Bronze age dating of timber from the salt-mine at Hallstatt, Austria

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Abstract

The prehistoric salt mine of Hallstatt together with its burial ground is one of the most prominent archaeological sites in Austria, which has also given name for the “Hallstatt period” (800–400 BC). Due to the perfect conservation in rock salt a great number of organic materials have been found, among mostly wooden artefacts. Currently, the major archaeological focus is on the Bronze Age salt mining activities with excavations taking place at the historic Christian von Tusch-Werk, Alter Grubenoffen mine.

Chronology building started at the Dachstein plateau, in the vicinity of Hallstatt, where tree-trunks were discovered in an alpine lake (Schwarzer See) and after recovery a spruce-larch chronology was compiled that dates back to 1475 BC. In addition, at the bog Karmoos, very close to the mining place of Hallstatt, preserved trees were intensively sampled resulting in a spruce chronology reaching even 1523 BC.

Over 500 samples were taken at the Christian von Tusch-Werk, Alter Grubenoffen. They also included samples from the recently discovered world’s oldest wooden staircase. The spectrum of wooden species encompassed Norway spruce, Silver fir, beech, European larch and maple. We were able to synchronize 128 samples, ending in a 282-year long floating chronology. While the staircase dated back to 1344 BC, the end year of the floating chronology dated even to 1245 BC. Tree felling dates showed clusters within the chronology, providing evidence for archaeologists to find construction phases and usage periods.

The Dachstein–Hallstatt spruce chronology currently holds 840 synchronized series, and includes samples from the lake at the Dachstein, from the Karmoos bog at Hallstatt, from the prehistoric Hallstatt salt mine, and from historical buildings, as well as living trees. The chronology covers the period between 1523 BC through 2004 AD.

Keywords: Historical dating; Dendrochronology; Hallstatt; Bronze age; Salt mine

Introduction

The prehistoric salt mine Hallstatt together with its burial ground is one of the most prominent archaeological sites in Austria, which has given also name for the “Hallstatt period” (800–400 BC). Currently, the major archaeological focus lays at the Bronze Age salt mining activities. Intensive excavations have taken place for the past 14 years at the Christian von Tusch-Werk, Alter Grubenoffen discovered during mining activities in 18th century. Due to the perfect preservation in rock salt, materials and human artefacts of organic origin like...
leather, fur, textiles, ropes made of lime-bast fibres, and numerous wooden artefacts have been found (Barth and Lobisser, 2002). Wooden findings refer to mining timbers, illumination chips, tool handles, bowls and cups and partially buildings at the surface.

First dendrochronological activities at Hallstatt go back to Hollstein (1974). He took four samples from the Hallstatt period mining place Kilb-Werk. It was possible to synchronize two fir samples (Abies alba Mill.) with the Villingen fir chronology (Hollstein, 1973), presenting the end date of 682 BC. Another spruce sample (Picea abies (L.) Karst.) ended at 686 BC, while an ash wood sample (Fraxinus excelsior L.) did not crossdate. Six years later Hollstein corrected the ending dates of his fir samples to 656 BC (Hollstein, 1980). Twenty years later Ruoff and Sormaz (1998, 2000) continued sampling. They took 189 samples across all available periods (Bronze Age, Hallstatt period and Latène period) and came up with crossdatings against the Villingen–Magdalenenberg chronology (Billamboz and Neyses, 1999) at 724 and 695 BC. Also, a number of floating chronologies were established.

The forest sites around Hallstatt built the source for all wood-logs used in prehistoric salt mining and they are located between 900 and 1500 m a.s.l. Most currently existing Bronze Age chronologies were established either at lower elevations, e.g. at lake settlements (Becker et al., 1985; Maeder and Sormaz, 2000; Billamboz, 2003); or at much higher elevations (Nicolussi and Lumassegger, 1998; Büntgen et al., 2004; Dellinger et al., 2004). The most promising already available reference chronology for dating timber of the salt mine originate from the Dachstein plateau (Grabner et al., 2001), close to Hallstatt, and this composite chronology, which dates back to 1474 BC, includes spruce and larch (Larix decidua Mill.) series that are highly climate-sensitive.

