Floodplain deposits, channel changes and riverbank stratigraphy of the Mekong River area at the 14th-Century city of Chiang Saen, Northern Thailand

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ABSTRACT

Riverbank stratigraphy and paleochannel patterns of the Mekong River at Chiang Saen provide a geoarchaeological framework to explore for evidence of Neolithic, Bronze-age, AD 5th Century *Yonok* and AD 14–16th Century *Lan Na* Cultures. Typical bank stratigraphy charted on the Thailand side is imbricate cobble gravel overlain by 5–10 m of reddish-brown sandy silt. The silt section is composed chiefly of 1/2 to 2-m thick layers of massive silt without paleosols interpreted as near-channel floodplain and gently-inclined levee deposits laid down by episodic, infrequent, large floods. The surface soil is dark-brown clay loam (<1-m thick) with abundant brick fragments, pottery shards and charcoal of *Lan Na* time. Brick ruins of 14–16th Century Buddhist temples are crumbling into the river at Chiang Saen Noi, and formerly did so at Chiang Saen until banks were stabilized by rock walls. Bank retreat from river erosion has been >20 m since *Lan Na* time, and has exposed a silt-filled moat. A radiocarbon age of 1475 cal yr AD was obtained from charcoal at the bottom of the moat, beneath 5.6 m of silt. Lag material from erosion of the silt banks contains Neolithic and Bronze Age artifacts out of stratigraphic context, as well as ceramics and bricks of *Lan Na* age. These artifacts as well Neolithic artifacts obtained from a 1972 excavation near the mouth of the Kham River indicate long human habitation of this riverbank area.

In northern Thailand the Mekong is mostly in a bedrock canyon, but shifting topography along the active strike-slip Mae Chan fault has formed the upstream 2–5-km wide floodplain at Chiang Saen, and downstream has diverted the river into a broad S-shaped loop in the otherwise straight course of the river. A 1.7-Ma basalt within the bedrock channel 45-km downstream of Chiang Saen indicates little vertical incision by the river. Satellite images show former channels in the Chiang Saen area, meander-point-bar scrolls (radii of curvature >1.2 km), and floodplain edges as arcuate cuts of similar curvature into the saprolite-mantled bedrock hills These features indicate channel avulsion occurred by meander loop cutoff in the past. Brick Buddhist monuments of the 14th–16th Century were built upon the floodplain with meander features on the Thai and Laos side of the river, indicating that these meandering channel features and the broader floodplain are mostly older than 600 years.

1. Introduction

During the dry-season, low water exposes a 10-m thickness of recent channel and floodplain deposits along the banks of the Mekong River near Chiang Saen Noi, Thailand. Study of the banks offers an inexpensive and more aerially extensive look at floodplain stratigraphy than that afforded by an archeological site excavation. Interpretation of these deposits and channel changes inferred from field observations, maps, and satellite imagery contributes to understanding the Quaternary history and river processes of this reach of the Mekong, and also to the relationship of the river to a long, little-known history of human habitation in the region. This paper describes features observed along the banks of Mekong in support of studies of the archaeology and Quaternary geology of the area. Descriptions of the bed and banks of the river are important, because the Mekong flow will soon be significantly regulated by upstream dams. Furthermore, much of the Thai riverbank in this area is currently being sealed from view and stabilized by masonry and rock walls to prevent erosion and facilitate development of the river bank.

2. Overview of the Mekong River at Chiang Saen

The Mekong River at Chiang Saen flows through subtropical mountains in the middle of its 4,880-km course from the Tibetan Plateau to the South China Sea (Fig. 1). Geomorphic characteristics of

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Fig. 1. Drainage basin of the Mekong River showing location of Chiang Saen, Thailand and the existing and proposed dams on the river in the Yunnan Province of China (dam locations from Nguyen, 2003).

the river south of China are discussed by Gupta and Liew (2007). At Chiang Saen the river flows across a local floodplain (Fig. 2). This area, known as the Golden Triangle of Thailand, Laos, and Myanmar,

receives a mean annual precipitation of 1700 mm/year, with 90% falling during the summer monsoon from May to September (Hoanh et al., 2003). The mean annual temperature is 25.5 °C. Very warm

afternoon temperatures of 31 to 36 °C are experienced in the hot dry season of February to May. This mountainous area with ridges up to elevation 1800 m was formerly covered by subtropical deciduous forest with tall Dipterocarp trees forming a canopy, and an undergrowth of bamboo and other species. Over the past century most of the hill slopes have been cleared of forest for swidden agriculture. Some slopes are partially reforested, and some very steep areas still contain pristine forest. Valleys were partly forested but were extensively logged for teak in the early 20th Century (le May, 1926) and cleared for pasture and cultivation. Valleys are mostly in rice paddies or are seasonally swampy areas covered with impenetrable thickets of thorny mimosa shrub (*Mimosa pudica*). Uncultivated riparian areas are commonly covered by tall grasses (e.g., *Imperata cylindrica*) and thickets of thorny mimosa, willow, scattered banana groves, and other trees. Most of the riparian area, however, is cultivated in row crops, including corn, squash, soy beans etc. Higher areas of the floodplain are planted in orchards, taking advantage of silt replenished by flood along terraces, levees, and back-levee areas.

2.1. Geomorphic and geologic setting

At Sop Ruak, the river flows southward from a straight 600-m deep canyon of granitic rocks onto a 2–5-km-wide floodplain. Granitic rocks crop out in the hills west of the floodplain at Chiang Saen. Granitic rocks, metavolcanic rocks, and metasedimentary rock occur in the canyon and surrounding hills downstream from Chiang Saen (Braun and Hahn, 1976). Rocks of all the surrounding hills are deeply weathered with a 2 to 20-m thick saprolite overlain by red soil profiles associated with subtropical residual soils that dominate the region.

Four km south of Chiang Saen, the river course is thrown into a broad S-shaped loop, and the southward course is deflected to the east by about 25 km, probably associated with recent offset along the Mae Chan fault (Fenton et al., 2003). Left-lateral shifting of high topography across the course of the river likely results in widening of the alluvial valley in the vicinity of Chiang Saen as the river attempts to continue its southward flow. The average gradient from Sop Ruak to Chiang Saen and then to Chiang Khong is 0.00035 (0.35 m/km) (read from 1:50,000 maps with 20-m contours). Several bedrock rapid reaches of locally steeper gradient occur about 30-km downstream of Chiang Saen. In the area known as the Wiang Nong Lom, located southwest of Chiang Saen (Fig. 2), tectonic warping along the Mae Chan fault has produced a northeast-trending downwarped area (7-km wide by 15-km long) that is filled with swamp sediment (Wood et al., 2004). Fenton et al. (2003) interpret this as a tectonic sag consistent with active left-lateral shear along the fault. The lower reaches of the Kok and Kham rivers are drawn into this low area as they empty into the Mekong (Fig. 2).

In a preliminary exploration of the area stretching between Sop Ruak and Chiang Khong, only one high-gravel terrace deposit was found. The deposit is exposed in a new roadcut (2 km north of Ban N-Ngao, Laos, and 14 km upriver from Chiang Khong). Weathered gravels occur at ~375-m elevation, about 15 m above the typical July high-river stage. Scant record of terraces suggests the river has not incised greatly into bedrock or fill in this area during the late Quaternary.

The low or negligible incision during the Quaternary is further supported by the occurrence of a 1.74±0.12 Ma corundum-spinel-bearing Quaternary-aged flow basalt (Barr and McDonald, 1981) which lies in the river channel along the 13-km reach above Chiang Khong, but is absent north of the Mae Chan fault. This K–Ar age is consistent with the normal paleomagnetic polarity determined at the Chiang Khong basalt outcrop where basalt extends below the low-water elevation (342 m). This basalt erupted from a shield volcano in Laos about 5 km east of the river and flowed into the canyon. Irregular and near-horizontal columnar jointing occurs at the contacts with older metavolcanic rock in the river bed, indicating the basalt flowed

into the canyon. Because the basalt lies in the river bed over a 13-km reach south of the fault, and the base is not perched above the river, it is inferred that the present river canyon south of the Mae Chan fault is at about the same level it established 1.7 million years ago. Bedrock reaches and rapids where the river is down cutting appear to be caused by tectonic lateral shift of high topography across the river channel, rather than uplift south of the fault. The river wanders through topography north and south of the fault to maintain grade and resume its southerly course. The floodplain sedimentation north of the fault appears to have been caused by lateral shifting topography along the fault and relative downwarping of the Chiang Saen area.

