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Pattern of abrupt climatic fluctuation in the East Asian Monsoon during the Last Glacial: Evidence from Chinese loess records

Enregistrement de fluctuations climatiques abruptes pendant le Dernier Glaciaire : preuve apportée par les archives de loess chinois

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ABSTRACT

Records of two loess sections located in mid-eastern and western margins of the East Asian Monsoon area captured 20 Dansgaard-Oescher events and six Heinrich events. All these suggested that the climate in the East Asian Monsoon area fluctuated rapidly on millennial to century timescales during the whole Last Glacial. We found that these loess-based events of rapid climate fluctuations were generally synchronous with those of GRIP records, but that there were differences between the Shagou loess section in the west and the Wangguan loess section in the east: the former was more sensitive to climate change than the latter. Compared with earlier studies on loess records covering the Last Glacial from neighboring areas, we discovered that the magnitude of Dansgaard-Oeschger cycles decreased gradually from west to east and we suggest that it resulted from the combined effect of the Westerlies and the East Asian Monsoon.

RÉSUMÉ

Deux sections de loess des marges moyenne-orientale et occidentale de l'aire de la mousson est-asiatique ont enregistré 20 évènements Dansgaard-Oescher et six évènements Heinrich. Ils suggèrent tous que le climat de l'aire de la mousson est-asiatique a fluctué rapidement à l'échelle du siècle au millénaire pendant tout le Dernier Glaciaire. Basés sur l'étude de loess, ces évènements de fluctuations rapides du climat se révèlent généralement synchrones des enregistrements GRIP, mais des différences sont observées entre la section loessique de Shagou à l'ouest et celle de Wangguan à l'est : la première a été plus sensible au changement climatique que la seconde. Par comparaison avec des études plus récentes à partir d'enregistrements sur des loess recouvrant le Dernier Glaciaire dans des régions proches, nous avons découvert que la magnitude des cycles Dansgaard-Oeschger décroît graduellement de l'ouest à l'est et nous suggérons que ceci résulte de l'effet combiné des Westerlies et de la mousson sud-asiatique.

1. Introduction

Marine records from the North Atlantic and ice cores of Greenland first promulgated that the last glacial period

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was characterized by a series of abrupt climatic events (e.g. Heinrich and Younger Dryas cold event; Dansgaard-Oeschger warm event) in the Northern Hemisphere high latitude area (Bond et al., 1993; Dansgaard et al., 1993; GRIP, 1993; Heinrich, 1988). Subsequent works revealed that these rapid climatic events may not be restricted to the North Atlantic area, but may have also occurred in other parts of the Northern Hemisphere. These records include ice cores (NGICPM, 2004; Yao et al., 2001), pollen (Benson et al., 1998), loess (Lü et al., 2004; Porter and An, 1995; Ren et al., 1996), stalagmites (Gently et al., 2003; Wang et al., 2001, 2008) and ocean sediments (David et al., 2003; Schulz et al., 1998). Despite the differences in the magnitude and variability from those of the North Atlantic, Heinrich and Dansgaard-Oeschger events (abbreviated as H and DO respectively) were well recorded. The Greenland events have been explained by changing rates of North Atlantic deep water formation, resulting in changing heat transport to the North Atlantic (Broecker, 1994). Wang et al. (2001) suggested that millennial-scale changes in the East Asian Monsoon during the Last Glacial may similarly result from massive and rapid changes in oceanic and atmospheric circulation patterns and may be affected by orbitally induced insolation variations. While it is clear that a rapid climatic shift occurred in the East Asian Monsoon area during the Last Glacial, the relationship it had with the climate transformations in the high or low latitude areas is still not clear. Understanding the driving mechanisms of extreme climatic events on sub-orbital scale strongly depends on comparative investigation of high-resolution paleoclimatic records in various areas of the global climate system.

