Precipitation changes in Dulan 515 BC–800 AD inferred from tree-ring data related to the human occupation of NW China

By Pavel Tarasov, Karl-Uwe Heussner, Mayke Wagner, Berlin, Hermann Österle, Potsdam and Shuzhi Wang, Peking

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Предметные слова: *СВ Цинхай-Тибет/Древесина можжевельника/Дендрохронология/Реконструкция количества осадков/История освоения*

Qinghai Province (transcription of Chinese names and terms follows the official Pinyin system) is one of the most promising areas for a multidisciplinary approach of natural scientists, archaeologists, historians and ethnographers in order to evaluate the role of anthropogenic and climatic factors in the regional environmental changes[1]. The province occupies a vast area in NW China between 32° and 39 °N and 90° and 103 °E. Situated at the northeastern edge of the Qinghai-Tibetan-Plateau, at the modern limit of the Pacific Monsoon, this area can be regarded as very sensitive to climatic changes. The modern climate of the region is transitional from warm sub-humid to cold semi-arid. A decrease in the mean January temperature from −7° to −18 °C and in the mean July temperature from 21° to 5 °C is parallel to the increase in elevation[2]. The annual precipitation sums reach ca 700 mm in the southeastern corner of Qinghai Province and decrease to about 50 mm northwestwards in the Qaidam basin. However, the whole area experiences a moisture deficit. The main part of precipitation falls during the summer season and is associated with air masses from the Pacific Ocean.

Historical[3] and palaeoenvironmental[4] records from China count long- and short-term climate changes as the main factor that influenced settlement dynamics and the peoples' economy during the Holocene time. From 515 BC to 800 AD, in the period covered by our tree-ring chronology the various parts of the vast territory of present-day Qinghai Province experienced a successive occupation by different land users (e.g. farmers, nomads and military forces). Belonging to several ethnic entities and systems of rule they came, stayed and left the area or perished there for diverse political reasons[5]. In order to get a comprehensive picture of the settlement history we deal closely with archaeological and historical[6] sources. Both are problematic, mainly because of the peripheral position of Qinghai area to the central China state. During the time under discussion it was never part of the Chinese Empire, except for the eastern most patches. Instead it was the homeland of several non-Han-Chinese peoples, perilous neighbours to the Han, who did not leave their own written accounts of their doings. So if the written sources of the Han-

[1] Wagner 2003.
[2] Zhang/Lin 1992; Zhonghua renmin gongheguo dituji 1994.
[3] Selivanov 1994; Ge et al. 2002.
[4] Winkler/Wang 1993; Ren 1998; Chen et al. 1999; Zhang et al. 2000; Herzschuh et al. 2003.
[5] de Crespigny 1984; Wang 1992; Franke/Twitchett 1994; Yü 1995; Bielenstein 1995; Twitchett 1997.
[6] Wilkinson 2000.

Chinese tell something about this territory it is mainly in the context of dealing with frontier disputes with rather a concept of alien people, i.e. "those who are not us in the west"[7], than real knowledge about them. Therefore despite the fact that the written sources cover a long period and contain useful pieces of information, they are one-sided and thus, biased. In contrast, archaeological sources for the study region are very poor. During the 1920s the Swedish geologist J. G. Andersson[8] made first discoveries and collections. More intensive and systematic archaeological research in Qinghai Province started only in the 1980s mostly as salvage excavations within the framework of road and railway construction. As a result a provincial atlas of all known cultural relics was published[9]. Nevertheless, the recent archaeological documentation is far from being complete and representative. One reason, the very short history of the fieldwork, has already been mentioned. Another reason is related to the unbalanced ratio of accounts of nomadic and sedentary groups in the archaeological record. Naturally settlers are overrepresented, while often traces of nomads are only represented by burial places. Therefore, at present we are able to extract the modes and the degree of human land use at certain time intervals from both archaeological and historical records in the way of general tendencies.

Tree-ring records are an important source of palaeoclimatic information at annual to centennial scale[10], integrated worldwide into research on global change[11]. In areas with strong human population pressure on the vegetation and landscape the importance of tree rings for the climate reconstruction increases compared to other often used proxies (e.g. pollen, lake sediments). Despite major progress in the dendroclimatological research in Central Asia[12], the area of Northwest China still suffers from a lack of information. Published tree-ring chronologies from China[13] and Mongolia[14] based on living trees cover the period of the recent past between the 3rd and the 20th century and focus mainly on the changes in temperature, which control the tree growth at the upper timberline. Reconstructions of hydrometeorological parameters are still rare[15]. The first published, 1835-year chronology based on living juniper trees growing in Dulan under rather dry climate conditions is also interpreted in terms of temperature variations[16].

The first aim of the present paper is to describe the results of the dendrochronological study of juniper trunks excavated from the tombs of the Tubo Kingdom in Dulan County, NE Qinghai[17]. Our ring-width chronology based on archaeological wood covers an interval of thirteen centuries, from 800 AD backwards and extends the previously published chronology to 515 BC. The second aim is to gain high-resolution climatic information from the Dulan tree-ring width chronology, using a comparison with instrumental temperature and precipitation records from the nearest meteorological station. The results are discussed in terms of broader-scale environmental and historical changes in Central Asia.

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7 Wang 1992, 98.
8 Andersson 1925.
9 Zhongguo wenwu dituji, Qinghai fence 1996.
10 Fritts 1976; Cook/Kairiukstis 1990; Schweingruber 1996.
11 Bradley 1989.
12 Block et al. 2003; Bräuning 2002; 2003; Gou et al. 2003.
13 Kang et al. 1997.
14 D'Arrigo et al. 2001a; 2001b.
15 Bräuning 2001; Huges et al. 1994; Pederson et al. 2001; Yuan 2003; Zhang et al. 2003.
16 Kang et al. 1997.
17 Wagner et al. 2002.

