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**Dendrochronology Lab**

# A Dendroarchaeological Analysis of a Violin

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## Abstract

In order to identify whether a violin bearing a Stradivarius label was indeed an authentic Stradivarius, the Mount Allison Dendrochronology Lab was contacted to determine the age of the wood. Silicone casts of the wood anatomy were taken and examined under a scanning electron microscope in order to identify the species of wood used. After comparing the ring-width measurements from the violin to chronologies of southern European forests, an end-date of 1877 was determined, establishing the violin as a copy.

## Introduction

Antonio Stradivari (1644-1737) was a Cremonese instrument-maker, most famous for his exceptional violins, whose high calibre and present-day value makes his name synonymous with superior quality and excellence. He built a number of instruments in his lifetime, but few survive today, and those remaining are treasured and treated with great care, spending their time in museums and in the hands of renowned musicians. Many have tried and failed to replicate Stradivari's genius in his work, and as a result thousands of Stradivari copies or fakes exist today; none with the truly magical sound and value only a Stradivarius can evoke. The chances of discovering a genuine Stradivarius are increasingly rare, and only a handful -if any- undiscovered Stradivari are thought to remain in existence.

However, in the fall of 2010, the Mount Allison Dendrochronology Lab was contacted by a client who, in the midst of home renovations, found an old violin hidden between the floors of the house. The violin showed signs of age, and bore the label 'Antonius Stradivarius, Cremonensis, Faciebat Anno 1734' (Figure 1). On the recommendation of a violin-builder and restorer in the United States, who examined the instrument and was able to confirm the quality of its construction, the client wished to have a dendrochronological analysis conducted in order to determine the end date of the violin, in order to assist in refuting or affirming the instrument's claim to authenticity. Dendroarchaeological applications in the field of stringed instruments have been carried out by numerous dendrochronologists over the past fifty years (see Bernabei et al., 2010;  Grissino-Mayer et al., 2004), with some success. While it is impossible for dendrochronological analysis to concretely prove that an instrument was made by Stradivarius himself, wood growth occurring after the violin was said to be made (1734) or after Stradivari's death (1737) would be able to effectively disprove the idea that the instrument is authentic. Likewise, an end date compatible with both the label and the maker's lifetime would lend strong support to the belief that the instrument is a genuine Stradivarius.

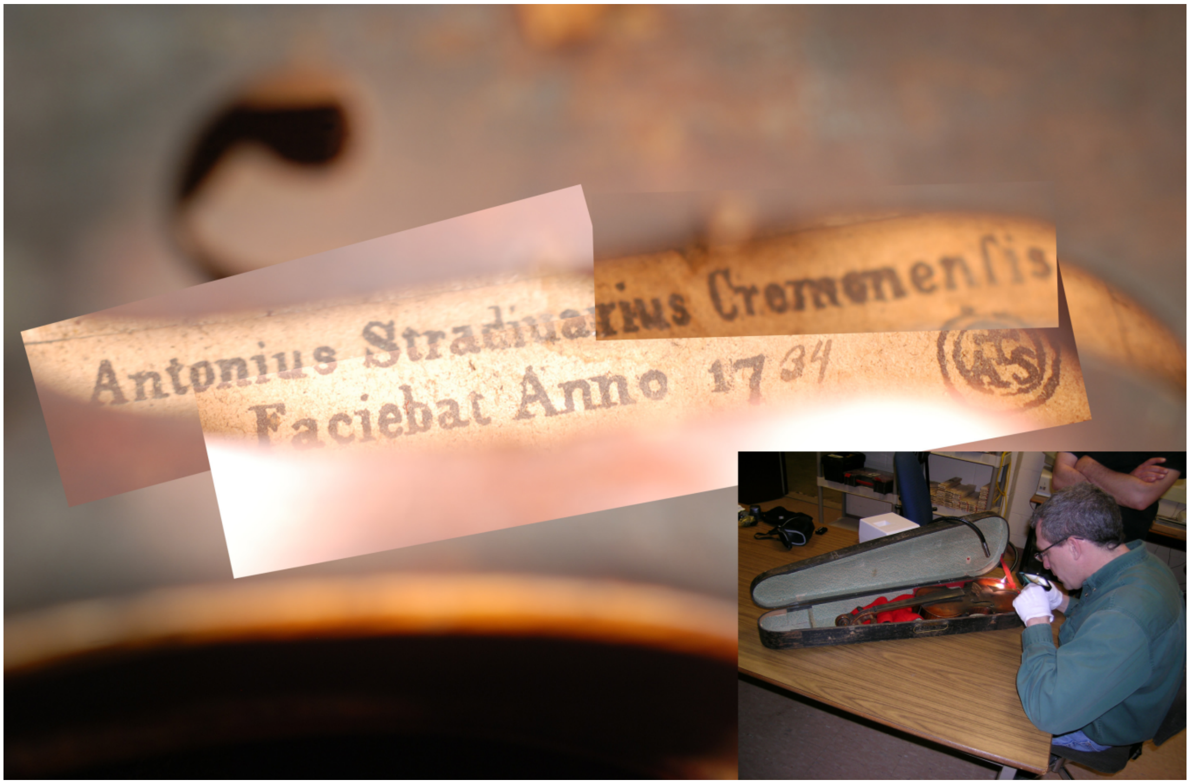


**Figure 1:** A composite photo showing the label on the inside of the violin. Inset: Dr. Colin Laroque examines the instrument.

