TREE-RING RESEARCH, *Vol. 74(1), 2018, pp. 50–62*
DOI: http://dx.doi.org/10.3959/1536-1098-74.1.50

THE FIRST DENDROCHRONOLOGICAL DATING OF TIMBER FROM TAJIKISTAN – POTENTIAL FOR DEVELOPING A MILLENNIAL TREE-RING RECORD

MAGDALENA OPAŁA-OWCZAREK[1]*, PIOTR OWCZAREK[2], OIMAHMAD RAHMONOV[3], and **TADEUSZ NIEDŹWIEDŹ[1]**

[1]Department of Climatology, Faculty of Earth Sciences, University of Silesia in Katowice, Będzińska 60, 41-200 Sosnowiec, Poland

[2]Department of Physical Geography, Institute of Geography and Regional Development, University of Wroclaw, Uniwersytecki Sq.1, 50–137 Wrocław, Poland

[3]Department of Physical Geography, Faculty of Earth Sciences, University of Silesia in Katowice, Będzińska 60, 41-200 Sosnowiec, Poland

ABSTRACT

We are reporting the first dendrochronological dating of timber from Tajikistan. Thirty samples were collected from two old buildings from a village located in the western Pamir-Alay; eight cores were taken from temple. Most of the construction wood was juniper species. The object chronologies cross-dated well with the previously published chronology based on living juniper trees from western Pamir-Alay. The results of dating revealed that investigated structures are composed of wood coming from several periods. The oldest pieces of wood dated back to the 11th and 12th Centuries. Most timber samples come from the turn of the 17th and 18th Centuries, which were probably the period of intense development of the Artuch village. Besides dating of the wood samples from these historic structures, our investigation provides the opportunity to extend the currently existing regional tree-ring chronology for future climate reconstruction of the Pamir-Alay and High Asia. Dated sequences were assembled into a 1012-year chronology spanning the period 945–2014 C.E. and strengthened the replication of its earliest part (with critical 0.85 EPS value since the beginning of the 13th Century).

Keywords: Central Asia, Pamir-Alay Mountains, Tajikistan, historical buildings, dendroarchaeology, tree-ring dating, timber, *Juniperus.*

INTRODUCTION

The Pamir-Alay mountain region played an essential role in the development of ancient civilizations in Central Asia. This former territory of Sogdiana, the ancient Indo-European civilization of Iranian people, was under the influence of different cultures during last 3000 years, including the Achaemenid Empire of Persia, Hellenistic Greco-Bactrian Kingdom, Imperial China, Arab Muslim, Mongol Empire (Hormatta *et al.* 1994; Litvinsky *et al.* 1996; Ghafurov 2011). This region, currently located within the political boundaries of Uzbekistan and Tajikistan, is rich in archaeological sites and settlement remains of different age. This diversity of material culture is related to the location of the region, which was crucial for the functioning of the "Silk Route" along which merchandise and ideas flowed between China, India, Iran and Europe. The Pamir-Alay Mountains are surrounded and crossed by main branches of this ancient network of trade routes. Many settlements were established along this route or their importance increased, especially during the Han (207 B.C.E.–220 C.E.) and Tang dynasty (618–907 C.E.) when the trade of Chinese silk was the most lucrative (Hulsewé *et al.* 1979; Hormatta *et al.* 1994; Litvinsky *et al.* 1996). The great Sogdian cities, such as Samarkand (Maracanda), Panjikent (Panchekanth) and Bukhara, were developed during these times in large agricultural oases located west of the Pamir-Alay Mountains in the Zarafshan River valley (Schafer 1963; Belenitskiy

*Corresponding author: magdalena.opala@us.edu.pl

et al. 1973; Dumper and Stanley 2006; Ghafurov 2011; Owczarek *et al.* 2017b). The branch of the Silk Route, which ran along this valley, merged the western Pamir-Alay region with the oases of Tarim Basin.

The development of trade affected the expansion of settlements in narrow mountain valleys in the middle and upper parts of the Zarafshan River basin. The archives discovered at the castle on Mount Mug (Mōg) in the upper course of Zarafshan River provided detailed information about first millennium history of the Common Era of this part of Sogdiana territory (Freiman *et al.* 1962–1963; Bogolyubov and Smirnova 1963).

The Arab conquest in the 8th Century and invasion of Central Asia by hordes of Chengez Khan in the second decade of the 13th Century devastated the region (Ghafurov 2011). Legal documents and letters concerning rural settlements, people and socio-economic relations of the Pamir-Alay Mountains are rare and require additional research methods. One of these is dendrochronology. Tree-ring analysis has proven to be a powerful dating method since the early works of A. E. Douglass, who dated ancient pueblos in southwestern US (Douglass 1921). In subsequent decades there have been many successful attempts of tree-ring research in dating of wooden construction elements of archaeological and historical monuments (Cufar 2007). Dendrochronological research in Central Asia primarily concerned monasteries, temples and tombs. The number of dendroarchaeological studies carried out in High Asia is still rather scarce (*e.g.* Zamotorin 1963; Marsadolov 1994; Schmidt *et al.* 1999; Vasiliev *et al.* 2001; Panyushkina *et al.* 2007, 2010; Baatarbileg *et al.* 2008; Bräuning *et al.* 2013; Scharf *et al.* 2013; Wang and Zhao 2013).

The Pamir-Alay region located on the border of Tajikistan, Uzbekistan and Kyrgyzstan is rich with archaeological sites and cultural remains. However, because of scarcity of written documents, the history of the mountain settlements is not well known. Rural buildings in this part of Central Asia are characterized by a typical construction style that has not been changed for hundreds of years. This is confirmed by archaeological excavations in ancient Panjikant, in northwestern Tajikistan (Belenitskiy *et al.* 1981). Typical for mountain villages, one- or two-storey houses, often with an inner courtyard and richly decorated wooden entrance gates, were built already in the 5th Century (Marshak 2003). This architectural continuity is very important in terms of analyzing the socio-economic, historical and political processes taking place in this area. Nowadays, some of the buildings are rebuilt or simply destroyed, and a new style of construction is introduced. Dendrochronological analyses are therefore an opportunity to preserve information about the origin and the history of unknown rural buildings in northwestern Tajikistan, the number of which is constantly decreasing.

The potential of dendrochronological analysis of wooden structures from Zarafshan Valley remained unexplored for a long time. Recent advances in the development of long tree-ring chronologies for this region (covering the time span 1005–2014 C.E.) allow for dating the historical structures (Opała *et al.* 2017). This regional chronology was constructed from junipers (*Juniperus semiglobosa* and *Juniperus seravschanica*) growing in the high-elevation sites in the western Pamir-Alay. The aim of this study was to perform dendrochronological dating, report on the history of the two buildings and a temple complex (sacred groves and temple) located in Pamir-Alay, northwestern Tajikistan and to extend the previously published regional tree-ring chronology for this region.

