"Medieval Warm Period" on the northern slope of central Tianshan Mountains, Xinjiang, NW China

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Received 26 January 2009; revised 20 March 2009; accepted 22 April 2009; published 4 June 2009.

[1] "Medieval Warm Period" is used to describe a past climate epochs in Europe and neighboring regions from the ninth to the fourteenth centuries. In order to discuss the palaeoclimate changes during the MWP on the northern slope of central Tianshan Mountains in Xinjiang Autonomous Region, northwestern China, three Holocene sediment profiles in Daxigou region, Caotan Lake and Sichang Lake located in different elevations and vegetation zones were chosen for further discussion. A multi-proxy reconstruction of the climate change in these three profiles using pollen, phytolith records, and the data of loss of ignition (LOI), grain size, and susceptibility showed that the climate was humid during the period corresponded in time with the MWP (from the middle of the Tang Dynasty to the middle of Yuan Dynasty). Complemented by tree-ring record, other pollen records, data of plant seeds and historical documents; we conclude that during the MWP the climate was humid on the north slopes of Tianshan Mountains in Xinjiang. **Citation:** Zhang, Y., Z. C. Kong, S. Yan, Z. J. Yang, and J. Ni (2009), ''Medieval Warm Period'' on the northern slope of central Tianshan Mountains, Xinjiang, NW China, *Geophys. Res. Lett.*, *36*, L11702, doi:10.1029/2009GL037375.

1. Introduction

[2] The Medieval Warm Period (MWP) was a time of unusually warm climate in Europe, lasting from about the ninth to the fourteenth centuries, which showed that the mean temperature was 0.5–1.6 °C higher than that prevailing around the turn of the twentieth century [*Lamb*, 1965]. In the last two decades, a lot of evidences derived from historical documents [*Zhang*, 1994], δ^{18}O of peat cellulose [*Hong et al.*, 2000] and stalagmite [Zhang et al., 2008], ice cores [*Shi et al.*, 1999], archeological data and tree rings [*Yang et al.*, 2003, 2009] suggest the existence of the MWP in the most part of China.

[3] The dryland of Xinjiang occupies a climatic transition zone between the Asian monsoons and westerly airflow. As a result of this location, the region is sensitive to changes in climate on timescales of decades to millennia [*Chen et al.*, 2009]. According to *Shi et al.* [2007], a strong signal of climate change from a warm-dry to a warm-wet pattern has already been observed in Xinjiang since 1987 based on an analysis of the hydrological and meteorological data base, basic circulation patterns and modeling studies for 40 years.

[4] How about the climate during the MWP in Xinjiang? In this paper, three Holocene sediment profiles in Daxigou region, Caotan Lake and Sichang Lake which are located in different elevations and vegetation zones on the northern slope of central Tianshan Mountains in Xinjiang, northwestern China, were selected for further discussion on the climate characteristic during the MWP.

2. Methods

2.1. Field Survey and Sampling

[5] Three exposed sediment profiles were sampled in Daxigou region (43°07′ N, 86°51′ E and 3450 m a.s.l), Caotan Lake (44°25.06 ′N, 86°01.26′ E, 380 m a.s.l) and Sichang Lake (44°18.6′ N, 89°8′ E and 589 m a.s.l), which were located at different region on the northern slopes of Tianshan Mountains, Xinjiang.

