MASS MOVEMENT EVENTS IN THE SOUTH-WEST SYDNEY BASIN DURING THE HOLOCENE

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INTRODUCTION

Mass movement on hillslopes has rarely been reported in the Sydney Basin. Dunkerley (1976) analysed small landslides formed on the Wianamatta Shales in the Razorback Range near Picton to the south-west of Sydney whilst Young (1977, 1978), after Walker (1963), analysed the debris deposits below the Illawarra Escarpment near Wollongong, south of Sydney. Recent research on hillslopes in the Lake Burragorang catchment (Sydney's major water supply) which are formed on Hawkesbury sandstone and Narrabeen Group rocks marking the southwestern margin of the Sydney Basin has revealed further evidence for mass movement events. The area is unique in that land use is dominantly National Park or Catchment Protected Area with minimal disturbance except in isolated localities where underground coal mining has triggered subsidence of the rock above (Cunningham 1988). Radiocarbon dating of hillslope sediments was used in this study to obtain an estimate of the timing of deposition, as the previous studies were not able to, or did not attempt to, constrain the age of movement beyond modern events.

The study area is a hillslope at Blue Gum Creek, a tributary stream within the Nattai catchment which drains an area of 44.6 km^2 and has headwaters at Thirlmere Lakes, 7 km south-west of Picton (Figure 1). The study site is on the south-west side of the valley (34° 13.19' S, 150° 29.63' E) and includes the upper, mid and lower slopes, foot slopes and valley floor. Cross-bedded quartzose units of the Hawkesbury sandstone form the ridge tops and cliffs and interbedded quartz sand and conglomerate units (probably also Hawkesbury) form the upper slopes. Interbedded shales and sandstones of the Narrabeen Group underlie the mid slopes and extend to the valley base (Ray 2003, Rose 1966). Approximately 50 m upstream of the study site a small tributary draining the hillslope enters Blue Gum Creek.

METHODS

Nine pits and an auger hole were positioned along a transect from the base of bedrock outcrop on the upper slopes, down into the valley floor. The pits were positioned by slope morphology (i.e., mid slope, lower slope, foot slope, valley floor) at intervals no greater than 100 m apart and the auger hole was located on the floodplain adjacent to Blue Gum Creek. The depth of the pits ranged from 90 cm to 365 cm with six of the nine reaching bedrock. The auger hole was thought to have reached bedrock. The stratigraphy of each pit was noted and the layers analysed in the field for texture, grain size, pH and colour (Munsell). Samples were taken and processed in the laboratory for bulk density and gravel:sand:mud ratio (dispersed and wet sieved before oven drying and weighing). Stratigraphic interpretation of geomorphic units was based on sediment texture (lithofacies), character and position in the landscape.

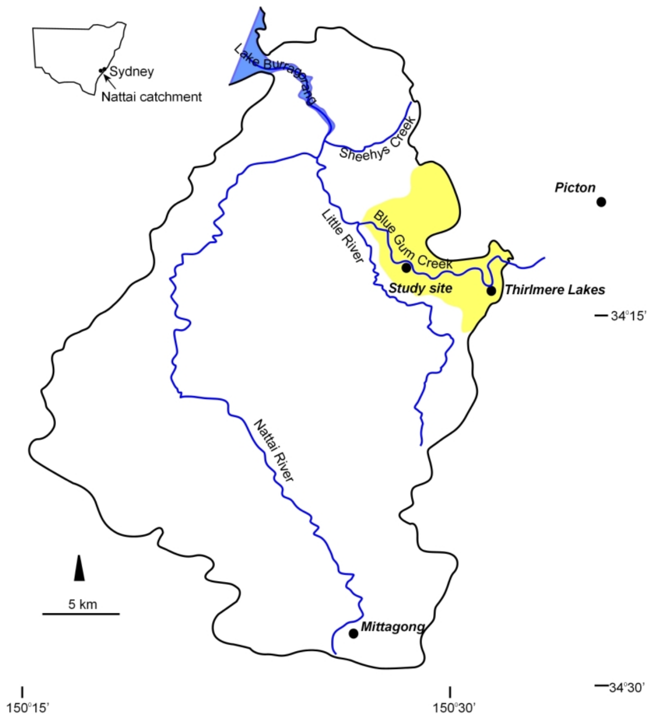

Figure 1: Nattai catchment showing the location of Blue Gum Creek and the study site.

