different planks.

In some cases, we can easily deduce that two wood elements come from the same log (Fig. 7a). In other cases, however, it is more problematic to come to a decision as the aforementioned criteria become less meaningful. In such situations, there is no definitive way to conclude if planks come from the same log or from neighboring trunks which grew in similar conditions (Fig. 7b)[9].

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[4] E. Jansma is promoter of the project *Digital Collaboratory for Cultural Dendrochronology (DCCD) A digital data library for dendrochronology*, of which KIK-IRPA is part from the beginning. This project makes thousands of dendrochronological data available to its members. http://vkc.library.uu.nl/vkc/dendrochronology/

[5] Lambert 2006 (CNRS-Laboratoire de Chrono-Écologie de l'Université de Franche-Comté – UMR 6249) for version II of *Dendron.* Version IV, also by G.-N. Lambert (scientific collaborator at the ULg), is as yet unpublished.

[6] These individual chronologies have mainly been constructed by J. Vynckier (formerly KIK-IRPA), P. Fraiture (KIK-IRPA, formerly ULg/CEA; Fraiture 2007) and I. Tyers (Dendrochronological Consultancy Ltd, Sheffield, formerly Dendrochronology Laboratory of the University of Sheffield).

[7] Fraiture 2007; Fraiture 2009a; Beuting 2004; Beuting 2011.

[8] These two criteria nevertheless suffer from imprecision since, even within a single oak, they can vary depending on the location of the sample in the trunk. Moreover, the number of rings in a sample, while it gives an idea of the age of the tree, also depends on the work involved in wood preparation.

[9] Fraiture in preparation.

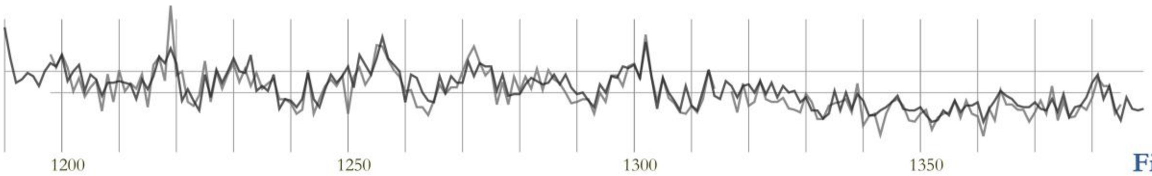



**Fig. 7a**

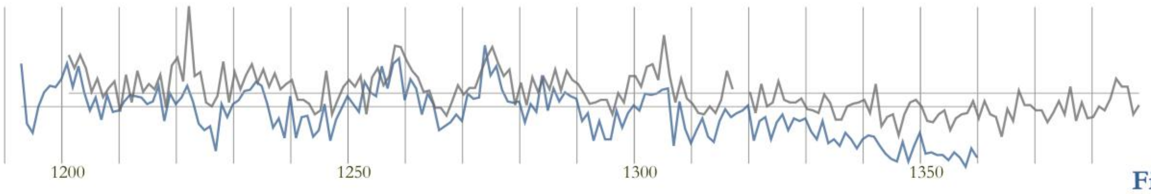



**Fig. 7b**

**Fig. 7.** Drawing of ring series originated from the same tree or from neighboring trees:

Fig. 7a**.** Ring series from two planks which are almost entirely identical; no doubt that the come from the same log.

Fig. 7c. Ring series from two planks showing excellent correlations, but not sufficient enough to conclude that all these planks originate from the same oak rather than from neighboring trees.



The tree-ring series of the same origin (dendrochronological sequences of the opposite sides of a plank or of different planks of the same tree) are grouped in dendrochronological means called here *individual chronologies*.

If several individual chronologies are obtained per support, these are again compared with each other. If they correlate without difficulty, they are assembled in their contemporaneous position (*synchronization*) in order to calculate the *mean chronology* of the panel, generally longer and more sensitive than the individual chronologies.

### *1.4.2. Dendrochronological dating*

The individual chronologies and/or mean chronology are then confronted by different tests of statistical calculations with the reference database in order to date the support. Determination of the exact position of a ring series to be dated on the reference chronologies dates the year of formation of each ring in an absolute way and, by extension, indicates in which period the tree lived.

Assembly of the chronologies or mean chronologies, by drawing and by computing, as well as the dating calculations are carried out using the *Dendron* system (version IV), after calibration of the dendrochronological series by an original transformation named "*corridor*"[10]. During the dating of a piece of wood, the *Dendron* program computes the dendrochronological sequence to be dated to all the chronologies of the reference database by a statistical test derived from the *Student test*, calculated using two correlation coefficients[11]. The software automatically computes this test for all the positions of the chronology to be dated on all the chronologies in the reference database. The program then supplies the five best results obtained on each reference chronology and the dendrochronologist selects the exact position of the wood to be dated among all these proposals, in function of the best correlation rates (*t* of *Student*) obtained with a limited risk of error (probability/security) and of the recurrence of this position on different chronologies in the reference database: this *replication* is indispensable to rule out any possibility of statistical chance (see tables under paragraph 2.2.5).

[10] LAMBERT 2006.

[11] LAMBERT 2006; 2011; LAMBERT *et al.* 2010.

## 1.5. Interpretation of the dendrochronological results

The date obtained for the last measured ring on the support informs us about the period in which the tree(s) was/were cut. This is determined with more or less precision depending on the presence or absence of sapwood on the panel (Fig. 8).

- Felling is determined to the exact year if the cambium[12], thus the complete sapwood, is preserved on the analyzed wood; this condition is rarely encountered when studying panel paintings (A).
- If part of the sapwood is present, representing around 10% of the cases, the heartwood[13] is entirely present, and only some of the sapwood rings have been removed. Since the number of sapwood rings is relatively stable within a given region, statistical data of the number of sapwood rings from oaks from the same age and provenance zone allow for the estimation of the felling of a tree within a date range (B)[14]
- Lastly, when no sapwood is preserved, it is impossible to determine the amount of heartwood rings removed (C or D) – in addition to the sapwood – during plank manufacture and, as a result, how many years separate the date of the last ring measured from the date of tree felling. The dendrochronological result then corresponds to a date after which the tree might have been felled; this is termed the *terminus post quem* for the felling. This *terminus post quem* is calculated as the date of the last heartwood ring measured, to which is added the minimum number of sapwood rings that the tree could have had.

This specificity of dendrochronological analysis of works of art, namely the almost systematic absence of sapwood, is due to the fact that this part of the wood, like the core, is unsuitable for the fabrication of quality supports since both are inclined to deform and/or rot. That is why these both parts are systematically removed during panel manufacture.

Let us remind that dates provided by dendrochronology refer to the period in which the trees were felled, and not to their utilization. The time interval between the cutting of the wood and its use in panels, hence, has to be estimated. This comprises the time required to square the trunk, transport the wood, cut it in planks, dry the planks and fabricate the panel as such. Historic and archaeological studies suggest that, for the period from the 15th to the 17th century, this could only take a couple of months[15]. Nevertheless some dendrochronological studies report a considerable time interval between the dendrochronological result and the known or estimated date of utilization[16]. Therefore no generalizations should be made concerning this subject. As a result, the proposed dendrochronological *terminus* for the felling is also given as *terminus post quem* for support manufacture.

[12] The *cambium* is the source of reproductive cells that form the sapwood toward the inner trunk. It is found on the periphery of the trunk between the sapwood and the bark.

[13] The *heartwood* is the biologically inactive part of the wood. A tree ring is formed in the sapwood; after a few years, it is transformed into heartwood.

[14] It can nevertheless vary considerably from one tree to another, according to parameters that are still poorly defined: growth rate, age of the tree, height of the trunk, width of the crown, conditions of the site… Estimation ranges stay thus rather broad. LAMBERT *et al.* 1988; RYBNÍCEK *et al.* 2006.

[15] FRAITURE 2007.

[16] FRAITURE 2007.

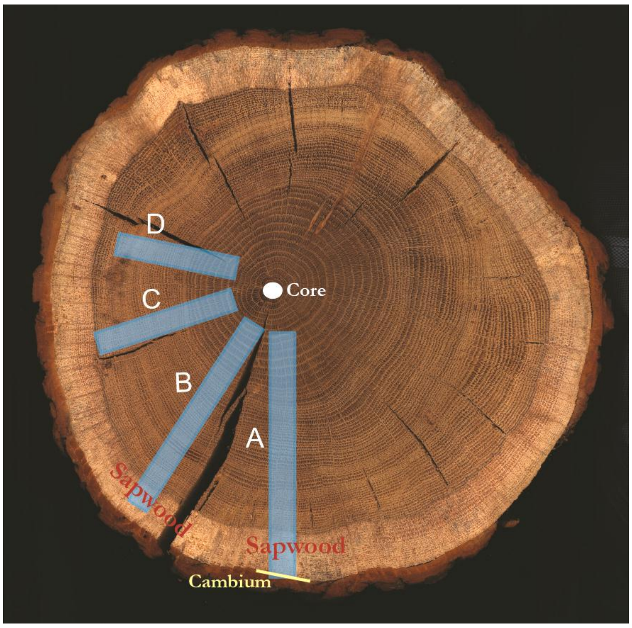



**Fig. 8.** Different possible situations influencing the interpretation of the felling date of the tree: plank with complete sapwood (A), plank with partial sapwood (B), planks without sapwood (in case C only sapwood is missing; in case D sapwood and some heartwood rings are missing).



## 1.6. Interpretation of the graphic illustrations produced by *Dendron IV*

The two following original types of graphs are used in this report to illustrate the quality of the dating results and to argument the proposed conclusions (see graphs under paragraph 2.2.7 and 2.2.8).

### *1.6.1. Cumulative histograms*[17]

The *cumulative histograms* (Fig. 9) represent the probability of the results obtained through *Dendron IV* during computing of a sequence to be dated on the reference chronologies. The proposition retained by the operator is featured in blue, for each chronology of the repository that gives this date. All the rejected proposals are represented in grey.

Two criteria have to be met in order to obtain a quality dating (class A). First the results for the retained date must have a high probability, which is translated by the presence of blue cells in the right part of the graph (the more the blue cells are to the right, the better the probability). Next, there must be a large difference between the results of the retained date and those of the rejected dates, which is marked by a clear demarcation of the blue cells to the right of the graphic and the cells located at the left; such a situation translates the fact that the only high probabilities are obtained for the retained date, reinforcing the reliability of the given result. In summary, the more the blue cells are situated in the right part of the graph and are distanced from the grey cells, the more the proposed result is credible. The following graphs illustrate three classes of results, from the most certain to the most hypothetical.

We consider this type of graph well adapted to illustrate results on the master/regional chronologies; it has the advantage of giving an idea of the geographical provenance of the studied woods in a blink of an eye.

[17] For the histograms, see YAMAGUCHI 1986. This use of the histograms is taken from GIRARDCLOS 1999; PERRAULT & GIRARDCLOS 2000. The concept of cumulating the diagrams is due to LAMBERT 2006.

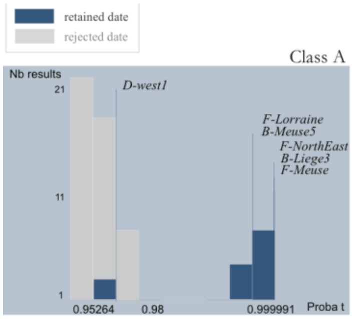



Fig. 9.1. This graph is of excellent quality: the obtained result (in blue) is given with high probability (concentration of the blue cells in the right part of the graph) by several chronologies; these furthermore are clearly demarcated from the rejected dates (large interval between most of the blue cells and the grey ones).

