

Measuring varve thickness using μ CT: a comparison with thin section

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Abstract. X-ray micro-computed tomography (μ CT) scans were performed on four varved sediment cores collected in Grand Lake (Labrador) and previously studied with thin sections. These scans allowed us to investigate the possibility of using μ CT as a substitute for thin sections to carry out counts and thickness measurements of varved sediments. Comparing varve counts of these two methods, μ CT counts are slightly higher than the ones made with thin sections. The difference in counts suggests that the petrographic study and a SEM analysis of a thin section remain necessary for determining the varve character of the laminae. Yet, μ CT allows measurements in multiple directions, improving the robustness of the counts and avoiding the manufacturing of continuous thin sections along sediment sequence. As for the thickness measurement, the μ CT analyses were made in two perpendicular directions. Not surprisingly, measurements made on the same cutting plane as the thin section are quite similar to the ones made on the latter. However, there are significant differences with measurements made on the perpendicular plane. This highlights the need to perform varve thickness measurements in at least two perpendicular directions for better estimates of varved sediment thicknesses. In addition, the study illustrates that μ CT is an effective way to select the least deformed zones with parallel varves to carry out the best possible thickness measurements.

1 Introduction

Examinations of sediment cores from lakes and oceans have provided insight into climate change and natural climate variation in different parts of the world through reliable paleoclimate reconstructions. These reconstructions required thorough examinations of sedimentary facies' structure and texture. Varves, are among the most influential sedimentary facies for paleoclimatic reconstructions. The term varve refers to a set of layers formed annually (Kemp, 1996; Hughen, 2013; De Geer, 1912). These annual sedimentation facies form cyclically in marine or lacustrine environments, with origins ranging from detrital, endogenous, biogenic, or a combination of these processes (Zolitschka et al., 2015; Schimmelmenn et al., 2016).

Detrital varves are the object of study in this project. They often show a regular alternation of light and dark beds of different grain sizes, with millimetric thicknesses (Ojala et al., 2012; Zolitschka et al., 2015). The advantage of studying varves is that they are high-resolution sedimentary sequences providing information on past abrupt environmental changes through variations in the structure, composition, and thickness of their distinct seasonal laminae (Ojala et al., 2012). The variations in structures and the thickness of their seasonal laminae can be the result of several independent factors, such as melting of snow, landslides, etc. Yet, with a good understanding of the sedimentary components of varves and the mechanisms controlling their formation, they can be good paleoclimate indicators (Gagnon-Poiré et al., 2021; Amann et al., 2017; Palmer et al., 2019; Hardy et al., 1996).

In addition, varved sediments contain their own chronology, which can be converted into calendar years with exceptionally high temporal resolution. Ultimately, they offer the possibility of calculating sediment flux rates (Ojala et al., 2012; Zolitschka et al., 2015; Emmanouilidis et al., 2020).

To analyse these varved sediments, the thin-section method is the most commonly used. To do this, the sediment core is continuously sampled by subsampling overlapping sediment blocks. These subsamples are then freeze-dried and impregnated with epoxy resin and cut into blocks to make thin sections (Normandeau et al., 2019; Francus and Asikainen, 2001). Counting and measuring varves is then done by image analysis of thin sections at the petrographic microscope and/or using SEM images in backscattered mode to improve the ability to define varve boundaries (Francus et al., 2008; Lapointe et al., 2019; Gagnon-Poiré et al., 2021; Soreghan and Francus, 2004). However, the sampling method, as well as the multiple steps needed for the preparation of thin sections, can induce sediment perturbations. This is because, for fine sediments, extracting the subsample can be difficult due to their stickiness. It therefore requires a great deal of meticulousness to separate them from the underlying sediment core without tampering them and to avoid any disturbances during the various stages of manufacture of the thin section (Normandeau et al., 2019).

Finally, there is the question of the representativeness of the sample analyzed: it has limitations associated with its 2D view (Bendle et al., 2015), which make it difficult to estimate the true thickness of the varves. However, X-ray micro-computed tomography (μ CT) allows the observation of objects with a resolution of a few micrometers and has the advantage of being a non-destructive technique. It allows viewing a volume instead of a plane, facilitating the study of the internal structures and orientation of a wide variety of geological objects (Cnudde and Boone, 2013; Voltolini et al., 2011; Bendle et al., 2015; Lisson et al., 2023; Cornard et al., 2023; Fabbri et al., 2024). This article aims to investigate the possibility of using (μ CT) as an analytical tool to measure varves in the frame of paleoclimatic studies. To do this, we tested the μ CT method on a sequence whose varves are easy to recognize, thick, not very disturbed and which have already been studied using the thin sections method. The objectives of this paper are to: (1) test if varve counts can be performed using μ CT, (2) test if varve thickness can be retrieved from μ CT images, (3) compare the thickness measurements obtained with those retrieved using the thin section method, and (4) evaluate the added value of μ CT as an analysis tool for varved sediments.

2.1 Sample selection

The study area is part of the Grenville Structural Province and is dominated by Precambrian granite, gneiss and acidic intrusive rocks (Gagnon-Poiré et al., 2021; Trottier et al., 2020).

70 The analyzed sediments come from Grand Lake, a 60 km long elongated lake, with a depth reaching 245 m (Trottier et al., 2020; Gagnon-Poiré et al., 2021). This fjord lake is located in a valley connected to the Lake Melville graben in the central Labrador region of Canada at 53°41'25.38" N, 60°32'6.53" W, approximately 15 m above sea level (Fig. 1) (Trottier et al., 2020; Gagnon-Poiré et al., 2021).

Grand Lake has two principal tributaries, the Naskaupi and Beaver Rivers, that remobilize ancient deltaic systems and terraces composed of fluvio-marine, marine, fluvio-glacial, lacustrine, and modern deposits. The availability of sediments along its 75 tributaries, combined with its great depth and high seasonal flow, have favored the formation and preservation of fluvial clastic laminated sediments (Gagnon-Poiré et al., 2021). Thereby, it is an excellent lake for the preservation of recent records of stratified fluvial clastic sediments (Gagnon-Poiré et al., 2021; Zolitschka et al., 2015). Four undisturbed sediment sequences (Fig. A1) were extracted in front of the deltas using a Uwitec gravity corer and are listed in Table 1. After recovery, these cores were cut into two halves. The first one was used for making thin sections, and their subsequent analysis with a scanning 80 electron microscope was reported in Gagnon-Poiré et al. (2021). The second halves were analyzed in this paper using a μ CT scanner.

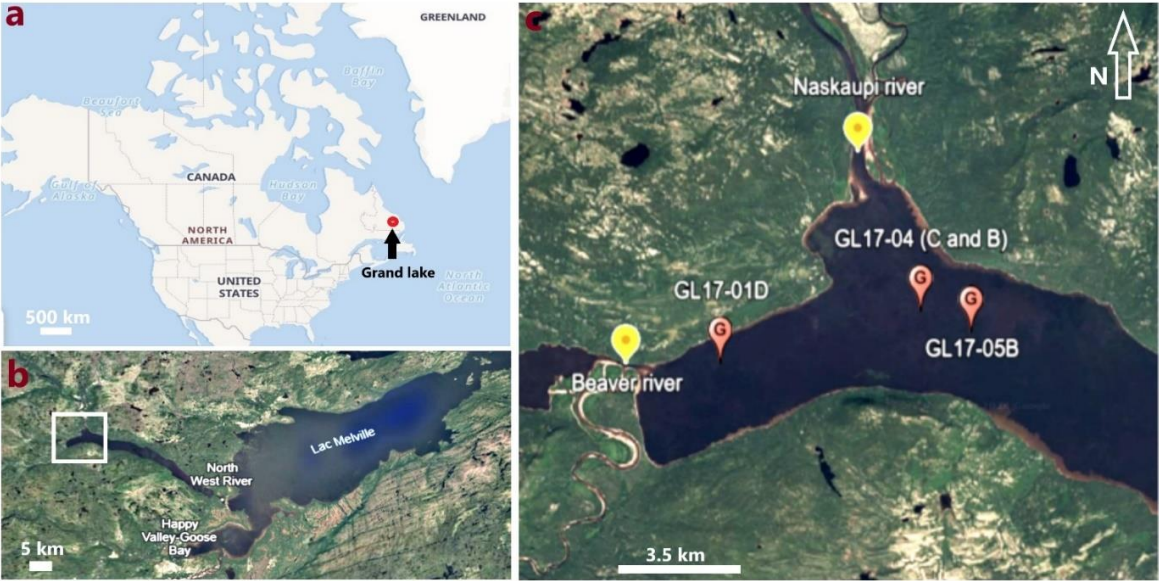


Figure 1: Study area. (a) Location of Grand Lake encircled in red on the map of Canada. (b) Location of the study area. (c) Study area with the location of the principal tributaries of Grand Lake (yellow pins) and the sediment cores 85 GL17-01D, GL17-04B, GL17-04C, and GL17-05B (© Google Earth 2023).

2.2 Measurement of varve thickness on thin sections

The making of thin sections was done in several steps (Fig. 2). First, the half sediment cores were subsampled using aluminum boxes, positioned with an overlap of approximately 1 cm to retrieve a continuous sequence along the sediment core (Francus & Asikainen, 2001).

90 The sediment was then frozen with liquid nitrogen to avoid the formation of large hexagonal ice crystals, which would deform the sediment. However, this step can cause cracks in the sediment block because freezing occurs too quickly (Normandeau et al., 2019). Next, the sediment was freeze-dried for 48 hours to sublime the ice without modifying the sediment structure (Normandeau et al., 2019).

The sediment was subsequently impregnated using a low viscosity Spurr epoxy resin and hardened by thermal curing for 48
95 hours. The final step consisted of cutting the impregnated block of sediments to manufacture thin sections (Lapointe et al., 2019). These thin sections were first digitized and analyzed under a petrographic microscope. Next, images in backscattered mode were acquired using the SEM (Zeiss Evo 50) at a voltage of 20 kV (Francus et al., 2008; Gagnon-Poiré et al., 2021; Lapointe et al., 2019) with a resolution of 1 $\mu\text{m}/\text{pixel}$ (Francus et al., 2002; Gagnon-Poiré et al., 2021). These 8-bits high resolution images made it possible to count varves, providing good contrast for features which frequently measure less than
100 0.5 mm and are difficult to measure otherwise (Francus, 1998; Lapointe et al., 2019). Varve thicknesses are manually acquired with a custom-made image analysis software (Francus and Nobert, 2007): varve boundaries are manually marked along a vertical line chosen by the user, and the software records varve thicknesses using vertical coordinates of each boundary. If sediment disturbances prevent reliable counts, additional vertical lines can be used for thickness measurements, but the software does not correct for the dip of the layers.

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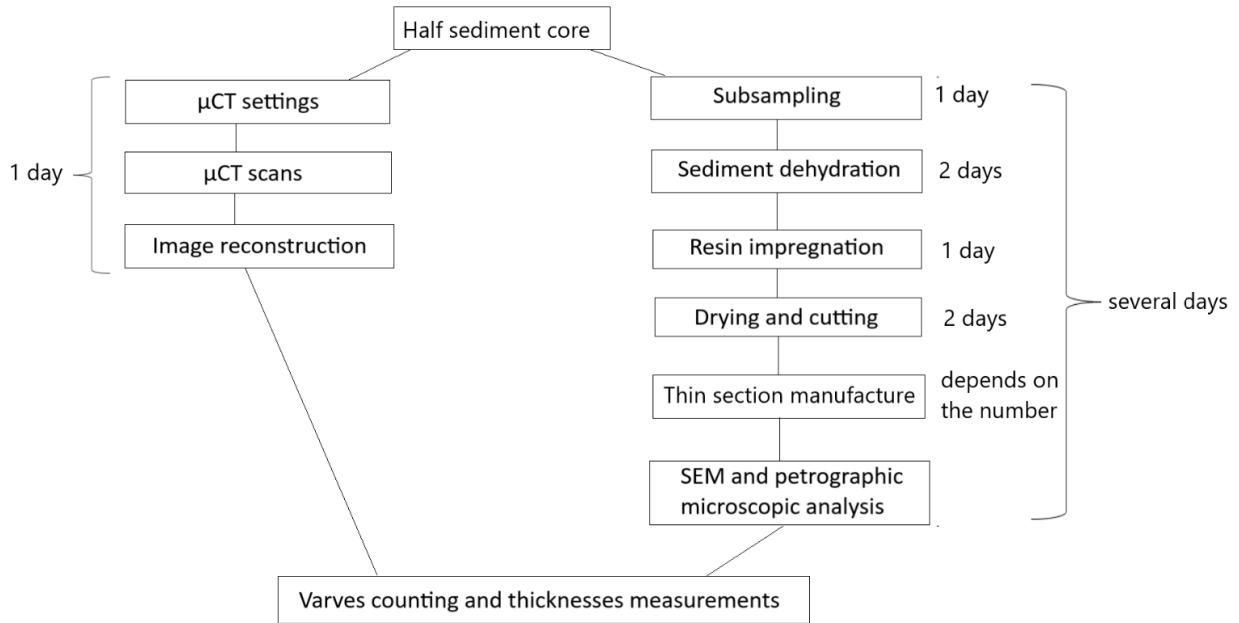
2.3 Experimental setting: μCT acquisition and reconstruction

The scans were made using a TESCAN CoreTOM μCT at INRS-ETE in Quebec City with the Aquila software (version 1.2.1) (Dewanckele et al., 2020). The TESCAN CoreTOM can image complete core samples up to 1.5 meters in length, with a spatial resolution of up to 3 micrometers. This makes it the ideal system for imaging fine laminations such as varves. The half-cores
110 were scanned in a vertical position with a custom-designed acrylic holder, maintaining the half sediment core in position during the scans using a foam half-core of the same size. Several instrumental acquisition parameters were tested to identify the best possible configuration to obtain high-resolution images with easily detectable varve boundaries. The best settings were a tube voltage of 140 kV, with an exposure time of 150 ms, an SDD (Source Detector Distance) of 500 mm, and an SOD (Source Object Distance) of 150 mm, resulting in a voxel size of 45 μm . Also, since the μCT uses a polychromatic beam and the
115 different components of the energy spectrum are not uniformly attenuated as they pass through an object, the lower energy component of the X-ray spectrum is more easily attenuated when it passes through a dense area. This creates brighter voxels during the reconstruction of the images that significantly reduce their quality. These brighter voxels are called beam hardening artifacts (Mcguire et al., 2023; Ahmed and Song, 2018). A 1.5 mm-thick aluminum filter was therefore used to reduce the

120 impact of this artifact on image quality (Rana et al., 2015; Ay et al., 2013). Smaller subsets of the scans, or Volumes of Interest (VOIs), were defined along the sediment cores where varves were clearly distinct. Individual VOIs (c.a. 30 mm wide, 450 mm thick, 40-60 mm long) (Fig. A2) overlapping each other over 10-20 mm were defined to ensure the continuity of the sedimentary sequence and to deal with the cone beam artifacts (see below). Image processing and analysis of these individual VOIs were also made easier for a regular laptop computer. The scanning time depended on the length of the sediment core and varied between 2h30 and 4h30. Subsequently, these scanned areas were reconstructed with *Panthera* (TESCAN proprietary software, version 1.5.0.21), with an average reconstruction time of 23 minutes per reconstructed VOI (Table 1).
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Table 1: Summary of the four sediment cores with the μ CT acquisition and reconstruction time.

Sediment core ID	Sediment core ID in Gagnon-Poiré et al. (2021)	Location		Length (cm)	μ CT Acquisition time	μ CT reconstruction time	μ CT total file size	VOIs number	Thin section total file size
		Latitude	Longitude						
GL17-04B	NAS-1A	53.749279	-60.820009	38	2h30	3h	45 GB	5	526 MB
GL17-01D	BEA-1	53.737257	-60.904032	98	3h30	5h	164 GB	13	975 MB
GL17-04C	NAS-1B	53.749279	-60.820009	102	3h30	5h30	122 GB	12	582 MB
GL17-05B	NAS-2	53.74438	-60.798786	131	4h30	6h30	135 GB	10	629 MB



130 Figure 2: Overview of the μ CT and thin section protocol.

The scans were performed using the STAMINA mode (Fig. 3). i.e., projections are acquired over a certain height of the sample while keeping the source and the detector steady as the sample rotates over 360°. Since the beam is conical in STAMINA scans, parts of the VOI outside the central plane of the beam are seen at a specific angle, causing blurred areas at the limit zones of the VOI when imaging horizontal features (Fig. 3) (Laeveren D. , 2020; Sheppard et al., 2014). Yet, the reconstructed VOIs presented blurred zones at their borders, hereby called the beam cone artifacts, which prevented clear distinction of the limits of the laminae (Laeveren D. , 2020; Sheppard et al., 2014). However, having overlapping VOIs allowed for easy distinction of laminae that were not visible on a single VOI. This allowed for numerical reconstruction of each sediment core.

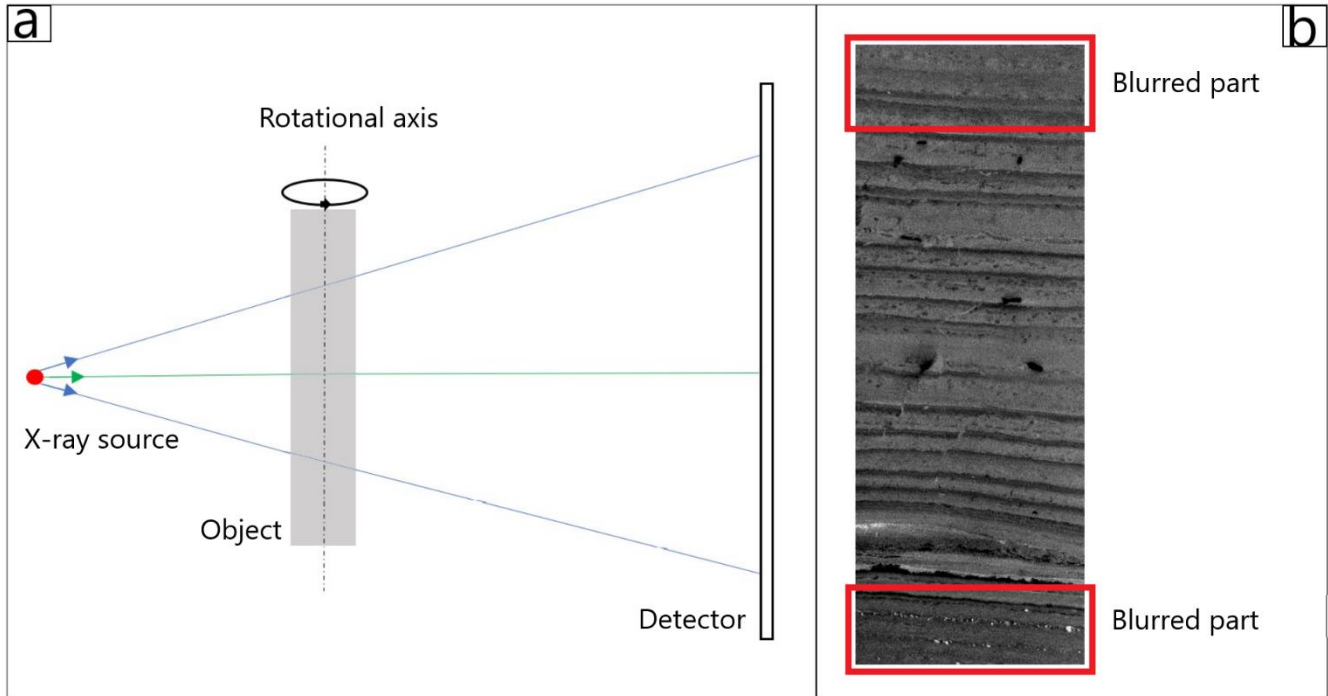


Figure 3: The formation of the beam cone artifact. (a) Presentation in STAMINA mode of the image acquisition mode. The conical X-rays from the source are absorbed by the object, and some of them are transmitted to the detector. The green x-ray follows the shortest distance to reach the detector, while the blue x-rays reach the detector at an angle that causes a mix of information in the vertical direction. (b) Example of a VOI reconstructed with the presence of beam cone artifact at its boundary parts.

2.4 Data analysis

The sediment core images were analyzed using the *Dragonfly* software (version 2022.1). Varve counting and thickness measurements were conducted in two (2) different, perpendicular directions, one of which aligns with the thin section cutting plane. Three (3) counts were performed in each direction on three (3) different cross sections (Fig. 4a) to ensure three (3) varve counts per direction and compute the average laminae thickness in each direction (Fig. 4a).

Afterwards, the μ CT counts were repeated twice in each of the two directions to verify the repeatability of the measurements. For thickness measurements, we observe that deformations tend to widen the varves in the centre of the sediment core. Thus, assuming that the varves are parallel at the time of deposition, we measure the smaller distance between two parallel varve limits to get as close as possible to the initial thickness of the varve before the deformations. The thicknesses were manually measured using the shortest line segment that separates two parallel varve borders perpendicular to them (Fig. 4b). The next step involved creating a thickness variation profile as a function of depth. Each varve was identified by the depth of its top and bottom boundaries, and its thickness calculated using the depth difference (Fig. A3). Thickness profiles were constructed by summing these values.

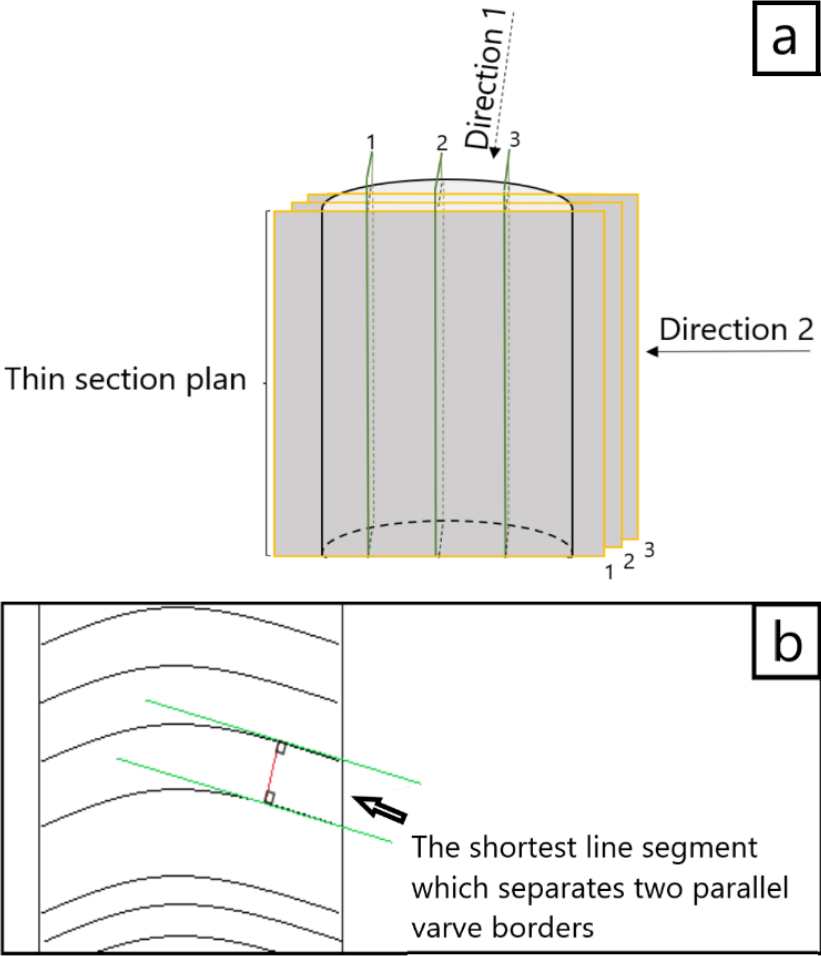


Figure 4: (a) A half sediment core, delimited by black outlines, indicates the directions in which thicknesses are measured. Measurements using μ CT are taken in two different directions, with three (3) measurements each. Green outlines indicate three cross sections selected in the 1st direction for counting and thickness measurements of varves, while orange outlines indicate three cross sections in the 2nd direction. The thin section plane corresponds to the first plane of measurements in direction 2. (b)

Presentation of the method used to measure varve thickness involves measuring the length of the shortest line segment between two parallel varve borders.