**Methods**

In December 2010, the violin was brought to the lab in order to undergo a preliminary examination, where members of the lab determined the suitability of the visible tree rings to dendrochronological analysis. In order for dendrochronology to be a viable option, there must be a minimum of fifty to sixty years of growth rings visible and available to be measured. A quick examination of the violin revealed that the front of the instrument was made up of two halves, each with around 100 rings. While the wood of the violin was in good condition, the violin itself was dirty and showed evidence of resin residue, obstructing the visibility of some of the rings. In order to leave the violin in the condition it was found in, and to avoid damaging any part of the wood or varnish, high resolutions scans were taken by an Epson 1640x scanner, with views of the front left and right sides, as well as both the front and back as wholes. Only the front of the violin proved to have rings which could be used for dendrochronological analysis. These scanned images were digitally manipulated by changing the contrasts and brightness of the images, using Adobe Photoshop, in order to increase the visibility of the rings, (Figure 2). The violin was given the lab code MAD Lab 10QS000.

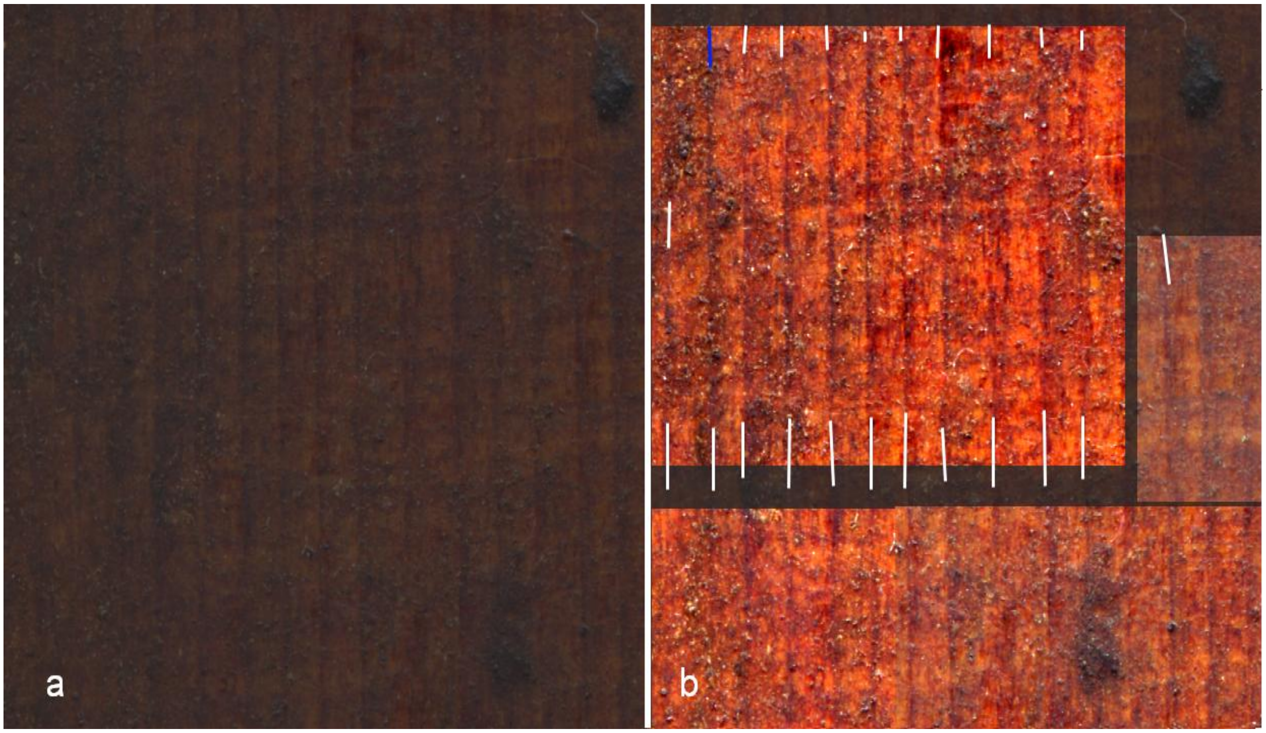
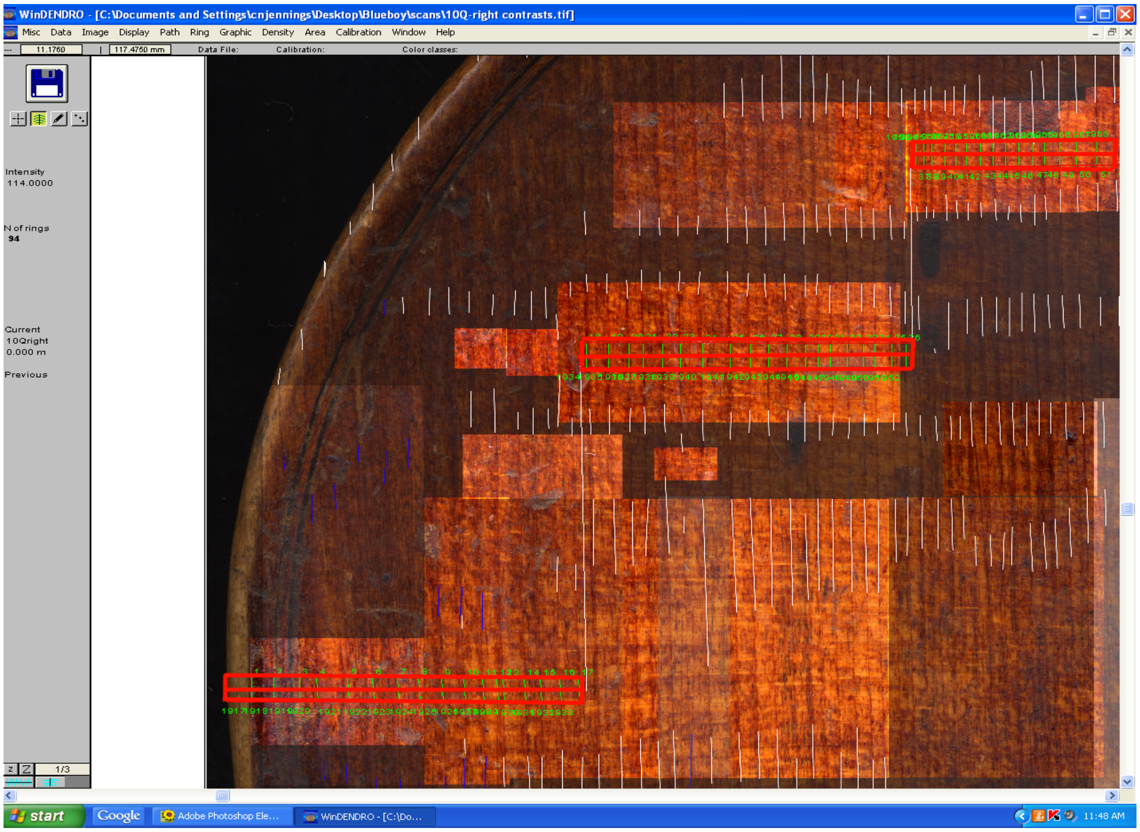