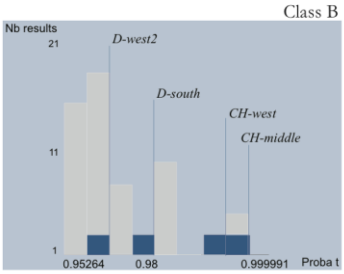



Fig. 9.2. This graph is of acceptable quality: the retained result (in blue) is given by two chronologies with good probability (on the right part of the graph) with a large interval with the majority of obtained results for the rejected dates (in grey). Furthermore, several supplementary chronologies propose the retained date (replication – other blue cells in the left part).

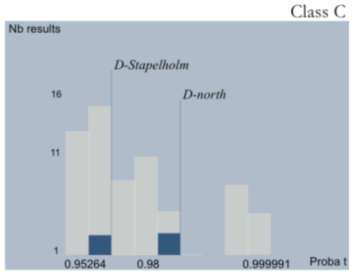



Fig. 9.3. This graph is mediocre: the results for the retained date (in blue) are of a quite weak probability (located in the left part of the graph), given by two chronologies only, and there is no interval with the obtained results for the rejected dates. The dating proposal shown here cannot be validated by such a graph.

### *1.6.2. Correlation fans*[18]

The *correlation fans* computed by *Dendron IV* (Fig. 10) show the replication of the date retained by the operator on the chronologies of the reference database as well as the quality of these results.

Two criteria have to be met in order to obtain a quality dating (class A). Firstly the more the proposed date is replicated, the more it is reliable, i.e. given by a large number of chronologies from the reference database. This is translated in the graph by numerous fan branches[19]. Next, the retained date has to be given by these chronologies with correlation rates higher than the threshold value defined as satisfactory (generally $t > 4$); this is shown in the graph by the location of the fan branches around the defined threshold (blue line) or, better even, at its right. In summary, the more the branches of the fan are numerous and located in the blue part of the graph, the more the retained date is reliable. The following graphs illustrate three classes of results, from the most certain to the most hypothetical.

This type of representation illustrates the quality of the correlations between the wood to be dated and

- site/local chronologies, which generally locate the provenance of the wood more precisely;
- or the individual chronologies of the reference database that come from artistic or archaeological material of a similar provenance.

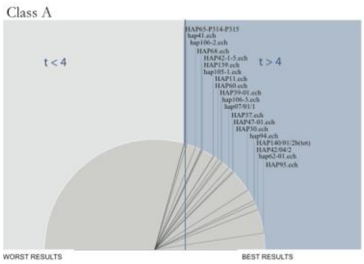



Fig. 10.1. This graph is of excellent quality: replication is high (many chronologies give the retained result) and good quality results are common (all the fan branches are located higher than the significant threshold value $t = 4$, right part of the graph).

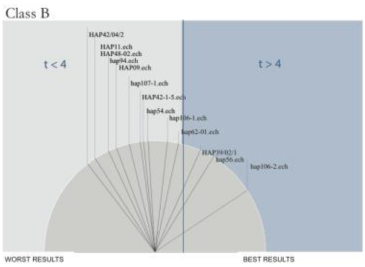



Fig. 10.2. The graph is of acceptable quality: replication is satisfactory (enough branches) and some chronologies give the retained result with rates higher than the threshold value of 4.

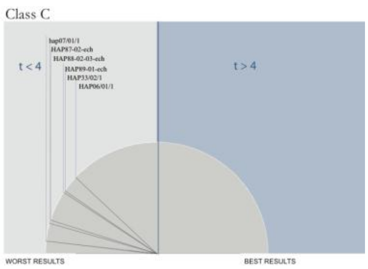



Fig. 10.3. The graph is mediocre: replication is low and it does not provide high quality results (the few branches are located on the left part of the graph, which corresponds to low probability). The dating proposal cannot be validated by such a graph.

[18] The principle of illustrating the correlations in a fan is due to LAMBERT 2006.
[19] In the version IV of *Dendron*, display is nevertheless limited to the 20 best results.

# 2. The *Ghent Altarpiece*: *Adam* and *Eve*
# Hubert and Jan van Eyck

## 2.1. Dendrochronological study

### *2.1.1. Study purpose*

This chapter presents the analysis process and results of the dendrochronological study of the oak supports of the wings of *Adam* and *Eve* from the *Ghent Altarpiece*, Ghent, St Bavo Cathedral. The expertise was carried out in May 2013 in the restoration studios of the Museum of Fine Arts in Ghent, in the framework of the restoration project 2012-2017 of the altarpiece[20] during which the panels were removed from their frame for the first time[21]. The study was carried out on request of the KIK-IRPA in order to complete the set of tree-ring data from the altarpiece[22].

### *2.1.2. Description of the supports and of the sampled tree-ring series*

See points 1.1 and 1.2

The supports are each composed of two vertical oak planks (*Quercus robur* or *petraea*), which are 15.6-20.1 cm wide (Fig. 11). Their thickness on the lower edges is 0.8 cm. The planks were full-radially cut (Fig. 1-4a, Fig. 12 to 15).

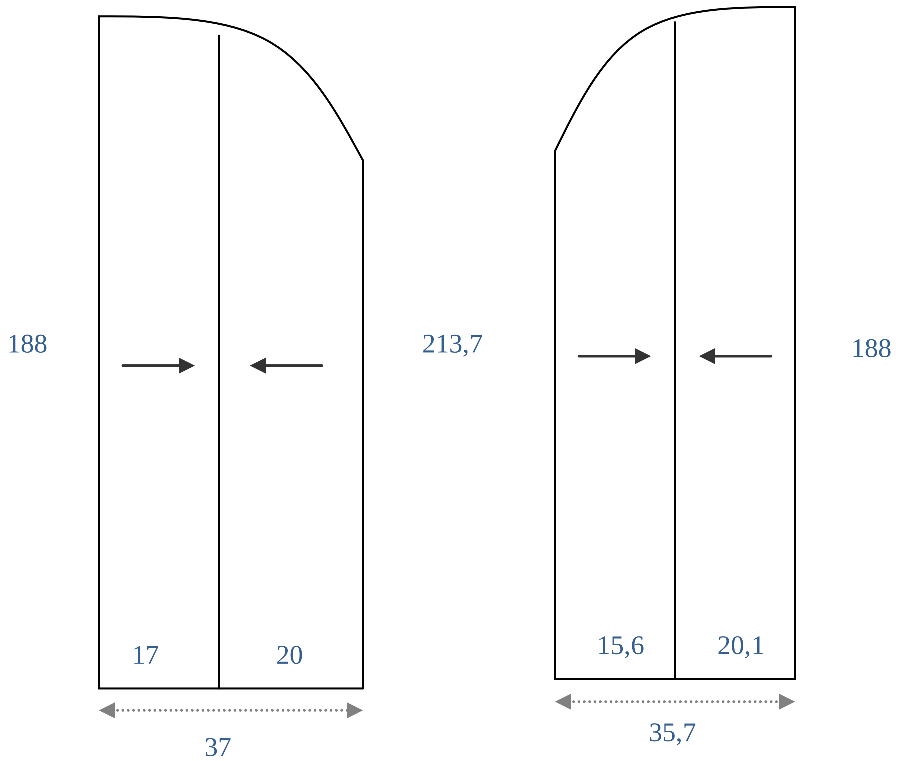



**Fig. 11.** Schematic of the oak supports of *Adam* (left) and *Eve* (right), seen from their front (measures in cm); the arrows indicate the direction of the wood growth, i.e. from core to sapwood.
© P. Fraiture, Dendrochronology lab, KIK-IRPA, Brussels

[20] See http://www.kikirpa.be/EN/249/461/Restoration%20of%20the%20Ghent%20Altarpiece.htm
[21] In 2010, in the framework of the international project for research and conservation of the *Ghent Altarpiece* initiated by the church fabric of St Bavo Cathedral (VAN GREVENSTEIN & SPRONK 2011), a previous examination of these panels was attempted by the author on the zones of the upper edges accessible without removal of the frame. However, the bending of the panels prevented precise recording of ring sequences that are sufficiently long to obtain a reliable date. Another attempt to date these two wings was undertaken by P. Klein, using X-rays that KIK-IRPA took in 1986 (see his report on http://closertovaneyck.kikirpa.be/). Our present results differ from his, probably because of imprecisions in the dendrochronological measurement of oak by X-rays.
[22] VYNCKIER 1999-2000 presents results obtained for five wings; FRAITURE 2011 presents the results for the central panels. A paper that compiles the three dendrochronological campaigns carried out by the KIK-IRPA will soon be published (FRAITURE, in preparation).

Only the lower edges of both panels could be studied since the upper edges are bended[23]. They were cleaned very superficially with a brush and blades (Fig. 12 to 15). For each plank, one tree-ring series was subsequently recorded by macro photography, and measured on-screen with a precision of 1/100th of a mm (Fig. 12, see point 1.2).

The following table presents the four tree-ring series recorded on the panel. The dendrochronological numbering system identifies the painting (**P452**), the plank (**/01**) and the side (**/2**)[24]. It must be noted that the series **P455/01/2** was measured in two separate segments because of a damaged zone in the wood that interrupts the continuity of the ring series (Fig. 14b).

| Dendrochronological sequence | Location | Number of measured rings | Average ring width (1/100th mm) |
|---|---|---|---|
| **P452/01/2** | *Adam*, left plank, lower side (seen from the front) | 70 | 217 |
| **P452/02/2** | *Adam*, right plank, lower side | 203 | 98 |
| **P455/01/2a**<br>**P455/01/2b** | *Eve*, left plank, lower side (seen from the front) | 43 + 101 | 72 |
| **P455/02/2** | *Eve*, right plank, lower side | 172 | 115 |

These dendrochronological sequences reveal growth rates that differ from one plank to another: P452/01/2 (*Adam*, left plank) shows a quite rapid growth all along the series, with an average ring width reaching 2 mm (Fig. 12). Two other planks reveal a growth rhythm that is quite rapid at the beginning of the growth, then regularly and progressively slows down in proportion to the tree's aging, until it becomes slow (P455/02/2, *Eve*, right plank, Fig. 13a-b) or very slow (P455/01/2, *Eve*, left plank, Fig. 14a and 14c) at the end of the growth. Finally, P452/02/2 (*Adam*, left plank, Fig. 15a-b) presents a slow and quite irregular growth from the beginning to the end of its ring series, with an average ring width below 1 mm[25].

The core was not preserved on any of the planks; nevertheless on one of them its near presence is revealed by extremely narrow rings at the beginning of the sequence, just before an abrupt acceleration of the growth rhythm (P455/01/2, *Eve*, left plank, Fig. 14a). The entire sapwood was removed during panel manufacture; all the recorded dendro-sequences are thus amputated of the last rings in the life of the trees.


**Fig. 12.** *Adam*, left plank, detail of the lower edge showing
- Full-radial cut;
- Rapid growth (wide rings reaching 2 mm for an average width);
- Tree rings visible after simple brushing thanks to their large width and the neatness of the wood surface;
- Example of a macro photo with scale to measure ring widths on-screen with a precision of 1/100th of a mm.



[23] See note 21.
[24] The '/1' was given to the attempted measurements on the upper sides by the author in 2010 (see note 21).
[25] A slow growth rate is characterized by rings that are less than 1 mm wide; a rapid growth by rings wider than 2 mm (FRAITURE 2007; BEUTING 2011).