MATERIALS AND METHODS

Study Area

The study area includes the Artuch village located in narrow Urech River valley in the upper part of the Zarafshan River basin (Sughd province, northwestern Tajikistan; Figure 1A, 1B). The Artuch village, elevation *ca.* 2000 m a.s.l., is surrounded by the high mountain massifs of the Zarafshan Range (Chimtarga Peak, 5489 m a.s.l.) that belongs to extensive Pamir-Alay mountain system. The study area has typical high-mountain relief characterized by steep slopes with numerous traces of mass movement processes partly connected with seismic activity (Owczarek *et al.* 2017a). The barren surface, which lacks continuous vegetation cover, dominates the landscape (Rahmonov *et al.* 2016; Figure 2A). The open woodland

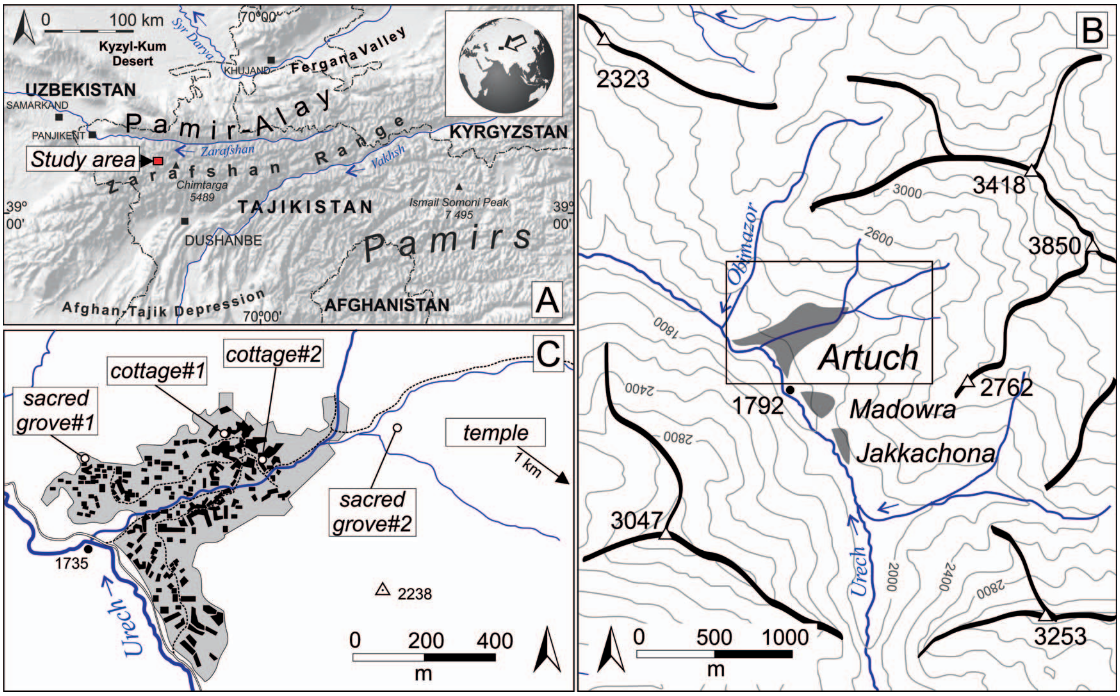

Figure 1. (A) Location of the study area on the background of the major geographical regions of the Central Asia. (B) Detailed location of the investigated Artuch village. (C) Sampled sites.

composed of juniper trees survives only in the high elevation (*ca*. 2800–3000 m) (Sadikov 2012). This part of the Pamir-Alay, surrounded by the Kyzyl-Kum desert plains, has a typical arid continental climate. The mean annual total precipitation is 271 mm with mean annual air temperature 6.6°C (Iskanderkul Meteorological Station). The Artuch village was established on the alluvial fan formed by right tributary of the Urech River (Figures 1C, 2A). The fan is inclined towards the west. The main square with mosque is located in its central part. The village has traditional low buildings built of bricks, clay and wood (Figure 2B–D).

Samples Processing and Dendrochronological Dating of Timber

The historical tree-ring samples came from five locations in the Zarafshan Range, western Pamir-Alay (Figure 1C). We sampled tree-ring cores from three architectural monuments in the Artuch village (2000 m a.s.l.; Table 1). Altogether, 10 samples were taken from cottage #1, and 20 cores were sampled within cottage #2. In addition, we investigated the remains of the temple located at a high-elevation site (3000 m a.s.l.) at a distance of 2.5 km from the village (Figure 1C). Eight samples were taken from the posts and roof construction of the temple.

We also performed tree-ring analysis of the sacred groves located in the vicinity of the village. These individual, very impressive sacred specimen trees, as well as their clusters, used to be an object of worship and protection. Sacred natural sites have been defined as areas with special significance to people and communities, and thus these sites have been managed as protected areas, which can be one of the oldest conservation systems. Such sacred sites serve for managing natural resources and conserving ecosystems through religious rules (Oviedo and Jeanrenaud 2007; Dudley *et al.* 2009). Therefore their age may provide additional information about the period when the settlement or temple complexes were founded and inhabited (Yadav *et al.* 2014).

All samples were manually taken using Pressler borer because the use of electromechanical

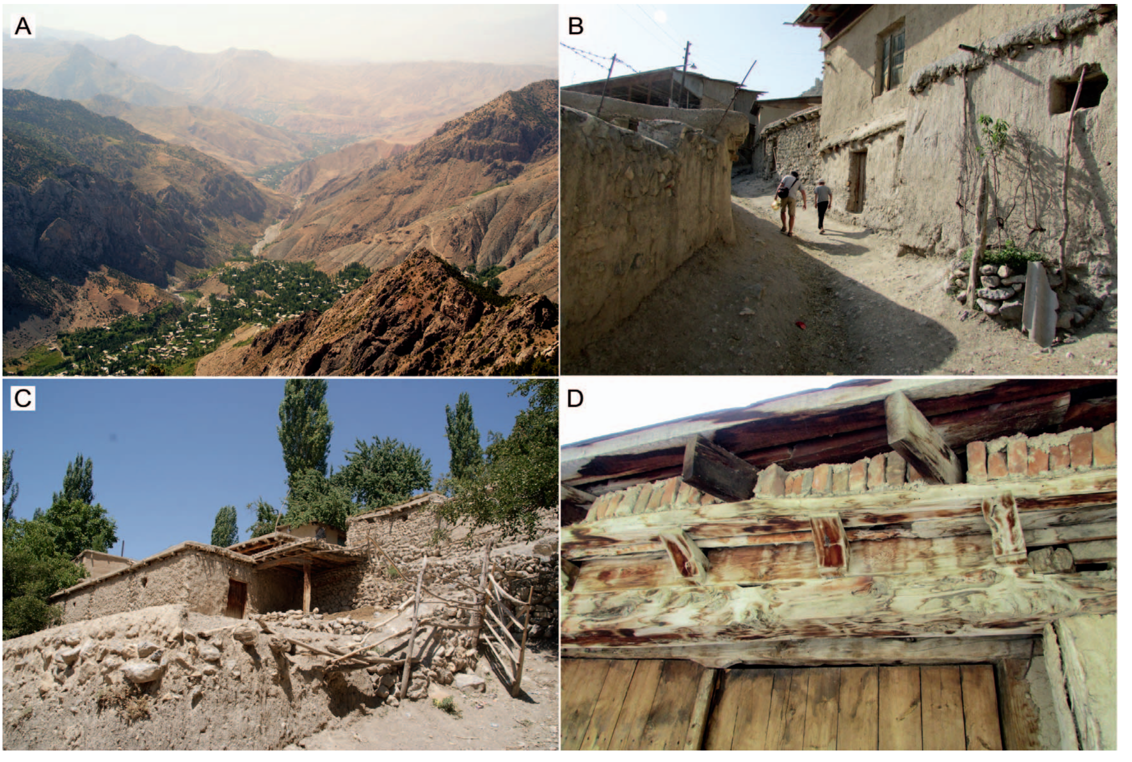

Figure 2. (A) General view of the Artuch village, situated within alluvial cone of small right tributary of the Urech River. (B) and (C) Typical traditional buildings of the central part of the village. (D) Construction elements made of juniper wood.