2.2. Flow

Mean annual flow of the Mekong at Chiang Saen is 2700 m³/s (85 billion m³/year), which is about 18% of the flow at the mouth in Vietnam. Dry season mean discharge (January through April) is 950 m³/s, of which 95% originates in China. Flow rises steadily through May and June to about 4000 m³/s. Superposed on this flow are 6 or more flood peaks as the summer monsoon storms pass through and drench the Mekong River basin with heavy rainfall. About 70% of the wet season flow originates in China (Mekong River Commission, 2005). Greatest flows and peaks usually occur in August through early November (Fig. 3). Annual peak flow is about 10,000 m³/s. Peak flood flows of 15,000 m³/s (stage at Chiang Saen of +10.5 m) have a return period of about 10 years (Nguyen, 2003).

Flow of the Mekong River is not greatly regulated at this time. The Manwan Dam (Fig. 2), tail-water elevation of 1,037 m, filled its reservoir in the 1992–1993 dry season with 0.92 billion m³ gross storage and 0.25 billion m³ active storage (Nguyen, 2003). The Dachaoshan Dam (Fig. 2) was completed in 2004, with 0.96 billion m³ gross storage, and 0.37 billion m³ active storage. Filling of the Dachaoshan reservoir in late July 2004 reduced the flow below the dam by 75% (O'Shea, 2004). However the Mekong River Commission (2005) concluded there is no evidence of systematic change in low-flow hydrology either in terms of long-term increase or dry-season discharge in the period of record 1960–2004. Subsequently, Lu and Siew (2006) reviewed available data and found a declining trend in the low season flows since the filling of the Manwan Dam reservoir. A number of other dams are proposed (Fig. 2). The 300-m high Xiaowan Dam is under construction. The high gross storage of 14.55 billion m³ and active storage of 0.99 billion m³ of this dam will greatly alter the flow of the river (Nguyen, 2003). The expected long-term downstream effects of these dams are increases in dry-season flows, and decreases in the summer monsoon high flows. However, it is uncertain what the dam operations will do to extreme flows of drought and flood years.

2.3. Floods

The greatest peak flow of record (1957–present), 3 September, 1966, flooded parts of the city of Chiang Saen with 1–2 m of water. Gauge height was 13.82 m at Chiang Saen, and flow was estimated at 23,500 m³/s (Mekong River Commission, 1994). Using the 1913–1991 daily discharge record at Vientiane, Adamson et al. (1999) estimate that the 26,000 m³/s peak flow slightly exceeds the 100-yr flood hydrograph. All other flood stages at Chiang Saen in the 1961 to 2004 record have been less than 11 m (Nguyen, 2003). Floods of August, 1998 and September, 2000 at the downstream site at Chiang Khan (Fig. 2), mentioned by Gupta et al. (2002), are most likely 5–10 year recurrence events. Flows in 2000, however, peaked in July and September, and the June-through-November flood-season volume (500 km³) of the 2000 event was more consistent with a 50-year recurrence, and was particularly severe in the basin below Vientiane (Mekong River Commission, 2005). The September 2000 flood is attributed to the heavy southwest monsoon season beginning 6–8 weeks too early in July, thereby causing water levels to rise rapidly in

the Mekong upstream from Vientiene. By late August, 2000 the main stream and tributaries were already at bank-full stage when successive tropical storms crossed the Indochina Peninsula from the South China Sea (Chapman, 2000). Tropical storms from the northeast are associated with eastern Pacific typhoons, and travel westward across the Indochina Peninsula. These storms are typically responsible for many of the August and September flood peaks. The Mekong River Commission (2005) points out a geographical split in the flood regime at about Vientiane. Downstream the flood hydrology is dominated by wet-season runoff from east-bank tributaries in Laos, whereas upstream, the Yunnan (China) component dominates.

2.4. Suspended sediment

During annual high flow, the river runs a muddy reddish-chocolate color, with the measured suspended-sediment load exceeding 350 mg/L and reaching 1200 mg/L during the rising high flow of 4290 m^3/s in 1994 (Fig. 3). In 1999, reported concentrations were as high as 2750 mg/L in early July at a flow of 4000 m^3/s (Walling, 2005). The time history of suspended-sediment measurements plotted against discharge demonstrate a clockwise hysteresis effect marked by high sediment concentrations at the onset of the rainy season (July–September), and then lower concentrations at a similar flow

Fig. 2. (a) Satellite image (LANDSAT, 01 November, 1989) of the Mekong River and the Golden Triangle area. Image processed by Michael J. Rymer, U.S. Geological Survey, Menlo Park, California). Thailand is the west side of river south of the Ruak River. Myanmar is north of the Ruak River, and Laos includes the islands and area east of the river. The reservoir partly shown on lower left side of image is the result of a weir being placed on the Lua River in the 1960s (b) Interpretation of image showing the floodplain of the Mekong River in the Chiang Saen area, floodplains of other tributary rivers, traces of abandoned channels, archaeological sites, and locations of river cross sections shown in Fig. 6, and panel of stratigraphic sections at Chiang Saen Noi (Fig. 7). Locations of ruins on the Laos is incomplete. Circled numbers 1, 2, and 3 are locations of artifacts found in lag gravels on river bank (Fig. 5): 1 = 10-cm bronze adze, 2 = polished stone shoulder adze (4 cm), and 3 = distance along gravel beach with numerous side-notched cobble fishing sinkers.
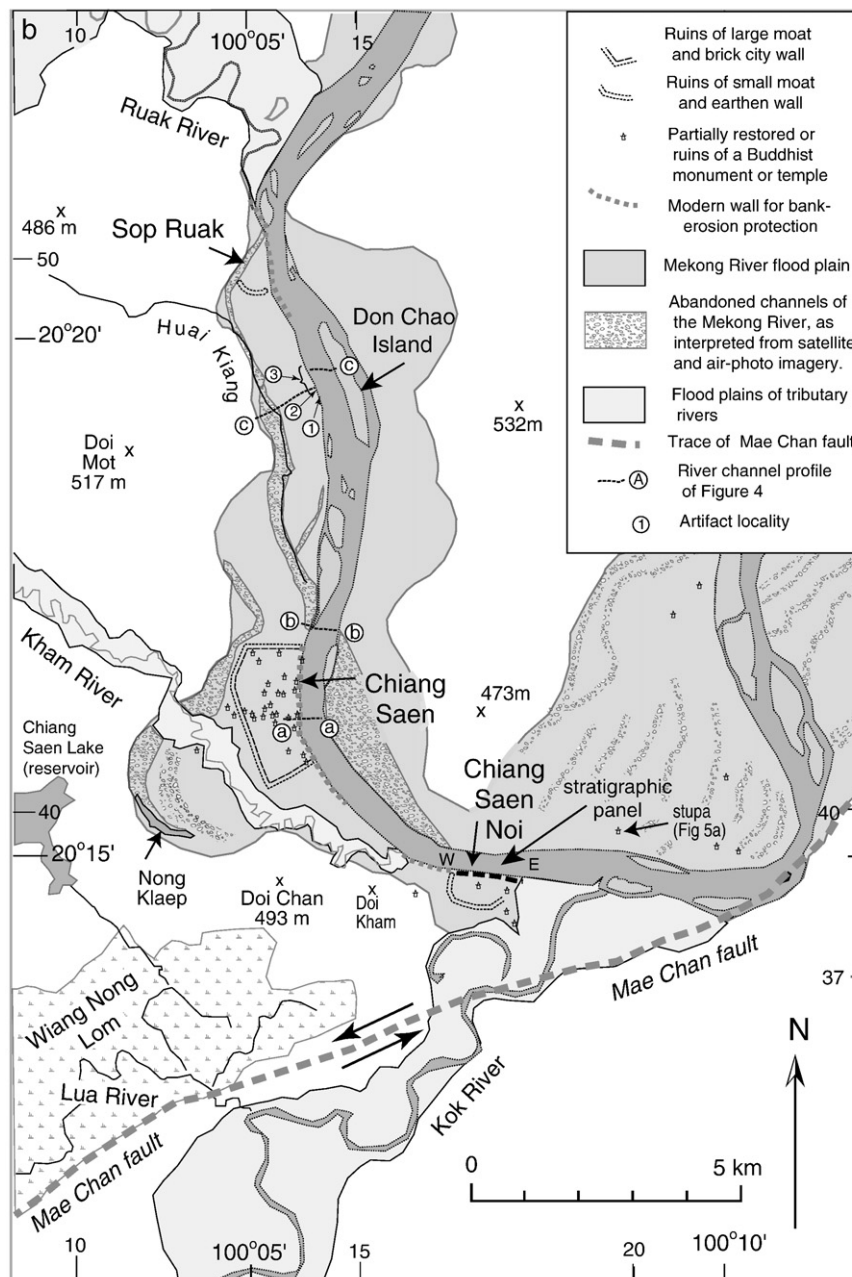
Fig. 2 (*continued*).

later in the season (October-December) (Fig. 3a). This effect, seen on other tropical rivers, is attributed to erosion of the easily mobilized material that has accumulated on hillslopes and to remobilization of sediment in the channel network (Picouet et al., 2001). The suspended-sediment data shows considerable scatter because of this effect (Fig. 3c and d). Estimated annual suspended-sediment discharge at Chiang Saen is 58.4 million metric tons (Mekong River Commission, 1994). On a drainage basin basis (189,000 km^2), the average yield of suspended sediment is 309 tons/km^2 yr at Chiang Saen, a high value similar to other Himalayan rivers of Asia (Summerfield and Hulton, 1994; Milliman and Syvitski, 1992).

