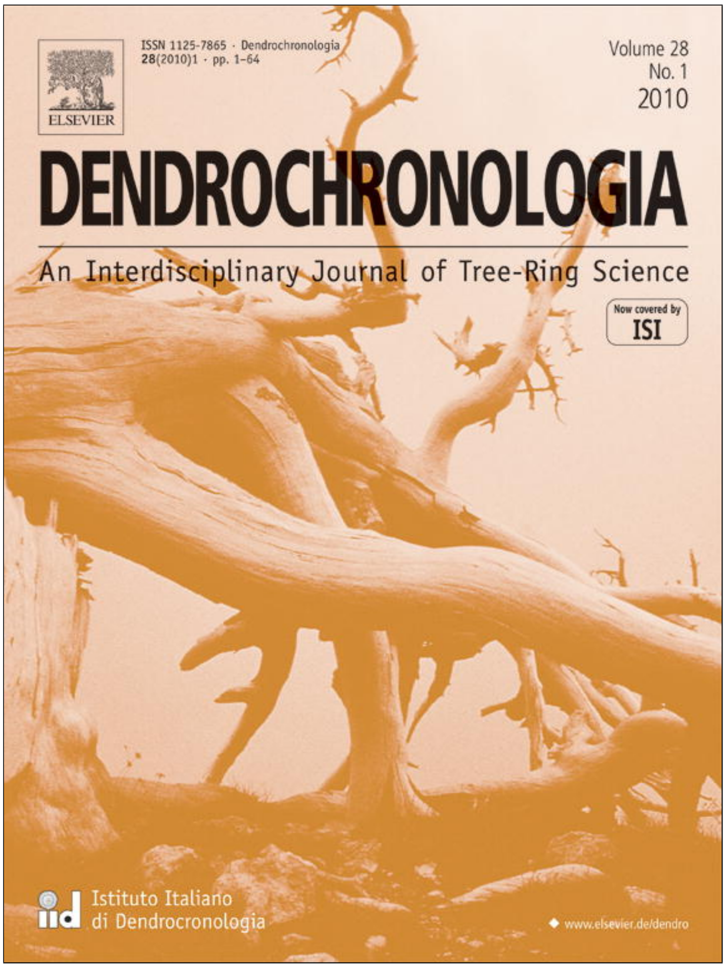
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ORIGINAL ARTICLE

# First tree-ring chronology from Andronovo archaeological timbers of Bronze Age in Central Asia

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## Abstract

We crossdated spruce (*Picea schrenkiana*) tree rings of archaeological timbers from the Asi-2 settlement and Turgen-1 barrow associated with the Andronovo in the Tian-Shan Mountains, an archaeological culture known for the development of pastoral transhumance in this particular area of the Eurasian steppe, in order to establish a chronological framework for the Bronze Age period of southeastern Kazakhstan. Age of the Asi-2 semi-subterranean house was determined by radiocarbon dating between ca. 1610 and 1490 cal. BC, which places the settlement in the transition between the Middle Bronze Age and Late Bronze Age. Sixty-two percent of tree-ring specimens (20 wood samples) collected from construction timbers of a collapsed roof, entryway and an interior wall of the house were suitable for crossdating. The crossdating success resulted in developing a 121-year tree-ring width chronology of the Asi-2 house and a 101-year tree-ring width chronology of the Turgen-1 barrow. The archaeological tree-ring width series have high mean sensitivity (0.2–0.4) and significant values of interserial correlation that indicate strong common signal in variance of the tree-ring indices. The archaeological timbers from the house and burial mound construction appear to have been cut in a closed-canopy stand of young spruce trees (40, 80 and 100-years old) at this high-elevation locality (2400 m *asl*). The Ulken tree-ring width record developed from modern spruce subalpine forest growing on a steep slope just 300 m above the archaeological site (2610–2760 m *asl*) showed a strong negative relationship with April temperature, mainly ($R = -0.61$, $R^2$ adj. = 0.37, $F_{(1,59)} = 35.03$ at $p < 0.000$). This is contrary to positive relationship between tree-ring widths and summer temperature that have been previously reported for the Tian-Shan upper tree-lines in the region. This negative relationship could be related to spring moisture stress when the growing season starts in April with mean daily temperature range from 4.4 to 9.9 °C and merely 50 mm of monthly precipitation. Likewise, tree-ring width variability in the archaeological records could be dominated by moisture availability in the area. This provides a framework of archaeological tree rings for modeling migration patterns of ancient cultures in search of pastures and water. The study suggests good dendrochronological potential of archaeological timbers from Andronovo archaeological sites of this region. We discuss peculiarities in application of climatically sensitive spruce tree rings to developing an Andronovo absolute chronology and reconstructing environmental changes for the 2nd millennium BC in Central Asia.
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***Keywords:*** Dendrochronology; Andronovo archaeological community; Tian-Shan; April temperature; Pastoral transhumant; Spruce (*Picea schrenkiana*)

