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Humification degree of peat and its implications for Holocene climate change in Hani peatland, Northeast China

HUANG Ting[1], CHENG Shenggao[1*], MAO Xumei[1], HONG Bing[2], HU Zhongxia[1], and ZHOU Ying[1]
[1] *School of Environment Studies, China University of Geosciences, Wuhan 430074, China*
[2] *State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002, China*
[*] *Corresponding author, E-mail: chengsg@cug.edu.cn*

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Abstract The humification degree of peat is a significant climatic proxy for paleoclimate change. Using the alkali-extraction method, a time series of absorbance values of the Hani peatland, Northeast China, was determined, which is used as an indicator for the humification degree of peat. Combined with ^{14}C dating data of peat cellulose, and compared with $\delta^{18}O$ and $\delta^{13}C$ time series of the cellulose in the Hani peatland, the evidence for the existence of 14 ka paleoclimate was provided. Higher humification degrees hint a warmer-wetter climate, and vice versa. It also reconstructs the four stages of Holocene climate evolution in this region: 11.5–9.8 cal ka B.P., warm and wet period; 9.8–9.0 cal ka B.P., cold and dry period; 9.0–4.8 cal ka B.P., warm and wet period; and 4.8–0 cal ka B.P., warm-wet and dry-cold alternation period. Meanwhile, it is revealed that the abrupt climate shifts signals such as the "8.2 ka" event and the "4.2 ka" event. Results showed that the Hani peat humification degree is of sensitive response to paleoclimate change. Therefore, it is a feasible method to analyze the relationship between paleoclimate change and peat humification degree.

Key words humification degree; Holocene; climate change; Hani peatland

1 Introduction

Peatland was normally formed in the Quaternary, especially in the Holocene. Since the formation of peat is mainly controlled by climate condition, peat deposition contains lots of palaeoclimatical and palaeoenvironmental information. In recent decades, a number of studies have reconstructed paleoenvironmental and paleoclimatic histories of peat by using pollen, plant macrofossils and the stable carbon and oxygen isotopic compositions of plant cellulose (Barber et al., 1994; Hong Yetang et al., 2001; Zhou Weijian et al., 2004; Xu Hai et al., 2006; Schröder et al., 2007), as well as other proxies such as testate amoebae (Charman, 2001) and biomarkers (Xie Shucheng et al., 2004; Zhou Weijian et al., 2005; Zheng Yanhong et al., 2007). Humification degree is used to describe the degree of decomposition of plant remains, which is an important proxy indicator for past climatic change since the process of plant decomposition has a close relation to the climatic conditions including temperature and humidity. A series of studies on proxy indicator from peat for past climatic change shows that humification degree has a close relationship to wetness of the peat-surface (Aaby and Tauber, 1975; Chambers, 1982; Blackford and Chambers, 1991; Chambers et al., 1997), and local reconstructions of peat-surface wetness can provide very useful information on past climatic change (Blackford and Chambers, 1993). Chinese scholars believe that humification degrees can response the variations of climate temperature and humidity (Wang Hua et al., 2004; Wang Hua et al., 2010)

Northeast China is a sensitive zone to climate change. Holocene peat mires and lakes are widely distributed in this region, with the advantages of rapid accumulation rates and continuous sedimentation. Lots of achievements have been obtained by using different climatic proxies from peat. For example, the stable carbon and oxygen isotopic compositions of plant cellulose (Hong Yetang et al., 2005, 2009) and the molecular and hydrogen isotopic compositions of lipid biomarkers (Seki et al., 2009; Zhou Weijian et al., 2010) have been examined in the Hani peat deposit from Northeast China to reconstruct the paleoclimatic history for the last 16 ka. However, scholars have paid little attention to peat humification degree of the Hani peatland, and a few of them analyzed the relationship between climate change and time sequence of humification degrees, so this paper attempts to explore the paleoclimate evolution in terms of the humification degree of peat.