Recent reviews of available data suggest a decline in low-season flows and in sediment flux at the Chiang Saen gage since the 1992 infilling of the reservoir of the Manwan Dam on the Upper Mekong (Lu and Siew, 2006; Kummu and Varis, 2007; Fu et al., in press).

No measurements of bedload transport are available for the Mekong River at Chiang Saen. The appearance of new sand bars at low water each year suggests that the annual transport of sand may be considerable through this reach. River-bed deposits consist chiefly of bars of medium sand, and some bars of imbricated sandy cobble gravel (Fig. 4d–f). Gravel bars have clasts with a typical median size of 7.5 cm and outsized clasts of 25 cm (Rothwell and Wood, 2004). Mobilization of cobble gravel probably occurs in the larger flood events, but might not occur annually.

2.5. Archaeology, cultural history and legends

The Mekong River has been an important travel route throughout Southeast Asian prehistory, but little is known of early human occupation of the Chiang Saen area. Flaked stone tools associated with hunter-gatherer societies have been found along the banks of the Mekong and in the hills surrounding the Chiang Saen area (Maleipan, 1972; Natapintu and Phommanodch, 1990; Hingham, 2002). Elsewhere in southeast Asia, flaked stone tools date back to about 18,000 BP, and are associated with the Hoabinian material culture (Hingham,
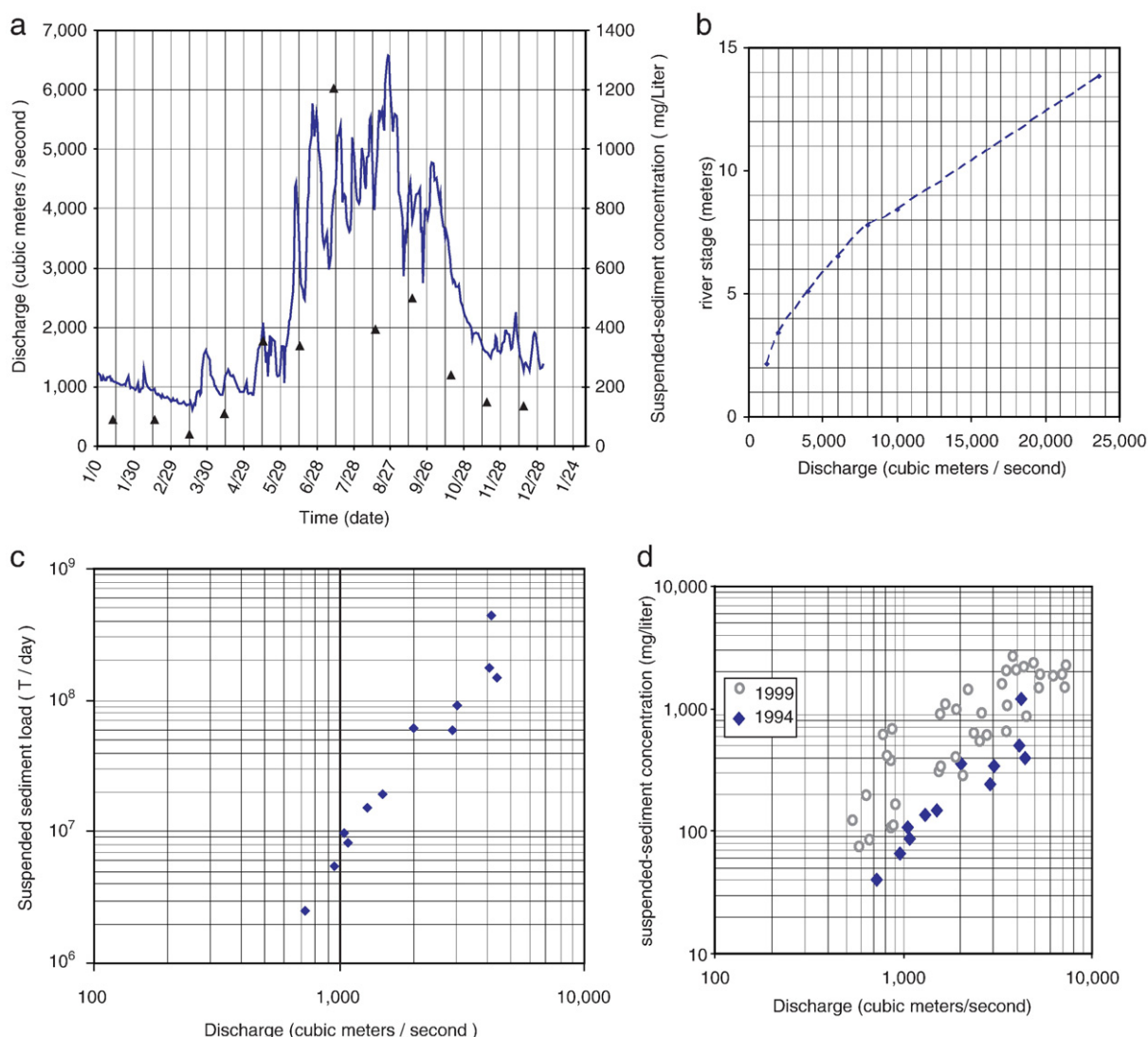
Fig. 3. (a) Discharge hydrograph and measured suspended-sediment concentrations for the 1994 calendar year at the Chiang Saen gauging station. (b) Stage-discharge rating curve for the Mekong River at Chiang Saen, extrapolated to the 3 September, 1966 high-flow value of 23,500 m³/s. (c) Suspended-sediment rating data (1994 measurements). (d) Suspended sediment concentration vs. discharge data for 1994 and 1999. Coincidentally, high values occur early in the wet season at similar flows: 1204 mg/l on 13 July, 1994, and 2760 mg/l in early July, 1999. Data are from the Mekong River Commission (1994). 1999 data are from Walling (2005) who has reviewed all available data in his report.

2002). In 1971, a 2-m deep trench was excavated at the foot of Doi Kham, however, no radiocarbon ages were obtained. The lowest cultural strata (1.0–1.75 m) contained unifaced tools and scrapers. Embedded in the middle strata were stone tools, stone adzes and chord-marked pottery (Maleipan, 1972). Bronze artifacts, including a 10-cm adz have been found loose among the gravels on the shore south of Sop Ruak (Fig. 5). It is uncertain when Bronze-age materials were brought into the Mekong travel routes. In Northeast Thailand bronze artifacts were dated within the period 1400–900 BC (Hingham, 2002). Although iron was being used in Southeast Asia in the period 300–500 BC, no Iron Age sites are known in northernmost Thailand. Iron tools were found associated with graves near Lamphun, and the material culture indicates a date within the period 500 BC to AD 200 (Hingham, 2002, p. 223; Pautreau et al., 1997). A radiocarbon date on burnt bone from a layer over one of these graves is 1490±50 BP (429–657 cal yr AD) (Pautreau et al., 2003).