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## Introduction

Tree rings are expedient to absolute calendar dating of archaeological occurrences in regions where long and widespread tree-ring records have been established. The American Southwest, Mediterranean, Europe and Siberia have long composite tree-ring records of mixed proveniences that extend back to the mid-Holocene and include archaeological timbers dating back to the Bronze Age in the Old World (Baillie and Brown, 1988; Dean, 1997; Manning et al., 2001; Panyushkina et al., 2007). In a few cases, these archaeological tree rings were successfully applied to environmental reconstruction to estimate climate change impact on the human cultures and societies of the past (Dean and Funkhouser, 1995; Hughes et al., 2001; Salzer and Kipfmueller, 2005). The use of tree-ring data as evidence for both dating and climatic reconstruction is essential for testing models of human behavior (Ahlstrom et al., 1995). In part, the ability of archaeologists to trace the social and cultural evolution of prehistoric communities in certain regions has been severely limited by inadequate chronologies (or time scales) and incomplete (or absent) high-resolution climatic proxies for particular periods of time and locations of specific interest. Inner Eurasia is one of these regions where the tree-ring evidence is sparse despite proximity of reported archaeological timbers.

We studied archaeological timbers recovered from a settlement and burial mound collected by the American–Kazakh Talgar project to evaluate the dendrochronological potential of the Andronovo timbers for their contribution to the absolute chronology of the Bronze Age and climate reconstruction in this part of Central Asia. The Talgar project explores origins and development of early pastoral transhumance during the Bronze Age period in Central Asia. Pastoral transhumance or the movement of nomads and their flocks or herds through large distance during different seasons of the year represents a series of adaptation strategies to geographical variations of climate. The Bronze Age herdsmen moved from pasture to pasture on a seasonal basis, thus exploiting forage and water resources necessary for the economic upkeep of their flocks and herds (sheep and goats, cattle and horses). In southeastern Kazakhstan the most common form of seasonal mobility for pastoral transhumants was based upon the use of different elevation zones. Herdsmen moved with their flocks and herds from the lowlands to higher elevations in the summer months and then returned to the lowlands for the fall, winter, and spring months (Frachetti, 2002; Chang et al., 2003). Although vertical transhumance is not the only form of pastoral mobility, it was more likely the type of pastoral mobility used in the Asi Valley, Tian-Shan Mountains. Modern Kazakh nomads still pursue pastoral transhumance economy in the Asi and Turgen summer pastures, seasonally migrating between lowland and high-mountain pastures.

The origins of this nomadic practice are associated with Indo-European tribes of the Andronovo Archaeological Community that occupied Inner Eurasia through the second millennium BC (Frachetti, 2002). In Andronovo archaeology, wood remains have often been reported at both burial mounds and settlements in the southern Urals, Siberia and Kazakhstan (Koryakova and Epimakhov, 2007). Yet, the Andronovo timbers are greatly underappreciated and rarely used for precise calendar dating of the archaeological occurrences. Despite the wood abundance, the Andronovo tree rings had not been used for radiocarbon wiggles until 2008. The calendar dates derived from the first radiocarbon wiggles established a cultural overlap of the two most important archaeological cultures of Andronovo (Fedorovo and Alakul) in the Southern Urals from 1780 to 1660 cal. BC (Panyushkina et al., 2008). This study challenged the longstanding debate on the relationship and origin of different groups of the Andronovo Archaeological Community in the Ural region using the far-reaching power of tree rings to refine the absolute (calendar) chronology of prehistoric human occupation in the Eurasian steppe during the 2nd millennium BC. It showed clearly that the Andronovo tree rings are the conquering source of highly resolved radiocarbon ages of the Bronze Age in Eurasia. Furthermore, potential application of the archaeological tree rings to evaluation of climatic impact on development of pastoral transhumant practice in the mountains of Central Asia and nomadic migrations across the region is just beginning to be exploited. Both annual and decadal variability of climate could determine forage and water availability, due to fluctuations in temperature and moisture regimes, and must therefore impact local and regional patterns of pastoral mobility during the Bronze Age and subsequent periods.