Table 1. General characteristics and location of investigated objects.

Site	Short Description	Geographical Coordinates	Altitude (m a.s.l.)	Number of Samples Taken/ Dated	Mean Number of Rings (min–max)	Species Genera
Cottage #1	Traditional building located in the central part of the village	39°20′05.10″N 68°06′37.18″E	1905	10/8	114 (43–369)	*Juniperus, Populus*
Cottage #2	Traditional building located in the eastern part of the village	39°19′01.05″N 68°06′44.39″E	1900	20/16	145 (48–757)	*Juniperus, Populus*
Temple	High elevation temple	39°20′10.05″N 68°08′04.48″E	2553	8/4	122 (69–159)	*Juniperus*
Sacred grove #1	Group of monumental juniper trees located near the village	39°20′00.80″N 68°05′58.55″E	1780	4/4	165 (50–337)	*Juniperus*
Sacred grove #2	Monumental juniper trees located near the temple	39°20′06.33″N 68°07′23.52″E	2160	1/1	497	*Juniperus*

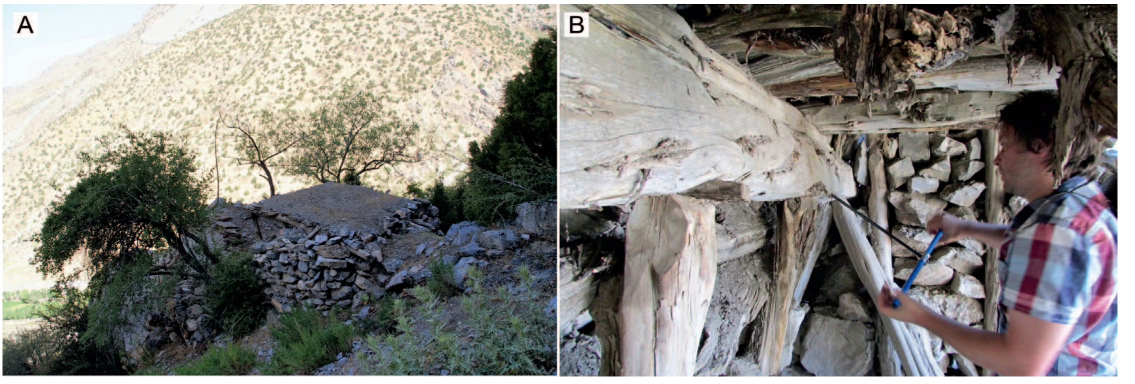

Figure 3. "Temple" site. (A) General view of the investigated temple. (B) The interior of the temple with beams of juniper tree and wooden frames with stone filling.

drills was not permitted (see Figures 3B, 7B). Next, the wooden materials were processed using the standard dendrochronological protocol (Baillie 1982; Speer 2010). Ring widths were measured to the nearest 0.01 mm by using the WINDENDRO digital measurement system (WINDENDRO 2010). The number of tree rings in each cross-section varied from 23 to 757. Only samples that had more than 45 tree rings were selected for further analysis. Crossdating, based on visual and statistical matching of ring-width patterns of the specimens, was accomplished using TSAP Win software (Rinn 2010) and checked using COFECHA program (Holmes 1983). Historical timber (individual cores from constructional elements) was crossdated against a regional tree-ring width chronology for Pamir-Alay (1005–2014 C.E.), which was composed of living juniper trees collected in the distance of 10 km from the Artuch village (Opała *et al.* 2017). The crossdating procedure was based on standard statistical parameters including "Gleichlaeufigkeit" (Glk) coefficient (Eckstein and Bauch 1969), correlation coefficient (r), t-value after Baillie-Pilcher (TVBP), t-value after Hollstein (TVH), and standard t-value (TV). To validate or exclude dating results we applied the following threshold conditions: Glk% >60, TV (standard t-value, TVBP or TVH) >4.0 and r>0.32, assuming that threshold values for all three of these parameters have to be exceeded.

For historical wood, a local chronology was developed. Series-length growth trends of all the samples were removed by dividing measured values by fitted values from modified negative-exponential curves. This resulted in dimensionless index series that were averaged together into a chronology using a robust mean calculation (Fritts 1976). At the final stage, absolutely dated historical wood was incorporated into a regional chronology. The ARSTAN software was used for detrending and for averaging series into chronologies (Cook and Holmes 1999).

RESULTS

The main building material of the analyzed wooden constructions was juniper wood. It is associated with the occurrence of almost exclusively living trees of *Junipers seravschanica*, *J. semiglobosa* and *J. turkestanica* in their natural stands in the Zarafshan Range. Samples of other species (*Populus*) were seldom employed, and were not examined because of the lack of a master chronology for this species. The timber from the Zarafshan Range shows reasonably good potential for tree-ring crossdating. The average number of rings on analyzed timber samples was 168 years. However, there were samples with a larger number of growth rings, with a maximum of 758 annual rings for timber and 497 annual rings for living trees from sacred groves (Table 1). Analyzed tree-ring sequences appeared to be sensitive to environment fluctuations. Mean sensitivity of tree-ring width series ranged between 0.15 and 0.50. Finally, calendar years for tree felling were established for a great number of timber samples (Table 2).

Table 2. Crossdating coefficients between the Pamir-Alay juniper chronology and the individual timbers from the historical buildings.

Lab Code	Overlap Period (years)	Glk %	r-Master	TVBP (TV)	Date Begin	Date End	Length of Series (years)	Outermost Ring Below Bark
Temple								
TJAR_06	108	58	0.353	5.0 (10.6)	1081	1188	108	yes
TJAR_05	159	61**	0.373	4.2 (6.8)	1398	1556	159	yes
TJAR_04	155	68***	0.342	5.3 (4.6)	1524	1678	155	no
Cottage #1								
TJHR_03b	53	60	0.739	4.0 (4.8)	1231	1273	43	yes
TJHR_07	371	59***	0.362	3.3 (4.7)	1412	1782	371	yes
TJHR_01	94	62*	0.336	4.0 (3.9)	1863	1956	94	yes
Cottage #2								
TJHB_03b	50	75***	0.464	4.2 (4.5)	1014	1063	50	no
TJHB_07b	107	60*	0.352	4.4 (7.8)	1056	1162	107	yes
TJHB_10	698	58***	0.405	4.1 (3.6)	552	1308	757	yes
TJHB_09b	71	65**	0.398	4.4 (5.5)	1241	1311	71	yes
TJHB_08b	210	56	0.484	4.6 (10.6)	1164	1373	210	no
TJHB_01	49	70**	0.450	4.2 (4.0)	1339	1387	49	no
TJHB_09a	74	64**	0.453	4.1 (4.7)	1488	1561	74	no
TJHB_02b	195	65***	0.329	6.2 (5.6)	1542	1736	195	no
TJHB_02a	330	64***	0.335	5.9 (7.3)	1427	1756	330	yes
TJHB_11	162	58*	0.371	4.0 (6.9)	1690	1851	162	no
TJHB_05	407	64***	0.408	6.2 (8.2)	1530	1936	407	yes
TJHB_03a	312	57**	0.375	4.7 (4.2)	1637	1948	312	no

Significance for the Glk-value:
* = 95.0%,
** = 99.0%,
*** = 99.9%.
Glk = Gleichlaeufigkeit coefficient, r-master = correlation (coefficient) with master chronology, TVBP = t-value after Baillie-Pilcher, TV = standard t-value, date begin = calendar year of the innermost ring, date end = year of the outermost ring.