The Chinese loess deposits provide unique long-term terrestrial records, and rapid climate fluctuations during the Last Glacial have been well documented in loess records (Lü et al., 2004; Porter and An, 1995; Ren et al., 1996). However, the majority of previous loess work covered a geographic area that is limited to the middle part of the Loess Plateau (Porter and An, 1995; Ren et al., 1996). In addition, the temporal resolution in these records is relatively low (Porter and An, 1995; Ren et al., 1996) and this can prevent a reliable reconstruction of abrupt climatic events. High-resolution loess records covering a wide geographic area of the Loess Plateau are greatly needed to verify the evolution of the East Asian Monsoon and assess its role in the climate system of the North Hemisphere during the Last Glacial. Therefore, we take two high-resolution loess records (the Wangguan loess section and the Shagou loess section which are located in mid-eastern and western margins, respectively, of the East Asian Monsoon area) as the research object (Fig. 1), and discuss the questions listed above.

2. Materials and methods

The Wangguan loess section (34°47′N, 111°16′E) is located on the second terrace of the south bank of the Yellow River. Detailed information of this 30-m eolian loess section is given in Guan et al. (2007). The Shagou loess section (37°33′ N, 102°49′ E) is situated on the fifth terrace of the Shagou River to the north of Qilian Mountains (see Pan et al., 2001 for more details). These two sections had thick loess during the Last Glacial: approximately 16 m with a sedimentary rate of 21.52 cm/ka of L1 stratum in the Wangguan loess section, and 28 m with a sedimentary rate of 37.65 cm/ka in the Shagou loess section. Because the L1 strata of both the Shagou and Wangguan sections are each the thickest sections within their neighboring areas, we had not discovered the obvious hiatus in the field. Therefore, we thought that the strata of the Shagou section and Wangguan section were continuous during the Glacial. We collected the samples at intervals of 5 cm for the whole profile in each case, except for the upper 3.35 m in the Shagou loess section L1, which was sampled at 2.5-cm intervals. All samples were gathered simultaneously to achieve good control of dating. Construction of the age models was detailed in Guan et al. (2007). The chronology of the Wangguan and Shagou loess sections were obtained with the Grain Size-Age Model (Porter and An, 1995). The obtained age controlling points are compared with the recent high-resolution stalagmite records of the Last Interglacial in China (Wang et al., 2001; Yuan et al., 2004), as the stalagmite records were precisely dated in a high resolution and were also obtained from the Quaternary sediments in the region of the East Asian Monsoon.

Since the grain size of loess is closely related to the loess-desert boundary shifting as a result of monsoon climate changes, or to the distance from the dust source (Ding et al., 1999; Ren et al., 1996; Yang and Ding, 2008), the expansion or shrinkage of desert during the Interglacial-Glacial cycle would result in the grain size becoming coarser or finer (Liu, 1985; An et al., 1991). Therefore, we can still employ the grain size to indicate the history of the East Asian Winter Monsoon under the present conditions. The median diameter (Md) of grain size has been found to be one of the most reliable winter monsoon proxies (An et al., 1991; Chen et al., 2000; Fang et al., 2002; Lü et al., 2004), so in this study, we use this parameter to track the evolution of the winter monsoon. The chemical components of the loess strata from China were found to respond strongly to palaeoclimatic fluctuations during the Quaternary period (Liu, 1985; Diao and Wen, 1999). Chemical indicators of distribution, migration, enrichment, etc. in the loess strata can be used to reconstruct palaeo-climatologic environments during the times when the loess was forming (Diao and Wen, 1999; Liu, 1985).

All air-dried samples were analyzed for grain size and chemical elements in the Key Laboratory of Western China's Environmental Systems, Lanzhou University. The grain size was measured with Mastersizer 2000 (Malvern Instruments Ltd., UK) with a measurement range of 0.02 to 2000 μm. The treatment procedures are as follows: 0.3 to 0.5 g of each sample is placed into a beaker and H_2O_2 is added. The solution is boiled for 30 min (to remove the organic matter), then diluted hydrochloric acid is added (to remove carbonate). The beaker is then filled with distilled water (making sure not to overflow), and after being left static for 24 h, the superstratum water is pumped away. Sodium hexametaphosphate (used as a dispersant) is added, and the resultant sample surged for 7 to 8 min, then