**Fig. 13a**

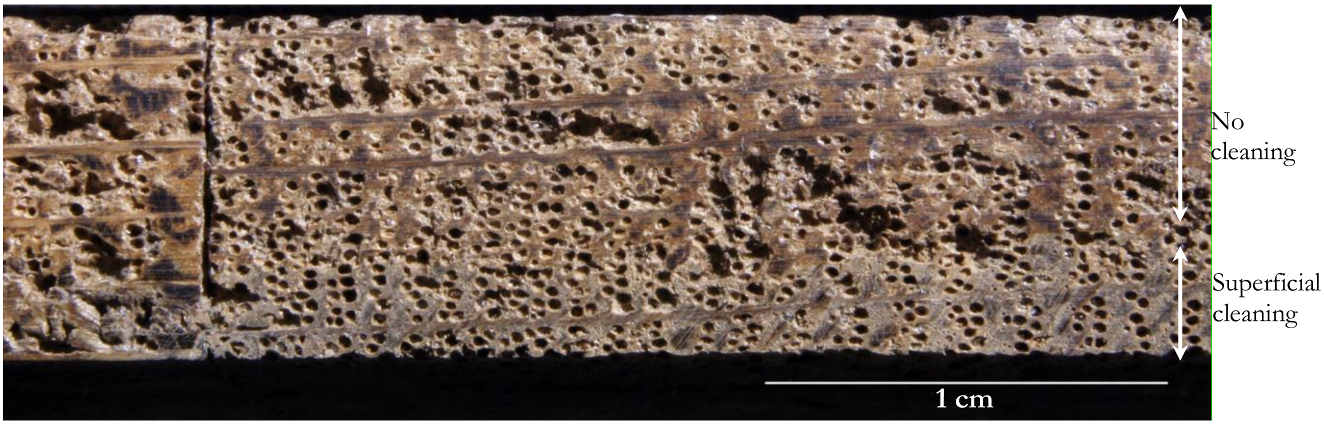



**Fig. 13b**

**Fig. 13.** *Adam*, right plank, details of the lower edge showing
- Full radial cut;
- Very slow growth rate, from the first tree rings (Fig. 13a) to the last ones (Fig. 13b);
- Tree rings visible after superficial cleaning of the wood surface with blades and brush (cleaning necessary because of the narrowness of the rings);
- The butt joint with the left plank (Fig. 13b).

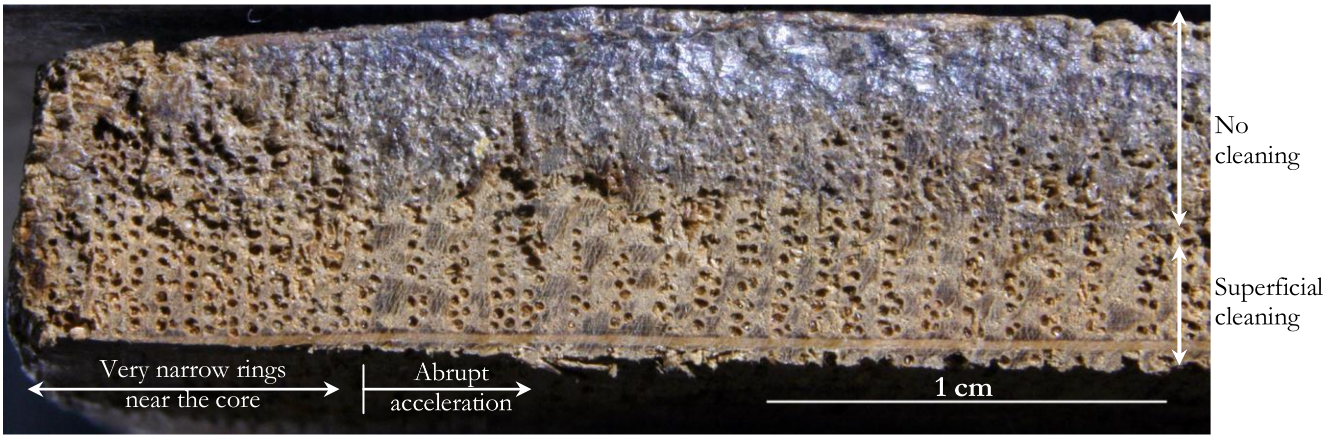



**Fig. 14a**

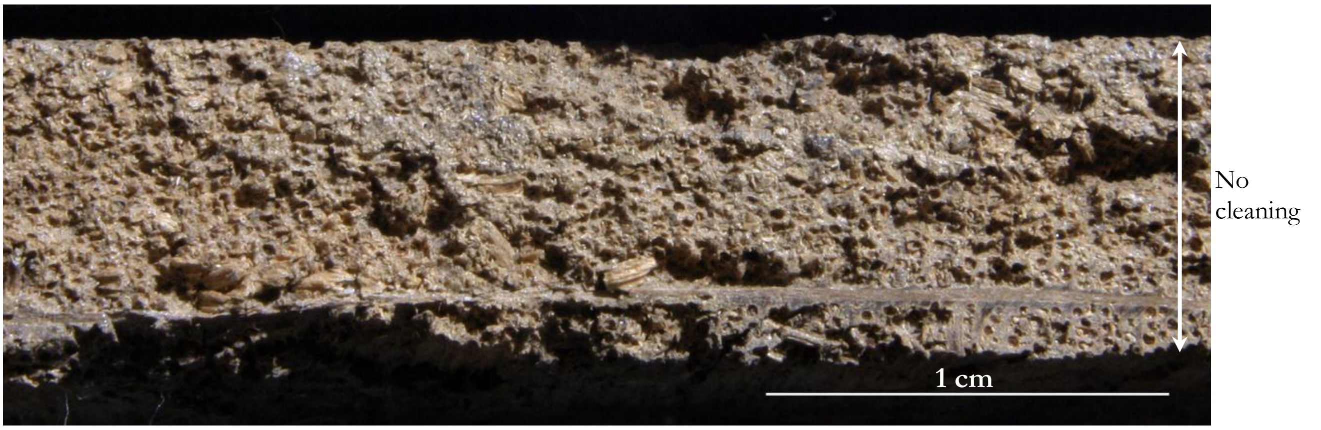



**Fig. 14b**

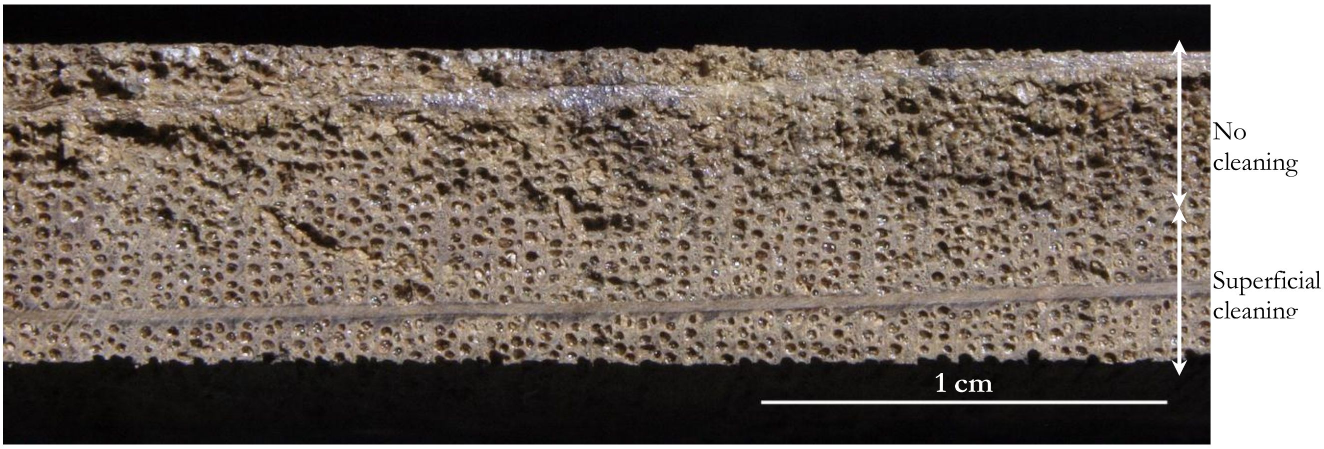
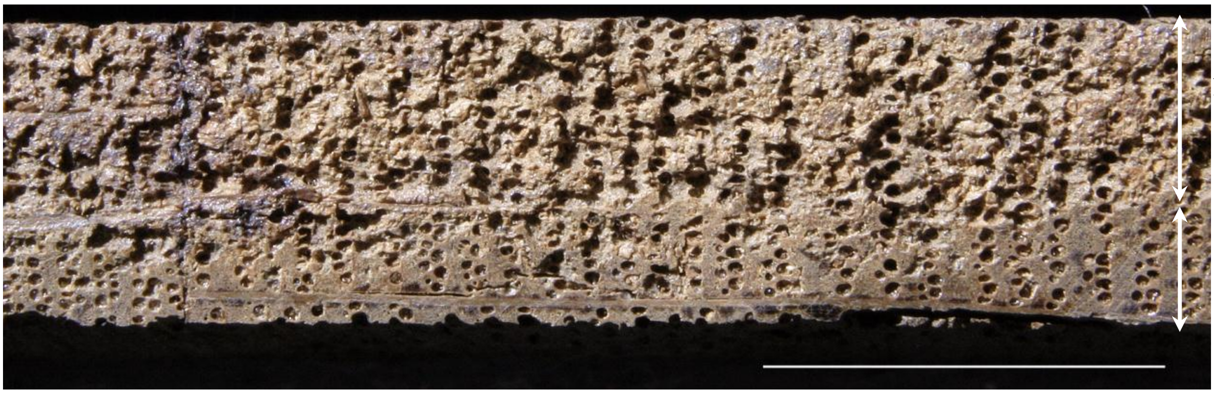



**Fig. 14c**

**Fig. 14.** *Eve*, left plank, details of the lower edge showing
- Full radial cut;
- Very narrow rings at the very beginning of the growth, revealing the near presence of the core (Fig. 14a), after which an abrupt acceleration of the growth is seen (Fig. 14a) which then regularly and progressively slows down in proportion to the tree's aging, until it becomes very slow (very narrow rings) (Fig. 14c);
- Tree rings visible after superficial cleaning of the wood surface with blades and brush (Fig. 14a-c, cleaning necessary because of some irregularities in the wood surface and the narrowness of the rings);
- Damaged wood (Fig. 14b) which interrupts the tree-ring series.


**Fig. 15a**



No
cleaning

Superficial
cleaning

**Fig. 15b**

**Fig. 15.** *Eve*, right plank, details of the lower edge showing

- Full-radial cut;
- A growth rate which regularly and progressively slows down in proportion to the tree's aging (tree rings which decrease in width from the beginning on Fig. 15a to the end on Fig. 15b);
- Tree rings visible after superficial cleaning of the wood surface with blades and brush (Fig. 15a-b, cleaning necessary because of some irregularities in the wood surface and the narrowness of the rings);
- The butt joint with the left plank (Fig. 15b).

### *2.1.3. Dendrochronological dating and interpretation of the results*

See points 1.3 and 1.4

The four tree-ring sequences recorded on the supports of *Adam* and *Eve* were compared to determine whether they contain planks that come from the same log; they were also compared to the previously analyzed planks of the altarpiece[26]. The remarkable correlation obtained between the ring series of P455/01/2 (*Eve*, left plank) indicates that it is certainly taken from the same oak tree as the right plank of the panel of the *Hermits*, named P30, a panel that is located in the lower section of the altarpiece (Fig. 16)[27]. This observation has allowed for the reconstruction of the complete series P455/01/2, which was measured in two segments (see point 2.1.2). The measures originating from the same log were assembled to give one dendrochronological chronology for this individual: it is named P30-P455-01-ech.