Temple

The small temple was built on steep slope with the western exposure at the elevation 2553 m a.s.l. It is located about 2.5 km to the east of the village (see Figure 1C). This simple construction is used as a place of prayer of local people and meditation with harmony of nature. The temple is surrounded by shrubs and small trees of different species (Figure 3A). Springs and a waterfall are located in the vicinity. The building is open to the northwest. Inside there are artefacts important to the local beliefs, like animal horns. The height of the temple is 2.4 m, and it is built of timber frames with stone infill (Figure 3B). Thus, only eight timber samples could be taken from this object, however four of them were broken from decay or could not be dated because of an insufficient number of rings. Only three samples (TJAR_04, TJAR_05, TJAR_06) from temple were successfully crossdated with the master chronology (Table 2). Their dating was confirmed with statistically significant t-values above 4.2 and good visual matching of tree-ring patterns. For one sample (TJAR_07) no convincing match could be found, graphically and statistically. The calendar age of the pieces of wood used for the temple construction varied, which may indicate the continuous use and ongoing maintenance of this historical structure. The earliest end date of wood (with outermost ring below bark) obtained for the vertical beam is 1188 C.E. This result is supported by very high t-value (TV = 10.6). The consecutive beams had end dates between 1556 and 1678 (Table 2).

Cottage #1 in the Artuch Village

Cottage #1 is located in the central part of the village (see Figure 1C). The farmyard consists of low residential building and outbuildings created on an irregular plan with flat roofs. They are single storey with small basements. The outbuildings have threshing floors. The cottage has a small later additional storey (Figure 4A). The farmyard forms a string of buildings closed from the

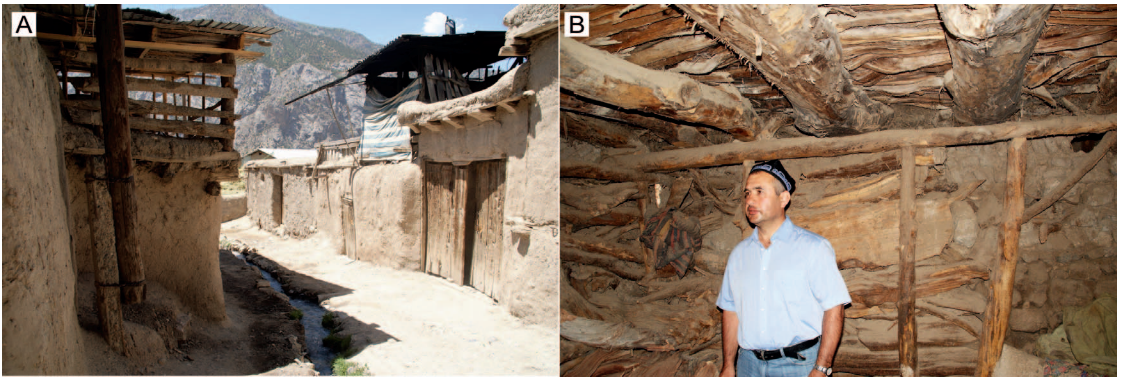

Figure 4. "Cottage #1" site. (A) The farmyard forms a string of buildings closed from the path; note small additional storey on right. (B) The interior of residential house, exposed beams of juniper wood.

walkway with an internal courtyard. The cottage is built of clay and bricks with wooden frames (Figure 4B). It is an example of typical residential building, common in the northwestern Tajikistan. The samples were collected from the main construction elements: joints and pillars. In cottage #1, eight out of 10 timber samples could be further analyzed, the remaining two samples being rotten. Of the eight samples processed, only three have been successfully dated (TJHR_03b, TJHR_07, TJHR_01). All analyzed statistical parameters were above critical thresholds. For the remaining four (TJHR_04, TJHR_03a, TJHR_05, TJHR_02, TJHR_06), the statistical parameters were lower and these samples could not be dated. The oldest sample from this building has outermost ring below bark and was dated to 1273 (TJHR_03b). Other wooden elements from this site, dated to the end of 18th Century, and also the middle 20th Century, indicate that the building was continuously used and repaired (Table 2).

Cottage #2 in the Artuch Village

Cottage #2 is located in the eastern part of the village (Figure 1C). The farmyard consists of a two-storey residential building and outbuilding with an "attic" for storing hay (Figure 5A). The complex is built on a plan in the letter L. The farmyard is built on the right bank of a small creek crossing the village. The complex is built of stones and bricks with a lot of the wooden elements (Figure 5B). The samples were collected mainly from joists. In this building the largest number of the samples could be taken because of the building's large dimensions and relatively easy access to the timber elements. As in the previous buildings, the obtained dates are very diverse. The oldest element of the building has an end date 1063 C.E. (TJHB_03b), which was proven by good visual and statistical match, but the age of the building cannot be precisely determined because of the lack of the outermost ring below bark in this sample. The second oldest sample was dated to 1162 C.E. (TJHB_07b). The cutting date of this beam can be precisely determined thanks to the presence of the outermost ring below bark. Four samples from cottage #2 were dated to the 14th Century and had cutting dates that showed clustering around 1308/1311 (TJHB_10, TJHB_09b) and 1373/1387 (TJHB_08b, TJHB_01). The other single timber was dated in the 16th Century (TJHB_09a). Five other samples that date from the mid-18th Century to the mid-20th Century, are the evidence of the contemporary use of the cottage (Table 2, Figure 6).