**Figure 2:** A portion of the scanned violin image, before (a) and after (b) changing contrasts. Notice the increase in visibility.

Once the rings had been revealed, they were counted and measured to an accuracy of 0.001 mm using the computer software program WinDendro. Two paths of measurement were taken from the front of the violin, one from the left and one from the right side. These paths followed the line of best visibility and began at the widest part of the violin in order to access rings located at the edge of the instrument (Figure 3). In order to ensure the strongest accuracy possible, two independent observers conducted the measurements on separate occasions, and these measurements were contrasted both graphically and statistically.

The time-series measurements were correlated to each other and created a floating chronology, which was compared to chronologies found from various sites in southern Europe (see Table 1). By comparing the growth patterns of the floating chronology to those of the reference sites, it can be determined when the rings found on the violin were formed (Figure 4).



WinDENDRO - [C:\Documents and Settings\cnjennings\Desktop\Blueboy\scans\10Q-right contrasts.tif]

11.1760 | 117.4750 mm Data File: Calibration: Color classes:

Intensity
114.0000

N of rings
94

Current
10Qright
0.000 m

Previous

**Figure 3:** One of the measurement paths on the scanned image of the violin.

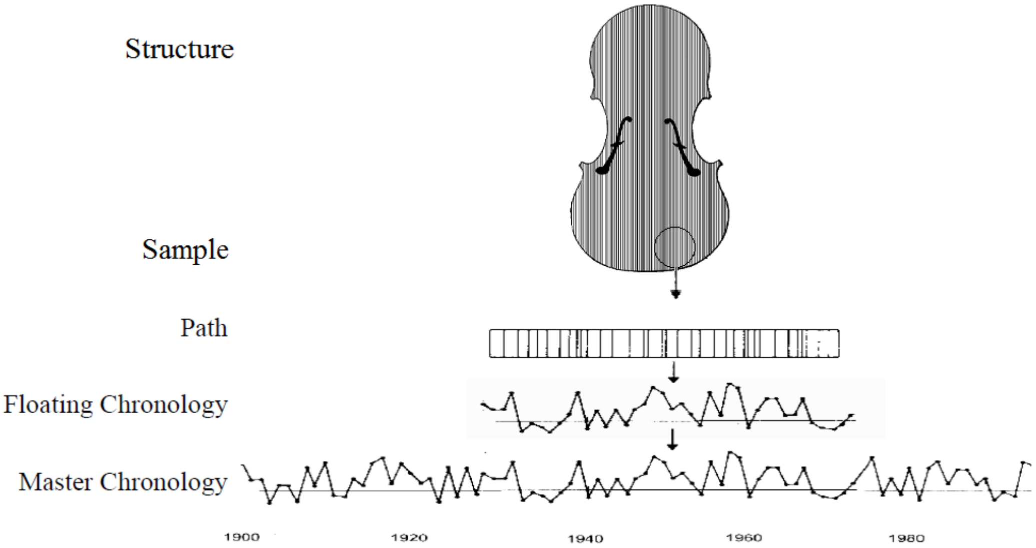


**Figure 4:** A diagram illustrating the method of measuring rings from the violin to create a floating chronology, which is matched to a master chronology in order to assign an accurate growth date.

The chronologies used for this project were found in the International Tree-Ring Database (ITRDB; http://hurricane.ncdc.noaa.gov/pls/paleo/fm_createpages.treering), which is an on-line database of established chronologies created by dendrochronologists around the world.

The statistical cross-dating program COFECHA (Holmes, 1986) was used to determine possible dates for the growth rings found on the violin. The program compares the floating chronology to the reference chronology at all possible positions, and then recommends various dates, providing a correlation value for each one. The correlation values can be used to indicate how well the floating chronology corresponds to the master at the dated position, with a higher correlation value indicating a stronger relationship. A correctly-dated sample would display high correlation patterns at one particular date and significantly lower correlation values elsewhere. While lower correlation values can indicate that a sample is inaccurately dated, they can still occur when a sample is accurately dated, indicating changes in variables such as ecological or climatic influences. For this reason, it is important to compare wood to chronologies originating in the same region as the sample itself. In this study, the origin of the wood remained a mystery, so chronologies spanning across southern Europe were used, stemming from the theory that should the violin be an authentic Stradivarius, the wood would have originated in the alpine areas near Cremona, and the instrument could therefore be dated properly.

**Table 1:** Site information for southern European chronologies, accessed from the International Tree-Ring Database. [1]Approximate distance from Cremona, Italy, was measured using Google Earth.

| **Site Name** | **Author** | **Location** | **Approx. Dist. (km)[1]** | **Altitude (m)** | **Years** | **ITRDB Code** |
|---|---|---|---|---|---|---|
| ***Picea abies:*** | | | | | | |
| Fodara Vedla Alm | Huesken | 46.63 12.1 | 231 | 1970 | 1598-1990 | ITAL025 |
| Cortina D'Ampezzo South | Schweingruber | 46.53 12.07 | 222 | 1900 | 1660-1975 | ITAL007 |
| Davos GR Dischma-Fluela | Bigler | 46.78 9.88 | 183 | 1800 | 1668-1999 | SWIT181 |
| Arosa GR Rot Tritt North | Schweingruber | 46.8 9.68 | 187 | 1940 | 1690-1975 | SWIT107 |
| Simmental, Iffgenalp | Schweingruber | 46.4 7.43 | 246 | 1900 | 1532-1986 | SWIT169 |
| Lauenen | Schweingruber | 46.42 7.32 | 254 | 1250 | 1500-1976 | SWIT177 |
| Obersaxen, Meierhof GR | Schweingruber | 46.73 9.08 | 192 | 1520 | 1537-1995 | SWIT173 |
| Falkenstein | Wilson | 49.1 13.33 | 507 | 1325 | 1540-1995 | GERM040 |
| ***Pinus cembra:*** | | | | | | |
| Fodara Vedla Alm | Huesken | 46.63 12.1 | 231 | 1970 | 1500-1990 | ITAL023 |
| Obergurgl | Giertz | 46.85 11.02 | 206 | 2000 | 1566-1971 | AUST002 |
| Tyrol Architectural Timbers | Giertz | 46.87 11.02 | 207 | 2050 | 1500-1976 | GERM21 |

The front of stringed instruments are traditionally made out of Norway spruce (*Picea abies* Karst.), however, other types of wood, such as maple and sycamore, are often used for different parts of the violin (Bernabei et al., 2010). The chronologies which were collected were from two different species; Norway spruce (*Picea abies* Karst.) and Swiss stone pine (*Pinus cembra* L.), chosen because of their previous use in other dendrochronological investigations of stringed instruments (Grissino-Mayer et al., 2004; Bernabei et al., 2010; Topham and McCormick, 1998; Topham and McCormick, 2000).

