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# THE OLDEST PARTS OF TURKU CATHEDRAL. C-14 CHRONOLOGY OF FIRE DAMAGED MORTARS

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FIONA BROCK

We have applied C-14 mortar dating to the fire damaged old structures in the medieval Cathedral of Turku, in SW Finland. Some of the mortars show no signs of fire damage and they present normal age-profiles, which give the age expected from the historical context. The oldest mortar carbonates are from the late 13<sup>th</sup> C. Fire damaged mortars have been partly de-carbonated and re-carbonated. The preserved part of the mortar carbonate gives the original age of the mortar while the re-carbonated part seems to date the fire event. We have tried to selectively remove the secondary, fire-damage related carbonates by partial leaching with diluted hydrochloric acid.



## INTRODUCTION

The church in medieval Turku is mentioned for the first time in an indulgence letter from 1259. The letter is preceded by a bulla from the pope Gregorius IX in which he demands that the Episcopal see of Finland should be moved to a more suitable place. The present location of the Cathedral by the Aura river is not explicitly mentioned, and it has been suggested that the letter refers to a transfer of the see from the original place in Nousiainen to Röntämäki about 1.6 kilometres further up the river (see the discussion in e.g. Gardberg *et al.* 2000). In 1291 Magnus I was, however, elected bishop in the sacristy and in the year 1300 the church was inaugurated as Cathedral. The present Cathedral (Fig. 1.) is not mentioned in this context. However, at this stage the Cathedral may have been a construction of which very little is preserved, since the Novgorodians had already burnt and destroyed the cathedral in 1318. Since then the Cathedral has been burnt repeatedly in wars and city fires. The chronology of the oldest parts of the Cathedral is therefore mainly based on the historical context in general and on written sources referring to the church indirectly (see documents in the chronicles: “The Black Book”; <http://193.184.161.234/DF/index.htm>).

In this article we will report radiocarbon ages from the structurally oldest mortared parts of the Cathedral. The C-14 ages are derived at using the mortar dating method presented in Lindroos (2005), Lindroos *et al.* (2007) and Heinemeier *et al.* (2010), in which the sample is dated in several CO<sub>2</sub> fractions forming an age profile extending from 0-100% dissolution ( $F=0-1$  where  $F$  is the dissolution progress variable). In this case the method is implemented on non-hydraulic lime mortars probably made from Precambrian marble, because marble has been quarried in the vicinity since the 14<sup>th</sup> century (Boström 1986). The marble is not considered problematic, since we have vast experience of dating mortars made from the Estremoz marble in eastern Portugal (e.g. Langley *et al.* 2011). The extensive fire damage is, however, a challenge and we will discuss its effect on the C-14 ages of the mortars. We have also made some attempts to selectively remove the contaminating fire-damage related carbonates by leaching with diluted hydrochloric acid.

*Fig. 1 (previous page). The Turku Cathedral seen from the south with the “All Saints Choir” to the right (Photo taken on May 16, 2011, by A.L.)*

## SAMPLING

When we planned the sampling in the Cathedral we were, of course, aware of different problems. Damages caused to the mortars by repeated fires could for instance challenge our possibilities to implement the method of mortar dating. We had some experience dating fire-damaged mortars in the churches of Sund and Kumlinge in the Åland Islands (Ringbom *et al.* 2005, Lindroos *et al.* 2007, Heinemeier *et al.* 2010) where we observed that the heat may destroy some of the mortar carbonate and new, easily soluble and dateable mortar minerals may form after the fire. We therefore tried to collect:

- A) Samples from the oldest parts of the church where fire damage had been minimal.
- B) Fire damaged samples from structures with known ages for reference.
- C) Samples from the structures we wanted to date regardless of fire damage effects.

The first samples (A) would be expected to be comparable with any other medieval non-hydraulic samples that we have previously dated and would give normal C-14 age profiles that could be interpreted accordingly. The second type of samples (B) would reveal what kind of profiles fire damaged, marble-based mortars produce and which part of the profile would identify a C-14 age corresponding to the known age. Most of the samples were, however, taken from more or less fire damaged structures with poorly known chronologies (C).

The first samples were collected in January 2007 (with a complementary sample was taken in June) and a second series of samples was taken in December the same year. Fig. 2 presents the position of the samples on the ground plan of the church and the samples are listed in Table 1. We managed to get samples without visible fire damage (A) from a tomb under the floor of the old pentagonal choir. We took reference samples from fire damaged mortars (B) from the All Saints Choir, built between 1466 and 1471 (Gardberg *et al.* 2000). Other structures sampled were Sacristy I where Magnus I was elected bishop, Sacristy II, the Chapel of the Holy Corps and the Chapel of Hemming (Fig. 2).

## RESULTS

A complete list of samples with numerical data for each one is given in Tab I. In this chapter we will consider the C-14 age profiles of the samples from the different structural units. The BP ages have been calibrated using OxCal 4.1 and values from IntCal 09. The samples from the Chapel of Hemming seem so contaminated by both marble and fire damage that they are only listed in Table 1. They will be discussed in a scientific context later.

