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Late Quaternary floodplain development along the Stung Sen River in the Lower Mekong Basin, Cambodia

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ABSTRACT

The Stung Sen River, the biggest tributary to Lake Tonle Sap in the Lower Mekong Basin in Cambodia, is characterized by large seasonal changes of water discharge under the Asian monsoon climate and seasonal changes in water level that reach at least 7 m and are controlled by the water level of the lake. The Stung Sen River floodplain consists of two geomorphic units: meander belt along the river channel and backmarsh. Coupled observations of outcrops along the river channel and arrays of sediment cores across the floodplain north of Kampong Chheuteal village and Kampong Thom City, c. 150 km and c. 70 km, respectively, reveal that floodplain environmental changes at c. 11 ka were possibly associated with the Holocene onset of the southeast Asian monsoon and probably with the emergence of Lake Tonle Sap. These observations also show that the present backmarsh–meander belt system was established about 5.5 ka along with the unique Mekong–Tonle Sap connection, characterized by a reversal in flow direction during the monsoon season. The meander belt materials are replaced as the river channel shifts on a decadal to centennial timescale. Backmarsh sediments at sites Kampong Chheuteal and Kampong Thom had a constant accumulation rate of about 0.5 mm/y during the Holocene, contrasting with rates of 0.1 mm/y during the late Pleistocene. At around 11 ka, a sand layer was deposited over all of the valley around Kampong Chheuteal, while wetlands enlarged around Kampong Thom, probably because of increased rainfall triggered by an enhancement of the Asian summer monsoon. This 11 ka horizon has since been covered by clayey sediments keeping pace with the accumulation of lacustrine sediments in Lake Tonle Sap.

1. Introduction

Fluvial lowlands, with their abundant water resources and locations for settlements, have accommodated a substantial portion of human habitation and food production during the Holocene. Fluvial processes, however, sometimes cause severe floods and landform changes, and recent studies describe the effects of Quaternary climate changes on fluvial landform development (e.g., Jain and Tandon, 2003; Hanson et al., 2006; Thomas et al., 2007; Hori et al., 2011). The relationship between fluvial plain development and long-term climate change is important for the sustainability of this crucial human habitat.

Fluvial plain geomorphology shows that the character of rivers varies with the climate zone (e.g., van Gelder et al., 1994; Staub et al., 2000; Latrubesse and Franzinelli, 2002; Khadkikar, 2003; Yamaguchi et al., 2006). Remarkably, rivers in low latitude monsoon regions are dominated by contrasts of discharge and water level influenced by seasonal rainfall resulting in marked changes in river processes during the year. Therefore, the role of the monsoon environment in low latitude fluvial plain development and flood potential is an important topic for fluvial geomorphology. However, case studies of fluvial plain development in low latitude monsoon regions are few. In particular, little is known about how climatic and hydrological changes after the last glacial period are related to fluvial landform evolution.

Research around the world has revealed the sensitivity of fluvial response to climate change and landform evolution after the last glacial period (e.g., Schulte et al., 2009; Tooth et al., 2009; Ishihara et al., 2012). Recent isotope analyses of speleothems and deep-sea cores have documented Quaternary climate change at high temporal resolution in monsoon regions of Asia (e.g., Mayewski et al., 2004; Webster et al., 2007; Zhang et al., 2008; Sinha et al., 2011); and learning how these climate changes, especially during the Pleistocene–Holocene transition, have affected fluvial systems is necessary to interpret river systems in low latitude monsoon regions. That task requires detailed description, classification, and dating of fluvial landforms and deposits to inform discussions about formation processes. Goodbred and Kuehl (2000) are one of the few researchers who carefully discussed past changes in fluvial systems resulting from changing climate regime in monsoon Asia, which explained the response of river sediment flux.