Numerous chronicles of China and Southeast Asia relate legends of early Thai people from southern Yunnan establishing kingdoms in this area before AD 700 (Wyatt, 2003; Onsakul, 2005), but archaeologists have yet to discover sites confirming the legends of this time. A

legendary kingdom of this time is called Yonok (Ongsakul, 2005). Three chronicles pertain to the Chiang Saen area. "The History of Muang Ngern Yang Chieng San" relates the legend of Lawa Chankaraj, who came down from heaven or the abode of devas. He was made King by popular consent in AD 638 and ruled for 138 years. His son, Lawa Kieng, rebuilt the whole city in AD 761 with walls, palaces and a post marking the city center. The new city extended to the Mae Sai River in the north. His brother, Lawa Koh Lawa Kua was King of Chieng Khong." The succession of rulers continues in the chronicle to the birth of Mangrai in AD 1242. The same legends are related in the Chiang Mai Chronicle translated by Wyatt and Wichienkeeo (1998), who also give a chronology of rulers from AD 639–AD 1259. The Sinhanavati Chronicles, also translated from palm-leaf manuscripts with Thai Yuan script, into French by Notton (1926), relate legends also of this period. Many chronicles imply an early city (before the founding of Chiang Saen in 1329 AD) near the mouth of the Kok River that was named Meuang Suwankhomkham; however, archeological evidence for that city has not been found (Onsakul, 2005). Penny and Kealhofer (2005) find evidence of land-use intensification beginning in the 2nd or 3rd Century in a radiocarbon-dated lake core at Phayao, 120 km south of Chiang Saen. Greatest sediment delivery to the

Fig. 4. Photo of a 14–16th Century stupa on the Laos bank and photos of the Mekong River channel and banks at low water. (a)Ruins of stupa located on the Laos bank across from the mouth of the Kok River (location shown on Fig. 2) (photo and location from John Roberts). (b) Excavated river bank showing 6-m thick silts above imbricate cobble gravel on the Thai side, 2.5 km south of Sop Ruak at profile c, and near the site of several Neolithic (?) artifacts found in lag gravels (Fig. 2). Height of person for scale is 1.8 m (March, 2003 photo). (c) River bank showing inclined sand layers overlain by 1 m of silt, at the forested downstream tip of Don Chao Island. Side channel between island and mainland Laos is on right side of photo. Bed material exposed in dry side channel is medium sand. River stage at Chiang Saen was +2.4 m (359.5 m), view is to southeast, (April 15, 2005). (d) View looking upriver at a sandy-cobble-gravel bar along Laos side of river across from Chiang Saen showing large-scale gravel-ripple bedforms (wavelength 10 m) extending into water near the people. Largest cobble maximum diameter is 25 cm, D_{50} median diameter from Wolman pebble count is 7.5 cm (Rothwell and Wood, 2004). Photo taken at low water (+2.0-m stage) in January, 2004. (d) Closeup of (e) Showing gravel-ripple bedforms and Laos women gathering green filamentous algae (*Spirogyra ?*) from cobbles. Algae (locally called "kai") is dried, fried, and used as a local food. (f) View looking upriver at the gravel bar at the upstream end of Don Chao Island showing 1.5-m slip-face of a sand bar advancing over imbricated cobble gravels. Box and maximum cobble size are both 20 cm. (April 15, 2005).
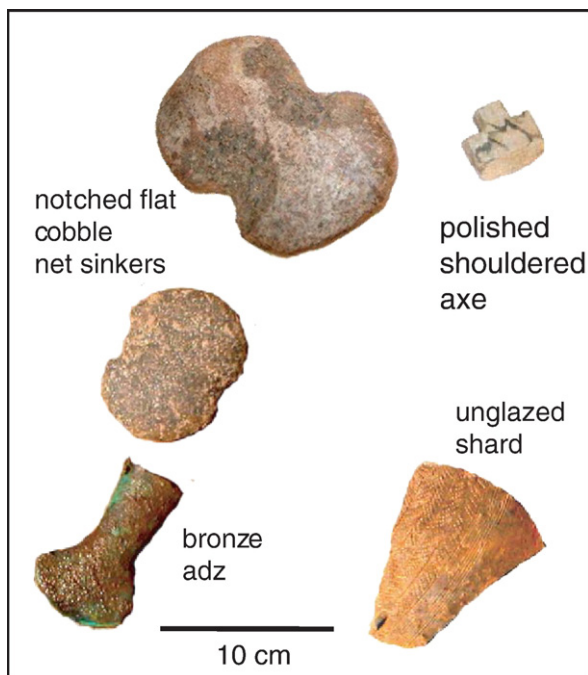
Fig. 5. Artifacts from lag gravels of eroding silt banks, 3 km south of Sop Ruak, on the Thai side of river, across from Don Chao Island (Fig. 2). Stratigraphic context is not known, but artifacts are clearly from the silt above imbricate cobble gravel (in a stratigraphy similar to, but perhaps of different age, than that at Chiang Saen Noi (Fig. 7)). The net sinkers and bronze adz suggest habitation of this part of the floodplain, more than 2500 years ago, or prior to the beginning of the Southeast Asian Iron Age (300–500 BC). Numerous glazed and unglazed pot shards, probably of 14th–16th Century age occur in the lag gravels as well as *in situ* within the upper 0.5 m of silt and surface soil.

lake occurred in the 13 and 14th Century. Their findings corroborate the times of the above legendary history, but it is surprising that no sites have yet been found along the Mekong.

King Mangrai was born in Ngoen Yang (the predecessor of Chiang Saen on the banks of Mekong) in AD 1239, and his realm marks the beginning of the prosperous *Lan Na* Kingdom of northern Thailand (Onsakul, 2005). The foundation of Chiang Saen as a walled fortress is credited to his grandson, Saen Phu, in AD 1329. "He had a moat dug around the city on three sides — the moat on the eastern side being the Mekong River — and had walls built on all three sides; and Saen Phu then reigned in that city which has been called Chiang Saen to the present day" (Wyatt and Wichienkeeo, 1998). "The chronicles say that Chiang Saen was built in muang mao year, s. 689 (AD 1327/28) [while other] chronicles say, on Friday, the second day of the waxing moon of the seventh month, (Friday 3 March 1329) the city of Chiang Saen was built….measuring 1500 fathoms by 700 fathoms [3000 by 1400 m] with five gates …."(Wyatt and Wichienkeeo, 1998).

The walled and moated city described in the chronicles exists today in various states of ruin. It is likely that many of the brick and laterite stupas (pagodas) and religious monuments were built before and after the official AD 1329 founding date. Many brick monuments are outside the city walls. The nearby towns of Sop Ruak and Chiang Saen Noi, and unstudied sites on the Laos bank also contain the remains of various structures and earthworks.

The Jinakalamali Chronicle states: "In 1325 Phaya Saen Phu founds a town at the confluence of the Mae Kok and the Mae Khong rivers and there makes a standing Buddha image from the pith of sandal wood" (Penth (1994). This town with its brick ruins is now called Chiang Saen Noi. "Noy" or *Noi* in Thai language translates to "little" in English. Since this place is said to have been founded 2 years earlier than Chiang

Saen, it may have been a trial foundation that was abandoned by the ruler (but not necessarily by the people) in favor the present city of Chiang Saen 4 km upstream (Penth (1994). At Chiang Saen Noi the river is presently eroding into brick structures embedded in the silt bank of the Mekong. This is the site of the riverbank stratigraphic panel described in this study, the location of which is shown in Fig. 2.

The northern Thai kingdoms were conquered by the Burmese in AD 1558. Under Burmese rule Chiang Saen became a strategic city of the north between the 17th and 18th Centuries. It is not known if Buddhist monuments continued to be built during Burmese occupation. According to Ongsakul (2005) far fewer stone inscriptions record support for Buddhism during Burmese rule than during the Mangrai dynasty. In the late 18th century as Siam gained strength the Burmese were driven from northern Thailand, and from their last stronghold at Chiang Saen in AD 1804 (Penth, 2000). The towns were mostly deserted until the end of the 19th Century. In AD 1913 Chiang Saen lay in ruins and was covered by jungle (le May, 1926). Construction of the modern city and restoration of Buddhist monuments has been ongoing since about 1950 (Lertrit, 1997).

3. Methods

Ground examination of the floodplain is limited to the Thai side of the river. The Laos side was examined only briefly from a boat; therefore, little detailed knowledge exists of its geomorphology. The available 1:50,000 topographic maps for Thailand and Laos have a 20-m contour interval. A limited number of field elevations (± 2 m) were determined on a floodplain transect using a roving and a fixed recording barometer (0.1 hPa, or 0.3 m precision). Flight lines for the 1986 Thailand Department of Lands stop at the Thai side of the river, so that stereographic coverage was not obtained along the river. Underwater channel profiles of the river were sounded from a small boat using a recreational quality fish and depth finder (Fig. 6). Configuration of strata along the bank, shown in Figs. 7 and 8, was charted from a boat motoring just offshore and taking a panel of about 100 digital pictures, and splicing them together using photo software. At low water, bank exposure is variable because of mantling by new sediment, slumping, and vegetation, but the top of the gravel is always conspicuous. Four stratigraphic sections were dug clean and described. Every year part of the bank is plastered by horizontally bedded terracettes of new silt, some 0.4-m thick, and some plastered on deposits of previous years, so that considerable excavation is required to verify bank stratigraphy. No carbonaceous or woody material for radio-carbon dating occurs in the sand or massive silt layers, except for the surface A horizon and material deposited in a depression 5-m deep, shown in Fig. 7.