[6] Fifty-two samples at intervals of 2 cm from the Daxigou region, 58 samples at 3 cm intervals from the Caotan Lake and 19 samples at 3–5 cm intervals in layers except the upper eolian sand layer for the Sichang Lake profile were collected. We treated all pollen samples of 30 g each with 10% HCl and 10% NaOH in the laboratory, followed by gravity liquid and acetolysis after sieving and chemical treatments. At least 300 pollen grains in each sample except at depths of 102–74cm, belonging to 39 pollen taxa, were counted in Daxigou profile. A total of 56743 pollen-spore grains and 65 pollen taxa, with a minimum of 300 terrestrial pollen grains for samples at depths of 66-0 cm, were identified in the sediment profile of Caotan Lake. Thirty-five pollen taxa and an average of 150 pollen grains were found in each sample for Sichang Lake profile. Pollen percentage for tree, shrubs, herbs, A/C (*Artemisia*/Chenopodiaceae) and AP/NAP (arboreal pollen/not arboreal pollen) ratio were calculated upon a pollen sum including fern spores except for Caotan Lake profile. Because large numbers of Polypodiaceae spores in Caotan Lake profile, which tends to occur locally in very high concentrations and reaches a minimum of 1000 grains per sample, could results in their over-representation and the distortion of the sum. Furthermore, following measurements were operated besides the pollen analysis: grain size measurement (determined by Mastersizer2000 laser particle distribution analyzer), loss on ignition (LOI) and susceptibility (determined by MS2 susceptibility analyzer).

2.2. Stratigraphy and Chronology

[7] Daxigou profile (110 cm deep) was dug at the headwater of the Urumqi River, which is located on the

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0094-8276/09/2009GL037375$05.00

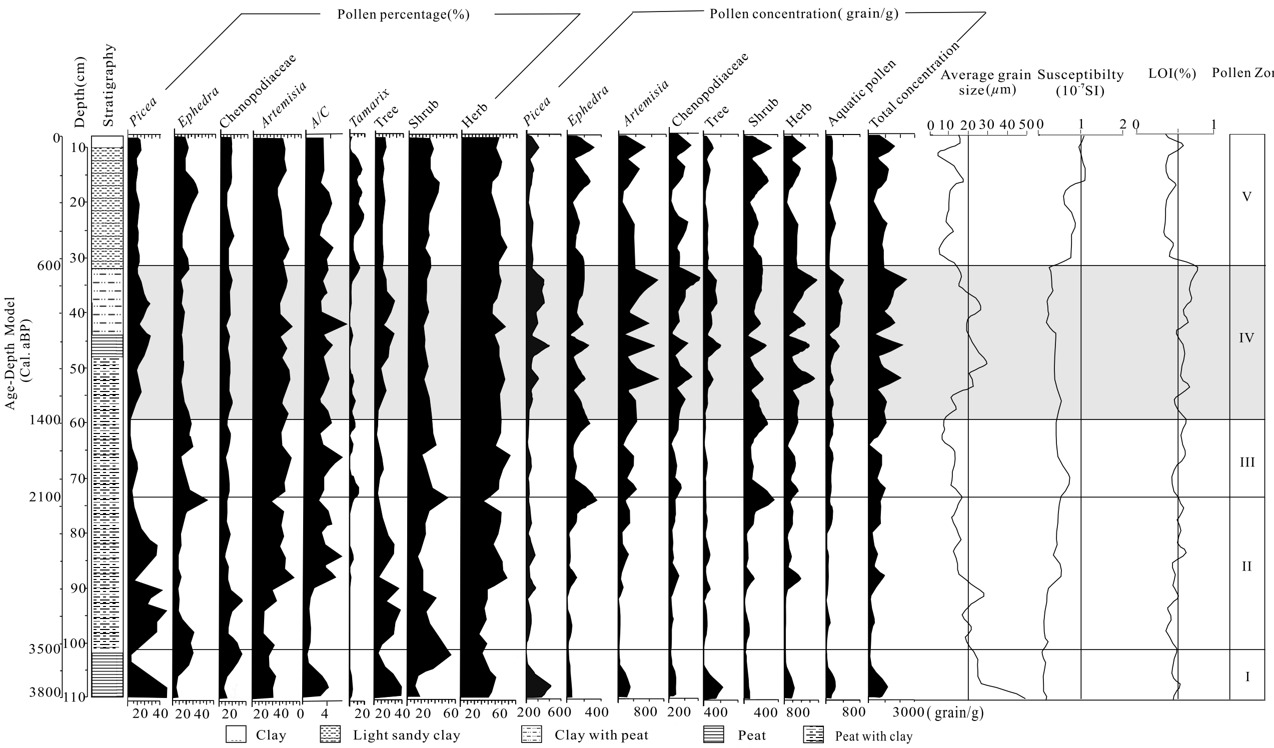

Figure 1. Pollen, grain size, susceptibility and LOI of Daxigou profile in Xinjiang, China.