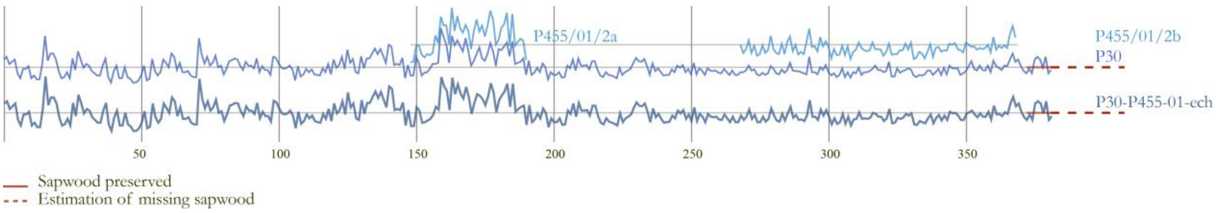



**Fig. 16.** Comparison of the dendrochronological series from *Eve*, left plank (upper light blue series, measured in two different segments P455/01/2a and P455/01/2b) and the *Hermits*, right plank (second series from the top P30), which come from the same log, and their mean chronology P30-P455-01-ech (bottom dark blue series).

No other pair of planks coming from the same tree was identified for the three remaining planks of *Adam* and *Eve*. Moreover, these three series and the chronology P30-P455-01-ech do not match significantly (see graph 2.2.5). For this reason, the four ring series were confronted separately with the reference database to date both supports.

Three can be dated in an incontestable way (tables and graphs 2.2.5). The most recent tree ring measured

- on P452/02/2 (*Adam,* right plank) is dated to **1406**;
- on P30-P455-01-ech (*Eve*, left plank, and *Hermits*, right plank) is dated to **1404**;
- on P455/02/2 (*Eve,* right plank) is dated to **1397**.

For the last plank P452/01/2 (*Adam,* left plank) a quite convincing date was obtained: the last tree ring would date from **1397** (?). It should nevertheless be considered <u>hypothetical</u> due to the quite low rates in the computing tests, below the thresholds judged as pertinent to assure a dating (tables and graphs 2.2.6). This uncertainty is most probably due to the rather short ring series which counts only 70 rings (see point 1.1).

[26] Vynckier 1999-2000; Fraiture 2011.

[27] Plank measured and dated by Vynckier 1999-2000.

The three assured positions and the hypothetical date are given by the regional and individual chronologies originating from the surroundings of the Baltic Sea (tables 2.2.6.1, 2.2.6.2); this indicates that the oaks of the three dated planks of *Adam* and *Eve* also come from this vast geographical zone, as is probably the case for the fourth plank of *Adam*, which is dated with uncertainty (Fig. 17). The origin of this imported wood is unspecified to this day; it seems however that several zones were exploited in the course of time, from the north of Poland to current Russia (Fig. 18)[28]. Numerous historical sources bear witness to considerable exportation of oaks from the north-east to the ancient Netherlands from the 14th century onwards, by intermediary of the Baltic ports[29]. Dendrochronology contributes to establishing this fact since the majority of the supports used by the Flemish painters from the 14th century until the middle of the 17th century, amongst others, are made of this type of wood.[30] Available in large quantities, it had mechanical properties suited for the manufacture of high quality planks.[31]


**Fig. 17.** Map showing the vast provenance zone supposed to have been exploited to supply so-called "Baltic" oaks to western Europe. Map after DUBY G., 2003, *Atlas historique mondial*, Paris, p. 74. Graph: VAN DER SLOOT E.

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[28] Several European laboratories are performing studies to specify these provenances. For a state of the question, see for example ECKSTEIN & WROBEL 2007 and FRAITURE 2009b.

[29] See for example BAILLIE 1984; TOSSAVAINEN 1994; ZUNDE 1998-1999.

[30] On the discovery of the use of so-called "Baltic" wood in art works by dendrochronology, see BAILLIE *et al.* 1985; ECKSTEIN *et al.* 1986. For the use of Baltic oak in Flemish art works, see for example VYNCKIER 1992; KEMPERDICK & KLEIN 1997; FRAITURE 2007, 2009a and 2012. For a state of the question, see ECKSTEIN & WROBEL 2007 and FRAITURE 2007.

[31] The harsh climate of this region leads to slow growing trees that produce soft wood that is little inclined to deform. In addition, the competition between individuals in these dense forests generates a rectilinear growth of the oaks, an important quality for the production of long planks.


**Fig. 18**. Map showing the exploitation zones of oak for export to western Europe, from 14th to 16th century, after archives. Map after DUBY G., 2003, *Atlas historique mondial*, Paris, p. 141; limits of exploitation zones after WAZNY 2005. Graph: VAN DER SLOOT E. © P. Fraiture, Dendrochronology lab, KIK-IRPA, Brussels

No trace of sapwood was preserved on the supports of *Adam* and *Eve*. However the right plank of the *Hermits*, which is from the same tree as P455/01/2 (*Eve*, left plank), still contains 9 sapwood rings, allowing for situate the felling of this tree P30-P455-01-ech in a time fork (see point 1.6). For the other planks without sapwood, the obtained results are *termini post quem* for the felling of the trees, dates after which the oaks were felled (see point 1.6). As the Baltic provenance zone of these trees is not precisely known, two statistical studies, one concerning oaks originating from northern Poland[32] and the other relating to living oaks from Baltic countries (Estonia, Latvia and Lithuania) and Finland[33], are combined in order to present the most reliable results.

For the *Adam* panel, the felling of

- oak P452/01/2 (*Adam,* left plank) would be situated after **1403 (?)** (1397? + 6);
- oak P452/02/2 (*Adam,* right plank) can be situated after **1412** (1406 + 6).

For the *Eve* panel, the felling of

- oak P455/02/2 (*Eve,* right plank) can be situated after **1403** (1397 + 6);
- oak P30-P455-01-ech (*Eve*, left plank, and *Hermits*, right plank) took place **between 1405 and 1431.**

Combining the results obtained for both panels, the **felling** of the trees used to manufacture the supports of ***Adam* and *Eve*** (and a part of the *Hermits* panel) can be placed **between 1412 and 1431.**

---

[32] ECKSTEIN *et al.* 1986. This study carried out on 179 oaks from northern Poland revealed that their sapwood counts between 9 and 36 rings.

[33] SOHAR *et al.* 2012. This recent study, carried out on 668 living oak trees from the Baltic countries (Estonia, Latvia and Lithuania) and from southern Finland demonstrated that their sapwood counts between 6 and 19 rings.

On this interval the time lapse between the felling in the forest and completion of the painting is superimposed. This includes squaring the trunk, cutting it into quarters, floating to the ports, transport by sea to distribution centers, cutting quarters into planks, drying (which may be fairly quick), possible storage in the different warehouses or workshops (wood merchants, panel makers, painting workshops) and support manufacture itself. Systematic estimation of the interval between the dendrochronological result and the date of use, in order to better identify the period of artistic production, is an unrealizable ideal, given the number and variability of the parameters affecting this length of time, even for works within a given period.[34] Hence it is not possible to narrow down the manufacture period of the panels: **they cannot have been made before 1412**, without being more precise.

### *2.1.4. Conclusion*

The dendrochronological study of the panel supports of *Adam* and *Eve*, each made of two oak planks, reveals that the left plank of the *Eve* panel certainly comes from the same oak as the right plank of the *Hermits* panel, located in the lower section of the *Ghent Altarpiece*. No other pair of planks coming from the same log was identified for the three remaining planks of *Adam* and *Eve*.

Three of the four ring series can be dated in an incontestable way and the presence of some sapwood rings on the plank of the *Hermits* that is linked with the *Eve* left plank allows for estimating the felling dates of the oaks **between 1412 and 1431** (last ring measured: 1406). Beyond this result, it is difficult to further specify when the painting was carried out because the lapse of time between the felling and the use of the wood remains unknown. For this reason, we propose the date **1412 as *terminus post quem* for support manufacture.** Unsurprisingly the oaks originated from the surroundings of the Baltic Sea.

A hypothetical date could be adduced for the fourth ring series, which corresponds to the rapidly grown left plank of *Adam*: the possible date (and provenance) is consistent with the aforementioned results. The uncertainty is due to the short length of its ring series.

The information extracted from the tree rings during this third campaign of dendrochronological analysis of the *Ghent Altarpiece* gives results that are perfectly coherent with the other parts of the ensemble[35].

[34] See, for example, KEMPERDICK & KLEIN 1997. In this article, the authors propose adding 25 years to the date of the last ring measured on 15th century paintings. They specify, however, that this interval of 25 years is not appropriate for all the analyzed works – it is too long for some. FRAITURE 2008; VANDEKERCHOVE *et al.* 2012.
[35] See VYNCKIER 1999-2000 ; FRAITURE 2011 and FRAITURE in preparation.

## 2.2. Dendrochronological data, tables and diagrams of the results

### 2.2.1. *Recapitulating table of the dating*

| Dendrochronological sequence | Location | Number of measured rings | Date of the 1st measured ring | Date of the 1st sapwood ring | Date of the last measured ring |
|---|---|---|---|---|---|
| **P452/01/2** | *Adam*, left plank | 70 | 1328 (?) AD | / | 1397 (?) AD |
| **P452/02/2** | *Adam*, right plank | 203 | 1204 AD | / | 1406 AD |
| **P30-P455-01-ech** | *Eve*, left plank, and *Hermits*, right plank | 382 | 1023 AD | 1395 AD | 1404 AD |
| **P455/02/2** | *Eve*, right plank, lower side | 172 | 1226 AD | / | 1397 AD |

### 2.2.2. *Values of the dendrochronological series measured on the supports of* Adam *and* Eve *(1/100 mm)*

**. P452/02/2**
LON 203
ORI 1204
TER 1406
LGT 3.726797
LAT 51.052999
ALT 18
_MI 44
_MX 170
_AV 97.728
VAL Widths

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 80 | 61 | 79 | 78 | 66 | 58 | 68 | 76 | 65 | 61 |
| 78 | 76 | 53 | 60 | 76 | 96 | 89 | 81 | 79 | 96 |
| 93 | 85 | 75 | 55 | 101 | 78 | 137 | 86 | 88 | 98 |
| 84 | 56 | 73 | 88 | 71 | 106 | 44 | 74 | 88 | 71 |
| 79 | 106 | 72 | 101 | 91 | 76 | 103 | 136 | 138 | 120 |
| 98 | 134 | 107 | 148 | 104 | 133 | 111 | 115 | 100 | 100 |
| 144 | 110 | 151 | 98 | 170 | 103 | 142 | 96 | 122 | 105 |
| 127 | 147 | 105 | 100 | 100 | 132 | 118 | 98 | 96 | 98 |
| 102 | 110 | 105 | 83 | 102 | 115 | 107 | 122 | 142 | 74 |
| 141 | 116 | 136 | 122 | 124 | 119 | 94 | 106 | 126 | 65 |
| 96 | 71 | 84 | 107 | 80 | 90 | 89 | 90 | 95 | 82 |
| 97 | 101 | 76 | 74 | 85 | 83 | 95 | 111 | 85 | 71 |
| 62 | 97 | 104 | 88 | 87 | 73 | 95 | 71 | 83 | 78 |
| 85 | 87 | 85 | 72 | 99 | 103 | 107 | 74 | 93 | 91 |
| 88 | 89 | 72 | 84 | 107 | 91 | 98 | 107 | 100 | 107 |
| 116 | 86 | 100 | 95 | 88 | 95 | 95 | 82 | 124 | 140 |
| 120 | 78 | 107 | 102 | 107 | 119 | 137 | 67 | 80 | 107 |
| 104 | 110 | 100 | 100 | 107 | 87 | 127 | 88 | 90 | 130 |
| 102 | 160 | 143 | 143 | 148 | 143 | 122 | 117 | 127 | 105 |
| 96 | 84 | 78 | 73 | 86 | 90 | 96 | 74 | 103 | 69 |
| 100 | 83 | , | ; | | | | | | |

