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Using geochemical stratigraphy to indicate post-fire sediment and nutrient fluxes into a water supply reservoir, Sydney, Australia

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Abstract Wildfire can lead to increased fine-sediment (and associated nutrient) delivery to water bodies downstream of burnt terrain. Burnt soils in the drainage basin of Sydney's principal water supply reservoir show enrichment in nutrient and trace element properties (Ca, Mg, P, K, Zn and Pb) in association with mineralization of organic matter. This work aims to explore the potential for using geochemical tracers to quantify the impact of severe wildfire on downstream sediment dynamics and further, to see if a useful record of changing river basin sediment dynamics is recorded in reservoir sediment. Whilst fire-induced changes in geochemistry appear to offer a useful means for discriminating surface sediment sources with respect to fire severity, comparison with the geochemical stratigraphy of the lake is hampered by variable sedimentation dynamics linked to water level fluctuation and overprinting of source signatures by process-related transformations. Further exploration of the factors affecting catchment source signatures and linkages within the system are required before the sedimentary record can be used to full advantage.

Key words Australia; nutrients; reservoir; sediment; tracing; wildfire

BACKGROUND

It has been suggested that wildfire events are increasing both in frequency and severity in fire-prone areas of the world as a result of climate change (Pausa, 2004). Whilst documentation of wildfire impacts on river basin sediment redistribution rates and processes is improving (e.g. Shakesby *et al*., 2003; Wallbrink *et al*., 2005; Blake *et al*., 2006; Doerr *et al*., 2006) there is a dearth of data to test the above hypothesis in terms of river basin sediment transfer. This work explores the role of fire-modified geochemical sediment tracers in recent sedimentary archives to fulfil this need in an Australian context.

Recent work has shown that wildfire impacts on runoff dynamics and sediment generation in forested river basins is complicated by enhancement or destruction of water repellent compounds in the soil (Doerr *et al*., 2006). Evidence presented from recent fire events in Sydney's water supply catchments suggest that severe burns with resultant higher surface soil temperature may lead to the development of a thin wettable surface soil layer over a strongly repellent subsurface soil, which can lead to mass shedding of the thin layer of surface soil following prolonged rainfall. Burnt material, with tightly bound mineral and organic components (Blake *et al.*, 2005), is rapidly conveyed to the drainage network via highly conductive ephemeral streams and gullies (Shakesby *et al.*, 2003). The timing of post-fire heavy rainfall is the critical driver for mass wasting by this process, which appears not to have occurred recently in the study area. Indeed, tracer work using mineral magnetic properties has indicated that large quantities of burnt material liberated from ridge-top and upper slope environments during wildfire events over the past few decades is stored for extended periods of time in footslope environments (Blake *et al.*, 2006). Against this background, this work aims to identify whether geochemical signatures can be obtained for severely burnt surface material, as compared to moderately burnt and unburnt, and further to identify if these signatures are present in downstream sediment sequences to enable the importance of severe wildfire event on downstream sediment dynamics to be quantified.

STUDY AREA

Work was undertaken in the Little River basin which drains into the Nattai River, a major input to Lake Burragorang, Sydney's principal water supply reservoir (Fig. 1). Lake Burragorang was formed in 1960 by the impoundment of Warragamba Dam. Water levels have fluctuated over the past 40 years in response to local climatic conditions. The basin is underlain by Triassic Sandstones and is a plateau-gorge type landscape with the lower reaches incised into Permian Mudstones (Tomkins *et al.*, 2004). Surface soil materials are typically sandy to sandy loam. The basin is largely forested with a variety of native eucalypt species (Shakesby *et al.*, 2003).

