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Sediment accumulation determined with ^{210}Pb geochronology for Strickland River flood plains, Papua New Guinea

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Abstract The Strickland River is the primary sediment source for the Fly River system, a large tropical river that ranks in the global top 20 for both water and sediment discharge. Over the past decade the Strickland sediment discharge has been gauged at many locations. Comprehensive studies are now underway to study the delivery, transport, and storage of sediment throughout this system. A key question regards the timing and rates of sediment accumulation on the flood plains. Here we present the first geochronological results from an intensive flood plain coring campaign conducted in 2003, outline our procedure for dating PNG sediment with ^{210}Pb geochronology, and summarize some early results from 36 cores. Flood plain accumulation rates appear to be highest upstream near the gravel–sand transition, low in the middle portion of the river, and higher again in the lower reaches of the Strickland near to its confluence with the Fly River. Overall patterns of sedimentation seem to be both spatially consistent, for series of cores collected along single flood plain transects, and temporally uniform in the sense that the nature of accumulation (constant or episodic) has not generally changed over the century of record.

Key words lead-210; flood plains; sediment accumulation; Strickland and Fly Rivers, Papua New Guinea

CONTEXT

The Strickland River drains a dynamic, mountainous region of Papua New Guinea's Western and Highlands Provinces (Fig. 1). Rapid, active deformation of the Papuan Fold Belt by the ongoing collision of the Pacific and Australian plates forms steep topographic expressions within weak sedimentary lithologies, which erode rapidly as a result of the up to 10 m of annual rainfall. Until recent mining in the headwaters of the Fly, the Strickland supplied at least 80% and 60% of the sediment and water discharge of the Fly River system, respectively (Dietrich *et al*., 1999).

There is a comprehensive research effort underway to monitor the supply, transport, and deposition of sediment throughout the Strickland River, including a study of flood plain sedimentation within the lowland portion of the river, similar to that previously undertaken for the Fly River (Dietrich *et al*., 1999). To quantify flood plain sediment accumulation over the last century, we conducted an intensive flood plain coring campaign to collect core samples for the application of ^{210}Pb geochronology. This work was closely coordinated with another study of the geochemistry of sediment cores, which will ultimately use duplicate cores to provide an independent means of dating sedimentation over the last decade (Apte *et al*., 2003; Swanson, *et al.*, 2004). Because ^{210}Pb is a naturally occurring radionuclide (half-life 22.3 years) derived from radon decay in the atmosphere and soil, and recent changes to the total sediment load of the lower river are minor (<10% over the past decade), ^{210}Pb systematics would not be substantially affected by slight changes in sediment efflux or source. This paper summarizes our first results from such analysis, based on a recently analysed subset of 36 cores. We anticipate that the preliminary interpretations presented here will be improved in the future with the addition of data from more cores, the development of a more sophisticated understanding of the ^{210}Pb systematics during floods, a better understanding of the timing and mechanics of flooding (from gauging records), and with the inter-comparison between ^{210}Pb results and accumulation rates derived from the aforementioned geochemical data.

THE FIELD CORING CAMPAIGN

In June 2003, we conducted a sampling campaign along several hundred of kilometres of the Strickland River flood plain. Five transect locations were selected along historically straight channel reaches (Figs 1 and 2) that had been previously surveyed in 1997. At these locations, transects perpendicular to the channel were cleared for distances of 100–450 m into both sides of the flood plain. These transects were surveyed to characterize the topography, and sediment cores were extracted every 25 or 50 m (from 0 to 100 m and >100 m, respectively). Cores were collected with a specially constructed 105-cm length, 2.5-cm diameter, thin walled soil probe, using field techniques specifically tailored for sampling of partially saturated river flood plains. Supplementary large-diameter cores were collected using several additional coring devices. Recovery was typically excellent, with most cores approaching 80–100 cm in length (in shorter cores, a hard sediment plug blocked the cutting head, preventing sediment entry). In addition to the five straight sections, we collected five additional flood plain transects across sinuous channel segments and one along the banks of an oxbow lake (Fig. 2). Together, the ~200 cores collected along these 11 flood plain transects should characterize a wide range of channel geometries and conditions, timing, and rates of sediment accumulation along hundreds of kilometres of the Strickland River.