4. Channel and floodplain description

4.1. Channel of the Mekong River

Along the Chiang Saen reach, the river has an alluvial bed and a floodplain (Fig. 2). The area north of Sop Ruak, where the river divides Myanmar and Laos, has not been examined, but the valley narrows and it is likely to have many bedrock rapid reaches. About 20 km downstream from Chiang Saen the river has reaches of narrow canyons and with bedrock rapids similar to the reaches described by Gupta et. al. (2002), 500 km further downstream. At low flow (+2 m at the Chiang Saen gage), the river channel near Chiang Saen is ~2–4 m deep, and about 0.5 km wide (Fig. 6). The banks stand 8–10 m above the low-flow stage, and are composed of thick silts that overlie sand and gravel (Figs. 4b and 7). The channel pattern is one of low sinuosity. Mid-channel and alternating bars of sand and some of sandy cobble gravel occur in the channel. The bars are typically 1 km long, up to 250-m wide and are spaced 1 to 2 km along the course of the river. The
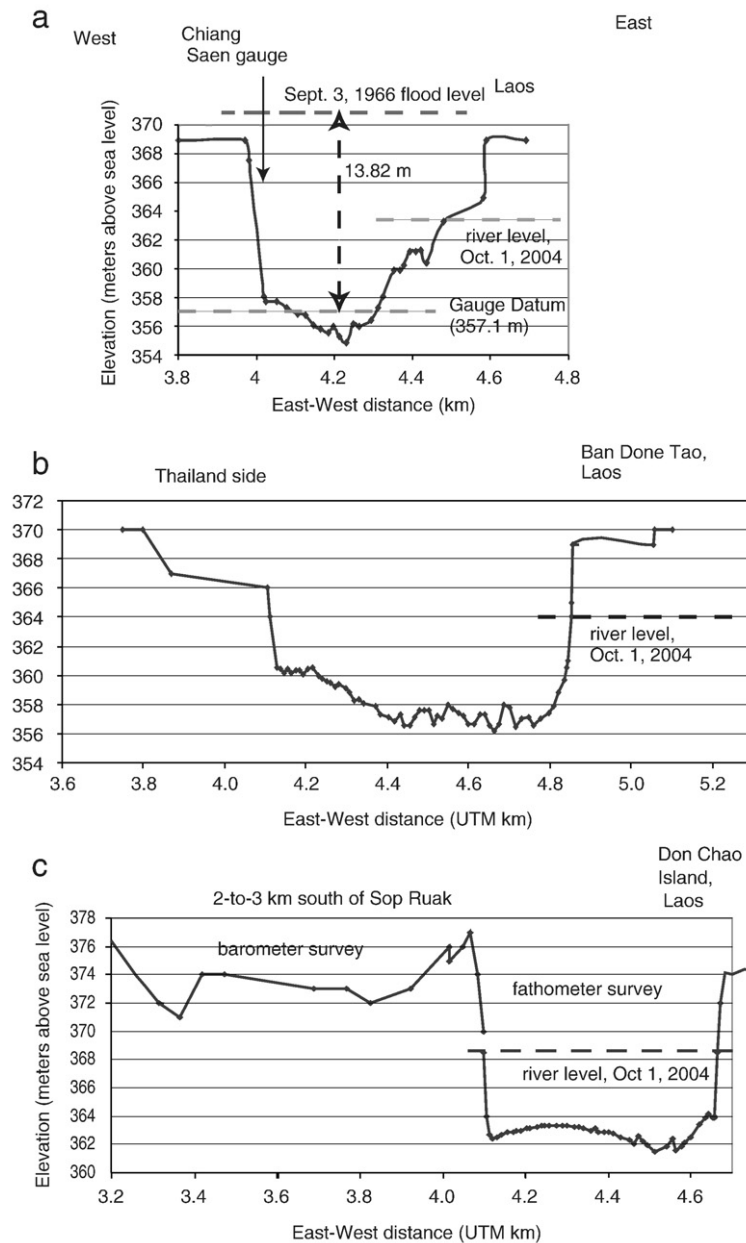
Fig. 6. Cross-sectional profiles of the Mekong River between Sop Ruak and Chiang Saen. Locations of profiles shown by circled letters, a, b, and c in Fig. 2. Zero datum of river gauge at Chiang Saen is 357.1 m above sea level, and elevations extrapolated to upriver sites using a river gradient of 0.00035.

larger mid-channel bars have evolved into islands. They are vegetated and forested on the downstream ends, with banks of vertically accreted sand and silt over gravel standing 6–10 m above low water. Where alternating bars form, typically a small or ephemeral flood channel runs between the bar and the mainland bank. Some flood channels become enlarged during large floods, and may become the dominant channel. Alternatively these side channels may be abandoned when not in flood and, thereby, serve as depositional sites for sand and silt. Ultimately they may be silt filled and merge with the mainland floodplain.

Many of the active alternating bars are composed of sandy cobble gravel, particularly on the upstream end. On active bars, the top of the cobble gravel is no more than 1 m above the +2 m low-water stage. In several instances, a sheet of sand has advanced over the gravel, with a 1–1.5-m slip face (Fig. 4f). At one alternating-bar locality across from

Chiang Saen, the gravel bar has dune-like bedforms that are similar to the large-scale gravel waves observed by Baker and Kochel (1988) on the Finke River of central Australia. These bedforms on the Mekong have a spacing of 10 m, and a peak-to-trough amplitude of 0.4 m (Fig. 4e and f).

The banks of the river on the Thai side, extending south from Sop Ruak to beyond the mouth of the Kok River, are eroding — probably several meters per decade in places. The Remains of a 14-16th Century brick-lined well, originally dug through 10 m of silt into underlying gravel, now lays in the bed of the river, indicating >20 m of bank recession in 600 years at Chiang Saen Noi. Stone and concrete walls have recently been constructed to protect parts of the towns of Sop Ruak, Chiang Saen, and Chiang Saen Noi (Fig. 2). This study was an opportunity to describe the sedimentary section that is still exposed, but which will eventually be covered by a protective wall.
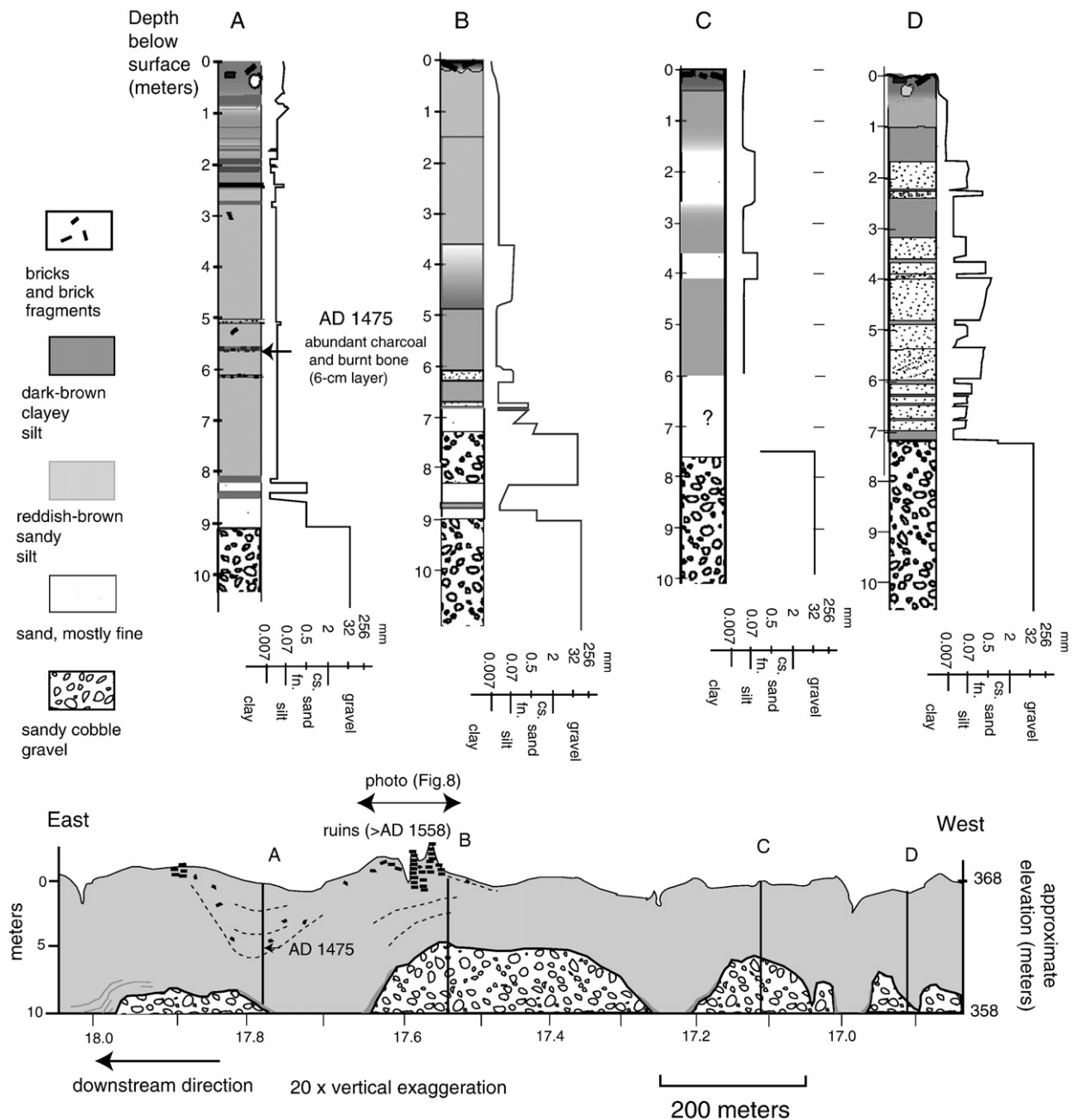
Fig. 7. River-bank stratigraphy at Chiang Saen Noi showing ruined 14th–16th-Century temple at site B See Fig. 2 for location of section. Numbers at bottom are UTM easting coordinates (India–Thailand Grid). Vertical exaggeration 20x. Line to the right of columns indicates the visually-estimated modal grain size by weight. Details of column A are shown in Fig. 9. River level at 358 m elevation is extrapolated from gage reading at Chiang Saen.