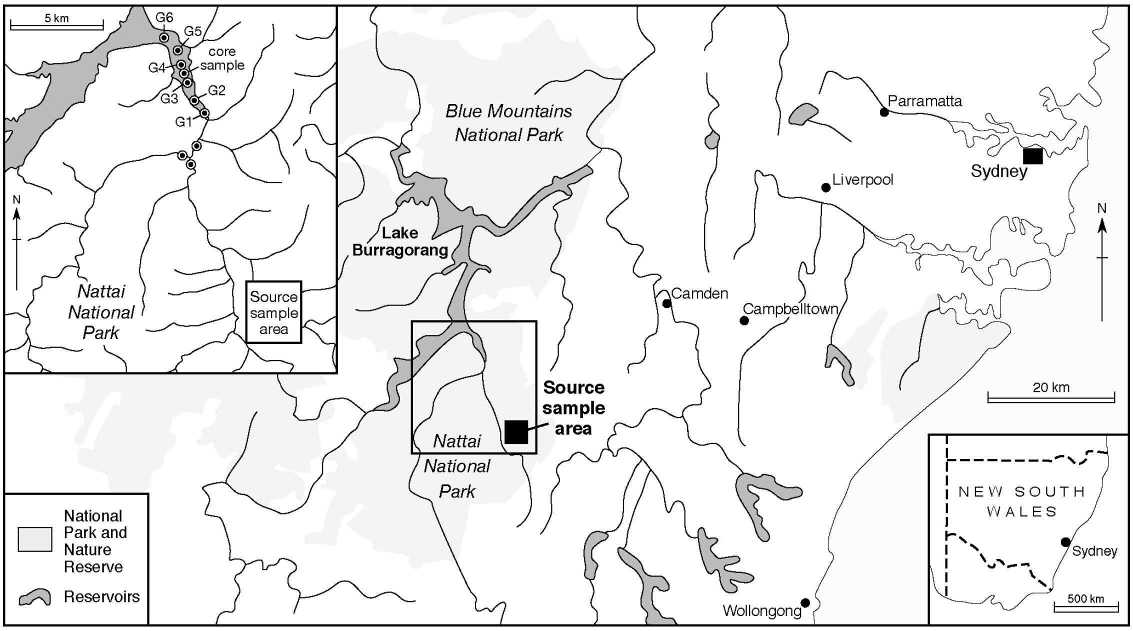

Fig. 1 Location of study area and sediment sampling sites (inset).

Fieldwork followed wildfire events in December and January 2001–2002 which were reported to be extreme for the locale. Fire events were followed by moderate intensity rainstorm events from January to May 2002 which delivered significant amounts of surface-derived material to the river network and reservoir (Wallbrink *et al*., 2005).

METHODS

Sampling locations are shown in Fig. 1. Samples of sediment source material were collected within the gorge-dissected landscape, from ridge-top and footslope units representative of areas experiencing contrasting fire severity, as described in Shakesby *et al*. (2003). Each sample population was combined to produce representative, spatially-integrated samples for slope units of known fire severity (based on a vegetation destruction index). Samples of recent sediment deposits were collected from the downstream channel network, which, along with a series of grab samples collected from the channel and mouth of the Nattai River through the Nattai arm of Lake Burragorang, link the slope environment to the lake sediment column. The <10-μm fraction was extracted from each sample for direct comparison of geochemical properties. A percussion coring device was used to collect a 1.6 m sediment core from the reservoir floor. The core was divided into stratigraphic units (A–G, Fig. 2) and the <10-μm fraction extracted from each.

All samples were analysed for major and minor elements using a Philips PW1480 wavelength dispersive XRF system using a dual anode Sc/Mo tube and algorithms developed by CSIRO Land and Water. Lake sediment samples were further analysed for ^{137}Cs and ^{210}Pb concentrations by gamma spectrometry. The results of source and lake sediment samples only are reported in this contribution.

RESULTS AND DISCUSSION

Geochemical signatures of burnt source material

When exploring the impact of wildfire severity on the mineral magnetic properties of burnt soil material, Blake *et al*. (2006) demonstrated that source material signatures in relation to fire severity were to some extent overprinted by process-driven changes in properties. In the fire-impacted Nattai basin, this largely relates to storage of previously burnt material in footslope regions, where a unique signature develops in the surface and subsurface material, possibly in relation to storage diagenesis and/or the influence of subsequent wildfire events. Similar complications are observed in the geochemistry data set. In order to isolate the impact of wildfire on source material geochemistry the ridge-top soil samples from unburnt, moderately burnt and severely burnt soils were explored aside from the full dataset. Whilst this represents a simplification of sediment sources within the basin, it permits a direct link to be made between wildfire and changes in source signatures in this contribution.

