^{14}C AMS DATING OF WOODEN CORES FROM HISTORIC BUILDINGS FOR ARCHAEOLOGICAL AND DENDROCHRONOLOGICAL RESEARCH IN HIGH ASIA

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ABSTRACT. We had the opportunity to collect valuable wooden core samples from historic monasteries, temples, and secular buildings in 4 regions of High Asia, namely Dolpo (Nepal), ancient Nyangpo, Gyalrong/Minyag, and Lhasa and surroundings (all on the Tibetan Plateau, China). Tree species collected for dating include *Pinus wallichiana* (Dolpo), *Juniperus tibetica*, *Pinus densata* and several species of the genera *Picea* (spruce), *Larix* (larch), and *Abies* (fir) on the Tibetan Plateau, which could not always be determined to the species level due to the parallel occurrence of species of the same genus in these regions. Some of the wood samples were successfully dendro-dated with local tree-ring chronologies, but many could not, indicating a potentially higher age than the existing local chronologies. By accelerator mass spectrometry (AMS) dating and wiggle-matching 199 ^{14}C samples from 73 collected timbers, it was possible to date these wood samples with high precision, and important information about the possible time of construction of these important historic buildings was obtained for the first time. Floating chronologies of ^{14}C-dated wood span the periods AD 650 to 900 in Dolpo and ~200 BC to AD 420 on the Tibetan Plateau. Besides dating of the wood samples from these historic monuments, ^{14}C AMS dating with wiggle-matching gives the opportunity to extend the range of the currently existing regional tree-ring chronologies for future environmental reconstructions on the Tibetan Plateau and the Himalayas.

INTRODUCTION

The Tibetan Plateau (TP) and the surrounding mountain areas contain old cultural landscapes that have been inhabited for millennia. Despite the existence of many cultural relics and old buildings, the number of tree-ring dated historical and archaeological objects is rather low (e.g. Gutschow 2001; Schmidt et al. 2001; Tarasov et al. 2003; Xinguo et al. 2003). This is due partly because the dating of old wood may be restricted by the limited number of regional reference chronologies for tree species used for construction, or by the limited length of existing chronologies, possibly not covering the time when the historic wood was cut.

In the last 15 yr, a network of more than 60 tree-ring chronologies of different species of living conifers from the Tibetan Plateau and western Nepal was compiled (Bräuning 2001; Bräuning and Mantwill 2004), covering a range of 300 to 1500 yr. Since forests with old trees and wood have become quite rare in regions of High Asia in the recent decades, older timber can only be found in ancient buildings. We recently sampled numerous wooden drill cores from historic buildings in 4 regions of High Asia and evaluated them dendrochronologically. In many cases, historic timber collected from remote areas in High Asia cannot be dated straightforwardly with standard dendrochronological procedures. Limitations are set by the availability of long and well-replicated standard chronologies for dendrochronological dating, by the use of different tree species for construction, by the high variability of local climate conditions at the site where trees used for constructions purposes had been growing, and by ring-width variations in the samples caused by local site disturbances in the highly dynamic mountain environments. In such cases, radiocarbon dating in combination with wiggle-matching is of great help to provide dates for wood samples of unknown ages. This may help to verify ambiguous dendrochronological dating results and to extend existing tree-ring chronologies with older historic samples. We applied ^{14}C wiggle-match dating on 73 wood samples collected from monasteries and temples in the Dolpo region (western Nepal), temples and

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ancient buildings in central Tibet mainly in the surroundings of Lhasa, as well as from historic tower buildings in southeast Tibet (Gongbu Jiangda County) and in western Sichuan Province (cultural regions Gyalyrong and Minyag). Figure 1 gives an overview of the sampling areas.

