

# EVIDENCE FOR ABRUPT CLIMATIC CHANGES ON NORTHWESTERN MARGIN OF EAST ASIAN MONSOON REGION DURING LAST DEGLACIATION

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**ABSTRACT:** Based on investigations of the Zhongwei Nanshan aeolian section situated in the southeastern margin of Tengger Desert, carbon-14 and TL (thermoluminescence) dating results and paleoclimatic proxies such as magnetic susceptibility and grain size, we inferred that the northwestern margin of East Asian monsoon region experienced abrupt climatic changes during the last deglaciation. Six oscillation events were identified: Oldest Dryas, Bølling, Older Dryas, Allerød, Intra-Allerød Cold Period (IACP) and Younger Dryas (YD). The summer monsoon was weaker during Oldest Dryas and Younger Dryas when the winter monsoon was stronger. However, during the B/A (Bølling/Allerød) period, the summer monsoon strengthened, reflected by magnetic susceptibility, when the winter monsoon also became strong, which is different from the paleoclimatic pattern established in the East Asian monsoon region. Furthermore, the summer monsoon was nearly in phase with the climate changes inferred from the oxygen isotopic records of Greenland ice cores. It could be speculated that the variations of the sea ice cover in the high latitudes of the North Hemisphere affected the high pressure of Asian continent and the changes of the winter monsoon inland. On the other hand, the sea ice cover variations might have indirectly caused the occurrence of ENSO events that has tightly been related to the summer monsoon in northwest margin of East Asian monsoon region.

**KEY WORDS:** last deglaciation; East Asian monsoon; abrupt climatic changes

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## 1 INTRODUCTION

The last deglaciation is a special period from the last glacial age to the Holocene when the climate experienced a series of abrupt climatic oscillations on centennial to millennium timescale according to the records from the deep sea sediments in north Atlantic (KAPUZ and JANSEN, 1992) and the ice cores in Greenland (JONSEN *et al.*, 1992). The last deglaciation took place between 15.07–11.65ka B. P. by ice layer count dating (STUIVER *et al.*, 1995). The  $\delta^{18}\text{O}$  variations from Greenland showed that the amplitude of temperature change was  $\sim 7^\circ\text{C}$  from the warm periods to the cold ones during the stage (JONSEN *et al.*, 1992). However, few reports on the climatic changes in East Asian monsoon region in this stage were presented. ZHOU Wei-jian *et al.* (1997) reconstructed the high-resolution climatic change history of the last

deglaciation by drawing loess-paleosol and peat sections, and compared the results with the climate events occurred in the Norway Sea. They considered that the climate of East Asian monsoon has a teleconnection with that of the north polar and the high latitude regions during the last deglaciation. The westerly belt and its corresponding atmospheric pressure system have played important roles in the process of teleconnection. Moreover, they emphasized that the rainfall of East Asian monsoon was controlled by the position of the monsoon front belt during the last deglaciation. However, WANG Jian-min *et al.* (1998) found a different scenario. The records derived from the Caoxian loess section showed that the winter monsoon variations coincided with the changes of  $\delta^{18}\text{O}$  from Greenland ice cores in GISP2, but the summer monsoon has no distinct connection with the changes in the last deglaciation. The relationship between the East Asian

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monsoon and the climate of high latitude region remains unclear, and the paleoclimatic information of the last deglaciation from different records in this region is inconsistent. Hence, we systemically investigated a loess-paleosol-sandy silt profile located in the south-eastern margin of Tengger Desert, and established the possible relationship between the changes of the East Asian monsoon and the variations of sea ice cover over the last deglaciation.

## 2 MATERIAL AND METHODS

The southeastern margin of Tengger Desert lies in the northwestern margin of East Asian monsoon region (GAO *et al.*, 1993). The climate in the region is very sensitive to the global changes (YE, 1992). The Zhongwei Nanshan section ( $37^{\circ}22'N$ ,  $105^{\circ}15'E$ ) is located beside the right of Zhong-Xing road (from Zhongwei to Xingrenbao) at the secondary terrace of Xiangshan Mountain (Fig. 1), 24.5km south to Zhongwei County seat. By investigating the outcropping section at alluvial gullies, it is found that there are 3 ubiquitous aeolian layers on the terrace. The aeolian deposition sequence includes Malan loess layer, Sandy silt layer and Holocene loess (interbedded with paleosol), which form a continuous sequence of 11.9m in thickness. From the top to bottom of the section, the lithofacies characteristics are listed in Table 1.