north slopes of Tianger Peak in the central Tianshan Mountains. Main vegetation is alpine and subalpine meadow here. Stratigraphy of this profile is composed of clay and barren peat (Figure 1). Two subsamples (at depths of 108–110 and 44–48 cm) were selected for ^{14}C dating and calibration, with the results of 890 ± 60 aBP (770 ± 30 cal. aBP) and 3640 ± 60 aBP (3900 ± 70 cal. aBP) respectively. ^{14}C dating was analyzed by the ^{14}C Laboratory of Institute of Geology, China Seismological Bureau. Ages of the remaining samples were interpolated by assuming that the sediment rate is constant between the two dated samples. Then the calendric chronology for this profile was established on the basis of these two dating.

[8] A 175 cm deep sedimentary profile was excavated at the Caotan Lake, which is located at the spring water spill belt in Shihezi city of the central Tianshan Mountains. The profile is consists of clayey silt, clay, and barren peat from the bottom up (Figure 2). The natural vegetation is *Phragmites* community, accompanied by *Scirpus tabernaemontani* and *Najas* spp. etc. Five subsamples (at the depths of 28–25, 45–42, 76–73, 112–109 and 175–172cm) were dated and calibrated, resulting of 1210 ± 70 aBP (1140 ±

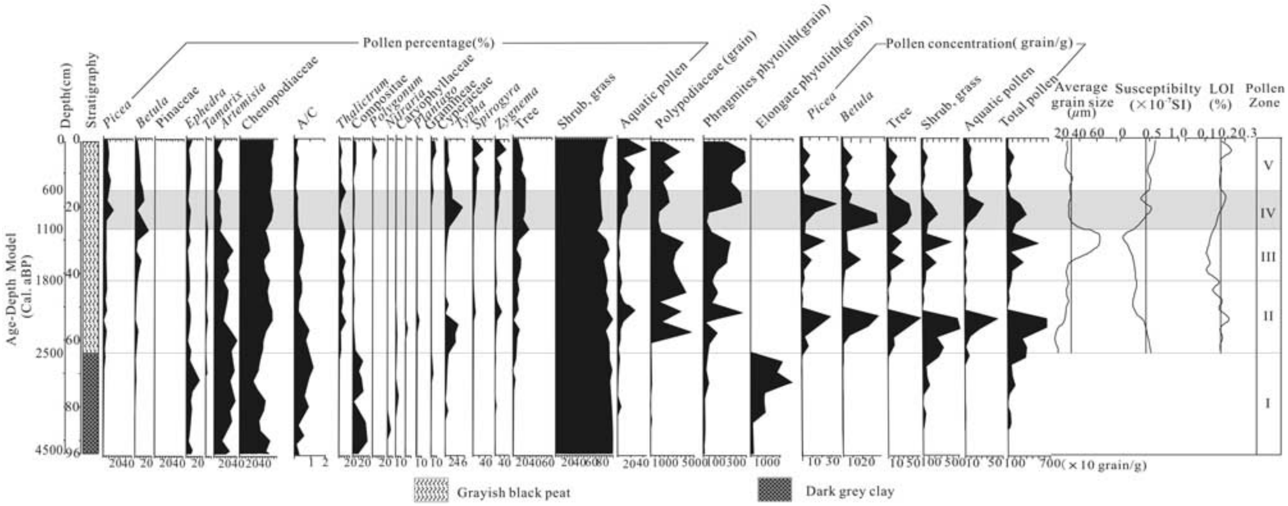

Figure 2. Pollen, grain size, susceptibility and LOI of Caotan Lake profile in Xinjiang (from 96 cm to the top of the sequence), China.