2.5 Comparing the different thickness measurements

Measurements using the μ CT were all conducted along the four sediment cores and were compared with those made on thin-sections by Gagnon-Poiré et al. (2021). However, comparisons with latter were only done at locations where thin sections were sampled and previously analyzed. Comparisons with thin sections were thus made throughout cores GL17-04B and GL17-01D, and on parts of sediment cores GL17-04C and GL17-05B. Thickness comparisons were made by locating the stratigraphic marker beds to ensure the same varves were compared. It was the average thicknesses of three counts made on μ CT direction 1, μ CT direction 2 and thin-sections that were compared with each other. This comparison was made using (1) linear regressions, (2) the percentage of average variation of thicknesses compared to the average value, and (3) the agreement concept (see below). The percentage of average variation of thicknesses compared to the average is obtained with the following

$$\text{formula: } \textit{Percentage of average variation of thicknesses} = \frac{\textit{mean standard deviation}}{\textit{mean thickness}} \times 100 \quad .$$

The study of the differences between thickness measurements on thin sections and those obtained from μ CT images was done using the agreement method of Bland and Altman ((Altman and Bland, 1983; Grenier et al., 2000; Ranganathan P, 2017). Agreement is a concept that refers to the idea that two or more independent measurements of the same quantity are equivalent (Ranganathan P, 2017). This method compares the observed difference between the values obtained for the same measurement by two different methods. To do so, it calculates the bias and the 95% confidence interval limits for each measurement and defines the agreement between the two series. The bias (mean of differences) and the limits of agreement represent the deviations of values from one method to another. The difference between the two measurement methods is presented as a function of the mean values obtained with each of the two methods (Fig. A4) (Altman, 1983; Grenier, 2000). For this paper, we define A_i as the thickness measured by method 1 for varve i and B_i as the thickness measured by method 2 for the same varve. *Difference between the two measurement methods for the varve $i = A_i - B_i$.*

$$\textit{Mean of the two measurement methods for the varve } i = \frac{A_i + B_i}{2}$$

$$\textit{Bias (or mean of differences)} = \frac{\sum_{i=1}^n (A_i - B_i)}{n}, \text{ where } n \text{ is the number of varves.}$$

Confidence interval at 95% = [Bias – 1.96 x STD; Bias + 1.96 x STD] , where STD is the standard deviation of the differences.

The agreement will be considered good between the two methods when two conditions are fulfilled: there are few points outside the confidence interval, and when the points outside the confidence interval are close to the limits of this interval. In this case study, we will define the agreement percentage as the percentage of points outside the confidence interval for each sediment core.

$$\textit{Percentage of agreement} = \frac{\textit{number of points outside the confidence interval}}{\textit{number total of points}} \times 100.$$

195 **3 Results**

3.1 Varve counting

Overall, the number of varves counted with the μ CT method is very similar to that of thin sections, except for the sediment core GL1704C, where the number of varves is slightly higher than that of the thin section (Table 2).

Table 2: summary of varve counting.

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Sediment cores	μ CT counts	Thin section counts
GL1704B	68-69	69
GL1701D	245-246	240-247
GL1704C	206-209	198
GL1705B	303-306	303

3.2 Thickness measurements

The mean varve thicknesses, measured using the μ CT and the thin sections in directions 1 and 2 are shown in Figures 5 to 8. The thickness differences are greater in direction 1 (GL17-04B - Fig. 5, GL17- 04C - Fig. 7, and GL17-05B - Fig. 8a-b) than in direction 2. As for GL17-01D (Fig. 6), the measurement differences are less significant and quite similar in both directions. Thickness measurements made on thin sections (Fig. 5-8) are overall less variable than those made on μ CT images.

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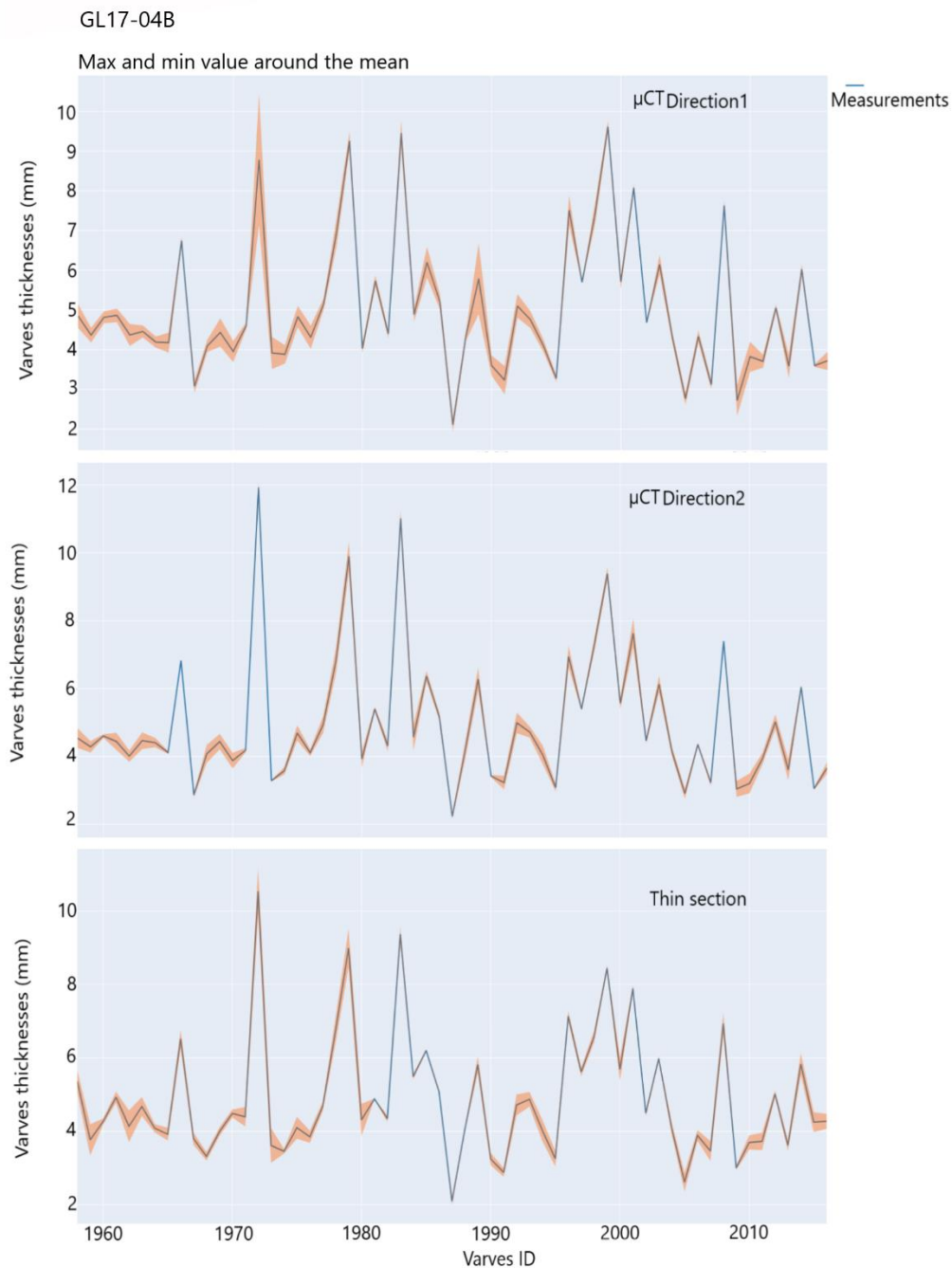


Figure 5: Mean varve thicknesses of the three measurements made in directions 1 (top panels) and 2 (middle panels) using the μ CT and on thin sections (lower panels) for cores GL17-04B. The maximum and the minimum values around the mean related to the measurements are shown in the orange shaded area, and the varve ID represent the identification of the varve over an interval.

GL17-01D

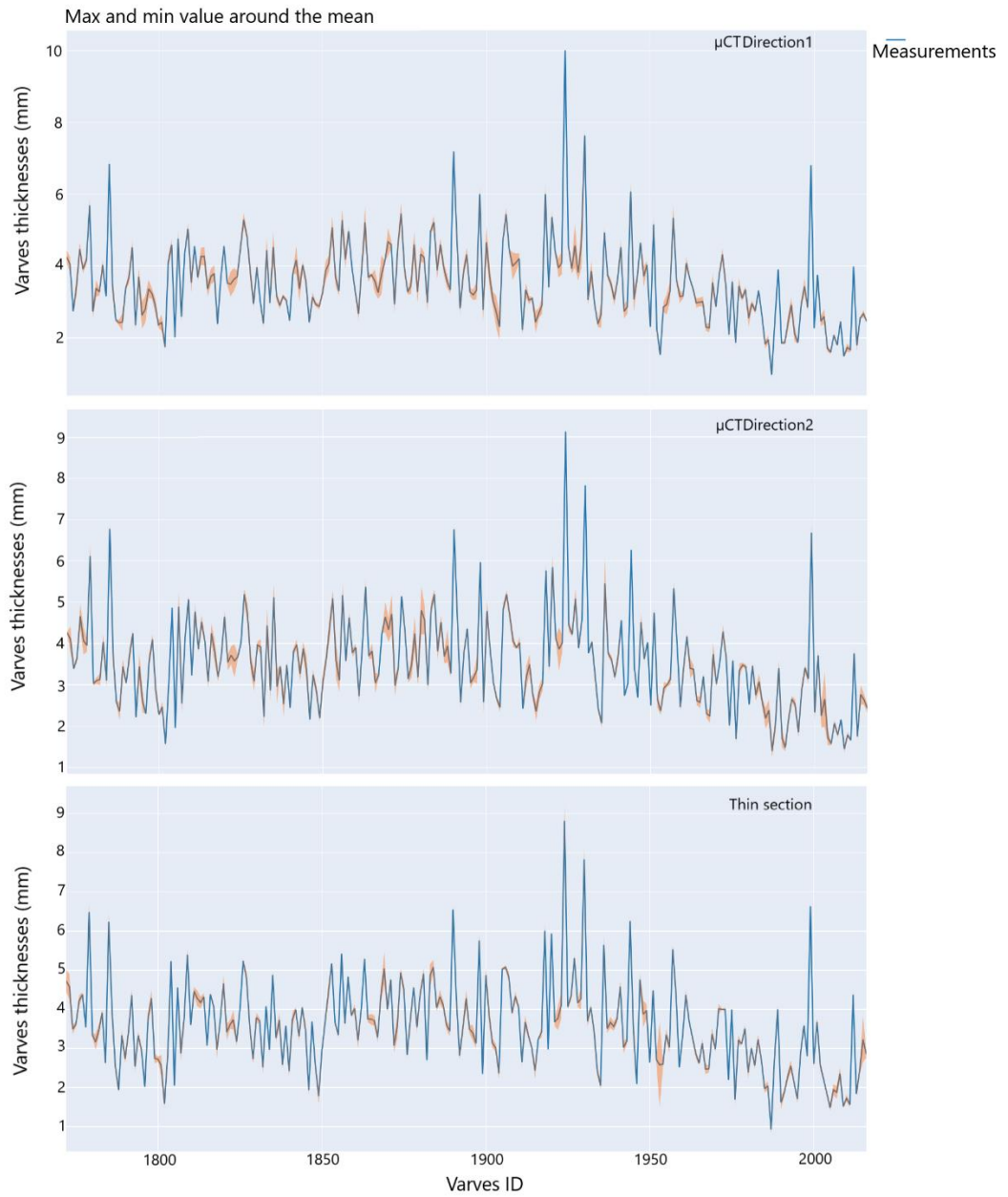


Figure 6: Mean varve thicknesses of the three measurements made in directions 1 (top panels) and 2 (middle panels) using the μ CT and on thin sections (lower panels) for cores GL17-01D. The maximum and minimum values around the mean relating to the measurements are shown in the orange shaded area, and the varve ID represents the identification of the varve over an interval.

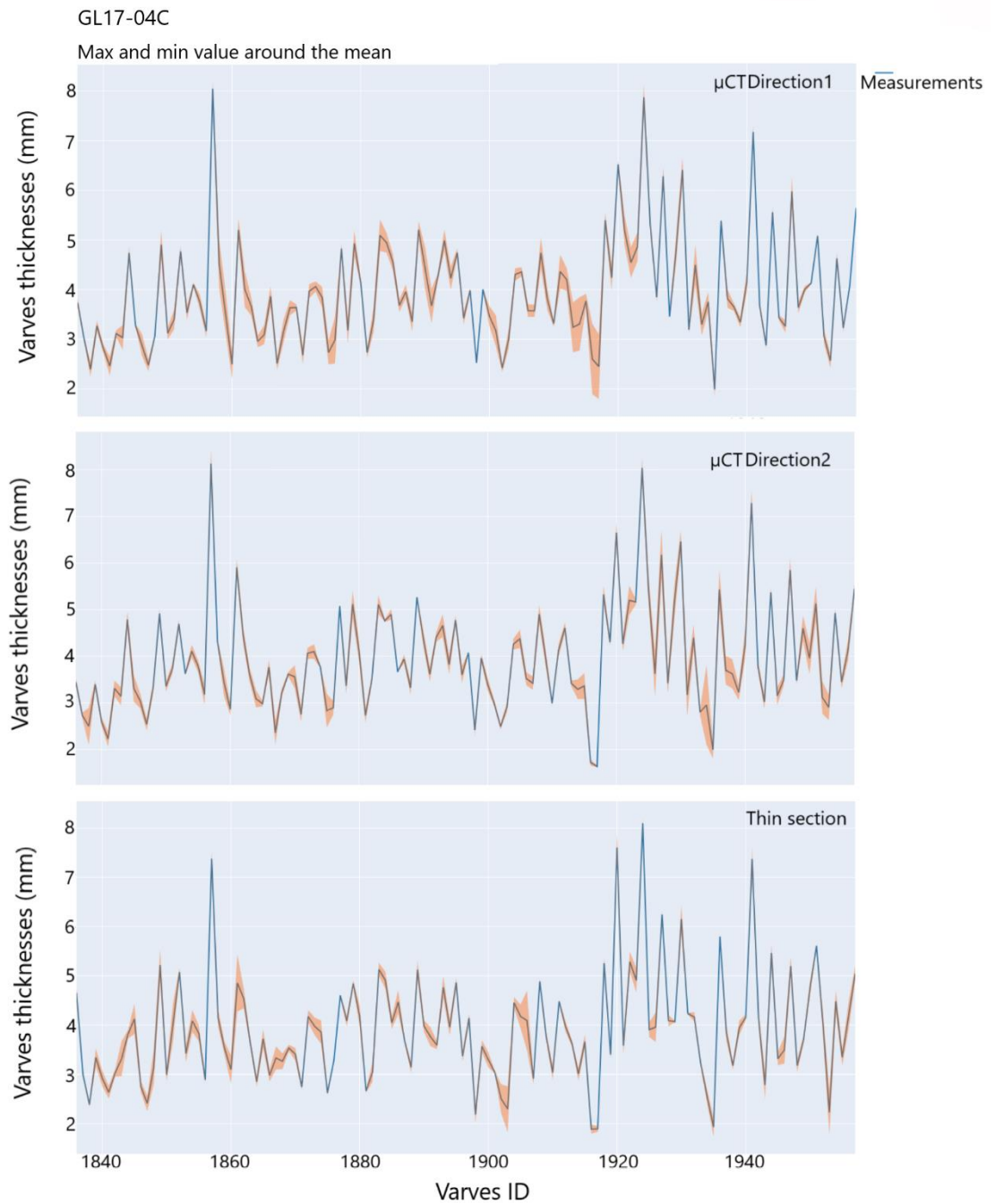
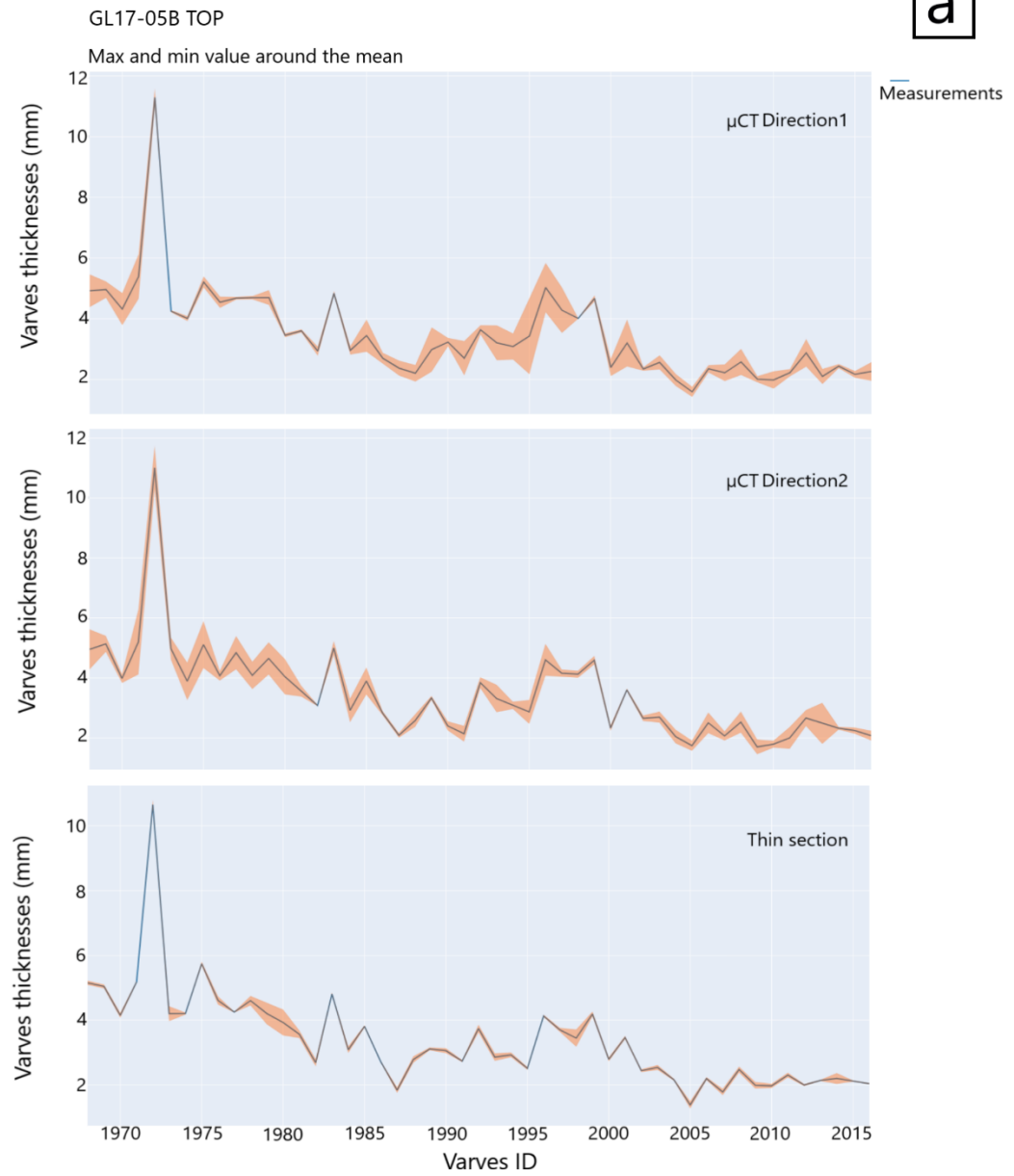
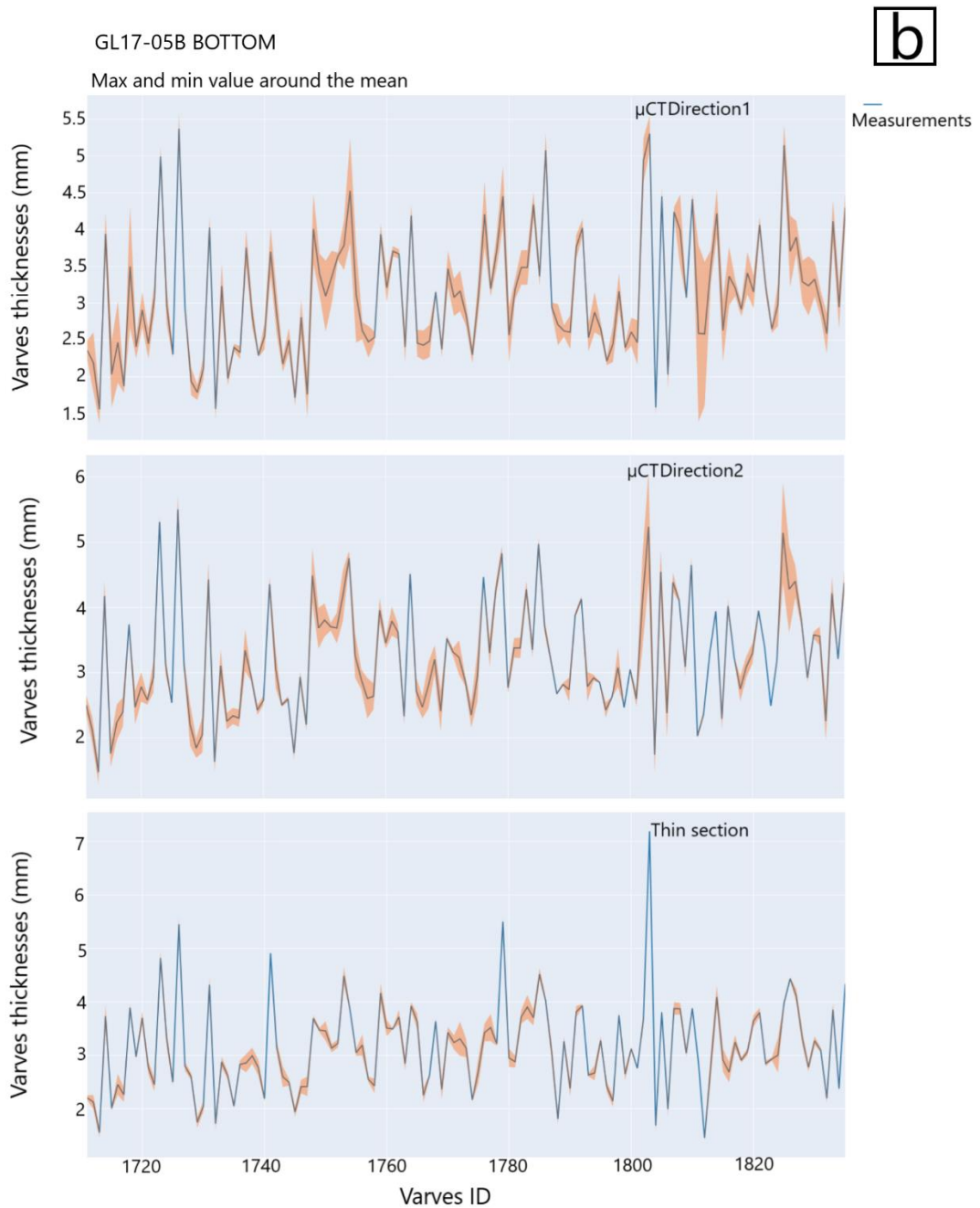


Figure 7: Mean varve thicknesses of the three measurements made in directions 1 (top panels) and 2 (middle panels) using the μ CT and on thin sections (lower panels) for core GL17-04C. The maximum and minimum values around the mean related to the measurements are shown in the orange shaded area, and the varves ID represents the identification of the varve over an interval.

a





235 **Figure 8: Mean varve thicknesses of the three measurements made in directions 1 (top panels) and 2 (middle panels) using the micro-CT and on thin sections (lower panels) for cores GL17-05B at the top (a), and at the bottom (b). The maximum and minimum values around the mean relating to the measurements are in the orange shaded area, and the varves ID represents the identification of the varve over an interval.**

3.3 Repeatability the μ CT thicknesses measurements

240 To evaluate the robustness of the thickness measurements made using the μ CT, the linear regressions and their determination coefficients R^2 have been calculated for the measures made on the same direction. They are all greater than 0.95, with maximum coefficients of 0.996 and 0.997 for the GL17-04B sediment core in directions 1 and 2 respectively. Core GL17-04C shows the next best correlations and GL17-01D with GL17-05B are those with the weakest, but still very high values (Fig. 9).