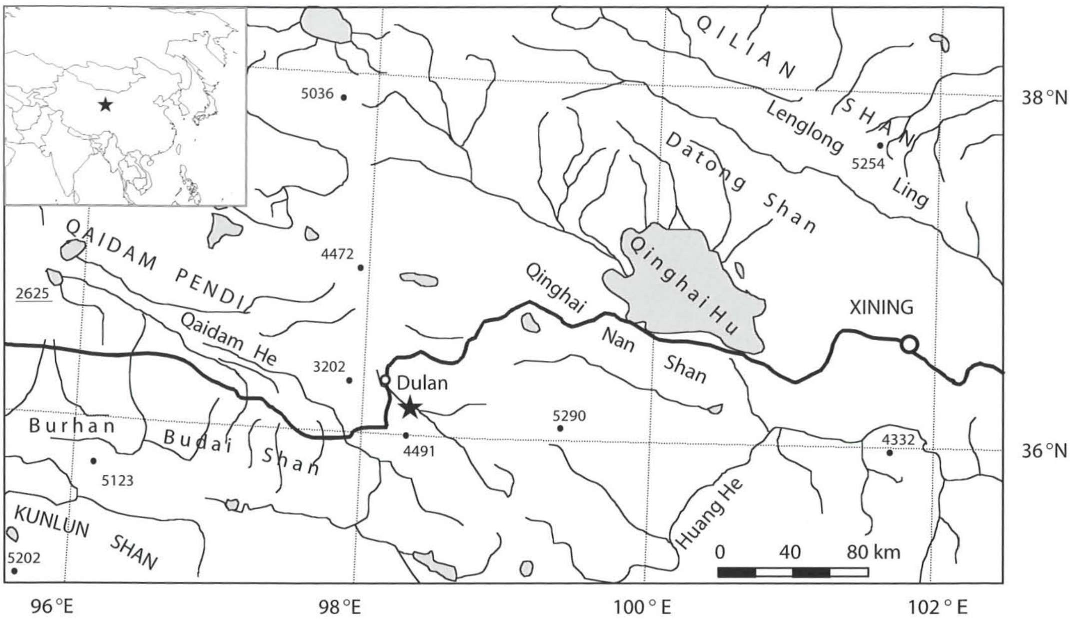

Fig. 1. Map showing location of studied tree-ring site with archaeological wood *(star)* in the eastern part of Qinghai Province with respect to the main rivers, lakes, mountain ridges and the highway connecting provincial capital Xining with Dulan. Smaller map shows the site location in Asia with respect to national borders.

Data and methods

Regional setting

Geographically, the study area of Dulan *(Fig. 1)* belongs to the SE macro-slope of Qaidam Pendi, which is a large closed basin with the bottom elevated to ca 2,600–2,700 m[18]. The present-day climate of the basin is very dry and continental. The modern vegetation of the area consists of various desert plants, including *Artemisia arenaria*, *Haloxylon ammodendron*, *Sympegma regelii*, *Salsola abrotanoides* and *Kalidium foliatum* as described in the Vegetation Atlas of China[19]. Less arid climate appears in the Burhan Budai Shan and several other mountain ridges, which belong to the Kunlun Shan, Qinghai Nan Shan and Qilian Shan systems bordering the Qaidam basin in the south, east and north. Mountains reach ca 4,500 m a.s.l. *(Fig. 1)* and are covered with dry steppe, scrub and forest vegetation. *Achnatherum splendens* and *Stipa breviflora* steppe covers the intermountain valleys and foothills in the vicinity of Dulan town, while scrubs of *Salix* and *Dasiphora parvifolia* and forest patches of juniper *(Sabina przewalskii)* grow at higher elevations at the distance of 10–20 km south, east and north-east from Dulan.

[18] Zhonghua renmin gongheguo dituji 1994.
[19] Vegetation Atlas of China 2001.

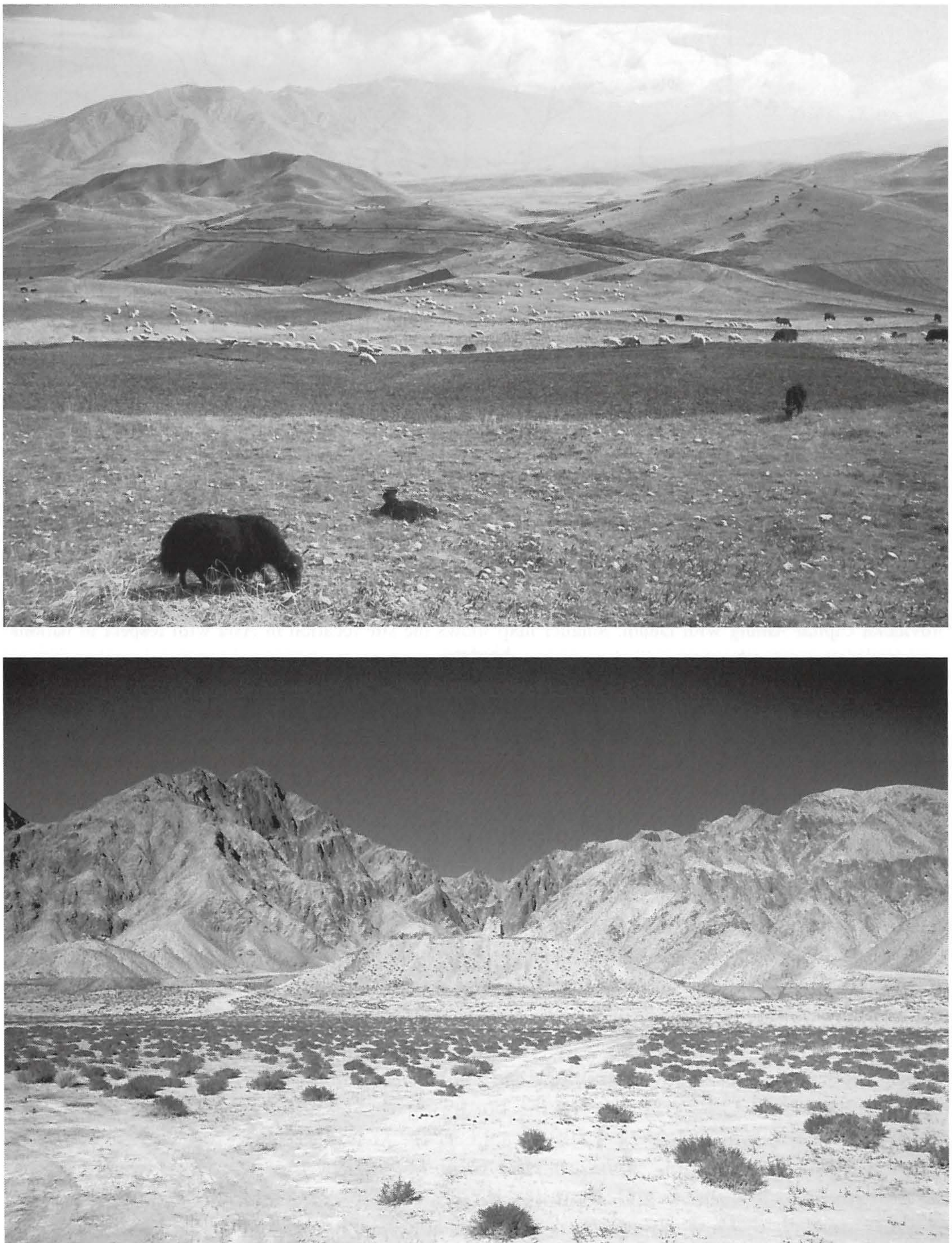

Fig. 2. *Upper plot*: Steppe vegetation is widely spread in the area between Dulan and Qinghai Lake at present. *Lower plot*: The largest tomb of the Tubo Kingdom (central part of the photo) in the Reshui Valley south of Dulan.