LABORATORY METHODS

The cores were packed in a horizontal position, shipped by air freight to the University of Washington, X-rayed to document stratigraphy, and archived in a cold room. Some of these cores were then cut at 2-cm intervals for analysis. Our laboratory procedure for establishing the geochronology of flood plain sediment is to dry the resulting 8–12-g depth incremental samples for 24 hours at 80°C and split the homogenized sediment samples for grain size analysis and ^{210}Pb geochemistry.

Particle size analysis involved duplicate runs for sizes <250 μm, separated by wet sieving, on Micromeritics 5100 Sedigraphs. Because Sedigraphs measure the X-ray opacity of a settling column over time, they can accurately measure the mass distributions of very fine particles, including a measurement of particle mass <1 μm, providing precise measurement of the clay fraction available to adsorb ^{210}Pb. Our Sedigraph procedures include a number of stirring, drying, and sonic bath cycles in a

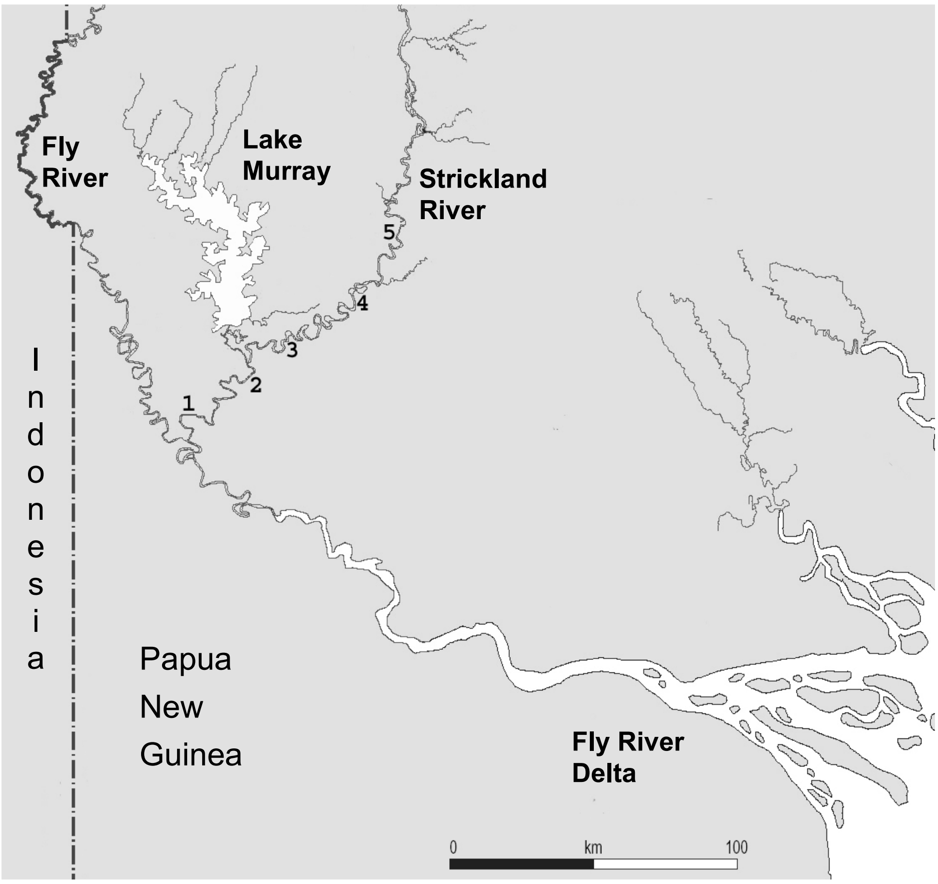

Fig. 1 Location of the Strickland River within PNG and the Fly River system. The five primary flood plain transect locations, shown as numerals 1–5, are straight reaches of channel selected to duplicate coring done by previous sampling work in 1997.

weak sodium metaphospate solution, a procedure designed to disperse clay nodules often found in flood plain soils. Sample concentrations and machine settings are selected to maximize the accuracy of determining the mass fraction of clay (<4 μm), which has been demonstrated to account for the majority of ^{210}Pb activity of fluvial sediment (Aalto & Nittrouer, 2005; Goodbred & Kuehl, 1998).