Sacred Groves

In the Artuch village there are two sacred groves, one located in the lower part of the village and the second in the upper part (Figure 1C, Table 1). These groves of juniper trees are of special religious importance to the local culture. Additionally, they are important for healing to indigenous people, according to local beliefs. Thus, these juniper trees are the only ones

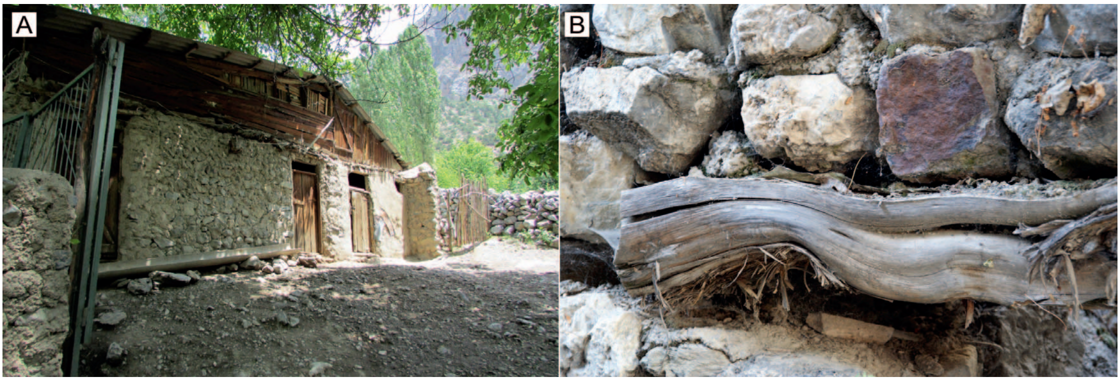

Figure 5. "Cottage #2" site. (A) The stony outbuilding with an "attic" for storing hay. (B) Wooden construction elements within stone wall.

that survive in the vicinity of the village. Any interference is prohibited and requires the approval of local authorities. The sacred groves are fenced and marked in the landscape. The Artuch sacred groves consist of several individual freestanding, impressive juniper trees with a well-developed crown. The height of the trees is about 8–10 meters (Figures 7A, 7B).

The result of dendrochronological investigation carried out in 2014 shows that the sacred trees are of different ages. The oldest juniper grows in the grove located close to the temple. The age of the tree (at the breast height) is 497 years. The second sacred grove comprises individual junipers having different ages: 50, 95, 127, 217 and 337 years.

Composite Regional Tree-Ring Chronology

Analyzed timber samples were well cross-dated with the master chronology for Pamir-Alay

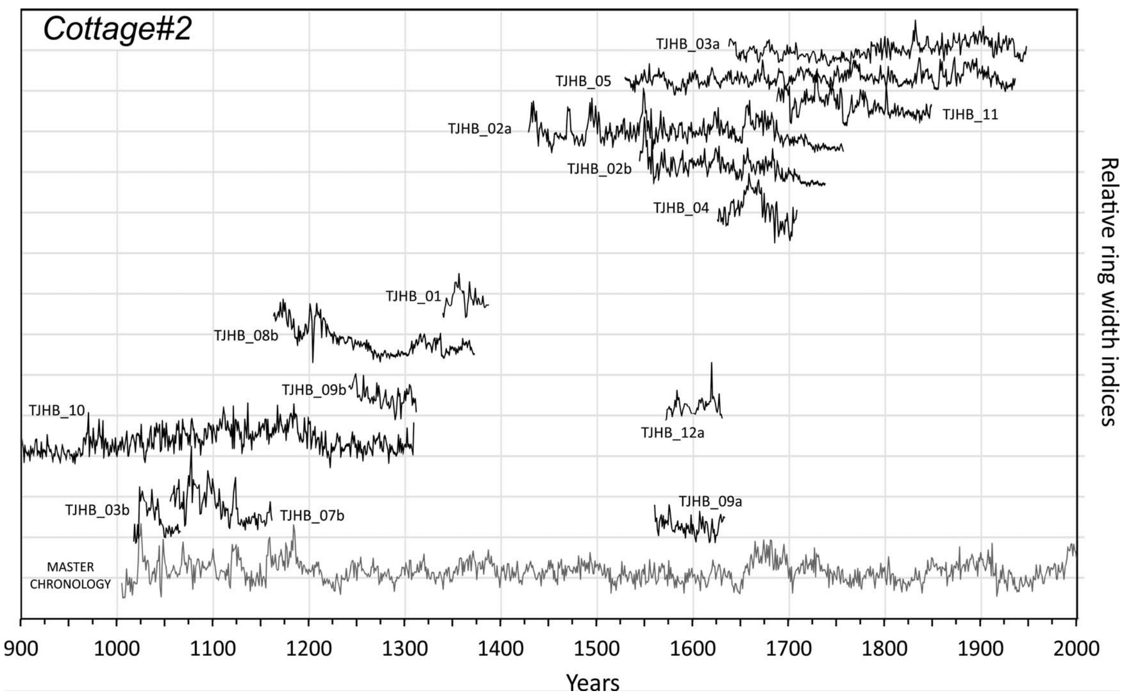

Figure 6. Positions of tree-ring width series from Cottage #2 constructions dated against Pamir-Alay master chronology.

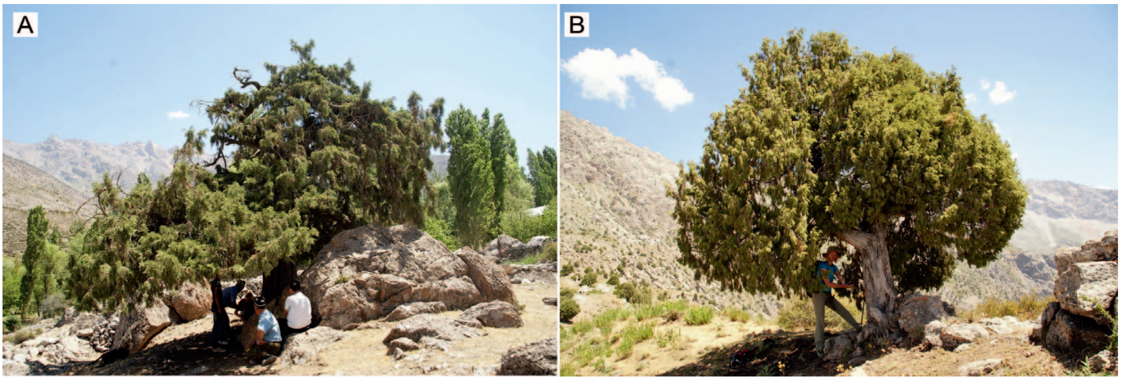

Figure 7. (A) Old-growth juniper from sacred grove with special significance to the local community. (B) Taking incremental core from juniper (*Juniperus seravschanica*) tree, representing one of the sacred natural sites in the western Pamir-Alay.

(mean $r = 0.445$). After crossdating and averaging, timber samples formed a 1012-year long historical wood chronology spanning 945–1956 C.E. Good agreement between living trees and historical wood chronologies is confirmed by crossdating parameters. The Glk value is 63 (significance for the Glk-value 99.9%) and t-value is 6.9 with the overlap between chronologies of 952 years. The time span of the previously constructed living-tree chronology for Pamir-Alay is 1005–2014 C.E. (1010 years; Opała *et al.* 2017). After the merging of the living-tree and archaeological chronologies, the new regional chronology now spans 945–2014 C.E., and is 1070 years long. The new chronology is only 59 years longer than the living-tree chronology, but the sample replication in the early part of the chronology is significantly improved, and thus the statistical properties of the regional chronology are improved as well (Figure 8). Incorporation of the construction wood into the regional chronology has improved the sample depth and climatic signal embedded in the chronology, expressed as higher values of EPS, since beginning of the 13th Century. Incorporation of the historical wood into a regional Pamir-Alay chronology will therefore enable reliable estimation of past climatic variation