Modern climate data

The meteorological observatory is located in the county centre Dulan (36° 17.46′ N, 98° 4.44′ E) at about 3,200 m. The distances from the observatory to juniper forest stands and to the study site with archaeological wood *(Fig. 1)* do not exceed 10–15 km, and the differences in the altitude do not exceed a few hundred meters. These constitute the basic requirements for the reliable climatic calibration of tree-ring data. The meteorological station has provided more or less continuous records of mean monthly temperature and precipitation since 1940. The annual precipitation of Dulan area averaged for the observation period is 188 mm, varying from 100 to 350 mm and mean annual temperature is 3 °C, varying from 1.7 to 4.7 °C. Mean temperatures of July and January are 15 °C and –10 °C, respectively *(Fig. 3)*. Both monthly temperature and precipitation values vary significantly from year to year *(Fig. 3)*. The seasonality of the climate is extremely well pronounced. The frost-free period lasts for about seven months and up to 80% of the annual precipitation sum falls from May to September.

Tree-ring data

The published tree-ring chronology from Dulan spans a 1835-year interval from 159 to 1993 AD[20]. This chronology is based on the data collected from living juniper *(Sabina przewalskii)* trees that grow south of Dulan town in the mountains that range from 3,100 to 3,800 m[21]. The sites with archaeological wood – tombs of the Tubo Kingdom, have been found in the mountain valley south of Dulan[22] *(Figs. 1, 2)*. Numerous juniper trunks excavated from the tombs by the researchers of the Archaeological Institute of Qinghai Province and the Archaeology Department of Bejing University have been sampled in the field and partly in the storeroom of the Institute in Xining. Collected wooden discs were polished and analysed in the Dendrochronological Laboratory of the German Archaeological Institute.

Methodology

Samples from 45 juniper trunks collected in the tombs at Dulan have been analyzed using standard dendrochronological methods[23] to obtain raw ring-width measurements *(Fig. 4)* and to generate a composite ring-width chronology, spanning the 1315-year interval. Ring widths of the polished discs were measured to the nearest 0.01 mm. The ring-width series were cross-dated and standardized with a conservative method using the software COFECHA[24] and ARSTAN[25].

[20] Kang et al. 1997.
[21] Kang et al. 1997; 2000; P. Sheppard, personal communication 2002.
[22] Xu/Zhao 1996; Xu 2002.
[23] Fritts 1976; Cook/Kairiukstis 1990.
[24] Holmes 1983.
[25] Cook/Holmes 1996.

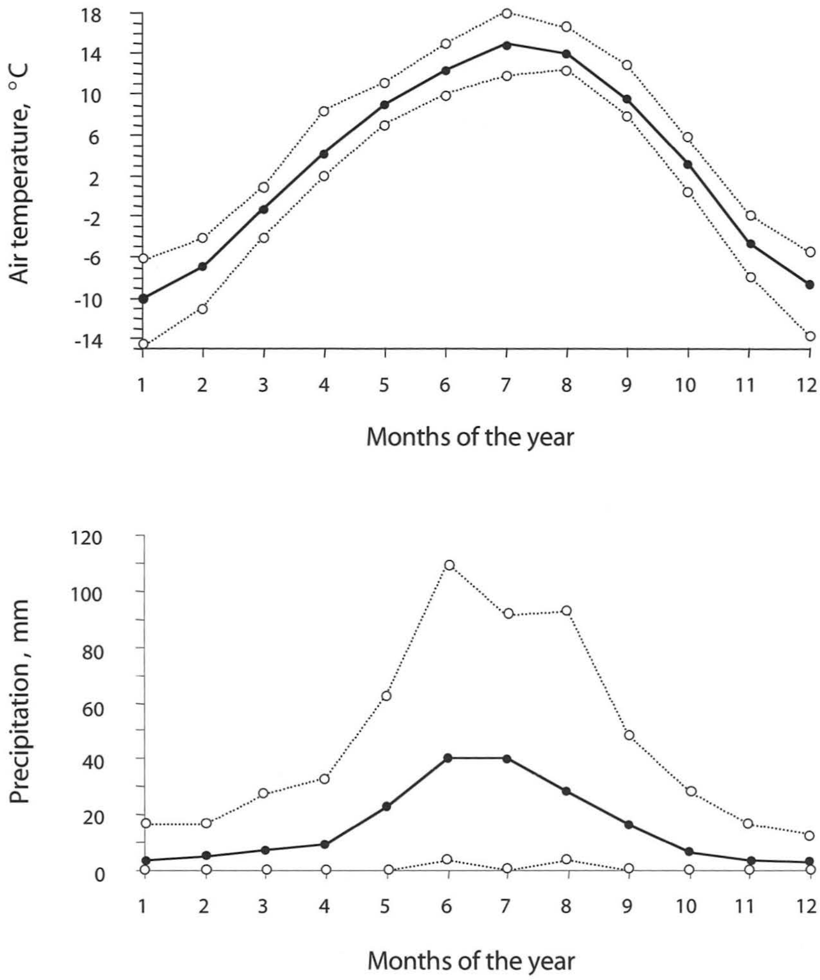

Fig. 3. Variations in the mean *(bold line)*, max *(upper dashed line)* and min *(lower dashed line)* values of monthly temperatures and precipitations recorded at Dulan meteorological observatory during 1940–2000.