Charcoal samples for radiocarbon dating

were taken from two pits and the auger, and from below a large boulder positioned within an adjacent gully. The charcoal was hand-picked from the sediment (> 500 μm) and forwarded to the University of Waikato Radiocarbon Dating Laboratory where standard chemical pre-treatments were employed before dating.

The elevation and distance of the pits and auger was determined by tape and clinometer survey tied to a benchmark of known elevation (established through differential GPS) at the study site. The survey was extended across the valley in a transect to each ridge top to establish the valley shape and slope morphology. Additional information on the geology of the site was added through analysis of bedrock outcrop along the transect and the bedrock encountered in the pits.

RESULTS

Valley morphology

The Blue Gum Creek study site shows an asymmetrical valley with sediment accumulating on the south-west slope (concave profile) and in the valley floor, compared with mostly outcrop on the north-east slope (convex profile). Slope angles on the south-west slope range from 30° to 40° on upper slopes; 10° to 30° on the mid slopes and 5° to 10° on the lower slopes. The foot slopes and floodplain are undulating with slopes ranging from 0° to 7°. Analysis of the geology revealed an easterly dip of 6° on the Hawkesbury and Narrabeen rocks. This implies that the south-west slopes are more likely to be susceptible to failure. It is possible that the study site cuts across the distal end of an alluvial fan complex that forms the present day lower foot slopes in the small tributary adjacent to the study site.

Valley stratigraphy

The sediments on the hillslope and in the valley floor can be broadly classified into five geomorphic units (or lithofacies) (see Figure 2):

1. *Colluvial mantle*, which occurs from the upper slopes to the lower slopes (Pits HMU to HBL). The mantle is characterized by large poorly sorted angular gravels within a sand-mud matrix (bulk density of the matrix material = 0.88-1.49 g cm^{-3}). The uppermost 5-7 cm is highly organic but this may be related to the bushfires in December 2001. Surface gravels decrease in size from average 18 cm to 6 cm downslope on the mid slope (with occasional larger boulders). On the lower slopes, the smaller gravels are absent and only partially buried large boulders can be found. A gully which dissects the mantle adjacent to the transect has large boulders (B-max > 1.5 m) composed of Hawkesbury sandstone chaotically arranged on the slope. Adjacent to, and below, the gully are lobes of poorly sorted gravels and boulders (and sands) with steep slip faces;
2. *Fluvial sands*, which occur in the base of the valley from around 170 cm below the surface. The thickness of the unit in Pit HFSU is 115 cm, increasing to 180 cm in the auger. The sands are typically coarse, moderately well sorted and clean, with only a slight brown or grey organic stain (clay content < 8 %). Rounded to sub-rounded gravels of B-max = 48 mm were found in the unit in Pit HFSL. A medium clay lens (10 cm thickness) coarsening upwards to sandy clay loam was encountered in Pit HFC. The clays were grey with mottles indicating a much lower energy fluvial environment compared to the surrounding sands. The water table was intersected at a depth of 2.8 m despite prolonged drought conditions;
3. *Floodplain deposits*, which overlie the fluvial sands and form the surface of the valley floor (Pit HFC and Auger HFP). These deposits consist of massive brown-black clay loams and sandy clay loams, 140-174 cm in thickness. The sediments are typical of overbank, floodplain deposition whereas the modern channel is transporting a sheet of coarse sand similar to the fluvial sand unit below;
4. *Intermixed deposits*, which consist of massive orange clayey sands (sub-angular to sub-rounded) with small well-rounded pebbles dispersed throughout, alternating with a thin angular gravel lens (B-max = 4 cm). This unit is termed intermixed as it is difficult to say with certainty the origin of the material i.e fluvial or colluvial, or alluvial fan; and,
5. *Lithified gravels*, which were encountered in the base of Pit HFSU below 325 cm. The thickness of this unit is at least 40 cm (as the pit did not reach bedrock). The sediments are characterized by sub-angular to sub-rounded gravels in a sandy clay loam matrix. The average bulk density of the unit is 2.006 g cm^{-3}, much higher than the clayey sands above (1.46-1.62 g cm^{-3}) and other units in the valley.