# Turku Cathedral

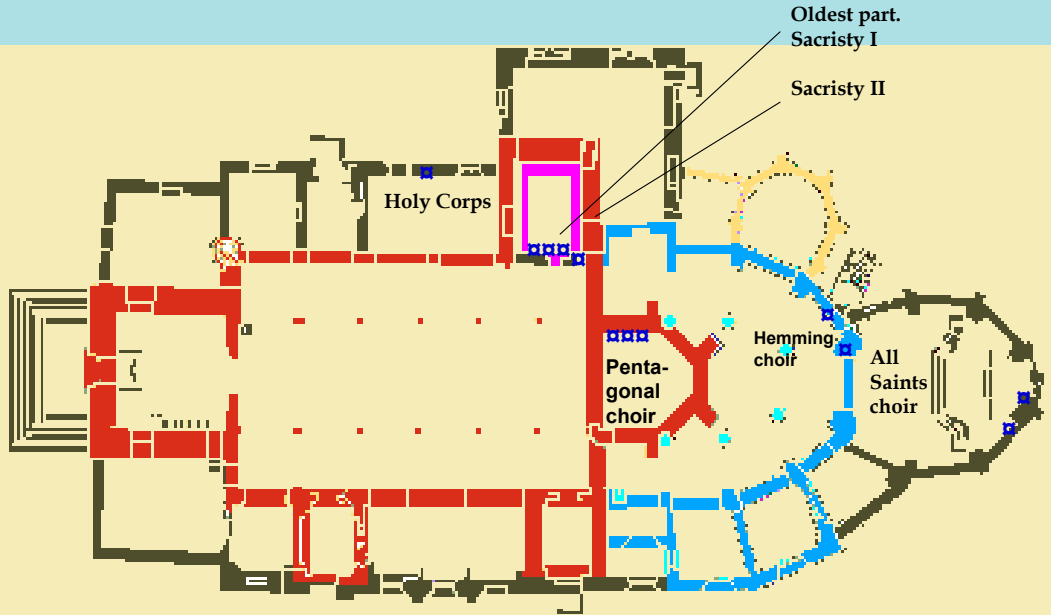


Fig. 2. Plan of Turku Cathedral (from Lindberg 1972-1973) presenting the different building units and the respective sampling sites (denoted with  $\square$ ).

The sampling site at the pentagonal choir (samples TTK 005, TTK 006, TTK 023) seemed to have escaped fire damage thanks to their low position in the tomb, under the floor of the choir. Their C-14 profiles (Fig. 3) are also free from indications of fire damage effects (see e.g. Ringbom *et al.* 2005). They are similar to other profiles from samples with severe contamination from geological carbonate, in this case marble from the Precambrian bedrock in the area. Consequently the profiles also display similar values in the first (left-hand) fractions but then diverge because of different amounts of contamination. This is a strong indication that the first CO<sub>2</sub> fractions of the samples reflect the common age of the binder carbonate and thus give a good estimation of the archaeological age of the samples (see e.g. Heinemeier *et al.* 2010).

The average weighted mean of the first CO<sub>2</sub> fractions of samples TTK 005, 006 and 023 gives the C-14 age 565±18 BP. Calibration results in a bimodal distribution (see Fig. 11) and gives the following calendar date ranges: 1325-1345 (33.8%) and 1390-1410 (34.4%) at 68,2% probability and 1310-1360 (50.7%) and 1380-1420 (44.7%) at 95,4% probability.

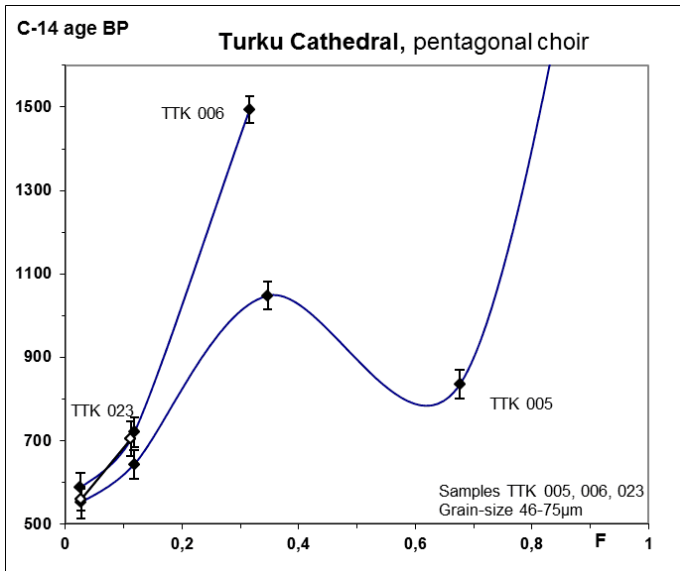


Fig. 3. C-14 profiles from the pentagonal choir. The profiles show no signs of fire damage. All three profiles start with overlapping ages (the two CO<sub>2</sub> fractions of sample TTK 023 are denoted with open dots).