## Materials and methods

The tree-ring specimens came from two locations on the southeastern slope of the Zailiysky Alatau Range (Fig. 1). We sampled tree-ring specimens from excavations of the Asi-2 settlement (43°14′ 59″N and 77°58′29″E) and Turgen-1 burial (43°13′43″N and 77°50′02″E), both identified as sites of the Andronovo Archaeological Community (Chang et al., 2003). The Asi-2 settlement is situated along the northern terrace of the Asi River at 2400 m *asl*. The Asi Valley is only 12 km away from the second location, the Upper Turgen Valley, an area with many Bronze Age burial mounds at elevation between 2180 and 2300 m *asl*. Archaeological sites of the Bronze Age are commonly found on the high steppe grasslands of upland plateaus. A number of burial mounds and crude rock art carvings, including an

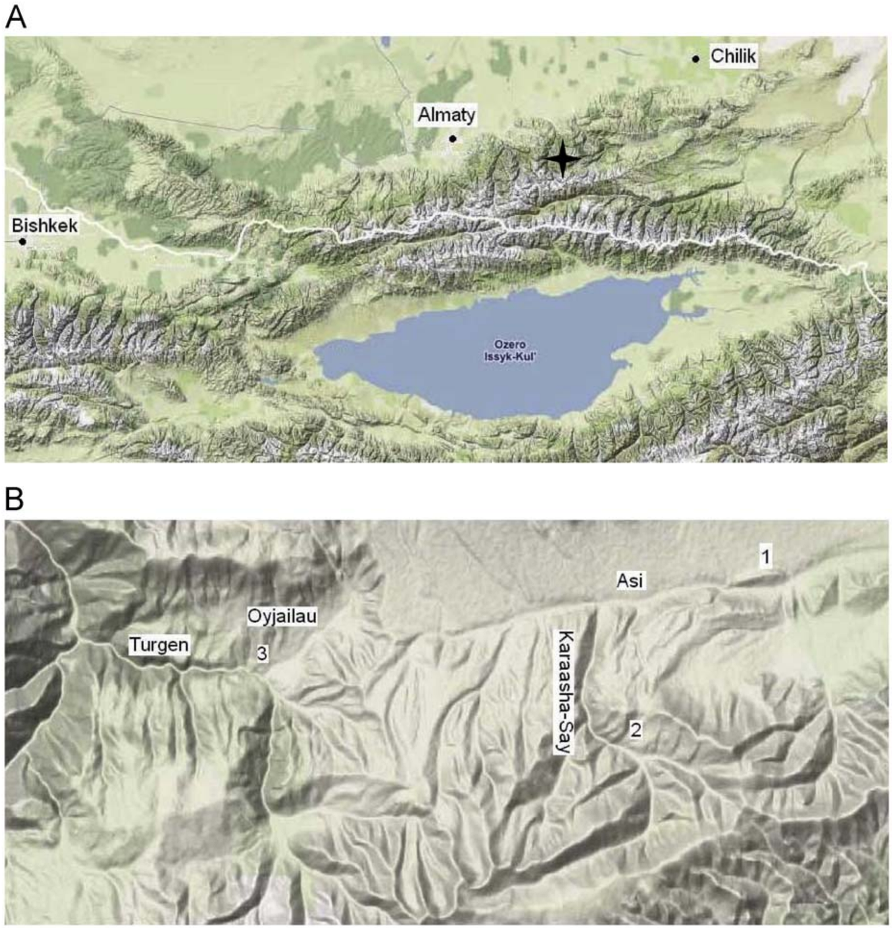


**Fig. 1.** Map of Zailiysky Alatau Range (Tian-Shan Mountains) northward from Lake Issyk Kul (Panel A, Scale: 1 cm = 20 km). The studied area is about 75 km from Almaty city. White line shows state border between Kazakhstan and Kyrgyzstan. Panel B (Scale: 1 cm = 1 km) depicts location of Asi-2 (1), Ulken (2) and Turgen (3) sites and proximity of the river valleys (labeled). Modified from http://maps.google.com.

image of a two-wheeled chariot with six spokes in each wheel, are documented by the archaeological survey just 2–3 km to the north of the Asi-2 settlement (Chang et al., 2003).