Radiocarbon ages

Radiocarbon ages for the four charcoal samples taken from selected sites on the hillslope are presented in Table 1. All ages are Mid - Late Holocene indicating that movement on the hillslope and sedimentation in the valley is relatively recent. The very young age in Pit HML may be due to tree fall and turnover of the soil. Conversely, the charcoal sampled in Pit HBL may have been subject to bioturbation. The ages of the gully fill and auger are considered to be reliable, indicating that movement of the boulder down the slope occurred around 1,400 years BP and sedimentation of 3.54 m in the valley has occurred within the last 7,000 years BP. The lithified unit in the base of Pit HFSU is expected to be older through the interpretation of stratigraphy (i.e., positioned below the fluvial sand unit).

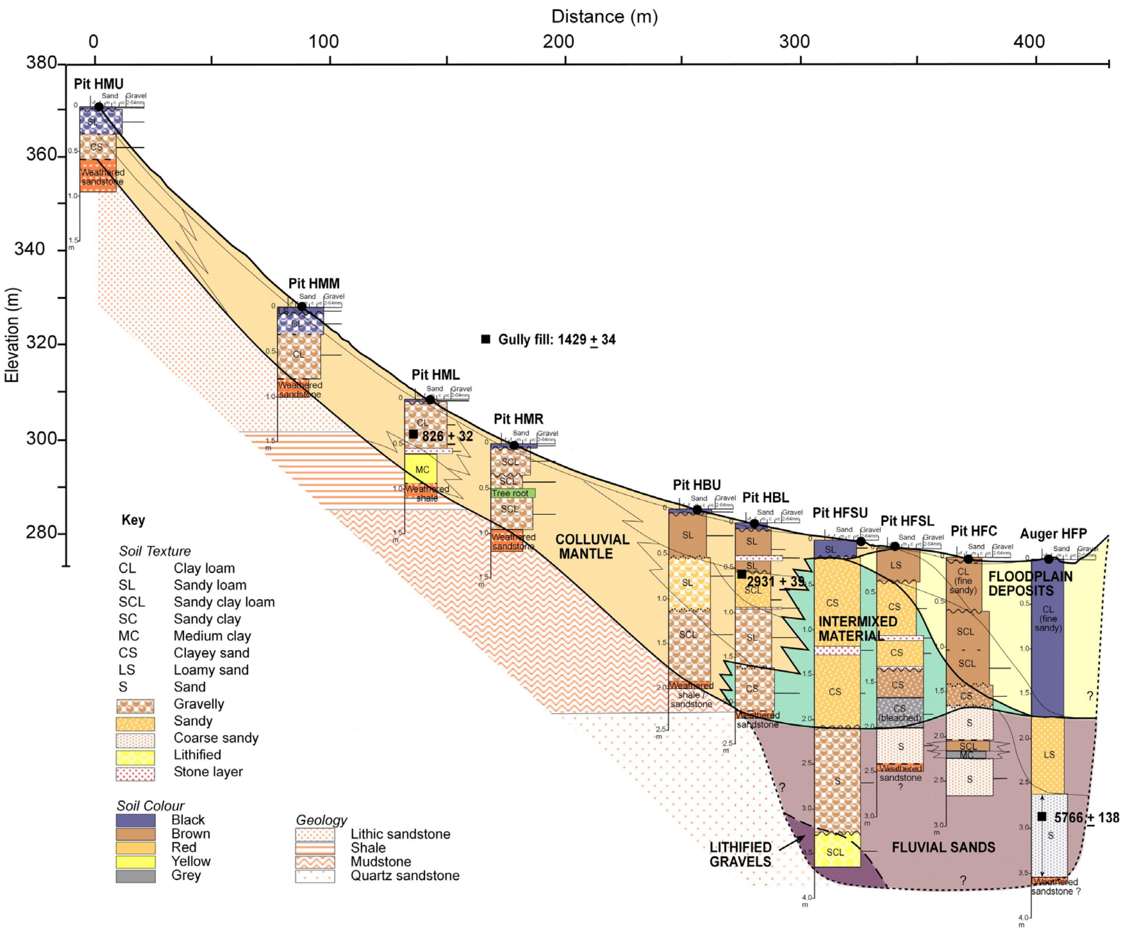

Figure 2: Profiles for each pit/auger hole at the Blue Gum Creek study site. Interpretation of geomorphic units (shaded) is based on sediment texture (black lines), character and position in the landscape. Radiocarbon ages (years BP) and sample locations are indicated by solid squares (VE = 1.8).

Table 1: Radiocarbon ages at Blue Gum Creek.