A significant intercorrelation of the archaeological ring-width chronology *(Fig. 4)* with the published ring-width chronology from Dulan living trees[26] helped to relate our floating chronology to the absolute time scale. The longest common growth interval for ancient and living trees was 628 years – long enough for successful cross-dating. The mean inter-series correlation coefficient was 0.7, suggesting that correlated tree rings contain common signals. To check the association between two chronologies in the overlapping interval (159–800 AD) a *sign test*[27] was also applied. The number of disagreements in signs (180) is much lower than required and the level of significance is above 0.99. In addition, such a comparison of two records helped to recognize that one year-ring (682 AD) is missing in the Dulan chronology[28] based on the samples from living trees.

[26] Kang et al. 1997; 2000; P. Sheppard, personal communication 2002.
[27] Fritts 1976.
[28] Kang et al. 1997.

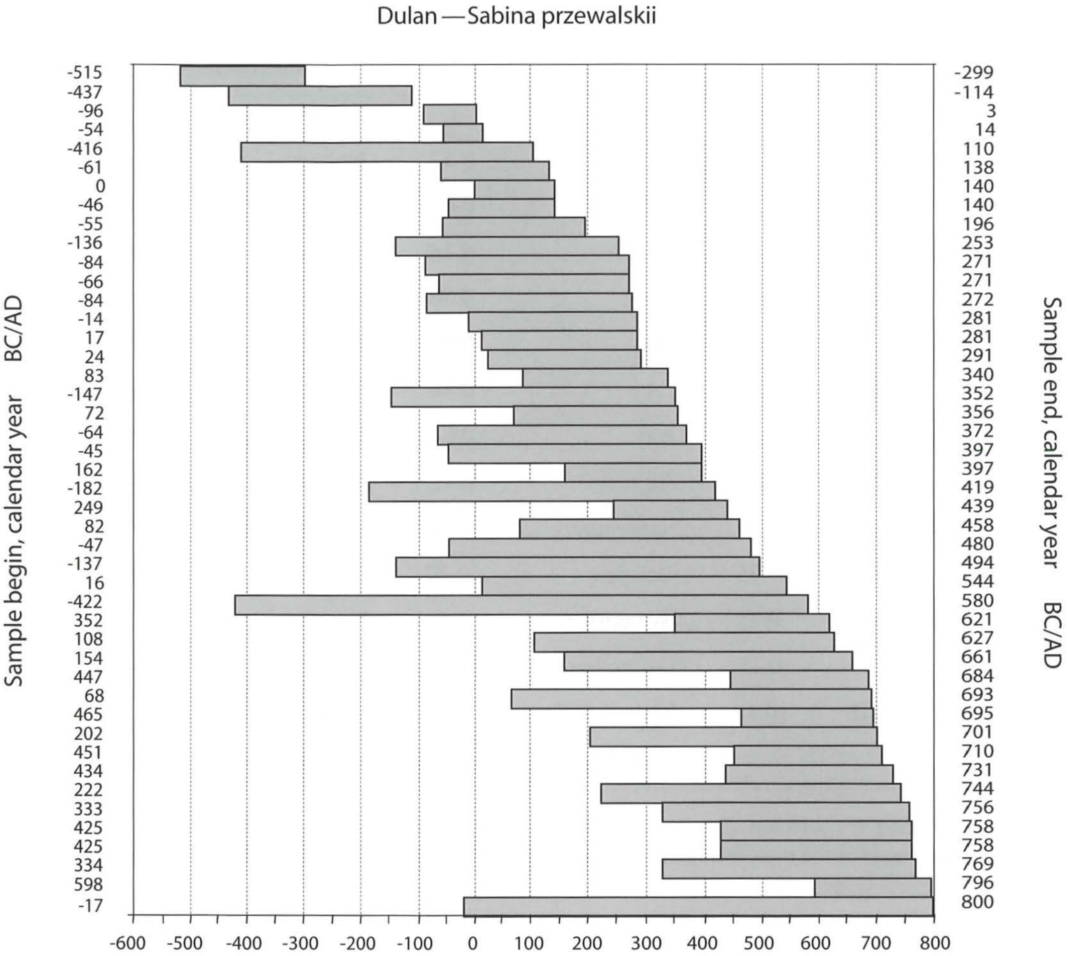

Fig. 4. Diagram showing composition of juniper wood samples used to build up a 1315-year chronology (515 BC–800 AD) for Dulan.

A variety of statistical techniques can be used for calibrating variations in tree-ring widths or indices with different climatic variables and for reconstructing changes in the past climate[29]. As the result of calibration climatic data are converted to tree-growth estimates, which are compared to the actual growth measurements. The equations giving the best correlation between estimates and measurements are then used to infer climate variations from the ring-width variations[30]. A typical approach to the reconstruction is identification of those climatic variables, which have a well pronounced effect on the tree growth on a particular site or in a particular region[31]. Among the diverse climatic parameters, variations in temperatures and precipitation of the preceding and current growing season (mean monthly values and summation or average for different time intervals) are often analysed[32].

[29] Cook/Kairiukstis 1990.
[30] Fritts 1976.
[31] Schulman/Bryson 1965.
[32] Fritts 1976.

Temperature (°C) Current year		Precipitation (mm) Current year		Precipitation (mm) Precedent year	
Period	r	Period	r	Period	r
January	-0.04	January	0.17	January	-0.03
February	-0.10	February	0.02	February	-0.03
March	-0.02	March	0.16	March	-0.09
April	-0.22	April	0.08	April	0.35
May	-0.09	May	0.41	May	0.16
June	-0.44	June	0.46	June	0.07
July	-0.01	July	0.04	July	0.19
August	-0.30	August	0.12	August	0.18
September	0.09	September	-0.03	September	0.29
October	0.23	October	-0.22	October	-0.09
November	0.32	November	0.6	November	-0.16
December	0.17	December	-0.2	December	0.28
Year (I-XII)	-0.17	Year (I-XII)	0.45	Year (I-XII)	0.33
		Precipitation (mm), water year (VII-VI)			0.67

Fig. 5. Correlation (r) between ring-width indices and mean values of the temperature and precipitation registered at the meteorological station in Dulan (36° 17.46′ N, 98° 4.44′ E, ca 3200 m).