The activity of ^{210}Pb is determined by counting the alpha activity of the ^{210}Po daughter. This approach gives precise measurements of ^{210}Pb activity with a sample size of only ~5 g (in contrast to the much lower precision of and tens of grams required for direct gamma assay of ^{210}Pb activity). Furthermore, the ^{210}Po daughter can be selectively leached from the exterior of the mineral grains to measure only mobile, exogenic ^{210}Pb activity, not mineral-locked, endogenic activity bound within the grains, that can represent significant noise—more than three times that of the exogenic component for radium-bearing sediment (Aalto & Nittrouer, 2005). We leach samples on a hot plate with 12 N nitric and 6 N hydrochloric acids, autoplating ^{210}Po onto silver planchetes suspended in a mild HCl solution (Nittrouer & Sternberg, 1981). These samples are then counted for ~48 h in alpha spectrometers. Care is taken to maintain consistent leaching of mobile ^{210}Po by matching acid volumes to sample masses and avoiding excessive heating and dissolution of the samples.

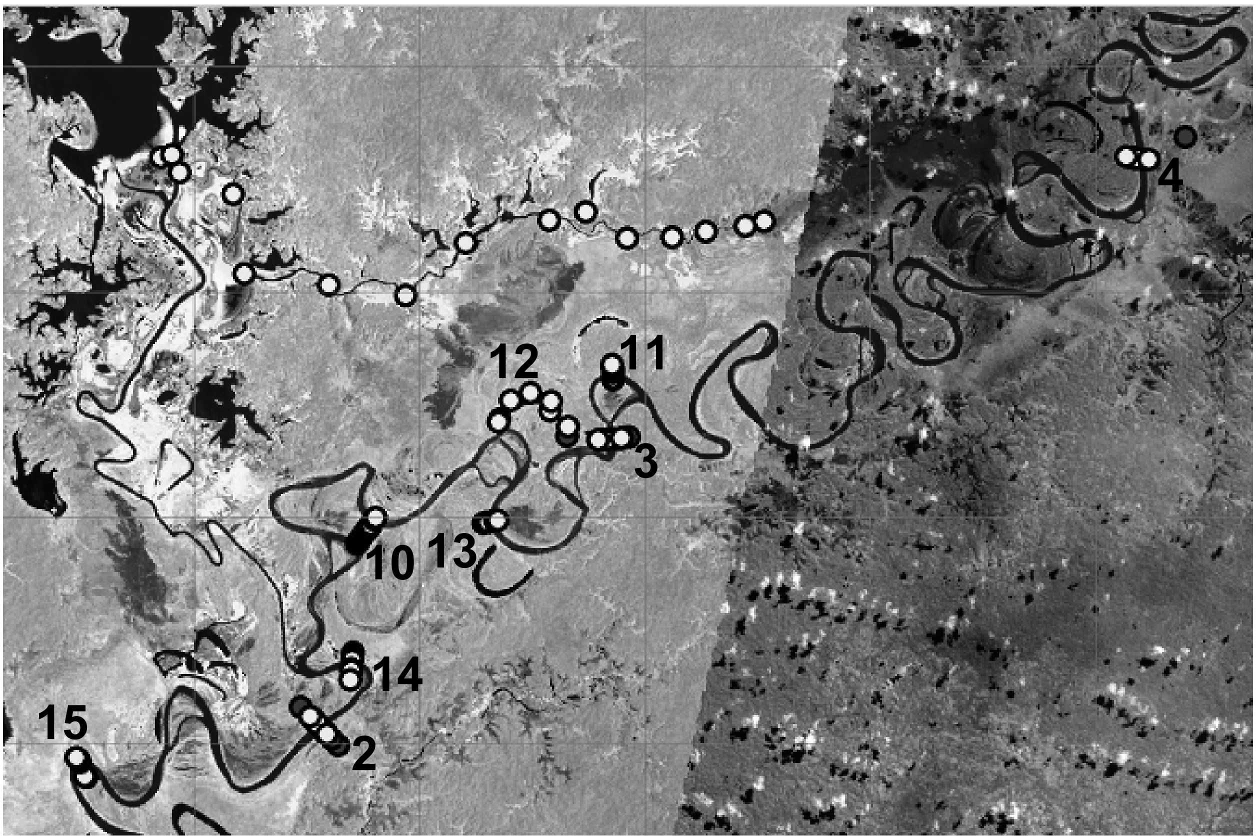

Fig. 2 Zoom map of flood plain transect locations 2–4 within the central portion of the Strickland River, depicting additional transects (10–15) taken to expand upon previous work. Exact coring locations are depicted (circles). Cross hatching is 10 km in scale.

CONSTRUCTION AND INTERPRETATION OF 210-PB PROFILES