4.2. Floodplain

The floodplain of the Mekong has several meters of broad relief related to abandoned channels and levees. Elevation of the floodplain at Sop Ruak is 373 m; 8.5 km downstream at Chiang Saen it is 369 m (0.0005 gradient). A natural levee occurs along parts of the Thai bank, but is now absent along the riverside of the walled city of Chiang Saen, perhaps because considerable bank erosion had occurred before a protective wall was constructed in the 20th Century. A profile of the silt levee south of Sop Ruak is shown in Fig. 6c. The levee at that site stands 3 to 4 m above the floodplain, with a backslope distance of 200 m where it merges with the floodplain. A relict flood channel (100-m wide and 3 m lower than the floodplain) runs along the west edge of the floodplain for a distance of 4 km south of Sop Ruak, and

then across the floodplain to the river (Fig. 2). The relict channel is now occupied by the Huai (stream) Kiang.

Northeast of Chiang Saen Noi (Fig. 2) the inside of the bend on the Laos side shows concentric vegetation bands on satellite views indicating point-bar lateral accretion. Concentric arcuate swales on the floodplain, about 250-m wide, northeast of the Nong Klaep (reservoir), also are visible on the satellite view (Fig. 2). These swales and the one dammed for the reservoir are interpreted as former meanders, which, therefore, indicate that the river formerly flowed and cut an arcuate edge to the floodplain against the hills. These swales are now mantled by thick silt and mostly cultivated as rice paddies: no gravel occurs at the surface anywhere in the floodplain. Arcuate scallops of similar radii of curvature (>1.2-km radii) form the edges of much of the Mekong floodplain against the saprolite mantled
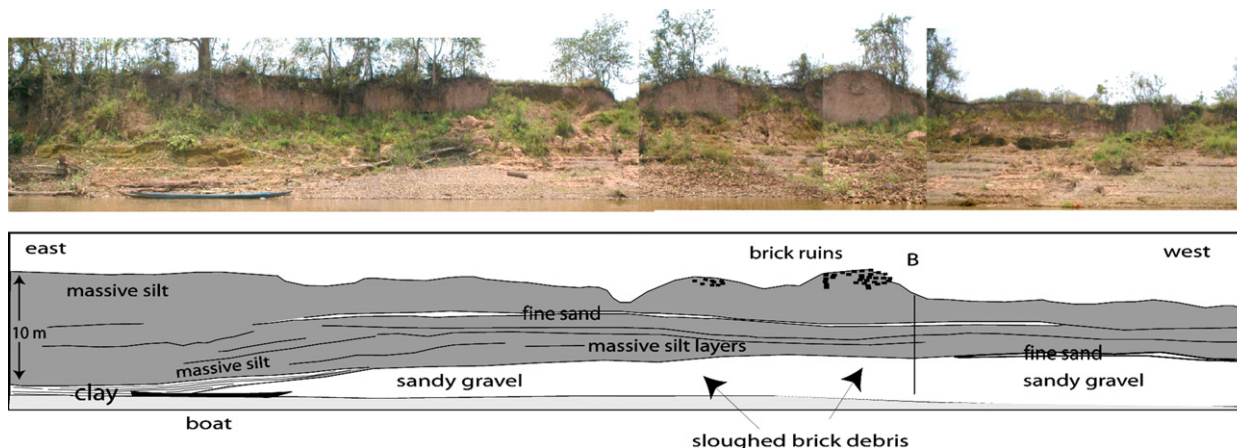
Fig. 8. Photograph of river bank at section B (Fig. 7) showing 14–16th Century brick structures crumbling into river as a result of bank erosion. At left side of photo (downriver) by boat, is a lens of thin-bedded clay over sandy cobble gravel. Dark shaded section is comprised of massive silt layers: each layer typically 0.8–2-m thick, and lower layers inclined to the left.

hills (Fig. 2), providing additional evidence that the river had a tendency to meander in the past. Most of the 14–16th Century towns and the Buddhist monuments on the Laos and Thai side were constructed on this floodplain (Fig. 2). Therefore these former channels must be older than 600 years.

The floodplain of the Kham River is incised 3.5 m into the 368-m-elevation Mekong floodplain, just south of Chiang Saen. The Kham River drains an area of ~550 km^2. It has a meandering channel ~20 m wide and banks 2–3-m high. Mean annual flow is 10 m^3/s. Six kilometers downstream of Chiang Saen, the Kok River flows into the Mekong. The Kok River has a 2–3 km wide active floodplain incised 4 to 5.5 m into the Mekong floodplain. It is a meandering river, with a channel width of ~150 m and banks 4 m high. The drainage basin extends into Myanmar, and is ~10,000 km^2 in area. Mean annual flow is 180 m^3/s and peak flows are 1000 m^3/s. The Kok River is navigable by small long tail boats to points upstream from the Myanmar border, even in the dry season.

The Mekong River was not observed at full flood during this study; however, at stage of 10.5 m (elevation 367.6) at Chiang Saen, the river would clearly overflow the banks or inundate part of the floodplain by back flow through tributary channels in many places. In the period of record since 1960, such flooding has only occurred twice, in 1966 and 1971. At a stage of 12.4 m (elevation 369.5), the city of Chiang Saen, its ancient monuments and much of the floodplain would begin to flood, but water would not likely be more than 1 m deep in most places. The 1966 flood reached a stage of 13.8 (elevation 370.2), and much of the Mekong floodplain must have been covered with 2 m of water, and that recurrence is considered slightly greater than 100 years (see discussion in 2.3). Just as in modern times, these floods did not prevent past societies from building towns on the on the levees, riverbanks and the floodplain. Thai houses in the past were built on wooden posts, so that the occupied house was typically 2 m above the ground, and temporary inundation was not a great risk. Long duration floods may destroy rice crops in low floodplain areas. Pirogues and riverboats were the major form of transport and commerce in the past, and riverbank settlements surely prospered despite infrequent major floods.

5. Stratigraphy of the river bank

At low water a 10-m thickness of floodplain and channel sediment is exposed in the river bank on the Thai side of the Mekong (Figs. 4b, 7, 8 and 9). Sandy cobble gravel is overlain by 5-10 m of sandy silt and sand. The stratigraphy is described in detail along a 2-km river bank at Chiang Saen Noi (Fig. 7), but the stratigraphy is similar along the entire 15-km bank from Sop Ruak to the mouth of the Kok River.