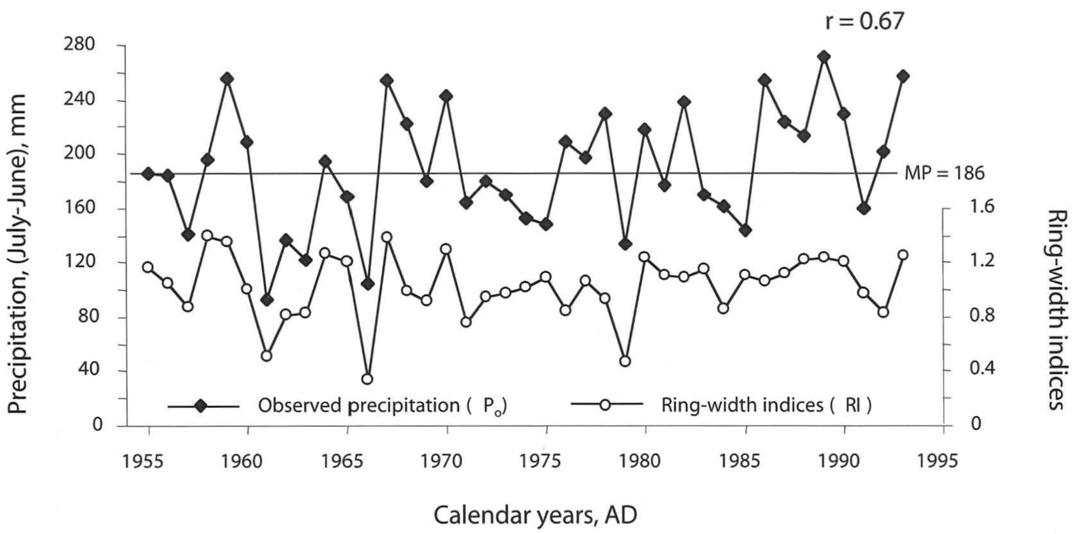

Fig. 6. Actual precipitation of the 'water year' (July of the previous year to June of the current year) and ring-width indices (Kang et al. 1997) from Dulan. MP = 186 mm is mean value of the 'water year' precipitation averaged for the observation period.

The latest part of the Dulan chronology[33] has been compared with the mean monthly temperature and precipitation values recorded at the meteorological station Dulan. The responses of the ring width of the particular year to the climate variables of the preceding and current year have been analysed. The results of this analysis demonstrate a weak negative and positive correlation between ring-width indices and mean monthly, seasonal and annual temperatures *(Fig. 5)*. Slightly better positive correlation ($r = 0.46$) has been found between ring-width indices and June precipitation of the current growing year. However, the best correlation of all ($r = 0.67$) exists between ring-width indices and precipitation of the period lasting from July of the previous year to June of the current year (namely 'water year') *(Fig. 6)*.

In Dulan a relationship between the precipitation of the water year (P) and ring-width indices (RI) can be described with a simple equation:

$$P = 123.7RI + 57.13, \quad (1)$$

Applying this equation to the modern ring-width data *(Fig. 6)* provides values of reconstructed precipitation explaining about 45% of the variations. The mean square error of the equation is 33.8 mm, and the mean relative error is 0.74.

Reconstruction results

The transfer function obtained through modern data has been applied to the fossil tree-ring data to establish the precipitation reconstruction. Results presented in *Fig. 7* demonstrate that reconstructed precipitation sums vary from ca 100 to ca 300 mm during the interval between 416 BC and 758 AD. Greater variations reconstructed outside this interval (e.g. 515–417 BC and 759–800 AD) are based on a limited data set of less than 3 samples *(Fig. 7)* and might be less reliable. These results are excluded from the following discussion. The reconstructed values are similar to the modern precipitation values recorded by the Dulan meteorological station *(Fig. 6)*. This would suggest that the hydrological regime of the study area between 416 BC–758 AD was not substantially different from that of today. However, such an interpretation would be too crude to allow an understanding of climate changes in the Dulan area. During the period for which instrumental records are available *(Fig. 6)* about half of the reconstructed values of precipitation lies above the mean annual precipitation sum (MP = 186 mm). By contrast, ca 60% of the precipitation values reconstructed from the fossil tree-ring data *(Fig. 7)* are below MP, suggesting that relatively dry years appeared more frequently in the past than at present. This can be interpreted as an evidence of a generally drier climate. A number of years with positive and negative precipitation anomalies (differences between the reconstructed value and MP) is counted by 25-year intervals *(Fig. 8)*. The results are placed to the tree groups *(Fig. 8)*. The 'left' group includes intervals with more than 70% (18 and more) relatively dry years, and the 'right' group includes intervals with more than 70% (18 and more) relatively wet years. Thus, intervals 324–300, 249–150, 74–50 BC, and 51–350,

[33] Kang et al. 1997; 2000; P. Sheppard, personal communication 2002.