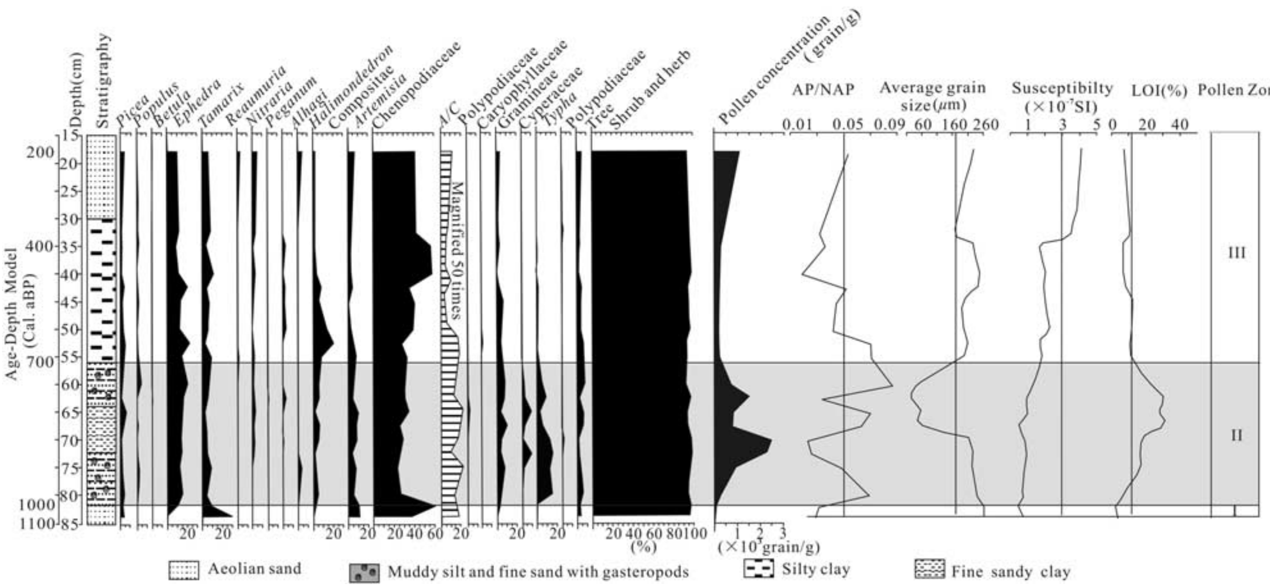

Figure 3. Pollen, grain size, susceptibility and LOI of Sichang Lake profile in Xinjiang, China.

100 cal. aBP), 1420 ± 60 aBP (1310 ± 30 cal. aBP), 2890 ± 70 aBP (3000 ± 135 cal. aBP), 4960 ± 190 aBP (5660 ± 210 cal. aBP) and 8240 ± 575 aBP (9240 ± 735 cal. aBP), respectively. The calendric ^{14}C data of other subsamples were interpolated with the same method described above for the Daxigou profile.

[9] Sichang Lake profile (84 cm deep) was dug at the ancient Sichang Lake, which was desiccated for years and located in the southeastern margin of the Gurbantunggut Desert. The profile consists of 6 layers. They are rust yellow sand, dark-gray muddy silt and fine sand with a great deal of gasteropods fossil such as *Radix acuminate* and *Gyraulus*, grayish white silty clay, dark-gray muddy silt and fine sand with some gasteropods fossil, grayish fine sandy clay, and rust yellow sand from the bottom up (Figure 3). The natural vegetation is sandy desert, mainly dominated by *Haloxylon ammodendro*, *Artemisia* and *Ephedra* species. Two subsamples (at the depth of 78–82 and 62–64cm) were selected for dating and calibration, with the results of 1000 ± 50 aBP (cal. 930 ± 85 aBP) and 665 ± 65 aBP (cal. 650 ± 55 aBP). The calibration data of the other subsamples were interpolated with the same method described above for the sequence of Daxigou. All ages for these three profiles have been calibrated using CALIB Version 5.0.1 [*Stuiver et al.*, 1998] based on a ^{14}C half-life of 5568a.