During the 2002–2004 field seasons the Kazakh–American Archaeological Expedition excavated the southern half of a semi-subterranean dry-laid stone house at the Asi-2 settlement about 170 $m^2$. The house structure has an interior area of 13 m × 13 m, two stonewall alignments and a timbered roof supported by posts. The house was divided into a few rooms by lower interior walls built from hard-packed gravel and yellow clay. Several round fire places or hearths constructed with large rocks up to 1 m in diameter were found on the floor level. An unexplained feature on the house floor was a stone slab (1 m × 25 cm) with evidence of intensive burning. There are two other floor levels in the interior of the house consisting of yellow clay (195–200 and 210–220 cm below the site datum).

The timbers found from the excavations at Asi-2 house are preserved in this archaeological context due to the cold ground conditions year round. The special layout of the timbers just above the floor level suggests that the Andronovo people used these timbers for roofing and flooring (Photo 1). The two largest pieces were uncovered from beams of burned and fallen roof (190 × 25 × 15 cm and 190 × 30 × 10 cm). Wood fragments up to 8 cm in diameter and 30 cm in length from partially burned upright posts were associated with roof supporting structures, the door jamb and, possibly, a fence along an exterior wall. Smaller construction timbers belonging to planks found at floor level measured about 50 cm in length, 2–3 cm in thickness and 5–10 cm in width. Additionally, charcoal and small unburned fragments of wood were found in large amounts within the burning area of the fire pits and on the floors. The archaeological timbers collected from the house were rotten, partially burned and flattened or mineralized in some cases. According to our experience it was better to sample the timbers and wrap them with plastic as soon as they were excavated in order to best preserved pieces

**Photo 1.** Asi-2 house timbers *in situ*. Claudia Chang is standing next to the long beams of collapsed roof possibly due to a fire (note burned lumber on the top pile). In low left corner, small planks are exposed below the horizon with the roof beams. Photo by P.Tourtellotte.

that might otherwise crack and fracture when they dry.

We collected 35 tree-ring specimens from the construction timbers of the Asi-2 house and one log specimen from the Turgen-1 burial mound. The specimens were carefully wrapped in stretchy clear plastic and secured with adhesive tape or glue for transportation. A few relatively solid samples were cut into cross-sections with a band saw and polished with 300 grit and then with 400 grit sand paper. Due to the intricate cracks and brittleness of the timbers, freshly shaved, sliced or wetted surfaces of the samples were required in order to determine the boundaries between individual rings. Since quantity of available tree rings is limited, both European (plotting tree-ring width measurements) and American (skeleton plotting) approaches to cross-dating were applied. Tree rings from each specimen were carefully inspected and counted. Fractured segments from a single specimen were matched with skeleton plotting and prepared for tree-ring widths measurement, where possible. We measured tree-ring widths from innermost rings (pith) to outermost rings using a Linux measurement system (0.01 mm precision) and replicated the sample measurements 2–5 times depending on number of fractured pieces. Multiple replications of tree-ring width series from one specimen were overlapped and averaged into one specimen tree-ring width series (Fig. 2). Accuracy of overlaps was evaluated with cross correlation statistics using program TSAP by RinnTech.

Additionally, we sampled living spruce trees (*Picea schrenkiana*) growing between elevation of 2610 and 2760 m *asl* in the Karaasha-Say Valley adjacent to the Asi Valley toward the southeast as a tributary. The upper tree-line stand, known as Ulken, was situated in a forest preserve protected by local Kazakh legislature. The Ulken forest is an open uneven-aged stand of spruce mixed with juniper krummholz. The sampled trees grow on a steep slope under temperate alpine conditions on well-drained soils. Twenty cores were taken from 15 trees with an increment borer at 1.3 m above tree base within a 1000 $m^2$ area (43° 21′N and 77° 50′E). Tree-ring analysis of living trees was made to establish a relationship between tree-ring width variability and climate. We developed a tree-ring width chronology from the Ulken detrended tree-ring width series with the Hugershoff growth curve and prewhitening with an autoregressive moving average model (program ARSTAN, Cook and Holmes, 1998). The tree-ring indices were calculated as the ratio between measured ring width and the corresponding value of the fitted curves. Climatic