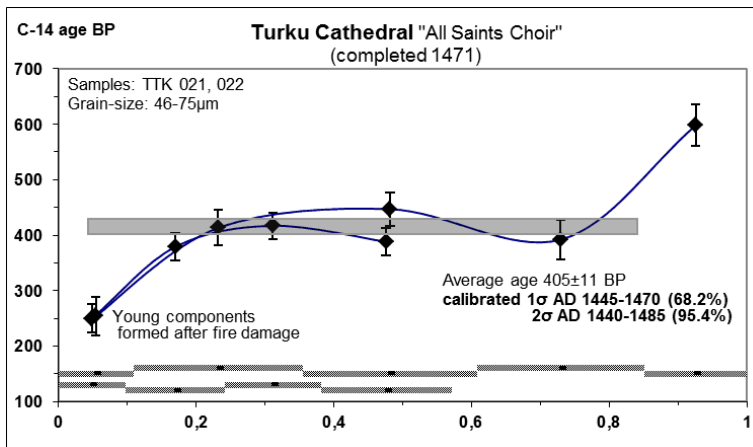


Fig. 4. C-14 profiles from fire damaged samples from the All Saints Choir in the eastern end of the cathedral. The grey bars along the X-axis show the relative size of the dated CO<sub>2</sub> fractions. The horizontal part of the profiles representing more than 70% of sample TTK 022 (the grey band) yield the expected archaeological age.

The All Saints Choir to the right in Fig. 2. was added to the Cathedral during the episcopate of Conrad Bitz (1460-1489). The construction started in 1466 and according to written sources a master mason named Henrik achieved his payment when the vaulting was finished in 1471 (The Black Book, op. cit.). The choir was damaged in the great fires of 1681 and 1827. We sampled this unit for reference to see what kind of age profiles the fire damaged samples would yield. Fig. 4 shows two C-14 profiles: TTK 022 representing complete dissolution of the sample and TTK 021 representing dissolution extending to 57% of the available carbon

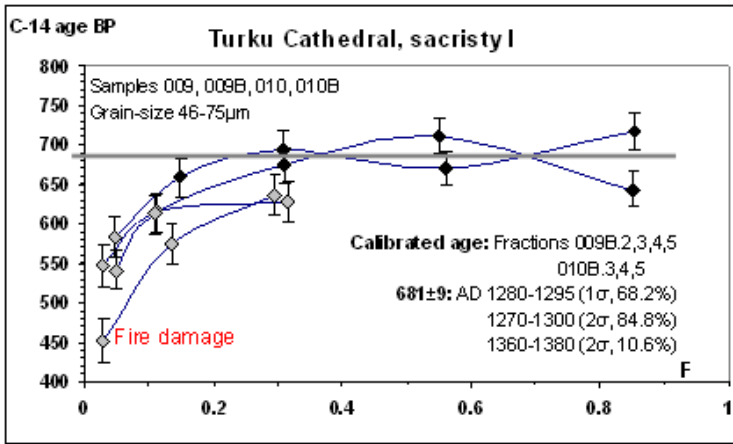


Fig. 5. C-14 profiles from the structurally oldest part of the cathedral, the first sacristy. The calibrated age was calculated from the average age of the CO<sub>2</sub> fractions denoted with black dots.

( $F=0.57$ ). The profiles are similar to the fire damaged profiles reported from the church of Sund (Ringbom *et al.* 2005). They start with ages that are too young for the choir, but may register the age of the fire in 1681 (if the graph would be extrapolated to cross the Y-axis). The central parts of the profile (TTK 022) have three CO<sub>2</sub> fractions with similar ages and together they comprise 74.2% of the carbon in the sample. The final fraction is clearly older because it has been produced by letting the sample react with the acid overnight and thus includes any possible slowly dissolving contaminant. Profile TTK-21 is similar, however, incomplete. The average weighted mean age of the mid-fractions,  $405\pm 11$ BP corresponds to the known archaeological age (see Fig. 4 for calibrated values). These results encouraged us to proceed analyzing the other fire damaged samples from the old parts of the church.

The oldest part of the church structurally is sacristy I. According to Kartano (1947-1948) Magnus I was elected bishop there in 1291, but the sacristy may have suffered severe damage in 1318 when the Novgorodians raided the church. After the destruction the church deteriorated further until restoration started in 1329 when three farmers donated a limestone hill for the construction works at the “church of Blessed Saint Mary and Saint Henrik in Åbo” (*The Black Book: “conferimus ecclesie beate Marie et sancti Henrici in Abo pro fabrica montem cementi” (Registr. eccl. Aboens. Sv. Dipl. IV n:o 2721. Svartboken n:o 49. Svartboken: Fol. 134 v.)*).

We have analyzed three samples (TTK 009, TTK 010, TTK 011) from the sacristy I unit; the results are presented in Fig. 5. Samples TTK 009 and TTK 010 were first analyzed as short