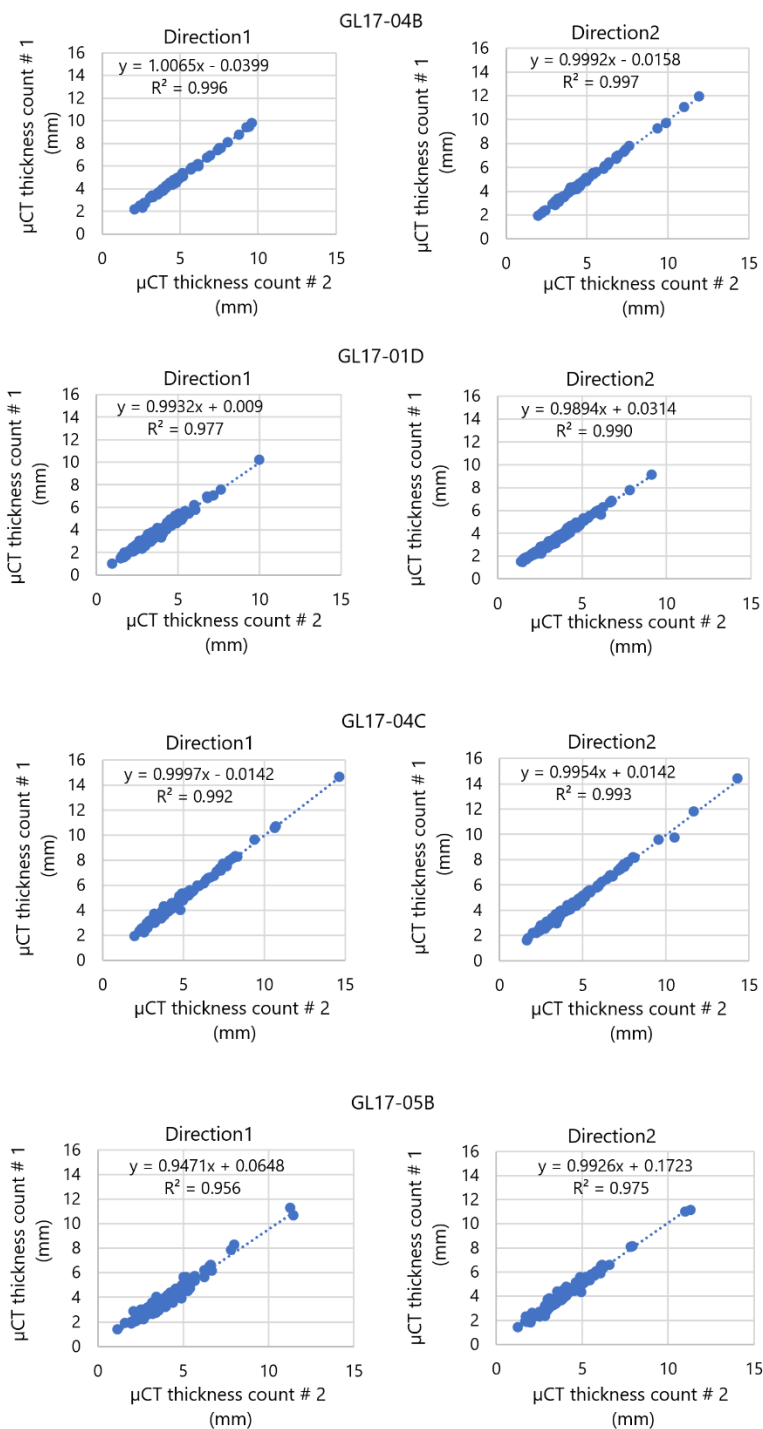
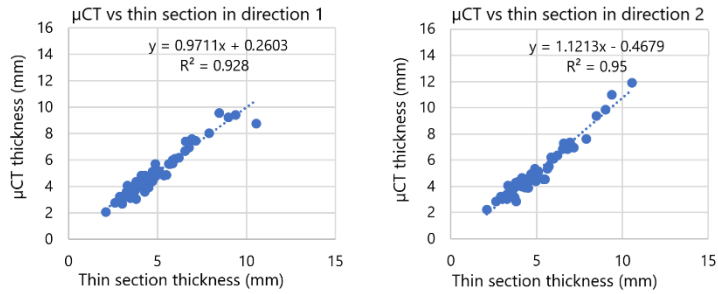


Figure 9: Linear regressions of the mean varve thicknesses measured with μ CT between directions 1 and 2 for each sediment cores (all measurements are in appendix B).

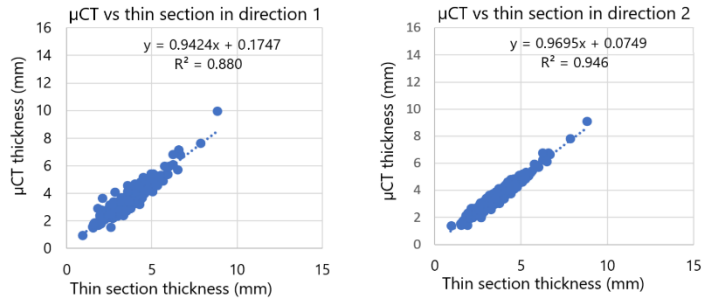
3.4 Comparison of measurements between μ CT and thin sections

The mean thickness measurements with μ CT in the two perpendicular directions are compared by linear regression with those obtained by the thin section method (Fig. 10). The determination coefficients R^2 varies from 0.768 to 0.828 for minimum correlation and values between 0.946 and 0.95 for maximum. In general, the correlations are better in the direction two (2).

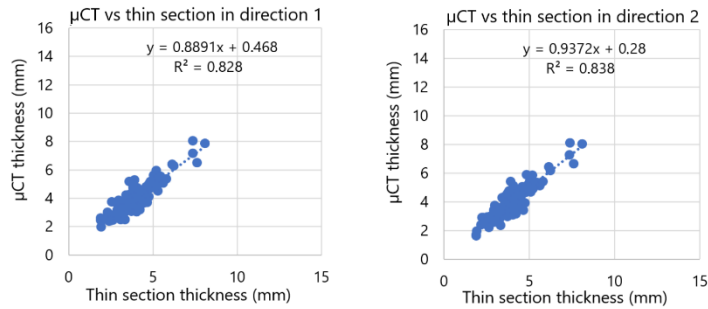
GL17-04B



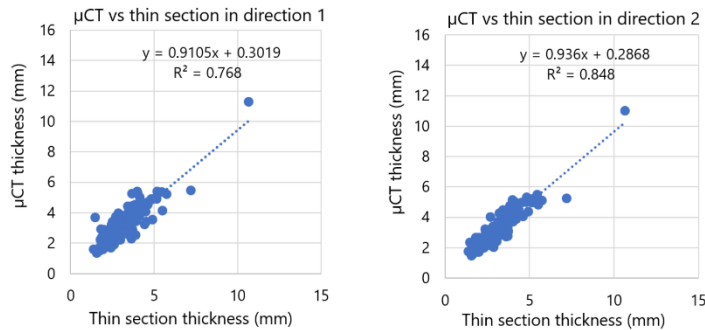
GL17-01D



GL17-04C



GL17-05B



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Figure 10: Linear regression between mean thickness measurements of μ CT and thin sections respectively on the sediment cores GL17-04B, GL17-01D, GL17-04C, and GL17-05B.

3.5 Percentage of average variation of thicknesses

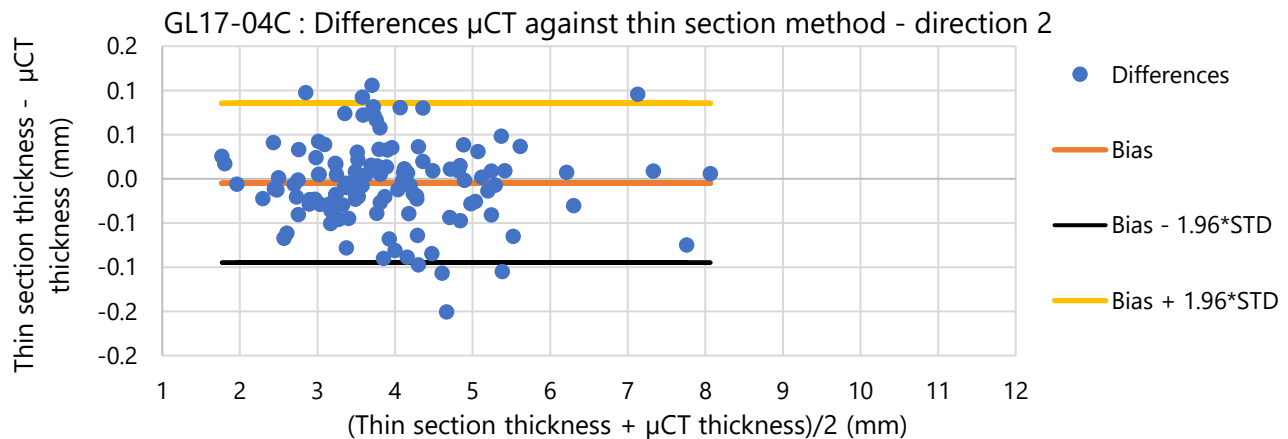
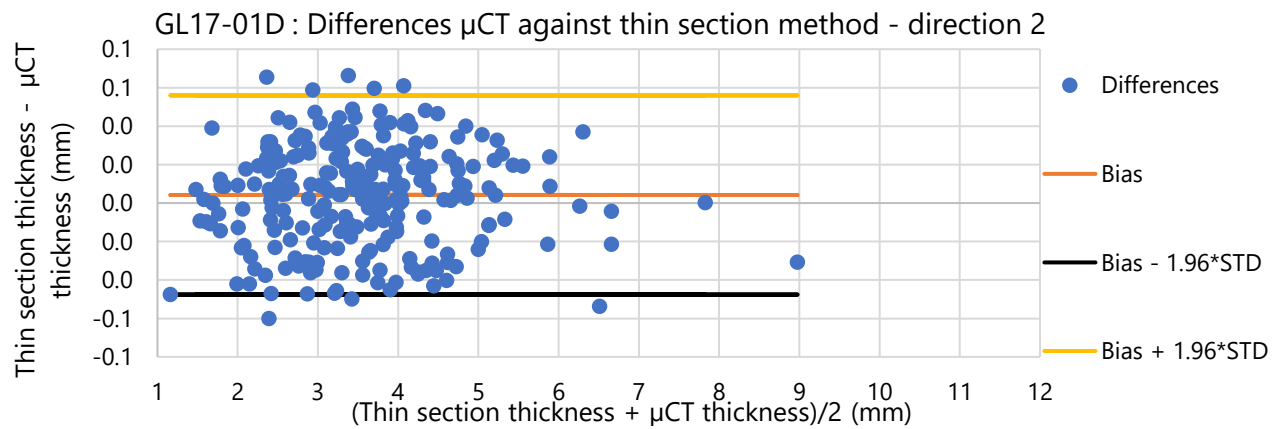
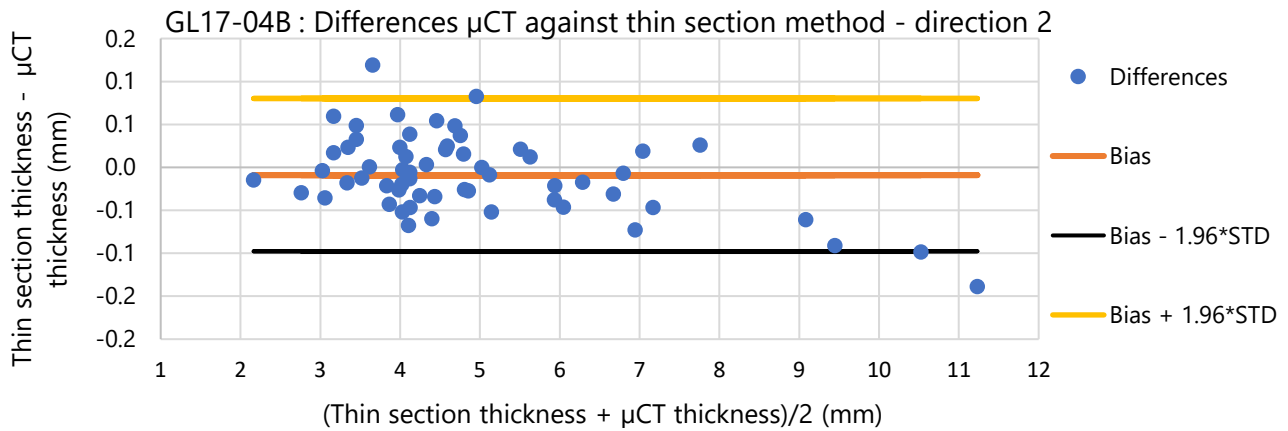
Overall, the average percentage variation of thickness compared to the average value is lowest with thin sections, except with GL17-04B. Direction #1 has the highest percentage of thickness variation compared to the second direction. The most important variations are observed with μ CT measurements on core GL17-05B, exceeding 5% compared to other cores. Conversely, with this sediment core, thin sections have the smallest variations in thickness compared to the average (Table 3).

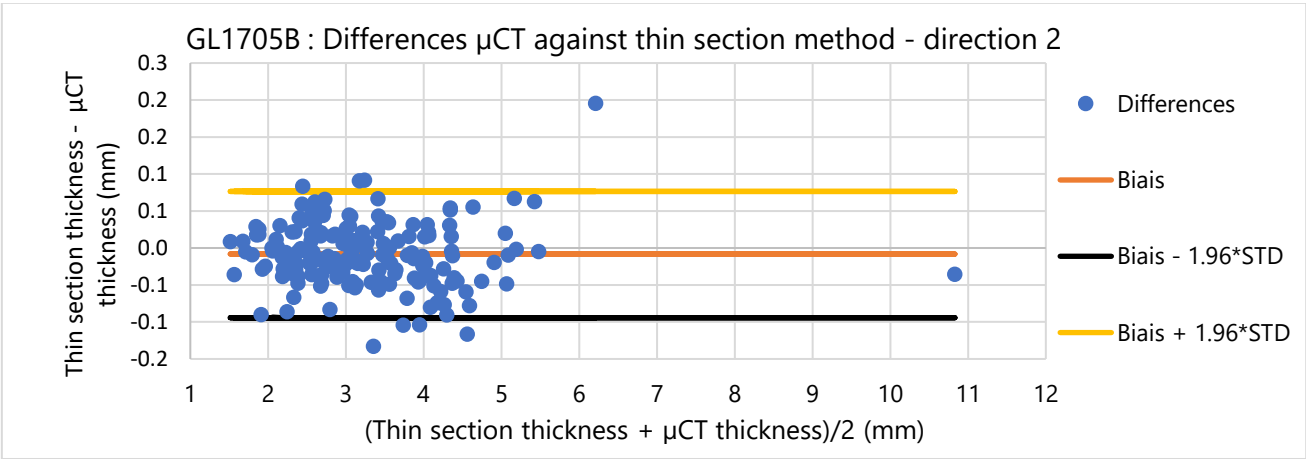
Table 3: Percentage of average variation of thicknesses compared to the average value.

Sediment cores	GL17-04B	GL17-01D	GL17-04C	GL170-5B TOP	GL170-5B BOTTOM
Direction 1	4.89 %	4.82 %	4.9 %	9.28 %	7.82 %
Direction 2	3.81 %	4.56 %	4.69 %	8.76 %	5.41 %
Thin section	4.32 %	3.79 %	4.29 %	2.87 %	3.59 %

3.6 Agreement study between the two methods

The output of the Bland and Altman agreement method applied on the μ CT direction #2 and the thin sections is presented in Figure 11. The results in direction #1 are presented in Appendix A (Figure A5). The thickness differences observed with a 95% confidence interval are as follows: for core GL140B between -0.9615 and 0.7292 mm , with a mean difference (bias) of -0.12 mm; for GL17-01D between -0.4760 and 0.5598 mm with a mean difference of 0.04 mm; for GL17-04C between -0.9483 and 0.8540 mm with a mean difference of -0.05 mm; and for GL17-05B between -0.9347 and 0.7721 mm with a mean difference of -0.08 mm (Fig. 11). Overall, with a 95% confidence interval, the maximum mean difference obtained is 0.12 mm. The percentage of agreement for GL17-04B, GL17-01D, GL17-04C, and GL17-05B is respectively 96.67%, 96.73%, 94.17%, and 91.95%.





275 **Figure 11: Agreement study in direction #2 between the two methods, respectively, on the sediment cores GL17-04B, GL17-01D, GL17-04C, and GL17-05B. The orange line represents the bias, and the two yellow and black lines are the limits of the 95% confidence interval. Note that the vertical axes do not have similar ranges.**

The table below presents a summary of the results obtained.

280 **Table 4: summary table of results.**

		GL17-04B	GL17-01D	GL17-04C	GL17-05B
Sediment core features (figure 1)		Varves slightly deformed	Varves slightly deformed; its upper part was broken	Varves deformed	Varves more deformed than the others
Varve counting		μ CT counts similar to thin sections ones	μ CT counts similar to thin sections ones	More varves counted with μ CT scans	More varves counted with μ CT scans
Varves thicknesses variations	μ CT	Small variations in direction 2	Similar variations in both directions	Small variations in direction 2	Small variations in direction 2
	Thin sections	Like μ CT results in the direction 2	Like μ CT results in the direction 2	Differents from μ CT results	Differents from μ CT results
R^2 (μ CT vs μ CT)	Direction 1	0.996	0.977	0.992	0.956
	Direction 2	0.997	0.990	0.993	0.975
R^2 (μ CT vs thin sections)	Direction 1	0.928	0.880	0.828	0.768
	Direction 2	0.95	0.946	0.838	0.848
Percentage of agreement		96.67%	96.73%	94.17%	91.95%

3.7 Thicknesses depth profiles

Sediment cores GL17-04C and GL17-04B show almost identical depth profiles in their common parts (Fig. 12). GL17-05B and GL17-01D cores show profiles with lower amplitude in their thickness variations. Stratigraphic correlations between the

285 cores can be performed.

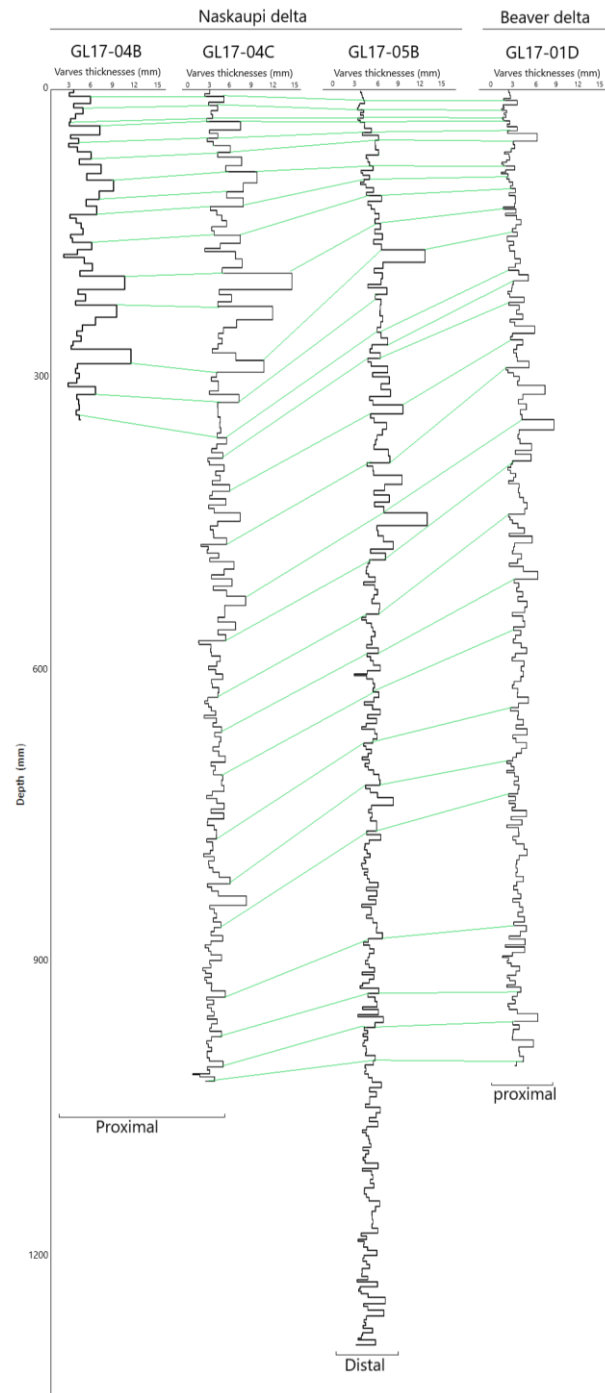


Figure 12: Depth profiles of the four (4) sediment cores GL17-04B, GL17-04C, and GL17-05B were sampled in front of the Naskaupi River delta. GL17-04B and GL17-04C come from the same drilling site. GL17-01D was sampled from the front of the Beaver River delta. Stratigraphic correlations have been made based on images of sediment cores.

4.1 Varve counting

The difference in the number of varves observed when counting with μ CT can be explained by several facts. First, 3D analysis with μ CT allows access to laminations not visible on the thin section plane (Fig. 13). Second, there are thin laminations not counted as varves in thin sections, unlike on μ CT 3D images (Fig. 14). This is because thin section observation at petrographic microscope and the SEM provides more information about lamina features, such as the grain size and grain orientation (Lapointe et al., 2019; Francus, 2006). In this case, the small lamina counted as a varve on the μ CT image was considered as a small event when observed on thin-section because it was not topped with a clay cap, that is the best criteria for accounting for a year of sedimentation (Gagnon-Poiré et al., 2021; Zolitschka et al., 2015). Future work could, however, explore if the gray levels values in clay layers could be used to help distinguish the clay cap.

300 Finally, the presence of deformations in the thin section seems to have an impact on the counting of the varves (Fig. 15). This is one of the great advantages of the 3D view: it allows visual and qualitative analysis of the inside of the sediment core to ensure choosing the best plane for the varved chronology and a wider choice of a region without disturbances.

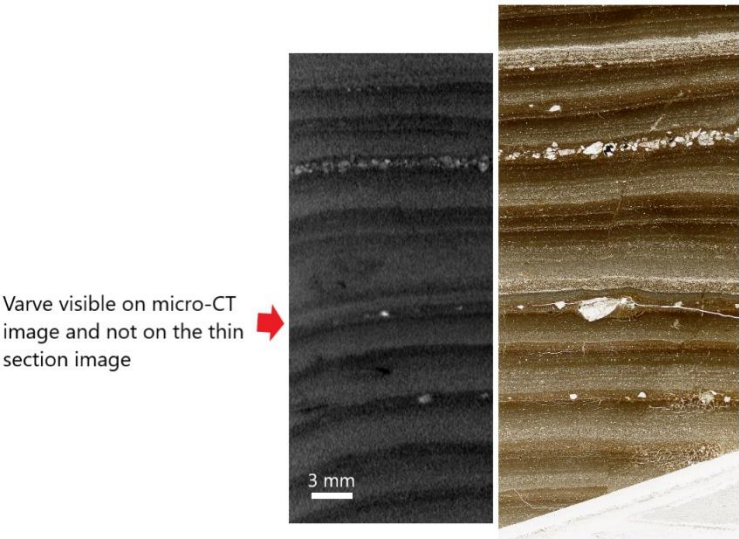


Figure 13: The sediment core GL17-04C shows a lamination that is not visible on the thin-section plane.

305 **4.2 Thickness measurements**

Direction #1 at μ CT displays larger thickness variations from their mean than direction #2. This can be explained by the fact that this direction presents laminae that are more disturbed. Thus, in the same direction, from one cross - section to another, the measured thicknesses vary. Similarly, GL17-04C and GL17-05B are the sediment cores with the most variations in

thickness. These two cores are the most deformed of the four (Fig. 16b and 16c): A deformation of the varve can induce a simple shift of the measurement point in the same cross - section, leading to an assessable difference in the measured thicknesses. Measuring the thickness of varves at the hinge of a folded boundary is significantly different from measuring the thickness on a perfectly horizontal varve. With the 3D vision of μ CT, it is possible to perform scans on larger areas at low resolution in order to select the least distorted areas to perform high - resolution scans (Fig. 17).

The measurements on the thin sections, for their part, present small variations with an average percentage variation of thicknesses of less than 5% (Table 3). This is explained by the fact that with high resolution images of thin sections, it is possible to see micro-variations in the thickness of the varve.

4.3 Repeatability of the μ CT method

Multiple thickness measurements using μ CT show that it is possible to repeat measurements with almost identical values when the laminations are slightly or not deformed. This is the case for the less disturbed core, GL17-04B, that has a correlation coefficient closest to one in both directions. It is much easier to reproduce varve thickness measurements almost identically on slightly disturbed sediment cores. More disturbed cores, such as GL17-05B, have lower correlation coefficients, but they are still quite close to 1. Nevertheless, this shows that even slight deformations impact the thickness measurements (Fig. 16).

4.4 Comparison of measurements between μ CT and thin sections

Linear regression lines in both directions show slightly different slopes and the best correlations between μ CT and thin section thickness measurements are obtained in direction #2. This is mainly because the direction #2 corresponds to the cutting plane of the sediment core, and therefore to the same direction as that of the thin sections. As a result, the points in this direction are significantly better aligned than those in the direction #1. As for the agreement study between the two methods, the GL17-04B and GL17-01D sediment cores show the best percentage of agreement above 95%, followed by GL17-04C with 94.17% (Table 4). With these sediment cores, the μ CT method can be used as a substitute for the thin section method for these measurements. Additionally, using μ CT with deformed sediment cores such as GL17-05B would effectively select the least deformed locations to perform better varve thickness measurements.

4.5 Using μ CT to study varved sediment

The use of thin sections is crucial for studying varved sediments (Bendle et al., 2015; Normandeau et al., 2019). Thin sections provide detailed information in one direction, enabling the identification of microstructures and defining sediment nature (Bendle et al., 2015; Brauer and Casanova, 2001; Gagnon-Poiré et al., 2021). Utilizing thin sections to classify and measure varve constituents at short, specific intervals has allowed for high temporal resolution environmental reconstructions (Bendle et al., 2015; Brauer and Casanova, 2001; Brauer et al., 2008; Gagnon-Poiré et al., 2021; Lauterbach et al., 2011). However, analyzing sediments with thin sections is time-consuming (Normandeau et al., 2019; Francus and Asikainen, 2001; Lotter and Lemcke, 2008).

340 Measuring varves with μ CT can save significant time (Ballo et al., 2023; Emmanouilidis et al., 2020). Indeed, manufacturing thin sections alone takes over ten days, while μ CT allows immediate core scanning without prior preparation. For a 1.5 m sediment core, data acquisition using μ CT takes only around one day, including parameter testing and scan reconstruction to ensure high- quality images (Fig. 2).