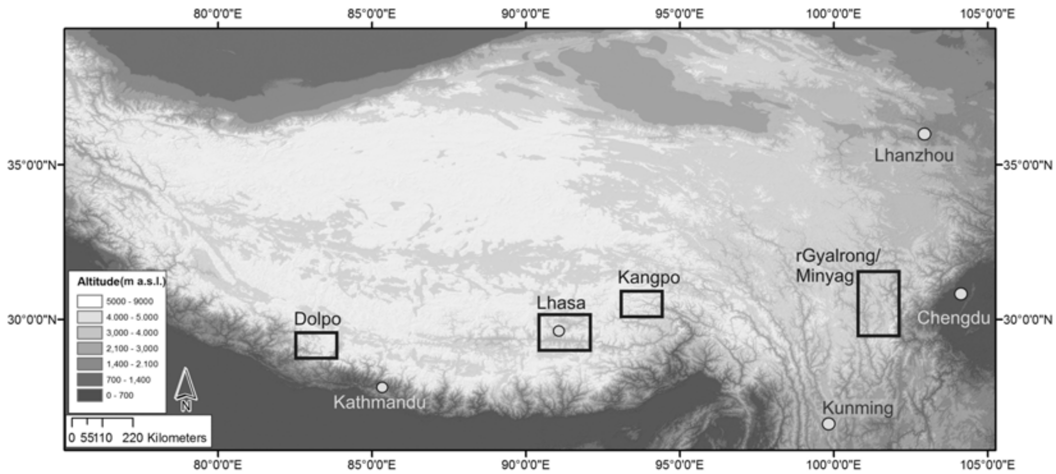

Figure 1 Relief map of the Tibetan Plateau with the sampling regions Dolpo (Nepal, for Details see Figure 3), Lhasa (for details see Figure 4), ancient Nyangpo/Kangpo, and Gyalrong/Minyag (eastern Tibet).

Because of the origin of the wood from ancient buildings, these ^{14}C dates could also have an important archaeological and historical component, since many of these buildings could be dated for the first time with enhanced precision. Especially the historic tower buildings of Tibet and Sichuan (Figure 2) are a special cultural heritage for which protection and in depth study only started in the last 15 years.

Figure 2 Towers in ancient Nyangpo

MATERIAL AND METHODS

Sampling Areas

Dolpo

Figure 3 shows the sampling region of Upper Dolpo in western Nepal and the location of a chronology derived from living trees. The Dolpo region of western Nepal is a barely studied region in the Inner Himalaya and is rather dry due to its position in the rain shadow of the main Himalayan crest line. The 9 wood samples were collected from the monasteries Lang Gompa, Nesar Gompa, Samling Gompa, and Tsakhang Gompa. All samples are from pine (*Pinus wallichiana*) from which a local tree-ring chronology exists, covering the period AD 1749–1998.

