Geomorphology 180–181 (2013) 109–119

Contents lists available at SciVerse ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Late Holocene flooding records from the floodplain deposits of the Yugu River, South Korea

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ARTICLE INFO

Article history:
Received 29 March 2012
Received in revised form 14 September 2012
Accepted 14 September 2012
Available online 23 September 2012

Keywords:
Flood
Floodplain deposits
Little Ice Age
Medieval Warm Period
ENSO activity

ABSTRACT

Predicting responses of regional hydrological cycles to global warming requires an understanding of past hydrological events on various timescales. This study investigated the variability of flooding as recorded in fluvial floodplain deposits. The percentage of sand-sized material in two cores collected from the floodplain of the Yugu River, one of the tributaries of the Keum River, central South Korea, has been tested as a proxy for the occurrence and magnitude of past flooding. The sand fraction of the floodplain deposits in cores KL28 and KL29, which record deposition over the last 3500 years, varied on multicentury timescales and suggests several past episodes of higher frequency large floods. These clusters of large floods seem to correlate well with Northern Hemisphere temperature anomalies and suggest that more frequent large floods occurred during the Medieval Warm Period (MWP) than during the Little Ice Age (LIA). The occurrence of more frequent large floods on the Keum River tributary may have been driven by intensified northerly winds over East Asia and resultant moisture convergence over Korea and/or a weakened thermal gradient between the tropical ocean and Asian continent. Furthermore, the centennial-scale changes in the sand fraction of the floodplain deposits were partly similar to remote El Niño–Southern Oscillation (ENSO) activity, implying a possible link between flooding in central South Korea and ENSO activity. This study has demonstrated that floodplain deposits have much potential for recording paleofloods though floodplains can be, and quite often are, very complex places in terms of their depositional history. In regions where natural lakes suitable for the study of paleohydrology and paleoclimate are lacking, well-controlled time-series data for the sand content at multiple sites in fluvial floodplains may be used to understand paleoflooding and extreme precipitation variability in the past.

1. Introduction

Flooding is a significant natural hazard to human society and can cause major economic losses as well as human casualties. Furthermore, flood magnitude and frequency are sensitive to even small changes in climate (Knox, 2000). To successfully mitigate flood hazards and plan the necessary hydraulic engineering requires an understanding of paleoflood characteristics on various spatial and temporal scales. Records of the magnitude and frequency of past flooding in a particular area can suggest the sensitivity of the area to flooding as well as the nature of possible changes (Benito et al., 2008). However, little is known of past flooding in many regions. Characterization of flood variability can be undertaken using historical and instrument-based records, but these data sets are generally too brief (decade to century scale) to convey information about long-term variability. Furthermore, in many regions, it is difficult to distinguish naturally occurring flooding from extreme hydrological events that resulted from anthropogenic land use changes (e.g., urbanization, cultivation) and modification of fluvial systems (channelization, dam construction).

Paleoflood records from floodplain deposits have much potential for preserving the details of past floods. In general, the evolution of floodplains is controlled primarily by deposition of coarse channel deposits (lateral and vertical accretion deposits) and finer overbank deposits (vertical accretion deposits) during flooding events. Recognizing the relative contributions of these two lateral and vertical deposit types has been difficult in floodplain sedimentary environments because of varying climatological and physiographical factors, which control the frequency and magnitude of overbank floods. Successive flood-related deposits can be distinguished from one another on the basis of several factors. These include changes in the physical characteristics of the flood deposits (e.g., grain size, color, and sediment composition); caps of clay or organic material; evidence of subaerial exposure at the upper surface such as archeological materials, vegetation rooted in the underlying deposit, or leaf litter; and changes in sediment induration, presence of desiccation cracks, or incipient soil development, any of which indicate surface exposure to external processes (Ely et al., 1996; Benito and Thorndycraft, 2005; Benito et al., 2008).

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0169-555X/$ – see front matter
http://dx.doi.org/10.1016/j.geomorph.2012.09.010

Many studies have suggested that changes in grain size in floodplain deposits can reveal the occurrence of large hydrologic events in the past (Knox, 1987, 2006; Walling et al., 1997; Benedetti, 2003; Lecce and Pavlowsky, 2004). For example, riverbank deposits in the upper Mississippi River floodplain indicate a negative correlation between sand content and organic carbon content in the sediments below the surface soil, reflecting the alternating influences of sand deposition during floods and organic enrichment by litter-fall between floods (Benedetti, 2003). Knox (2006) pointed out that the fraction of overbank alluvial sediment that is transported and deposited as sand increases with flood magnitude and that the size of the sand fraction can serve as an indicator of past flooding and a proxy for its magnitude. Sand-sized material is most abundant near the channel and decreases with distance across the floodplain, contributing to decreased sediment thickness with distance from the channel. Water that inundates the floodplain during high energy flooding is able to transport coarser sediment in suspension farther from the main channel, such that an increase in the average grain size in sediment can be assumed to represent an increase in the magnitude of the flooding event (Walling et al., 1997; Knox, 2006). Thus, time-series grain size data for floodplain deposits may reflect variability in the intensity and frequency of hydrologic events, providing information on temporal variation in past flooding, which is important in predicting future hydrologic events.