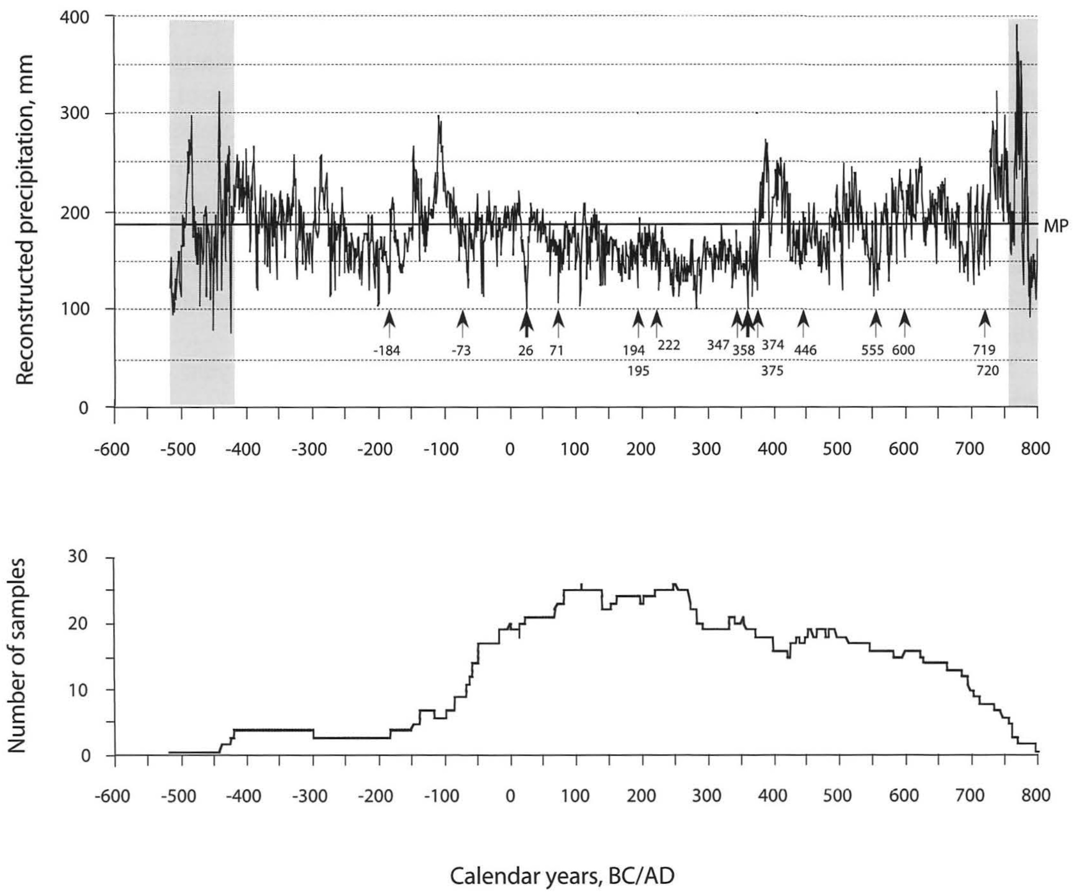

Fig. 7. *Upper plot:* Changing precipitation of the 'water year' (July of the previous year to June of the current year) reconstructed using juniper ring-width indices from Dulan. Grey colour marks the parts of the curve where chronology is based on a limited number of samples (less than four) and the reconstruction is less reliable. Arrows with a number indicate the years with missing tree rings. *Lower plot:* Changing sample size over time (515 BC–800 AD).

426–475 AD experienced a relatively dry climate with average P_r values varying from 140 mm (251–275 AD) to 171 mm (324–300 BC) and average ring-width indices of 0.67–0.92 *(Fig. 8)*. Intervals which experienced more favourable moisture conditions than the main part of the record are relatively short, occurring 416–375, 349–325, 299–275, 124–75 BC, 376–425, 501–525, 576–675 AD and after 726 AD. The relatively wet intervals are characterised by average P_r values of 243–196 mm and average ring-width indices of 1.12–1.5. A comparison of the results from *Fig. 7* and *Fig. 8* suggests that the missing rings are associated with the dry years and mainly occur during the intervals with a relatively dry climate. However, the years with low precipitation that appeared during the intervals with more favourable conditions might also cause the missing rings (e.g. 26, 555, 600, 719 and 720 AD).

Interval, years BC/AD	Number of years with negative/ positive P_r anomaly	P_r averaged by 25-year interval mm	RI averaged by 25-year interval	Climate characteristic
BC 399-375	7/18	201	1.17	Relatively wet
BC 374-350	12/13	185	1.03	Similar to present
BC 349-325	4/21	204	1.18	Relatively wet
BC 324-300	19/6	171	0.92	Relatively dry
BC 299-275	7/18	207	1.21	Relatively wet
BC 274-250	16/9	173	0.93	Similar to present
BC 249-225	24/1	158	0.81	Relatively dry
BC 224-200	22/3	165	0.87	Relatively dry
BC 199-175	20/5	164	0.86	Relatively dry
BC 174-150	25/0	163	0.85	Relatively dry
BC 149-125	9/16	203	1.18	Similar to present
BC 124-100	1/24	232	1.41	Relatively wet
BC 99-75	5/20	202	1.17	Relatively wet
BC 74-50	19/6	169	0.91	Relatively dry
BC 49-25	12/13	179	0.99	Similar to present
BC 24-0	14/11	186	1.04	Similar to present
AD 1-25	12/13	181	1.00	Similar to present
AD 26-50	13/12	183	1.02	Similar to present
AD 51-75	23/2	165	0.88	Relatively dry
AD 76-100	21/4	167	0.89	Relatively dry
AD 101-125	20/5	165	0.88	Relatively dry
AD 126-150	19/6	168	0.90	Relatively dry
AD 151-175	25/0	155	0.80	Relatively dry
AD 176-200	24/1	156	0.80	Relatively dry
AD 201-225	22/3	161	0.84	Relatively dry
AD 226-250	25/0	149	0.74	Relatively dry
AD 251-275	25/0	140	0.67	Relatively dry
AD 276-300	25/0	145	0.71	Relatively dry
AD 301-325	24/1	154	0.79	Relatively dry
AD 326-350	25/0	153	0.78	Relatively dry
AD 351-375	23/2	145	0.71	Relatively dry
AD 376-400	6/19	212	1.25	Relatively wet
AD 401-425	3/22	223	1.34	Relatively wet
AD 426-450	21/4	163	0.86	Relatively dry
AD 451-475	20/5	171	0.92	Relatively dry
AD 476-500	15/10	180	0.99	Similar to present
AD 501-525	7/18	199	1.15	Relatively wet
AD 526-550	15/10	182	1.01	Similar to present
AD 551-575	14/11	169	0.91	Similar to present
AD 576-600	6/19	199	1.15	Relatively wet
AD 601-625	3/22	215	1.27	Relatively wet
AD 626-650	5/20	196	1.12	Relatively wet
AD 651-675	7/18	199	1.15	Relatively wet
AD 676-700	16/9	174	0.94	Similar to present
AD 701-725	16/9	179	0.98	Similar to present
AD 726-750	1/24	243	1.50	Relatively wet

Fig. 8. Temporal variations in the reconstructed precipitation (P_r) of the water year (July–June) inferred from Dulan ring-width indices (RI) presented for 25-year intervals.

Discussion and conclusions

The interval from 500 BC to 800 AD experienced several climate oscillations (e.g. 'Iron Age Cooling' and 'Medieval Warm Epoch') recorded in the palaeoenvironmental and archaeological studies dealing with the different regions of Eurasia[34]. As indicated by the name of these climate events, the major attention when discussing them has been paid to temperature changes. Until recent times very few adequately dated and high-resolution proxy records from Central Asia were available for comparison with our precipitation reconstruction in Dulan.