Our study area, the Stung Sen River in Cambodia (Fig. 1A) is in the low latitude monsoon region of the Lower Mekong Basin. It is the largest river flowing into Lake Tonle Sap and originates in the Dangrek Mountains on

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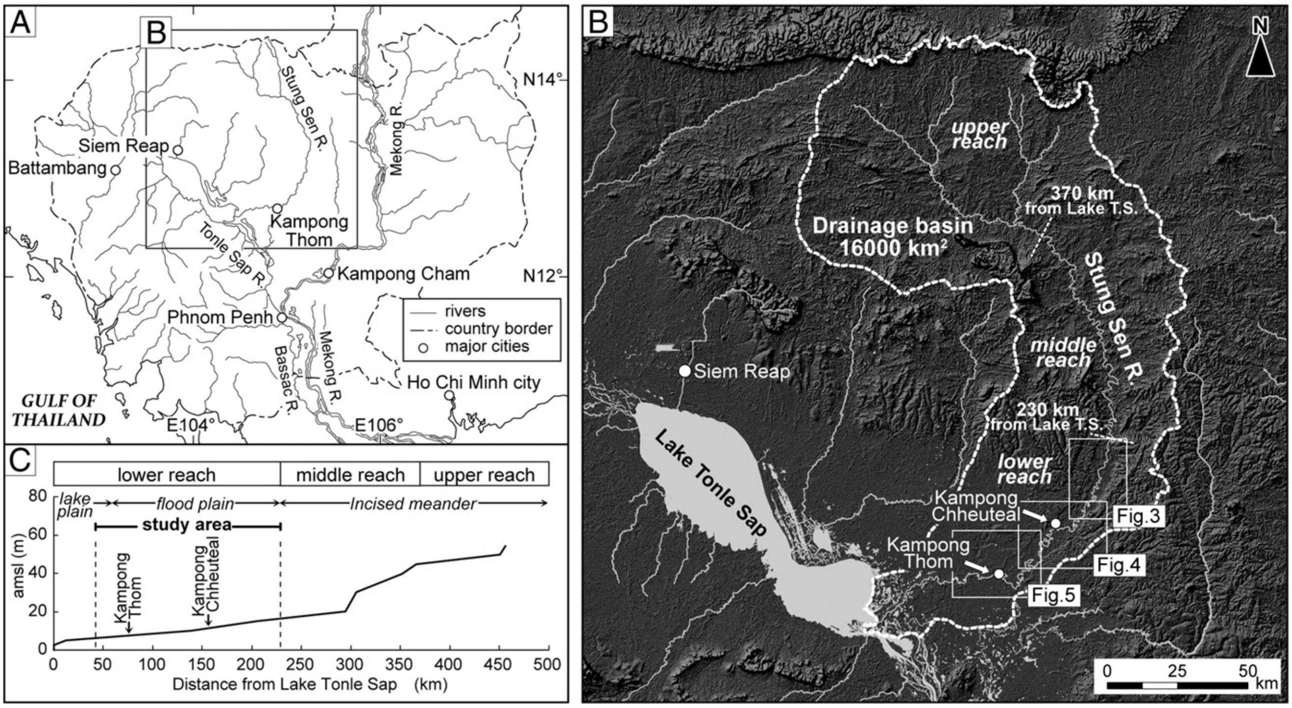

Fig 1. Map of Cambodia (A), map of the Stung Sen River drainage basin (B), and longitudinal profile of the main stream derived from 1:50,000 topographic maps (C). The Stung Sen River drainage basin is outlined in (B) with a dashed line.

the border between Cambodia and Thailand (Fig. 1B). Most fluvial research in Indochina has focused on the downstream reaches of large rivers (e.g., Ta et al., 2002; Allison et al., 2003; Tanabe et al., 2003; Storms et al., 2005; Nguyen et al., 2010; Proske et al., 2011), and fluvial behavior in the hinterland is not well characterized. Further, while most fluvial geomorphic studies in Cambodia have targeted the downstream portion of the main Mekong River (e.g., Hori et al., 2007; Tamura et al., 2007, 2009; Kubo, 2008; Meshkova and Carling, 2012), very few have taken up its inland tributaries such as the Stung Sen River.