Each viable European chronology found on the ITRDB was run through the program COFECHA in order to verify its strength as a chronology. Problem samples were eliminated (a problem sample was defined as any which had an inter-series correlation less than 0.3281, which is considered statistically significant using 50-year segments), as were any dates before 1500, as practised in the Grissino-Mayer et al. (2004) analysis of the famous 'Messiah' violin, because any earlier dates were not necessary in dating the violin. Any chronologies which did not have sufficient data to support later manufacture dates were also eliminated. The raw data was compiled to make a compound reference chronology for each species. The violin measurements were compared to the individual and compound chronologies, and the correlations were presented both graphically and statistically in order to ensure the highest possible degree of confidence in the results. The program ARSTAN (Holmes *et al*. 1986) was used to present the data and results visually, standardizing the ring width data and then creating graphs with the results.

### *Species Identification*

Due to the species-specific nature of growth response to climatic and environmental conditions, it is important that the floating chronology is compared to a master chronology made up of the same species or a species which is known to react in the same way to climate variables. A scanning electron microscope (SEM) can be used to complete wood identification, by investigating the anatomical structure of the wood and revealing specific characteristics which point to a species. Traditionally, a small portion of wood is removed from the sample, and then cut to reveal the radial and tangential sections, before being prepared for the SEM at Mount Allison's Digital Microscopy Facility (http://mta.ca/dmf/). In the case of the violin, it was impossible to remove samples from the violin, in order to preserve the condition of the instrument. Instead, a silicone cast of the wood was taken from the inside of the instrument, where the wood lay exposed and without varnish. A liquid silicone base was mixed with an accelerant, which acted as a catalyst in causing the silicone to solidify. An imprint of the cellular structure was lifted from the wood when the applied gel had hardened. While the anatomical structure was inversed, the imprint was still clear enough to provide a great representation of the cellular structure. These silicone casts were taken from various parts of the violin where the wood was exposed and without varnish, although some were unsuccessful in picking up the cellular structure to the degree of precision that is required for SEM analysis. By pipetting the liquid silicone into the body of the violin through the right f-hole, it was possible to reach the underside of the front piece, as well as the inner surface of the back. Silicone casts were also taken from the end-pin, which had previously been chipped and so revealed the raw wood, and the end-pin hole, as well as numerous other points on the violin (Figure 5).

**Figure 5:** Taking silicone samples from the violin- 1) the base and accelerant are mixed, 2) pipetting the mixture into the violin while it is still in a liquid state, 3) removing the hardened silicone cast after it has hardened.

After it was removed, the silicon cast was mounted on a SEM stub and coated in carbon paint and gold, allowing it to be conductive in the SEM. This process allows the SEM operator to magnify any area of the replicate cast from 500 to 10,000X, depending on the size and homogeneity of the object of interest.

## **Results and Discussion**

The high-resolution scans of the violin revealed a total of 92 rings on each half of the front side, offset by one year. The two sets of measurements from each observer showed strong correlation (the bass side correlating at 0.774 and the treble at 0.719), indicating that the measurements were indeed accurate and that no rings were missed while measuring. The two sets of measurements were combined to form a 'master' data set, which was then used in the comparisons to the regional chronologies.

The traditional method of forming the front of the violin involves cutting a wedge from a tree which is then split in two, where the two halves are then placed with their outer edge meeting in the centre of the wood (Bernabei et al., 2010; Topham and McCormick, 1998; Topham and McCormick, 2000). This results in the youngest wood being found in the centre of the instruments, while the earlier growth is found at the perimeters. From initial observation, it appeared as though this was the case in the violin, due to the alignment of late wood and early wood. In order to confirm this theory, the measurements from the treble and bass (right and left sides, respectively) were compared to one another using COFECHA. The measurements were graphed in order to visually compare their similarities and differences (Figure 6). The statistical and visual analysis resulted in high correlation values (intercorrelation of 0.660), indicating that the halves did indeed come from two parts of the same tree.