2 Study region

The Hani peatland (42°13′N, 126°31′E) is situated at Hani Village, Liuhe County, Jilin Province, Northeast China, with an altitude of about 900 m (Fig. 1). This peatland was developed from the Holocene, with the maximum thickness of 9.6 m (Qiao Shiying, 1993). It is the largest peat deposit in Northeast China. Genetically, this peatland is a typical lava-dammed lake. In this area there preveals a continental humid climate, with windy dry spring, short cool summer, mild cool autumn and long cold winter. The annual average temperature is 4.1℃, with the highest annual average temperature of 5.1℃ and the lowest annual average temperature of 3.1℃. The monthly average temperatures vary between −18℃ and 22℃ from January to July. The average annual precipitation is 743.3 mm, mostly concentrated in summer, which thus provided an adequate volume of water for the formation of peatland.

3 Materials and method

The sampling site is near the center of the Hani peatland with the drill core being as deep as 900 cm. Modern grassroot layer with a thickness of 20 cm was removed, and the rest was divided into 5 cm intervals and consigned to the laboratory at Wuhan City. Stratigraphically, the peat core was divided into 10 layers based on different compositions and colors (Fig. 2). From top to bottom, these layers are described as follows: grass root layer, light brown peat layer, brown peat layer, dark brown peat layer, light brown layer, dark brown layer, dark brown layer containing tephra, dark brown peat layer, black brown layer and greenish-gray clay peat. Variations in the stratigraphy of the core shown in Fig. 2 suggested that changes in local climate would affect peat accumulation in the mire (Schröder et al., 2007; Hong Yetang et al., 2009; Seki et al., 2009).

The chronology of the peat core was studied by ^{14}C accelerator mass spectrometry (AMS), and the preparation of samples was conducted according to Hong Bing et al. (2009). As the material for dating, 13 plant cellulose sub-samples were collected from the peat core and measured at the AMS Laboratory of the National Institute for Environmental Studies in Tsukuba, Japan. By using CALIB 4.3 software (Stuiver and Reimer, 1993) for calibration, the chronology data of the sequence from the Hani peatland was obtained.

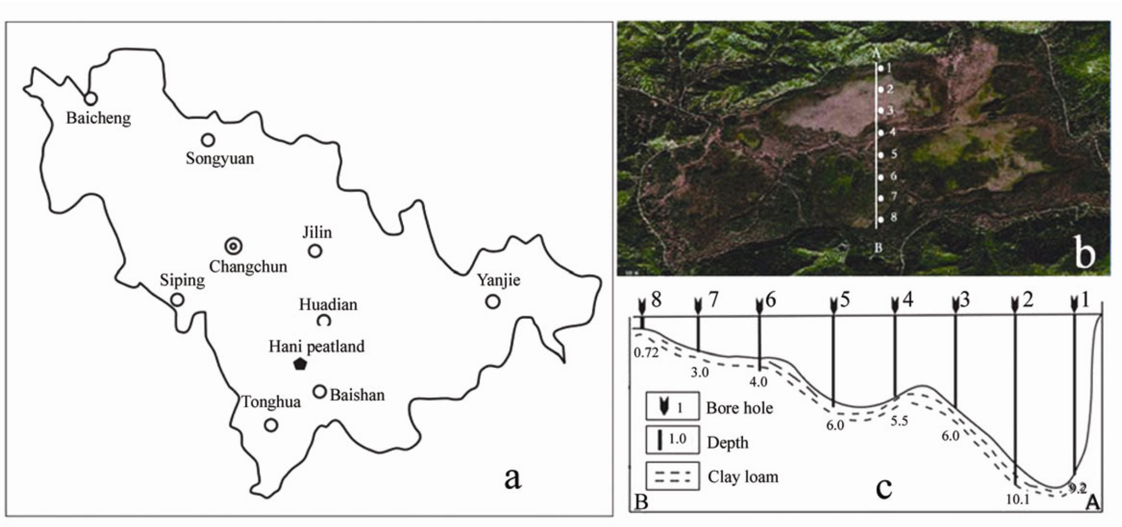

Fig. 1. Location of the Hani peatland. a. The map of Jilin Province showing the location of the Hani peatland; b. the remote sensing image of the Hani peatland; c. geological section of the Hani peatland (profile of the white line in b).

