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The history of palaeoflood and palaeoclimate recorded in the flood deposits of the Kherlen River, Mongolia

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A B S T R A C T

This study examines the 1500-year history of massive floods as recorded in the slackwater deposits of the Kherlen River basin in Mongolia. The study area is located along the Kherlen River in Baganuur district, Ulaanbaatar. Site HL1 has a flood frequency of 89 years and an accumulation rate of 1.2 mm/y over approximately 1500 years. Site HL2 has a flood frequency of 72.2 years and an accumulation rate of 1.46 mm/y during about 700 years. The range of calculated value for flood frequency and annual accumulation rate during the period of the 10th century to the early 20th century at site HL1 is entirely different from that in other periods. It is considered that the palaeohydrological environment of the study site during that time might have been influenced by climatic change as well as geomorphological and hydrological change. Based on the results of identification of discrete flooding and age dating (^{137}Cs and ^{14}C), the sedimentary layers of HL1 and HL2 were divided into 4 periods (period 1: 1960–2012, period 2: 970–1960, period 3: 533–970, period 4: 427–533) and 2 periods (period 1: 1960–2012, period 2: 1290–1960), respectively. The authors suggest that the past climate of the region was greatly influenced by the East Asia summer monsoon. It is suggested that the occurrence of the large-scale floods in eastern Mongolia was influenced by the strengthening and weakening of the summer monsoon due to climate change.

1. Introduction

Research on climate change over the last thousand years in East Asia is mostly based on the investigation of lacustrine sediments using the methods of pollen analysis, dendrochronology, grain size, magnetic susceptibility, stable isotope, TOC and C/N. Studies of flood deposits, which contain hydrological environment records spanning as few as tens of years to as many as a few thousands of years have scarcely been ever conducted (Dean, 1999; Zhang et al., 2003; Henderson and Holmes, 2009; Holmes et al., 2009; Xue et al., 2010; Li et al., 2015; Sun et al., 2016). Slackwater flood deposits refer to fine sand and silt accumulated in areas where the flow rate is reduced during the flood (Baker, 1987). Lacustrine sediments record the successive patterns of change caused by flowing water, while the slackwater deposits are discontinuous records of severe climatic events caused by massive floods. Deposits can be examined and classified by the characteristics of individual flood event from the slackwater deposits which were recorded the abrupt climate phenomenon (Jones et al., 2001; Thorndycraft and Benito, 2006; Zhang et al., 2013).

Palaeoflood hydrology involves the use of geological evidence to reconstruct flood frequency and magnitude for recent, historical, or ancient flood events. The most commonly utilized palaeostage indicators (PSIs) are slackwater flood deposits. These deposits can be applied for the estimation of palaeoflood magnitude and frequency. And to do that, it should be distinguished individual flood events in flood deposits studies. Criteria for distinguishing individual flood events in sedimentary layer are as follows; abrupt vertical grain size variations, organic layers, color changes, buried paleosols, slop colluvium and mudcracks (Baker, 1987). These properties which are indicators of the subaerial exposure indicating the recession of a major flood have been applied in numerous flood studies (Ely, 1997;

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Benito et al., 1998; Greenbaum et al., 2000; Jones et al., 2001; Thorndycraft et al., 2005a; Macklin et al., 2006; Sridhar, 2007; Benito et al., 2010; Huang et al., 2010, 2013; Zielhofer et al., 2010; Dezileau et al., 2014; Zha et al., 2015).

The north limit of the Asian summer monsoon is located in close proximity to the border of Mongolia and China in the direction from southwest to northeast at present, the monsoonal/arid transitional zone is formed around this limit in East Asia (Zhang and Lin, 1992). Especially, this zone is sensitive to climate variations of arid and wet resulting from interactions of monsoon and arid (westerlies) climate systems with different circulation systems (Sun et al., 2009). Most research related to past climate change is carried out intensively on lacustrine sediments from the inner part of China which located on the northern limit of the summer monsoon (Zhang and Lin, 1992; Xiao et al., 2004; Ji et al., 2005; Sun et al., 2009; Zhang et al., 2012a; Jiang et al., 2014). Similarly, it is considered that the inland of Mongolia close to the boundary of north limit has been influenced to some extent by the summer monsoon (Zhang et al., 2012b). According to Zhang et al. (2012b), the results of analyzing the wetting index from the oxygen and carbon isotopes show that the limit of summer monsoon during 1968–1978 was moved more northwest (in the direction of the inland area of Mongolia) than the limit of summer monsoon during 1979–1998. The results of various studies on climate change of the past millennium in China and Mongolia (Fowell et al., 2003; Fukumoto et al., 2012; Tian et al., 2013; Chen et al., 2015) have shown by region. To show a different aspect of climate change by areas even during the same period means that this zone is sensitive to climate change.

This study intends to estimate the frequency and average time interval of extreme floods in the past by using the flood deposits from the inner part of Mongolia, and classify the periods of dry and wet according to the effects of the summer monsoon in order to compare the results of research in the surrounding area.