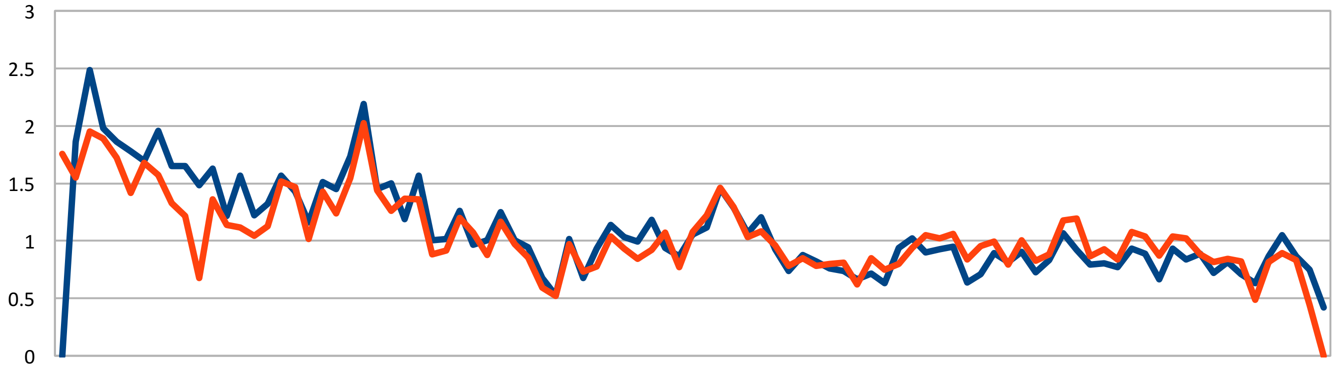


**Figure 6:** A comparison of measurements (mm) from the bass (blue) and treble (red) halves of the instrument. Note the obvious similarities between the two halves, as well as how the bass side extends one year later while the treble side begins one year earlier.

Each of the chronologies which had been selected from the International Tree-Ring Database was run through the program COFECHA to check its correlation. The results from those tests are represented in Table 2. Only those chronologies with an inter-series correlation above 0.3281 (statistically significant) and with sufficient data to support various possible manufacture dates of the violin were used. Of the remaining chronologies, all correlated at values between 0.436 and 0.621. The data for each site was then compiled into two regional master chronologies, one for each species studied. These chronologies were also checked for correlation, and both correlated at statistically significant values, with Norway spruce (*Picea abies*) correlating at 0.503, and Swiss stone pine (*Pinus cembra*) at 0.514.

**Table 2:** The interseries correlation for the European site chronologies, with Norway spruce (*Picea abies*), Swiss stone pine (*Pinus cembra*).

| **Site** | **Species** | **Interseries Correlation** |
|---|---|---|
| Fodara Vedla Alm | *Picea abies* | 0.528 |
| Cortina D'Ampezzo South | *Picea abies* | 0.553 |
| Davos GR Dischma-Fluela | *Picea abies* | 0.488 |
| Arosa GR Rot Tritt North | *Picea abies* | 0.59 |
| Simmental, Iffgenalp | *Picea abies* | 0.621 |
| Lauenen | *Picea abies* | 0.436 |
| Obersaxen, Meierhof GR | *Picea abies* | 0.592 |
| Falkenstein | *Picea abies* | 0.616 |
| | | |
| Fodara Vedla Alm | *Pinus cembra* | 0.524 |
| Obergurgl | *Pinus cembra* | 0.605 |
| Tyrol Architectural Timbers | *Pinus cembra* | 0.501 |

Once the measurements from the violin had been compared to the species-specific regional chronologies, they were compared to each individual chronology (once again using the program COFECHA), in order to ensure that significant results would be represented through multiple tests. Potential dates which were repeated throughout the tests were noted and investigated further. Two potential end-dates were repeatedly represented- the spruce chronology pointed to an end date of 1877, meaning the violin would definitely be a copy, while the pine chronologies also recommended an end date of 1732, suggesting that the instrument could indeed be a genuine Stradivarius (see Table 3).

**Table 3:** COFECHA-generated correlation values for recommended dates.

| | | **Correlation Value** | |
|---|---|---|---|
| **Site Name** | **Species** | **Bass- 1877** | **Treble- 1876** |
| Regional Spruce Chronology | *Picea abies* | 0.582 | 0.569 |
| Fodara Vedla Alm | *Picea abies* | 0.351 | 0.494 |
| Cortina D'Ampezzo South | *Picea abies* | 0.314 | 0.346 |
| Davos GR Dischma-Fluela | *Picea abies* | 0.402 | 0.45 |
| Arosa GR Rot Tritt North | *Picea abies* | 0.297 | 0.448 |
| Simmental, Iffgenalp | *Picea abies* | 0.402 | 0.315 |
| Lauenen | *Picea abies* | 0.286 | 0.248 |
| Obersaxen, Meierhof GR | *Picea abies* | 0.384 | 0.458 |
| Falkenstein | *Picea abies* | 0.606 | 0.531 |
| | | **Bass- 1732** | **Treble- 1731** |
| Regional Pine Chronology | *Pinus cembra* | 0.202 | 0.239 |
| Fodara Vedla Alm | *Pinus cembra* | 0.157 | 0.252 |
| Obergurgl | *Pinus cembra* | 0.162 | 0.156 |
| Tyrol Architectural Timbers | *Pinus cembra* | 0.249 | 0.225 |

Using ARSTAN, the measurements were detrended and graphed at both possible positions, to provide a visual reference in dating the instrument (Figures 7 and 8). While the statistical and visual analysis indicated a stronger preference to the later date (1877), the uncertainty concerning the instrument's date could only be fully eliminated by verifying the species of the wood used in making the instrument.