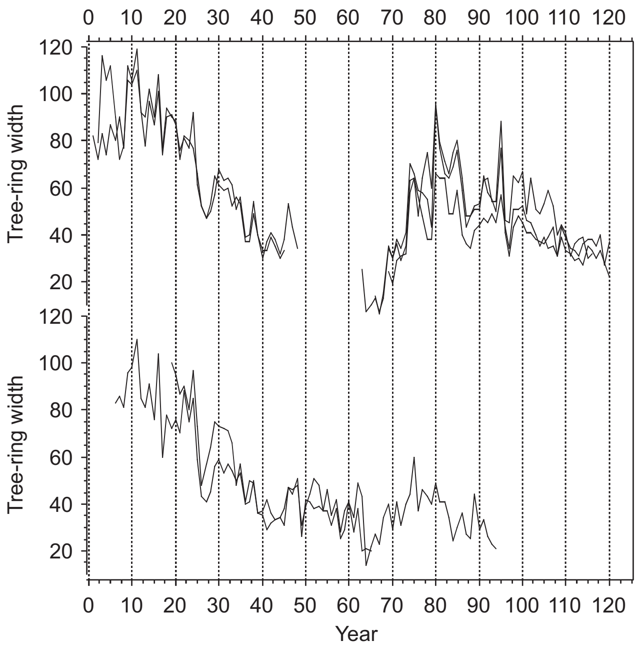


**Fig. 2.** Tree-ring width series from specimen Asi-2–16 fractured into three parts (left, right and bottom). To reconstruct the tree-ring sequences of this largest specimen we measured 2–3 replications of tree-ring widths from each piece that were overlapped and averaged into a 120 year tree-ring width series.

response function (stepwise multiple regression) was run for a 12-month period from October of the previous year to November the current year. Both monthly and daily temperature and precipitation observations from the mountain meteorological station Narin (41° 26′N, 76°E, 2039 m *asl*) for period 1931–1991 (www.meteo.ru) were used in the climatic modeling.

## Results

The Andronovo timbers exhibit reasonably good potential for tree-ring crossdating. The number of counted rings from the house timbers varies from 120 for big pieces (roof beams in our case) to 12–35 rings (planks and poles, respectively). Most wood samples have pith but are missing the outer rings, thus complicating an accurate estimation of tree-cutting dates. A couple of specimens had the outermost rings (terminal rings) and even bark preserved. Unfortunately, these specimens were small in diameter and the total ring count was insufficient for crossdating to establish tree-cutting dates. A total of 62% collected samples (20 tree-ring specimens) were suitable for crossdating. Nineteen percent of specimens could not be crossdated because of small number of tree rings and tree-ring width distortions. Another 19% of samples were excluded from the analysis because of unrecognizable boundaries between rings due to decay, flattening or fracturing. Measured tree-ring widths appeared to be sensitive to environment fluctuations. Mean sensitivity of tree-ring width series ranges between 0.2 and 0.4. The crossdated segments of tree-ring widths have significant coefficients of interserial correlation (R is 0.5 on average). The tree rings have a number of well-defined and replicated signature years including several frost rings that we used to overlap eight specimens each with fewer than 50 rings. Most overlaps of crossdated specimens are more than 50 years (Fig. 3). The overlapping tree-ring series from 19 specimens resulted in a 121-year tree-ring chronology of Asi-2 house (Fig. 4).

Three radiocarbon dates measured on Asi-2 wood from a roof beam, and interior and exterior walls were consistent with the overlaps of the crossdated samples. Calibrated radiocarbon dates place the floating 121-year tree-ring chronology between ca. 1640 and 1490 BC (Table 1). The developed radiometric sequence indicates that the Asi-2 site was built during the transition between the Middle Bronze Age and Late Bronze Age.

The only tree-ring specimen from the Turgen burial mound is a log 18 cm in diameter. The Turgen tree-ring sequence comes from a young spruce tree with 101 rings (Fig. 4). This specimen from the burial is better preserved than wood in the house and has a complete cross-section from pith to the outmost rings. The age of Turgen timber is associated with the mid-Andronovo period based on the burial complex and ritual (personal communication with A. Goryachev, author of excavations).