This paper is dealing with setting up a Dachstein–Hallstatt chronology and the dating of wooden samples that originate from the Christian von Tusch-Werk, Alter Grubenoffen Bronze Age salt mines at Hallstatt. The chronology building is shown in chronological order by presenting data from the major sampling sites.

Material and methods

Dachstein–Schwarzer See

The Dachstein group is a triassic limestone formation of the northern rim of the alps, with strong karst topology, high elevations (highest peak 2995 m a.s.l.) and plateau characteristics. The distance to Hallstatt is about 15 km. The small crater-like lake Schwarzer See (47N31, 13E49; 1450 m a.s.l.; see Fig. 1) is surrounded by steep rocky slopes and cliffs. Dead and broken trees have dropped-off and slid downwards into the water of the lake where they became instantly preserved. During a 2 weeks campaign in summer 1999 a team of
professional divers recruited through the Austrian military and dendrochronologists were lifting trees (Fig. 2A) from underwater to cut off disks, and return the trees back into the water after sampling. In total, 211 trees were successfully lifted and sampled. The disks were dried carefully afterwards. In addition, 80 living trees (two cores per tree, spruce and larch) were cored at breast height.

Hallstatt–Karmoos

Hallstatt is located within the northern limestone-alps (Fig. 1), which are characterized by heavy rainfalls and cold temperatures (Bohm, 1992; Auer, 1993). Due to the forest ecotype in the montane region (900–1400 m a.s.l.) at Hallstatt the dominating species are spruce, fir and beech (Fagus sylvatica L.) (Kilian et al., 1994). The subalpine region (above 1400 m a.s.l.) is dominated by spruce with patches of larch.

In summer 2004 eight small cavities (1 \times 2 \text{m}, down to the clay level) were dug (Fig. 2B) at the Karmoos bog (47N33, 13E38; 1390 m a.s.l.). The bog is bordered by steep slopes, which ensured that trees broken down by wind or snow did fall into the bog. The trunks became instantly preserved in the humid milieu. It was possible to extract more than 300 logs from different soil depths, with diameters ranging between 5 and 50 cm. Disks were cut off and immersed in a rock-salt (NaCl) saturated solution for five weeks. Afterwards, the disks were slowly dried. Fifteen living spruce trees were also sampled by taking two cores per tree at breast height.

Hallstatt–Christian von Tusch-Werk, Alter Grubenoffen (Tusch)

The Christian von Tusch-Werk, Alter Grubenoffen site is situated within the plane of the main tunnel Kaiserin Christina Stollen with the access entrance at 930 m a.s.l. The prehistoric salt mining site can be reached by walking 600 m horizontally into this tunnel. The archaeological excavations that have been taking place, about 100 m below the actual surface, started in the year 1992. More than 500 cores from mining timbers were taken by using a regular dry-wood-corer and a power-drilling machine. The wet cores were glued onto wooden sticks and dried carefully.

Most of the timbers used in the mines have broken into pieces as soon – in prehistoric time – surface material, i.e. mostly clay, has filled up the mine. However, a recent discovery (Reschreiter and Barth, 2005) has revealed a complete wooden staircase that is according to current knowledge supposed to be the world’s oldest wooden staircase (see Fig. 3).

Hallstatt-recent living trees (Rec)

Living trees of the species spruce, fir and beech were sampled at four different sites by taking two cores per tree at breast height, with at least 13 trees per site. These four sites were located between 900 and 1450 m a.s.l.

Hallstatt-historical samples (His)

More than 200 wood samples from historic buildings and mines were taken around the salt mining sites at Hallstatt. Since it was not possible to access this site through roads or ox-paths prior the 1960s, all large-sized prehistoric and historic timbers originate from closeby forest sites.

Measurements and data treatment

Dry disks and mounted cores were sanded until individual tracheids became visible. Wood species were identified by microscopic analysis (Wagenfuhr, 1989) and the tree-rings were measured to the nearest 0.01 mm using the LINTAB measuring device (www.rinntech.de). All ring-width series of living trees were cross-dated (Stokes and Smiley, 1996; Swetnam
et al., 1985) and checked for dating and measurement errors using COFECHA (Holmes, 1983), and by visual synchronization.