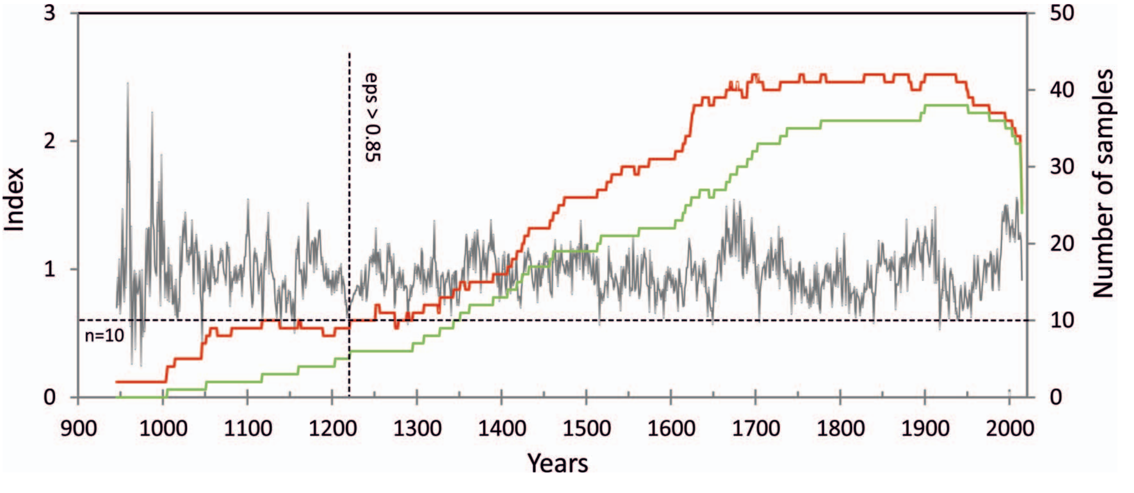

Figure 8. 1070-year-long juniper tree-ring width chronology based on living trees (chronology previously published by Opała *et al.* [2017]) and relict material (this study) from the Zarafshan Range, western Pamir-Alay, with sample replication of previous (green line) and new composite (living and historical wood) chronologies (red line).

over the last eight centuries in future paleoclimatic reconstructions.

DISCUSSION

The majority of dendrochronological research in the Central Asia and surrounding areas were conducted for the purpose of dendroclimatological analysis (*e.g.* Esper *et al.* 2002; Shao *et al.* 2010; Yadav *et al.* 2011; Grießinger and Bräuning 2012; Davi *et al.* 2015; Opała *et al.* 2017). Dendroarchaeological investigations were carried out in different parts of Central Asia: Nepal, Kazakhstan, Mongolia, China (*e.g.* Schmidt *et al.* 1999; Vasiliev *et al.* 2001; Baatarbileg *et al.* 2008; Panyushkina *et al.* 2007, 2010). Recently many studies have been also realized in Altai region (*e.g.* Agatova *et al.* 2014, 2016; Büntgen *et al.* 2016). Typically dendrochronological investigations were conducted in large ancient and historical sites, such as archaeological excavations, monasteries, and castles. This study is among the first that concentrates on small, rural constructions in High Asia. Our results are important because of the lack of information about small settlements in contrast to the large towns or monasteries.

Dendrochronological dating of timber from Artuch village in western Tajikistan indicates settlement activity in this area from at least the 11th–13th Centuries. Historical sources indicate that the Urech River valley was inhabited in the first millennium C.E. or earlier. In the small town Panjrud, located *ca*. 3 km to the northwest of our study area, famous Persian poet Rudaki was born in 858 C.E. and died in *ca*. 941. It is well documented that this settlement was a relatively large village at that time (Ghafurov 2011). Although little is known about the early development of the Artuch village, it is believed that the nearby Panjrud could influence the process of settlement in other parts of the valley.

Most of historical samples from this area dated back to the 17th and 18th Centuries, most likely a period of intense development of the village. Different dates of the wooden elements within the analyzed objects indicate the individual replacement with new materials and constant usage of the buildings. Although the analysis is based on a relatively small amount of timber material, similar results are obtained for all investigated buildings.

The most important possible limitation for the interpretation of tree-ring dates may arise from the reuse of old timber. This common practice was attributable to the fact that juniper has a very high natural resistance to decay (Mukhamedshin and Talancev 1982; Scheffer and Morrell 1998; Morrell *et al.* 1999). Its wood is characterized by high density and durability. It shows excellent resistance to termite and fungal attack (xylophagous fungi; Morrell 2010). The juniper wood is also extremely durable in contact with the soil (Morrell *et al.* 1999), has low shrinkage, and does not tend to crack. Even after contact with water, it does not deteriorate, and after drying it preserves its dimensional stability. Juniper heartwood has a high resistance to rot and decay (Mukhamedshin and Talancev 1982). Furthermore, climate is also a very important factor affecting juniper wood decomposition. In semi-arid environments wood decay is much slower than in wet areas (Murphy *et al.* 1998).

Building practices continued in this area for hundreds of years, as evidenced by excavations in many archaeological sites in the ancient Sogdiana (Murshak 2003), where one- or two-storey houses were built with the use of sun-dried bricks or stones with wooden timber frames. Juniper-wood carvings, columns and remnants of wooden ceilings found in the ancient Panjikent archaeological site (5th Century C.E.), in the vicinity of the study area, are preserved in very good condition (Azarpay 1981). Buildings were composed of several rooms of which the central room usually contained a hearth. Smoke additionally affected the preservation of wood by protecting it from xylophagous insects. Durable and resistant to external factors, juniper material and continuing style of building construction facilitated the reuse of wood. An additional factor that affects the reuse of wood is the deficit of raw material. Juniper forests occupy relatively small areas and are located in inaccessible high-altitude sites, which makes wood very valuable material. Short stems and a high degree of taper make it difficult to obtain long and wide logs. Long beams are rare but a very desirable building material, so they are commonly re-used.

The timber samples correlate well with the local chronology constructed from living junipers growing at the maximum distance of 10 km from the village, indicating the local origin of the material. During the sampling, we tried to find beams with bark and outermost ring below bark. However, only part of the collected timbers have outermost ring below bark, necessary for the year of tree felling to be determined precisely. For the correct interpretation of the dendrochronological dates, it is important to know whether the builders use green or dried wood. In the latter case, the last growth ring under the bark will be a few years earlier than the time of building.

The additional complication in interpreting the results of dendrochronological dating is the occurrence of dead or partially dead juniper trees in the forest. The phenomenon of gradual dieback of very old juniper trees starts from the crown-top downward, resulting in stunted growth (Mukhamedshin and Talancev 1982; Murzakulov 2015). These relict trunks could also have been used as a building material.

In summary, at best the dates we obtained indicate the timing of tree death, but not the exact date of building construction. This circumstance may be influenced by several behaviors, such as reuse of wooden elements from pre-existing constructions, use of relict wood, and possible seasoning of wood. All the limitations must considered in interpreting felling dates and building dates.

CONCLUSIONS

Junipers (*Juniperus semiglobosa*, *J. seravschanica* and *J. turkestanica*) are common long-lived species in the Zarafshan Valley, Pamir-Alay Mountains. The juniper wood is the main construction material in the mountainous villages. The results of this study revealed that all investigated buildings are made of wood coming from several periods. The development of dendroarchaeological research in the high mountain villages in the Central Asia is important considering the small amount of archaeological and historical data, but limitations must be considered in interpretation of dendrochronological dating.