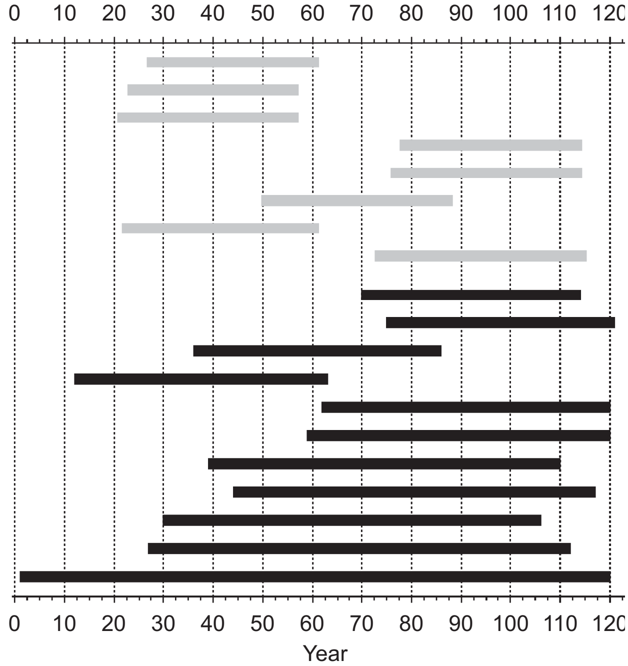


**Fig. 3.** Overlaps of tree-ring specimens in the 121-year chronology of Asi-2 house. Black bars: tree-ring series of more than 50 rings, whose overlaps were verified with correlation statistics. Grey bars: tree-ring series less than 50 years, whose overlaps were validated with both signature years from skeleton plotting and correlation of tree-ring width series.

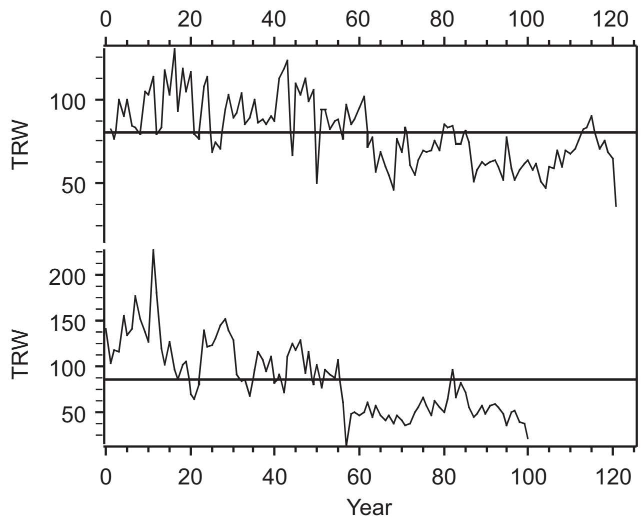


**Fig. 4.** Andronovo tree-ring width chronologies of spruce from Asi-2 settlement (top) and Turgen burial (bottom) dated to the Middle Bronze Age (ca. 3500 year ago). TRW -tree-ring widths.

**Table 1.** Radiocarbon dates for the Asi-2 excavated house.

| Location and depth below the site datum | Wood specimen ID | C14 Lab sample ID | Radiocarbon age, BP | Calibrated age, Cal yrs BC |
|---|---|---|---|---|
| Interior, collapsed roof, 150 cm | 4 | Beta-183399 | 3300 ± 70 | 1640–1500 |
| Exterior wall with entryway, 150–160 cm | 3a | Beta-183400 | 3260 ± 60 | 1610–1490 |
| Interior wall, 174 cm | 2 | Beta-171114 | 3260 ± 70 | 1620–1490 |

**Table 2.** Main statistics of tree-ring width chronologies form archaeological timbers (Asi-2 and Turgen) and living trees of the upper tree-line (Ulken).

| Site | Span, years | Number of trees | Mean width, mm | Mean sensitivity | Autocorrelation Lag 1 | Variance 1st eigenvector, % | Mean correlation with master |
|---|---|---|---|---|---|---|---|
| Asi-2 | 121 | 19 | 0.85 | 0.21 | 0.76 | 38.4 | 0.57 |
| Turgen | 101 | 1 | 0.78 | 0.22 | 0.83 | n/a | n/a |
| Ulken | 432 | 15 | 0.79 | 0.23 | 0.73 | 45.4 | 0.62 |

Table 2 shows that the main statistics for chronologies from the Asi-2 house and Turgen burial are comparable. The high degree of common variance in the Asi-2 chronology population suggests strong common signal in the tree-ring width variability, which is likely caused by climatic factor (factors) limiting spruce growth at this high elevation locality. There is high probability that the trees were cut in the valley surroundings at an elevation about 2400 m *asl*. According to our material, only spruce timbers (*P. schrenkiana*) were utilized in the house and the Turgen burial construction. The age-related variability of the crossdated tree-ring width series showed two main trends: (1) enhanced growth and (2) suppressed juvenile growth followed by rapid increase of growth toward the end, or no trend (fluctuations around mean tree-ring width). The means of the tree-ring width series vary widely from 0.45 to 1.26 mm. It could result from stand competition dynamics and evidence for the harvesting of these trees in a closed-canopy stand. The occurrence of a closed-canopy stand of spruce suggests sufficient moisture adequate for coniferous forest at this elevation ca. 3500 years ago, which could correspond to both a wetter climate and more pristine conditions of mountain ecosystems. At present, this elevation is mainly occupied by subalpine grasslands. The modern upper tree-line in the northern Tian-Shan (2700–2800 m *asl*) is about 300 m higher than the archaeological sites and the vertical zone of closed mountain spruce forest is about 300–400 m lower. It is possible that we have evidence of at least a 300-m change in the vertical gradient of this mountain ecosystem. The main factors contributing to *P. schrenkiana* recruitment on upper tree-lines of the inner Tian-Shan Mountains are spring precipitation and high minimum temperatures of several consecutive summers (Wang et al., 2005). In order to demonstrate that climatic trend driving the changes in vertical distribution of spruce forest habitat we identified the main climatic factor limiting spruce growth at this locality.