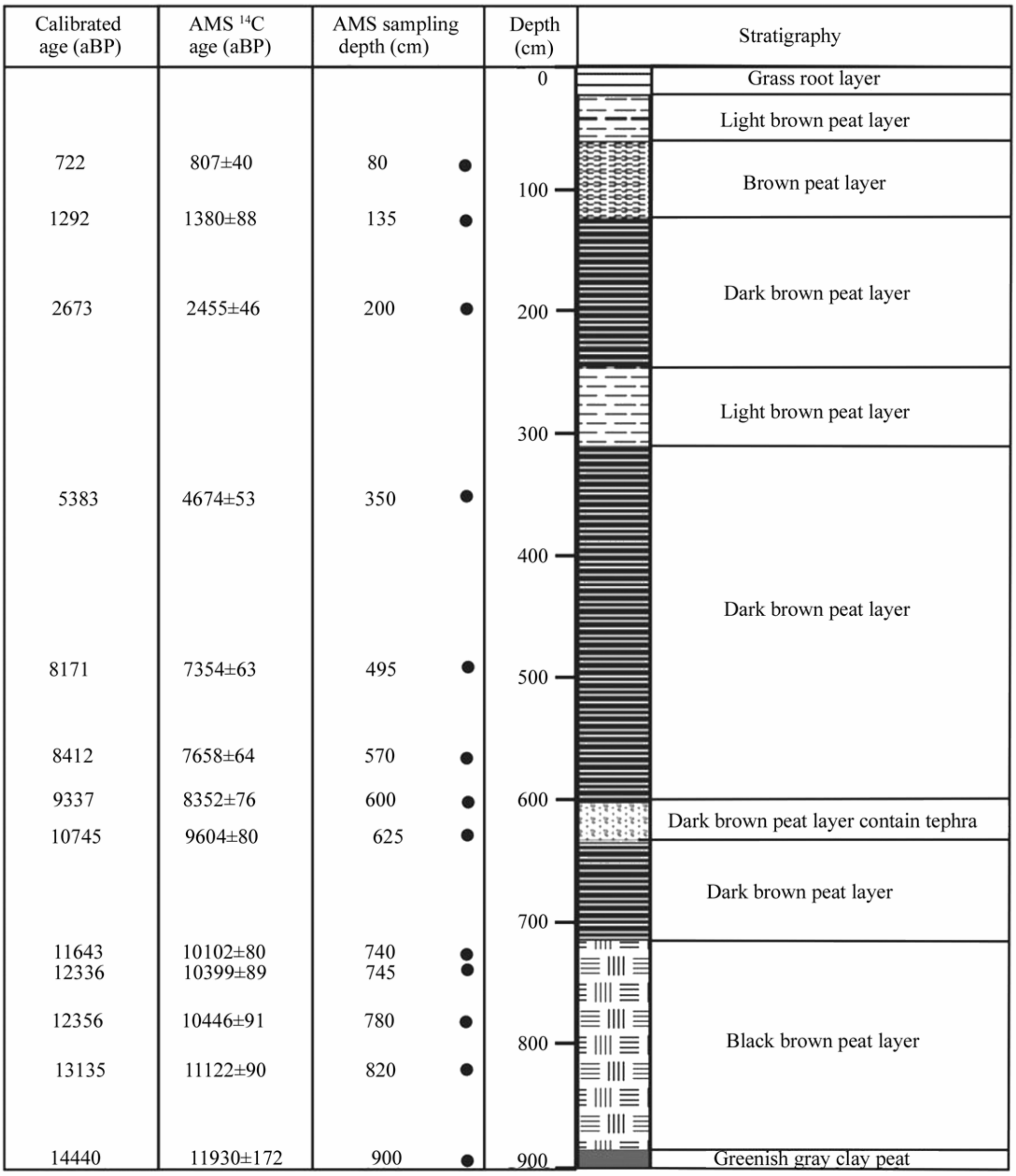

Fig. 2. Stratigraphy and ^{14}C- age data of the peat core from the Hani peatland.

