Quaternary International xxx (2015) 1–11

Contents lists available at ScienceDirect

Quaternary International

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

Formation and infilling of oxbow lakes in the Ishikari lowland, northern Japan

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
Floodplain
Oxbow lake
River meandering
Sedimentary facies
Sedimentation rate

ABSTRACT

Oxbow lakes are common landforms in meandering river floodplains. Despite the possible importance of oxbow lakes in floodplain evolution, little is known about sedimentary facies and sedimentation rates of oxbow fills, their formation ages and their persistence in the landscape. We analyzed infilling records by interpretation of borehole cores from four oxbow lakes in the Ishikari lowland, northern Japan. The borehole sediments were interpreted as basal coarse-grained streambed sediments (Unit 1) succeeded by channel fills before complete disconnection (Unit 2) and overbank deposits after complete disconnection (Unit 3). Unit 2 is thick in one core but very thin or absent in the other cores. This difference may result from the diversion angles of the incipient oxbow at the time of cutoff rather than the cutoff mechanism (meander cutoff or local avulsion). Detailed chronology based on the ^{14}C ages, tephra analysis, and ^{137}Cs suggests that the oxbow lakes formed during the last centuries and the sedimentation rates are approximately 45–90 mm/y in Unit 2 and 3.9–22.0 mm/y in Unit 3. Oxbow lakes in the Ishikari lowland may persist in the landscape during 600–1300 years since the initiation of cutoff. The relationship between the production rate of oxbow lakes and their persistence suggests that the production rate of oxbow lakes was high during 1899–1959. The number of oxbow lakes in the landscape may be variable in time scales of several decades or a century depending on the production rate of oxbow lakes.
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1. Introduction

Oxbow lakes are common geomorphic features in meandering river systems. They are formed by cutoff and remove more than a single meander in a given occurrence (Allen, 1965; Erskine et al., 1992; Toonen et al., 2012). Bed load sedimentation during the first phase of oxbow infill is well understood (Fisk, 1947; Bridge et al., 1986; Shields and Abt, 1989; Hook, 1995; Constantine et al., 2010; Dieras et al., 2013). The formation and infilling of oxbow lakes at the first phase of infill is strongly controlled by the diversion angle between the active channel and the abandoned channel. The diversion angle determines the strength of flow into the abandoned channel and the rapidity of plug bar development (Fisk, 1947; Constantine et al., 2010). The relationship between the diversion angle and the plug bar development is generally observed in other areas (Toonen et al., 2012). The plug bar is generally formed within a few years to decades of cutoff initiation (Gagliano and Howard, 1984; Bridge et al., 1986).

Oxbow lakes are eventually filled up with fine-grained overbank deposits. Citterio and Piégay (2009) suggested that the rates of overbank sedimentation in oxbow lakes are related to the overbank flow frequency. However, researches on infilling of oxbow lakes by fine-grained overbank sedimentation after the development of plug bar are relatively scarce. The rates of oxbow infilling appear to be variable between different environments (3–71 mm/y in oxbow lakes along English rivers, Lewis and Lewin, 1983; 45–140 mm/y in oxbow lakes along the Hunter River, Australia, Erskine et al., 1992; 0–26 mm/y in French rivers, Citterio and Piégay, 2009). The time scales of persistence of oxbow lakes in the landscape may be also variable even in the same area. Gagliano and Howard (1984) discussed that the oxbow infilling is completed as little as one century or as long as 1500 years depending on the sedimentation rates of oxbow fills. The conceptual model of oxbow formation and infilling proposed by Toonen et al. (2012) envisaged that the oxbow infilling is completed in several centuries. The persistence of oxbow lakes in

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http://dx.doi.org/10.1016/j.quaint.2015.06.016
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Please cite this article in press as: Ishii, Y., Hori, K., Formation and infilling of oxbow lakes in the Ishikari lowland, northern Japan, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.06.016

the landscape is considered to be dependent on the initial depth of oxbow lakes and the sedimentation rates of oxbow fills (Gagliano and Howard, 1984).

The relationship between the production rate of oxbow lakes and their persistence is important in terms of floodplain evolution because it determines the number of oxbow lakes preserved in a given reach. If an oxbow lake is produced in a given period and the oxbow lake is filled up with sediments in the period, only a single oxbow lake is always present in the floodplain, although some old meander scars may be present. We should assess the time scales of production of oxbow lakes and their persistence to evaluate the number of oxbow lakes preserved in the landscape. However, few studies evaluated the relationship between the production rate of oxbow lakes and their persistence based on detailed chronology of oxbow fills. Evaluating the persistence of oxbow lakes in the landscape is also important in terms of floodplain evolution because oxbow fills are resistant to lateral migration and may lower river migration rates (Sun et al., 1996; Hudson and Kesel, 2000).