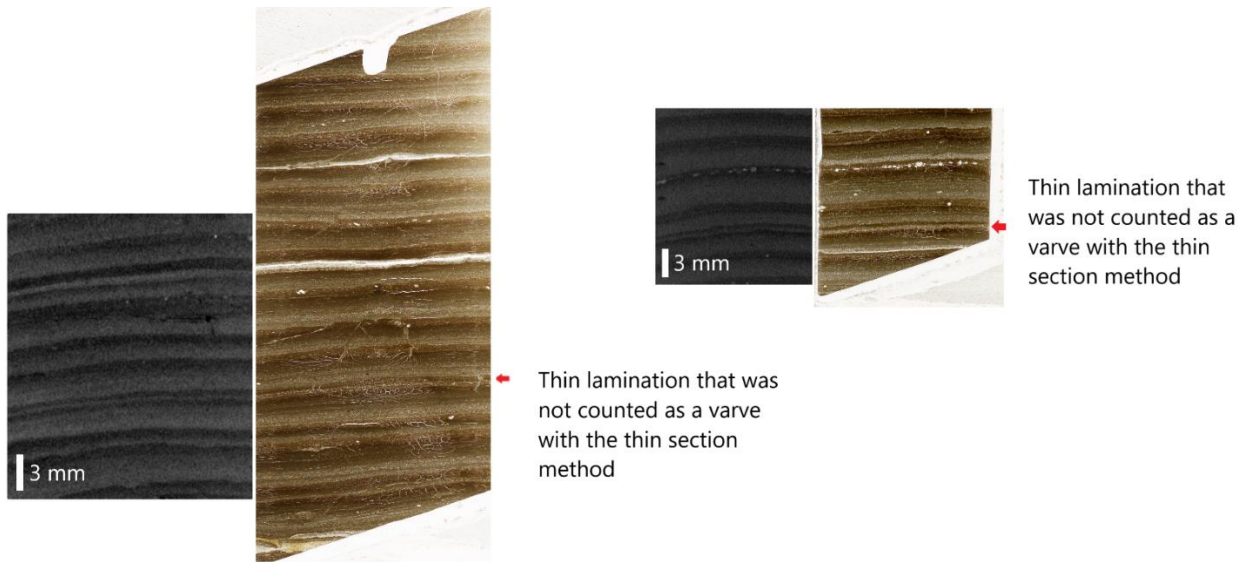
Using μ CT would also enhance efficiency, as scanning entire cores prior to sectioning would aid in selecting optimal cutting
345 planes for thin sections, especially in cases of disturbances (Fig. 15). This is a major advantage. Furthermore, for accurate varve chronology and error estimation, conducting multiple counts in different directions is key (Roop et al., 2016; Ballo et al., 2023; Ojala et al., 2012; Zolitschka et al., 2015; Martin-Puertas et al., 2021; Żarczyński et al., 2018). In this study, twelve (12) counts were conducted, including six (6) in two perpendicular planes of the sediment core, enhancing understanding of varve three-dimensional structure.

350 To more easily detect missing layers or erosional features, it is necessary to steer the counts in parts of the volume that are less affected by disturbances, and to make multiple measurements of layers with thickness lateral variations. The μ CT also offers the possibility of easily obtaining variations in sediment thicknesses along several sediment cores. This is more practical for performing stratigraphic correlations (Fig. 12).

However, the reconstructed μ CT data are large files (Table 1), so it is necessary to have high-capacity computers for their
355 analysis. Careful planning needs to be conducted prior to analyzing an entire sequence. For this study, 170 GB were needed for a sediment core 1.5 m long with a resolution of 45 μ m. If a higher resolution is needed because laminations are thinner, files will be even larger. For example, to scan GL17-01D at 30 μ m, the file size will be 223 GB, so 36% larger than those at 45 μ m. Also, image quality can be affected by artifacts like beam hardening and beam cone artifact, which can prevent the boundaries of the varves from being clearly distinguished (Laeveren D. , 2020; Sheppard et al., 2014; Meganck et al., 2009;
360 Davis, 2022). It is important to pay attention to all these details before validating the μ CT images (Fig. 18).

A compromise has therefore to be considered to have sufficient resolution to obtain accurate thickness measurements and to have quality images with reduced acquisition and reconstruction times (Du Plessis et al., 2017; Chatzinikolaou and Keklikoglou, 2021; Dewanckele et al., 2020). It is necessary to find the minimum resolution allowing the laminae to be easily distinguished in the shortest possible scanning and reconstruction times. In this case study, it was possible to go well below
365 the resolution of 45 μ m (voxel size) obtained for the analysis of the four sediment cores, but this did not provide additional information. Indeed, at 45 μ m we can easily distinguish the smallest lamination, which is 0.92 mm thick (~21 voxels). These limits are visible up to 77 microns (~12 voxels). Beyond that, the limits of the lamina become blurred (Fig. 19). Thus, to observe varves of 1 mm and to have sharpness of the boundaries, we would need a minimum of about 13 voxels per varve.

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Figure 14: Sediment core GL17-04C shows laminations that are not counted as varves in the thin sections. These laminations are counted as varves with μ CT scans, but there is no sedimentological interpretation with μ CT scans to confirm that they are actually varves.

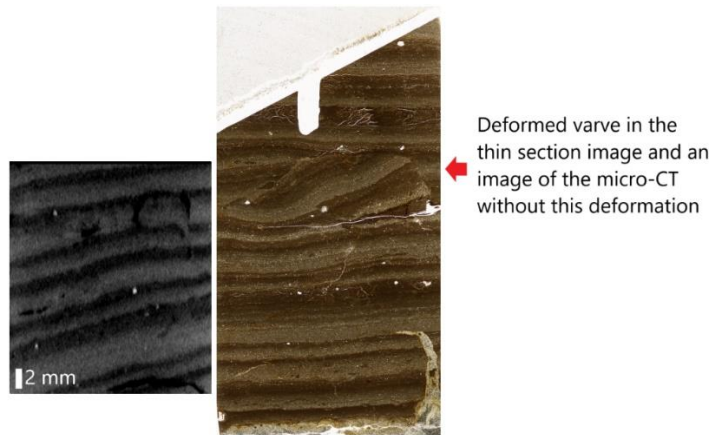


Figure 15: The deformation of varves in the thin section plane and the corresponding varve with μ CT image in the sediment core GL17-05B.

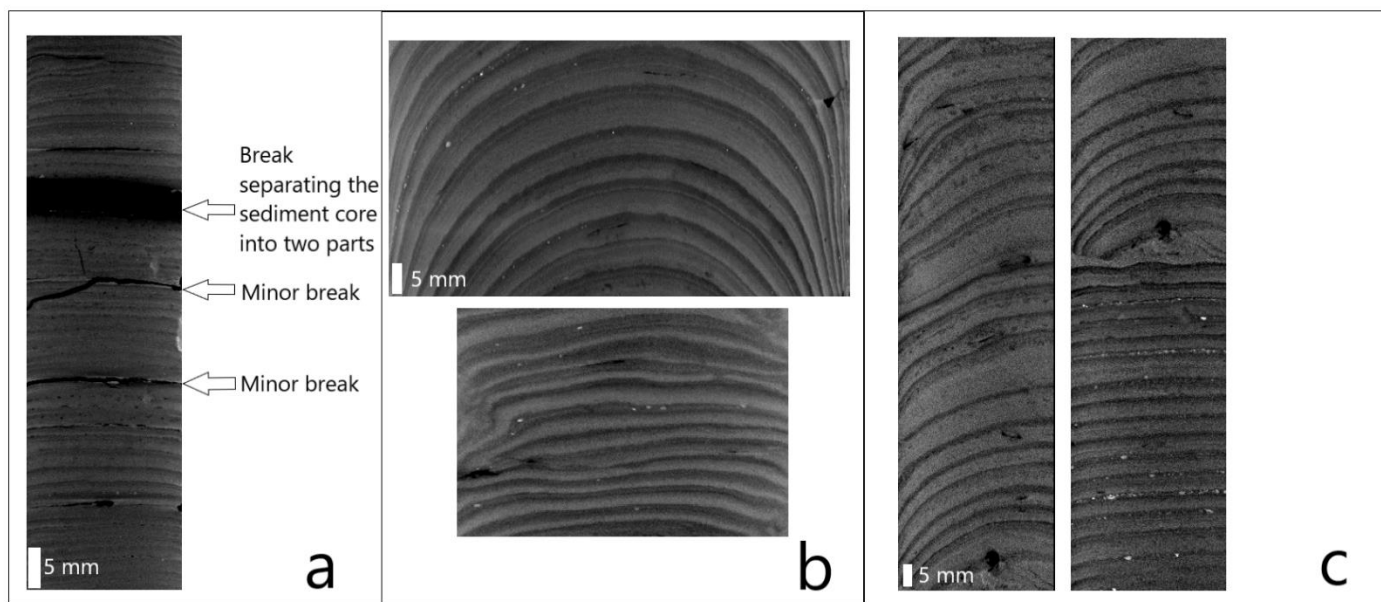


Figure 16: (a) The sediment core GL17-01D has broken parts. (b) Deformations are present in the sediment core GL17-05B. (c) The sediment core GL17-04C displays oblique laminations with variable thickness, along with flat and horizontal laminations with constant thicknesses.

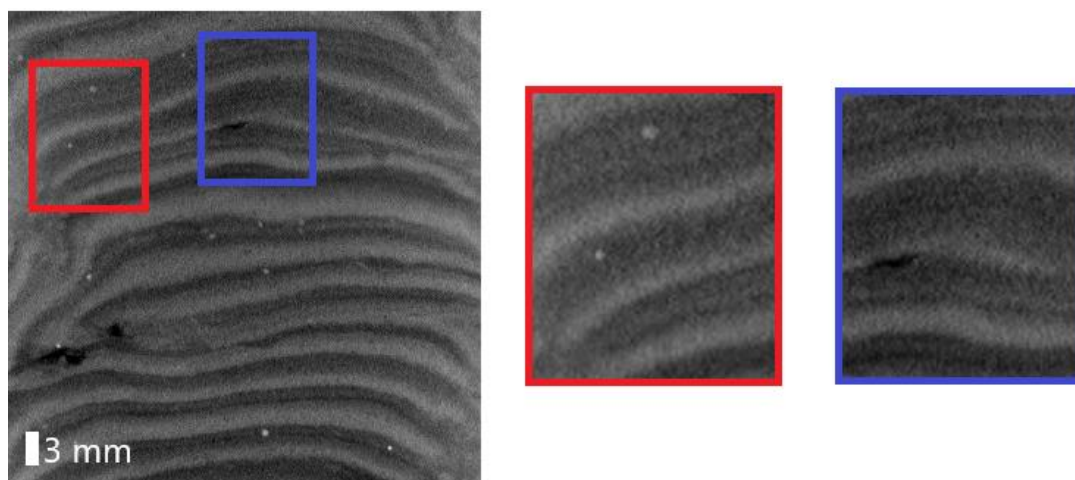


Figure 17: Large VOIs allow you to choose where to do more precise scans within small VOIs. The images with red and purple outlines show how the thickness can vary for the same varve.

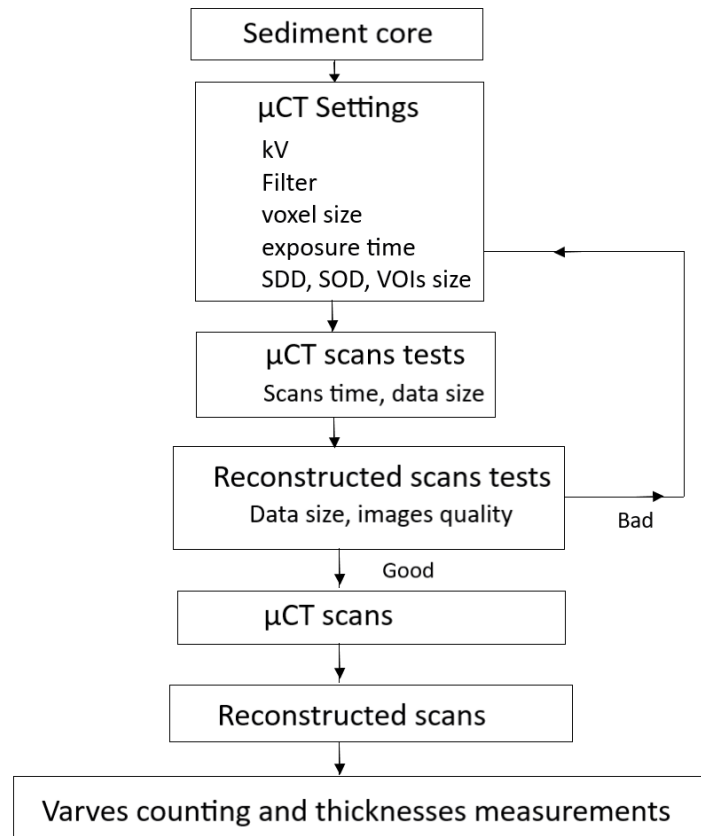


Figure 18: Summary of the steps to follow in scanning and reconstructing sediment cores.

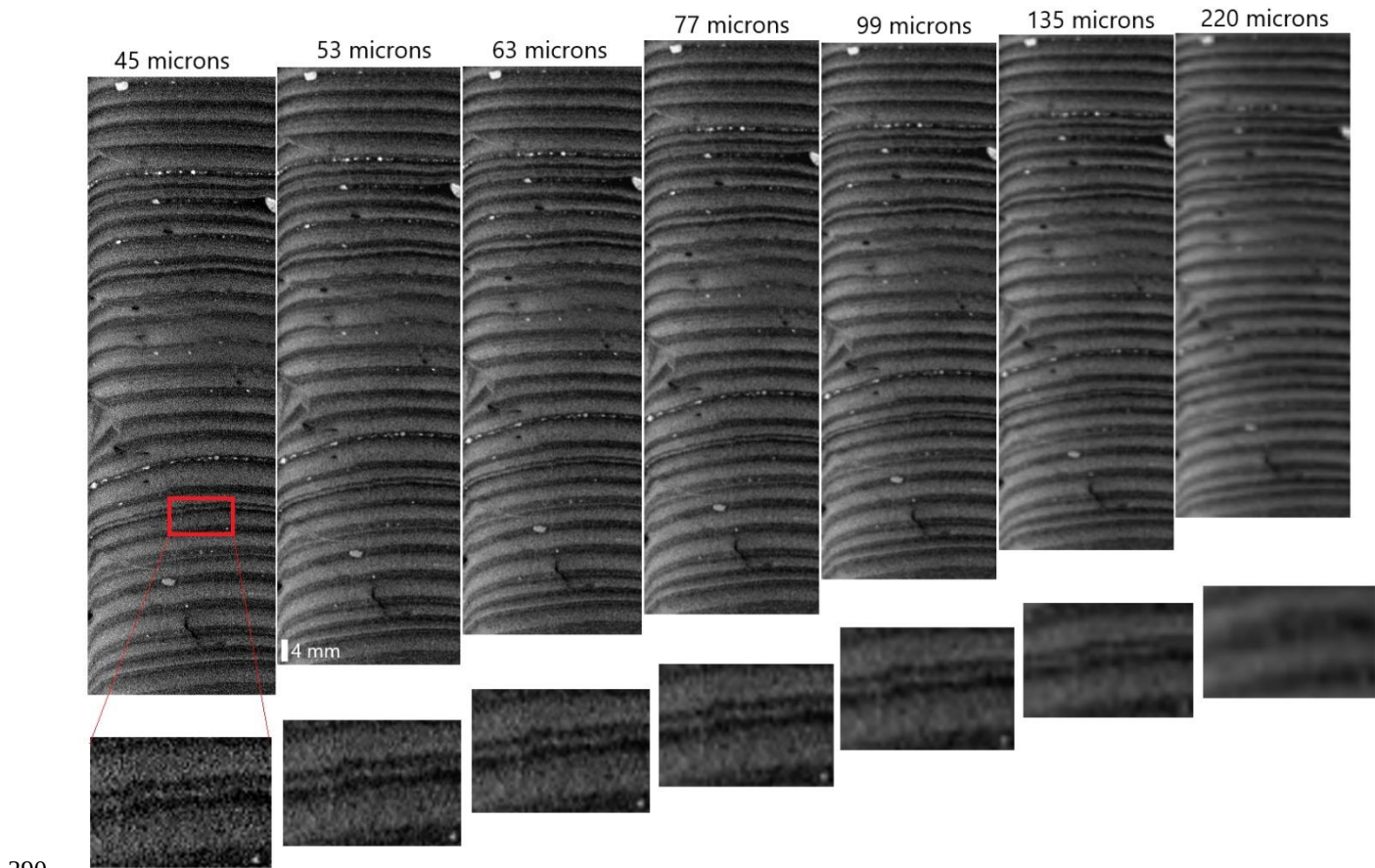


Figure 19: The ability to observe the limits of the smallest stratification depending on the resolution of the μ CT images.

5 Conclusion

The well-preserved sequence of thick and undisturbed varves in Grand Lake has allowed to test the use of μ CT to perform varve counts and thickness measurements. Making multiple counts in at least two perpendicular directions allows for obtaining robust varve counts. In addition, with this study it was possible to know the number of voxels needed to observe the limits of varves of millimetric thickness.

The key results are as follows:

- The μ CT with its high resolution, makes it possible to visualise and study varves of millimetre size and below millimetre.
- The μ CT has the potential to reveal the three-dimensional structure of varves and facilitate the detection of missing layers or erosion characteristics.

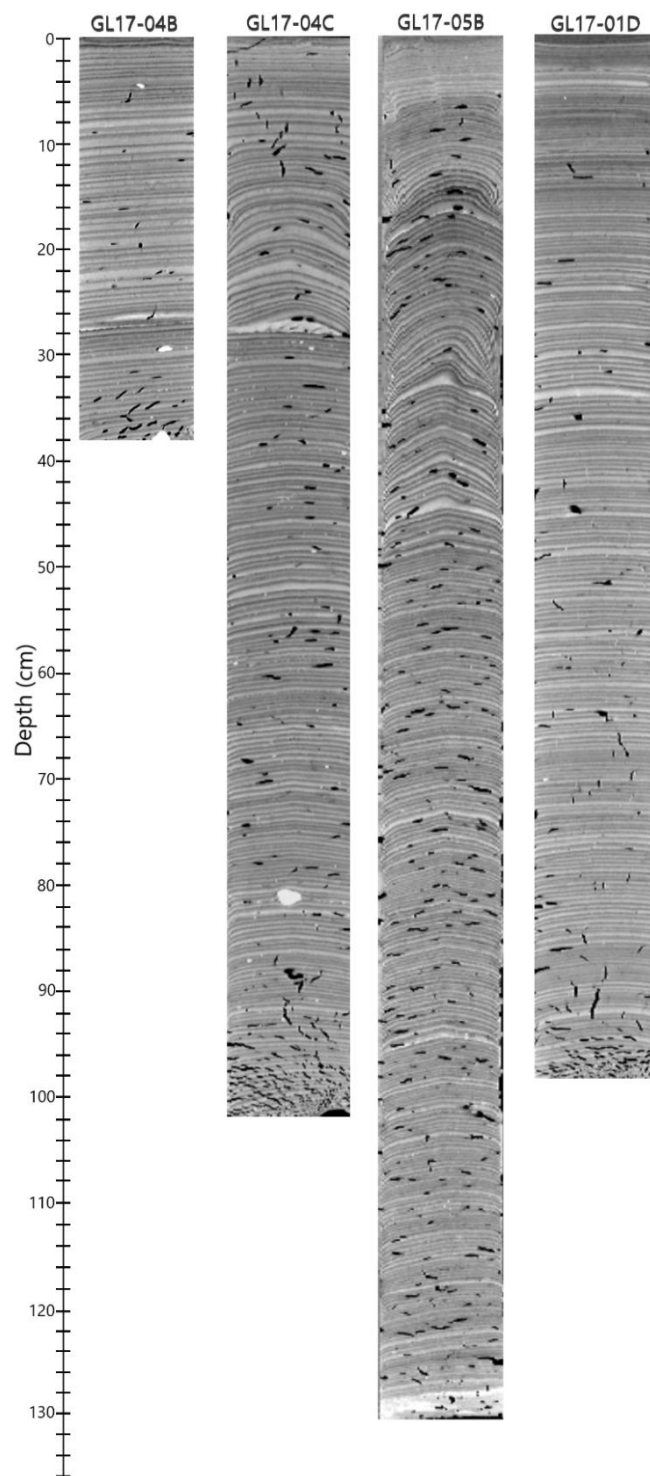
- The μ CT offers the ability to perform multiple layer measurements in multiple directions, resulting in robust thickness measurements in varves with lateral thickness variations.

405 - In the case of deformed sediment cores, the μ CT has the advantage of making it easier to choose the best area for measurements.

Finally, thin sections are still necessary to determine the nature of the varved sedimentary facies and remain essential for contentious cases. However, μ CT offers the possibility of no longer making continuous thin sections along a sedimentary sequence for counting and constitutes a powerful tool to improve the quality of the thickness measurements through the access
410 of a 3D view, allowing for choosing the most representative part of the varved record.

Appendices

Appendix A: Additional images of sediment cores, VOIs shapes, the depth model profile, and information on the agreement study in direction 1.



415 **Figure A1:** CT scan images of the four sediment cores GL17-04B, GL17-04C, GL17-01D and GL17-05B used in this study.

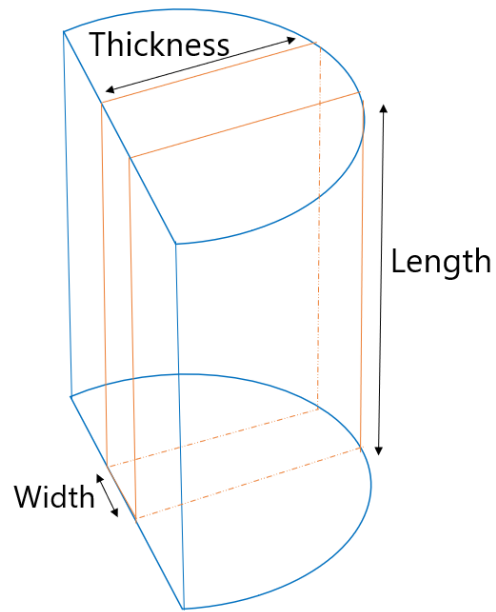


Figure A2: Orange box showing the shape of Volumes of Interest (VOIs) in the half sediment cores (in blue).

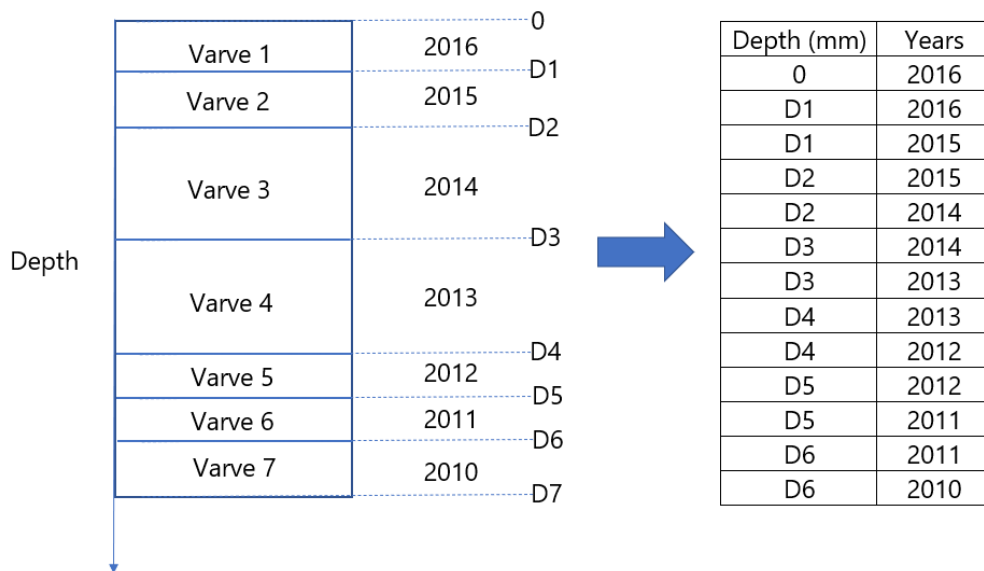


Figure A3: Depth profile calculation model considering that each varve is characterized by two distinct depths.