Our analytical procedure is to make 8–20 measurements of clay-normalized excess (XS) ^{210}Pb activity at many discrete depths throughout a core to deduce what rates and/or timing of sediment accumulation best explain that activity profile. This interpretive methodology follows the "CIRCAUS" approach (constant initial river-reach clay activity, unknown sedimentation) that we have now tested for five different river systems (Aalto, 2002; Aalto *et al.*, 2002, 2003; Aalto & Nittrouer, 2005). The basic concept is to specifically measure the activity of mobile ^{210}Pb, which adsorbs primarily to clay surfaces. If the XS portion of this activity due to soil radon decay can be determined and the XS deconvolved into the river sediment and meteoric rainout components, it is then possible to identify features and trends in the XS activity profiles that can precisely quantify the rates and/or dates of the associated sediment accumulation.

Three system-wide unknowns must be determined for an effective application of ^{210}Pb geochronology to flood plains: meteoric fallout rate, supported background activity, and initial concentration of XS ^{210}Pb activity in river sediment carried over bank during floods (He & Walling, 1996; Walling *et al.*, 1992). Cores taken from elevated terraces along the Strickland River exhibit a supported "meteoric cap" ^{210}Pb activity of 22–24 DPM (decays per minute) per cm^2 (Fig. 3(a)), an inventory that should vary little over the study area (the atmosphere is well mixed on a daily basis