By using the alkali-extraction method (Blackford and Chambers, 1993), the humification degree of Hani peat sample was determined. The details are presented as follows. After cooling and drying as the pretreatment, the peat sample was ground by means of an agate mortar, and sieved through a 60-mesh screen and mixed uniformly; 0.2000 g peat sub-sample was weighed and put into a 250 mL beaker; the prepared fresh 100 mL of 0.1 mol/L sodium hydroxide solution was added into the beaker and then heated at 100℃ for one hour in order to fully extract humic acid (200 mL). Then, the solution was moved into a 250 mL volumetric flask after cooling, and distilled water was added to the total volume of 250 mL; 10 mL of solution was then taken and put into centrifuge tubes and centrifuged for 20 minutes at a speed of 2500 rpm; 5 mL of suspension was extracted into the 10 mL colorimetric tube and diluted to the graduation, shaken well and tested on a Shimadzu UV-VIS-3000-type spectrometer with a wave length of 540 nm. Absorbance values can be determined, with distilled water as the blank. These absorbance values obtained were used to express humification degrees of peat.

4 Results

4.1 Palaeoclimatic significance of humification degree of the Hani peat

The formation of peat is the result of interactions among various kinds of natural factors such as water, temperature, geography, landform, vegetation and so on. Among these factors, water and temperature are two most important factors. Moisture and heat directly affect type, growth, development of marsh plant, the amount of microbial decomposition and decomposition intensity. It also can affect the accumulation of peat. Peat humification degree has been used to quantitatively characterize the degree of peat decomposition, and its effecting factors contain microbial activity, hydrothermal condition, soil pH and plant type (Chai Xiu, 1993). Scholars believe that warm and humid climatic conditions, on one hand, can promote plant primary productivity, and, on the other hand, can enhance the microbial decomposition ability. The two aspects of the comprehensive effect will increase peat humification. On the contrary, cold and dry climatic conditions can weaken the primary productivity of plant but reduce the microbial decomposition, which would cause the reduction of peat humification. Therefore, peat humification degree reflects the comprehensive influence of humic decomposition, and indirectly reflects the impact of water and heat conditions (Wang Hua et al., 2004, 2010).

As shown in Fig. 3a, the time series of absorbance values record proximately 14 ka paleoclimate information. In order to explain paleoclimate changes implied by humification degrees, we compare (Fig. 3a) the $\delta^{18}O$ temperature time series (Fig. 3b) with the $\delta^{13}C$ time series (Fig. 3c) of Hani peat cellulose. The results showed that the time series of Hani peat humification degrees has the same changing trend with the $\delta^{18}O$ temperature time series, but shows an opposite changing trend with respect to the $\delta^{13}C$ time series.