### . P452/01/2

LON 70
ORI 1328 (?)
TER 1397 (?)
LGT 3.726797
LAT 51.052999
ALT 18
_MI 116
_MX 418
_AV 217.232
VAL Widths

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 320 | 349 | 296 | 290 | 173 | 248 | 242 | 249 | 418 | 291 | |
| 144 | 192 | 232 | 310 | 224 | 272 | 400 | 370 | 306 | 242 | |
| 262 | 225 | 237 | 230 | 187 | 181 | 187 | 228 | 127 | 127 | |
| 197 | 138 | 175 | 186 | 239 | 123 | 176 | 274 | 138 | 245 | |
| 177 | 168 | 183 | 284 | 179 | 208 | 163 | 212 | 199 | 230 | |
| 240 | 199 | 246 | 277 | 185 | 185 | 121 | 161 | 175 | 187 | |
| 145 | 198 | 188 | 160 | 201 | 190 | 141 | 116 | 221 | , | ; |

### . P455/01/2ab

LON 222
ORI 1171
TER 1392
LGT 3.726797
LAT 51.052999
ALT 18
_MI 42
_MX 135
_AV 72.472
VAL Widths

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 42 | 43 | 70 | 71 | 55 | 50 | 56 | 54 | 58 | 88 |
| 75 | 120 | 105 | 105 | 73 | 135 | 96 | 121 | 100 | 93 |
| 106 | 96 | 65 | 96 | 115 | 95 | 105 | 86 | 105 | 130 |
| 115 | 72 | 81 | 101 | 107 | 127 | 70 | 125 | 70 | 77 |
| 82 | 79 | 46 | , | , | , | , | , | , | , |
| , | , | , | , | , | , | , | , | , | , |
| , | , | , | , | , | , | , | , | , | , |
| , | , | , | , | , | , | , | , | , | , |
| , | , | , | , | , | , | , | , | , | , |
| , | , | , | , | , | , | , | , | , | , |
| , | , | , | , | , | , | , | , | , | , |
| , | , | , | , | , | , | , | , | , | , |
| 72 | 58 | 65 | 80 | 58 | 70 | 53 | 56 | 71 | 58 |
| 63 | 87 | 65 | 58 | 56 | 74 | 56 | 77 | 86 | 61 |
| 72 | 55 | 60 | 56 | 77 | 99 | 68 | 69 | 61 | 85 |
| 69 | 78 | 69 | 49 | 65 | 54 | 55 | 70 | 54 | 69 |
| 48 | 60 | 64 | 76 | 66 | 63 | 61 | 63 | 76 | 65 |
| 65 | 64 | 53 | 60 | 74 | 55 | 56 | 56 | 63 | 63 |
| 74 | 64 | 76 | 48 | 50 | 60 | 57 | 49 | 60 | 73 |
| 51 | 66 | 68 | 60 | 63 | 62 | 74 | 72 | 75 | 65 |
| 63 | 59 | 76 | 72 | 68 | 69 | 64 | 66 | 65 | 66 |
| 72 | 59 | 85 | 64 | 70 | 66 | 71 | 66 | 90 | 104 |
| 84 | , | ; | | | | | | | |

**. P455/02/2**

LON 172
ORI 1226
TER 1397
LGT 3.726797
LAT 51.052999
ALT 18
_MI 44
_MX 237
_AV 115.228
VAL Widths

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 135 | 147 | 106 | 92 | 135 | 57 | 87 | 113 | 97 | 98 |
| 77 | 108 | 75 | 98 | 125 | 67 | 62 | 77 | 75 | 97 |
| 140 | 156 | 140 | 156 | 149 | 176 | 204 | 227 | 192 | 228 |
| 136 | 150 | 90 | 138 | 128 | 119 | 160 | 154 | 237 | 171 |
| 122 | 140 | 107 | 150 | 147 | 202 | 184 | 151 | 141 | 153 |
| 150 | 107 | 141 | 158 | 194 | 142 | 151 | 152 | 128 | 100 |
| 131 | 126 | 87 | 116 | 115 | 104 | 127 | 136 | 140 | 143 |
| 113 | 142 | 153 | 164 | 147 | 126 | 142 | 95 | 109 | 84 |
| 98 | 89 | 89 | 93 | 142 | 188 | 178 | 127 | 106 | 127 |
| 125 | 130 | 136 | 117 | 131 | 177 | 139 | 123 | 108 | 136 |
| 91 | 93 | 118 | 78 | 105 | 88 | 85 | 73 | 87 | 72 |
| 109 | 70 | 88 | 135 | 87 | 91 | 101 | 96 | 65 | 85 |
| 97 | 71 | 79 | 60 | 78 | 79 | 86 | 92 | 103 | 73 |
| 86 | 44 | 76 | 65 | 68 | 74 | 81 | 86 | 108 | 92 |
| 110 | 97 | 79 | 90 | 114 | 79 | 94 | 104 | 127 | 106 |
| 88 | 96 | 129 | 106 | 107 | 154 | 129 | 101 | 83 | 78 |
| 90 | 85 | 119 | 83 | 104 | 111 | 121 | 104 | 69 | 67 |
| 107 | , | ; | | | | | | | |

### *2.2.3. Values of the chronology constructed from both series from the same log: right plank of the* Hermits *(P30) and left plank of* Eve *(P455/01/2) (1/100 mm)*

**. P30-P455-01-ech**

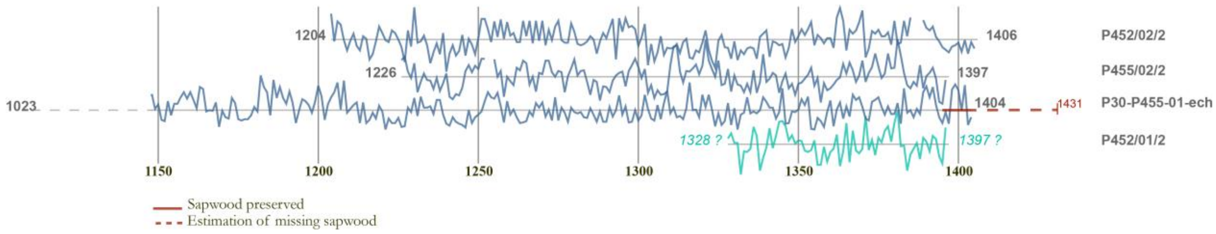
LON 382
ORI 1023
TER 1404
LGT 4.393918
LAT 50.842372
ALT 90
_MI 40
_MX 140
_AV 73.092
VAL Widths

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 90 | 95 | 80 | 85 | 90 | 60 | 50 | 70 | 70 | 75 |
| 50 | 55 | 47 | 47 | 80 | 140 | 87 | 102 | 102 | 90 |
| 65 | 50 | 52 | 62 | 50 | 92 | 67 | 107 | 90 | 72 |
| 80 | 77 | 65 | 60 | 55 | 55 | 77 | 92 | 52 | 40 |
| 65 | 77 | 50 | 50 | 73 | 52 | 48 | 40 | 40 | 45 |
| 55 | 76 | 45 | 48 | 91 | 65 | 55 | 62 | 90 | 82 |
| 73 | 102 | 95 | 67 | 83 | 62 | 62 | 65 | 55 | 52 |
| 52 | 136 | 100 | 81 | 95 | 77 | 83 | 98 | 73 | 76 |
| 58 | 70 | 86 | 88 | 92 | 90 | 76 | 67 | 85 | 77 |
| 77 | 71 | 92 | 63 | 75 | 67 | 67 | 57 | 96 | 93 |
| 81 | 72 | 70 | 72 | 77 | 68 | 45 | 75 | 53 | 58 |
| 70 | 63 | 68 | 58 | 56 | 55 | 71 | 62 | 80 | 58 |
| 90 | 72 | 78 | 95 | 70 | 111 | 83 | 91 | 63 | 60 |
| 97 | 71 | 92 | 92 | 103 | 113 | 101 | 112 | 98 | 83 |
| 122 | 118 | 78 | 80 | 78 | 93 | 50 | 78 | 49 | 49 |
| 83 | 77 | 55 | 56 | 59 | 62 | 69 | 84 | 79 | 139 |
| 122 | 114 | 78 | 138 | 108 | 126 | 109 | 100 | 121 | 102 |
| 71 | 92 | 108 | 105 | 99 | 87 | 104 | 128 | 111 | 74 |
| 97 | 106 | 113 | 127 | 84 | 127 | 75 | 80 | 84 | 86 |
| 51 | 87 | 56 | 61 | 72 | 63 | 81 | 73 | 47 | 63 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 56 | 56 | 63 | 51 | 52 | 77 | 71 | 90 | 66 | 92 |
| 77 | 77 | 78 | 68 | 86 | 86 | 67 | 55 | 52 | 63 |
| 57 | 55 | 53 | 50 | 72 | 56 | 63 | 66 | 70 | 82 |
| 93 | 86 | 85 | 91 | 75 | 56 | 81 | 65 | 71 | 62 |
| 55 | 56 | 57 | 68 | 63 | 77 | 72 | 78 | 62 | 70 |
| 58 | 83 | 58 | 71 | 66 | 56 | 71 | 66 | 65 | 66 |
| 61 | 60 | 70 | 63 | 56 | 66 | 56 | 56 | 68 | 60 |
| 66 | 79 | 62 | 69 | 56 | 56 | 66 | 57 | 62 | 81 |
| 68 | 59 | 57 | 71 | 59 | 72 | 84 | 64 | 69 | 60 |
| 61 | 58 | 68 | 97 | 66 | 66 | 60 | 79 | 68 | 78 |
| 66 | 52 | 63 | 53 | 56 | 71 | 53 | 66 | 50 | 61 |
| 62 | 74 | 62 | 63 | 62 | 64 | 73 | 71 | 66 | 66 |
| 58 | 63 | 80 | 54 | 55 | 64 | 62 | 64 | 71 | 68 |
| 72 | 52 | 51 | 58 | 56 | 54 | 63 | 70 | 54 | 64 |
| 69 | 59 | 68 | 60 | 75 | 72 | 73 | 68 | 60 | 60 |
| 71 | 74 | 77 | 70 | 65 | 72 | 66 | 66 | 75 | 61 |
| 86 | 70 | 71 | 67 | 74 | 71 | 90 | 103 | 85 | 90 |
| 75 | 65 | 60 | 70 | 60 | 90 | 95 | 90 | 72 | 95 |
| 60 | 67 | ; | | | | | | | |

### *2.2.4. Visual comparisons between the four ring series from both supports, calibrated by the "corridor" method*

see point 1.4.2




As the series of both supports do not match, they are not assembled in a mean chronology: each series is dated individually (the first 125 rings of P30-P455-01-ech have been cut off in order to provide a readable graph).

## *2.2.5. Dating calculations for the three dated series*[36]

The calculations for synchronization are carried out using the *Dendron* software program (version IV), after calibration of the dendrochronological series by an original transformation method called *corridor* (see point 1.4.2)[37].