Climatic changes that control variability in the intensity and frequency of hydrologic events, including atmospheric circulation, have been considered one of the main factors in flood variability (e.g., Ely et al., 1993, 1994, 1996; Knox, 2000; Carson et al., 2007; Huang et al., 2007; Zielhofer and Faust, 2008). In the United States, investigation of Holocene paleoflood variability has focused primarily on two regions: the upper Mississippi valley (e.g., Knox, 1993, 2000) and the southwestern U.S. (e.g., Ely et al., 1993; Ely, 1997). Large middle Holocene floods in these two regions do not coincide, which was interpreted as a function of large-scale tropospheric westerly circulation (Knox, 2000). With regard to fluvial activity in the India region, Kale (2007) suggested that the century- to millennium-scale variations were closely linked to long-term fluctuations in monsoon strength during the late Quaternary. Recently, Huang et al. (2007) investigated Holocene paleoflood variability in the semiarid loess regions of China (the middle reaches of the Yellow River drainage basin) based on slackwater deposits. They suggested that great floods occurred as a result of extreme rainstorms in summer caused by rare, intensive meridional airflows involving northwestward-moving tropical cyclone systems from the Pacific (Huang et al., 2007). These studies emphasize the importance of obtaining data with good age control and high resolution from flood deposits for identifying the relationship between past flooding and changes in regional-scale atmospheric circulation.

The present study focused on the grain size of paleoflood deposits, which would have been directly controlled by physical factors such as energy conditions, and on the floodplain settings with mainly vertical accretion deposits to trace possible successive flooding records. The principal objectives of the present study are to test the sand fraction of the floodplain deposits as a proxy for paleoflooding in terms of spatial and temporal changes in sand content, to reconstruct the variability in past floods (e.g., clusters of more/less frequent large floods) and to investigate the implications of this information from the viewpoint of atmospheric circulation change in East Asia.

2. Sampling sites and methods

Since most large rivers in central Korea have been disturbed by anthropogenic land-use changes (e.g., urbanization, cultivation) and modification of fluvial systems (channelization, dam construction), it is difficult to find sites suitable for reconstructing paleo-flood records. The catchment of the Yugu River, one of the main tributaries of the Keum River in Gongju City, central South Korea (Figs. 1 and 2), is a recently developed area and expected to provide a well-preserved site for tracing past fluvial activity. The study sites are located on a floodplain in the lower part of the Yugu River. Topographically, the floodplain is situated in a small basin surrounded by low mountains. The river is 35.5 km long and feeds into the Keum River. The Gongju area is underlain by various rock types, including Precambrian metasedimentary rock, granitic gneiss of unknown age, Mesozoic granite, uncharacterized sedimentary rocks, and basic and acidic dyke rocks. The catchment area of the Yugu River is underlain predominantly by mica schist (including calc-silicate rock, quartzite, and graphitic schist interbedded with migmatitic gneiss and biotite gneiss) and banded gneiss. Quaternary alluvial deposits are present along the river valley (Fig. 2). Most of the land in the floodplain has been leveled and cultivated, and therefore the near-surface parts of sediment cores in the area have been disturbed.

Present-day summer season (June to September) hydrologic events in study site, central Korea, include heavy rainfall and flooding, controlled predominantly by the East Asian summer monsoon, namely the Changma front ("Mei-yu" in Chinese), a quasistationary feature. Fig. 3 shows the monthly temperature and precipitation record for Deajeon (30 km from the study site), which is typical for central South Korea.

The hydrologic history of the Yugu River was studied using three cores (KL28, KL29, and KR07) with a 90% recovery rate. Cores were collected during a survey of aggregate resources in Gongju City (Fig. 2). The 10-m-long KL28 core was sampled at ~2.2-cm intervals between core depths of 65 and 440 cm, and the 8-m-long KL29 core was sampled at 2.2-cm intervals between core depths of 70 and 530 cm (surface layers were excluded). The lower parts of both cores consisted mainly of sand- and granule-grade material. The 11-m-long KR07 core was collected from the present-day channel and was used only for sediment description and age dating of the bottom sediment. Macrofossils (such as wood, plant fragments, and charcoal) were not present in the cores of KL28 and KL29 in sufficient abundance for age dating (except for KR07 with a wood fragment), and ^{14}C dating was performed on total organic matter at the AMS facility of the Korea Institute of Geoscience and Mineral Resources (KIGAM).

For grain size analysis at ~2.2-cm intervals, about 300 mg of dry sample was treated with 35% H_2O_2 to decompose organic matter and boiled in 1 N HCl for 1 h to remove carbonates and iron oxides. After rinsing with distilled water, the samples were treated with an ultrasonic vibrator for 15 s to keep them in suspension and to facilitate dispersion. Grain size analysis was then performed using a Mastersizer 2000 laser analyzer, which automatically provides the mode and median size of samples.

3. Results

Radiocarbon dates ($n = 6$) from organic matter in core KL29 provide a depositional chronology (Table 1). In core KL29, ^{14}C dating identified a modern radiocarbon age (<1950 AD) at 81 cm depth and an age of 3210 ^{14}C YBP at 510 cm depth. The ages do not deviate from a steady increasing age trend with depth, suggesting that alluvial deposition took place progressively and without reworking over the last ~3500 years (Figs. 4 and 5). Radiocarbon ages were converted to calendar years according to the method of Stuiver and Reimer (1993) and Reimer et al. (2004). Sediment depth and elevation (cm) were then plotted against calibrated age (cal YBP) by regression using a third-order polynomial ($n = 6$, $r = 0.998$). In the age-dating results for core KL28 ($n = 9$), modern radiocarbon occurs at 100 cm depth, and an age of 9430 ^{14}C YBP occurs at 428 cm depth. A nearly steady increase in age with depth was evident for the past ~10,000 years (Figs. 5 and 6). Sediment elevation (cm) was then plotted against calibrated age (cal YBP) by regression using a third-order polynomial ($n = 9$, $r = 0.998$).