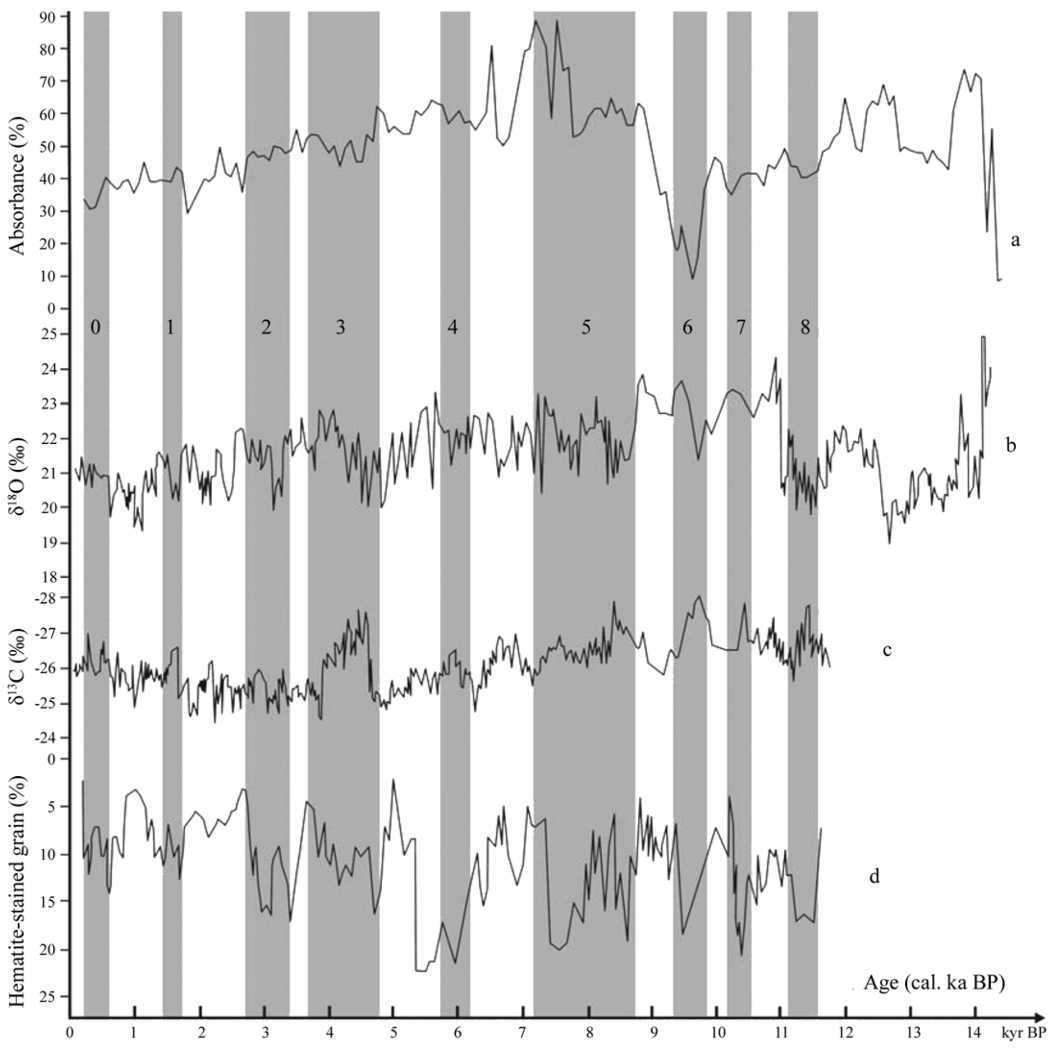

Fig. 3. Comparison of climate variations between the Hani peatland and the climate change of the North Atlantic Ocean. a. The time series of Hani peat humification degrees; b. the $\delta^{13}C$ time series of the plant remain cellulose in the Hani peatland (Hong Yetang et al., 2005); c. the $\delta^{18}O$ temperature proxy record of Hani peat cellulose (Hong Bing et al., 2009; Hong Yetang et al., 2009); d. the Holocene record of drift ice for MC52-VM29-191 core in the North Atlantic Ocean (Bond et al., 2001). Numbers from 1 to 8 indicate eight IRD events of the North Atlantic Ocean (Bond et al., 2001). Number 0 indicates the "Little Ice Age" event (Bond et al., 2001). Gray bands trace the comparison of the variation trends between humification degree and other climatic proxies.

It has been confirmed that the $\delta^{18}O$ temperature time series of Hani peat cellulose can sensitively indicate changes in both climate and land surface temperature. The larger the $\delta^{18}O$ value is, the warmer the climate will be, and vice versa (Hong Bing et al., 2009; Hong Yetang et al., 2009). Previous studies confirmed that the stable carbon isotopic composition of peat plant cellulose can be served as a proxy indicator for the past climate change, and the higher the $\delta^{13}C$ of peat cellulose is, the smaller the soil moisture or precipitation will be, and vice versa (Hong Yetang et al., 2001). Based on the comparison, the climatological significance of Hani peat humification degree can be explored; higher humification degree values of the Hani peat reflect a warmer-wetter climate, while lower values reflect a colder-drier climate.