SAMPLE	CO <sub>2</sub> fraction (%)	Reaction time (s)	<sup>14</sup> C age BP years	+/- years	δ <sup>13</sup> C ‰	Labnumber*
<b>Acid. Grain-size fraction &amp; Total carbon yield</b>						
<b>TTK 005 Pentagonal choir</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, 10.5%	0-5,3	10	<b>552</b>	38	-21,7	AAR-11016-1.1
	5,4-18	40	<b>643</b>	34	-9,8	AAR-11016-1.2
	19-51	408	<b>1048</b>	34	-10,8	AAR-11016-1.3
	52-84	336	<b>835</b>	35	-11,6	AAR-11016-1.4
	85-100	overnight	<b>2241</b>	39	-10,1	AAR-11016-1.5
<b>TTK 006 Pentagonal choir</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, 10.3%	0-5.1	17	<b>587</b>	35	-22,4	AAR-11094-1
	5,2-19	80	<b>720</b>	35	-8,9	AAR-11094-2
	20-45	240	<b>1494</b>	33	-10,8	AAR-11094-3
<b>TTK 009 Sacristy I</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, 3.5%	0-6	n.r	<b>546</b>	26	-24,4	OxA-X-2209-7
	7-23	n.r	<b>614</b>	25	-11,3	OxA-X-2210-47
	24-42	n.r	<b>628</b>	25	-9,1	OxA-X-2210-48
<b>TTK 009B Sacristy I</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, n.r.	0-9,4	n.r.	<b>583</b>	25	-22,5	OxA-X-2226-30
	9,5-20	n.r.	<b>659</b>	25	-10,2	OxA-X-2226-31
	21-42	n.r.	<b>693</b>	23	-9,1	OxA-X-2227-50
	43-71	n.r.	<b>670</b>	22	-10,4	OxA-X-2227-51
	72-100	n.r.	<b>717</b>	24	-11,0	OxA-X-2227-51
<b>TTK 009B Sacristy I</b>						
HCl (0.7%, per volume), 101-150µm, 6.6%	0-4.5	n.r.	<b>1623</b>	35	-14,9	AA87306
	4,6-10	n.r.	<b>863</b>	35	-9,3	AA87307
	40864,0	n.r.	<b>896</b>	35	-10,0	AA87308
	18-26	n.r.	<b>776</b>	35	-10,6	AA87309
	26-41	n.r.	<b>661</b>	35	-10,8	AA87310
<b>TTK 010 Sacristy I</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, 3.6%	0-5.9	n.r.	<b>451</b>	35	-26,9	OxA-X-2209-8
	6-21	n.r.	<b>574</b>	35	-14,6	OxA-X-2210-49
	22-38	n.r.	<b>636</b>	35	-11,8	OxA-X-2210-50
<b>TTK 010B Sacristy I</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, n.r.	0-9,8	n.r.	<b>541</b>	25	-22,6	OxA-X-2226-32
	9,9-22	n.r.	<b>612</b>	24	-9,7	OxA-X-2226-33
	23-40	n.r.	<b>674</b>	22	-7,7	OxA-X-2227-53
	41-70	n.r.	<b>711</b>	22	-9,1	OxA-X-2227-54
	71-100	n.r.	<b>643</b>	22	-9,3	OxA-X-2227-55
<b>TTK 011 Sacristy I</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, 9.9%	0-6.8	7	<b>573</b>	35	-23,0	AAR-11017-1
	6,9-24	46	<b>599</b>	35	-9,0	AAR-11017-2
	25-57	330	<b>612</b>	38	-7,4	AAR-11017-3
	58-90	432	<b>615</b>	55	-8,6	AAR-11017-4
	91-100	overnight	<b>793</b>	42	-9,7	AAR-11017-5
<b>TTK 017 Sacristy II</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, 9.9%	0-10	n.r.	<b>551</b>	27	-26,0	OxA-X-2250-50
	11-30	n.r.	<b>620</b>	23	-9,4	OxA-X-2250-43
	31-50	n.r.	<b>875</b>	23	-8,8	OxA-X-2250-44
	51-81	n.r.	<b>748</b>	24	-9,9	OxA-X-2250-45
	82-100	n.r.	<b>842</b>	24	-10,2	OxA-X-2250-46
<b>TTK 019 "Hemming choir"</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 76-150µm, 4.5%	0-11	n.r.	<b>267</b>	23	-12,9	OxA-X-2256-11
	40907,0	n.r.	<b>350</b>	23	-6,4	OxA-X-2257-9
	31-49	n.r.	<b>393</b>	23	-8,6	OxA-X-2257-10
	50-78	n.r.	<b>436</b>	23	-8,8	OxA-X-2257-11
	79-100	n.r.	<b>604</b>	23	-8,7	OxA-X-2257-12
<b>TTK 020 "Hemming choir"</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, n.r.	0-9.8	n.r.	<b>196</b>	24	-19,2	OxA-X-2256-12
	9,9-29	n.r.	<b>374</b>	24	-6,8	OxA-X-2257-13
	30-48	n.r.	<b>544</b>	23	-9,3	OxA-X-2257-14
	49-77	n.r.	<b>445</b>	23	-10,2	OxA-X-2257-15
	78-100	n.r.	<b>571</b>	23	-10,2	OxA-X-2257-16
<b>TTK 021 All Saints choir</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 76-150µm, 6.1%	0-6	n.r.	<b>250</b>	25	-25,7	OxA-X-2210-51
	7-16	n.r.	<b>379</b>	25	-10,0	OxA-X-2210-52
	17-36	n.r.	<b>417</b>	24	-10,0	OxA-X-2210-53
	37-57	n.r.	<b>388</b>	25	-12,5	OxA-X-2210-54
<b>TTK 022 All Saints choir</b>						
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, 7.6%	0-11	18	<b>254</b>	35	-24,4	AAR-11018-1
	13485,0	80	<b>413</b>	32	-6,9	AAR-11018-2
	37-61	330	<b>447</b>	30	-9,0	AAR-11018-3
	62-85	444	<b>392</b>	36	-9,6	AAR-11018-4
	86-100	overnight	<b>598</b>	37	-11,0	AAR-11018-5

