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Latest pleistocene to holocene alluvial basin construction: An example from the Nara Basin, central Japan

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ABSTRACT

The response of alluvial plains or basins located upstream from the limit of marine deposition to allogenic forcing, such as sea level and climate change, has received little attention compared with adjacent coastal plains. This study investigates the stratigraphy and evolution of an alluvial basin in Nara, Japan, which has formed along the middle reaches of the Yamato River and its tributaries since around the Last Glacial Maximum (LGM), based on the analysis of newly collected radiocarbon-dated sediment cores and by collating existing borehole logs, radiocarbon ages, and burial depths of dated archaeological remains. Major fluvial incision did not occur in the basin during the sea-level lowstand around the LGM. In addition, the latest Pleistocene to Holocene strata (<5 m thick) are extremely thin compared with the southern part of the Osaka Plain, which is located in the lower reaches of the river. These observations indicate that the base level fluctuations caused by eustatic sea level change, and tectonic subsidence related to active faults in the surrounding mountains, have had little influence on deposition in the basin since around the LGM and that the basin has been a zone of sediment transfer or transport.

The burial depths of dated archaeological remains suggest that the thickness of sediment that has accumulated over the last 2000 years is around 1–2 m across large areas of the basin. The expansion of secondary forest caused by human disturbance in the historical period, and repeated landslide-induced river-bed uplift downstream from the outlet of the basin, may have promoted flood deposition in the basin.

1. Introduction

Since around the time of the Last Glacial Maximum (LGM), glacio-eustatic sea level change has been the main control on the evolution of modern coastal and near-coastal fluvial depositional systems. Thus, much research into latest Pleistocene to Holocene sequences has been carried out in coastal lowlands by applying sediment facies analysis and sequence stratigraphic concepts (Allen and Posamentier, 1993; Hori et al., 2002; Tanabe et al., 2015). In contrast, the stratigraphy and evolution of alluvial plains or basins located beyond the upstream limits of sea level influence have received less attention (Blum and Törnqvist, 2000), probably because of the lack of thick fluvial strata as well as limited age control. Other allogenic forcing, such as climate change, which is characterized by the high-amplitude 100-kyr periodicity of glacial–interglacial cycles, and tectonic activity, may also be responsible for alluvial stratigraphy (Shanley and McCabe, 1994). For example, alluvial sedimentation of the Ganga Megafan has been discussed in relation to climatically induced changes in discharge and sediment supply and tectonics as well as base-level change (Singh, 1996; Shukla et al., 2001; Goodbred, 2003). Sedimentation and incision of alluvial megafans in the Venetian–Friulian Plain, Italy, since the LGM was controlled mainly by climate change and related eustasy (Fontana et al., 2008). Additionally, intense human intervention in drainage basin has also influenced sedimentation rate and grain size of alluvial plains or basins (Dambeck and Thiemeyer, 2002; Marchetti, 2002).

Japanese Islands are characterized by a narrow and elongated shape with mountains and hilly lands occupying a large percentage of the land and the mountain ranges are often bordered by faults (Oguchi et al., 2001). Thus, small alluvial plains and intermontane basins commonly occur. Formation of fluvial terraces in the plains and basins in relation to Late Pleistocene climate change has been clarified well by applying tephrochronological method to the fluvial

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surfaces (e.g., Ono and Hirakwa, 1975). On the other hand, sediment facies, age, and evolution of alluvial strata formed at the plains and basins since around the LGM are less well known due to limited exposure of deposits in outcrop and shortage of borehole cores.

Analyses of borehole logs and tephra layers showed that Yamagata and Aizu basins, both of which are intermontane basins located at the northern Japan, have stored deposits with 10 m or more thick during the last 30,000 years (Yamanoi, 1986; Suzuki et al., 2016). Ohkubo (2007) suggested that the distribution of gravel deposits expanded on the Kotoh Plain on the east shore of Lake Biwa, central Japan, between 80,000 and 30,000 years before present in response to glacial–interglacial cycles. These studies recognized the Aira–Tanzawa (AT) tephra, which was erupted from Aira caldera, southern Kyushu, at approximately 30,000 cal BP (Smith et al., 2013). The tephra is very useful because it is widespread in Japan and its age is just before the LGM (26,500–19,000 cal BP; Clark et al., 2009). Additional studies of alluvial plains and basins are still required to improve our understanding of alluvial architecture and its evolution.

The Nara Basin in Japan contains the middle reaches of the Yamato River and its tributaries (Fig. 1). The lower reaches of the Yamato River have contributed to the formation of the adjacent coastal lowlands, the southern part of the Osaka Plain (i.e., the Kawachi Plain; Yasuda, 1977). The basin and the coastal lowlands are bounded by the Ikoma and Kongo mountains, which were uplifted during the Quaternary (Huzita, 1968). Previous studies have recorded the alluvial stratigraphy (Matsuoka and Nishida, 1980; Joint Research Group on the Geomorphological Recognition and Land Utilization of Pre- and Protohistoric Japanese Peoples (hereafter Joint Research Group), 1986; Kansai Geological Survey Association and AIST, 2009), the prehistoric and historic environment (Joint Research Group, 1987; Barnes et al., 2005), and pollen spectra around the LGM (Ooi, 1992) based mainly on the analysis of short sediment cores obtained using hand-operated augers. However, the influence of allogenic forcing on the evolution of the basin has not been considered in any detail. Moreover, the relationship between the evolution of the basin and the adjacent coastal plain remains unclear.