4.2 Holocene climate evolution of the Hani peatland

The time series of peat humification degrees of the Hani peatland (Fig. 3a) records about 14 ka change of climate, and provides a continuous proxy record from the last deglaciation through the Holocene. This paper focuses on climate change in the Holocene, which is about 11.5 ka B.P. The comparison between peat humification degrees and other climate proxies such as $\delta^{18}O$ time series (Fig. 3b) and $\delta^{13}C$ (Fig. 3c) time series of the Hani peatland shows that the climate evolution of Hani has involved the following stages.

4.2.1 Warm and wet period (11.5–9.8 cal ka BP) (Fig. 3a)

During this period, the values of peat humification degree fluctuated over a small range. After the 11.5 cal ka B.P., the values started to increase, corresponding to the beginning of the Holocene. It is commonly thought that the Holocene started from a warming process. Combined with the $\delta^{18}O$ curves of the Hani peat, at about 11.6 cal. ka B.P., the Hani $\delta^{18}O$ increased again suddenly after a short decrease following the end of the YD event, and at about 11.3 ka B.P. the $\delta^{18}O$ increased gradually and lasted till 9.8 ka B.P. (Fig. 3b) (Hong Bing et al., 2009). The $\delta^{13}C$ suddenly dropped to the valley from a peak, then began to rise. Around 10.3 ka B.P., the value reached a peak (Fig. 3c). Research on pollen record informed that during 11.4–8.3 cal ka B.P. the pollen concentrations in Gushan Tun peat profiles increased, which implies that the climate became warm and the temperature increased (Liu Jinling, 1989).

4.2.2 Dry and cold period (9.8–9.0 cal ka B.P.)

During the period from about 9.8 to 9.0 cal. ka B.P., the humification degree of peat was kept at a lower level, although there were fluctuations. It is during this time period that the $\delta^{18}O$ values of cellulose obviously decreased, which indicates cold climate conditions in this period. The $\delta^{13}C$ values increased significantly during this period, reflecting drier climate conditions.

4.2.3 Warm and wet period (9.0–4.8 cal ka B.P.)

This period is called the Holocene Megathermal, which refers to a warm period roughly at the interval from 9.0 to 5.0 cal ka B.P., and different regions may have experienced different ages. It has been suggested that the Holocene Megathermal is around 8.5–3.0 ka B.P. in the Chinese mainland (Shi Yafeng and Kong Zhaogu, 1992). Peat humification degree fluctuated greatly around 8.0 cal ka B.P. with two peaks, indicating the warmest period in the Holocene. Subsequently, the values suddenly decreased, but the minimum value was still higher than the average values of other periods. Based on the variation trend of average values of Hani ($\delta^{18}O$ was about 21‰), the Holocene Megathermal is at about 11–3 cal. ka B.P., generally in accord with the climate status reflected by the Jinchuan pollen record, and the Jinchuan peat record of Jilin in the northeast of China is at about 10–3 cal ka B.P. (Hong Yetang et al., 1997). The curve of humification degree versus time during this period can be broadly divided into three intervals: dramatic change during 8.2–6.5 cal ka B.P., indicating a climate change from warm to cold in or from wet to dry; a smooth curve occurred between 6.5 ka B.P. and 5.3 cal ka B.P., with a slight evaporation generally reflecting a relatively stable warm and humid climate with a high humification degree; a rough curve appeared during 5.3–4.8 cal ka B.P., with significantly decreasing humification degree, indicating a dry and cold climate period.

4.2.4 Dry-cold and warm-wet alternation period (4.8–0 cal ka B.P.)

Around 4.5 cal. ka B.P., there were two low peaks of humification degree, then the values began to rise for quite a long period of time, and then decreased. Around 1.8 cal ka B.P., there was a low peak on the humification degree curve, and then the values started to increase. At the same period, the $\delta^{18}O$ time series displayed similar fluctuations. These results show that the climatic condition of this region is in a dry-cold and warm-wet alternation state. The 5.0 ka $\delta^{18}O$ time series of the Jinchuan peatland recorded four periods during dry-cold and warm-wet alternations: ancient low-temperature fluctuation period, warm climate period, cold climate period, and modern warming period (Hong Yetang et al., 1997).