The upper surface of the gravel in the banks ranges to 5 m above the low-water line and extends to at least 1 m below low-water, so the

gravels are at least 6 m thick in places. The undulating gravel surface, as seen in the bank exposure, suggests bars separated by channels (Fig. 7). Rounded gravel clasts are up to 13 cm in diameter; the estimated modal size is 7 cm. Flat clasts are imbricated where observed on fresh vertical exposures (Fig. 4b).
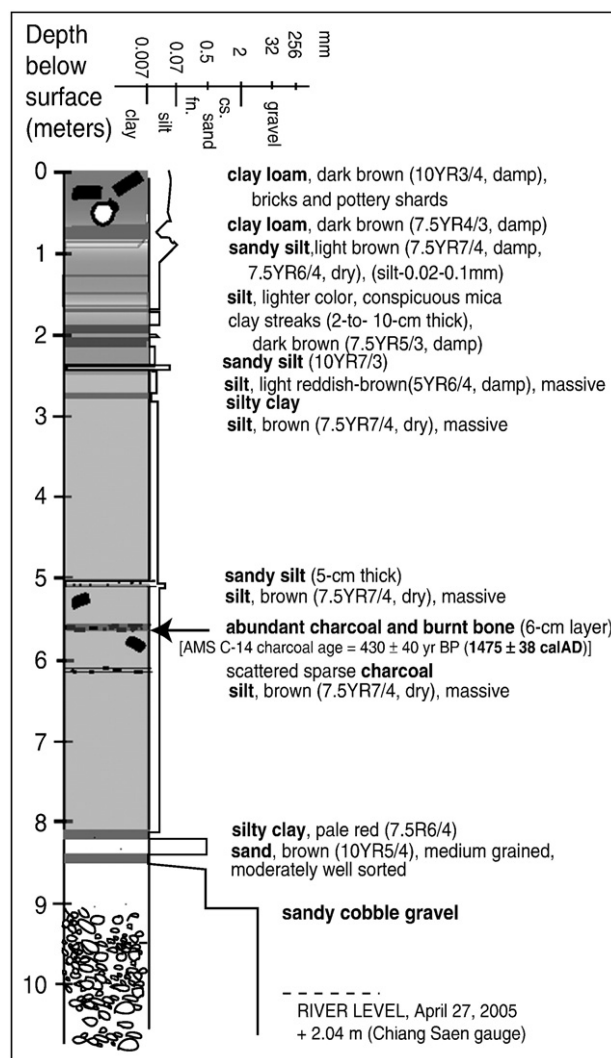
Fig. 9. Detailed description of section at site A (location of radiocarbon date). Line to the right of column indicates the visually-estimated modal grain size by weight.

In the 20–80-m wide lows between paleo-gravel bars, the gravels are mantled by thin-bedded clay conforming to the upper surface of the gravel. Clay is about 1 to 2 m thick and pinches out upslope (Figs. 7 and 8). Over the clay are layers of massive sandy silt, showing crude bedding as layers 10–50 cm thick, and conforming to the clay and gravel surface below. Total thickness of these conforming layers filling lows between gravel bars is ~3 to 5 m.

Sand layers (10–80-cm thick) interbedded with silt occur in the northernmost detailed section (section D) of the stratigraphic panel of Fig. 7. In most of the bank sections, however, sandy silt is dominant, with only thin sand beds. Over these basal silts are massive reddish brown (7.5 YR 7/4) sandy-silt layers, individually 0.8 to 2 m thick. No paleosol profiles occur in the entire gravel, sand or silt sections illustrated in Figs. 5b, 7 and 8, or other observed banks in the area. Nor was any organic material suitable for radiocarbon dating found in the silts, except as described below. The only profile development is at the surface. This soil is a dark-brown (10 YR 3/4) 20–80-cm thick clay loam, which contains abundant post-13th-Century brick fragments and glazed and unglazed pottery shards (Figs. 7 and 9).

When describing the southernmost section (section A, Fig. 7), we discovered a 6-cm thick lens of silt, at a depth of 5 m, containing charcoal and minor burnt bone (interpreted as a cooking fire). The AMS age (UGA No. 12230) of charcoal from the layer is 430±40 years BP (1475±38 cal yr AD). The layer is overlain by a massive 2-m thick silt layer and then about 7 thin layers of silt with sandy partings (each about 10-cm thick). Upon further excavation in April, 2006 brick and pottery fragments and rare charcoal were found scattered within the overlying layers and adjacent layers that fill a 5-m deep trough (Fig. 9). The trough may be an old excavation associated with the brick temple or monastery complex just now being exposed by river erosion or the trough may be the continuation of earthen moat shown in Fig. 2, which was subsequently back-filled with flood sediment containing rare cultural debris. The moat would likely have been excavated in AD 1325 (see section 3). Thus, it may be possible to more thoroughly age-date and interpret the trough fill stratigraphy (Fig. 9) in future studies.

As shown in Fig. 8, some of the massive silt layers are inclined a few degrees, and the silt depositional surfaces may have as much as 5 m of relief. These are most likely levee deposits which make up a sub-stantial part of the bank section. Inclined layers complicate the lateral correlation of silt layers along the bank where exposures are poor on account of bank sloughing, vegetation, or plastering of recent silt against the bank. In other words silt layers cannot be projected horizontally with confidence. Thus, in Figs. 7 and 8, the foundations of the brick ruins are in silt deposits older than the 15th Century radiocarbon date. Work in progress is attempting to date the older sandy silts and the underlying gravel by OSL (optically stimulated luminescence) methods.

6. Discussion

6.1. Channel changes and earthworks

The point bar meander pattern at Nong Klaep (Fig. 2) indicates that the main channel of the Mekong at one time flowed just east of or through the area now occupied by the ruins of the 14th Century city of Chiang Saen. Therefore, that meander channel must be older than 600 years. Because the point-bar morphology is preserved and still visible it is probably younger than Pleistocene (i.e. <11,000 years), but a more precise age of the cutoff is not yet known.

Part of the channel that at one time flowed to Nong Kloep is preserved, bordering the hills north of the Kham River; and it is also partly dammed at the present time and used as a reservoir just northeast of the city wall of Chiang Saen. That channel created an arcuate scallop into the east side of the floodplain 2 km north of Chiang Saen (Fig. 2). It is likely that this abandoned channel was used to collect small stream runoff and maintain the water level in the protective moat around Chiang Saen particularly in the dry season, when the river was low, and offensive armies could move over dry land.

Arcuate scallops into the bordering hills of the floodplain (Fig. 2), as well as the previously discussed meander pattern, indicate that the present straight and somewhat braided river channel of the Mekong had a greater tendency to meander in the past. Using the classic plot of mean annual discharge (Q) versus river gradient (s) from Leopold and Wolman (1957), the Mekong (2700 m^3/s, 0.00035 m/m) falls right on the line ($s=0.012\ Q^{-0.44}$) that separates meandering rivers from braided rivers (see Bridge (2003) for a metric-standard unit plot). Schumm (1985) argues that rivers with parameters close to the meandering-braided threshold should have a history characterized by transitions in morphology from braided to meandering and vice versa. These transitions can be caused by changes in the nature of discharge or changes in sediment load or caliber caused by anthropogenic changes as well as natural climate and vegetation change. For example a sinuous channel might become straight and braided if an increase in precipitation in the headwaters increased the annual and peak discharges. The same change might also occur if the sediment load increased and aggradation occurred. The gradient of the channel would increase to transport the load, and that gradient increase can be accomplished by a reduction in sinuosity. An increase in load at Chiang Saen could have occurred with intensification of land use in upstream in Yunnan (China). Channel changes in central Thailand have been attributed to Holocene climate change (Bishop and Godley, 1994), but clearly a better chronology of Mekong channel changes and knowledge of Holocene climates and population in the upstream Mekong basin will be needed to apply these concepts to the Mekong. Presently, there is concern that the proposed dam projects in Yunnan will decrease the present load downstream and leading to channel scour, bank erosion, and perhaps channel pattern changes (Gupta and Liew, 2007).

Other channel changes, which are more of archaeological interest, are the abandonment of the former Mekong flood channel now occupied by Huai Kiang, south of Sop Ruak (Fig. 2). That channel could have served as a western defensive water body for the small 14–16th Century town of Sop Ruak. If so, Sop Ruak may have been at the head of an island, with the ditch and earthen wall (Fig. 2) providing a southerly protection from unwanted invaders.