TTK 023 Pentagonal choir							
H <sub>3</sub> PO <sub>4</sub> (85%), 46-75µm, 10.2%	0-5.3	n.r.	<b>559</b>	26	-22,8	AAR-11498-1	
	5.4-17	n.r.	<b>704</b>	41	-8,9	AAR-11498-2	
TTK 023 Pentagonal choir							
HCl (0.7%, per volume), 46-75µm, 6.3%	0-7.7		<b>847</b>	37	-16,0	AA83726	
	7.8-32		<b>1257</b>	39	-8,8	AA83727	
	33-78		<b>1421</b>	39	-9,7	AA83728	
	79-95		<b>1854</b>	38	-9,6	AA83729	
TTK 027 Chapel of the Holy Corps							
HCl (0.7%, per volume), 46-75µm, n.r	0-20		<b>200</b>	34	-17,0	AA80347	
	21-41		<b>224</b>	34	-15,2	AA80348	
	42-60		<b>345</b>	35	-14,8	AA80349	
	61-80		<b>330</b>	35	-14,1	AA80350	
	81-100		<b>406</b>	35	-14,1	AA80351	
TTK 028 Chapel of the Holy Corps							
HCl (0.7%, per volume), 46-75µm, n.r	0-20		<b>710</b>	47	-15,8	AA80352	
	21-40		<b>562</b>	37	-15,5	AA80353	
	41-60		<b>569</b>	38	-15,2	AA80354	
	61-80		<b>575</b>	35	-14,8	AA80355	
	81-100		<b>659</b>	37	-13,8	AA80356	
TTK 029 Chapel of the Holy Corps							
HCl (0.7%, per volume), 46-75µm, n.r	0-20		<b>255</b>	35	-13,0	AA80357	
	21-40		<b>281</b>	34	-11,3	AA80358	
	41-60		<b>264</b>	34	-11,5	AA80359	
	61-80		<b>312</b>	34	-11,2	AA80360	
	81-100		<b>494</b>	35	-10,8	AA80361	

\* AAR=Aarhus, AA=Arizona, OxA- X=Oxford

### Table I

A complete list of samples from Turku Cathedral.

profiles (Tab. I), extending to only 30% dissolution. The first fractions gave divergent ages and there were so many young contaminants that the short profiles did not define a conclusive age, although the third fractions seem to converge. We decided to re-analyze the samples in complete profiles (samples denoted TTK 009B and TTK 010B in Tab. I) to see if the profiles really converge or just cross each other.

We got conclusive results: 78% of the carbon in sample TTK 009B gives the same age as 91% of the carbon in sample TTK 010B. A combined calibration for the CO<sub>2</sub> fractions denoted as filled dots in Fig. 5. presents the age 681±9 BP and the calibrated age 1280-1295 (68.2% probability) or 1270-1300 (84.8%) and 1360-1380 (10.6%) at 95,4% probability. This result is in excellent agreement with the historical context according to which Magnus I was elected bishop in the sacristy in 1291. The third sample TTK 011 (Fig. 6) gives a significantly younger age of 596 ±19 BP and there is no obvious fire damage effect because the first CO<sub>2</sub> fraction is not significantly younger than the second ditto. Our interpretation is that this mortar is from a repair after the destruction by the Novgorodians in 1318.

The diverging ages of the first CO<sub>2</sub> fractions of the different samples indicate secondary growth of calcite after fire damages. Also these secondary minerals are old and reflect the age of fires in the early history of the cathedral. This is in accordance with historical records that the first sacristy was the only unit not to be destroyed in the great fire of 1827 (Gardberg *et al.* 2000, p.218).

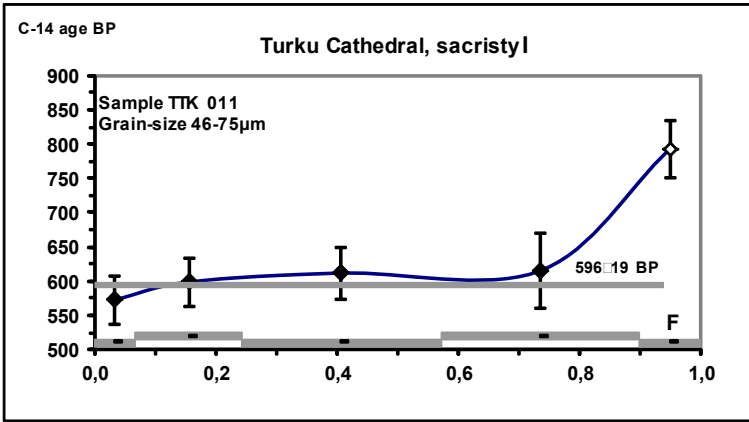


Fig. 6. C-14 profile of sample TTK 011. The sizes of the CO<sub>2</sub> fractions are denoted with grey bars along the X-axis. It is probably from a repair after the destruction in 1318. After calibration there is a bimodal distribution with the age spread over the 14th century: 1310-1360 (55.7%) and 1385-1400 (12.5%) calAD at 68,2% probability and 1300-1370 (73.1%) and 1380-1410 calAD (22.3%) at 95,4% probability.

So far we have analyzed only one sample, TTK 017 from the second sacristy. Structurally this unit is coeval with or slightly older than the pentagonal choir and our C-14 results are similar to those of the choir: 565±18 BP for the choir and 551±27BP for the second sacristy. The results for the second sacristy (Fig. 7) are only preliminary and are based on only one sample. However, the C-14 profile looks like a normal profile (with marble contamination), where the C-14 age BP can be read from the first CO<sub>2</sub> fraction, but the isotopic composition of the carbon ( $\delta^{13}\text{C} = -26\text{‰}$  vs PDB; Tab. I) is very light and indicates that there probably is a fire damage component in the sample. Since it does not have a significant effect on the C-14 age it may be that the fire has occurred soon after the construction.