2. Study area

The study area is located along the Kherlen River in Baganuur district, Ulaanbaatar, which is the capital city of Mongolia (Fig. 1). The river has its origin in the south slopes of the Khentii Mountains. It flows to a southern direction in the upstream of a high mountainous area and an eastern direction in the mid-downstream of the plain area, flowing into the Hulun Lake in China and meets the Amur River in Russia (Fig. 1). The Kherlen River drainage basin consists of a steppe region and the Khentii Mountains, the upper stream of Kherlen River, becoming a taiga zone. The river is 1090 km in length and has a drainage area of 116, 400 km^2 (National statistical office of Mongolia, 2006). The main stream of the Kherlen River generally represents a braided channel river with great amplitude of discharge and dominant bed load. This river shows the hydrological characteristics of an arid region where transmission loss clearly occurred.

The Kherlen River drainage basin is geologically underlain by the stratum of green schist forming from volcanoes of the Neoproterozoic (Ochirbat et al., 2010). The geology of the river surroundings is formed by the granitoid complex of the Paleozoic and Mesozoic, and the volcanic complex of the Mesozoic and Cenozoic (Administration of Land Affairs, Geodesy and Cartography, 2004).

The mean annual temperature of Baganuur district including the study sites is ~ −2.2 °C, with the mean temperature ranging from −48 °C in January to 37 °C in August. The mean annual precipitation is 250 mm, with approximately 70% of it concentrated in the summer season from June to August. The study area represents a typical arid continental climate with the great annual amplitude and little precipitation.

Sampling site HL1 (47° 41′ 13″ N, 108° 27′ 43″ E, 1,298m a.s.l.) is located on the tributary mouth of the Kherlen River (Fig. 1). The tributary flows from the town of Baganuur to the Kherlen River. The tributary junction angle is about 90° to the mainstream and the sampling site is close by to the junction (Fig. 2). Flood sediments of this site were deposited by backflooding to the tributary associated with large-scale floods occurring by the Kherlen River. Low hills are situated along both banks of tributary.

The site HL2 (47° 41′ 14″ N, 108° 27′ 33″ E, 1,301m a.s.l.) is located in the upstream direction of the tributary which is approximately 200 m away from site HL1 (Figs. 1 and 2). The sediment thickness of this site is 110 cm. This site was mostly influenced by the hydrological condition of the tributary and also the supply of sediments in the main channel associated with the large-magnitude floods of the Kherlen River, because this site (HL2) is located on the more inner side of the tributary compared to site HL1.

3. Methods

Slackwater deposit analysis is one of the most widely used palaeoflood ways to estimate the magnitude and frequency of discrete flood events (Kochel and Baker, 1988). Research involves the classification of discrete flood units and the chronology of certain layers for estimating the magnitude and frequency of palaeofloods.

Individual flood events were differentiated based on: 1) vertical grain size changes, 2) color changes, 3) organic contents changes 4) laminations, and 5) existence of colluvial deposits.

Grain size analysis is the analytical method of finding the depositional environment of the past. The results of grain size analysis of flood deposits can be used to estimate the velocity of a running fluid at that time (Kochel and Baker, 1982; Benito et al., 1998; Peng et al., 2005; Amireh, 2015; Liu et al., 2016). Grain size was analyzed by using a sieve and grain-size analyzer. The grain size ranging from -4ø to 0ø was analyzed by sieve, and that from 1ø to 12ø by grain-size analyzer. The grain size of samples in this study was analyzed using the Shimadzu SALD-2000 analyzer at the laboratory of Natural Science & Technology, Kanazawa University in Japan. The samples were pretreated prior to grain size analysis.

Property and formation processes of soil were analyzed using the soil color index. The soil color of deposits in this study was confirmed on the basis of the Munsell scale. The soil color of deposits was measured at two conditions of dry and wet samples.

The occurrence of organic contents in flood deposits indicates a discontinuity of flood events (Kochel and Baker, 1982; Partridge and Baker, 1987; Ely, 1997). An abrupt increase in organic content means that the plants were able to grow thickly owing to the time difference between one flood and the next flood. After the occurrence of one flood, plants grow in the topsoil layer of flood deposits and over time these plants are buried by the deposits which occur during the next flood. As a result, the discontinuity of floods and the individual flood can be classified based on change of organic contents. The organic contents of each layer of the flood deposits were measured by the ignition loss method.

The ages of slackwater deposits were generally measured in radiocarbon dating by using seeds, organic matters and charcoals within sediments (Partridge and Baker, 1987; Yang et al., 2000; Jones et al., 2001; Sheffer et al., 2003; Panno et al., 2004; Thorndycraft et al., 2005a; Benito et al., 2008) and OSL (optically stimulated luminescence) dating (Greenbaum et al., 2000; Kale et al., 2000; Sridhar, 2007; Haberlah et al., 2010; Huang et al., 2010). The artificial remains were also used to estimate the age, and ^{137}Cs, a radioactive isotope, was utilized for dating of latest flood deposits (Thorndycraft et al., 2005b).

^{137}Cs dating can be used to date the sediments of flood events