The Ulken tree-ring widths from a spruce stand located near the Asi-2 archaeological site were correlated with climatic parameters of the closest high-elevation weather station (Narin). Because no trees presently grow at the elevation of the archaeological sites, we climbed up 300 m on a steep slope along the Asi River's tributary to the nearest spruce stand at the upper tree line limit. The mean annual temperature observed at the Narin station is +2.7 °C, July temperature is +16.5 °C, January temperature is −16.1 °C and total precipitation is only 568 mm. The warm season (mean day temperature above 0 °C) lasts from April to October. The precipitation maximum occurs from May to July. Dendroclimatic analysis of the modern spruce tree-ring chronology from the Ulken site indicates that tree-ring width variability of spruce has a strong climatic signal associated with early growth season temperature. However, the temperature-spruce growth relationship is dominantly negative. The climatic response function of the Ulken tree-ring chronology showed significant correlation with April and August monthly temperature, negative and positive, respectively. April temperature has the highest correlation coefficient ($R = -0.6$). There is also a positive impact of May precipitation on the spruce growth.

The daily observations of spring–summer temperature were averaged in pentads (5-day mean) to determine more precisely a climatic window of the estimated relationship. It seems that temperature pentads from April 6th to April 30th have the strongest negative

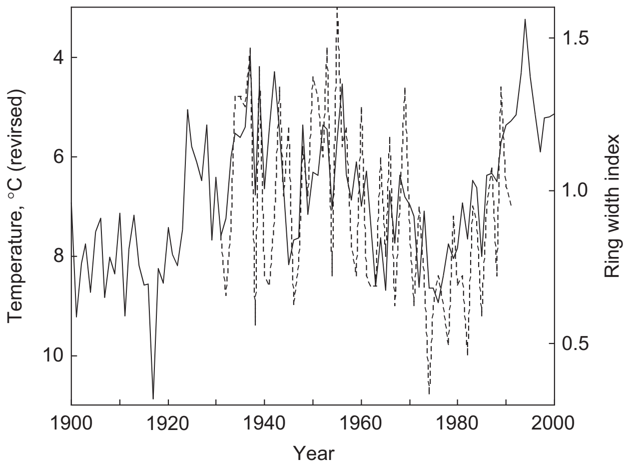


**Fig. 5.** Observed April temperature from the Narin weather station is plotted against the Ulken tree-ring width chronology. The temperature axis is reversed because the relationship between these two records is negative ($R = -0.61$).

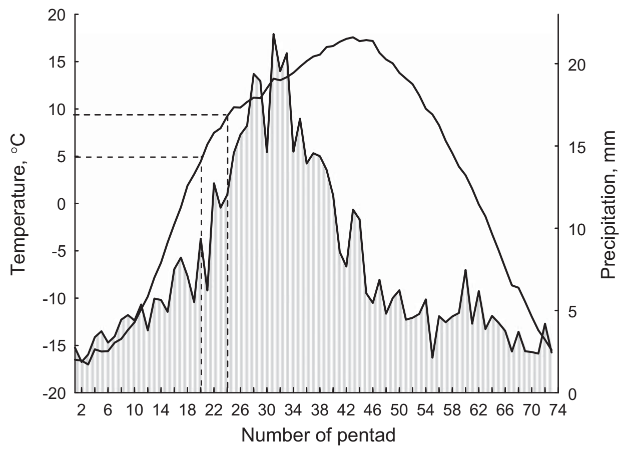


**Fig. 6.** Precipitation (grey bars) and temperature (solid line) pentads (mean for 5 days) from daily observations at the Narin weather station. Horizontal and vertical dotted lines show #20–#24 pentads that correspond to period from April 6th to April 30th.