Some of our dating attempts were made at a stage when we were testing different acid hydrolysis techniques. We tried to characterize the carbonate contaminants by exposing them to different acids and observing their reactions. The heavily contaminated samples from the Turku Cathedral were useful in these experiments. The first sample we tested was TTK 023 from the pentagonal choir with no signs of fire damage. We used 0.7% (by volume; 2ml 37% HCl in 100ml water) hydrochloric acid, which we injected on the sample powder in consecutive batches. Each batch of the acid was allowed to react completely to produce one fraction of CO<sub>2</sub>. We had earlier got some encouraging results using this method on samples from Sweden (Ranta and Lindroos 2009) and from Rome (Hodgins *et al.* 2011). It seemed that the diluted hydrochloric acid would be more selective and leave some of the contaminants un-dissolved. This time we got different results: the diluted acid would dissolve the contaminants first and the first two CO<sub>2</sub> fractions yielded ages that were several hundred years older than when 85% phosphoric acid was used

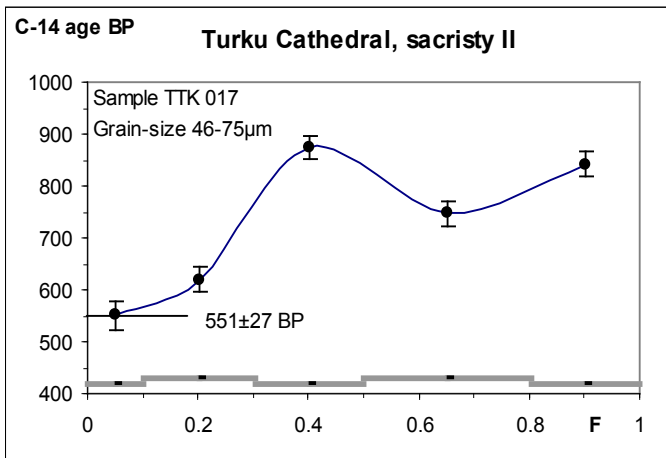


Fig. 7. C-14 profile for sacristy II. The BP age 551±27 is similar to that of the pentagonal choir (565±18). The calibrated result is presented graphically in Fig. 11.

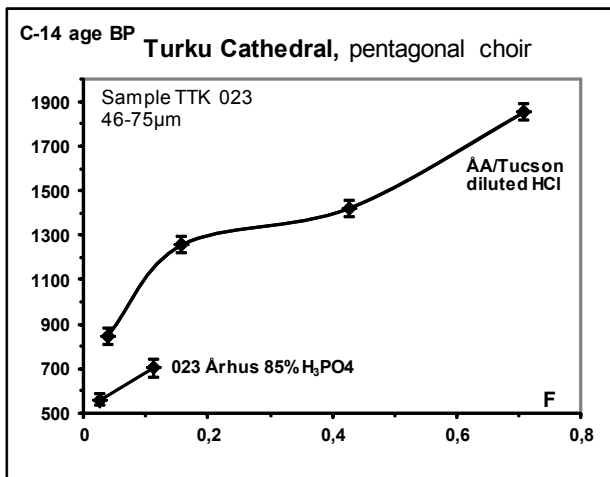


Fig. 8. C-14 profile of sample TTK 023 produced with diluted HCl compared with the two CO<sub>2</sub> fractions produced using 85% phosphoric acid. The latter also occur in Fig. 3.

(Fig. 8). Unfortunately this sample was so contaminated that the following CO<sub>2</sub> fractions also yielded very old ages.

We then tried a less contaminated sample to see if the contaminants would be exhausted before the binder carbonate and if later CO<sub>2</sub> fractions would then give uncontaminated binder ages. The aim was to see if it was possible to eliminate both the young carbonates formed after fires and the old carbonates from unburned marble and have uncontaminated CO<sub>2</sub> for dating in the later fractions. We decided to try the new method on sample TTK 009B from the fire damaged oldest part of the cathedral, Sacristy I (Fig. 9). Originally we also wanted to test whether dry sieved samples would have less (young) secondary carbonates so we used the dry-sieved 101-150µm grain-size window instead of the finer, wet-sieved grain-size fractions used previously.