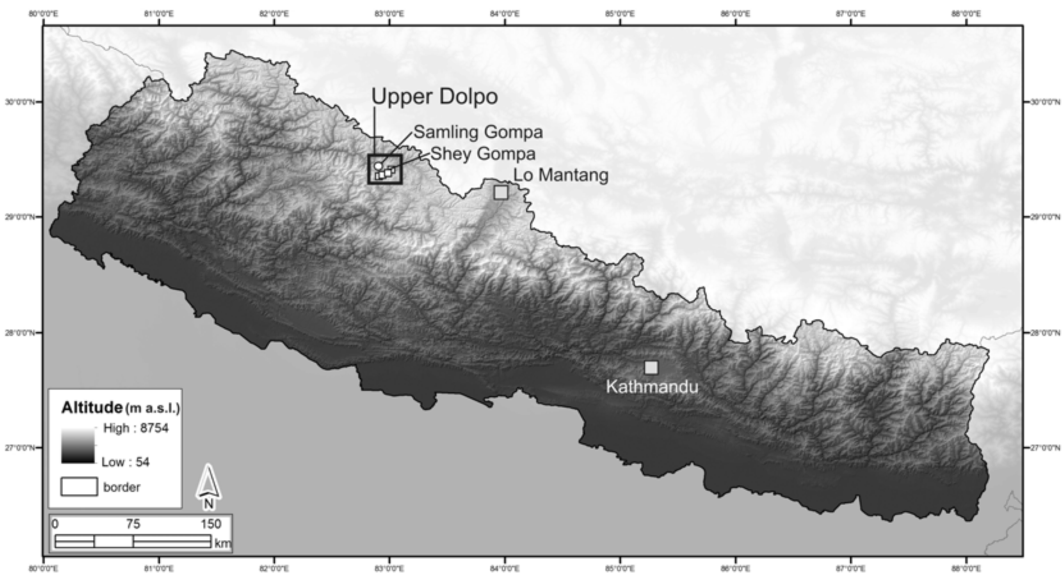

Figure 3 Map of Nepal with sample area Upper Dolpo and sites of historic wood collection (squares) and living *Pinus wallichiana* (Himalayan pine) tree chronology (Samling Gompa).

Central Tibet

Figure 4 shows the sampling sites from central Tibet, mainly from Lhasa and its surroundings. We collected altogether 39 core samples for ^{14}C dating, hoping that these samples may close the time gap between a floating tree-ring chronology created from 4 wood samples from the main monastery in Tibet, the Jokhang in Lhasa collected and ^{14}C dated during a previous dating effort, and chronologies gained from living trees.

Tower Samples from Tibet and Sichuan

The historical tower buildings in several regions of southeast Tibet and Sichuan are a special cultural heritage that have been sparsely studied. Neither their purpose nor their creators or the time when they were built are known exactly. Because many of the towers are threatened by collapse and deterioration, there is an urgent demand for their preservation. Knowing their exact age may help to understand better the cultural and historical context of their development and their function. Previously existing ^{14}C dates, although numerous (82 towers dated) and in the same time range, lacked

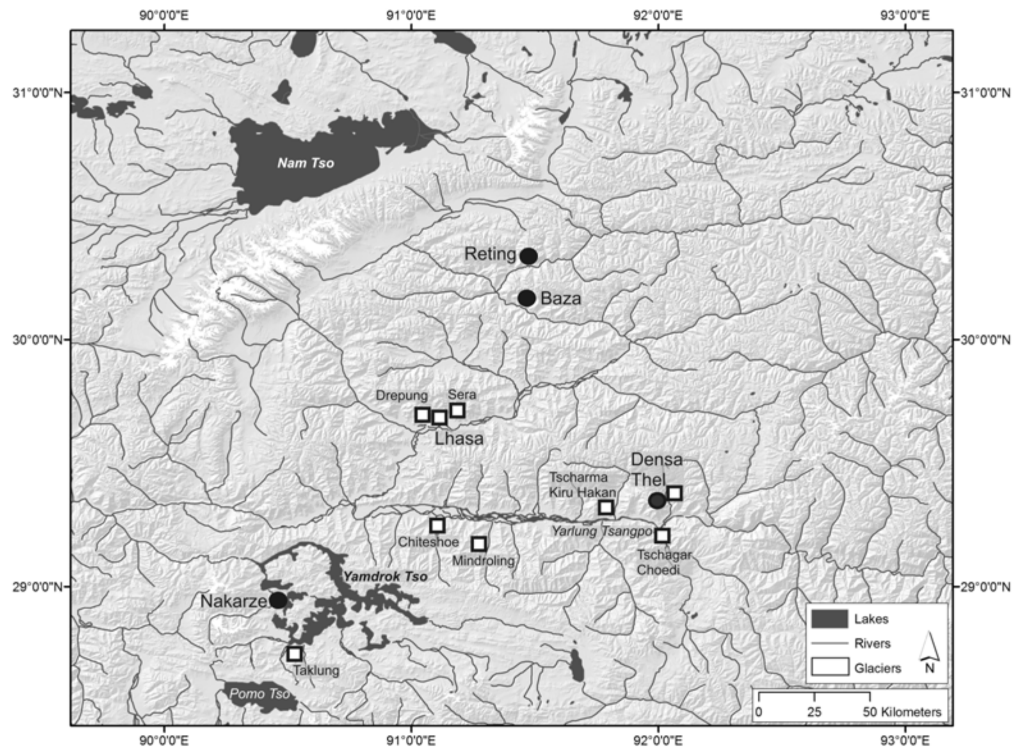

Figure 4 Map of the surroundings of Lhasa with sample sites of historic timber (white squares) and sites of living tree chronologies derived from *Juniperus tibetica* (Tibetan juniper, black circles).