4.3 Response to abrupt climate shifts

Evidence from the Greenland ice cores indicated the stability of Holocene climate and instability of glacial climate, including the abrupt shift from the late glacial period to the postglacial period (Anklin et al., 1993). Relative to the ice age, the Holocene climate was warm. Therefore, study on the Holocene cooling event is an important aspect of abrupt climate change. Comparison between peat humification degree (Fig. 3a) and climate change of the North Atlantic Ocean (Fig. 3d) shows that the Holocene abrupt climate change presented very clearly in the North Atlantic Ocean. Dye hematite displayed 8 to 9 cold events during the Holocene, which happened at 0.4–0.6, 1.4, 2.8, 4.3, 5.9, 8.2, 9.5, 10.3 and 11.1 ka, respectively, as numbers 0–8 from left to right in the gray part in Fig. 3. The climate proxies of the Hani peatland including humification degree, $\delta^{18}O$ and $\delta^{13}C$ sequences, completely recorded the Holocene climate and environmental evolution, including the Holocene abrupt climate change events, especially the "8.2 ka" event and the "4.2 ka" event.

The "4.2 ka" event represents the strongest abrupt climate change which occurred in the Late Neolithic period since the Mid-Holocene 5 ka. The strong change of $\delta^{13}C$ sequence can be seen in Fig. 3c. $\delta^{13}C$ values suddenly became larger during 4.2–4.8 ka, indicating that the climate became dry; the $\delta^{18}O$ values showed a constant change during 4.0–5.0 ka, with a sharp decline at about 4.3 ka. The strongest performance indicated that the climate was getting colder. The Hani peat humification degree fluctuated abnormally during this period, and there were two troughs for about 300 a. The above information shows that the Hani peatland strongly responses to the "4.2 ka" event.

The "8.2 ka" event is a temperature anomaly in the Early Holocene, and it is one of the most noticeable temperature anomalies in the Holocene. The sensitive Hani humification degree record provides an opportunity for slow evaluation of the "8.2 ka" event in the Western Pacific region. Figure 3a shows a broad humification degree peak at about 7.8–8.3 cal. ka B.P., implying that during this period the climate was cold. From Fig. 3b, it can be seen that at about 8.3 cal. ka B.P. there was a broad $\delta^{18}O$ peak. In addition, some concentrated areas of lower $\delta^{18}O$ values or a small sharp peak at around 8.2 cal. ka BP on the Hani $\delta^{18}O$ curve can be found (Hong Bing et al., 2009). It is concluded that the broad Hani humification degree and $\delta^{18}O$ peak at around 7.8–8.3 cal. ka B.P. genuinely reflect cold climate signals, and the signals provide paleotemperature evidence for the existence of the sharp "8.2 ka" event in the Western North Pacific region.

5 Conclusions

Peat is a spongy deposit that consists of organic matter with varying degrees of decomposition, humus and mineral matter. The main component in peat is plant organic matter, which accounts for more than 30% in general (Chai Xiu, 1993). The time sequence of Hani peat humification degrees is a proxy indicator of paleoclimatic change, in which a higher humification degree corresponds to a wetter-warmer climate, and a lower humification degree corresponds to a drier-colder climate. Compared with $\delta^{18}O$ and $\delta^{13}C$ time series of the cellulose in the peat, the Holocene paleoclimatic condition in Hani was reconstructed. As an important carrier of information, the Hani peat humification degree also records signals of abrupt climate shifts in the Holocene, including the "8.2 ka" event and the "4.2 ka" event. Therefore, it is a feasible method to analyze the relationship between peat humification degree and paleoclimate change. It is significant for further exploration on the response of regional climate change to global change.

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