- **P452/02/2: *Adam*, right plank**

*Chronology P452/02/2 compared to the Baltic chronologies of the IRPA-KIK reference database*

*Student test* : - *t* > 4 = significant
- *t* > 5 = good
- *t* > 6 = very good

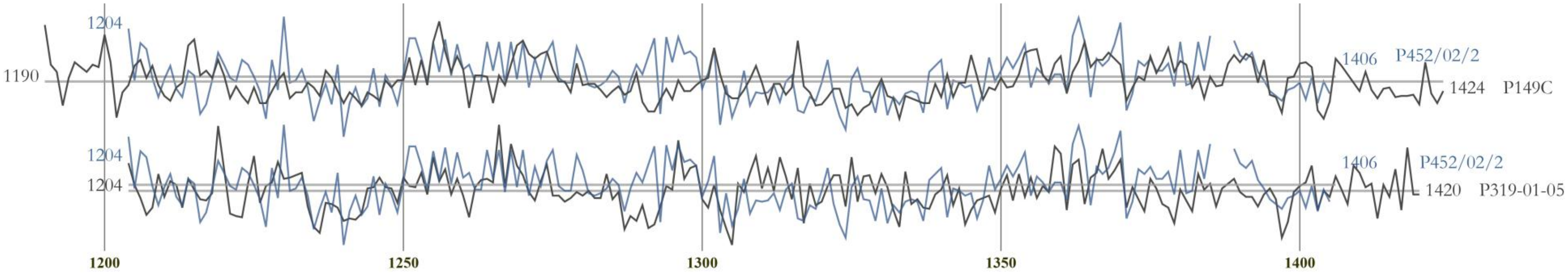
A larger replication gives a more convincing retained date (see point 1.4.2).

| ***P452/02/2 : 1204 – 1406 AD*** | | | | | | |
|---|---|---|---|---|---|---|
| *t* of *Student* | Probability/ security | Corr. coeff. 1 | Corr. coeff. 2 | Length | Chronology of the reference database | © reference |
| 5.47 | 0.999972 | 0.4 | 0.29 | 197 | P149C | VYNCKIER (formerly KIK-IRPA) |
| 5.38 | 0.999969 | 0.33 | 0.35 | 194 | P40 | VYNCKIER (formerly KIK-IRPA) |
| 5.34 | 0.999969 | 0.37 | 0.3 | 197 | P319-01-05 | FRAITURE (KIK-IRPA) |
| 5.27 | 0.999966 | 0.46 | 0.21 | 197 | P149AB.ECH | VYNCKIER (formerly KIK-IRPA) |
| 5.28 | 0.999965 | 0.42 | 0.27 | 182 | P133 | VYNCKIER (formerly KIK-IRPA) |
| 5.2 | 0.999964 | 0.42 | 0.25 | 190 | P466/04/1 | FRAITURE (KIK-IRPA) |
| 5.11 | 0.99996 | 0.3 | 0.37 | 183 | P21-B | VYNCKIER (formerly KIK-IRPA) |
| 5 | 0.999958 | 0.29 | 0.36 | 188 | P24 | VYNCKIER (formerly KIK-IRPA) |
| 4.97 | 0.999955 | 0.37 | 0.32 | 163 | P47C | VYNCKIER (formerly KIK-IRPA) |
| 4.88 | 0.999954 | 0.33 | 0.3 | 197 | P123C | VYNCKIER (formerly KIK-IRPA) |
| 4.86 | 0.999954 | 0.33 | 0.3 | 197 | P138 | VYNCKIER (formerly KIK-IRPA) |
| 4.67 | 0.999946 | 0.31 | 0.3 | 196 | P30 | VYNCKIER (formerly KIK-IRPA) |
| 4.5 | 0.999929 | 0.38 | 0.29 | 146 | P319/03/1a-bis-tot | FRAITURE (formerly ULg/CEA) |

**P452/02/2** gives very good results: the retained position, **1406**, shows a significant replication and good quality synchronization rates with several chronologies of the reference database for the Baltic region (the following table shows a selection of the most significant results produced by *Dendron IV*, those of which the *t* of *Student* > 4.5).

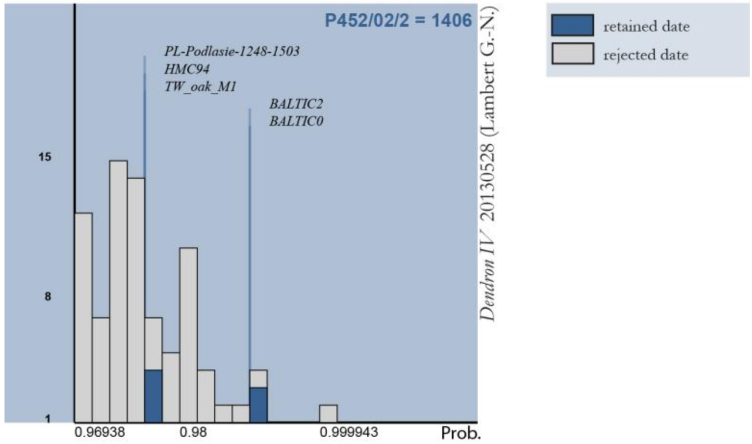
[36] See point 2.2.8 for the constitution of the reference database used to produce the tables and graphs.
[37] LAMBERT 2006.

*Verification of the dating of P452/02/2 by visual comparisons with two reference chronologies: P149C (VYNCKIER formerly KIK-IRPA) and P319-01-05 (FRAITURE KIK-IRPA)*



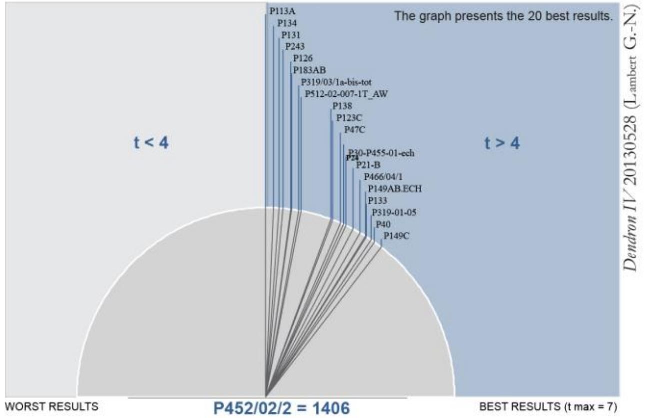

In both cases, the quality of the correlation between P452/02/2 and the reference chronologies assures the proposed date **1406**.

*Cumulative histograms of the chronological positions proposed by* Dendron IV *in comparing P452/02/2 to master and site chronologies in the KIK-IRPA reference database*




The results obtained for P452/02/2 are between class A and B quality (see point 1.6.1 and Fig. 9.2): the retained date **1406** is given by several regional and site Baltic chronologies, but without excellent probabilities (blue cells are not demarcated from the grey ones and are not located in the right part of the graph).

*Correlation fan produced by* Dendron IV *for the chronological position retained for P452/02/2 compared to individual chronologies of the KIK-IRPA database*




The results obtained for P452/02/2 are of class A quality (see point 1.6.2 and Fig. 10.2): numerous individual Baltic chronologies propose the retained date **1406** with synchronization rates that exceed the significant threshold of $t = 4$ (all the branches of the fan are located in the blue part of the graph).

- **P30-P455-01-ech: *Eve*, left plank, and *Hermits*, right plank**

*Chronology P30-P455-01-ech compared to the Baltic chronologies of the KIK-IRPA reference database*

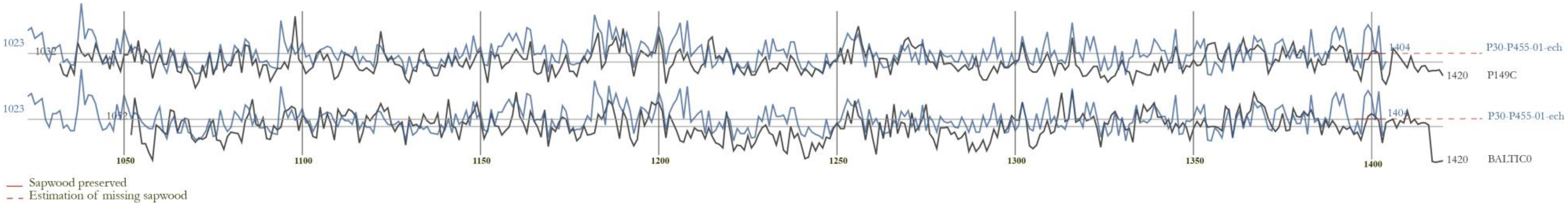
*Student test* : - *t* > 4 = significant
- *t* > 5 = good
- *t* > 6 = very good

A large replication gives a more convincing retained date (see point 1.4.2).

| *P30-P455-01-ech : 1023 – 1404 AD* | | | | | | |
|---|---|---|---|---|---|---|
| *t* of *Student* | Probability/ security | Corr. coeff. 1 | Corr. coeff. 2 | Length | Chronology of the reference database | © reference |
| 11.39 | 0.999995 | 0.5 | 0.43 | 372 | P149C | VYNCKIER (formerly KIK-IRPA) |
| 9.14 | 0.999995 | 0.41 | 0.4 | 352 | BALTIC0 | TYERS unpublished |
| 8.94 | 0.999995 | 0.44 | 0.48 | 241 | P203CD-ech | VYNCKIER (formerly KIK-IRPA) |
| 8.75 | 0.999995 | 0.45 | 0.38 | 304 | GRIMSBY1 | GROVES 1992 |
| 8.65 | 0.999995 | 0.43 | 0.4 | 305 | P208AC.ECH | VYNCKIER (formerly KIK-IRPA) |
| 8.36 | 0.999995 | 0.41 | 0.64 | 133 | P203E | VYNCKIER (formerly KIK-IRPA) |
| 8.22 | 0.999995 | 0.37 | 0.48 | 248 | P149AB.ECH | VYNCKIER (formerly KIK-IRPA) |
| 7.78 | 0.999994 | 0.33 | 0.41 | 332 | P137 | VYNCKIER (formerly KIK-IRPA) |
| 7.72 | 0.999994 | 0.46 | 0.39 | 225 | P466/04/1 | FRAITURE (KIK-IRPA) |
| 7.63 | 0.999994 | 0.45 | 0.4 | 224 | P134 | VYNCKIER (formerly KIK-IRPA) |
| 7.49 | 0.999993 | 0.49 | 0.55 | 115 | P512-03-ech1_vs2 | FRAITURE (KIK-IRPA) |
| 7.15 | 0.999993 | 0.33 | 0.49 | 206 | P46C | VYNCKIER (formerly KIK-IRPA) |
| 7.02 | 0.999993 | 0.36 | 0.29 | 374 | DCCD_oak_DB_ 1450_M1 | FRAITURE unpublished |
| 6.97 | 0.999992 | 0.39 | 0.52 | 147 | BALTIC2 | HILLAM & TYERS 1995 |
| 6.8 | 0.999992 | 0.35 | 0.38 | 256 | BALTIC1 | HILLAM & TYERS 1995 |
| 6.7 | 0.999992 | 0.33 | 0.4 | 254 | P21-B | VYNCKIER (formerly KIK-IRPA) |
| 6.47 | 0.999991 | 0.35 | 0.46 | 180 | P223A2.ECH | VYNCKIER (formerly KIK-IRPA) |
| 6.34 | 0.999991 | 0.36 | 0.38 | 214 | P138 | VYNCKIER (formerly KIK-IRPA) |
| 6.22 | 0.99999 | 0.39 | 0.45 | 153 | P312-ech | FRAITURE (KIK-IRPA) |
| 6.15 | 0.99999 | 0.38 | 0.3 | 261 | HMC94 | TYERS unpublished |
| 6.01 | 0.999986 | 0.45 | 0.33 | 170 | P308/01 | FRAITURE (KIK-IRPA) |
| 5.91 | 0.999986 | 0.27 | 0.46 | 200 | P319-01-05 | FRAITURE (KIK-IRPA) |
| 5.78 | 0.999982 | 0.31 | 0.36 | 231 | P123C | VYNCKIER (formerly KIK-IRPA) |
| 5.81 | 0.999981 | 0.39 | 0.37 | 174 | P11 | VYNCKIER (formerly KIK-IRPA) |
| 5.8 | 0.999978 | 0.37 | 0.46 | 134 | P117 | VYNCKIER (formerly KIK-IRPA) |
| 5.79 | 0.999978 | 0.31 | 0.49 | 152 | P6 | VYNCKIER (formerly KIK-IRPA) |
| 5.72 | 0.999974 | 0.48 | 0.48 | 87 | HAP140/01/2b | FRAITURE (formerly ULG/CEA) |
| 5.59 | 0.999973 | 0.33 | 0.43 | 159 | P128A | VYNCKIER (formerly KIK-IRPA) |
| 5.49 | 0.999973 | 0.31 | 0.35 | 221 | P226RL | VYNCKIER (formerly KIK-IRPA) |
| 5.48 | 0.999973 | 0.29 | 0.33 | 260 | P24 | VYNCKIER (formerly KIK-IRPA) |
| 5.6 | 0.999972 | 0.37 | 0.49 | 115 | P118B | VYNCKIER (formerly KIK-IRPA) |