Kang et al.[35] compared their tree-ring chronology to the mean monthly temperatures from Dulan meteorological observatory and used the correlation between the ring-width indices and the mean temperature of the autumn months for the reconstruction of 'warm' and 'cold' spells in the area during the past eighteen centuries. In the present study we have found that ring-width data from Dulan correspond better to the precipitation of the 'water year' lasting from July of the previous year to June of the current year. This result is in agreement with the ecological and dendroclimatological studies of juniper trees in regions with dry climate. In the BIOME1 vegetation model juniper species are attributed to the 'eurythermic conifer' plant functional type, whose growth is primarily limited by moisture conditions and not by temperature[36]. It has been found that climatic conditions, which produce narrow rings in *Juniperus osteosperma* (species growing in Colorado, USA) are mainly droughts occurring during the period from October of the prior year to May of the analysed year[37]. Furthermore, the latter study reports that ring widths of juniper are markedly affected by total precipitation ($r = 0.78$). Ring widths of conifers in semiarid regions often have negative correlation with variations in monthly temperatures, and direct correlation with variations in monthly precipitation[38]. These relationships can be easily explained in terms of the physiological processes limiting tree growth, e.g. by a water stress caused by low precipitation or/and high temperatures. In the case of Dulan, where mean summer temperatures do not exceed 15–17 °C *(Fig. 3)*, low precipitation seems to be the most probable reason for the water deficit. Moreover, a recently published new interpretation[39] of the ring-width chronology from Dulan considers spring (May–June) precipitation as an important factor ($r = 0.58$, $p < 0.001$) influencing tree growth in the area. This conclusion is consistent with our results.

The reconstructed values of the annual precipitation values during 416 BC–758 AD vary from 100 to 300 mm, thus are not different from the modern instrumental record in Dulan. The Zhang et al.[40] study based on living and fossil wood from Dulan mainly discusses climate changes during the last 1500 years. However, it points that the spring precipitation lay in a relatively low level of variability around the mean, between 326 BC and the end of the 3rd century AD. Our reconstruction suggests that relatively dry years with precipitation below modern mean value did occur more frequently in the past than they do now. Further analysis of the results suggests that intervals with more than 70% of

[34] Selivanov 1994; Lamb 1995.
[35] Kang et al. 1997.
[36] Prentice et al. 1992; Sykes et al. 1996.
[37] Fritts 1976.
[38] Fritts 1976.
[39] Zhang et al. 2003.
[40] Zhang et al. 2003.

relatively dry years and average precipitation of ca 140–170 mm occurred 324–300, 249–150, 74–50 BC, 51–350 and 426–475 AD. Intervals of relatively wet climate (average precipitation of 240–200 mm) are reconstructed 416–375, 349–325, 299–275, 124–75 BC, 376–425, 501–525, 576–675 AD and after 726 AD.

Comparison of our results with the other hydrological reconstructions from Central Asia reveals the following. Pollen and sedimentary records from Telmen Lake (48° 50′ N, 97° 20′ E, 1789 m) in Central Mongolia[41] suggest that in the lake basin the interval 500 BC–350 AD was characterized by relatively moist conditions. The wet phase was interrupted by the arid excursion dated to about 2000 cal BP (ca 50 BC). It corresponds to the relatively dry interval with very few 'wet' years in our record. Furthermore, the arid interval reconstructed between ca 1600 and 1200 cal BP[42] (350–750 AD) has only partial correspondence with the long aridity phase reconstructed in Dulan from 51 to 375 AD and 426–475 AD. A relatively long phase with wetter conditions started in Dulan about 575 AD, e.g. more than 150 years earlier than in Mongolia. Traces of the short but pronounced aridity episode found in the Telmen Lake record in ca 550 AD coincide with the cold temperatures and summer frost AD 536–545 suggested by tree-ring records from Central Mongolia[43]. Ring-width data from Dulan also suggest relatively dry years between 537–565 AD (24 of 28 years). A combination of tree-ring width depressions with historical[44] and glaciological data from different parts of the world suggests a worldwide volcanic dust veil in 536 AD[45]. The linkage between tree rings and volcanic events is a matter of scientific discussion[46]. However, a single volcanic eruption probably is not enough to explain the period of drought that lasted more than 20 years as reconstructed in Dulan.

The data in *Fig. 8* suggest that the longest phase with relatively dry conditions occurred in Dulan from 51 to 375 AD and continued 426–475 AD after a period of slight climate amelioration. The radiocarbon date of 1590 ± 140 uncal BP from the peat layer deposited in the eastern part of the Aral Sea[47] points to a very deep regression of the lake around the 4^{th}–5^{th} century AD. At the time (5^{th} century AD) Khwarezm – the great agricultural state in the Amu Darya River delta – experienced a severe economical crisis.

These pieces of evidence combined together suggest a very dry climate in the southern part of Central Asia, consistent with records from Dulan. Sedimentary records from Yiema Lake (39° 06′ N, 103° 40 ′E) situated in NW China close to the Mongolian border also suggest a drought around 1500 cal BP[48] (ca 450 AD). This drought corresponds well to the dry interval reconstructed in Dulan *(Fig. 8)*. Pollen and sedimentary data from palaeolake Eastern Juanze (41.89° N, 101.85° E, 892 m) that had existed in the Alashan Gobi, NW China since ca 10,000 cal BP suggest a desiccation of the lake soon after 2000 cal BP[49].

Relating our reconstructed climate characteristics with the chronology of culture-historical events in the Qinghai-Gansu area, we have observed the following phenomena.

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41 Fowell et al. 2003.
42 Fowell et al. 2003.
43 D'Arrigo et al. 2001a; 2001b.
44 Rampino et al. 1988.
45 Baillie 1994.
46 Schweingruber 1996.
47 Tarasov et al. 1996.
48 Chen et al. 1999.
49 Herzschuh et al. 2003.