Nara is also well known as the ancient capital of Japan and for its historical ruins, and many excavations of remains have been performed in the basin. Thus, it is possible to estimate sediment thickness and its accumulation rate during the historical period based on the depth of the ruins below the present surface.

The purpose of this study is to clarify the latest Pleistocene to Holocene stratigraphic architecture and evolution of the Nara Basin, which was strongly influenced by allogenic forcing including human interference. We analyzed sediment cores recovered from the central part of the basin as well as collating existing borehole logs, published radiocarbon data, and data related to the depth of remains from the Yayoi and Kamakura periods (ca. 2500–600 cal BP).

2. Study area

The Nara Basin, located in central Japan (Fig. 1), extends 15 km east–west and 30 km north–south (Fig. 2). The basin is bordered to the west by the Ikoma and Kongo mountains and to the east by the Kasagi Mountains. Active faults with a north–south strike run along the eastern (Sangawa et al., 1985) and southwestern margins of the basin (Hirouchi, 2004). The vertical slip rate of these faults is estimated to be 0.03–0.3 m/kyr (Sangawa et al., 1985; Hirouchi, 2004).

The Yamato River runs east to west through the basin and is the trunk stream (Figs. 2 and 3), although the upper reaches of the river are known as the Hatsuse River. The drainage area of the river covers 1070 km^2 and it is 68 km long. Confluences with numerous tributaries (e.g., the Saho River) that originate in the surrounding mountains occur around the center of the basin. Many of these channels were artificially constrained under the Jori system (a land information system in ancient and medieval Japan). The river flows through the narrow Kamenose section where it cuts across the Ikoma Mountains (Figs. 1 and 2). Landslides have occurred repeatedly along the north bank of the river at Kamenose and have caused ephemeral uplift of the river bed. The river joins the Ishi River at Kashiwara, and then runs west through the southern part of the Osaka Plain (also known as the Kawachi Plain), finally flowing into Osaka Bay near Sakai. The channel was artificially shifted to its present position in 1704 AD by dredging of the late Pleistocene upland (i.e., the Uemachi Upland). The former channel flowed north to northwest near Kashiwara and emptied into Kawachi-gata Bay, which formed during the Holocene transgression. The river joined the Yodo River after infilling the lagoon.

Late Cretaceous Ryoke granitoids are common in the surrounding mountains. Sedimentary rocks of the late Pliocene to early Pleistocene Osaka Group are found mainly at the foot of the mountains. Neogene andesite lava and intrusive rocks, as well as the Ryoke granitoids, are exposed at Kamenose.

The latest Pleistocene to Holocene sequence in the basin is subdivided, in ascending order, into the Yamanobe and Ikaruga formations (Matsuoka and Nishida, 1980). The Yamanobe Formation is composed of sand, silt, and peat, although the spatial continuity of the sedimentary facies is poor. The gravels in the coarse sand layers are composed of chert and quartz. Radiocarbon ages obtained from peat or peaty mud, mainly from the upper or uppermost parts of the formation, range between 34,000 and 21,500 uncalibrated ^{14}C yr BP (Matsuoka and Nishida, 1980). The formation also contains the AT tephra. The lower boundary of the formation is poorly defined. The Ikaruga Formation consists mainly of medium to coarse sand and silt, and shows significant spatial variability. The surface layer, of approximately 50 cm in thickness, is fortified soil. Radiocarbon ages suggest that the Ikaruga Formation was deposited during the Holocene (Matsuoka and Nishida, 1980; Joint Research Group, 1986).

3. Methodology

Two cores (MK1 and MK2) were recovered from the central part of the Nara Basin (Fig. 2), with MK1 being located ~200 m east of MK2. The MK1 and MK2 cores were recovered at elevations of 45.1 and 45.9 m above sea level, respectively, and the cores were 14 and 11 m long, respectively. The cores were split, photographed, and described. Pieces of wood and plant fragments were subjected to radiocarbon dating by accelerator mass spectrometry (AMS) at Beta Analytic. Calibrated ages were obtained using the Calib 7.1 program (calib.qub.ac.uk/calib/calib.html; Stuiver and Reimer, 1993), which is based on the IntCal13 calibration curve (Reimer et al., 2013).

We also obtained borehole logs from previous drilling operations in the Nara Basin (Ministry of Land, Infrastructure, Transport and Tourism, http://www.kunijiban.pwri.go.jp/, viewed Oct. 2013) and analyzed them to estimate the sediment thickness that has accumulated since the LGM. On the basis of grain size data and standard penetration tests from these earlier boreholes, as well as the lithostratigraphy and radiocarbon ages of the cores recovered from our MK site, we concluded that the silt and clay deposits (standard penetration test N values of ~5) and the sand and/or gravel deposits (N values of ~10) were deposited after or around the LGM. Furthermore, we assumed that the peat deposits that we correlated with the top or upper horizon of the Yamanobe Formation represent the surface deposits that formed around the LGM.

Previous studies have reported radiocarbon dates from organic

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