3. Pollen Assemblages and Climate Reconstruction

3.1. Daxigou Sediment Profile in the Alpine and Subalpine Meadow Vegetation Zone

[10] Based on variations in pollen concentration, main pollen percentages, grain size and LOI value, pollen diagram of Daxigou sediment profile was categorized into five pollen zones (Figure 1). In Zone I (110–102 cm; 3800–3500 cal. aBP), remarkable high values of *Picea* pollen in both percentages and concentration were recorded. Similarly, relatively higher pollen concentration of aquatic plants and total pollen, A/C and AP/NAP ratios, pollen concentration of aquatic plants, and average granularity value reflected that the climate was more humid than present. *Picea* percentages ranged from 25% to 35%, but its pollen concentration decreased rapidly to 1.7grain/g in Zone II (102–74 cm; 3500–2100 cal. aBP). Lower A/C and AP/NAP ratios, pollen concentration of aquatic vegetation and LOI value compared to Zone I indicated a dry climatic condition. From 2100 to 1400 cal. aBP in Zone III (74–60 cm), *Picea* percentage reached its lowest values in the profile, whereas its concentration began to increase. Total concentration of aquatic pollen, total pollen concentration and the A/C ratio were higher relative to Zone II, suggesting that the climate became wetter than Zone II and vegetation coverage increased. The pollen assemblages from Zone IV (60–32 cm; 1400–600 cal. aBP) showed that the prominent peaks of pollen concentrations of total pollen, arboreal, shrub, aquatic, herb and LOI value in this zone implied a more humid climate condition. Since 600 cal. aBP (Zone V, 32–0 cm), the climate was not more humid than the former stage because pollen concentration and percentage of *Picea* decreased obviously, but those of *Artemisia*, Chenopodiaceae and *Ephedra* were high.

3.2. Caotan Lake Profile in the Wetland Vegetation Zone

[11] According to a multi-proxy reconstruction in Caotan Lake using pollen, phytolith records, and the data of LOI, grain size, and susceptibility, four pollen-assemblage zones were distinguished from 96 cm to the top of the sequence (Figure 2). In Zone I (99–66 cm; 4500–2500 cal. aBP), remarkable lowest pollen percentages of arboreal and aquatic plants, concentrations of total pollen, aquatic plants, Polypodiaceae spore, trees, shrub and herb, and relatively lower values of fan-shaped and square phytolith and higher values of elongate and point-shaped phytolith as an indicator of a cold and dry climate [*Lu et al.*, 1996] suggested a dry climatic condition, which was not favorable for the accumulation of peat. Since 2500 cal. aBP, higher concen-

tration of total pollen, aquatic plants, shrub and herb and arboreal pollen, and high content of fan-shaped phytolith showed that the climate became wetter than in Zone I and the wetland developed with abundant freshwater aquatic plants, which contributed to peat accumulation. Nevertheless, alternate periods of humid and dry climate occurred during that period. Concentration of total pollen, aquatic plants, shrub and herb and arboreal pollen were at the second highest values in Zone II (66–42 cm; 2500–1800 cal. aBP). Secondly, high content of *Phragmites* fan-shaped phytolith, as indicators of a warm and humid climate, and higher susceptibility and LOI values but lower grain-size indicated the climate was more humid than at present. However, from 1800 to 1100 cal. aBP (Zone III; 42–27 cm), lower concentration of total pollen, aquatic plants, shrub and herb, arboreal pollen, and amounts of aquatic plants, Polypodiaceae spores and typical *Phragmites* fan-shaped phytolith than those in Zone II, and the lowest value of LOI and susceptibility suggested a dry climate. Compared with Zone III, *Phragmites* fan-shaped phytolith as the implication of a warm and humid climate increased again in Zone IV (27–15 cm; 1100–600 cal. aBP). Percentages of shrub and herb decreased, while those of arboreal pollen composed by *Betula* and *Picea* increased greatly with a peak value of 27%, implying a high plant diversity and biomass with abundant aquatic plants. But since cal. 600 aBP (Zone V; 15–0 cm), concentration of total pollen, aquatic plants, shrub and herb, and arboreal pollen decreased again to their minimal values in the peat layers. However, pollen percentages of shrub and herb increased compared with Zone IV, while those of arboreal pollen decreased rapidly, reflecting a drier climate.