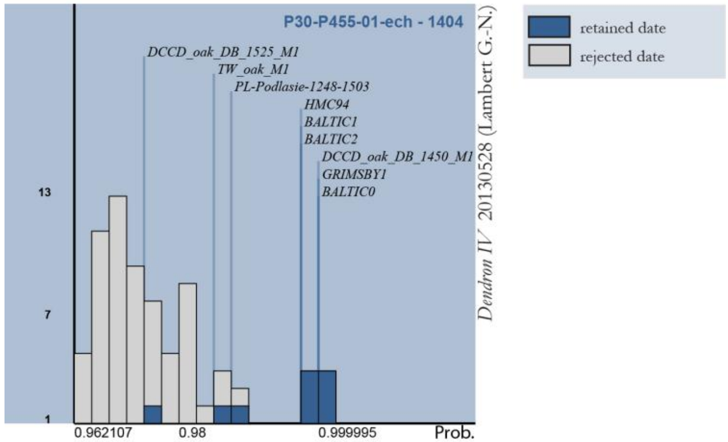
P30-P455-01-ech gives excellent results: the retained position **1404** shows a strong replication and high quality synchronization rates with numerous chronologies of the reference database for the Baltic region (the following table shows a selection of the most significant results, those of which *t* > 5.5).

*Verification of the dating of P30-P455-01-ech by visual comparisons with two reference chronologies: P149C (VYNCKIER formerly KIK-IRPA) and BALTIC0 (TYERS unpublished)*



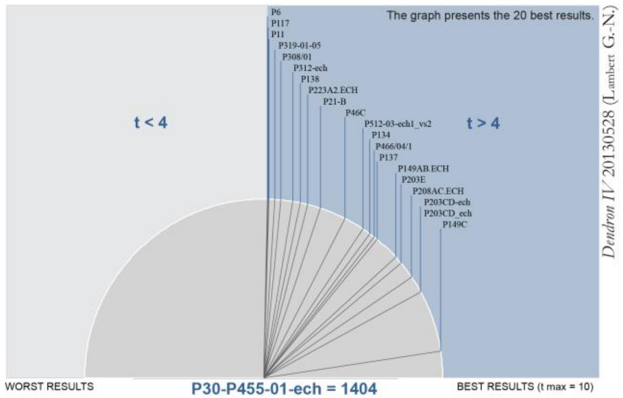

In both cases, the quality of the correlation between P30-P455-01-ech and the reference chronologies assures the proposed date **1404**.

*Cumulative histograms of the chronological positions proposed by* Dendron IV *in comparing P30-P455-01-ech to master and site chronologies in the KIK-IRPA reference database*




The results obtained for P30-P455-01-ech are of class A quality (see point 1.6.1 and Fig. 9.1): the retained date **1404** is given by several regional and site Baltic chronologies, with a strong demarcation for many of them (several blue cells are located in the right part of the graph).

*Correlation fan produced by* Dendron IV *for the chronological position retained for P30-P455-01-ech compared to individual chronologies of the KIK-IRPA database*




The results obtained for P30-P455-01-ech are of class A quality (see point 1.6.2 and Fig. 10.1): numerous individual Baltic chronologies propose the retained date **1404** with synchronization rates that exceed the significant threshold of $t = 4$ (all branches of the fan are located in the blue part of the graph).

- **P455/02/2: *Eve*, right plank**

*Chronology P455/02/2 compared to the Baltic chronologies of the KIK-IRPA reference database*

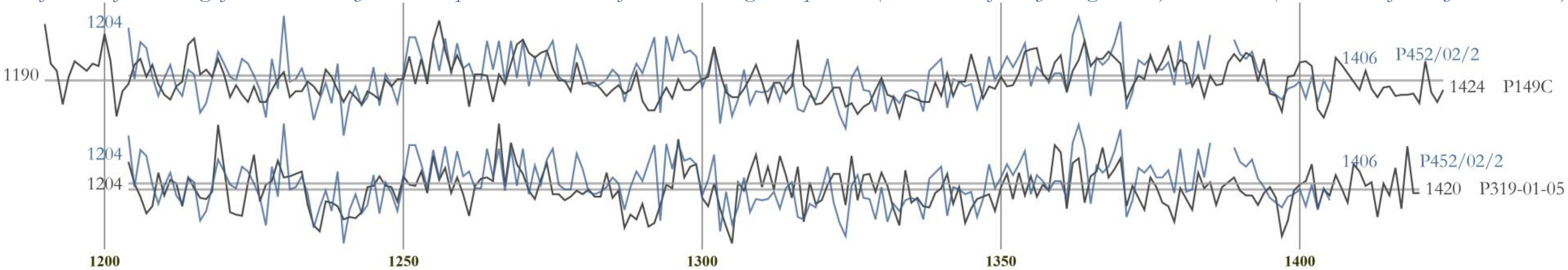
*Student test* : - *t* > 4 = significant
- *t* > 5 = good
- *t* > 6 = very good

A large replication gives a more convincing retained date (see point 1.4.2).

| ***P455/02/2 : 1226 – 1397 AD*** | | | | | | |
|---|---|---|---|---|---|---|
| *t* of *Student* | Probability/ security | Corr. coeff. 1 | Corr. coeff. 2 | Length | Chronology of the reference database | © reference |
| 5.02 | 0.999955 | 0.47 | 0.35 | 106 | hap94.ech | FRAITURE (formerly ULG/CEA) |
| 4.75 | 0.999946 | 0.32 | 0.35 | 159 | hap41.ech | FRAITURE (formerly ULG/CEA) |
| 4.65 | 0.99994 | 0.39 | 0.26 | 166 | P26A | VYNCKIER (formerly KIK-IRPA) |
| 4.44 | 0.999927 | 0.32 | 0.31 | 167 | P113K | VYNCKIER (formerly KIK-IRPA) |
| 4.37 | 0.999922 | 0.34 | 0.27 | 167 | BALTIC1 | HILLAM & TYERS 1995 |
| 4.27 | 0.999915 | 0.37 | 0.23 | 167 | P134 | VYNCKIER (formerly KIK-IRPA) |
| 4.08 | 0.999903 | 0.33 | 0.26 | 167 | DCCD_oak_DB_ 1450_M1 | FRAITURE unpublished |

**P455/02/2** gives rather low quality but nevertheless significant results: the retained position **1397** shows an indicative replication for synchronization rates higher than the threshold of *t* = 4 (the following table shows a selection of the most significant results produced by *Dendron IV*, those of which *t* of *Student* > 4).

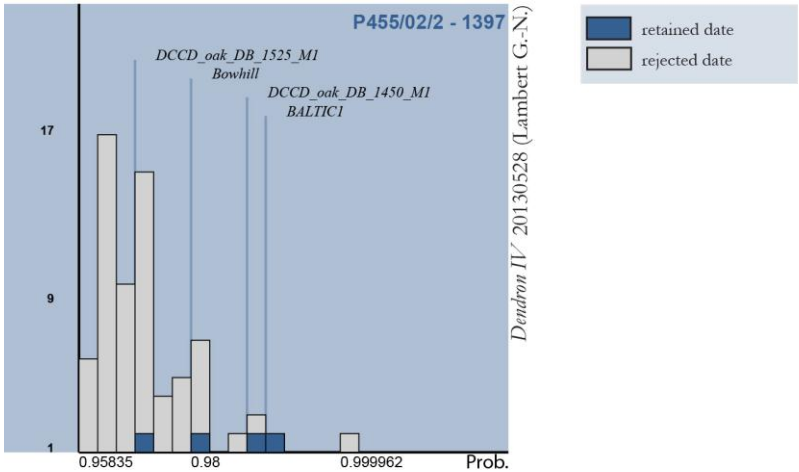
*Verification of the dating of P455/02/2 by visual comparisons with two reference chronologies: hap41.ech (FRAITURE formely ULg/CEA) and P26A (VYNCKIER formerly KIK-IRPA)*




In both cases, the quality of the correlation between P455/02/2 and the reference chronologies assures the proposed date **1397**.

*Cumulative histograms of the chronological positions proposed by* Dendron IV *in comparing P455/02/2 to master and site chronologies in the KIK-IRPA reference database*

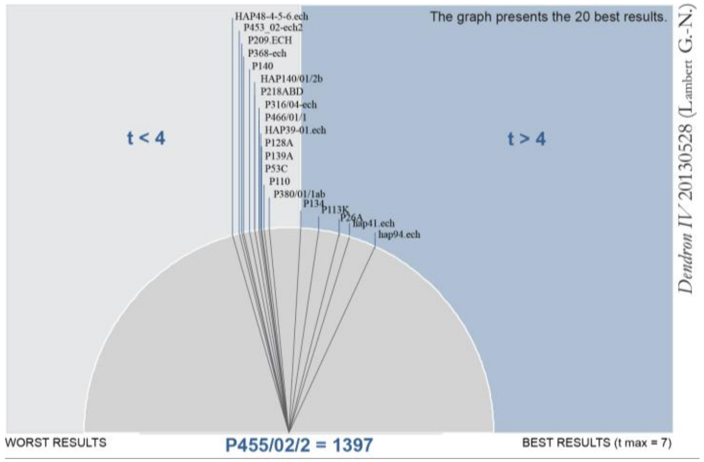
See point 1.6.1




The results obtained for P455/02/2 are between class A and B quality (see point 1.6.1 and Fig. 9.2): the retained date **1397** is given by several regional and site Baltic chronologies, but without excellent probabilities (blue cells are not demarcated from the grey ones and are not located in the right part of the graph).

*Correlation fan produced by* Dendron IV *for the chronological position retained for P455/02/2 compared to individual chronologies of the KIK-IRPA database*

See point 1.6.2




The results obtained for P455/02/2 are between class A and B quality (see point 1.6.2 and Fig. 10.2): numerous individual Baltic chronologies propose the retained date **1397** but only some synchronization rates exceed the significant threshold of $t = 4$ (only some branches of the fan are located in the blue part of the graph).

### *2.2.6. Dating calculations for the hypothetical result: P452/01/2,* Adam, *right plank*[38]

The calculations are carried out using the *Dendron* IV (see 2.2.5).