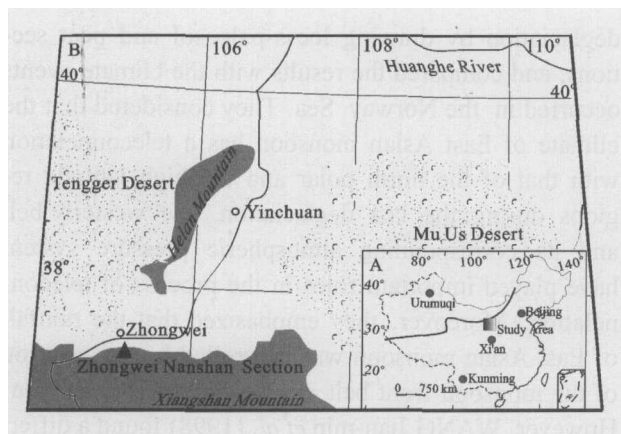


Fig.1 Locations of study area and Zhongwei Nanshan section (The solid line in Fig. A indicates the location of the maximum of precipitation front in the East Asian monsoon region in August) (WEI and GASSE, 1999)

The sandy silt in Zhongwei Nanshan section deposited 270cm in thickness during the last deglaciation. The proxy of magnetic susceptibility (MS) was measured in situ at 2cm interval and its resolution is about 30 years. The samples for grain size analyses were col-

Table 1 Lithofacies characteristics of Zhongwei Nanshan section

Sequence	Lithofacies	Thickness(cm)
Holocene loess	Brown-yellow, abundant roots, big holes	90
Paleosol	Yellow-brown, artificial mycelium	40
Holocene loess	Brown-yellow, abundant roots, big holes	30
Sandy silt layer	Gray-yellow, loose, uniform lithology	550
Malan loess	Primrose yellow, hard and tight	480

lected at 10cm interval with resolution of ~150 years and analyzed by the sieving and pipette method.

## 3 RESULTS

### 3.1 Chronology

TL dating shows the ages of the top and bottom of the sandy silt layers are  $11.4 \pm 0.8$ ka B. P. and  $19.12 \pm 1.4$ ka B. P., respectively (Fig. 2). The  $^{14}C$  age of the bottom of the Holocene loess is  $10.78 \pm 0.13$ ka B. P., and its corresponding calendar age is 12.8ka B. P. The material for  $^{14}C$  dating was the total organic matter in the bottom of the Holocene loess. Since the aeolian deposits always have the complicated origin of organic carbon, the  $^{14}C$  age will be affected by "old carbon" and tend to be older than the real age. Therefore, the ages of sandy silt layer in the section will be determined by TL dating method with  $^{14}C$  age as a supplement chronological proof. The TL age of the top sandy silt deposit approximates to the age of Younger Dryas (YD) event recorded by GISP2 ice core. The YD events terminated in 11.65ka B. P. (ice layer count age) recorded by GISP2 ice cores (STUIVER *et al.*, 1995). The sandy silt deposited during the last glacial maximum (LGM). During this period, the Tengger Desert invaded southeasterly to certain extent, and the source area of the deposits was closer to the section site than ever (QIANG *et al.*, 2000). In addition, the landscape in the southeastern margin of Tengger Desert was the typical arid desert at that time. The lithology of sandy silt layer had generally no change over the last glacial maximum. We can reach that the rate of sandy silt deposition might have little variation. Therefore, the beginning age of the oldest Dryas event can be obtained by linear interpolation method. It is 15ka B. P. and similar to the corresponding age (15.07ka B. P.) in GISP2 record (STUIVER *et al.*, 1995). According to the two ages of  $11.4 \pm 0.8$ ka B. P. and 15ka B. P., the occurrence ages of the abrupt climatic changes events recorded by the Zhongwei Nanshan section can be obtained by using the linear interpolation method. For example, the B/A (Bølling/Allerød) warmer event oc-