Sample location and depth/ (geomorphic unit)	**Lab. Code**	**Radiocarbon age (years BP)**	**Calibrated age (years BP)/(probability)**
Pit HML, 30-40 cm below the surface (colluvial mantle)	Wk 15040	826 $\pm$ 32	765-665 (95.4 %)
Fill material found exposed below a boulder in the gully (colluvial mantle)	Wk 15039	1,429 $\pm$ 34	1,390-1,260 (95.4 %)
Pit HBL, 50-65 cm below the surface (colluvial mantle)	Wk 15041	2,931 $\pm$ 39	3,210-2,920 (95.4 % / 91.8 %)
Auger HFP, 268-354 cm below the surface (fluvial sands)	Wk 15042	5,766 $\pm$ 138	6,900-6,200 (95.4 %)

DISCUSSION

The characteristics and arrangement of sediments on the Blue Gum Creek hillslope point to mass movement events by debris flows and rock fall. The site matches the description given by Costa (1984) on the geomorphology of debris flows namely, steep upper and mid slopes of > 15°, overlying the interbedded sandstone and claystone sediments of the Narrabeen Group, which are prone to weathering and failure, mud content of the sediments of between 10-20 % giving rise to a slurry when wet, and the deposition of sediment lobes at the base and sides of drainage lines with the largest boulders at the front of the surge forming steep slip faces. The evidence for rockfall is through the chaotic arrangement of large boulders composed of Hawkesbury sandstone (the uppermost unit which forms the exposed cliffs) on the mid and lower slopes overlying colluvium. It seems likely that the impacts from the boulders rolling and sliding down the slope would trigger further mass movement of the colluvial mantle material.

Plate 1: Hawkesbury sandstone boulders chaotically arranged within the gully as a result of rock fall (photo taken from the gully side). Charcoal within the surge material below the boulder was sampled for radiocarbon dating (Wk 15039) to give the timing of movement.

The Mid – Late Holocene timing of mass movement on the hillslope and sedimentation in the valley is significant. Prior to 7,000 years BP, the valley was eroded to bedrock, at least in parts, with the lithified unit in Pit HFSU possibly representing an older valley fill. Post-7,000 years BP the valley began to aggrade (minimum sedimentation rate of 0.46 mm a^{-1}) which implies an abundant sediment source from the headwaters, tributaries and surrounding slopes. The radiocarbon dates show that sediment movement from the upper slopes to the lower slopes at the Blue Gum Creek site was from at least 3,000 years BP, but movement is likely to be older as the dates come from the upper parts of the pits. The problem is that there is little evidence for the incorporation of the colluvial gravel material into the fluvial sediments in the valley, except perhaps the thick sand and gravel unit in Pit HFSU, which shows angular to sub-rounded gravels. It appears that the coarser material is now being stored on the lower slopes and only the sands, muds and organics are winnowed through to the fluvial system.

The evidence for mass movement events during the Mid - Late Holocene is contrary to the widely held view that landscapes during this part of the Holocene were relatively stable especially during the past 3,000-4,000 years (Williams 1978). Instead, this study provides support for Mid – Late Holocene valley fill aggradation in other areas of southeastern Australia (e.g., Fryirs & Brierley 1998). Whether the mass movement events were triggered by broader changes in regional climate, or are a response to repeated isolated large magnitude rainfall events (e.g., Rutherford *et al.* 1994, Young 1978), or are simply a response to intrinsic thresholds as argued by Prosser *et al*. (1994), is unknown. Given the scale of movement on the slopes and the extent of valley aggradation, which is clearly a response to sediment supply from within the catchment, exceedance of thresholds seems unlikely. Further investigation is warranted to determine the frequency and impact of large magnitude rainfall events compared to regional climate change.

CONCLUSIONS

Recent research in the Lake Burragorang catchment, located in the south-west of the Sydney Basin, has revealed evidence for mass movement events on hillslopes and sedimentation in the valley during the Mid – Late Holocene. The study area, a hillslope at Blue Gum Creek, is characterized by five geomorphic units including a colluvial mantle formed by debris flows and rock fall, and fluvial sands in the valley which were deposited from 7,000 years BP. This study is the first to attempt to identify the timing of mass movement events on hillslopes beyond modern events. Mass movement and valley aggradation may be a response to a culmination of isolated large magnitude rainfall events or alternatively may reflect broader regional climate change during the Holocene.

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