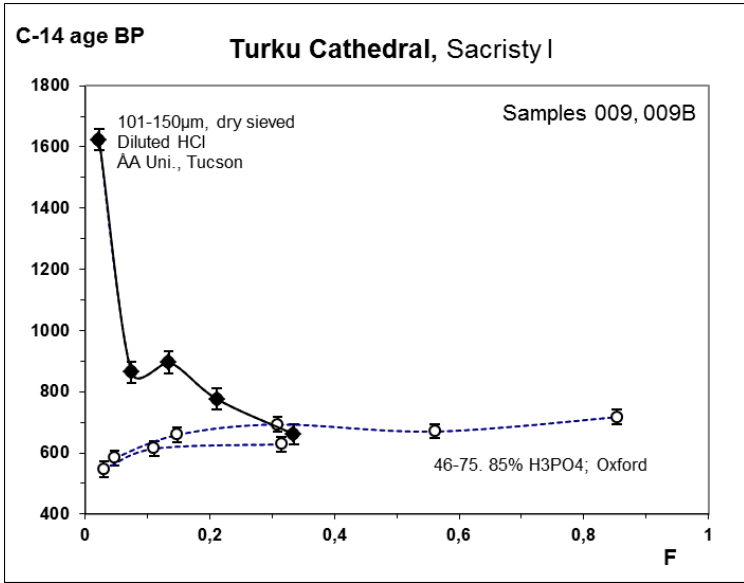


Fig. 9. C-14 profiles for sample TTK 009 produced using both 85% phosphoric acid and 0.7% hydrochloric acid (HCl). The profile were HCl was used shows two age maxima indicating that the major part of two different contaminants had been dissolved before 30% dissolution ( $=F<0.3$ ) was completed. The empty dots are results from 85%  $H_3PO_4$  dissolution (Tab 1. and Fig. 5). The fifth filled dot gave a similar age as the profiles from  $H_3PO_4$  dissolution. Note that this time we used the dry-sieved grain-size 101-150 $\mu$ m

Fig. 9 shows that at least two kinds of contaminants can be removed before 30% of the carbonate material is dissolved when diluted HCl is used in the hydrolysis. This is indicated by the two age maxima; for the first and third  $CO_2$  fraction. Either there are two different old contaminants or there is one old contaminant and a short outburst of  $CO_2$  from recrystallizations at about  $F=0.1$  (10% dissolution or at the second fraction) creating a local minimum. The fifth  $CO_2$  fraction gave a similar age to the  $CO_2$  fractions produced by  $H_3PO_4$  hydrolysis and used for dating the sacristy. In this case it really seemed that 30% dissolution would have removed the contaminants. Unfortunately we could not continue the profile for economic reasons.

The samples from the Chapel of the Holy Corps (TTK 028) were only dated using diluted HCl. We dated three samples but only one of them turned out to be from the original structure. Two of them were from later repairs that were both heavily contaminated and fire damaged and did not give well-defined ages (Tab. 1). The age of the chapel is fairly well known, having been built during the time of bishop Magnus II Tavast (1412-1450) as a burial chapel for himself and his family. He donated a cast-iron fence to the chapel with the year 1425 inscribed. Our mortar sample was dated as a complete profile in five  $CO_2$  fractions (Fig. 10). The

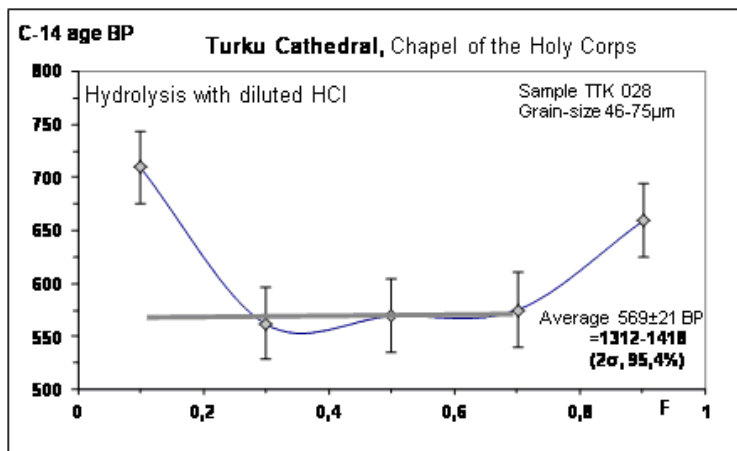


Fig.10. C-14 profile from the Chapel of the Holy Corps produced using 0.7% (by volume) HCl. The C-14 age given is the weighted average of the three mid-fractions representing 60% of the carbon in the sample.

first CO<sub>2</sub> fraction is clearly contaminated by an old contaminant. It comprises the most easily soluble 20% of the sample. This is similar to the profile produced with diluted HCl in Fig 9, but the contamination is less severe. Thereafter comes three CO<sub>2</sub> fractions with very similar C-14 ages, representing 60% of the sample and giving an older age than the iron fence. The last CO<sub>2</sub> fraction (81-100%) is slightly contaminated by a slowly dissolving contaminant.

## DISCUSSION AND CONCLUSIONS

In Fig.11 we have compiled the average ages of the mortar samples from the different building units into a mutual plot together with some well-established chronological data. The mortars can be arranged chronologically in the same order as the different building units follow each other structurally in Fig. 2 and there is no discrepancy with the chronological data from the written sources. The profile in Fig. 10 gave a slightly older age than expected, but in this case we were testing a new type of hydrolysis that seem to dissolve contaminants more readily than earlier used phosphoric acid hydrolysis. This new variant of hydrolysis may be useful if the samples contain both unburned marble and secondary carbonates formed after fire damage, because it seems that the diluted acid dissolves these contaminants more rapidly than the bulk of the binder carbonate that we want to date (Figs 9-10 and sample TTK 026 and 027 in Tab I).

The resolution of the C-14 method when applied to the 14<sup>th</sup> century is unfortunately too low to see any difference between for example the pentagonal choir and the Chapel of the Holy Corps.