Figure 2 (a)–(c) presents a series of bi-variate plots showing fire induced changes in the CaO and MgO, P_2O_3 and K_2O, and PbO and ZnO concentrations of the <10-μm

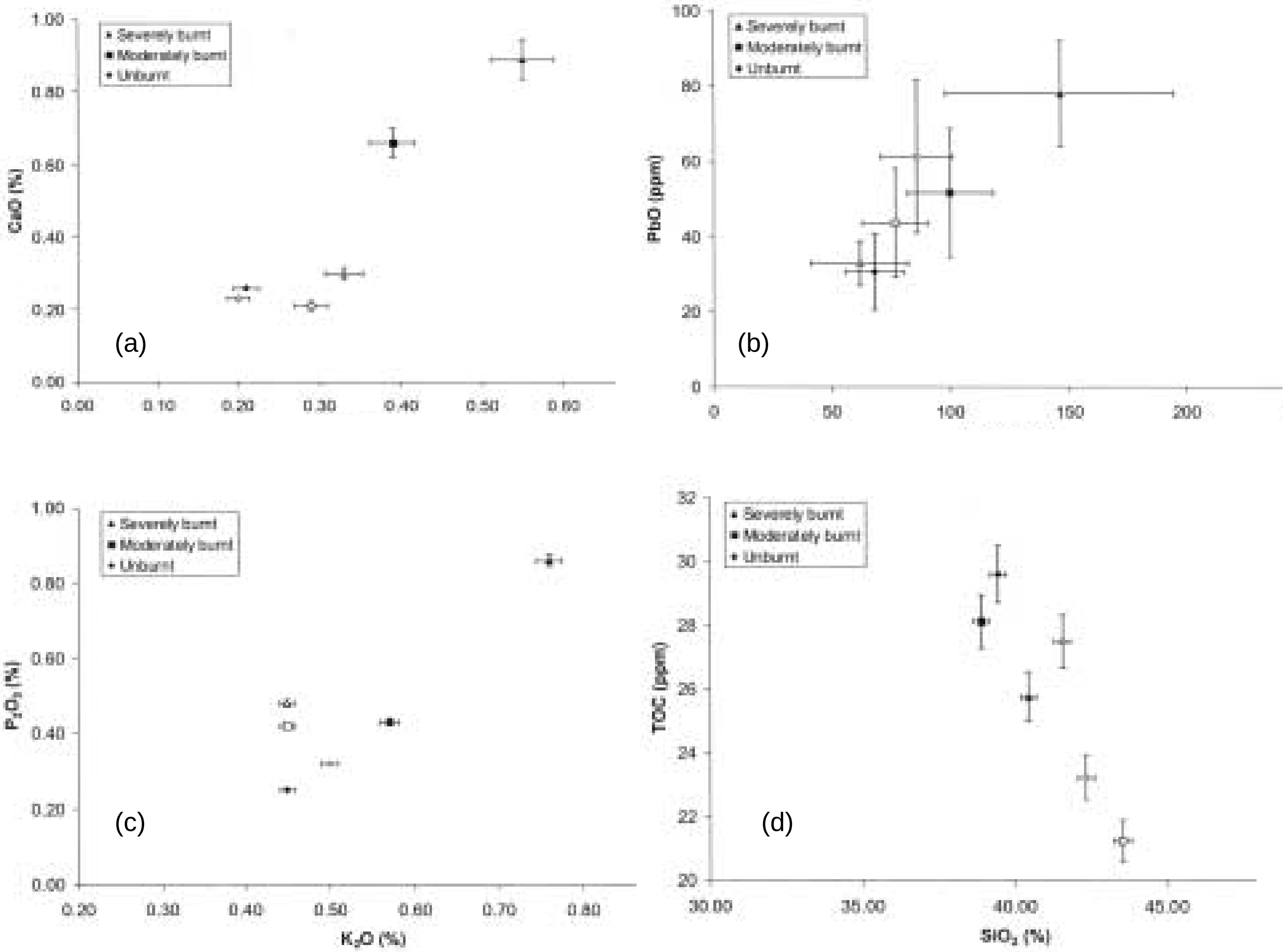

Fig. 2 Changes in geochemical properties of ridge-top soil under a range of burn severities (error bars represent analytical uncertainty), where filled shapes indicate surface and open shapes indicate subsurface material.