precision since they were carried out by conventional carbon dating from 1999 to 2009 (Darragon 2005, 2013). In 2004, we were able to gather wooden drill cores from towers from historic sites in the regions of Nyangpo (Gongpupo, Jiangda County), Gyalrong, and Minyag in the eastern part of the Tibetan Plateau, which is inhabited by different ethnic groups. The most ancient samples were collected in Gongbu Jiangda, in 2006 and 2007. Twenty-five wood samples were ^{14}C dated.

METHODS

The material was collected from monasteries or other historic buildings with the help of increment borers with a diameter of 5 mm (see Figure 5) or in the form of discs from exchanged wooden beams. In the tree-ring laboratory of the Institute of Geography of the University Erlangen-Nuremberg, the surface of all samples was smoothed with razor blades and the contrast of the wood was enhanced by rubbing white chalk into the wood surface. From the anatomical wood structure, the tree species was determined up to the genus level. Ring width was measured with a precision of 0.01 mm with a LINTAB measuring table (Rinntech Company, Germany). The samples contained between 32 and 543 tree rings. For samples with more than 100 rings, the gap between multiple ^{14}C-dated rings is 50 rings; for shorter cores the gap is smaller. The measured tree-ring series from the historic objects were first statistically compared with regional reference chronologies established from living trees of the same tree genus as the sample (Table 1, Figure 1). In some cases, if the sample contained a sufficient number of rings (>80) and was of an age covered by the available reference chronologies from living trees, dendrochronological dating was directly accomplished by cross-dating the wood sample with the help of visual tree-ring pattern inspection (Stokes and Smiley

1968) and statistical tests (*t* test, sign test) with the software TSAP (Rinn 1996). If no statistically valid dendro-dating could be accomplished, samples were assumed to be potentially older than existing chronologies and used for ^{14}C dating. For the Nyangpo and Gyalyrong/Minyag regions, local tree-ring chronologies did not yield dating results, which might be a consequence of the climatically more complex structured mountain areas of southeast Tibet and western Sichuan, where the representative distance of local tree growth pattern is smaller than in central Tibet.

Table 1 Living tree chronologies used as dating references for historic wood samples. For the location of the sampling regions, see Figure 1.

Region	Site	Tree species	Latitude	Longitude	Elevation (m asl)	Length (cm)	Period
Dolpo	Samling Gompa	*Pinus wallichiana*	32°06′N	98°51′E	4300	250	1749–1998
Lhasa	Densa Thel	*Juniperus tibetica*	29°18′N	91°58′E	4450	785	1214–1998
	Nakarze	*Juniperus tibetica*	28°58′N	90°28′E	4500	315	1680–1994
	Baza	*Juniperus tibetica*	30°06′N	91°36′E	4140	244	1756–1999
	Reting	*Juniperus tibetica*	30°18′N	91°31′E	4300	918	1081–1998
Nyangpo	Pasum Tso	*Abies delavayi* var. motouensis	29°59′N	93°59′E	3900	264	1741–2004
Gyalyrong/ Minyag	Gongga Shan	*Picea balfouriana*	29°34′N	102°00′E	2800	454	1548–2001
	Suopu	*Picea balfouriana*	30°50′N	101°54′E	3400	377	1628–2004