3.3. Sichang Lake Profile in the Typical Desert Zone

[12] Three pollen-assemblage zones were divided based on lithology features, the vertical variations in main pollen percentages, pollen concentration, grain size and LOI value of Sichang Lake profile (Figure 3). In Zone I (84–82 cm; 1100–1000 cal. aBP) and Zone III (56–18 cm; 700–200 cal. aBP), the lowest value of total pollen concentration, *Picea* and *Typha* percentage, coarser grain size and the minimum LOI value suggested a very dry climate. But during that period of from 1000 to 700 cal. aBP in Zone II (82–56 cm), A/C and AP/NAP values, total concentration, and pollen percentages of aquatic plants were much higher than those in other two zones. In addition, some gastropods, such as *Radix acuminate* and *Gyraulus*, were found in the sediment with thin grain size and the maximum LOI value, indicating a humid climate.

4. Discussions and Conclusions

[13] Pollen analyses of Daxigou, Caotan Lake and Sichang Lake profiles, for more details published in papers of *Zhang et al.* [2004a, 2004b, 2008], reflected that during the period, approximately corresponding to the MWP, the climate was humid. Some aquatic intrazonal helophyte and gasteropods such as *Radix acuminate* and *Gyraulus* existed nearby the fresh Sichang Lake from 1000 to 700 cal. aBP. In Daxigou region, the Climatic Optimum since 3800 cal. aBP prevailed between 1400 and 600 cal. aBP, due to the maximum value of pollen concentrations of total pollen and arboreal, shrub, aquatic and herb. From 1100 to 600 cal. aBP, flourishing aquatic plants, such as *Phragmites*, *Typha* and *Sparganium*, and freshwater green algae, dominated in the Caotan Lake. It is noticeable that the grain-size data shows good agreement with the pollen-based inference of the humidity change in these three profiles. In general, the lower average granularity usually indicates a wet environment over the lake region, such as Caotan Lake and Sichang Lake [*Chen et al.*, 2004]. But the indication significance of sediment grain sizes in Daxigou is different from that in Caotan and Sichang Lakes. The reason may be that they are located at different latitudes. The elevation of Daxigou profile is about 3450 m, which is five times higher than that of Caotan Lake (380 m) and Sichang Lake (589 m) profiles. And the distance between Daxigou region and snow line is very near, only about 500m. It is likely that more glacial meltwater and high precipitation rates dring a wet period would enhance the soil erosion and increase the transport capacity of streams, leading to more, coarser clastic materials available for stream transport and subsequent deposition in the Daxigou region. Therefore, higher grain size would reflect a humid climate in Daxigou region.

[14] Furthermore, the MWP event can be recognized in three pollen records on the north slopes of Tianshan Mountains. Between 1650 and 550 cal. aBP, the water level of Ebinur Lake kept on rising and reached a higher position based on pollen analysis [*Yan et al.*, 2003]. Large numbers of aquatic intrazonal helophyte dominated by *Typha, Phragmites* and *Carex* and diatoms were identified in Dongdaohaizi profile, a terminal lake of the Urumqi river, and the A/C ratio was relative higher, pointing to a similar humid trend for the period of 1270–305 cal. aBP [*Yan et al.*, 2004]. *Yan and Kan* [1993] reported that at the depth of 60–15cm (^{14}C dating of 590 ± 80 cal. aBP) of Dongheba profile in the Jimusaer County, relatively higher percentages of aquatic plants (dominated by *Typha* and *Phragmites*) also indicated a humid climate.