correlation with the tree-ring growth (Fig. 5). Linear stepwise regression function for the April temperature and tree ring records calculated the following calibration statistics: $R = -0.61$, $R^2$ adj. $= 0.37$, $F_{(1,59)} = 35.03$ at $p < 0.000$. It suggests that the temperature signal for April is persistent in the tree-ring width variability. The mean temperature of the selected pentads increases from 4.4 to 9.9 °C during this period corresponding to the beginning of the growing season. The average snow pack is very low because of the winter dry season and the precipitation as rain only begins the fourth week of April (Fig. 6). Thus, this temperature relationship could be explained in the context of moisture stress. When temperature in the early part of the growing season is rising rapidly, increased evaporation and meager precipitation causes a negative impact on the spruce cambial activity. Hence, spring moisture stress is limiting spruce tree-ring variability at this locality and links spruce distribution to moisture availability. We found published evidence of only one such strong and inverse relationship of tree-ring width and spring temperature from upper tree-lines of the Central Asia established by spruce and juniper (Glazovskiy and Solomina, 1989). Most commonly tree rings show a positive correlation with temperature from July to August or June through September (Esper et al., 2002; Esper et al., 2003). Tree growth at the upper tree-lines eastward from Kazakhstan corresponds solely with precipitation due to less mesic conditions. For example, variability of spruce tree-ring widths from the Inner Tian-Shan Mountains (NE China) was mainly related positively to annual precipitation (Wang et al., 2005). Juniper tree rings from the northeastern Tibetan Plateau are limited by spring precipitation (May–June) (Huang and Zhang, 2007). The sundry climatic responses of modern tree rings suggest that climatic signals in the Andronovo floating tree-ring width records from the upper elevations could be controlled by climate variations restricted to moisture availability. To avoid misinterpretations in environmental reconstruction, a climatic signal of the floating tree-ring width record should be verified independently with additional tree-ring parameters (e.g. ring morphology, stable isotope composition) or other climatic proxies.

## Conclusions

The study of Bronze Age timbers suggests good potential for applying tree rings to absolute dating of Andronovo archaeological occurrences in the Tian-Shan Mountains. We developed a 121-year tree-ring width chronology of Asi-2 house that spans ca. 1610 to 1490 BC and a 101-year tree-ring sequence of Turgen burial mound. This is the first floating tree ring chronology from an Andronovo Archaeological Community in Central Asia. Importantly, timbers of settlements and burial mounds are suitable for crossdating, and identified as the same tree species. The Andronovo archaeological timbers can be crossdated and utilized for (1) developing a high-resolution radiocarbon chronology and (2) compositing the same age tree-ring sequences from different archaeological sites in the area. This offers an opportunity to precisely define calendar ages of numerous archaeological occurrences associated with the Andronovo Community in Central Asia, which will greatly contribute to developing a refined Bronze Age chronology of Eurasian steppe based on both radiometric and dendrochronological sequences. Because only young spruce trees were used in the house construction and the burial mound of Andronovo

Archaeological Community at this locality, we do not expect the archaeological tree rings to contribute to a long-term chronology of spruce in near future. There are, however, wood in other archaeological sites neighboring the Turgen Valley that span a two-millennium time period from about 1600 BC through AD 1300 (Chang et al., 2003), which might produce an array of floating chronologies and potential overlaps with long-term records from mountains of Central Asia.

Our assessment of the potential of the archaeological timbers for climatic reconstruction is cautious at the moment. Although, we determined a strong climatic signal in the archaeological tree-ring record at the study locality, uncertainty of archaeological wood origins, complex topography and a variety of climatic responses will complicate interpretation of climate variability derived from other floating tree-ring chronologies of this mountain region. Apparently, temperature signals might have different time windows (spring, summer) or signs (positive, negative) and moisture availability adds important input to tree growth variability in the region as well. Our study locality, because of estimated response of living trees to spring moisture stress, we conclude the likelihood is high of applying the Andronovo tree rings to models on pasture and water resources necessary for the pastoral transhumance economics and related to it nomad migrations. The 121-year tree-ring record suggests one relatively wet period (from year 1 to year 65) and dry and warm period (from year 66 to year 121) that correspond to the decades of large and low tree-ring growth, respectively (Fig. 4). Therefore, further research is needed on climatic response of spruce radial growth from a wide range of vertical ecological conditions in the region to improve our understanding of environmental signals in archaeological floating tree-ring records.

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