*Chronology P452/02/2 compared to the Baltic chronologies of the KIK-IRPA reference database*

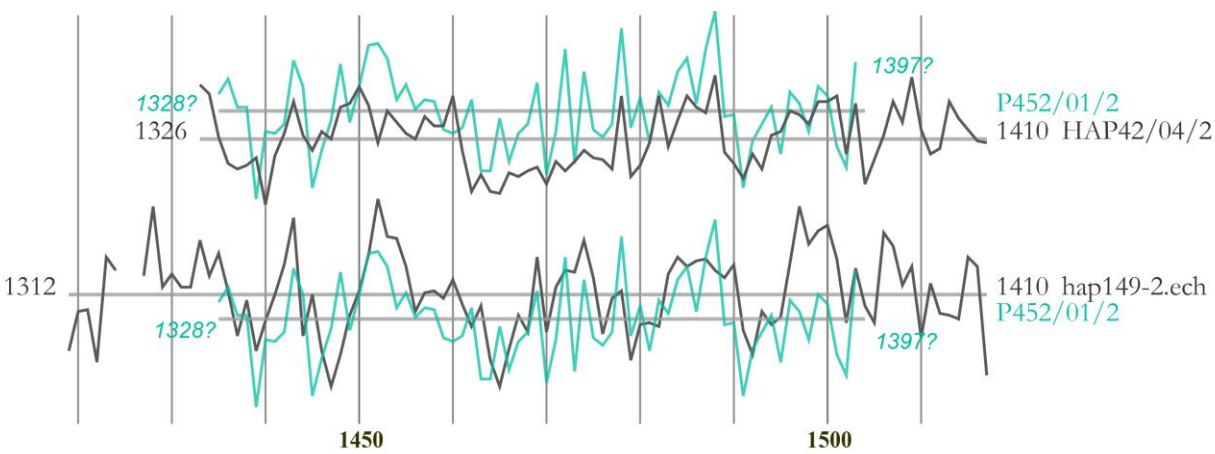
*Student test* :  - *t* > 3.2 = significant
- *t* > 4 = good
- *t* > 5 = very good

in relation with the short length of the ring series (70).
A large replication gives a more convincing date (see point 1.4.2).

| *P452/01/2 : 1328 – 1397 AD ?* | | | | | | |
|---|---|---|---|---|---|---|
| *t* of *Student* | Probability/ security | Corr. coeff. 1 | Corr. coeff. 2 | Length | Chronology of the reference database | © reference |
| 4.63 | 0.999931 | 0.52 | 0.38 | 70 | HAP42/04/2 | FRAITURE (formerly ULg/CEA) |
| 4.45 | 0.999919 | 0.51 | 0.38 | 70 | hap149-2.ech | FRAITURE (formerly ULg/CEA) |
| 3.47 | 0.999515 | 0.38 | 0.35 | 70 | hap153-1.ech | FRAITURE (formerly ULg/CEA) |
| 3.28 | 0.999136 | 0.33 | 0.38 | 70 | HAP68.ech | FRAITURE (formerly ULg/CEA) |
| 3.2 | 0.998857 | 0.3 | 0.39 | 70 | P316/01-ech | FRAITURE (KIK-IRPA) |

**P452/01/2** gives rather poor results: replication is low, too few chronologies in the reference database give synchronization rates high enough to propose the retained position 1397 as certain. These results constrain us to retain this date as hypothetical (the following tables present the results produced by *Dendron* IV with a minimal theoretical security of 0.9999 (99.9%), corresponding to *t* > 3.2).

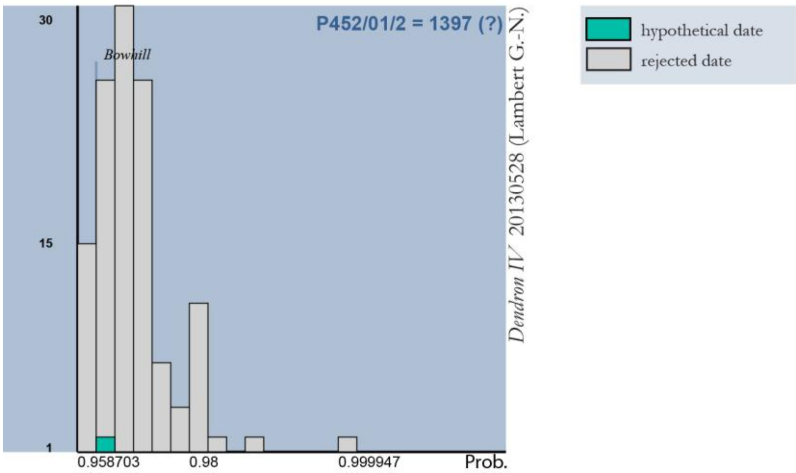
*Verification of the dating of P452/01/2 by visual comparisons with two reference chronologies: HAP42/04/2 and hap149-2.ech (FRAITURE formerly ULg/CEA)*




In both cases, P452/01/2 matches the reference chronologies rather convincingly; nevertheless, this chronological position should be considered as a hypothetical dating: 1397(?)

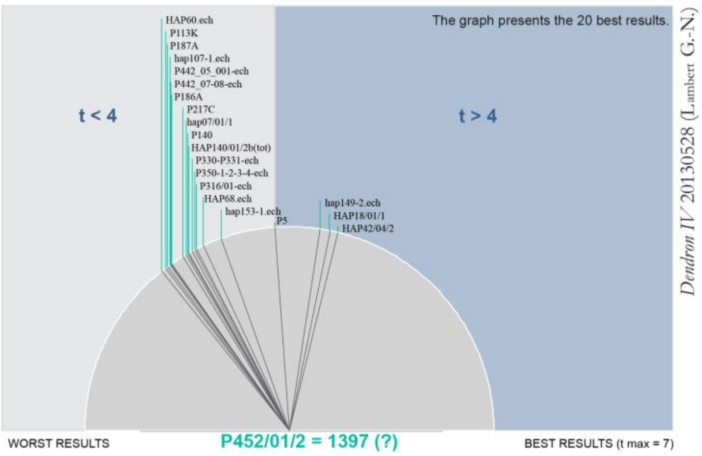
[38] See point 2.2.8 for the constitution of the reference database used to produce the tables and graphs.

*Cumulative histograms of the chronological positions proposed by* Dendron IV *in comparing P452/01/2 to master and site chronologies in the KIK-IRPA reference database*
See point 1.6.1




The results obtained for P452/01/2 are of class C quality (see point 1.6.1 and Fig. 9.1 for the interpretation of this type of graphs): the proposed date 1397 (?) is obtained only on one Baltic chronology (Bowhill), without any demarcation for it, meaning that the result for the proposed date does not give any good correlation rate with master or site Baltic chronologies. The retained chronological position 1397 (?) should not been accepted on the basis of this graph only.

*Correlation fan produced by* Dendron IV *for the chronological position retained for P452/01/2 compared to individual chronologies of the KIK-IRPA database*
See point 1.6.2




The results obtained for P452/01/2 are of class B quality (see point 1.6.2 and Fig. 10.2 for the interpretation of this type of graph): numerous individual Baltic chronologies give the proposed date 1397 (?). Nevertheless, few of them give synchronization rates that exceed the significant threshold of t = 4 (most of the branches of the fan are located in the grey part of the graph, to the left). These results combined with the shortness of the ring series (70 tree rings) constrain to consider the retained chronological position as a hypothetical dating[39].

[39] *Idem.*

## • Master and site chronologies

| Chronology | © | Material provenance | First ring | Last ring | Length |
|---|---|---|---|---|---|
| ***BALTIC0*** | Tyers, unpubl. | "Baltic", artistic and archaeological material from UK | 1052 | 1420 | 369 |
| ***BALTIC1*** | Hillam & Tyers, 1995 | | 1148 | 1597 | 450 |
| ***BALTIC2*** | Hillam & Tyers, 1995 | | 1257 | 1615 | 359 |
| ***BALTIC3*** | Tyers, unpubl. | | 1342 | 1633 | 292 |
| ***Bowhill*** | Groves, 2004 | "Baltic", archaeo. material, Exeter, Devon, UK | 1161 | 1483 | 323 |
| ***RKHbrrl*** | Tyers, unpubl. | "Baltic", archaeological material from UK | 1482 | 1640 | 159 |
| ***GRIMSBY1*** | Groves, 1992 | "Baltic", archaeological material from UK | 1100 | 1405 | 306 |
| ***Pl-051200_Gdansk*** | Eckstein *et al.*, unpubl. | ast-Pomerania and Gdansk (north of Poland) | 996 | 1985 | 990 |
| ***D-051000_Lubeck*** | Wrobel & Eckstein, unpubl. | Hansetown of Lübeck (Schleswig-Holstein, D) | 457 | 1723 | 1267 |
| ***Pl-Wolin.ref*** | Wazny, unpubl. | Wolin island (north-west of Poland) | 1554 | 1986 | 433 |
| ***PL-Podlasie*** | Wazny, unpubl. | Podlasie (east of Poland) | 1248 | 1503 | 256 |
| *RP_oak_chrono_1_15e* | Pukiene, Fraiture, unpubl.* | Vilnius (Lithuania) | 1202 | 1472 | 271 |
| *RP_oak_chrono_2_16e* | Pukiene, Fraiture, unpubl.* | Vilnius (Lithuania) | 1448 | 1530 | 83 |
| *TW_oak_M1* | Wazny, Fraiture, unpubl.* | Poland (unknown location) | 1262 | 1503 | 242 |
| *TW_oak_M2* | Wazny, Fraiture, unpubl.* | Poland (unknown location) | 1194 | 1473 | 280 |
| *TW_oak_M3* | Wazny, Fraiture, unpubl.* | Poland (unknown location) | 1526 | 1699 | 174 |
| *TW_oak_M4* | Wazny, Fraiture, unpubl.* | Poland (unknown location) | 1398 | 1686 | 289 |
| *TW_oak_M5* | Wazny, Fraiture, unpubl.* | Poland (unknown location) | 1463 | 1648 | 186 |
| *TW_oak_M6* | Wazny, Fraiture, unpubl.* | Poland (unknown location) | 1375 | 1599 | 225 |
| *TW_oak_M7* | Wazny, Fraiture, unpubl.* | Poland (unknown location) | 1388 | 1633 | 246 |
| *TW_oak_M8* | Wazny, Fraiture, unpubl.* | Poland (unknown location) | 1497 | 1668 | 172 |
| *DCCD_oak_DB_1525-M1* | Fraiture *et al.*, unpubl.* | "Baltic", artistic and archaeological material from Belgium, UK, The Netherlands, Spain… | 1256 | 1614 | 359 |
| *DCCD_oak_DB_1525_M3* | Fraiture *et al.*, unpubl.* | | 1331 | 1634 | 304 |
| *DCCD_oak_DB_1525_M2_b* | Fraiture *et al.*, unpubl.* | | 1335 | 1599 | 265 |
| *DCCD_oak_DB_1525_M2_c* | Fraiture *et al.*, unpubl.* | | 1348 | 1601 | 254 |
| *DCCD_oak_DB_1450_M1* | Fraiture *et al.*, unpubl.* | | 1030 | 1523 | 494 |

* The asterix refers to the *DCCD* project and a current dendro-provenance research (see note 4).

## • Individual chronologies

KIK-IRPA's database comprises around 400 individual chronologies independent from regional and site chronologies, which cover the time period of the ring series from the *Altarpiece*. They come from archaeological material and art works, and have been constructed by different labs (code ref.: AA_PaF_BALTE_indiv_20130726). These chronologies are unpublished.

- KIK-IRPA (J. Vynckier, P. Fraiture): 300 chronologies
- ULg/CEA (P. Fraiture): 80 chronologies
- Dendrochronological Consultancy Ltd, Sheffield (I. Tyers): 10 chronologies

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