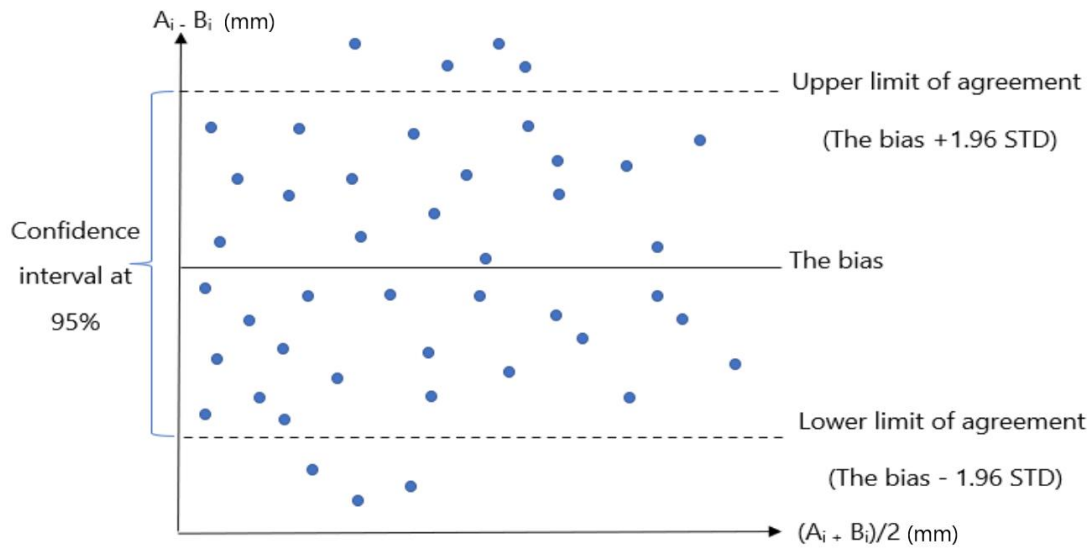
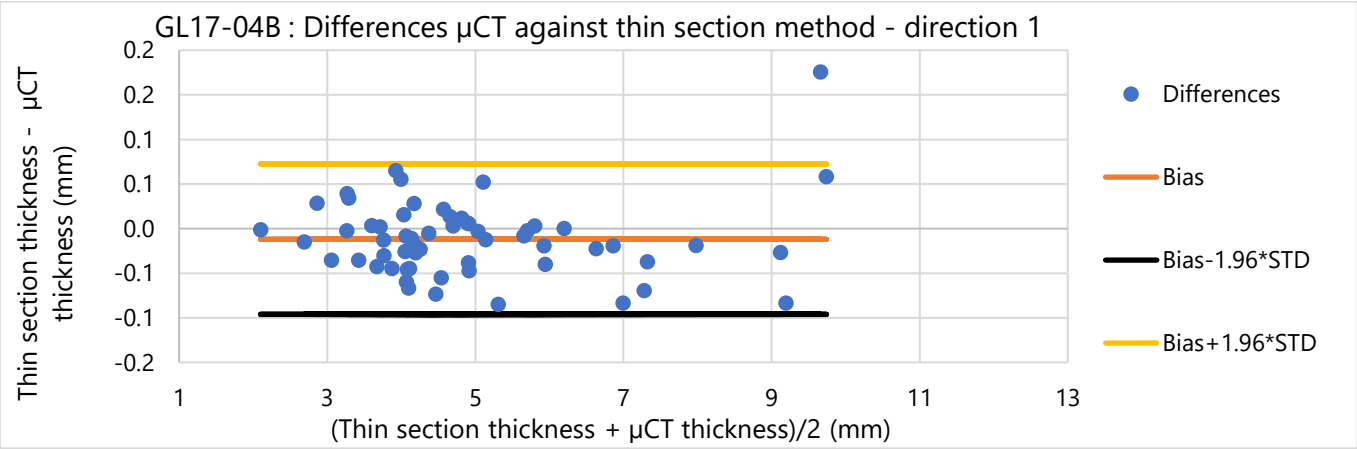


Figure A4: Presentation of the interval in which 95% of the differences between two methods are included. Each blue point represents the result of the difference $A_i - B_i$ between two measurements. The Upper and Lower limits of agreement are the limits of the confidence interval at 95%. The difference $A_i - B_i$ between the two measurement methods is expressed as a function of the mean values $(A_i + B_i)/2$ of results of the two methods.



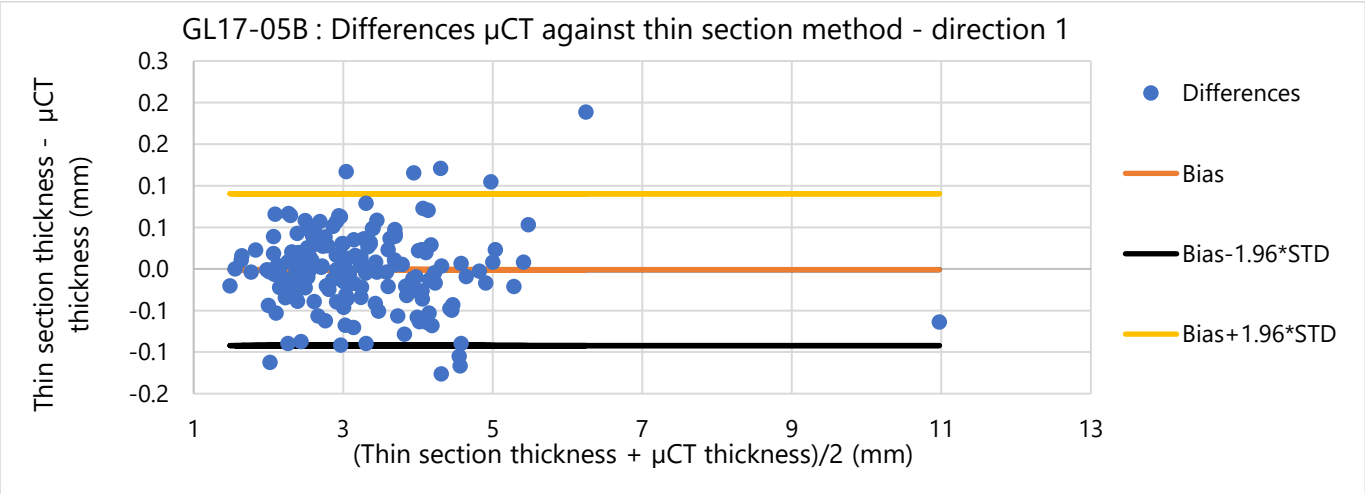
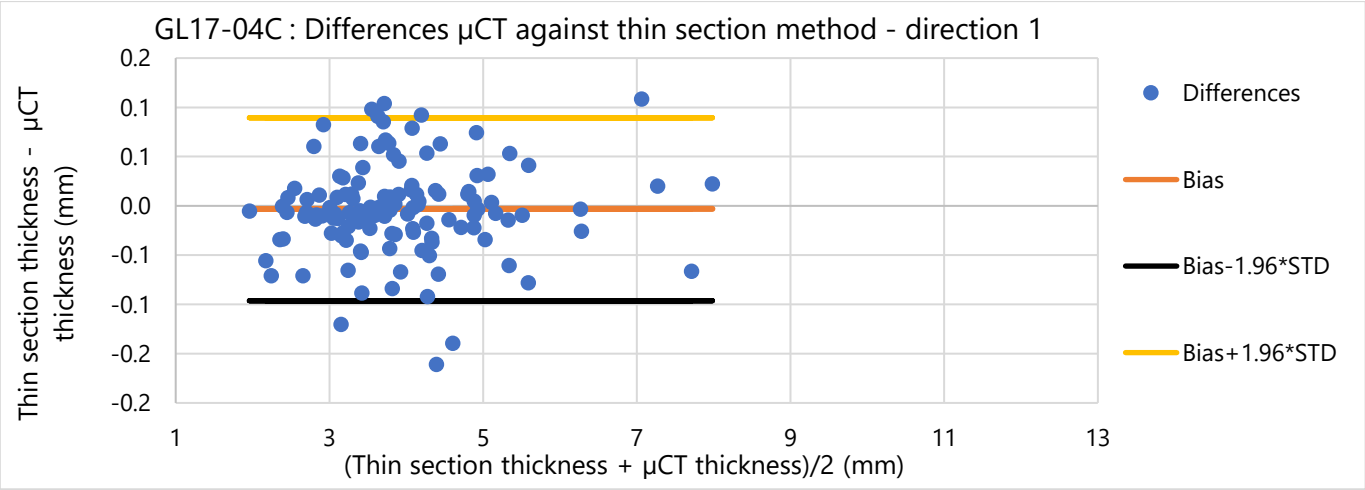
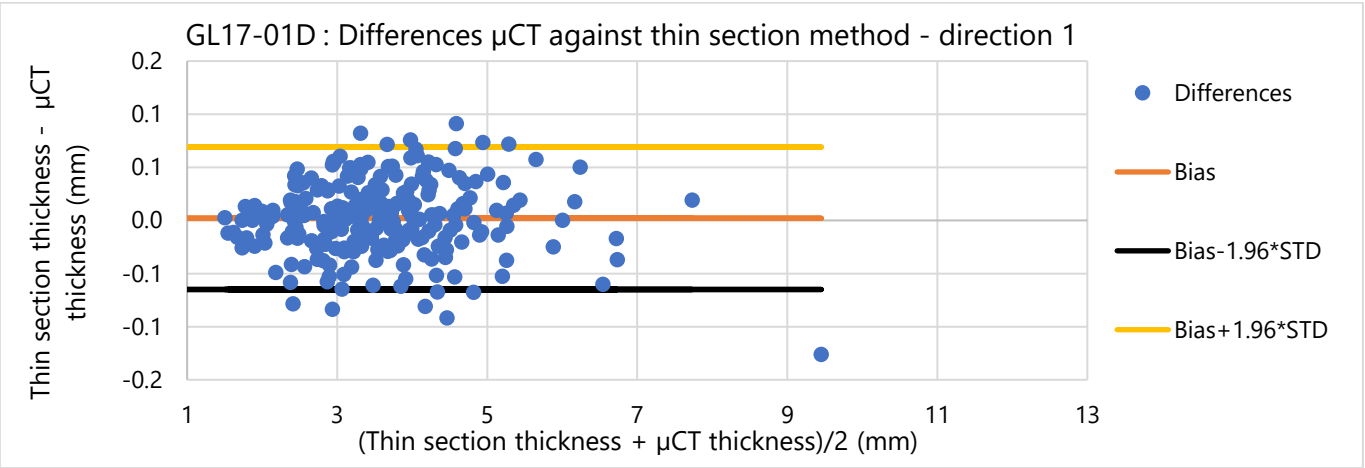


Figure A5 Agreement study in the direction 1 of the two (2) methods respectively on the sediment cores GL17-04B, GL17-01D, GL17-04C and GL17-05B. The orange line represents the bias, and the two yellow and black lines are the limits of the 95% confidence interval.

Appendix B: Thickness measurements with μ CT and thin sections

Table B1 The thickness measurements with μ CT and thin sections

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GL17-04B												
Years	μ CT measurements direction 1				μ CT measurements direction 2				Thin section measurements			
	1 st Count	2 nd Count	3 rd Count	Mean	1 st Count	2 nd Count	3 rd Count	Mean	1 st Count	2 nd Count	3 rd Count	Mean
2016	3.46	3.80	3.90	3.72	3.46	3.75	3.77	3.66	4.49	4.24	4.09	4.27
2015	3.58	3.64	3.58	3.60	3.06	3.09	3.02	3.06	4.23	4.53	3.99	4.25
2014	6.12	6.06	5.89	6.02	5.98	6.10	6.05	6.04	5.80	5.56	6.14	5.83
2013	3.81	3.69	3.25	3.58	3.95	3.34	3.54	3.61	3.56	3.51	3.78	3.62
2012	5.05	5.14	4.97	5.05	4.79	5.20	5.08	5.02	4.94	5.11	5.01	5.02
2011	3.87	3.71	3.54	3.71	3.89	3.80	4.12	3.94	3.54	3.65	3.99	3.72
2010	4.23	3.76	3.48	3.82	3.31	2.88	3.43	3.21	3.76	3.85	3.48	3.70
2009	2.28	2.93	2.95	2.72	2.98	3.30	2.85	3.04	2.95	3.00	3.07	3.01
2008	7.64	7.73	7.52	7.63	7.45	7.37	7.38	7.40	7.25	6.70	6.85	6.93
2007	3.12	3.00	3.24	3.12	3.16	3.33	3.20	3.23	3.16	3.55	3.68	3.46
2006	4.28	4.23	4.50	4.34	4.31	4.40	4.36	4.36	3.96	3.73	3.99	3.89
2005	2.74	2.93	2.63	2.77	2.86	2.79	3.08	2.91	2.40	2.89	2.56	2.62
2004	4.20	4.23	4.44	4.29	4.03	4.30	4.11	4.15	4.28	3.98	4.02	4.09
2003	6.39	5.90	6.15	6.15	6.08	6.39	5.90	6.12	5.98	5.22	6.04	5.75
2002	4.72	4.68	4.65	4.68	4.46	4.39	4.54	4.46	4.56	5.18	4.40	4.71
2001	8.15	8.10	7.98	8.08	7.14	7.89	7.85	7.63	7.95	7.93	7.78	7.89
2000	5.78	5.52	5.84	5.71	5.67	5.66	5.37	5.57	5.94	5.80	5.33	5.69
1999	9.73	9.45	9.66	9.61	9.44	9.53	9.18	9.38	8.44	8.37	9.52	8.78
1998	7.54	7.11	7.59	7.41	7.53	7.16	7.23	7.31	6.49	6.49	6.76	6.58
1997	5.69	5.67	5.73	5.70	5.46	5.39	5.36	5.40	5.49	5.62	5.74	5.62

1996	7.08	7.67	7.78	7.51	6.78	6.75	7.31	6.95	7.05	7.29	7.07	7.14
1995	3.35	3.18	3.30	3.28	3.20	2.99	3.06	3.08	3.49	3.09	3.18	3.25
1994	4.27	4.09	3.96	4.11	4.00	3.80	4.34	4.05	4.22	4.15	3.69	4.02
1993	5.00	4.61	4.66	4.76	4.65	4.90	4.60	4.72	4.65	4.95	5.02	4.87
1992	5.43	5.01	4.86	5.10	4.92	5.32	4.73	4.99	4.61	4.50	5.04	4.72
1991	3.62	3.16	2.92	3.23	3.39	3.01	3.30	3.23	2.86	3.01	2.78	2.88
1990	3.33	3.65	3.82	3.60	3.40	3.46	3.41	3.42	3.42	3.23	3.09	3.24
1989	4.77	6.38	6.21	5.79	6.24	6.63	5.96	6.28	5.66	5.72	6.07	5.82
1988	4.46	4.26	4.27	4.33	3.95	4.16	4.45	4.19	4.04	4.01	4.12	4.06
1987	1.92	2.17	2.23	2.11	2.20	2.19	2.32	2.24	2.14	1.98	2.16	2.09
1986	5.41	5.04	5.16	5.20	5.28	5.06	5.15	5.16	5.06	5.13	5.04	5.08
1985	5.87	6.10	6.63	6.20	6.24	6.54	6.33	6.37	6.20	6.22	6.17	6.20
1984	4.94	5.02	4.69	4.88	4.74	4.83	4.13	4.57	5.57	4.83	4.42	4.94
1983	9.32	9.23	9.80	9.45	11.15	11.14	10.76	11.02	9.25	10.26	10.60	10.03
1982	4.45	4.28	4.47	4.40	4.28	4.17	4.49	4.31	4.36	4.25	4.42	4.35
1981	5.59	5.76	5.85	5.73	5.45	5.33	5.42	5.40	4.89	4.88	4.88	4.88
1980	4.06	4.13	3.90	4.03	4.05	3.65	4.08	3.93	4.82	4.02	4.10	4.31
1979	8.99	9.43	9.35	9.26	10.34	9.88	9.48	9.90	8.41	9.12	9.43	8.99
1978	7.36	6.73	6.78	6.96	7.25	6.54	6.70	6.83	7.11	6.41	6.77	6.76
1977	5.16	5.01	5.29	5.15	4.72	4.89	5.20	4.94	4.54	4.78	4.72	4.68
1976	4.64	4.21	4.08	4.31	4.04	4.23	4.07	4.11	3.84	4.02	3.69	3.85
1975	5.12	4.59	4.79	4.83	4.95	4.55	4.58	4.69	4.06	3.82	4.41	4.10
1974	3.85	4.13	3.67	3.88	3.64	3.45	3.65	3.58	3.39	3.47	3.51	3.46
1973	4.23	4.06	3.46	3.92	3.29	3.30	3.27	3.29	3.82	3.95	3.07	3.61
1972	7.34	8.43	10.58	8.78	11.73	12.03	12.02	11.93	10.13	10.21	11.27	10.54
1971	4.53	4.69	4.57	4.60	4.14	4.26	4.15	4.18	4.60	5.48	4.10	4.73
1970	4.25	3.89	3.73	3.96	3.80	4.14	3.70	3.88	4.41	3.31	4.61	4.11
1969	4.58	4.69	4.03	4.43	4.32	4.30	4.70	4.44	4.06	3.85	3.38	3.77
1968	4.17	3.92	4.20	4.10	4.01	3.86	4.37	4.08	3.19	3.36	4.41	3.65
1967	3.11	3.21	2.90	3.07	2.92	2.88	2.80	2.87	3.75	3.98	2.67	3.46
1966	6.84	6.72	6.67	6.74	6.84	6.80	6.84	6.83	6.74	6.26	6.56	6.52
1965	4.26	4.38	3.90	4.18	4.09	4.10	4.17	4.12	3.76	3.91	4.10	3.92

1964	4.31	4.23	4.04	4.19	4.53	4.44	4.26	4.41	3.98	4.06	4.20	4.08
1963	4.62	4.32	4.44	4.46	4.23	4.45	4.72	4.47	4.92	4.70	4.41	4.68
1962	4.67	4.31	4.13	4.37	3.90	3.93	4.20	4.01	3.77	4.03	4.61	4.14
1961	4.82	5.05	4.72	4.86	4.42	4.71	4.20	4.44	4.75	5.01	5.02	4.93
1960	4.67	4.97	4.81	4.82	4.55	4.60	4.66	4.60	4.36	4.23	4.20	4.26
1959	4.57	4.31	4.22	4.37	4.10	4.34	4.42	4.29	4.03	3.99	3.28	3.77
1958	5.14	4.85	4.55	4.85	4.86	4.45	4.31	4.54	5.05	5.42	5.64	5.37

GL17-01D												
	μCT measurements direction 1				μCT measurements direction 2				Thin section measurements			
Years	1 st	2 nd	3 rd	Mean	1 st	2 nd	3 rd	Mean	1 st	2 nd	3 rd	Mean
	Count	Count	Count		Count	Count	Count		Count	Count	Count	
2016	2.46	2.43	2.48	2.46	2.46	2.32	2.53	2.44	2.97	2.82	2.78	2.86
2015	2.79	2.59	2.64	2.67	2.63	2.77	2.52	2.64	2.82	2.98	3.89	3.23
2014	2.57	2.53	2.56	2.55	2.60	2.66	3.04	2.77	2.53	2.39	2.36	2.43
2013	1.88	1.90	1.60	1.79	1.72	1.70	1.83	1.75	1.93	1.73	1.86	1.84
2012	3.96	4.01	4.00	3.99	3.91	3.66	3.72	3.76	4.30	4.34	4.48	4.37
2011	1.66	1.61	1.75	1.67	1.67	1.67	1.64	1.66	1.63	1.52	1.53	1.56
2010	1.66	1.66	1.87	1.73	1.75	1.87	1.75	1.79	1.64	1.82	1.74	1.73
2009	1.50	1.50	1.47	1.49	1.37	1.54	1.43	1.45	1.48	1.56	1.51	1.52
2008	2.48	2.48	2.41	2.46	2.16	2.17	2.15	2.16	2.53	2.33	2.20	2.35
2007	1.82	1.76	1.82	1.80	1.72	1.84	1.81	1.79	1.78	1.79	2.06	1.88
2006	2.12	2.08	2.03	2.08	2.02	2.03	2.16	2.07	2.07	1.80	1.95	1.94
2005	1.60	1.55	1.66	1.60	1.54	1.57	1.62	1.58	1.48	1.56	1.41	1.48
2004	1.76	1.61	1.76	1.71	1.89	1.73	1.54	1.72	1.78	1.84	1.91	1.84
2003	2.48	2.48	2.83	2.60	2.02	2.58	3.36	2.65	2.16	2.17	2.22	2.18
2002	2.62	2.38	2.40	2.47	2.38	2.44	1.93	2.25	2.45	2.70	2.56	2.57
2001	3.80	3.72	3.75	3.76	3.79	3.76	3.58	3.71	3.78	3.66	3.59	3.68
2000	2.31	2.25	2.25	2.27	2.62	2.15	2.23	2.33	2.47	2.69	2.66	2.61
1999	6.76	6.80	6.86	6.81	6.80	6.84	6.40	6.68	6.57	6.62	6.72	6.64
1998	2.73	2.85	2.96	2.85	3.25	3.21	2.99	3.15	2.81	2.85	2.75	2.80
1997	3.20	3.57	3.54	3.44	3.47	3.33	3.42	3.41	3.55	3.65	3.55	3.58

1996	3.02	2.91	2.83	2.92	2.90	2.99	2.73	2.87	2.91	2.81	2.97	2.90
1995	1.86	1.91	1.85	1.87	1.87	1.98	1.71	1.85	1.60	1.72	1.81	1.71
1994	2.06	2.36	1.94	2.12	2.47	2.67	2.46	2.53	2.17	2.11	2.19	2.16
1993	2.88	2.74	3.14	2.92	2.65	2.73	2.59	2.66	2.70	2.41	2.55	2.55
1992	2.36	2.26	2.65	2.42	2.10	2.30	2.08	2.16	2.14	2.30	2.34	2.26
1991	1.86	1.83	1.92	1.87	1.40	1.47	1.58	1.48	1.81	1.88	1.93	1.87
1990	1.82	1.89	1.88	1.86	1.97	1.61	1.56	1.71	1.75	1.42	1.65	1.60
1989	3.89	3.93	3.90	3.91	3.47	3.55	3.19	3.40	3.92	3.99	4.09	4.00
1988	2.56	2.40	2.48	2.48	1.82	2.15	2.13	2.03	2.55	2.73	2.78	2.69
1987	1.03	0.90	0.99	0.97	1.40	1.54	1.26	1.40	0.95	1.00	0.82	0.92
1986	2.00	2.03	1.83	1.95	2.38	2.65	2.12	2.38	2.17	1.99	1.96	2.04
1985	1.87	1.92	1.70	1.83	2.47	1.98	2.12	2.19	1.88	2.07	1.95	1.97
1984	2.70	2.60	2.63	2.64	2.70	2.51	2.51	2.57	2.70	2.65	2.80	2.72
1983	3.33	3.35	3.28	3.32	3.00	2.93	3.30	3.08	3.13	3.37	3.19	3.23
1982	2.66	2.79	2.81	2.75	2.64	2.70	2.92	2.75	2.65	2.57	2.47	2.56
1981	2.86	2.95	3.05	2.95	3.38	3.52	3.48	3.46	3.00	3.06	2.96	3.00
1980	2.35	2.50	2.81	2.55	2.56	2.52	2.50	2.53	2.32	2.27	2.57	2.39
1979	3.40	3.40	3.24	3.35	3.50	3.41	3.40	3.44	3.39	3.53	3.60	3.51
1978	3.09	3.04	3.19	3.11	3.51	3.41	3.52	3.48	3.12	3.09	3.14	3.12
1977	3.22	3.46	3.66	3.45	3.50	3.18	3.38	3.35	3.33	3.09	3.19	3.20
1976	1.87	1.76	1.97	1.87	1.58	1.70	1.79	1.69	1.54	1.86	1.67	1.69
1975	3.65	3.67	3.38	3.57	3.51	3.60	3.65	3.59	4.00	3.94	4.04	3.99
1974	2.15	2.00	2.13	2.09	1.99	2.13	1.92	2.01	2.17	2.23	2.17	2.19
1973	3.56	3.59	3.29	3.48	3.58	3.77	3.58	3.64	3.94	4.04	4.00	3.99
1972	4.14	4.47	4.36	4.32	4.42	4.33	4.12	4.29	4.01	4.00	3.99	4.00
1971	3.77	3.83	3.67	3.76	3.58	3.51	3.52	3.54	3.87	4.13	4.04	4.01
1970	2.93	2.83	2.85	2.87	3.08	2.95	3.04	3.02	3.05	2.98	2.91	2.98
1969	3.44	3.35	3.83	3.54	3.60	4.07	3.57	3.75	3.38	3.23	3.51	3.37
1968	2.15	2.30	2.40	2.28	2.42	2.19	2.12	2.24	2.48	2.56	2.39	2.48
1967	2.42	2.26	2.22	2.30	2.32	2.40	2.19	2.30	2.48	2.59	2.34	2.47
1966	3.09	3.10	2.85	3.01	3.21	3.14	3.26	3.20	3.23	3.03	3.14	3.13
1965	2.99	2.89	3.12	3.00	2.64	2.67	2.42	2.58	2.68	2.58	2.61	2.62