As a case study of a river in a low latitude monsoon region, this paper shows findings from the lower Stung Sen River near Lake Tonle Sap (Fig. 1B) that document characteristics of tributary fluvial behavior under the strong influence of monsoon seasonality and climate change after the late Pleistocene. Landform observations by topographic mapping and aerial photography were combined with repeated field investigations and drill core analyses with radiocarbon dating to identify the sedimentary succession of fluvial deposits. Drill core data already reported by Nagumo et al. (2010, 2011) and newly obtained drill core interpretations are integrated into this study, and fluvial processes and subsequent landform development are discussed in relation to long-term river bed evolution and water level fluctuation of the lake.

2. Regional setting and previous studies

2.1. Lower Mekong Basin in Cambodia

The Lower Mekong Basin includes the area downstream of Yunnan province in China to the South China Sea, an area with major tributary systems. As the Mekong enters Cambodia (Fig. 1A), it flows across relatively flat land; and its delta system begins at Phnom Penh where distributaries begin to branch from the river toward the South China Sea (MRC, 2005).

The Lower Mekong Basin has been investigated in detail since the 1950s given its potential for water resources, transportation, and electric power development (e.g., UN/ECAFE, 1957; Mekong Reconnaissance Team, 1961). Tributaries in the Lower Mekong Basin have received similar attention for the same reasons, and the Mekong Reconnaissance Team (1961) investigated the major Mekong tributaries, including the Stung Sen River. However, an early study by Carbonnel and Guiscafré (1965) is one of only a few hydrological and sedimentological investigations of Lake Tonle Sap in Cambodia.

The Cambodian part of the Lower Mekong Basin is characterized by a unique natural flood control system involving the Mekong and Lake Tonle Sap. Whereas the river flows into the South China Sea in the dry season, it also flows into the lake in the monsoon season by reversing the flow of the Tonle Sap River. Masumoto et al. (2007) showed that between 2003 and 2005 the lake surface area enlarged from c. 1600 to 12,000 km^2 in the monsoon season and that the lake level at Chong Khneas, near the northern coast of the lake, and increased to c. 9 m above sea level (asl) in the monsoon season from its lowest level of c. 1 m. This annual cycle ensures reliable rice cultivation and rich fishery resources because of the influx of floodwater and fertile sediments, and the Mekong–Tonle Sap region is a vital resource for the Cambodian people (MRC/WUP-FIN, 2003, 2007; Hortle et al., 2004; MRC, 2005). On the other hand, this hydrological cycle combined with the flat landscape has produced flood disasters, such as the severe floods between August and early October 2011.

After the end of the Cambodian civil conflict in the 1990s, hydrologic, sedimentological, and geomorphological investigations began in the Mekong–Tonle Sap region. Okawara and Tsukawaki (2002) used clay mineral analyses in the northern part of the lake to determine that sediment inflow from the Mekong into Lake Tonle Sap began c. 5 ka. Day et al. (2011) similarly concluded that the initiation of water and sediment input from the Mekong started between c. 4.5 and 4 ka. Penny (2006) argued from the presence of mangrove pollen that the lake was influenced by tidal and saline waters during the early to middle Holocene, >7.0 to c. 5.5 ka, and that it has had hydraulic connections to the South China Sea via the Mekong throughout the Holocene. In a review of studies of Holocene sediment accumulation of the lake, Kummu et al. (2008) documented a net sediment accumulation rate of 0.1–0.16 mm/y during the last 5500 years, a rate smaller than in the early Holocene; for instance in core studies, Penny et al. (2005) reported a rate of 2.48 mm/y between c. 7.9 and c. 7.3 ka, and Tsukawaki et al. (1997) reported a rate of 1.2 mm/y during c. 6.0–5.6 ka.