Ring series were standardized to remove low-frequency variability that included age-related trends, stand development and local disturbances (Cook et al., 1990). A cubic smoothing spline with 50% cut-off at 30-year wavelength was applied to each series and the original measured values divided by the fitted curve values (Cook and Peters, 1981).

Tree-ring series of the prehistoric samples were dated using \( t \)-values and the \textit{Gleichläufigkeit} computed by the TSAP software (www.rinntech.de), supplemented by visual checking of the plots. The first step was to crossdate the unknown samples against each other, following Baillie (1995). These floating series were checked against existing chronologies (East-Austrian fir, -spruce and -larch chronologies \textcopyright BOKU Vienna (Wimmer and Grabner, 1998; Grabner and Wimmer, 2006); Southern Germany fir chronology (820–1985 AD) \textcopyright University Stuttgart Hohenheim; Villingen-Magdalenenberg fir chronology (811–593 BC) \textcopyright Landesamt für Denkmalpflege Hemmenhofen (Billamboz and Neyses, 1999); and the middle European oak chronology (5100 BC–1996 AD) \textcopyright Labor für Dendrochronologie Zürich and University Stuttgart Hohenheim (Becker et al., 1985).

Chronologies were compiled by calculating mean values of dated and indexed tree-ring series, and compared then with existing chronologies using TSAP (www.rinntech.de). Dating quality was also checked by running the COFECHA software (Holmes, 1983).

### Results and discussion

#### Dachstein–Schwarzer See

In total, 211 trees were successfully lifted and sampled. In the samples, 66% of them were spruce, 21% larch and 13% belonged to stone pine (\textit{Pinus cembra} L.), which reflects approximately the today’s composition of species in that area (Kilian et al., 1994).

Due to poor crossdating stone pine had to be removed from further consideration. It was possible to crossdate most of the spruce and larch samples resulting into a composite chronology dating back to 1475 BC (Table 1). The mean age of the trees was 202 years; the maximum number of tree-rings was 528 in spruce and 718 in larch. The composite chronology was then compared and cross-correlated with regional standards for larch and stone pine of Tyrol and the Swiss Alps (Nicolussi and Lumassegger, 1998), which resulted in a 3474-year long spruce/larch chronology (Table 1, Fig. 4). Statistics for the Dachstein–Schwarzer See (Sws) chronology (Table 1) show that the spruce and larch trees correlate

| Table 1. Main statistics of the chronologies |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Choro.          | Species        | First year     | Last year      | Time span      | No. of series  | m. segm. length | m. series intercorr. | sens.          |
| Sws             | P. A.          | 1475           | 2003           | 528            | 202            | 0.570          | 0.201           |
| Hkm             | P. A.          | 2003           | 2004           | 302            | 103            | 0.511          | 0.203           |
| Tusch           | P. A.          | 1245           | 2004           | 282            | 62             | 0.460          | 0.201           |
| Sws, Hkm, Tusch| P. A.          | 1523           | 2004           | 3528           | 128            | 0.450          | 0.200           |
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\( m. \text{ segm. length} \) = mean segment length, \( m. \text{ series intercorr.} \) = mean series intercorrelation, \( m. \text{ sens.} \) = average mean sensitivity, \( S. \text{ Germany} \text{ Fir} \) = southern Germany fir chronology (820–1985 AD) \textcopyright University Stuttgart Hohenheim, \( S. \text{ Germany} \text{ Oak} \) = middle European oak chronology (5100 BC–1996 AD) \textcopyright Labor für Dendrochronologie Zürich and University Stuttgart Hohenheim; \( Ovl \) = overlap, \( Glk \) = \textit{Gleichläufigkeit}, \( TvH \) = \textit{t}-value according to Hollstein.)
well (mean series intercorrelation = 0.57) both exhibiting a high mean sensitivity (0.201) which is due to the strong influence of summer temperatures on tree growth (Gindl et al., 1998). Sample depth in segments before 70 AD of this chronology was poor (Fig. 4), and dominated by larch wood.