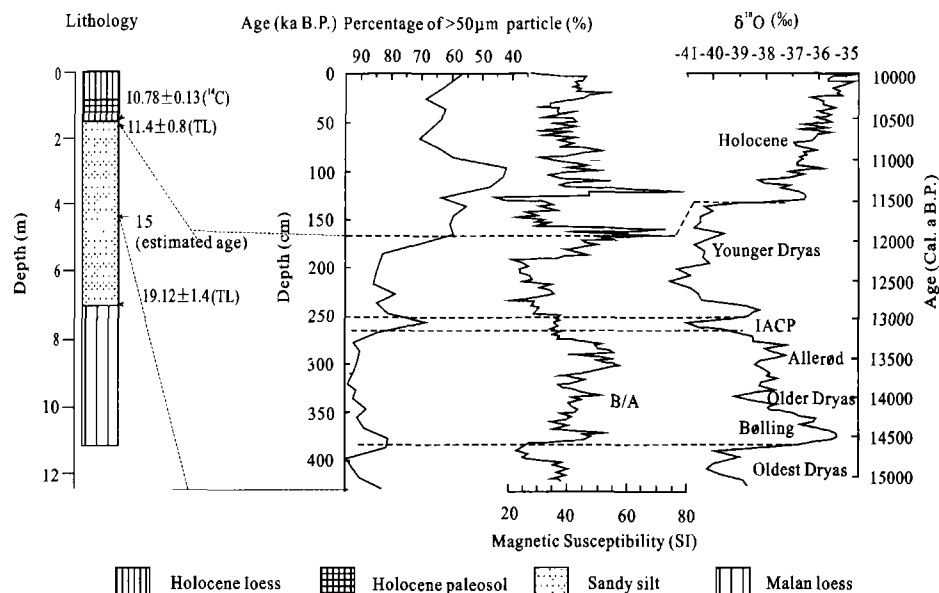


Fig. 2 Lithofacies of Zhongwei Nanshan section and comparison between the curves of magnetic susceptibility and grain size (>50 $\mu\text{m}$ ) of Zhongwei Nanshan section and the  $\delta^{18}\text{O}$  curve of GISP2 (STUIVER *et al.*, 1995) during the last deglaciation

curred between 14.40–12.87ka B. P. and the YD period was 12.64–11.4ka B. P. The ages of these events are similar to those recorded by GISP2 ice core (STUIVER *et al.*, 1995), which allow us to compare the two records from the different regions. On the other hand, when taking the well comparability between our curves and the  $\delta^{18}\text{O}$  curve of GISP2 into account, it seems to be reasonable that the last deglaciation in the northwestern margin of East Asian monsoon region occurred between 15–11.4ka B. P.

### 3.2 Reconstruction of Palaeoclimate

Zhongwei Nanshan section has high deposition rates. Therefore, the proxies in this paper have such high resolutions that they can effectively reflect the abrupt climatic events on centennial to millennial timescales during the last deglaciation. Magnetic susceptibility (MS), a summer monsoon proxy, directly indicates the amount of precipitation in the monsoon regions (SUN *et al.*, 1995). The component of grain size can effectively indicate the strength of winter wind field and aridity extent of the dust source area (PORTER and AN, 1995). Particularly, the weight percentage of >20 $\mu\text{m}$  or >50 $\mu\text{m}$  grains is a good indicator for the strength of winter monsoon (CHAPPELL and POLACH, 1991).

The variations of >50 $\mu\text{m}$  grain size and MS show that both the summer monsoon and the winter monsoon increased in the Bølling and Allerød intervals,

and they became weak during Younger Dryas (Fig. 2). The change pattern is not in agreement with the previous work, i.e. weakening winter monsoon always occurs during periods of strong summer monsoon (ZHOU, 1997). The grain size curve also demonstrates that the winter monsoon during B/A interval was stronger than that of YD interval, and the winter monsoon of Oldest Dryas was stronger than that of YD.

The precipitation derived from MS in this region increased during B/A interval, but decreased during the periods of Oldest Dryas, Older Dryas, IACP and YD (Fig. 2). The summer monsoon of Bølling is weaker than that of Allerød. The  $\delta^{18}\text{O}$  values of GISP2 ice core is an effective indicator of the air temperature changes in the high latitude regions of the North Hemisphere. Compared with the  $\delta^{18}\text{O}$  curve of GISP2, the MS curve shows good consistence with it in change amplitude, duration and abruptness, though the proxy of MS indicates the rainfall in the northwestern margin of the East Asian monsoon region. However, the stronger winter monsoon derived from grain size proxy took place during B/A period when the climate in the high latitude regions of the North Hemisphere was optimum during the last deglaciation. It seems to be a puzzle. We infer that there must be a certain relationship between the rainfall changes in the study area and the variations of air temperature in the high latitude region.