Besides useful information in the chronological or human historical context, the developed tree-ring records can serve as a valuable regional archive of past environmental and climatic variations. The analyzed historic wood helped to extend and improve the previously constructed millennial juniper tree-ring chronology for the Pamir-Alay Mountains. This new composite chronology is 1070 years long and spans the period of 945–2014 C.E. and contains a considerable potential for dating historical objects and as a climatic archive.

ACKNOWLEDGMENTS

The study was funded by the Polish National Science Centre (NCN) grant number 2013/09/B/ST10/00634. P. Owczarek was financed by University of Wroclaw. The publication has been (partially) financed from the funds of the Leading National Research Centre (KNOW) received by the Centre for Polar Studies of the University of Silesia, Poland. The local authorities are acknowledged for the sampling permissions. The authors want to thank Rahmonov family and Łukasz Małarzewski for help in sampling part of the material.

The authors would like to thank Steven W. Leavitt, Katarina Cufar and the two anonymous reviewers for helpful comments and suggestions.

REFERENCES CITED

Agatova, A. R., R. K. Nepop, I. Y. Slyusarenko, V. S. Myglan, and V. V. Barinov, 2016. Archaeological sites as markers of Neopleistocene-Holocene hydrological system transformation in the Kurai and Chuya basins, Southeastern Altai: Results of geomorphological and geoarchaeological studies. *Archaeology Ethnology and Anthropology of Eurasia* 44(4):26–34.

Agatova, A. R., R. K. Nepop, I. Y. Slyusarenko, V. S. Myglan, A. N. Nazarov, and V. V. Barinov, 2014. Glacier dynamics, palaeohydrological changes and seismicity in southeastern Altai (Russia) and their influence on human occupation during the last 3000 years. *Quaternary International* 324:6–19.

Azarpay, G., 1981. *Sogdian Painting: The Pictorial Epic in Oriental Art.* University of California Press, Berkeley, CA USA.

Baatarbileg, N., W. K. Park, G. C. Jacoby, and N. K. Davi, 2008. Building history of Mandal Monastery in Mongolia based on tree-ring dating. *Dendrochronologia* 26(2):63–69.

Baillie, M. G. L., 1982. *Tree-Ring Dating and Archaeology.* University of Chicago Press, Chicago, IL USA.

Belenitskiy, A. M., I. B. Bentovich, and O. G. Bolshakov, 1973. *Srednevekovyi gorod Srednei Azii (Medieval cities of Central Asia). USSR Academy of Science, Institute of Archeology*, Nauka Press, Leningrad. [in Russian.]

Belenitskiy, A. M., B. I. Marshak, and V. I. Raspopova, 1981. The Sogdian city at the beginning of the Middle Ages: Results and methods of the study of ancient Panjikent. [in Russian.] *Soviet Archaeology* 2:94–110.

Bogolyubov, M., and O. Smirnova, 1963. *Khozyaistvennye dokumenty, Sogdiiskie dokumenty s gory Mug (Economic documents, Sogdian documents from Mount Mōg) 3*, Moscow. [in Russian.]

Bräuning, A., A. Scharf, W. Kretschmer, and I. Burchardt, 2013. Beyond dating: Archeological wood as a source of information of environmental changes in High Asia. *TRACE* 11:154–157.

Briffa, K. R., and P. D. Jones, 1990. Basic chronology statistics and assessment. In *Methods of Dendrochronology*, edited by Cook, E.R., and L.A. Kairiukstis, pp. 137–152. Kluwer Academic Publishers, Dordrecht, Netherlands.

Büntgen, U., V. S. Myglan, F. C. Ljungqvist, M. McCormick, N. Di Cosmo, M. Sigl, J. Jungclaus, S. Wagner, P. J. Krusic, J. Esper, J. O. Kaplan, M. A. C. de Vaan, J. Luterbacher, L. Wacker, W. Tegel, and A. V. Kirdyanov, 2016. Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660 AD. *Nature Geoscience*. DOI: 10.1038/ngeo2652.

Cook, E. R., and R. L. Holmes, 1999. *USERS MANUAL for Program ARSTAN.* Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ USA.

Cufar, K., 2007. Dendrochronology and past human activity – A review of advances since 2000. *Tree-Ring Research* 63(1):47–60.

Davi, N. K., R. D'Arrigo, G. C. Jacoby, E. R. Cook, K. J. Anchukaitis, B. Nachin, M. P. Rao, and C. Leland, 2015. A long-term context (931–2005 C.E.) for rapid warming over Central Asia. *Quaternary Science Reviews* 121:89–97.

Douglass, A. E., 1921. Dating our prehistoric ruins: How growth rings in trees aid in the establishing the relative ages of the ruined pueblos of the Southwest. *Natural History* 21(1):27–30.

Dudley, N., L. Higgins-Zogib, and S. Mansourian, 2009. The links between protected areas, faiths and sacred natural sites. *Conservation Biology* 23(3):568–577.

Dumper, M. R. T., and B. E. Stanley, 2006. *Cities of the Middle East and North Africa: A Historical Encyclopedia.* ABC-Clio, Santa Barbara, CA USA.

Eckstein, D., and J. Bauch, 1969. Contribution to the rationalization of a dendrochronological procedure and analysis of its significance. *Forstwissenschaftliches Centralblatt* 88:230–250. [in German.]

Esper, J., F. H. Schweingruber, and M. Winiger, 2002. 1300 years of climatic history for western Central Asia inferred from tree-rings. *The Holocene* 12(3):267–277.

Freiman, A. A., V. A. Livshits, M. N. Bogolyubov, and O. I. Smirnova, 1962–1963. *Sogdiiskie dokumenty s gory Mug. Chtenie, perevod, kommentarii* (Sogdian documents from Mt. Mug. Reading, translation, commentaries) I–III. Moscow. [in Russian.]

Fritts, H. C., 1976. *Tree Rings and Climate.* Academic Press, London.

Ghafurov, B., 2011. *Tajiks. Volumes 1 & 2: Pre Ancient, Ancient and Medieval History.* Dushanbe, Tajikistan.

Grießinger, J., and A. Bräuning, 2012. Asian summer monsoon history in Southern Tibet for the late Holocene: Results from a network of tree-ring isotope chronologies. *Journal of the Nepal Geological Society* 45:70–71.

Holmes, R. L., 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* 43: 69–78.

Hormatta, J., B. N. Puri, and G. F. Etemadi, 1994. *The Development of Sedentary and Nomadic Civilizations: 700 B.C. to A.D. 250. History of Civilizations of Central Asia.* Volume 2. UNESCO Publications, Paris.

Hulsewé, A. F. P., M. Loewe, and G. Ban, 1979. *China in Central Asia: The Early Stage, 125 B.C.–A.D. 23: An Annotated Translation of Chapters 61 and 96 of the History of the Former Han dynasty (Sinica Leidensia).* Brill-Leiden, Netherlands.

Litvinsky, B. A., Zh. Guang-da, and R. Shabani Samghabadi, 1996. *The Crossroads of Civilizations: A.D. 250 to 750. History of Civilizations of Central Asia.* Volume 3. UNESCO Publications, Paris.