[15] Records of microfossil and plant seeds in the Lop Nur Lake further demonstrate the existence of the MWP in the north of Xinjiang. The MWP of the Lop Nur area was first proposed by Hundington in 1907 [*Ma et al.*, 2008]. He pointed out that there was a favorable climate from the 9th to the 16th century and that the Lop Nur expanded again in the Middle Ages. *Ma et al.* [2008] collected a lot of plant seeds from 67 to 74cm in the center of the Lop Nur Lake, which were identified as submerged and emergent aquatic plants, such as *Potamogeton pectinatus*, *Potamogeton lucens*, *Scirpus tabernaemontani* and *Phragmites*. Moreover, ostracods (*Condoniella albicans*, *Condona copessa*, *Eucrypris inflata*, *Limonocythere inopinata*, *Darwioula stevenoni*), Charophytes (*Lamprothaminiom*) and snails (*Blanorbidae*, *Radix auricularia*, *Lymnaea staynalis*) were also recorded. The vegetation remains at the depth from 67 to 74cm was dated to 871 ± 45 cal. aBP. Interpolated with the ^{14}C dating ages and sedimentation rates, the bottom of this section was estimated to date to 1250 cal. aBP. Microfossils and plant seeds were abundant in that stage, C, N and stable elements were high in content in the sediments, while Rb/Sr, Ba/Sr, and Ti/Sr were in a steady low value, indicating a wetter fresh or brackish lake environment.

[16] Additionally, it should be mentioned that humid climate in the Middle Ages were also registered by a 2326-year tree ring data of *Sabina przewalskii* for Dulan area in western China [*Zhang et al.*, 2003] and that historical records in Xinjiang (The Historical Book of Song written by Shen Yue) show the occurrences of snow disasters in the first year of Yonglong Period (1020 aBP) and rainstorms and floods in Gaochang (i.e. Turpan in Xinjiang) in the third year of Kaibao period of the North Song Dynasty (980 aBP).

[17] From the above evidences, we conclude that during the MWP (from the middle of the Tang Dynasty to the middle of Yuan Dynasty), the climate was humid in the north of Xinjiang. *Chen et al.* [2006] examined the pollen and carbonate content of sediments from Bosten Lake and concluded that the MWP was warm and dry in south of Xinjiang, which is different from the above conclusion. *Yang et al.* [2003] used proxy palaeoclimate data, like ice-cores, peat-cellulose, tree-rings, pollen assemblages and sedimentary pigments, to derive a 2000-year temperature history of the northeastern, southern and western sections of the Tibetan Plateau. Result showed that in the case of the northeastern sector of the Plateau, all of the maximum-warmth intervals occurred during the MWP; while in the case of the western sector, they occurred near the end of the Roman Warm Period; and in the case of the southern sector they occurred during both warm periods. Therefore, the MWP was manifest differently in different parts of China especially in the Tibetan Plateau and Xinjiang, and the climate varied in time and space during the period. Maybe the sample resolution and the interpretation to different sediment records account for the difference.

[18] **Acknowledgments.** This research was jointly funded by the National Natural Science Foundation of China (NSFC grants 40601104, 30590383 and 90102009), the Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry and the innovation project of the Chinese Academy of Sciences (CAS grant KZCX1-10-05). We thank the reviewers for their comments that help improve the manuscript.