The Ishikari River, northern Japan, enters a region of low-gradient fluvial and coastal lowlands in its lower reaches called the Ishikari lowland (Fig. 1). Here the river is a single-channel meandering river system accompanied by many oxbow lakes and widespread peatlands. Kinoshita (1961), in a fundamental study of river meandering, analyzed maps and aerial photographs of the Ishikari lowland dating from 1899 to 1959 and described how and where meander cutoffs occurred. It appears that regional avulsion of the river has not occurred in the last several thousand years, because oxbow lakes are found only near the present channel and no residual channels related to avulsion are present (Sakaguchi, 1974). Moreover, evidence from the IK1 borehole in the Ishikari lowland (Figs. 1 and 2) shows that avulsion has not occurred near that site since sea-level rise decelerated around 7000 years ago (Ishii et al., 2014).

For this study, we obtained borehole cores from four oxbow lakes in the Ishikari lowland to investigate the formation ages of these oxbow lakes and the sedimentary facies and sedimentation rates of their fills. In this paper, we evaluate the persistence of oxbow lakes in the landscape based on the detailed chronology of oxbow fills and examine whether the number of oxbow lakes in the modern floodplain is consistent with the relationship between the recent production rate of oxbow lakes and their persistence.

2. Regional setting

The Ishikari River originates on Mount Ishikari (1967 m elevation) on the island of Hokkaido and flows to the Japan Sea. The river has a drainage area of approximately 14,330 km^2 and is currently 268 km long, but it was longer than 300 km before artificial modifications.

The mean annual precipitation (1974–2010) is 1130 mm/y at Naie (Fig. 2), of which approximately half occurs during the summer monsoon months (May–October). Hokkaido receives heavy snow (600–900 cm/y at Iwamizawa) in winter during the East Asian Winter Monsoon. Most of the large flooding events occur during the summer monsoon (Tada et al., 1961), and changes in summer precipitation strongly influence the frequency and strength of floods. The mean annual discharge at Tsukigata (1973–2013) is 340 m^3/s and the mean annual peak flow there is 3100 m^3/s (Fig. 2). The annual peak flow occurs as a result of summer precipitation or snowmelt in spring. The mean annual suspended sediment load is 2.10×10^6 t/y (Yamazaki and Yamashita, 2004).

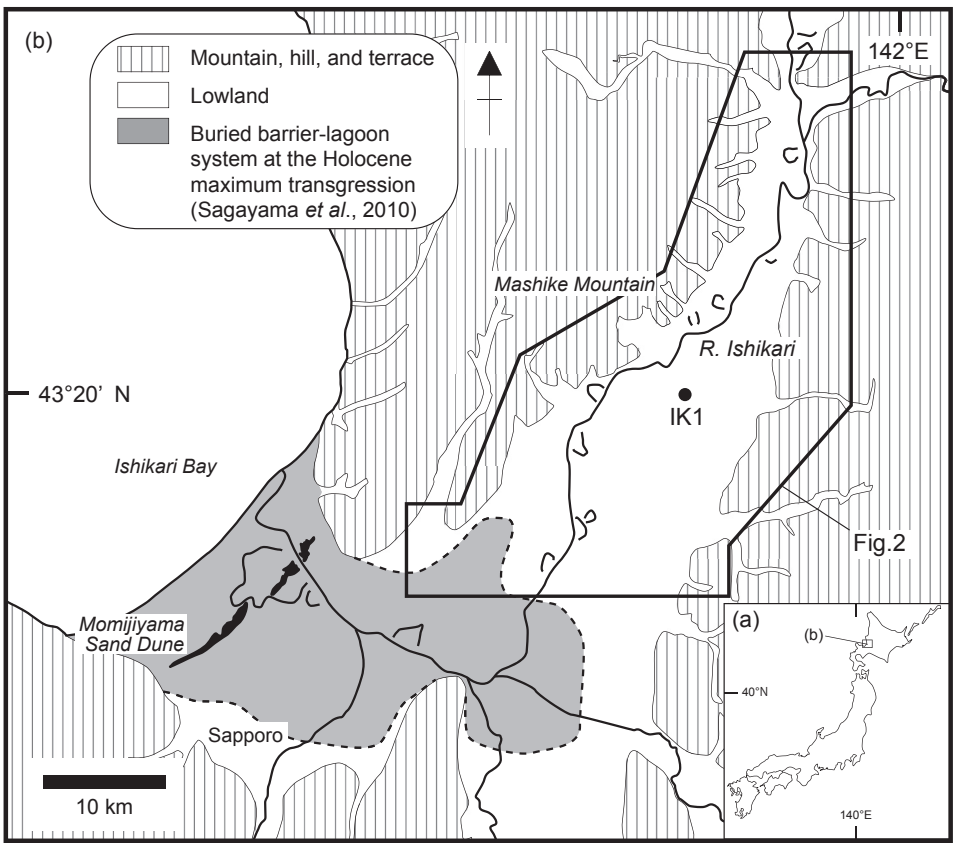

Fig. 1. Location map of the Ishikari lowland showing geomorphology of the study area.

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