1964	2.94	2.87	3.12	2.98	2.63	2.51	2.73	2.62	2.79	2.99	2.83	2.87
1963	3.35	3.43	3.35	3.38	3.27	3.39	3.47	3.38	3.36	3.29	3.27	3.31
1962	3.68	3.68	3.64	3.67	3.41	3.64	3.16	3.40	3.69	3.73	3.67	3.70
1961	3.96	3.99	4.29	4.08	4.11	4.21	4.20	4.17	4.51	4.26	4.33	4.37
1960	3.16	3.11	3.24	3.17	3.58	3.3	3.36	3.41	3.31	3.25	3.36	3.31
1959	3.35	2.99	3.12	3.15	2.55	2.35	2.48	2.46	2.48	2.53	2.55	2.52
1958	3.60	3.68	3.51	3.60	3.96	3.95	3.97	3.96	4.46	4.40	4.21	4.36
1957	5.00	5.44	5.59	5.34	5.41	5.47	5.13	5.34	5.46	5.68	5.46	5.53
1956	3.46	3.44	2.98	3.29	3.19	2.99	3.25	3.14	3.19	3.02	2.88	3.03
1955	2.74	2.80	3.25	2.93	2.99	3.05	2.97	3.00	3.33	3.48	3.23	3.35
1954	2.82	2.75	3.01	2.86	2.77	3.05	2.95	2.92	2.68	2.61	2.50	2.60
1953	1.59	1.53	1.48	1.53	2.31	2.48	2.32	2.37	1.33	3.22	3.19	2.58
1952	2.26	2.29	2.13	2.23	2.46	2.84	2.62	2.64	2.60	2.82	2.71	2.71
1951	5.39	5.09	4.99	5.16	4.81	4.85	4.58	4.75	4.58	4.45	4.41	4.48
1950	2.20	2.42	2.31	2.31	2.56	2.49	2.45	2.50	2.60	2.67	2.64	2.64
1949	4.13	3.92	4.05	4.03	4.01	4.07	4.00	4.03	4.14	3.97	3.77	3.96
1948	3.78	3.96	3.41	3.72	3.69	3.64	3.56	3.63	3.87	4.22	3.54	3.88
1947	4.58	4.66	4.70	4.65	4.43	4.75	4.37	4.52	4.58	4.91	4.78	4.76
1946	3.55	3.68	3.78	3.67	2.71	2.68	2.69	2.69	2.10	2.11	2.06	2.09
1945	3.29	2.69	3.24	3.07	3.36	3.47	3.34	3.39	3.76	3.24	3.44	3.48
1944	5.80	6.27	6.16	6.08	6.30	6.25	6.26	6.27	6.16	6.40	6.20	6.25
1943	3.08	2.78	2.73	2.86	3.02	3.04	3.03	3.03	3.25	3.22	3.09	3.19
1942	2.62	2.96	2.63	2.74	2.73	2.78	2.71	2.74	2.85	3.13	3.10	3.03
1941	4.60	4.68	4.31	4.53	4.55	4.54	4.60	4.56	4.51	4.75	4.48	4.58
1940	3.57	3.71	3.58	3.62	3.69	3.85	3.5	3.68	3.82	3.64	3.79	3.75
1939	2.99	3.28	2.95	3.07	3.26	3.12	3.19	3.19	3.43	3.65	3.60	3.56
1938	3.59	3.55	3.36	3.50	3.54	3.61	3.69	3.61	3.50	3.74	3.75	3.66
1937	3.74	3.82	3.66	3.74	3.85	3.71	3.73	3.76	3.62	3.40	3.50	3.51
1936	5.04	4.96	4.79	4.93	5.68	5.91	4.78	5.46	5.92	5.45	5.58	5.65
1935	2.93	2.77	2.24	2.65	2.01	2.00	2.22	2.08	2.10	2.09	1.95	2.05
1934	2.47	2.30	2.39	2.39	2.35	2.45	2.41	2.40	2.48	2.29	2.49	2.42
1933	2.91	2.88	3.04	2.94	3.26	3.22	3.04	3.17	3.31	3.45	3.55	3.44

1932	3.62	4.19	3.77	3.86	4.02	3.99	4.11	4.04	4.06	3.98	4.10	4.05
1931	2.91	3.16	3.11	3.06	3.76	3.77	3.78	3.77	3.66	3.56	3.84	3.69
1930	7.43	7.67	7.81	7.64	7.85	7.85	7.78	7.83	7.50	8.04	7.94	7.83
1929	3.97	4.58	5.3	4.62	4.65	4.56	4.52	4.58	4.58	4.11	4.11	4.27
1928	3.64	4.05	3.77	3.82	3.98	3.87	3.83	3.89	4.27	4.05	4.17	4.16
1927	3.90	4.71	5.11	4.57	5.15	5.29	4.82	5.09	5.33	5.19	5.40	5.31
1926	4.06	3.95	3.78	3.93	4.29	4.23	4.16	4.23	4.27	4.46	4.31	4.35
1925	4.47	4.65	4.62	4.58	4.28	4.50	4.52	4.43	4.00	4.12	4.07	4.06
1924	9.97	9.97	10.07	10.00	9.13	9.04	9.22	9.13	9.03	8.34	9.10	8.82
1923	4.38	3.74	4.16	4.09	3.97	4.23	3.84	4.01	3.82	4.01	4.48	4.10
1922	3.77	3.83	4.25	3.95	4.33	3.96	3.30	3.86	3.94	3.42	3.96	3.77
1921	4.44	4.39	4.35	4.39	4.13	4.08	4.18	4.13	3.76	3.71	3.56	3.68
1920	5.21	5.53	5.35	5.36	5.50	6.00	6.05	5.85	6.01	5.88	5.92	5.94
1919	3.34	3.50	3.39	3.41	3.61	3.32	3.39	3.44	2.98	2.99	2.94	2.97
1918	5.94	6.32	5.75	6.00	5.79	5.88	5.63	5.77	5.98	6.18	5.86	6.01
1917	3.15	2.95	2.66	2.92	2.90	3.20	2.97	3.02	3.25	3.52	3.48	3.42
1916	2.83	2.67	2.56	2.69	2.80	3.01	2.65	2.82	3.24	3.23	3.24	3.24
1915	2.34	2.79	2.19	2.44	2.15	2.33	2.59	2.36	2.22	2.60	2.46	2.43
1914	3.13	3.06	3.11	3.10	2.64	2.82	2.81	2.76	3.06	3.01	2.98	3.02
1913	3.08	3.15	2.93	3.05	3.30	3.44	3.75	3.50	3.24	3.36	3.36	3.32
1912	3.48	3.43	3.11	3.34	3.45	3.20	2.91	3.19	3.55	3.86	3.62	3.68
1911	2.17	2.14	2.36	2.22	2.42	2.44	2.41	2.42	2.54	2.68	2.71	2.64
1910	4.04	4.27	4.32	4.21	4.02	3.87	4.16	4.02	4.00	4.04	4.11	4.05
1909	4.26	3.79	4.22	4.09	3.89	3.93	3.90	3.91	4.20	4.42	4.38	4.33
1908	4.20	4.24	3.56	4.00	3.92	4.20	4.04	4.05	3.95	3.95	3.82	3.91
1907	4.45	4.46	4.37	4.43	4.56	4.63	4.80	4.66	4.76	4.96	4.77	4.83
1906	5.49	5.60	5.25	5.45	5.16	5.11	5.30	5.19	5.07	5.13	5.02	5.07
1905	4.63	4.75	4.61	4.66	4.88	4.70	4.94	4.84	5.02	5.06	5.01	5.03
1904	2.73	2.11	2.09	2.31	2.51	2.33	2.52	2.45	2.23	2.54	2.32	2.36
1903	2.45	3.24	2.51	2.73	2.60	2.74	2.66	2.67	3.05	2.89	3.10	3.01
1902	2.83	3.02	3.29	3.05	3.05	2.98	3.13	3.05	3.05	3.08	3.27	3.13
1901	3.68	3.99	3.42	3.70	3.91	3.85	3.76	3.84	3.95	3.62	3.94	3.84

1900	5.04	4.76	4.19	4.66	4.43	4.96	4.97	4.79	4.83	4.72	5.08	4.88
1899	2.77	3.10	2.48	2.78	2.29	2.62	2.83	2.58	2.30	2.42	2.33	2.35
1898	5.87	5.88	6.27	6.01	6.05	5.89	5.97	5.97	5.92	5.60	5.76	5.76
1897	3.09	3.29	3.59	3.32	3.67	3.01	3.41	3.36	3.25	3.12	3.01	3.13
1896	3.32	3.04	3.24	3.20	3.29	3.07	3.19	3.18	3.18	3.44	3.58	3.40
1895	3.41	3.23	3.20	3.28	2.90	3.08	3.16	3.05	3.38	3.57	3.52	3.49
1894	4.14	4.33	4.50	4.32	4.38	4.28	4.41	4.36	4.51	4.05	4.29	4.28
1893	3.94	3.91	3.61	3.82	3.69	3.87	3.77	3.78	3.63	3.56	3.40	3.53
1892	3.01	2.71	2.76	2.83	2.46	2.68	2.59	2.58	2.92	2.70	2.83	2.82
1891	4.96	4.59	4.95	4.83	4.68	4.81	4.47	4.65	4.46	4.29	4.16	4.30
1890	7.29	7.15	7.14	7.19	6.83	6.78	6.69	6.77	6.60	6.63	6.42	6.55
1889	3.31	3.46	3.25	3.34	3.25	3.40	3.18	3.28	3.55	3.49	3.29	3.44
1888	3.78	3.54	3.42	3.58	4.26	3.49	4.09	3.95	3.62	3.70	3.47	3.60
1887	3.78	4.12	3.96	3.95	3.79	3.77	3.50	3.69	4.20	3.99	4.12	4.10
1886	4.80	4.47	4.51	4.59	4.53	4.34	4.68	4.52	4.13	4.36	4.47	4.32
1885	3.65	3.85	4.15	3.88	3.88	3.58	3.98	3.81	3.95	4.12	4.06	4.04
1884	5.34	4.99	5.31	5.21	5.27	5.24	5.06	5.19	5.27	5.04	4.92	5.08
1883	4.99	4.91	5.03	4.98	4.71	4.81	5.02	4.85	4.58	4.87	5.16	4.87
1882	2.76	2.92	3.27	2.98	3.16	2.84	2.99	3.00	2.74	2.76	2.57	2.69
1881	4.24	4.38	4.09	4.24	4.17	4.81	4.73	4.57	4.76	5.02	4.96	4.91
1880	4.33	4.12	4.55	4.33	5.14	4.14	5.13	4.80	4.39	4.32	4.49	4.40
1879	3.57	3.01	3.27	3.28	3.07	3.41	3.08	3.19	3.68	3.37	3.58	3.54
1878	4.42	4.35	5.03	4.60	4.00	4.71	4.01	4.24	4.58	4.50	4.59	4.56
1877	3.67	3.20	3.50	3.46	3.62	3.13	3.64	3.46	3.62	3.88	3.73	3.74
1876	3.21	3.34	3.28	3.28	3.23	3.05	3.16	3.15	2.74	2.96	2.81	2.84
1875	3.91	3.78	4.14	3.94	4.29	4.42	4.20	4.30	4.38	4.65	4.45	4.49
1874	5.20	5.45	5.74	5.46	5.10	5.22	5.11	5.14	5.00	5.01	4.81	4.94
1873	4.79	4.39	4.51	4.56	3.39	3.51	3.35	3.42	3.81	3.21	3.68	3.57
1872	3.24	2.80	2.77	2.94	2.87	2.82	3.25	2.98	2.99	3.27	2.96	3.07
1871	4.66	4.47	4.66	4.60	5.17	4.77	4.21	4.72	4.65	4.76	4.86	4.76
1870	5.06	4.30	4.66	4.67	4.02	4.59	4.39	4.33	3.94	4.08	3.98	4.00
1869	4.12	4.12	4.15	4.13	4.29	5.03	4.61	4.64	5.03	4.64	5.46	5.04

1868	3.17	3.89	4.22	3.76	4.26	4.25	4.26	4.26	4.20	4.60	4.31	4.37
1867	3.09	3.44	3.26	3.26	3.19	3.26	3.27	3.24	3.25	3.42	3.18	3.28
1866	3.89	3.61	3.26	3.59	3.23	2.77	3.14	3.05	3.56	3.80	3.77	3.71
1865	3.79	3.73	3.74	3.75	3.61	3.87	3.97	3.82	3.88	3.74	3.61	3.74
1864	3.81	3.57	3.68	3.69	3.63	3.70	3.77	3.70	3.68	3.86	3.73	3.76
1863	5.73	5.00	4.93	5.22	5.58	5.31	5.23	5.37	5.35	5.29	5.23	5.29
1862	4.15	3.92	3.84	3.97	3.86	4.00	3.90	3.92	4.04	3.99	4.01	4.01
1861	2.51	2.89	2.62	2.67	2.54	2.76	2.88	2.73	2.98	3.34	3.27	3.20
1860	3.34	3.22	3.36	3.31	3.80	3.90	4.01	3.90	3.95	3.98	4.14	4.02
1859	4.00	3.99	3.93	3.97	3.86	3.67	3.80	3.78	3.87	3.78	3.89	3.85
1858	4.83	5.07	5.01	4.97	4.75	4.52	4.62	4.63	4.84	4.78	4.88	4.83
1857	4.33	3.91	4.32	4.19	3.64	3.48	3.62	3.58	3.62	3.55	3.74	3.64
1856	4.98	5.61	5.25	5.28	5.33	5.31	4.87	5.17	5.47	5.45	5.35	5.42
1855	3.41	3.16	3.35	3.31	2.79	3.29	3.25	3.11	3.37	3.27	3.39	3.34
1854	3.49	3.94	3.66	3.70	4.03	3.55	3.17	3.58	3.63	3.70	3.67	3.67
1853	5.37	5.13	4.73	5.08	5.19	5.21	4.88	5.09	5.15	5.12	5.24	5.17
1852	3.85	4.29	4.09	4.08	4.63	4.28	4.13	4.35	4.57	4.19	4.49	4.42
1851	4.13	3.89	3.59	3.87	3.75	3.66	3.44	3.62	3.63	3.78	3.66	3.69
1850	3.33	3.24	3.15	3.24	2.93	3.29	3.04	3.09	2.98	2.87	2.99	2.95
1849	2.94	2.92	2.78	2.88	2.30	2.18	2.12	2.20	1.91	1.56	1.87	1.78
1848	2.92	2.88	3.00	2.93	2.82	2.75	3.01	2.86	2.54	2.67	2.51	2.57
1847	3.14	3.26	3.01	3.14	3.12	3.36	3.24	3.24	3.63	3.68	3.74	3.68
1846	2.41	2.40	2.5	2.44	2.23	2.18	2.08	2.16	1.84	2.06	1.89	1.93
1845	3.68	3.63	3.36	3.56	3.73	3.12	3.27	3.37	3.31	3.63	3.51	3.48
1844	4.10	3.93	4.05	4.03	3.81	3.76	4.06	3.88	4.00	4.10	4.04	4.05
1843	3.37	3.72	3.01	3.37	3.46	3.28	3.07	3.27	3.18	3.34	3.42	3.31
1842	4.02	4.59	3.89	4.17	4.11	3.94	3.86	3.97	4.01	3.92	4.04	3.99
1841	3.78	3.77	3.89	3.81	3.81	3.88	3.73	3.81	3.87	3.81	3.53	3.74
1840	2.52	2.43	2.50	2.48	2.53	2.42	2.39	2.45	2.42	2.56	2.27	2.42
1839	3.05	3.00	3.10	3.05	3.38	3.54	3.52	3.48	3.60	3.62	3.51	3.58
1838	3.22	3.10	3.15	3.16	2.84	2.49	2.27	2.53	2.49	2.59	2.66	2.58
1837	2.81	3.00	2.90	2.90	3.38	3.48	3.46	3.44	3.56	3.93	3.69	3.72

1836	3.31	3.06	3.15	3.17	2.50	3.09	3.28	2.96	3.18	3.24	3.39	3.27
1835	4.84	4.75	4.00	4.53	5.46	5.01	4.89	5.12	4.96	4.89	4.78	4.88
1834	2.90	3.06	2.97	2.98	2.60	2.90	3.09	2.86	2.92	2.90	3.06	2.96
1833	4.18	4.84	4.30	4.44	4.78	4.01	4.52	4.44	4.06	4.07	4.10	4.08
1832	2.25	2.47	2.50	2.41	2.48	1.99	2.21	2.23	2.36	2.67	2.52	2.52
1831	3.05	3.07	3.01	3.04	4.11	3.73	3.92	3.92	3.68	3.79	3.64	3.70
1830	4.03	3.83	4.04	3.97	3.97	3.88	4.04	3.96	3.88	3.83	3.64	3.78
1829	3.08	2.85	2.93	2.95	2.93	3.38	2.96	3.09	2.60	2.83	2.75	2.73
1828	3.88	3.59	4.08	3.85	3.40	3.46	3.79	3.55	3.43	3.72	3.56	3.57
1827	4.89	4.72	4.89	4.83	4.42	4.84	4.88	4.71	4.96	4.80	4.68	4.81
1826	5.10	5.49	5.28	5.29	5.27	5.03	5.28	5.19	5.28	5.23	5.19	5.23
1825	4.52	4.46	4.65	4.54	3.99	4.05	3.99	4.01	4.00	3.99	4.03	4.01
1824	3.82	3.59	x	3.71	3.74	3.66	3.62	3.67	3.29	3.09	3.14	3.17
1823	3.57	3.97	3.34	3.63	3.66	3.94	3.15	3.58	3.87	3.45	3.87	3.73
1822	3.12	3.59	3.79	3.50	3.48	3.77	3.90	3.72	3.50	3.72	3.60	3.61
1821	3.49	3.59	3.49	3.52	3.39	3.48	3.76	3.54	3.18	3.48	3.60	3.42
1820	4.63	4.53	4.50	4.55	4.55	4.82	4.58	4.65	4.89	4.61	4.49	4.66
1819	3.65	3.68	3.59	3.64	3.76	3.64	3.65	3.68	3.69	3.77	3.69	3.72
1818	2.33	2.47	2.37	2.39	3.30	3.20	3.09	3.20	2.73	3.06	3.10	2.96
1817	4.03	3.77	3.57	3.79	3.74	4.11	3.56	3.80	4.01	4.11	4.07	4.06
1816	3.61	3.96	3.57	3.71	4.52	4.09	4.14	4.25	4.36	4.41	4.38	4.38
1815	3.34	3.59	3.17	3.37	3.17	3.17	2.91	3.08	3.05	3.05	3.12	3.07
1814	4.41	3.97	4.42	4.27	4.03	4.16	3.99	4.06	4.39	4.35	4.21	4.32
1813	4.10	4.54	4.18	4.27	4.71	4.44	4.42	4.52	4.32	4.02	4.18	4.17
1812	3.80	3.59	3.67	3.69	3.84	3.95	3.81	3.87	4.08	4.48	4.28	4.28
1811	4.54	4.55	4.57	4.55	4.89	4.52	4.90	4.77	4.57	4.46	4.35	4.46
1810	3.85	3.30	3.47	3.54	3.16	3.27	3.26	3.23	3.63	3.55	3.62	3.60
1809	4.85	5.08	5.18	5.04	4.98	5.03	5.19	5.07	5.54	5.27	5.38	5.40
1808	4.33	4.34	4.36	4.34	4.12	4.16	4.26	4.18	3.68	3.90	3.72	3.77
1807	2.46	2.73	2.58	2.59	2.29	2.67	2.70	2.55	2.61	2.98	3.04	2.88
1806	4.62	5.03	4.64	4.76	5.24	4.47	4.96	4.89	4.51	4.63	4.54	4.56
1805	1.97	1.96	2.13	2.02	2.02	1.90	1.95	1.96	2.11	1.96	2.08	2.05

1804	4.55	4.77	4.45	4.59	4.89	4.84	4.87	4.87	5.14	5.36	5.17	5.22
1803	3.95	4.12	4.26	4.11	3.05	2.97	3.14	3.05	3.06	2.68	2.80	2.85
1802	1.80	1.68	1.76	1.75	1.64	1.53	1.54	1.57	1.72	1.58	1.47	1.59
1801	2.17	2.47	2.64	2.43	2.33	2.52	2.55	2.47	2.86	2.50	2.34	2.57
1800	2.37	2.46	2.28	2.37	2.29	2.25	2.31	2.28	2.67	2.71	2.80	2.73
1799	3.16	2.81	2.79	2.92	2.67	3.05	2.90	2.87	2.74	2.62	2.87	2.74
1798	3.38	3.09	3.23	3.23	4.21	3.98	4.11	4.10	4.26	4.10	4.50	4.29
1797	3.65	3.30	3.16	3.37	3.51	3.49	3.76	3.59	3.63	3.92	3.80	3.78
1796	2.37	3.04	3.00	2.80	2.30	2.30	2.31	2.30	1.97	2.09	2.00	2.02
1795	2.88	2.81	2.20	2.63	2.88	2.57	2.35	2.60	2.86	2.99	3.02	2.96
1794	3.80	3.88	3.43	3.70	3.54	3.71	3.08	3.44	3.44	3.25	3.30	3.33
1793	2.23	2.45	2.39	2.36	2.24	2.18	2.23	2.22	2.39	2.70	2.51	2.53
1792	4.44	4.37	4.75	4.52	4.26	4.31	4.16	4.24	4.52	4.30	4.26	4.36
1791	3.56	3.62	3.86	3.68	3.88	3.74	3.51	3.71	3.49	3.45	3.28	3.41
1790	3.45	3.40	3.31	3.39	3.06	3.01	3.07	3.05	2.86	2.76	2.60	2.74
1789	2.69	2.43	2.20	2.44	3.37	3.31	3.65	3.44	3.31	3.46	3.23	3.33
1788	2.34	2.43	2.51	2.43	2.23	2.23	2.61	2.36	1.97	1.86	1.98	1.94
1787	2.54	2.48	2.47	2.50	2.57	2.56	2.64	2.59	2.54	2.69	2.42	2.55
1786	3.36	3.73	3.20	3.43	3.65	4.04	3.53	3.74	4.12	3.88	3.82	3.94
1785	6.75	6.82	6.96	6.84	6.73	6.90	6.71	6.78	6.49	6.23	6.01	6.24
1784	3.16	3.13	3.19	3.16	3.26	3.04	3.01	3.10	2.73	2.52	2.64	2.63
1783	4.08	4.15	3.86	4.03	4.23	4.03	3.86	4.04	3.82	3.98	3.94	3.91
1782	3.23	3.39	3.22	3.28	3.00	3.11	3.28	3.13	3.29	3.55	3.56	3.47
1781	3.37	3.15	3.62	3.38	3.15	3.01	3.15	3.10	3.38	3.15	2.97	3.17
1780	2.86	2.82	2.53	2.74	3.08	2.99	3.03	3.03	3.37	3.38	3.28	3.34
1779	5.78	5.8	5.48	5.69	6.03	5.9	6.43	6.12	6.68	6.23	6.56	6.49
1778	4.28	4.13	4.06	4.16	3.80	3.96	4.10	3.95	3.57	3.50	3.55	3.54
1777	3.95	4.01	3.79	3.92	4.10	3.72	4.38	4.07	4.38	4.32	4.43	4.38
1776	4.27	4.59	4.55	4.47	4.32	4.9	4.76	4.66	4.08	4.34	4.27	4.23
1775	3.48	3.14	3.66	3.43	3.74	3.55	3.64	3.64	3.68	3.62	3.55	3.62
1774	2.78	2.73	2.72	2.74	3.42	3.36	3.41	3.40	3.38	3.49	3.62	3.50
1773	4.29	3.90	3.97	4.05	3.86	4.00	4.44	4.10	4.95	4.37	4.42	4.58

1772	4.13	4.47	4.16	4.25	4.29	4.24	4.25	4.26	4.43	4.99	4.75	4.72
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GL17-04C												
	μCT measurements direction 1				μCT measurements direction 2				Thin section measurements			
Years	1 st Count	2 nd Count	3 rd Count	Mean	1 st Count	2 nd Count	3 rd Count	Mean	1 st Count	2 nd Count	3 rd Count	Mean
1957	5.65	5.62	5.66	5.64	5.47	5.52	5.35	5.45	5.20	4.89	5.02	5.04
1956	4.09	4.07	4.07	4.08	3.88	4.31	4.20	4.13	4.01	4.06	4.51	4.19
1955	3.16	3.22	3.31	3.23	3.56	3.31	3.48	3.45	3.36	3.51	3.18	3.35
1954	4.60	4.53	4.75	4.63	5.03	4.85	4.90	4.93	4.70	4.25	4.51	4.49
1953	2.71	2.42	2.57	2.57	3.04	3.09	2.59	2.91	1.95	1.98	2.77	2.23
1952	3.03	2.94	3.21	3.06	3.46	2.77	3.12	3.12	4.12	4.21	3.79	4.04
1951	5.13	5.08	5.03	5.08	4.72	5.31	5.36	5.13	5.60	5.59	5.64	5.61
1950	4.12	4.12	4.15	4.13	3.89	4.32	3.66	3.96	4.89	4.77	4.61	4.76
1949	3.96	3.97	4.08	4.00	4.84	4.31	4.65	4.60	3.64	3.70	3.79	3.71
1948	3.74	3.51	3.66	3.64	3.39	3.55	3.48	3.47	3.10	3.11	3.32	3.18
1947	6.20	6.09	5.65	5.98	6.08	5.89	5.58	5.85	5.40	5.07	5.12	5.20
1946	3.13	3.27	3.38	3.26	3.44	3.63	3.41	3.49	3.65	3.65	3.18	3.49
1945	3.42	3.39	3.49	3.43	2.99	3.36	3.11	3.15	3.28	3.47	3.21	3.32
1944	5.66	5.48	5.53	5.56	5.25	5.43	5.43	5.37	5.67	5.35	5.36	5.46
1943	2.85	2.95	2.83	2.88	3.19	2.90	2.97	3.02	2.59	2.66	3.10	2.78
1942	3.65	3.76	3.63	3.68	3.91	3.71	3.73	3.78	4.19	3.98	4.23	4.13
1941	7.21	7.28	7.03	7.17	7.51	7.33	7.02	7.29	7.21	7.63	7.28	7.37
1940	4.05	4.02	4.37	4.15	4.53	4.26	3.91	4.23	4.21	4.10	4.16	4.16
1939	3.43	3.37	3.23	3.34	3.20	3.08	3.40	3.23	3.86	4.12	3.86	3.95
1938	3.59	3.74	3.62	3.65	3.71	3.89	3.28	3.63	3.23	3.09	3.21	3.18
1937	3.95	3.89	3.61	3.82	3.92	3.35	3.82	3.70	3.66	3.91	3.95	3.84
1936	5.34	5.45	5.37	5.39	5.89	5.34	5.06	5.43	5.77	5.78	5.84	5.80
1935	2.14	1.99	1.83	1.99	2.20	1.87	1.91	1.99	1.73	1.99	2.08	1.93
1934	3.60	3.69	3.97	3.75	2.27	2.70	3.90	2.96	2.68	2.41	2.56	2.55
1933	3.49	3.34	3.06	3.30	2.88	2.75	2.78	2.80	3.28	3.22	3.18	3.23
1932	4.18	4.94	4.37	4.50	4.23	4.24	4.72	4.40	4.13	4.28	4.10	4.17