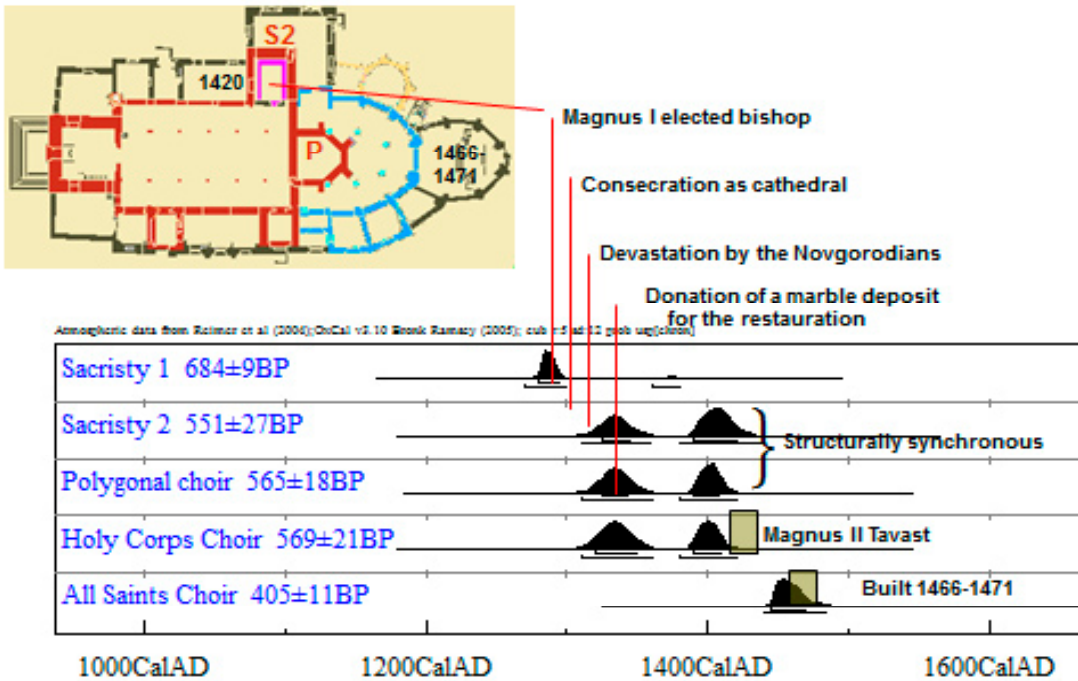


Fig. 11. Multi-plot presenting the average ages of the samples from the different building units together with some archaeological data from written sources. The bimodal age distributions for Sacristy II, the pentagonal choir and the Chapel of the Holy Corps are a general C-14 method-related problem.

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## REFERENCES

Boström R.: "The History of the Stone and Mineral Industry in Finland". *Geological Survey of Finland, Bulletin 336*, ed. H. Tanskanen, (1986) 273-298

Bronck-Ramsey C.: Development of the radiocarbon calibration program. *Radiocarbon* 43, 2A (2001) 355-363.

Gardberg C. J., Heininen S. and Welin P. O.:  
Nationalhelgedomen Åbo Domkyrka 1300-2000. Tammi Förlag,  
Helsingfors, (2000) 384p

Heinemeier J., Ringbom Å, Lindroos A. and Sveinbjörnsdóttir Á. E.: "Successful AMS  $^{14}\text{C}$  dating of non-hydraulic lime mortars from the medieval churches of the Åland Islands, Finland". *Radiocarbon*, Vol. 52, No. 1 (2010): 171-204.

Hodgins G.W.L., Lindroos A., Ringbom Å., Heinemeier J, and Brock F.: "14C dating of Roman mortars – preliminary tests using diluted hydrochloric acid injected in batches", in Proceedings from Building Roma Aeterna, conference in Rome March 23-25 2008, in *Commentationes Humanarum Litterarum, Societas Scientiarum Fennica*, eds. Åsa Ringbom and Robert Hohlfelder, (2011) in print.

Kartano, E.: "Lisiä Turun tuomiokirkon syntyhistoriaan". Suomen Museo 1947-1948.

Langley, M.M., Maloney S. J., Ringbom Å, Heinemeier J. and Lindroos A.: "A Comparison of Dating Techniques at Torre de Palma, Portugal: Mortars and Ceramics", in Proceedings from Building Roma Aeterna, conference in Rome March 23-25 2008, in *Commentationes Humanarum Litterarum, Societas Scientiarum Fennica*, eds. Åsa Ringbom and Robert Hohlfelder (2011), in print.

Lindroos A.: *Carbonate Phases in Historical Lime Mortars and Pozzolana Concrete: Implications for  $^{14}\text{C}$  Dating* (diss.). Åbo: Åbo Akademi University (2005) 92p.

Lindroos A., Heinemeier J., Ringbom Å., Braskén M. and Sveinbjörnsdóttir Á.E.: "Mortar dating using AMS  $^{14}\text{C}$  and sequential dissolution: examples from medieval, non-hydraulic lime mortars from the Åland Islands, SW Finland". *Radiocarbon*, Vol. 49, No. 1 (2007): 47-67.

Ranta, H. and Lindroos, A.: "Murbruksdatering, Läckö slott, Linköping", in *Byggnadsarkeologisk undersökning av Läckö slott*, eds Sofia Lindberg and Hanna Menander (2008): 38-40.

Ringbom Å., Bartholin T., Klein P., Lindroos A., Sveinbjörnsdóttir Á.E., and Heinemeier J., "Naturvetenskaplig datering", in Ringbom & Remmer, *Ålands kyrkor, Volym III, Sund och Vårdö*, Mariehamn 2005, 100-110.