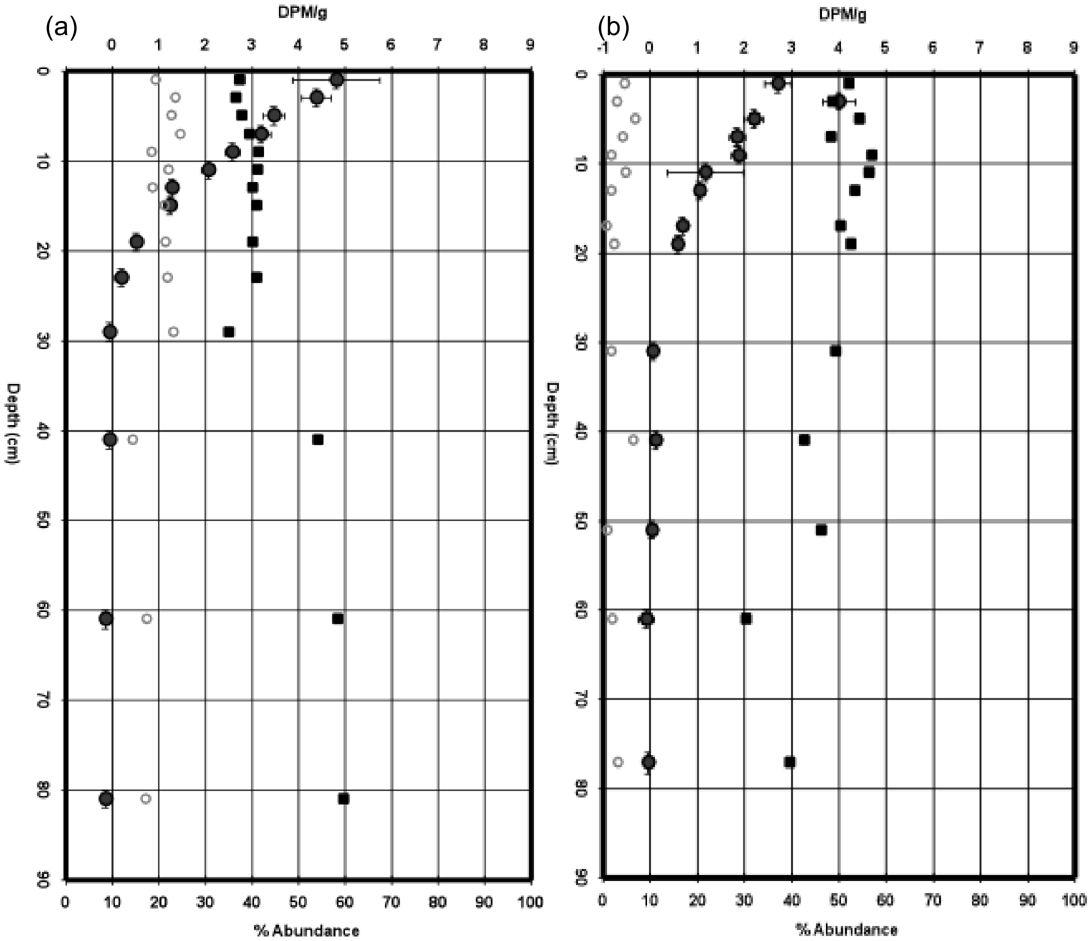

Fig. 3 Cores with low sediment accumulation rate. Large filled circles are clay-normalized excess ^{210}Pb activity (decays per minute per gram clay), black squares are percent clay (particles <4 µm), and small open circles are percent sand. Error bars and depth intervals are shown for activities. (a) Terrace core, elevated well above the modern flood plain. Meteoric rainout rate of ^{210}Pb supports a "meteoric cap" XS activity of 23 DPM per cm^2, a rate found in other terrace cores. XS activity is mostly adsorbed in the top 10–15 cm. (b) Flood plain core "4 R – 150 m," which shows no evidence for sediment accumulation—the meteoric cap XS activity of 24 DPM cm^{-2} closely mirrors the signature of a non-deposition terrace core.

over 100 km scales). To determine supported background activity, a "plateau activity" plot (Aalto & Nittrouer, 2005) was made for clay concentration *vs* all data from deeper zones of uniform activity (the slope is set by all "plateau" data points and the intercept is adjusted to the terrace data known to be at background activity). The resulting supported activity line (activity (DPM g^{-1}) = (0.19 × clay) + 0.50) indicates that Strickland River sediment does not produce much radon (or contain much radium) within the fine fractions, as compared to other fluvial environments with radon-producing clays (Aalto & Nittrouer, 2005). For each analysed core depth, the predicted supported activity from this line was subtracted from the total measured activity to determine the XS activity per gram of clay at each discrete depth. Finally, the XS activity of fresh river sediment recently transported onto the flood plain ranged from 1.2 to 1.4 DPM g^{-1} clay, as determined at six locations throughout the system.