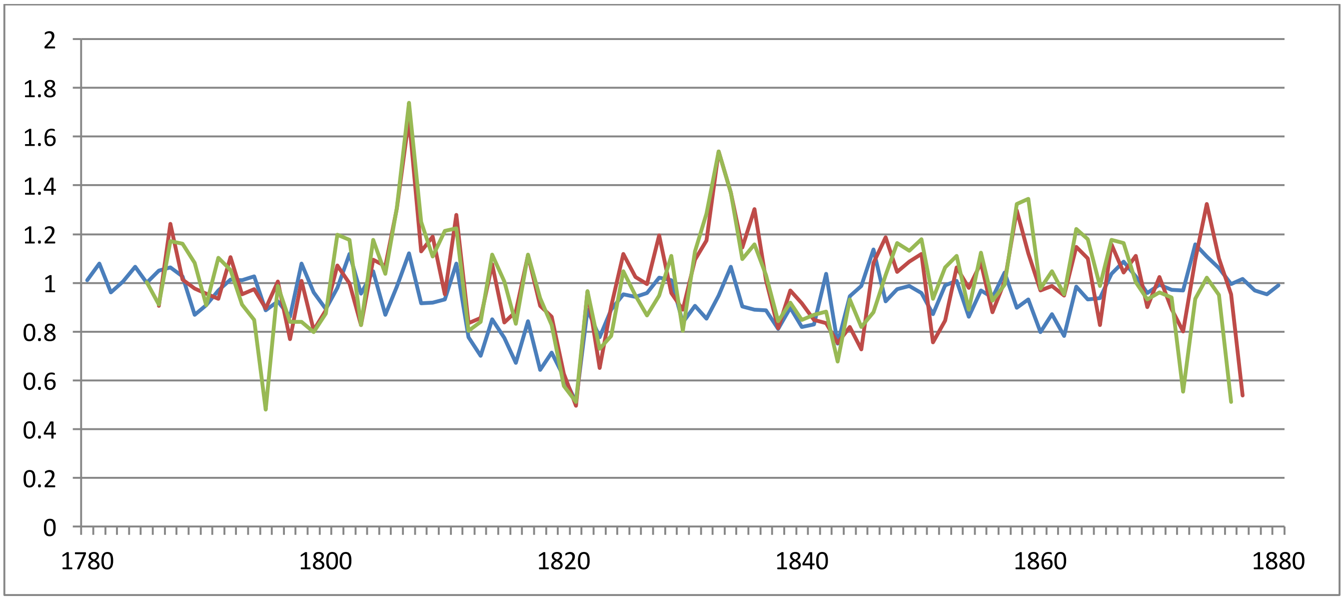


**Figure 7:** A comparison of the standardized ring-width patterns for the spruce regional chronology (blue) with the bass (red) and treble (green) measurements, at a potential end-date of 1876/77.