References

Chen, F. H., X. Z. Huang, J. W. Zhang, J. A. Holmes, and J. H. Chen (2006), Humid little Ice Age in arid central Asia documented by Bosten Lake, Xinjiang, China, *Sci. China Ser. D*, *49*, 1280–1290.
Chen, F. H., J. Holmes, B. Wünnemann, and Z. C. Yu (2009), Holocene climate variability in arid Asia: Nature and mechanisms, *Quat. Int.*, *194*, 1–5.
Chen, J. A., G. J. Wan, D. D. Zhang, F. Zhang, and R. G. Huang (2004), Environmental records of lacustrine sediments in different time scales: Sediment grain size as an example, *Sci. China Ser. D*, *47*, 954–960.
Hong, Y. T., H. B. Jiang, T. S. Liu, L. P. Zhou, J. Beer, H. D. Li, X. T. Leng, B. Hong, and X. G. Qin (2000), Response of climate to solar forcing recorded in a 6000-year δ^{18}O time-series of Chinese peat cellulose, *Holocene*, *10*, 1–7.
Lamb, H. H. (1965), The early medieval warm epoch and its sequel, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, *1*, 13–37.
Lu, H. Y., N. Q. Wu, and T. S. Liu (1996), Seasonal climatic variation recorded by phytolith assemblages from Baoji loess sequence in central China over the last 150000a, *Sci. China Ser. D*, *26*, 629–639.
Ma, C. M., F. B. Wang, Q. Y. Cao, X. C. Xia, S. F. Li, and X. S. Li (2008), Climate and environment reconstruction during the Medieval Warm Period in Lop Nur of Xinjiang, China, *Chin. Sci. Bull.*, *53*, 3016–3027.
Shi, Y. F., T. D. Yao, and B. Yang (1999), Decadal climatic variations recorded in Guliya ice core and comparison with the historical documentary data from east China during the last 2000 years, *Sci. China Ser. D*, *42*, 91–100.
Shi, Y. F., Y. P. Shen, E. Kang, D. L. Li, Y. J. Ding, G. W. Zhang, and R. J. Hu (2007), Recent and future climate change in northwest China, *Clim. Change*, *80*, 379–393.
Stuiver, M., P. J. Reimer, E. Bard, J. W. Beck, G. S. Burr, K. A. Hughen, B. Kromer, G. McCormac, J. van der Plicht, and M. Spurk (1998), INTCAL98 radiocarbon age calibration, 24,000–0 cal BP, *Radiocarbon*, *40, 1041–1083.*
Yan, S., and Y. P. Kan (1993), Human activities and environmental changes during the history periods in Jimsar region (in Chinese with English abstract), *Geogr. Symp. Arid Zone*, *3*, 162–175.
Yan, S., G. J. Mu, H. Nobuhiko, U. Masao, and H. Naomi (2003), Environmental evolution information from Aiby Lake since the last 2500a (in Chinese with English abstract), *Arid Land Geogr.*, *26*, 227–232.
Yan, S., S. F. Li, Z. C. Kong, Z. J. Yang, and J. Ni (2004), The pollen analyses and environment changes of the Dongdaohaizi area in Urumqi (in Chinese with English abstract), *Quat. Sci.*, *24*, 463–468.
Yang, B., A. Bräuning, and Y. F. Shi (2003), Late Holocene temperature fluctuations on the Tibetan Plateau, *Quat. Sci. Rev.*, *22*, 2335–2344.
Yang, B., J. S. Wang, A. Bräuning, and E. Jan (2009), Late Holocene climatic and environmental changes in arid central Asia, *Quat. Int.*, *194*, 68–78.
Zhang, D. E. (1994), Evidence for the existence of the Medieval Warm Period in China, *Clim. Change*, *26*, 289–297.
Zhang, P. Z., et al. (2008), A test of climate, sun, and culture relationships from an 1810-year Chinese cave record, *Science*, *322*, 940–942.
Zhang, Q. B., G. D. Cheng, T. D. Yao, X. C. Kang, and J. G. Huang (2003), A 2,326-year tree-ring record of climate variability on the northeastern Qinghai-Tibetan Plateau, *Geophys. Res. Lett.*, *30*(14), 1739, doi:10.1029/2003GL017425.
Zhang, Y., Z. C. Kong, Z. J. Yang, S. Yan, and J. Ni (2004a), Vegetation changes and environmental evolution in the Urumqi River Head, central Tianshan Mountains since 3.6 ka B. P.: A case study of Daxigou profile, *Acta Bot. Sin.*, *46*, 655–667.
Zhang, Y., Z. C. Kong, S. Yan, Z. J. Yang, and J. Ni (2004b), ''Medieval Warm Period'' in Xinjiang-rediscussion on paleoenvironment of the Sichanghu profile in Gurbantunggut Desert (in Chinese with English abstract), *Quat. Sci.*, *24*, 701–708.
Zhang, Y., Z. C. Kong, J. Ni, S. Yan, and Z. J. Yang (2008), Pollen record and environmental evolution of Caotanhu wetland in Xinjiang since 4550 cal. a BP, *Chin. Sci. Bull.*, *53*, 1049–1061.

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