Marsadolov, L. S., 1994. Problems and prospects of absolute tree-ring dating for the Sayan–Altay archaeological monuments (first millennium B.C.). In *Tree-Rings, Environment, and Humanity: Proceedings of the International Conference*, edited by J. S. Dean, D. M. Meko, and T. W. Swetnam, pp. 557–566. Radiocarbon, Tucson, AZ.

Marshak, B. I., 2003. The archaeology of Sogdiana. *The Silk Road* 1(2):2–8.

Morrell, J. J. 2010. *Decay and Termite Resistance of Western Juniper Sapwood and Heartwood under Tropical Conditions: 32-Month Report*. Department of Wood Science & Engineering. Oregon State University, Corvallis, OR USA. http://juniper.oregonstate.edu/natural-durability32.pdf

Morrell, J. J., D. J. Miller, and P. F. Schneider, 1999. *Service Life of Treated and Untreated Fence Posts: 1996 Post-Farm Report. Forest Research Laboratory. Research Contribution 26*. Forest Research Laboratory, Oregon State University, Corvallis, OR USA.

Mukhamedshin, K. D., and N. K. Talancev, 1982. *Juniperus Forests (Forest, Light Forest, Scrubs)*. Lesnaia Promyshlennost Press, Moscow. [in Russian.]

Murphy, K. L., J. M. Klopatek, and C. C. Klopatek, 1998. The effects of litter quality and climate on decomposition along an elevational gradient. *Ecological Applications* 8:1061–1071. doi:10.1890/1051-0761(1998)008[1061:TEOLQA]2.0.CO;2

Murzakulov, S. S., 2015. Ecological and silvicultural bases of conservation and sustainable development of *Juniperus* forests of southern Kyrgyzstan. *Izvestia Sankt-Peterburgskoi lesotekhnicheskoi akademii* 212:42–54. [in Russian.]

Opała, M., T. Niedźwiedź, O. Rahmonov, P. Owczarek, and Ł. Małarzewski, 2017. Towards improving the Central Asian dendrochronological network—New data from Tajikistan, Pamir-Alay. *Dendrochronologia* 41:10–23.

Oviedo, G., and S. Jeanrenaud, 2007. Protecting sacred natural sites of indigenous and traditional peoples. In *Protected Areas and Spirituality*, edited by Mallarach, J. M., and T. Papayannis. IUCN and Publicacions de l'Abadia de Montserrat, Gland, Switzerland.

Owczarek, P., M., Opała-Owczarek, O. Rahmonov, and M. Mendecki, 2017a. 100 years of earthquakes in the Pamir region as recorded in juniper wood: A case study of Tajikistan. *Journal of Asian Earth Sciences* 138:173–185.

Owczarek, P., M. Opała-Owczarek, O. Rahmonov, A. Razzokov, Z. Jary, and T. Niedźwiedź, 2017b. Relationships between loess and the Silk Road reflected by environmental change and its implications for human societies in the area of ancient Panjikent, central Asia. *Quaternary Research* 1–11. doi:10.1017/qua.2017.69.

Panyushkina, I. P., C. Chang, A. W. Clemens, and N. Bykov, 2010. First tree-ring chronology from Andronovo archaeological timbers of Bronze Age in Central Asia. *Dendrochronologia* 28:13–21.

Panyushkina, I. P., I. Y. Sljusarenko, N. I. Bykov, and E. Bogdanov, 2007. Floating larch tree-ring chronologies from archaeological timbers in the Russian Altai between *ca*. 800 BC and 800 AD. *Radiocarbon* 49(2):693–702.

Rahmonov, O., T. Niedźwiedź, M. Opała, Ł. Małarzewski, and P. Owczarek, 2016. Landscape degradation and its effect on the soil-vegetation relations within juniper forest in the Fann mountains (western Pamir-Alay). In *Landscape and Landscape Ecology. Proceedings of the 17th International Symposium on Landscape Ecology, 27–29 May 2015*, edited by Halada, Ľ., A. Bača, and M. Boltižiar, pp. 168–175. Nitra, Slovak Academy of Sciences, Bratislava, Slovakia.

Rinn, F., 2010. *TSAP-Win: Time Series Analysis and Presentation for Dendrochronology and Related Applications. User reference.* Heidelberg, Germany. http://www.rimatech.com.

Sadikov, Ch., 2012. *The Juniperus Forests of Catchment of Iskander River (Tajikistan)*. Lambert Academic Publishing, Germany. [in Russian.]

Schafer, E. H., 1963. *The Golden Peaches of Samarkand: A Study of T'ang Exotics.* University of California Press, Oakland, CA USA.

Scharf, A., A. Bräuning, W. Kretschmer, B. Wegner, and F. Darragon, 2013. ^{14}C AMS dating of wooden cores from historic buildings for archaeological and dendrochronological research in High Asia. *Radiocarbon* 55(2–3):1358–1365.

Scheffer, T. C., and J. J. Morrell, 1998. *Natural Durability of Wood: A Worldwide Checklist of Species. Research Contribution 22.* Forest Research Laboratory, Oregon State University, Corvallis, OR USA.

Schmidt, B., T. Wazny, K. Malla, E. Höfs, and M. Khalessi, 1999. Chronologies for historical dating in High Asia/Nepal. In *Tree-Ring Analysis. Biological, Methodological and Environmental Aspects*, edited by Wimmer, R., and R. E. Vetter, pp. 205–211. CABI Publishing, Oxon UK; New York USA.

Shao, X., Y. Xu, Z.-Y. Yin, E. Liang, H. Zhuand, and S. Wang, 2010. Climatic implications of a 3585-year tree-ring width chronology from the northeastern Qinghai-Tibetan Plateau. *Quaternary Science Reviews* 29(17–18):2111–2122.

Speer, J. H., 2010. *Fundamentals of Tree-Ring Research*. The University of Arizona Press, Tucson, AZ, USA.

Vasiliev, S. S., N. A. Bokovenko, K. A. Chugunov, V. A. Dergachev, A. A. Sementsov, J. U. Sljusarenko, and G. I. Zaitseva, 2001. Tree-rings, wiggle matching and statistics in the chronological studies of Scythian age sites in Asia. *Geochronometria* 20:61–68.

Wang, S., and X. Zhao, 2013. Re-evaluating the Silk Road's Qinghai Route using dendrochronology. *Dendrochronologia* 31(1):34–40.

Wigley, T., K. R. Briffa, and P. D. Jones, 1984. On the average value of correlated timeseries, with applications in dendroclimatology and hydrometeorology. *Journal of Applied Meteorology and Climatology* 23:201–213.

WINDENDRO, 2010. *Manual.* Regent Instrument Inc, Quebec, Canada.

Yadav, R. R., A. Bräuning, and J. Singh, 2011. Tree-ring inferred summer temperature variations over the last millennium in western Himalaya, India. *Climate Dynamics* 36(7):1545–1554.

Yadav, R. R., K. G. Misra, B. S. Kotlia, and N. Upreti, 2014. Age of Himalayan cedar outside its natural home in the Himalayas. *Current Science* 106(7):932–935.

Zamotorin, I. M., 1963. About possibility of relative dating of territorially remote constructions by the tree-ring analysis in the Gorny Altai. *Soviet Archaeology* 2:131–138. [in Russian.]

Received 27 June 2017; accepted 5 August 2017.