**Hallstatt–Karmoos**

It was possible to extract 313 tree trunks out of the bog. The variation of wood-species was dominated by spruce (94%), followed by fir (3%) and larch (3%). The tree-ring series indicate impacts coming from forest stand development and competition. Successful synchronization was possible by detrending tree-ring series, poor correlations were found on the raw data. Cross-dating was done by internal synchronization and by checking the dates against the Sws chronology. In total, 302 tree-ring series were synchronized and with inclusion of the living trees a chronology reaching back to 1523 BC resulted (Table 1, Fig. 4). Statistics of the Hallstatt–Karmoos (Hkm) chronology show good synchronization (Table 1). After adding Sws and Hkm data, possible dating errors were checked with COFE-CHA, resulting in a 3528 year long chronology with high series intercorrelations and average mean sensitivity (Table 1).

The stem accumulation varied over time (Fig. 4): several phases had much higher numbers of samples, i.e. 900–750 BC, 250–480 AD, 800–1050 AD and 1180–1280 AD. For most of these periods showing higher sample depth in the bog of Hkm, sample depth was also higher at Sws (i.e. 250–480, 800–1050 and 1180–1280 AD), which suggests that common reasons like heavy snow falls or higher storm frequencies might be behind this coincidence.

**Hallstatt–Christian von Tuschwerk–Alter Grubenoffen (Tusch)**

Sampling activities have yielded so far cores from over 500 mining timbers, including the world’s oldest wooden staircase (Fig. 3). The spectrum of the wooden species comprises 47% spruce, 43% fir, 8% beech and 1% for larch and maple (Acer spp.) each. The main wood species used in recent mining are spruce and fir (Sell, 1989; Bosshard, 1974). Fewer samples were found for the species beech, maple and larch. When compared with the forest ecotype (Kilian et al., 1994) suggested for that time, a far high proportion of beech-wood could be expected. However, we hypothesize that beech wood was mostly used as fire wood. The small number of larch found in the mine indicates that most larches were used for housing constructions, as supported by the few findings of buildings (Blockbauten, Barth and Lobisser, 2002).

It was possible to compile a 282-year long floating chronology by synchronizing 128 samples, including the cores from the wooden staircase. This floating chronology includes spruce, fir, larch, beech and maple samples. The clustering of mining timbers with the same felling date is an important source of information for archaeologists about construction phases and time-spans of using the mining cavities. Statistics for the floating chronology showed good overall synchronization (mean series intercorrelation = 0.46), even though the mean segment length was short (62 tree-rings) with five wood species included (Table 1).

The mine timber floating chronology (Tusch; Table 1, Fig. 4) was crossdated in various ways. The crossdating with the Sws chronology led to the ending date of 1245 BC. The key figures for this dating were (computed by TSAP): Overlap = 232 years; Gleichläufigkeit = 63%; t-value (Hollstein) = 4.8; t-value (Bailie–Pilcher) = 4.7. According to Eckstein and Bauch (1969) due to the length of the series (overlap is 232 years) the dating is highly significant with \( p < 0.001 \). Billamboz (2005) mentioned three quality classes of dating (A, B and C) and the Tusch chronology would comply with class A. At this stage it was not possible to synchronize the...
The Tuschem chronology with other major standard chronologies such as the middle European oak chronology. The dating with the Hkm chronology showed no significant result, while dating with the composite chronology of Sws and Hkm presented weak results for 1245 BC. To confirm the ending date of the Tuschem chronology, the data sets of Sws were pooled with Hkm, Tuschem (with exclusion of beech and maple samples), the historical samples and the living trees from Hallstatt (His and Rec). The dates of the Tuschem samples were confirmed by COFECHA (Table 1). There were no exclusions of mining timbers due to wrong dating, or due to weak series intercorrelations. The Dachstein–Hallstatt chronology (in total 1051 series) that has mainly spruce samples and small numbers of larch and fir series included showed good interseries correlation (0.471) at a mean segment length of 140 tree-rings. The chronology is 3531 years long, spanning from 1526 BC through 2004 AD, and connects with the southern German fir chronology (Glk = 52; TvH = 4.5), the Villingen Fir chronology (Glk = 60; TvH = 5.5), as well as the middle European oak chronology (Glk = 53; TvH = 4.3) (Table 1). The monospecific spruce chronology (1523 BC to 2004 AD) showed better internal statistics (interseries correlation = 0.508) and higher correlations to the southern German fir chronology (Glk = 60; TvH = 9.8), the Villingen Fir chronology (Glk = 62; TvH = 5.7), as well as the middle European oak chronology (Glk = 53; TvH = 4.5) than the composite chronology (Table 1).