#### 4 DISCUSSION AND CONCLUSIONS

The climatic oscillations on centennial to millennial timescales during the last deglaciation might not be directly driven by the solar radiation because the solar radiation was close to its maximum during the YD interval (KUTZBACH and STEET-PERROTT, 1985). These oscillations might result from the interactions among sea, land and atmosphere in the global climatic system. The sea ice cover changes in the high latitude regions of the North Hemisphere were regarded as one of the main forcing factors of climate changes (MAYEWSKI *et al.*, 1994). The rapid variations of sea ice cover and the massive discharges of iceberg played important roles in the radiation balance and the thermohaline circulation of ocean (MAYEWSKI *et al.*, 1994), and could affect the meridional gradient of air temperature and the regional atmospheric circulation (FAWCETT *et al.*, 1997). Generally, abrupt warming in the high latitude regions of the North Hemisphere during the last deglaciation had relations to the formation of NADW (North Atlantic Deep Water) that can promote transportation of the warm sea surface current from tropic sea area northward. For example, the YD cooling might result from reduction of the formation of NADW (LEHMAN and KEIGWIN, 1992). Therefore, we can infer that the sea ice cover must be smaller during the B/A period than that of YD. Modern meteorological data (WU *et al.*, 1999) demonstrates that the increase of sea ice cover in the Kara Sea and the Barents Sea in winter results in the weak winter monsoon in the East Asian monsoon regions, and causes reduction of winter winds cross China in February, vice versa. The grain size of the Zhongwei Nanshan section reflects that the winter monsoon in B/A stage was stronger than that of YD. The results from WU Bing-yi *et al.*, (1999) might provide us an explanation for the winter monsoon changes in the study area. Our results may reflect the regional responses to the atmospheric circulation regulated by the sea ice cover variations on the centennial to millennial timescales in the high latitude regions of the North Hemisphere.

Since the stronger winter monsoon climate occurs when the precipitation decreases in the East Asian monsoon regions, the coincidence between the summer monsoon and the  $\delta^{18}\text{O}$  variations of Greenland ice core may not be interpreted by the displacement of the monsoon front belt (ZHOU *et al.*, 1997). The climatic records from Zhongwei Nanshan section show that both the winter monsoon and the summer monsoon were stronger than ever during the B/A period. Here,

we tentatively explain the relationship between the rainfall changes in the study area and the air temperature changes in the high latitude regions of the North Hemisphere. Lots of inspection studies and modeling studies show that the East Asian monsoon circulation connects tightly with the activities of ENSO events (HUANG and WU, 1989; XU and ZHU, 1999). ZHOU Jie *et al.* (1999) thought that the rainfall oscillations in YD period might be related to the ENSO activities. In fact, the annual timescale change of sea ice cover in the Greenland Sea, the Kara Sea and the Barents Sea can produce the atmospheric circulation anomalies in the North Hemisphere, and cause the circulation abnormality of the teleconnection pattern in Pacific and North America (PNA) (WU *et al.*, 1997). The ENSO events always take place when the rate of sea ice cover variation in winters is of maximum (WU *et al.*, 1997). The strong winter monsoon observed in the Asian monsoon region can also stimulate the occurrence of ENSO event (LI, 1988). HUANG Rong-hui and WU Yi-fang (1989) proved that the ENSO occurrences could result in the rainfall anomalies in East Asian monsoon region. In particular, the study area can obtain more precipitation during the decline stage of ENSO events (HUANG and WU, 1989). The occurrences of ENSO events might be affected by the strong winter monsoon. Furthermore, the stronger winter monsoon is attached to reduction of sea ice cover in the high latitudes. In the study area, the winter monsoon and summer monsoon all increased during the B/A period, which result from the changes of sea ice cover in the high latitude regions of the North Hemisphere.

In summary, the climate changes in the northwestern margin of the East Asian monsoon experienced a series of abrupt oscillations on centennial to millennial timescales during the last deglaciation. The changes of winter and summer monsoons in the study area would all be affected by the variations of sea ice cover in the high latitude regions of the North Hemisphere. They have the connections with the air temperature variations inferred from the  $\delta^{18}\text{O}$  value of GISP2 ice core. The relationship between the two records was established via the atmospheric circulations in the low and high latitude regions or the south and north hemispheres. It is worth noting that our plausible explanation is based on limited records and need to be checked by the more proxy data from other locations. Further work need to be carried out in order to understand the responses of the palaeoclimatic changes in the northwestern margin of East Asian monsoon region to global changes.

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