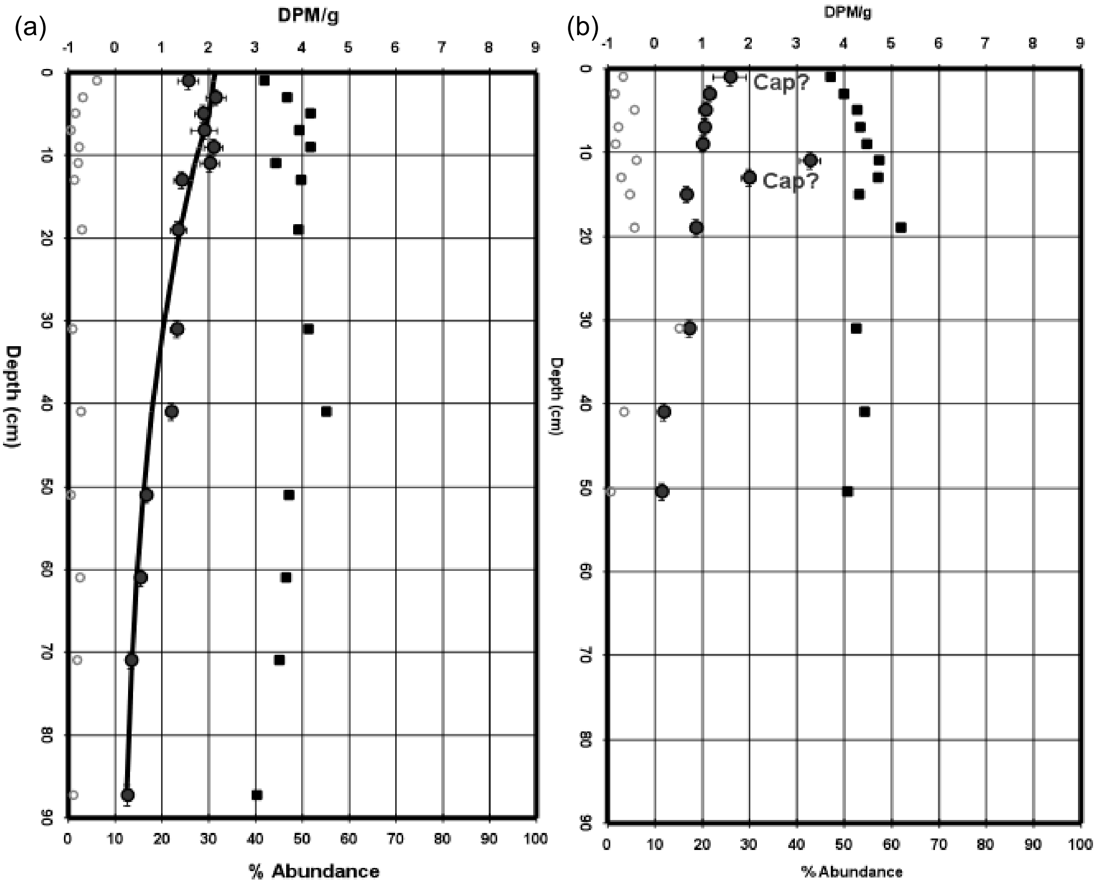

Fig. 4 Cores with higher sediment accumulation rates, symbols as in Fig. 3. (a) Flood plain core "5 L – 250 m", which shows evidence for constant sediment accumulation at 1.2 cm year^{-1} (fit line), a higher rate typical for this transect. (b) Flood plain core "1 L – 200 m", which shows evidence for two episodes of recent sediment accumulation above old (XS = 0) sediment deeper than 40 cm. The top 10 cm of sediment dates to 2000 (±4 years) with a meteoric cap that dates to 2001. Below that, the sediment from 10–35 cm dates to 1990 (±5 years), with a 1994 cap. This is consistent with the recent arrival of two pulses of sediment, the first in the early 1990s and the second within the last few years—a characteristic result for cores from some transects.

DISCUSSION OF RESULTS AND FUTURE WORK

Based on the preceding ^{210}Pb systematics, interpretations were made from the activity profile data of 36 cores. Preliminary analysis suggests that significant portions of the flood plain have received little or no sediment over the past 100 years. Cores from such regions (Fig. 3(b)) essentially mirror the profiles in terrace cores: a fully-grown meteoric cap developed within the first 15–20 cm that overlies old sediment of zero XS activity (> 3–4 half-lives or 67–90 years in age). Other areas have experienced rapid sediment accumulation, either a single massive deposit or constant at very high rates (Fig. 4(a)). In such cases the accumulation rates are so high that the core bottom (at 80–100 cm depth) ^{210}Pb activity is still well above the supported activity. Another pattern emerges where higher XS activity deposits overlie old sediment of zero activity (Fig. 4(b)). In these cases, there appears to be a change in the rate of deposition.

The patterns described here are derived from early interpretations of 36 cores. Additional depths from these cores will be analysed to better document the exact shape of the ^{210}Pb XS activity profiles and substantiate the interpretations presented in this paper. More importantly, more than 150 cores remain to be analysed, four times the number that have been evaluated to date, and the inter-comparison with geochemistry cores remains. A smaller core set is also available for the Fly River. New profiles from these cores will serve to assess and greatly expand upon the current profiles from a subset of cores selected from six flood plain transects along the Strickland River.

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