The dating of the 128 samples from the Christian von Tuschem-Werk, Alter Grubenoffen resulted in a variety of end dates between 1458 and 1245 BC (Fig. 5). There were several phases with many samples dating to the same year: 1382, 1366, 1344 and 1343, 1277 and 1245 BC. These phases might be attributed to intensive prehistoric salt-mining. All samples dated to 1344 and 1343 BC belonged to the well preserved world’s oldest wooden staircase (Mielke, 1993; Reschreiter and Barth, 2005; Figs. 3 and 5). The staircase is split into two parts; the lower part built 1343 BC, and upper one in 1344 BC. All wood components of the staircase presented waney edges dating to the same year, making it clear that the staircase was manufactured at once. This staircase is a masterpiece of prehistoric handicraft (Reschreiter and Barth, 2005). The steps itself can be adjusted to the slope of the whole staircase by a simple turning and fixing process. Steps and inlay-boards are alternating mounted in the groove at the stringers. Due to the rectangular tenon at both ends of the steps, the angle between the stringer and the step can be adjusted. The orientation of the step is fixed by the following inlay-board. The stringers are fixed together by small tree trunks acting as a bolt. The steps and the boards in between are split of small tree trunks (spruce and fir). Also the stringers and the bolt were made of spruce and fir wood, only one
fixing element is of maple. The staircase was probably pre-produced outside and assembled according to the current situation in the mine, i.e. adjusting the slope (Reschreiter and Barth, 2005).

Conclusions and future perspective

Intensive sampling of living trees, prehistoric and historic wooden constructions took place in the region of Hallstatt. Sub fossil tree trunks preserved in the water of an alpine lake and from a high elevation bog were lifted and sampled. It was possible to synchronize these samples and to combine to a long chronology, bridging from 1526 BC to 2004 AD. Using the new chronology, it was for the first time possible to date Bronze Age samples from Hallstatt. Out of more than 500 samples 128 cores were dated. The recently found world’s oldest wooden staircase was dated to 1344 BC.

Since all the trees are well defined in terms of their growing site a high potential for long-term climate reconstructions is anticipated. Therefore more samples in bogs of Hallstatt should be lifted and analysed.

The archaeological excavations in the Christian von Tusch-Werk, Alter Grubenoffen will be continued. A lot of samples out of this excavation are expected for the next years. These wooden artefacts will be sampled and dendrochronological dated. Due to the long history of excavations in Hallstatt a lot of wooden samples from all periods (Bronze Age to Latène-period) are existing. All these samples will be dendrochronological dated using the new Hallstatt–Dachstein chronology.

Acknowledgements

We thank Andre Billamboz (Hemmenhofen, Germany) for providing the Villingen chronology. Setting up the Dachstein–Schwarzer See chronology was funded by the Austrian Science Foundation (FWF 9200-GEO), and the dating of the prehistoric wooden artefacts took place in the region of Hallstatt. Sub fossil tree trunks preserved in the water of an alpine lake and from a high elevation bog were lifted and sampled. It was possible to synchronize these samples and to combine to a long chronology, bridging from 1526 BC to 2004 AD. Using the new chronology, it was for the first time possible to date Bronze Age samples from Hallstatt. Out of more than 500 samples 128 cores were dated. The recently found world’s oldest wooden staircase was dated to 1344 BC.

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