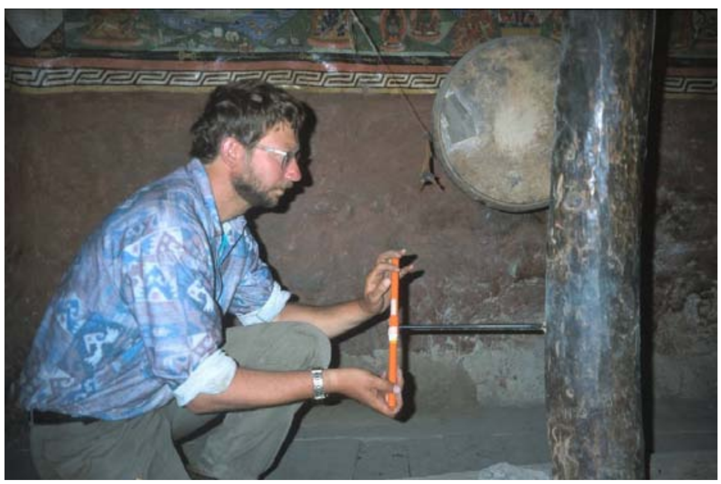

Figure 5 Coring in the monastery Tsakhang Gompa with an increment borer

^{14}C dating was done in the Erlangen AMS Laboratory. Wood samples were purified by AAA treatment, then combusted in an elemental analyzer, reduced to graphite, and measured at the Erlangen AMS facility, according to our standard laboratory protocols (Morgenroth et al. 2000). Ages were calibrated at the 95.4% confidence limit by the in-house program Cal09 using IntCal09 (Reimer et al. 2009). For wiggle-matching, OxCal v 3.10 software (Bronk Ramsey 2009) was employed, using IntCal09 data. For modern results (>100 pMC, after AD 1950), wiggle-matching with OxCal is usually not possible, but for this project the bomb peak calibration results of these recent samples are precise enough. For these samples we thus just give the bomb peak calibration results for the outermost ring instead of a wiggle-matching result.

RESULTS AND DISCUSSION

Samples from Dolpo

Table S1 (online Supplementary file) lists the full results of the samples from Dolpo. Figure 6 shows the timescale of wood samples collected from living trees ("Samling living") and dendro-dated samples from various monasteries. One sample (Lang Gompa) that only had 63 rings could only reliably dated dendrochronologically after confirmation of the obtained results (AD 1743–1804) by verification of ^{14}C wiggle-match dating (Bräuning et al. 2011). All dendrochronologically dated samples were merged with the tree-ring series from living trees to a regional average "Dolpo" chronology. However, some of the discovered ^{14}C-dated wood samples are considerably older than the Dolpo regional chronology (Bräuning et al. 2011), and are thus still floating without time.

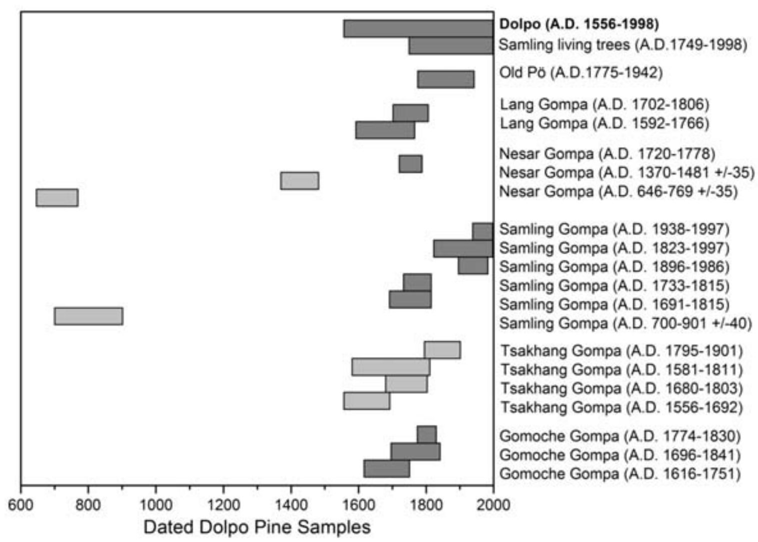

Figure 6 Existing chronologies from living trees ("Samling living trees," dark gray) and chronologies derived from the new AMS results (light gray). All living and historic wood samples are from Himalayan pine (*Pinus wallichiana*). "Dolpo" includes all dendrochronologically dated wood samples from the living trees and from various historic buildings shown in detail.