1931	3.26	3.18	3.14	3.19	2.78	3.66	3.08	3.17	4.24	4.24	4.21	4.23
1930	6.22	6.32	6.69	6.41	6.70	6.42	6.25	6.46	5.83	6.37	6.26	6.15
1929	4.85	4.49	4.96	4.77	5.38	5.34	4.71	5.14	4.08	4.05	4.09	4.07
1928	3.45	3.45	3.47	3.46	3.19	3.54	3.55	3.43	3.98	4.20	4.09	4.09
1927	6.28	6.46	6.11	6.28	5.60	6.60	6.33	6.18	6.30	6.27	6.18	6.25
1926	3.95	3.77	3.81	3.84	3.72	3.10	4.06	3.63	4.30	3.74	3.84	3.96
1925	5.37	5.37	5.17	5.30	5.41	5.71	5.13	5.42	4.08	3.86	3.79	3.91
1924	8.16	7.75	7.71	7.87	7.91	7.92	8.28	8.04	8.03	8.21	8.04	8.10
1923	5.03	5.02	4.53	4.86	5.12	5.24	5.14	5.17	5.19	4.83	4.71	4.91
1922	4.34	4.39	4.90	4.54	5.01	5.56	5.03	5.20	5.20	5.51	5.15	5.29
1921	5.05	5.00	5.54	5.20	4.40	4.30	4.10	4.27	3.65	3.39	3.72	3.59
1920	6.52	6.45	6.60	6.52	6.44	6.63	6.88	6.65	7.63	7.87	7.31	7.61
1919	3.98	4.24	4.50	4.24	4.23	4.31	4.37	4.30	3.33	3.40	3.47	3.40
1918	5.45	5.51	5.24	5.40	5.44	5.42	5.12	5.33	5.12	5.27	5.37	5.25
1917	2.97	2.66	1.72	2.45	1.63	1.66	1.63	1.64	1.85	1.96	1.87	1.89
1916	3.12	2.89	1.79	2.60	1.73	1.78	1.65	1.72	1.97	1.91	1.79	1.89
1915	3.78	3.91	3.62	3.77	3.07	3.40	3.62	3.36	3.81	3.64	3.54	3.66
1914	2.76	3.83	3.33	3.31	3.41	3.05	3.42	3.29	2.86	3.10	3.05	3.00
1913	2.80	3.13	3.79	3.24	3.35	3.47	3.43	3.42	3.56	3.66	3.67	3.63
1912	4.46	4.02	4.13	4.20	4.66	4.69	4.48	4.61	4.08	3.86	3.97	3.97
1911	4.01	4.69	4.39	4.36	4.00	4.11	4.25	4.12	4.46	4.48	4.51	4.48
1910	3.38	3.29	3.27	3.31	3.01	3.02	2.95	2.99	2.89	3.19	3.04	3.04
1909	3.93	3.56	3.94	3.81	3.86	3.86	4.19	3.97	3.77	3.69	3.84	3.77
1908	4.75	4.42	5.05	4.74	4.92	5.09	4.70	4.90	4.92	4.83	4.91	4.89
1907	3.68	3.60	3.44	3.57	3.38	3.31	3.58	3.42	2.82	3.01	2.93	2.92
1906	3.44	3.69	3.60	3.58	3.37	3.54	3.65	3.52	3.76	4.79	3.74	4.09
1905	4.40	4.25	4.42	4.36	4.48	4.49	4.15	4.37	4.43	3.97	4.13	4.18
1904	4.32	4.42	4.17	4.30	4.21	4.18	4.39	4.26	4.50	4.54	4.33	4.46
1903	3.14	2.78	3.11	3.01	2.82	2.90	3.02	2.91	2.82	2.16	1.92	2.30
1902	2.43	2.49	2.34	2.42	2.47	2.56	2.45	2.49	2.38	2.84	2.29	2.50
1901	3.49	3.16	2.87	3.17	2.96	2.96	3.07	3.00	3.02	3.05	3.07	3.04
1900	3.66	3.47	3.26	3.46	3.38	3.54	3.27	3.40	3.44	3.13	3.32	3.30

1899	4.00	4.00	4.01	4.00	4.01	4.01	3.86	3.96	3.45	3.57	3.69	3.57
1898	2.53	2.57	2.48	2.53	2.35	2.54	2.34	2.41	2.33	1.99	2.23	2.18
1897	3.93	4.03	3.99	3.98	4.07	4.07	4.09	4.08	4.09	4.24	4.10	4.14
1896	3.56	3.30	3.41	3.42	3.68	3.74	3.39	3.60	3.33	3.29	3.49	3.37
1895	4.84	4.69	4.70	4.74	4.72	4.89	4.71	4.77	4.96	4.78	4.84	4.86
1894	4.04	4.15	4.49	4.23	3.91	3.59	3.97	3.82	3.77	4.05	4.05	3.96
1893	4.86	4.87	5.24	4.99	4.53	4.94	4.51	4.66	4.97	4.54	4.79	4.77
1892	4.33	4.20	4.26	4.26	4.36	4.34	4.52	4.41	3.60	3.67	3.51	3.59
1891	3.53	4.06	3.42	3.67	3.79	3.52	3.53	3.61	3.98	3.61	3.71	3.77
1890	4.83	3.99	4.48	4.43	4.31	4.58	4.24	4.38	3.86	3.98	4.10	3.98
1889	5.18	5.05	5.38	5.20	5.25	5.25	5.29	5.26	4.92	5.22	5.24	5.13
1888	3.51	3.41	3.14	3.35	3.24	3.25	3.49	3.33	3.19	3.23	3.02	3.14
1887	3.98	3.81	4.08	3.96	3.93	3.86	4.04	3.94	3.64	3.73	3.66	3.68
1886	3.56	3.67	3.81	3.68	3.67	3.67	3.66	3.67	4.67	4.54	4.20	4.47
1885	4.54	4.73	4.40	4.56	5.03	4.86	4.81	4.90	4.02	4.19	3.94	4.05
1884	5.17	4.89	4.78	4.95	4.79	4.76	4.74	4.76	5.04	4.72	4.98	4.91
1883	4.85	5.45	4.98	5.09	4.97	5.34	5.02	5.11	5.24	5.17	4.98	5.13
1882	3.33	3.18	3.67	3.39	3.43	3.56	3.53	3.51	2.97	3.27	2.89	3.04
1881	2.66	2.85	2.69	2.73	2.68	2.91	2.61	2.73	2.65	2.65	2.71	2.67
1880	4.20	4.07	4.16	4.14	4.26	4.22	3.86	4.11	4.24	3.95	4.37	4.19
1879	5.18	4.67	4.95	4.93	4.80	5.20	5.36	5.12	4.76	4.88	4.87	4.84
1878	2.90	3.21	3.42	3.18	3.37	3.19	3.54	3.37	4.21	4.02	4.02	4.08
1877	4.75	4.92	4.80	4.82	5.11	5.04	5.08	5.08	4.61	4.61	4.58	4.60
1876	3.49	2.90	2.56	2.98	3.02	2.93	2.74	2.90	3.28	3.29	3.28	3.28
1875	2.46	2.90	2.84	2.73	2.77	3.22	2.51	2.83	2.60	2.59	2.68	2.63
1874	4.03	3.62	3.88	3.84	3.75	3.76	3.79	3.77	4.13	3.68	3.77	3.86
1873	4.15	4.08	3.95	4.06	4.20	3.92	4.18	4.10	3.85	4.18	3.90	3.98
1872	3.99	3.82	4.10	3.97	3.93	4.14	4.12	4.06	4.13	4.08	4.32	4.17
1871	2.63	2.88	2.53	2.68	2.58	2.80	2.89	2.76	2.75	2.79	2.68	2.74
1870	3.57	3.69	3.66	3.64	3.73	3.67	3.28	3.56	3.56	3.32	3.35	3.41
1869	3.72	3.72	3.46	3.63	3.67	3.58	3.6	3.62	3.49	3.50	3.61	3.54
1868	3.16	2.91	3.39	3.15	3.16	3.32	3.18	3.22	3.24	3.12	3.44	3.27

1867	2.65	2.47	2.41	2.51	2.08	2.57	2.43	2.36	3.33	3.57	3.10	3.33
1866	3.72	4.10	3.78	3.87	3.95	3.70	3.65	3.77	3.07	2.85	3.03	2.98
1865	3.31	3.00	2.96	3.09	2.94	3.05	2.96	2.98	3.61	3.94	3.62	3.72
1864	3.06	2.83	2.98	2.96	3.29	2.94	3.03	3.09	2.75	2.86	2.95	2.85
1863	3.47	3.84	3.66	3.66	3.43	3.69	3.69	3.60	3.72	3.56	3.65	3.64
1862	3.59	4.25	4.16	4.00	4.45	4.26	4.62	4.44	4.66	4.64	4.31	4.53
1861	4.98	5.18	5.44	5.20	5.93	6.07	5.72	5.91	4.54	4.51	5.52	4.86
1860	2.42	2.25	2.82	2.50	3.00	2.85	2.74	2.86	3.29	3.24	2.77	3.10
1859	3.22	4.02	3.39	3.54	3.79	3.24	3.32	3.45	3.55	3.65	3.39	3.53
1858	3.97	4.87	4.72	4.52	4.29	4.37	4.30	4.32	4.14	3.98	4.33	4.15
1857	7.87	8.12	8.15	8.05	7.86	8.46	8.08	8.13	7.37	7.24	7.54	7.38
1856	3.27	3.04	3.19	3.17	3.37	2.94	3.23	3.18	2.94	2.83	2.90	2.89
1855	3.90	3.74	3.60	3.75	3.66	3.79	3.91	3.79	3.66	3.87	3.97	3.84
1854	4.15	4.08	4.07	4.10	3.95	4.17	4.21	4.11	4.34	3.94	3.97	4.08
1853	3.58	3.37	3.65	3.53	3.66	3.60	3.62	3.63	3.24	3.47	3.57	3.42
1852	4.83	4.83	4.65	4.77	4.74	4.74	4.60	4.69	5.13	4.99	5.11	5.08
1851	3.23	3.61	3.35	3.40	3.66	3.86	3.69	3.74	4.51	3.82	3.86	4.06
1850	3.26	3.06	3.04	3.12	3.23	3.45	3.39	3.36	2.86	3.11	3.01	2.99
1849	4.85	5.21	4.65	4.90	4.96	4.98	4.81	4.92	5.57	5.08	5.02	5.22
1848	3.07	3.03	3.08	3.06	3.28	3.25	3.45	3.33	2.75	3.40	3.29	3.15
1847	2.62	2.41	2.41	2.48	2.40	2.57	2.65	2.54	2.38	2.28	2.58	2.41
1846	2.67	3.11	2.88	2.89	3.11	2.86	3.15	3.04	2.76	2.64	2.86	2.75
1845	3.30	3.29	3.24	3.28	3.24	3.63	3.07	3.31	3.81	4.42	4.15	4.13
1844	4.60	4.83	4.78	4.74	4.90	4.60	4.87	4.79	3.85	3.87	3.72	3.82
1843	2.95	2.84	3.31	3.03	2.95	3.33	3.15	3.14	3.44	2.92	3.59	3.32
1842	3.09	3.19	3.06	3.11	3.40	3.12	3.42	3.31	3.02	3.11	2.96	3.03
1841	2.28	2.66	2.44	2.46	2.39	2.23	2.06	2.23	2.75	2.66	2.50	2.64
1840	2.84	2.72	2.88	2.81	2.69	2.52	2.57	2.59	3.02	2.74	3.01	2.92
1839	3.20	3.22	3.39	3.27	3.48	3.38	3.33	3.40	3.40	3.14	3.49	3.34
1838	2.53	2.42	2.23	2.39	2.10	2.51	2.89	2.50	2.43	2.34	2.39	2.39
1837	3.02	2.98	3.05	3.02	2.74	2.79	2.67	2.73	3.02	2.96	3.02	3.00
1836	3.64	3.77	3.80	3.74	3.39	3.41	3.53	3.44	4.55	4.67	4.75	4.66

GL1705B												
	μCT measurements direction 1				μCT measurements direction 2				Thin section measurements			
Years	1 st Count	2 nd Count	3 rd Count	Mean	1 st Count	2 nd Count	3 rd Count	Mean	1 st Count	2 nd Count	3 rd Count	Mean
2016	2.42	2.45	1.91	2.26	2.03	2.26	1.95	2.08	2.03	2.06	2.02	2.04
2015	2.27	2.18	2.05	2.17	2.13	2.31	2.30	2.25	2.12	2.10	2.14	2.12
2014	2.42	2.51	2.38	2.44	2.29	2.31	2.38	2.33	2.02	2.35	2.23	2.20
2013	2.36	1.87	2.06	2.10	2.85	2.92	1.70	2.49	2.12	2.15	2.15	2.14
2012	2.90	3.31	2.41	2.87	2.92	2.69	2.39	2.67	2.02	2.01	1.96	2.00
2011	2.12	2.19	2.35	2.22	1.83	2.42	1.76	2.00	2.33	2.22	2.36	2.30
2010	1.66	2.19	2.10	1.98	1.70	1.92	1.76	1.79	1.91	2.04	1.97	1.97
2009	1.93	2.12	1.97	2.01	1.98	1.52	1.61	1.70	2.10	1.89	1.98	1.99
2008	2.37	3.07	2.29	2.58	2.90	2.49	2.20	2.53	2.43	2.41	2.58	2.47
2007	2.18	2.51	1.97	2.22	2.12	1.90	2.19	2.07	1.67	1.85	1.82	1.78
2006	2.38	2.45	2.22	2.35	2.90	2.29	2.33	2.51	2.22	2.14	2.22	2.19
2005	1.70	1.67	1.40	1.59	1.94	1.65	1.64	1.74	1.27	1.49	1.39	1.38
2004	1.98	2.17	1.78	1.98	2.13	2.22	1.79	2.05	2.19	2.13	2.16	2.16
2003	2.70	2.69	2.29	2.56	2.64	2.55	2.90	2.70	2.63	2.49	2.50	2.54
2002	2.32	2.30	2.41	2.34	2.71	2.71	2.55	2.66	2.48	2.39	2.45	2.44
2001	3.28	3.93	2.39	3.20	3.56	3.65	3.60	3.60	3.43	3.52	3.44	3.46
2000	2.48	2.08	2.62	2.39	2.29	2.27	2.44	2.33	2.81	2.72	2.84	2.79
1999	4.74	4.71	4.55	4.67	4.75	4.56	4.47	4.59	4.22	4.10	4.24	4.19
1998	4.00	4.02	4.01	4.01	3.99	4.18	4.21	4.13	3.15	3.68	3.50	3.44
1997	4.11	5.10	3.63	4.28	4.06	4.29	4.13	4.16	3.74	3.63	3.73	3.70
1996	4.75	5.94	4.39	5.03	4.32	5.22	4.28	4.61	4.11	4.17	4.11	4.13
1995	2.87	4.86	2.55	3.43	2.82	2.5	3.29	2.87	2.56	2.49	2.48	2.51
1994	2.99	3.55	2.71	3.08	3.01	3.03	3.23	3.09	2.90	2.87	3.01	2.93
1993	3.84	3.06	2.72	3.21	2.91	3.23	3.81	3.32	2.99	2.76	2.83	2.86
1992	3.54	3.55	3.81	3.63	3.87	3.65	4.01	3.84	3.61	3.84	3.77	3.74
1991	3.33	2.53	2.24	2.70	2.43	1.92	2.08	2.14	2.76	2.70	2.74	2.73
1990	3.36	3.09	3.24	3.23	2.50	2.48	2.23	2.40	3.06	2.98	3.13	3.06
1989	2.82	2.35	3.78	2.98	3.26	3.39	3.35	3.33	3.08	3.16	3.09	3.11

1988	2.35	1.89	2.37	2.20	2.44	2.48	2.82	2.58	2.88	2.68	2.79	2.78
1987	2.62	2.36	2.13	2.37	2.12	2.15	2.00	2.09	1.94	1.78	1.80	1.84
1986	2.89	2.66	2.54	2.70	2.78	2.80	2.91	2.83	2.71	2.69	2.74	2.71
1985	2.96	4.01	3.36	3.44	3.77	3.53	4.40	3.90	3.84	3.77	3.81	3.81
1984	3.08	2.98	2.81	2.96	3.05	3.23	2.48	2.92	3.01	3.05	3.20	3.09
1983	4.84	4.76	4.91	4.84	4.75	5.06	5.20	5.00	4.77	4.85	4.80	4.81
1982	2.79	3.09	2.92	2.93	3.07	3.10	x	3.09	2.73	2.77	2.56	2.69
1981	3.66	3.58	3.56	3.60	3.51	3.76	3.41	3.56	3.52	3.47	3.69	3.56
1980	3.49	3.49	3.38	3.45	3.49	4.66	3.98	4.04	4.38	3.77	3.63	3.93
1979	4.98	4.57	4.55	4.70	5.12	4.07	4.77	4.65	3.82	4.40	4.39	4.20
1978	4.69	4.75	4.64	4.69	3.93	3.73	4.60	4.09	4.76	4.57	4.47	4.60
1977	4.69	4.63	4.72	4.68	4.21	5.08	5.24	4.84	4.27	4.24	4.24	4.25
1976	4.35	4.56	4.72	4.54	4.24	4.06	3.92	4.07	4.50	4.75	4.58	4.61
1975	5.03	5.21	5.39	5.21	4.37	5.04	5.93	5.11	5.81	5.70	5.71	5.74
1974	4.09	4.00	3.93	4.01	3.20	4.06	4.41	3.89	4.17	4.23	4.21	4.20
1973	4.26	4.21	4.27	4.25	4.62	4.97	5.35	4.98	3.94	4.36	4.30	4.20
1972	11.6	11.03	11.25	11.29	10.18	11.48	11.37	11.01	10.80	10.63	10.53	10.65
1971	6.02	5.56	4.59	5.39	4.53	6.45	4.62	5.20	5.14	5.21	5.18	5.18
1970	4.92	4.09	3.94	4.32	4.00	4.12	3.83	3.98	4.23	4.09	4.12	4.15
1969	5.10	4.65	5.13	4.96	5.35	5.22	4.84	5.14	5.04	5.10	4.98	5.04
1968	4.30	5.25	5.21	4.92	5.72	4.65	4.49	4.95	5.09	5.14	5.22	5.15
GAP												
1835	4.17	4.18	4.55	4.30	4.55	4.21	4.38	4.38	4.29	4.36	4.36	4.34
1834	3.01	3.20	2.63	2.95	3.20	3.23	3.20	3.21	2.43	2.36	2.34	2.38
1833	4.42	4.05	3.87	4.11	4.47	3.96	4.22	4.22	3.75	3.99	3.82	3.85
1832	2.88	2.54	2.34	2.59	1.95	2.55	2.27	2.26	2.11	2.19	2.29	2.20
1831	3.12	3.05	2.79	2.99	3.70	3.41	3.57	3.56	3.08	3.14	3.07	3.10
1830	3.59	3.15	3.24	3.33	3.61	3.52	3.60	3.58	3.27	3.36	3.20	3.28
1829	2.78	3.39	3.54	3.24	2.85	2.99	2.92	2.92	2.69	2.84	2.80	2.77
1828	3.61	3.05	3.21	3.29	3.90	3.71	3.81	3.81	3.21	3.45	3.29	3.31
1827	4.15	3.75	3.79	3.90	4.64	4.15	4.41	4.40	4.23	3.99	4.12	4.11
1826	3.66	4.21	3.25	3.71	4.94	3.61	4.29	4.28	4.41	4.42	4.46	4.43

1825	5.16	4.87	5.41	5.15	4.35	5.88	5.2	5.14	3.96	3.96	4.02	3.98
1824	3.30	2.92	2.73	2.98	3.14	3.22	3.19	3.18	2.68	3.31	3.01	3.00
1823	2.62	2.62	2.71	2.65	2.49	2.49	2.49	2.49	2.92	2.91	2.96	2.93
1822	3.18	3.33	3.15	3.22	3.37	3.40	3.39	3.39	2.83	2.81	2.91	2.85
1821	4.16	3.95	4.08	4.06	3.92	3.95	3.97	3.95	3.88	3.72	3.80	3.80
1820	3.30	3.26	2.90	3.15	3.14	3.45	3.30	3.30	3.63	3.76	3.54	3.64
1819	3.55	3.60	3.08	3.41	2.93	3.25	3.09	3.09	3.00	3.08	3.12	3.07
1818	2.95	2.81	2.99	2.92	2.94	2.56	2.75	2.75	2.92	2.86	2.95	2.91
1817	3.10	3.32	3.21	3.21	3.23	3.25	3.24	3.24	3.19	3.40	3.16	3.25
1816	2.95	3.41	3.74	3.37	3.92	4.12	4.02	4.02	2.81	2.47	2.79	2.69
1815	3.10	2.50	2.29	2.63	2.46	2.12	2.29	2.29	2.67	3.02	3.05	2.91
1814	4.57	4.15	3.94	4.22	3.92	3.96	3.94	3.94	4.33	3.99	3.95	4.09
1813	3.67	3.23	3.57	3.49	3.30	3.27	3.31	3.29	2.86	2.98	2.52	2.79
1812	1.84	2.22	3.69	2.58	2.39	2.32	2.37	2.36	1.42	1.45	1.50	1.46
1811	1.74	2.07	3.96	2.59	2.07	1.99	2.03	2.03	2.86	2.87	2.86	2.86
1810	4.42	4.49	4.33	4.41	4.76	4.53	4.66	4.65	3.88	3.85	3.91	3.88
1809	3.11	3.05	3.07	3.08	3.23	2.94	3.10	3.09	2.99	3.14	3.01	3.04
1808	3.62	3.81	4.54	3.99	4.08	4.14	4.11	4.11	3.78	3.85	3.99	3.87
1807	4.31	4.18	4.23	4.24	4.53	4.24	4.39	4.39	3.93	3.74	3.96	3.88
1806	2.17	1.81	2.11	2.03	2.77	1.99	2.38	2.38	2.13	1.97	1.88	1.99
1805	4.44	4.59	4.33	4.45	4.23	4.88	4.53	4.55	3.79	3.77	3.86	3.81
1804	1.47	1.69	1.59	1.58	1.48	2.00	1.74	1.74	1.62	1.81	1.63	1.69
1803	5.03	5.43	5.45	5.30	4.40	6.07	5.24	5.24	7.15	7.23	7.19	7.19
1802	4.88	4.68	5.27	4.94	3.38	4.79	4.09	4.09	3.65	3.79	3.59	3.68
1801	2.16	2.76	2.48	2.47	2.48	2.71	2.60	2.60	2.77	2.76	2.74	2.76
1800	2.52	2.48	2.83	2.61	3.07	3.02	3.05	3.05	3.14	3.14	3.08	3.12
1799	2.46	2.33	2.40	2.40	2.46	2.47	2.47	2.47	2.57	2.60	2.77	2.65
1798	3.24	2.89	3.35	3.16	3.38	2.78	3.08	3.08	3.73	3.81	3.71	3.75
1797	2.20	2.45	2.69	2.45	2.61	2.62	2.63	2.62	2.11	2.06	2.26	2.14
1796	2.16	2.27	2.21	2.21	2.31	2.54	2.43	2.43	2.51	2.42	2.32	2.41
1795	2.56	2.75	2.64	2.65	2.84	2.86	2.85	2.85	3.31	3.20	3.32	3.28
1794	2.69	2.75	3.19	2.88	2.87	2.96	2.93	2.92	2.83	2.63	2.56	2.67