The Former Han dynasty (202 BC–23 AD), which had its capital in Chang'an (present-day Xi'an), for the first time extended Chinese territory towards the present-day Xining *(Fig. 1)*. During the reign of Wang Mang (9–23 AD) even the Qinghai Lake district was incorporated. Remnants of city walls are still visible today above the surface and tombs are frequently opened up by soil erosion and construction work. However, this maximum extension did not last and during the Later Han dynasty (25–220 AD) it was lost again. The native inhabitants of this area were tribes, which are called either Qiang[50] or "semi-nomadic Tibetans"[51], still without reliable knowledge about their ethnicity. According to written sources the Chinese colonisation, like the setting up of self-sufficient agricultural garrisons, was clearly politically motivated and driven by the main task to prevent the Qiang from allying with the Xiongnu, the tribes of the northern steppes. Nevertheless, between the first census in 2 AD and the second census in 140 AD approximately 70% of the Han-Chinese inhabitants (amounting to 6.5 million people) left the territory in a "vast voluntary migration from north to south"[52] due to pressure from the Qiang who filled the emptied areas. The tribes migrated into the western Chinese territories with such a tremendous amount of people that they soon outnumbered the Chinese, who during the 1st century AD still tried to accommodate them in dependent states[53]. But the eastward movement of the tribes further increased dramatically in the 2nd century AD until the Chinese hold on the western regions ended and with it the Han Empire itself. Whether the migration was impelled by population pressure[54], and if so what caused the population growth, are questions that must remain unsolved at the moment. At any event, the local tribes dominated the area until the Tuyuhun, nomads from the northeastern steppe regions, entered the area around the Qinghai Lake, intermarried with the indigenous elite[55] and kept the reign until they were overthrown by the Tibetans in 680 AD. The Tibetan Kingdom Tubo (Tufan) had started to grow in power since the first half of the 7th century and had expanded its territory rapidly by mid-century. By destroying the Tuyuhun Kingdom the Tibetans became the immediate north-western neighbours of the Han-Chinese Tang Empire persistently threatening the traffic routes, the Silk Route. Even the remains of the grave goods left by the robbers in Dulan[56] prove the enormous benefit they earned from controlling the far distant trade. Just as several hundred years before, the Chinese tried to fight and to contain them by attacks, invasions, and marriage alliances and by founding agricultural garrisons. And again these farmer-soldiers' outposts did not survive for long.

The remarkable event of the forced and voluntary Qiang mass-migration into the western Chinese territories[57] coincides with the interval of relatively dry climate from 51 to 225 AD. The long dry period continued until 375 AD when the Tuyuhun had already settled around Qinghai Lake. As the Qiang settled east of the Huang He (Yellow) River during the first centuries AD, pastoral tribes in general dominated the whole of northern China for about 350 years until the next central Chinese Empire, the Sui dynasty, was

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[50] de Crespigny 1984; Wang 1992; Yü 1995.
[51] Bielenstein 1995, 270.
[52] Bielenstein 1995, 241.
[53] Yü 1995.
[54] Yü 1995.
[55] Franke/Twitchett 1994.
[56] Xu/Zhao 1996; Xu 2002.
[57] de Crespigny 1984.

founded in 581 AD. The lack of precipitation might have been one of the main reasons explaining why "the balance of advantage had shifted from Chinese-style peasant agriculture to non-Chinese pastoral economy"[58]. The relatively wet periods between 576 and 675 AD brought about a strong Tibetan Kingdom side by side with a strong Chinese Empire, the Tang dynasty (618–907 AD).

In conclusion, the results of the reconstruction based on the 1315-year archaeological wood chronology from Dulan is the first attempt to gain information on annual changes in precipitation for this area and it demonstrates a big potential for dendroclimatological studies in NW China. We have shown that the driest phase reconstructed from Dulan tree-ring data occurred during the first centuries AD, synchronously with the arid events recorded in NW China and in Central Asia. Less correspondence occurs when results from further north (e.g. Central Mongolia) are compared. The occurrence of dry conditions in NW China as well as in Middle Asia seems to be in agreement with a change in population dynamics and land use to a strengthening of the herdsmen and a weakening of the farmer society in these regions. However, more data is required for a better understanding of the climatic changes and for proof of their relationship with cultural shifts. Our further efforts will be to improve the tree-ring data set in Qinghai Province and to get more high-resolution palaeoclimatic information from the existing data, including isotope and late wood density analyses of tree rings and archaeological and historical sources analyses[59].

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[58] de Crespigny 1984, 75.

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Pavel E. Tarasov
Alfred-Wegener-Institut for
Polar and Marine Research
Telegrafenberg A43
D-14473 Potsdam
paveltarasov@mail.ru

Karl-Uwe Heussner
Mayke Wagner
Deutsches Archäologisches Institut
Eurasien Abteilung
Im Dol 2–6
D-14195 Berlin

Shuzhi Wang
Archaeological Institute of the
Chinese Academy of Social Sciences
27 Wangfujing Road
100710 Beijing
P. R. China

Hermann Österle
Potsdam-Institut für
Klimafolgen-Forschung
Telegrafenberg PF 60 12 03
D-14412 Potsdam

Резюме

В статье представлены результаты дендрохронологических и дендроклиматических исследований, выполненных в районе Дулан (провинция Цинхай, СЗ Китай). Образцы древесины можжевельника *(Sabina przewalskii)* были отобраны в 1999 году из стволов, обнаруженных в могильниках эпохи Тубо (Туфан), датированных 7–8 вв. н.э. Построенная с учетом анализа ширины годичных колец можжевельника дендрохронологическая шкала охватывает 1315 лет в интервале между 800 годом н.э. и 515 годом до н.э. Корреляционный анализ индексов ширины годичных колец *Sabina przewalskii* в районе метеостанции Дулан (36° 17,46′ с.ш., 98° 4,44′ в.д., около 3200 м) и среднемесячных значений температуры и осадков в период с 1940 по 1993 год позволяет сделать вывод о том, что прирост можжевельника в исследуемом районе определяется суммарным количеством осадков, выпавших с июля предыдущего года по июнь текущего года. Полученная трансфер-функция используется для реконструкции атмосферных осадков по образцам археологической древесины. Результаты реконструкции позволяют считать относительно

засушливыми 324–300, 249–150, 74–50 годы до н.э., а также 51–350 и 426–475 годы н.э. Наиболее благоприятными условиями увлажнения характеризуются 416–375, 349–325, 299–275 и 124–75 годы до н.э., а также в 376–425, 501–525 и 576–675 годы н.э. Сравнительный анализ исторических данных и реконструированных палеоклиматических показателей указывает на то, что длительная фаза с относительно сухим климатом (51–350 годы н.э.) совпадает по времени с запустением земледельческих поселений-гарнизонов в восточном Цинхае, а ослабление влияния китайской династии Хань в обширном регионе между озером Цинхай и городом Чанань (современный Сиань) сопровождается продвижением скотоводческих племен в восточном направлении – с Тибета на равнины. В период увлажнения климата (576–675 годы н.э.) – более благоприятный для земледелия – проникновение на запад китайской династии Тан (618–907 годы н.э.) постоянно наталкивается на сопротивление сильного Тибетского государства, контролирующего торговые пути в Среднюю Азию.