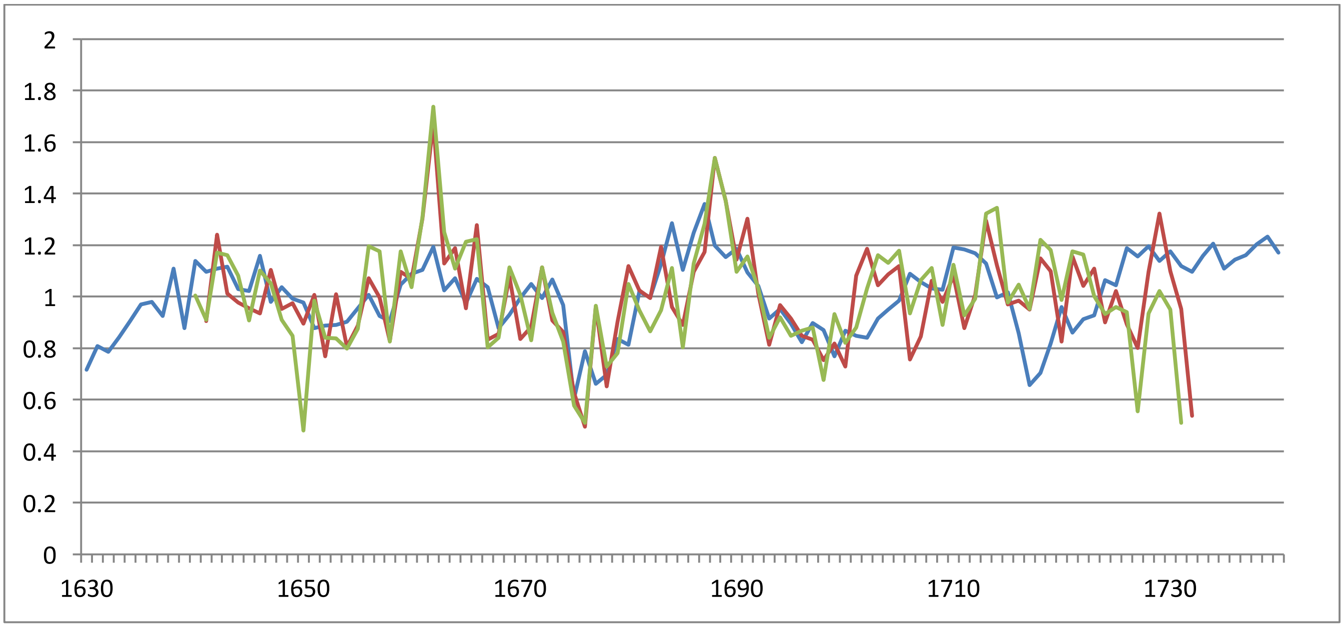


**Figure 8:** A comparison of the standardized ring-width patterns for the pine regional chronology (blue) with the bass (red) and treble (green) measurements, at a potential end-date of 1731/32.

*SEM Analysis*

The silicone casts were analyzed in the Mount Allison Digital Microscopy Facility. Typically, wood anatomy is analyzed using both tangential and radial views of the wood; however, because of the way the violin was made, only radial views of the wood were exposed. Certain anatomical particularities distinguish spruce from pine, such as the shape of the pits, their texture, and characteristics of the tracheids. The silicone casts were able to reveal these characteristics with enough detail to determine that the wood was indeed Norway spruce (*Picea abies*) (Figure 9). This finalized the evidence that the violin was indeed made after 1877, and therefore a copy.

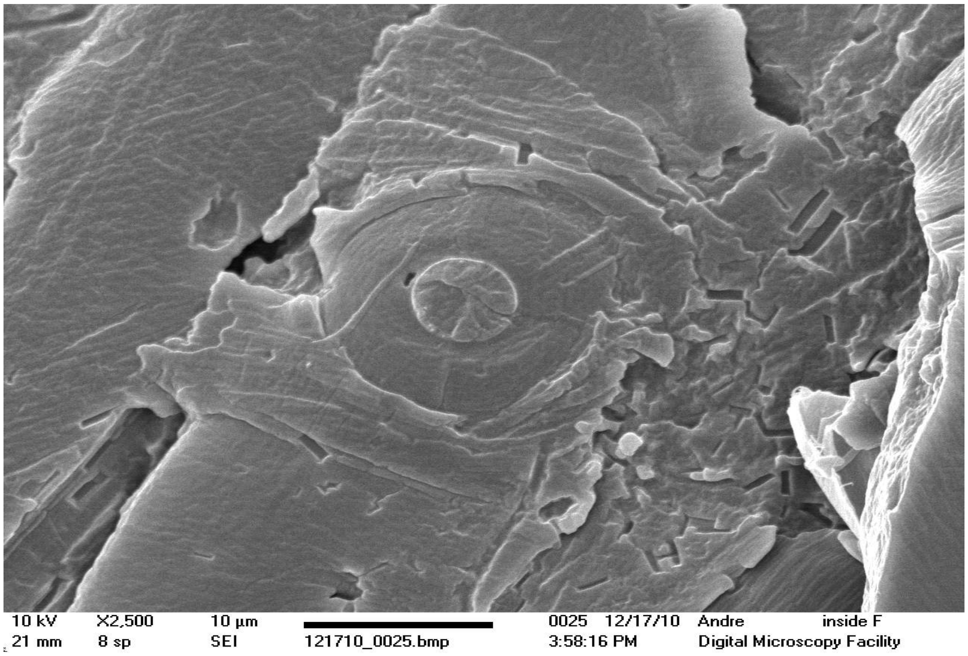


**Figure 9:** An example of a piceoid shaped pit visible in the silicone cast replicate at 2,500x magnification. These cells are characteristic of the wood anatomy in *Picea* sp.

## Conclusion

The dendrochronological analysis of the violin revealed 92 measurable rings on the front of the violin. These rings indicated a high correlation to the regional spruce chronology, indicating an end-date of 1877. In order to confirm this date, scanning electron microscope technology was used to determine that the instrument was indeed made from Norweigan spruce (*Picea abies*). The new methodology was able to confirm the evidence against the violin's authenticity, and reaffirm above a 99.9% confidence level that the instrument was built after 1877, proving that it was indeed a copy.

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