1793	2.69	2.58	2.33	2.53	3.01	2.56	2.79	2.79	2.64	2.60	2.66	2.63
1792	3.92	4.00	4.15	4.02	4.17	4.08	4.13	4.13	3.96	3.89	3.93	3.93
1791	3.61	3.75	3.93	3.76	3.84	3.92	3.88	3.88	3.75	3.94	3.76	3.81
1790	2.87	2.50	2.45	2.61	2.92	2.56	2.74	2.74	2.22	2.41	2.50	2.38
1789	2.65	2.54	2.68	2.62	2.84	2.80	2.82	2.82	3.33	3.17	3.28	3.26
1788	2.83	2.39	2.91	2.71	2.69	2.66	2.68	2.68	1.70	1.87	1.86	1.81
1787	3.02	2.90	2.91	2.94	3.15	3.24	3.20	3.20	2.86	3.14	3.12	3.04
1786	5.07	4.86	5.30	5.08	3.61	3.81	3.71	3.71	3.97	4.05	4.06	4.02
1785	3.23	3.47	3.40	3.37	5.07	4.86	4.98	4.97	4.43	4.48	4.64	4.52
1784	4.15	4.40	4.47	4.34	3.23	3.47	3.35	3.35	3.76	3.81	3.54	3.70
1783	3.54	3.23	3.69	3.49	4.15	4.40	4.28	4.28	3.98	3.65	4.08	3.90
1782	3.54	3.23	3.69	3.49	3.54	3.23	3.37	3.38	3.60	3.85	3.71	3.72
1781	3.04	3.23	3.31	3.19	3.53	3.23	3.38	3.38	2.75	2.95	2.94	2.88
1780	2.56	2.19	2.95	2.57	2.68	2.86	2.77	2.77	2.92	3.13	2.80	2.95
1779	4.91	4.30	4.15	4.45	4.72	4.94	4.83	4.83	5.46	5.58	5.46	5.50
1778	3.47	3.91	3.80	3.73	4.15	4.37	4.26	4.26	3.18	3.25	3.22	3.22
1777	3.21	3.09	3.30	3.20	3.09	3.51	3.30	3.30	3.65	3.23	3.68	3.52
1776	4.51	3.70	4.42	4.21	4.47	4.48	4.45	4.47	3.28	3.60	3.39	3.43
1775	3.37	3.06	2.90	3.11	2.52	3.27	3.03	2.94	2.86	2.45	2.83	2.71
1774	2.32	2.18	2.40	2.30	2.24	2.57	2.24	2.35	2.13	2.18	2.20	2.17
1773	2.87	2.95	2.67	2.83	2.82	2.96	2.84	2.87	3.28	2.95	3.17	3.13
1772	3.32	3.33	2.85	3.17	2.96	3.26	3.48	3.23	2.94	3.46	3.52	3.31
1771	2.81	3.12	3.31	3.08	3.25	3.36	3.34	3.32	3.24	3.11	3.37	3.24
1770	3.69	3.51	3.21	3.47	3.53	3.56	3.48	3.52	3.55	3.38	3.36	3.43
1769	2.49	2.35	2.29	2.38	2.48	2.07	2.68	2.41	2.17	2.52	2.39	2.36
1768	3.18	3.11	3.16	3.15	2.96	3.27	3.38	3.20	3.66	3.58	3.66	3.63
1767	2.70	2.50	2.26	2.49	3.05	2.96	2.4	2.80	2.65	2.60	2.63	2.62
1766	2.66	2.32	2.31	2.43	2.30	2.47	2.64	2.47	2.11	2.37	2.29	2.25
1765	2.40	2.66	2.31	2.46	2.49	2.87	2.8	2.72	3.45	3.71	3.71	3.62
1764	4.08	4.13	4.36	4.19	4.58	4.44	4.52	4.51	3.97	3.84	3.96	3.92
1763	2.64	2.27	2.31	2.41	2.48	2.27	2.24	2.33	2.71	2.94	2.88	2.84
1762	3.63	3.74	3.64	3.67	3.53	3.75	3.59	3.62	3.87	3.61	3.67	3.72

1761	3.78	3.70	3.64	3.71	3.83	3.55	3.99	3.79	3.49	3.50	3.49	3.49
1760	3.01	3.23	3.39	3.21	3.43	3.55	3.38	3.45	3.55	3.34	3.64	3.51
1759	4.02	3.78	4.01	3.94	4.10	3.75	4.02	3.96	4.09	4.37	4.04	4.17
1758	2.46	2.61	2.54	2.54	2.86	2.57	2.48	2.64	2.33	2.38	2.58	2.43
1757	2.66	2.53	2.24	2.48	2.96	2.39	2.47	2.61	2.60	2.53	2.51	2.55
1756	2.63	2.51	2.74	2.63	2.76	3.06	2.87	2.90	3.05	3.42	3.11	3.19
1755	2.60	2.90	3.84	3.11	3.06	3.65	3.07	3.26	3.03	3.12	3.00	3.05
1754	4.98	4.89	3.71	4.53	4.87	4.64	4.75	4.75	3.86	3.85	3.82	3.85
1753	3.43	3.83	4.09	3.78	4.49	3.75	4.31	4.18	4.51	4.31	4.64	4.49
1752	3.63	3.69	3.59	3.64	3.53	3.95	3.57	3.68	3.28	3.13	3.25	3.22
1751	3.43	2.97	3.67	3.36	3.68	3.66	3.77	3.70	3.18	3.05	3.18	3.13
1750	3.25	3.48	2.56	3.10	4.10	3.66	3.66	3.81	3.27	3.63	3.47	3.46
1749	3.40	3.11	3.67	3.39	3.34	3.95	3.76	3.68	3.50	3.48	3.43	3.47
1748	3.60	4.53	3.90	4.01	4.96	4.25	4.26	4.49	3.70	3.62	3.74	3.69
1747	2.10	1.49	1.69	1.76	2.10	2.28	2.23	2.20	2.22	2.58	2.45	2.42
1746	2.83	2.57	3.03	2.81	2.85	3.03	2.92	2.93	2.43	2.28	2.53	2.42
1745	1.80	1.75	1.60	1.72	1.75	1.87	1.68	1.77	1.91	2.04	1.88	1.94
1744	2.58	2.31	2.61	2.50	2.59	2.56	2.64	2.60	2.55	2.51	2.43	2.50
1743	2.17	2.28	2.07	2.17	2.52	2.47	2.52	2.50	2.38	2.75	2.66	2.60
1742	3.16	2.64	2.75	2.85	2.72	3.25	3.19	3.05	3.12	3.25	3.08	3.15
1741	4.07	3.47	3.56	3.70	4.40	4.44	4.23	4.36	4.93	4.91	4.88	4.91
1740	2.60	2.69	2.35	2.55	2.52	2.66	2.55	2.58	2.17	2.15	2.25	2.19
1739	2.32	2.29	2.27	2.29	2.46	2.47	2.34	2.42	2.76	2.92	2.63	2.77
1738	2.80	2.68	3.00	2.83	2.98	2.86	2.96	2.93	2.91	3.16	2.90	2.99
1737	3.82	3.95	3.49	3.75	3.69	3.06	3.28	3.34	2.90	2.67	3.00	2.86
1736	2.41	2.23	2.35	2.33	2.39	2.37	2.15	2.30	2.75	2.89	2.86	2.83
1735	2.38	2.45	2.37	2.40	2.20	2.37	2.44	2.34	2.00	2.09	2.06	2.05
1734	1.87	2.01	2.05	1.98	2.27	2.37	2.12	2.25	2.59	2.70	2.56	2.62
1733	3.46	2.87	3.37	3.23	3.36	2.86	3.1	3.11	2.91	2.76	2.95	2.87
1732	1.45	1.73	1.51	1.56	1.49	1.78	1.63	1.63	1.70	1.62	1.84	1.72
1731	3.88	4.03	4.18	4.03	4.27	4.73	4.28	4.43	4.29	4.20	4.47	4.32
1730	2.17	1.94	2.23	2.11	2.33	1.78	2.04	2.05	2.13	1.94	2.08	2.05

1729	1.91	1.74	1.72	1.79	1.88	1.97	1.68	1.84	1.64	1.84	1.77	1.75
1728	2.13	1.76	1.92	1.94	1.95	2.56	2.09	2.20	2.65	2.63	2.53	2.60
1727	2.95	2.98	2.84	2.92	3.10	3.06	3.22	3.13	2.71	2.81	2.87	2.80
1726	5.60	5.16	5.35	5.37	5.74	5.42	5.35	5.50	5.56	5.32	5.48	5.45
1725	2.35	2.26	2.3	2.30	2.53	2.56	2.52	2.54	2.55	2.43	2.52	2.50
1724	3.08	3.15	2.67	2.97	2.98	3.25	3.10	3.11	3.18	3.31	3.47	3.32
1723	4.93	5.14	4.91	4.99	5.39	5.32	5.22	5.31	4.96	4.75	4.75	4.82
1722	3.19	2.85	3.19	3.08	3.09	2.66	3.04	2.93	2.34	2.42	2.59	2.45
1721	2.66	2.26	2.43	2.45	2.52	2.56	2.66	2.58	2.65	2.86	2.81	2.77
1720	2.69	3.16	2.88	2.91	2.53	2.86	2.96	2.78	3.61	3.84	3.65	3.70
1719	2.50	2.49	2.23	2.41	2.18	2.66	2.57	2.47	3.02	2.97	2.94	2.98
1718	3.96	3.99	2.55	3.50	3.70	3.78	3.73	3.74	3.81	3.92	3.94	3.89
1717	1.91	1.94	1.77	1.87	2.65	2.30	2.24	2.40	2.13	2.39	2.26	2.26
1716	1.90	3.00	2.50	2.47	1.92	2.37	2.42	2.24	2.54	2.23	2.59	2.45
1715	2.55	1.76	1.79	2.03	1.53	1.82	1.92	1.76	2.01	2.05	1.97	2.01
1714	4.23	3.67	3.93	3.94	3.93	4.20	4.39	4.17	3.72	3.54	3.95	3.73
1713	1.67	1.66	1.34	1.56	1.42	1.34	1.66	1.47	1.64	1.46	1.57	1.56
1712	1.75	2.28	2.55	2.19	1.89	2.28	2.18	2.12	2.17	1.98	2.23	2.13
1711	2.45	2.42	2.21	2.36	2.67	2.42	2.42	2.50	2.23	2.15	2.23	2.20

445 **Author contributions**

Marie-Eugenie Jamba and Pierre Francus conceptualized the project. Marie-Eugenie Jamba performed the formal data analysis. Pierre Francus acquired funding. Marie-Eugenie Jamba and Antoine Gagnon-Poiré performed the investigation. Marie-Eugenie Jamba developed the methodology. Pierre Francus provided supervision. Marie-Eugenie Jamba wrote the original draft. Marie-Eugenie Jamba, Pierre Francus, and Guillaume St-Onge reviewed and edited the paper.

450 **Competing interests**

The authors declare that they have no conflict of interest.

Disclaimer

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References

Ahmed, O. M. H. and Song, Y.: A Review of Common Beam Hardening Correction Methods for Industrial X-ray Computed Tomography, *Sains Malaysiana*, 47, 1883-1890, 10.17576/jsm-2018-4708-29, 2018.

Altman, D. G. and Bland, J. M.: Measurement in Medicine: The Analysis of Method Comparison Studies, *Journal of the Royal Statistical Society. Series D (The Statistician)*, 32, 307-317, 10.2307/2987937, 1983.

Amann, B., Lamoureux, S. F., and Boreux, M. P.: Winter temperature conditions (1670–2010) reconstructed from varved sediments, western Canadian High Arctic, *Quaternary Science Reviews*, 172, 1-14, <https://doi.org/10.1016/j.quascirev.2017.07.013>, 2017.

Ay, M. R., Mehranian, A., Maleki, A., Ghadiri, H., Ghafarian, P., and Zaidi, H.: Experimental assessment of the influence of beam hardening filters on image quality and patient dose in volumetric 64-slice X-ray CT scanners, *Phys Med*, 29, 249-260, 10.1016/j.ejmp.2012.03.005, 2013.

Ballo, E. G., Bajard, M., Støren, E., and Bakke, J.: Using microcomputed tomography (μ CT) to count varves in lake sediment sequences: Application to Lake Sagtjernet, Eastern Norway, *Quaternary Geochronology*, 75, 10.1016/j.quageo.2023.101432, 2023.

Bendle, J. M., Palmer, A. P., and Carr, S. J.: A comparison of micro-CT and thin section analysis of Lateglacial glaciolacustrine varves from Glen Roy, Scotland, *Quaternary Science Reviews*, 114, 61-77, 10.1016/j.quascirev.2015.02.008, 2015.

Brauer, A. and Casanova, J.: Chronology and depositional processes of the laminated sediment record from Lac d'Annecy, French Alps, *Journal of Paleolimnology*, 25, 163-177, 10.1023/A:1008136029735, 2001.

Brauer, A., Haug, G. H., Dulski, P., Sigman, D. M., and Negendank, J. F. W.: An abrupt wind shift in western Europe at the onset of the Younger Dryas cold period, *Nature Geoscience - NAT GEOSCI*, 1, 520-523, 10.1038/ngeo263, 2008.

Chatzinikolaou, E. and Keklikoglou, K.: Micro-CT protocols for scanning and 3D analysis of *Hexaplex trunculus* during its different life stages, *Biodiversity Data Journal*, 9, 10.3897/BDJ.9.e71542, 2021.

Cnudde, V. and Boone, M. N.: High-resolution X-ray computed tomography in geosciences: A review of the current technology and applications, *Earth-Science Reviews*, 123, 1-17, 10.1016/j.earscirev.2013.04.003, 2013.

- 490 Cornard, P. H., Degenhart, G., Tropper, P., Moernaut, J., and Strasser, M.: Application of micro-CT to resolve textural properties and assess primary sedimentary structures of deep-marine sandstones, *The Depositional Record*, <https://doi.org/10.1002/dep2.261>, 2023.
- Davis, G.: Development of two-dimensional beam hardening correction for X-ray micro-CT, *Journal of X-Ray Science and Technology*, 30, 1-12, 10.3233/XST-221178, 2022.
- 495 De Geer, G.: A Geochronology of the past 12,000 years, In *Compte rendu du Congrès Géologique International*. Stockholm, 11, 241-253, 1912.
- Dewanckele, J., Boone, M. A., Coppens, F., D, V. A. N. L., and Merkle, A. P.: Innovations in laboratory-based dynamic micro-CT to accelerate in situ research, *Journal of microscopy*, 277, 197-209, 10.1111/jmi.12879, 2020.
- Du Plessis, A., Broeckhoven, C., Guelpa, A., and Roux, S.: Laboratory x-ray micro-computed tomography: a user guideline for biological samples, *Gigascience*, 6, 1-11, 10.1093/gigascience/gix027, 2017.
- 500 Emmanouilidis, A., Unkel, I., Seguin, J., Keklikoglou, K., Gianni, E., and Avramidis, P.: Application of Non-Destructive Techniques on a Varve Sediment Record from Vouliagmeni Coastal Lake, Eastern Gulf of Corinth, Greece, *Applied Sciences*, 10, 10.3390/app10228273, 2020.
- 505 Fabbri, S. C., Sabatier, P., Paris, R., Falvard, S., Feuillet, N., Lothoz, A., St-Onge, G., Gailler, A., Cordrie, L., Arnaud, F., Biguenet, M., Coulombier, T., Mitra, S., and Chaumillon, E.: Deciphering the sedimentary imprint of tsunamis and storms in the Lesser Antilles (Saint Martin): A 3500-year record in a coastal lagoon, *Marine Geology*, 471, 107284, 10.1016/j.margeo.2024.107284, 2024.
- Francus, P.: An image-analysis technique to measure grain-size variation in thin sections of soft clastic sediments, *Sedimentary Geology*, 121, 289–298, 10.1016/s0037-0738(98)00078-5, 1998.
- Francus, P.: *Image Analysis, Sediments and Paleoenvironments*, Springer Dordrecht, 330 pp, 10.1007/1-4020-2122-4, 2006.
- 510 Francus, P. and Asikainen, C. A.: Sub-sampling unconsolidated sediments: a solution for the preparation of undisturbed thin-sections from clay-rich sediments, *Journal of Paleolimnology*, 26, 323-326, 10.1023/a:1017572602692, 2001.
- Francus, P. and Nobert, P.: An integrated computer system to acquire, process, measure and store images of laminated sediments in 4th International limnogeology congress, Barcelona, Spain, 11-14 July, 2007.
- 515 Francus, P., Bradley, R. S., Lewis, T., Abbott, M. B., Retelle, M., and Stoner, J. S.: Limnological and sedimentary processes at Sawtooth Lake, Canadian High Arctic, and their influence on varve formation, *Journal of Paleolimnology*, 40, 963-985, 10.1007/s10933-008-9210-x, 2008.
- Gagnon-Poiré, A., Brigode, P., Francus, P., Fortin, D., Lajeunesse, P., Dorion, H., and Trottier, A.-P.: Reconstructing past hydrology of eastern Canadian boreal catchments using clastic varved sediments and hydro-climatic modelling: 160 years of fluvial inflows, *Climate of the Past*, 17, 653-673, 10.5194/cp-17-653-2021, 2021.
- 520 Grenier, B., Dubreuil, M., and Journois, D.: Comparaison de deux méthodes de mesure d'une même grandeur : méthode de Bland et Altman, *Annales Francaises D Anesthesie Et De Reanimation - ANN FR ANESTH REANIM*, 19 128-135, 10.1016/S0750-7658(00)00109-X, 2000.
- Hardy, D. R., Bradley, R. S., and Zolitschka, B.: The climatic signal in varved sediments from Lake C2, northern Ellesmere Island, Canada, *Journal of Paleolimnology*, 16, 227-238, 10.1007/BF00176938, 1996.
- 525 Huguen, K. A.: Marine Varves, in: *Encyclopedia of Scientific Dating Methods*, edited by: Rink, W. J., and Thompson, J., Springer Netherlands, Dordrecht, 1-8, 10.1007/978-94-007-6326-5_162-1, 2013.
- Kemp, A. E. S.: *Palaeoclimatology and Palaeoceanography from Laminated Sediments*, Geological Society Special Publication 116, London, 258 pp, 1-897799-67-5, 1996.
- 530 Laeveren D. , S. R.: *Helical Scanning with Iterative Reconstruction Technology : The Next Generation in microCT*, ThermoFisher scientific, 2020.

- Lapointe, F., Francus, P., Stoner, J. S., Abbott, M. B., Balascio, N. L., Cook, T. L., Bradley, R. S., Forman, S. L., Besonen, M., and St-Onge, G.: Chronology and sedimentology of a new 2.9 ka annually laminated record from South Sawtooth Lake, Ellesmere Island in this NOAA depository: <https://www.ncdc.noaa.gov/paleo/study/33214>, Quaternary Science Reviews, 222, 10.1016/j.quascirev.2019.105875, 2019.
- 535 Lauterbach, S., Brauer, A., Andersen, N., Danielopol, D. L., Dulski, P., Hüls, M., Milecka, K., Namiotko, T., Obremska, M., and Von Grafenstein, U.: Environmental responses to Lateglacial climatic fluctuations recorded in the sediments of pre-Alpine Lake Mondsee (northeastern Alps), Journal of Quaternary Science, 26, 253-267, 10.1002/jqs.1448, 2011.
- Lisson, K., Van Daele, M., Schröer, L., and Cnudde, V.: An integrated methodology of micro-CT and thin-section analysis for paleoflow reconstructions in lacustrine event deposits, EGU General Assembly Conference Abstracts, Vienna, Austria, May 01, 2023, 10.5194/egusphere-egu23-14489, 2023.
- 540 Lotter, A. F. and Lemcke, G.: Methods for preparing and counting biochemical varves, Boreas, 28, 243-252, 10.1111/j.1502-3885.1999.tb00218.x, 2008.
- Martin-Puertas, C., Walsh, A. A., Blockley, S. P. E., Harding, P., Biddulph, G. E., Palmer, A. P., Ramisch, A., and Brauer, A.: The first Holocene varve chronology for the UK: Based on the integration of varve counting, radiocarbon dating and tephrostratigraphy from Diss Mere (UK), Quaternary Geochronology, 61, 101134, 10.1016/j.quageo.2020.101134, 2021.
- 545 McGuire, A. M., Smith, C. D., Chamberlin, J. H., Maisuria, D., Toth, A., Schoepf, U. J., O'Doherty, J., Munden, R. F., Burt, J., Baruah, D., and Kabakus, I. M.: Reduction of beam hardening artifact in photon-counting computed tomography: Using low-energy threshold polyenergetic reconstruction, Journal of cardiovascular computed tomography, 17, 356-357, 10.1016/j.jcct.2023.08.007, 2023.
- 550 Meganck, J. A., Kozloff, K. M., Thornton, M. M., Broski, S. M., and Goldstein, S. A.: Beam hardening artifacts in micro-computed tomography scanning can be reduced by X-ray beam filtration and the resulting images can be used to accurately measure BMD, Bone, 45, 1104-1116, 10.1016/j.bone.2009.07.078, 2009.
- Normandeau, A., Brown, O., Jarrett, K. A., Francus, P., and De Coninck, A.: Epoxy impregnation of unconsolidated marine sediment core subsamples for the preparation of thin sections at the Geological Survey of Canada (Atlantic), Geol. Surv. Canada., Technical Note 10, 10.4095/313055, 2019.
- 555 Ojala, A. E. K., Francus, P., Zolitschka, B., Besonen, M., and Lamoureux, S. F.: Characteristics of sedimentary varve chronologies – A review, Quaternary Science Reviews, 43, 45-60, 10.1016/j.quascirev.2012.04.006, 2012.
- Palmer, A. P., Bendle, J. M., MacLeod, A., Rose, J., and Thorndycraft, V. R.: The micromorphology of glaciolacustrine varve sediments and their use for reconstructing palaeoglaciological and palaeoenvironmental change, Quaternary Science Reviews, 226, 10.1016/j.quascirev.2019.105964, 2019.
- 560 Rana, N., Rawat, D., Parmar, M., Dhawan, D. K., Bhati, A. K., and Mittal, B. R.: Evaluation of external beam hardening filters on image quality of computed tomography and single photon emission computed tomography/computed tomography, Journal of medical physics, 40, 198-206, 10.4103/0971-6203.170790, 2015.
- Ranganathan P, P. C., Aggarwal R.: Common pitfalls in statistical analysis: Measures of agreement, Perspect Clin Res., 8, 187-191, 10.4103/picr.PICR_123_17, 2017.
- 565 Roop, H., Levy, R., Dunbar, G., Vandergoes, M., Howarth, J., Fitzsimons, S., Moon, H., Zammit, C., Ditchburn, R., Baisden, T., and Yoon, H.: A hydroclimate-proxy model based on sedimentary facies in an annually laminated sequence from Lake Ohau, South Island, New Zealand, Journal of Paleolimnology, 55, 1–16, 10.1007/s10933-015-9853-3, 2016.
- Schimmelmann, A., Lange, C. B., Schieber, J., Francus, P., Ojala, A. E. K., and Zolitschka, B.: Varves in marine sediments: A review, Earth-Science Reviews, 159, 215-246, 10.1016/j.earscirev.2016.04.009, 2016.
- 570 Sheppard, A., Latham, S., Middleton, J., Kingston, A., Myers, G., Varshot, T., Fogden, A., Sawkins, T., Cruikshank, R., Saadatfar, M., Francois, N., Arns, C., and Senden, T.: Techniques in helical scanning, dynamic imaging and image

segmentation for improved quantitative analysis with X-ray micro-CT, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 324, 49-56, 10.1016/j.nimb.2013.08.072, 2014.

575 Soreghan, M. and Francus, P.: Processing Backscattered Electron Digital Images of Thin Section, in: Image Analysis, Sediments and Paleoenvironments, edited by: Francus, P., Springer Netherlands, Dordrecht, 203-225, 10.1007/1-4020-2122-4_11, 2004.

580 Trottier, A. P., Lajeunesse, P., Gagnon-Poiré, A., and Francus, P.: Morphological signatures of deglaciation and postglacial sedimentary processes in a deep fjord-lake (Grand Lake, Labrador), Earth Surface Processes and Landforms, 45, 928-947, 10.1002/esp.4786, 2020.

Voltolini, M., Zandomenighi, D., Mancini, L., and Polacci, M.: Texture analysis of volcanic rock samples: Quantitative study of crystals and vesicles shape preferred orientation from X-ray microtomography data, Journal of Volcanology and Geothermal Research, 202, 83-95, 10.1016/j.jvolgeores.2011.02.003, 2011.

585 Żarczyński, M., Tylmann, W., and Goslar, T.: Multiple varve chronologies for the last 2000 years from the sediments of Lake Żabińskie (northeastern Poland) – Comparison of strategies for varve counting and uncertainty estimations, Quaternary Geochronology, 47, 107-119, 10.1016/j.quageo.2018.06.001, 2018.

Zolitschka, B., Francus, P., Ojala, A. E. K., and Schimmelmann, A.: Varves in lake sediments – a review, Quaternary Science Reviews, 117, 1-41, 10.1016/j.quascirev.2015.03.019, 2015.

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