At this point it is important to compare the substantial moat and brick city wall of Chiang Saen with earthworks of Sop Ruak and Chiang Saen Noi. The moat at Chiang Saen is at least 7 m deep, and 20 m wide. The inner side of the moat faces a brick wall which rises 5 m above the full moat. The earthen moat at Sop Ruak is 5–6-m deep and about 9 m wide, with an earthen wall rising 4–5 m above the full moat. The earthen wall now slopes about 45°, but may have been steeper when constructed. The moat at Chiang Saen Noi is mostly filled in, but appears to have been of similar dimensions. It is questionable whether these earthworks were effective deterrents against invaders. Perhaps they were used primarily for water supply (Boyd et al., 1999). According to Parry (1992), however, a water depth of 3 m would be sufficient to deter an assault involving battle elephants; thus, the earthworks would indeed have offered some protection.

The Thai river bank south of Sop Ruak (across from Don Chao Island) had a long history of occupation, because Neolithic fishing sinkers, a polished stone adz and Bronze Age artifacts were found in the lag gravels, having eroded out from the silt banks (Figs. 2 and 5). Abundant glazed potshards and broken pottery of post-13th-Century Lan Na civilization occur in the upper meter of soil at this locality. These finds establish this area north of Chiang Saen as habitable and a popular fishing area for several thousand years.

6.2. Riverbank and floodplain sedimentation and stratigraphy

Sandy cobble gravel overlain by sand and thick silt is the common stratigraphy of the riverbank on the Thai and Laos banks and also on Don Chao Island. Gravel never occurs at the floodplain surface. Nor do any gravel terraces occur in the area. Tops of active gravel bars are no more than 1 m above the +2-m low-water stage at Chiang Saen, but gravel does occur in the bank stratigraphy at about +5 m and is always overlain by at least 5 m of sand and silt (Fig. 7). This low-level of gravel, suggests little Quaternary incision by the river.

No data are available on depth of valley fill beneath the floodplain, but fill of the Wiang Nong Lom along the Mae Chan fault (Fig. 2) is interpreted from proprietary seismic data to be 170-m thick (Wood et al., 2004), and is related to filling of tectonic subsidence rather than aggradation. No bedrock protrusions occur in the floodplain shown in Fig. 2, Based on the above, an estimate of valley-fill thickness, accommodated by tectonic movement, might be 50 to 100 m.

Silt dominates the bank sediment, but sand layers are observed in sections C and D of Fig. 7. These are interpreted as bedload sand over gravel in the main channel (Fig. 5f), or of side channels such as pictured in Fig. 5c. The river was not observed at full flood nor have the types of sediment been examined out on the floodplain; therefore, the possibility that sand in section C (Fig. 7) is the deposit of a crevasse splay spreading sand into a lower floodplain area cannot be discounted.

We are impressed by the prevalence, and the thickness of the massive reddish-brown silt layers, as well as the lack of any discernable soil profiles in the 10-m riverbanks. The 0.5-m thick dark-brown "A" horizon of the surface soil developed over at least 500 years in many places. Because not even a thin "A" horizon paleosol occurs on any of the silt layers in the section, none of the silt layers we examined aged at the surface for more than a few hundred years, prior to burial by another silt layer. Many of the massive silt layers are 1–2-m thick. These thick silts are likely either levee or near-channel overbank deposits. Silt deposition on the floodplain by a large river in flood is greatest adjacent to the channel and levees. The thickness of the silt-deposit diminishes exponentially away from the main channel, so that deposition more than 0.5 km from a channel is less than a few centimeters (Kesel et al., 1974; Allison et al., 1998; Aalto et al., 2003). The Mekong flood waters carry a substantial silt load (Fig. 3) so that any low area of the nearby floodplain to which flood waters flow at low velocity could receive a considerable thickness of silt sediment.

This leads us to a simple calculation to determine if it is reasonable for one flood event to deposit a meter of silt. If we consider floodwater bearing 1200 mg/l of suspended silt, and if half of the load settles as sediment of dry density 1.4 g/cm^3, then to deposit 1 m of sediment over each square cm of surface would require 230 l of muddy flood water delivered to each square cm of the area. To deposit a meter of silt over a side channel that is 10-m wide and 200-m long (20×10^6 cm^2 area) would require 4.6×10^9 l (4.6×10^6 m^3) to flow to that area. Consider a flow 2 m deep through a 10 m channel width. A flow velocity of 1 m/s through a 2×10 m^2 channel cross section will bring 1.73×10^6 m^3 of muddy floodwater through the side channel each day. Therefore, 1 m of sediment could conceivably settle over the 20×200 m^2 area in 4.6/1.73=2.7 days. In conclusion, a single-event sedimentation of meter thick layers is feasible for large sub-tropical river side channels and low floodplain areas within a few hundred meters of the main channel.

Aalto et al. (2003) found that floodplain sedimentation along the Beni tributary of the Amazon River occurs in sediment packages 20–80 cm thick, and some up to 2 m. They concluded that episodic sedimentation is the predominant mechanism of floodplain accumulation, and with a system-wide recurrence of about 8 years. Their cores were within 3 km of the channel.

Because the entire floodplain in the Chiang Saen area is only 2–5 km wide, the depositional sites exposed along the river banks are near-channel sites, and, thus, subject to high rates of deposition. Reported average rates in the literature for large tropical rivers are 2- to 5-cm/year determined by Aalto et al. (2003) within 700 m of the Beni and Masmore River channels and >4 cm/year on levees, and 0.3 to 1.4 cm/year within 300 m of the channel of the Brahmaputra (Allison et al., 1998), but data from individual floods is not given.

When viewing a stack of floodplain silt, one must consider the frequency of floods and particularly the distance of the site from the channels delivering sediment. Most of the bank sediment along this reach of the Mekong is from within a km of the channel, and much of the thickness is accumulated from episodic floods depositing near-channel or levee deposits 0.5 to 2 m thick. It was learned that projecting layers horizontally in areas of poor exposure can lead to a serious misinterpretation, having observed that inclined silt layers associated with levees and channel fill are common in the bank stratigraphy.

7. Conclusions

Deposition of the 2–5-km wide floodplain of the Chiang Saen area, in otherwise rock-canyon reaches of the Mekong, was caused by lateral shifting of topography and tectonic downwarping along the active strike-slip Mae Chan fault. Lack of elevated gravel terraces and occurrence of a 1.7-Ma basalt flow in the bed of the river south of the fault suggest that the river has not significantly incised bedrock or fill during the Quaternary, and channel changes have occurred mostly by lateral migration.

Field observations of the riverbank combined with study of satellite images provide a beginning framework for understanding the historical fluvial geomorphology and archaeology of the area. Riverbank stratigraphy consists of sandy cobble gravel overlain by 5–10 m of sandy silt. Sandy silt layers are typically massive and 0.5–2-m thick. Some silt beds are inclined a few degrees indicating that levee and near channel deposits are a major component of the silt section. Identification of inclined beds shows that layers cannot be correlated horizontally through areas of poor exposure. The bedded silt layers are without buried soil horizons and suggest a short surface residence time (<few hundred years) before being covered by another flood deposit. Age of gravel and silt is presently unknown. Datable organic matter, such as charcoal, has been found only in the surface "A" horizon and within an infill deposit of a 5.6-m deep infilled moat of the 14–16th Century. The "A" horizon and infill contain brick fragments and pottery shards of *Lan Na* culture. An AMS C-14 age of 1475±38 cal yr AD is on charcoal from a hearth layer near the base of the infill deposit exposed in the riverbank at Chiang Saen Noi, At this site brick Buddhist monuments at the top of the bank are crumbling into the river as a result of bank erosion.

Neolithic and Bronze-Age artifacts eroded from the silt banks occur out of stratigraphic context, as lag material on the river shores. No cultural materials from the legendary Yonok kingdom (~0–700 AD) have been identified in the area, although this area is believed to have been an important migration route and site of river commerce during that time.

Satellite images show former meander and point-bar scrolls on the floodplain upon which the 14–16th Century towns and Buddhist monuments of the *Lan Na* Kingdom were built on the Laos and Thai side of the river. These patterns and the pervasive channel gravel deposits under the floodplain silts indicate major lateral migration across the floodplain area is more than 600 years old. A relatively straight channel with alternate bars presently courses through the area, rather than a meandering river, which suggests a change in river regime may have occurred in the Holocene, caused perhaps by land-use intensification, climate change, or tectonic activity along the Mae

Chan fault. Understanding the causes will require a more precise knowledge of chronology than is presently available.

Acknowledgements

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