Samples from Central Tibet

Table S2 (online Supplementary file) gives the full dating results for the wood samples from central Tibet. Figure 7 shows the existing chronologies, and the newly derived, still-floating tree-ring chronologies that could extend the existing ones, with surprisingly old dates from the Lhasa Tsuklakhang, one of the most important religious sites of Tibetan Buddhism.

Tibet and Sichuan Tower Samples

Table S3 (online Supplementary file) lists the results from the Tibetan Towers wood samples. The results cover the timescale from the 12th century AD up to now, with most dates in the 14th century (some previous dating results go back to the 4th century AD, corroborating the first records of such towers in Chinese annals dating from the Hou Han Dynasty, AD 25–220; Darragon 2005).The oldest towers are found at the highest altitude, in ancient Nyangpo in the southeast of the Tibetan Autono-

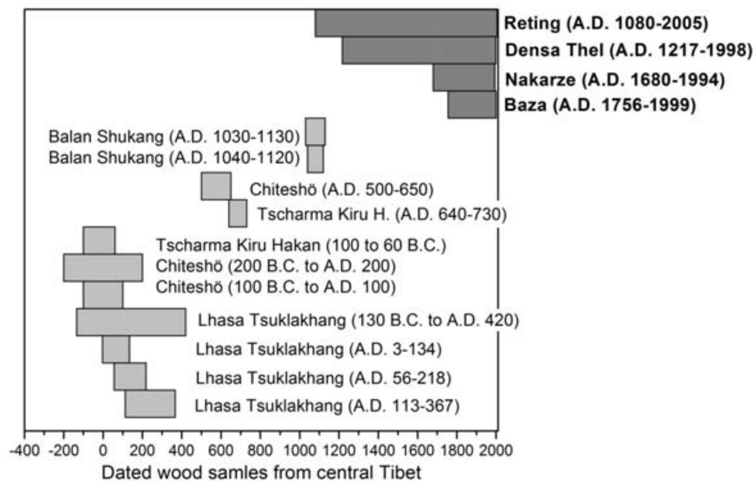

Figure 7 Existing chronologies from living trees from the vicinity around Lhasa (dark gray, for locations see Figure 4) and floating chronologies from ^{14}C-dated wood. All living and historic wood samples are from Tibetan juniper (*Juniperus tibetica*).

mous Region. The towers are very singular cultural and historical monuments. The exact AMS ^{14}C dating of these monuments is a very important step in the further investigation of these objects and could support the efforts to declare these monuments as an UNESCO World Heritage Site.

DISCUSSION AND CONCLUSIONS

Our ^{14}C dates clearly indicate the high potential ages of wood from historic buildings in High Asia. Some samples date back to the 7th century AD and are to our knowledge the oldest tree-ring samples collected from western Nepal (Bräuning et al. 2011) and the oldest from central Tibet. The heterogeneous ages of the material excavated from the towers of western Sichuan indicates that also in former times, wood in older buildings had been replaced during repair work and that caution is needed to derive ages of historic buildings relying on dated wood from very few samples. The scattered dates that stretch over a period including the whole last millennium indicate that there has not been a single specific tower construction period, but that the tradition of tower building also for non-military purposes has been followed for centuries.

The samples from southern Tibet (Lhasa area) might offer a possibility for construction of more than 2 millennia of tree-ring chronologies that are of high climatic sensitivity in this region and thus may offer an opportunity for reconstructing moisture variations (Grießinger et al. 2011; He et al. 2013). On the other hand, long-term growth rates and ring-width variations in old wood may provide information about changing growing conditions and environmental change (Bräuning et al. 2013) and the determination of the origin of historic wood, so-called dendro-provenancing (Bräuning 2001) including the reconstruction of former timber trade routes and historic forest use. A detailed analysis of all these applied scientific questions is certainly beyond the scope of this paper. To carry out such quantitative analyses, a higher number of historic wood materials need to be recovered and dated with ^{14}C dating and dendrochronology to enable the construction of long, possibly multi-millennial tree-ring chronologies for environmental reconstructions. In High Asia, the potential of historic and archaeological wood is still at the beginning of its scientific utilization.

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