fraction of representative composite surface and subsurface soil samples under the three fire severity classifications (unburnt, moderately burnt severely burnt). Figure 2(d) indicates changes in ratio of mineral to organic matter. Clear increases in the concentrations of Ca and Mg are observed in burnt surface soil relative to unburnt surface and subsurface samples. Similar patterns are observed for P_2O_3 and K_2O. The severely burnt surface material has the highest concentration in all cases. This is in accord with observations by Harden *et al.* (2004) and Owens *et al.* (2006), who observed increased macronutrient concentration in mineral surface soil due to mineralization of canopy foliage and litter. The partitioning of these signals between mineral and organic/ash components of the surface soil presents an important consideration for tracing work that seeks to exploit wildfire-induced changes in properties. Although recent work has suggested that organic and mineral components of burnt soil material are transported in union (Shakesby *et al.*, 2003; Blake *et al.*, 2005), separation of sediment constituents must be considered in the interpretation of the source of downstream materials. The pattern shown by trace metals in the source materials is similar in terms of the surface response, although an increase in the concentrations of subsurface materials is also apparent. Previous studies indicate that trace metal concentrations may be enhanced due to mineralization of organic matter or reduced in response to vaporization at very high temperature. Data suggest the former mechanism led to the observed transformations during these events. Figure 2(d) shows an expected decline in organic matter in the burnt surface samples. The observed differences offer potential to discriminate sediment source with respect to fire severity notwithstanding the potential limitations outlined above. However, an important requirement is the preservation of geochemical signatures in downstream deposits, as explored in the next section.

Geochemical profiles in the lake sediment column

The above results indicate that fire-modified signatures may be used to trace sediment from landscape units that have experienced contrasting degrees of wildfire impact, providing that a reasonable range of source signatures in the system have been obtained. Unravelling the full complexities of process-driven transformations of signatures is beyond the scope of this contribution, but it is possible to explore the potential for interpreting the geochemical stratigraphy of the lake sediment column in terms of changing sediment source dynamics and fire history.

Figure 3 shows a schematic representation of the lake core stratigraphy based on laboratory observations (after Blake *et al*., 2004). The particle size properties of each core slice (Fig. 4(a)) support laboratory descriptions and suggest that the lower units comprise the original flood plain sediment of the drowned Nattai Valley (corroborated

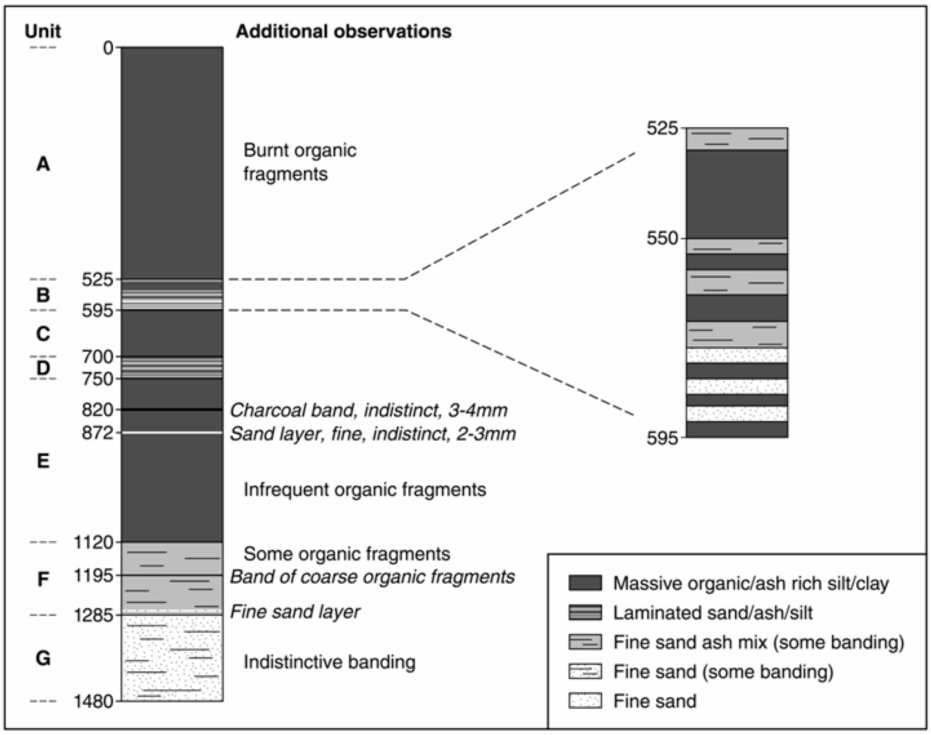

Fig. 3 Schematic representation of the Lake Burragorang sediment core.

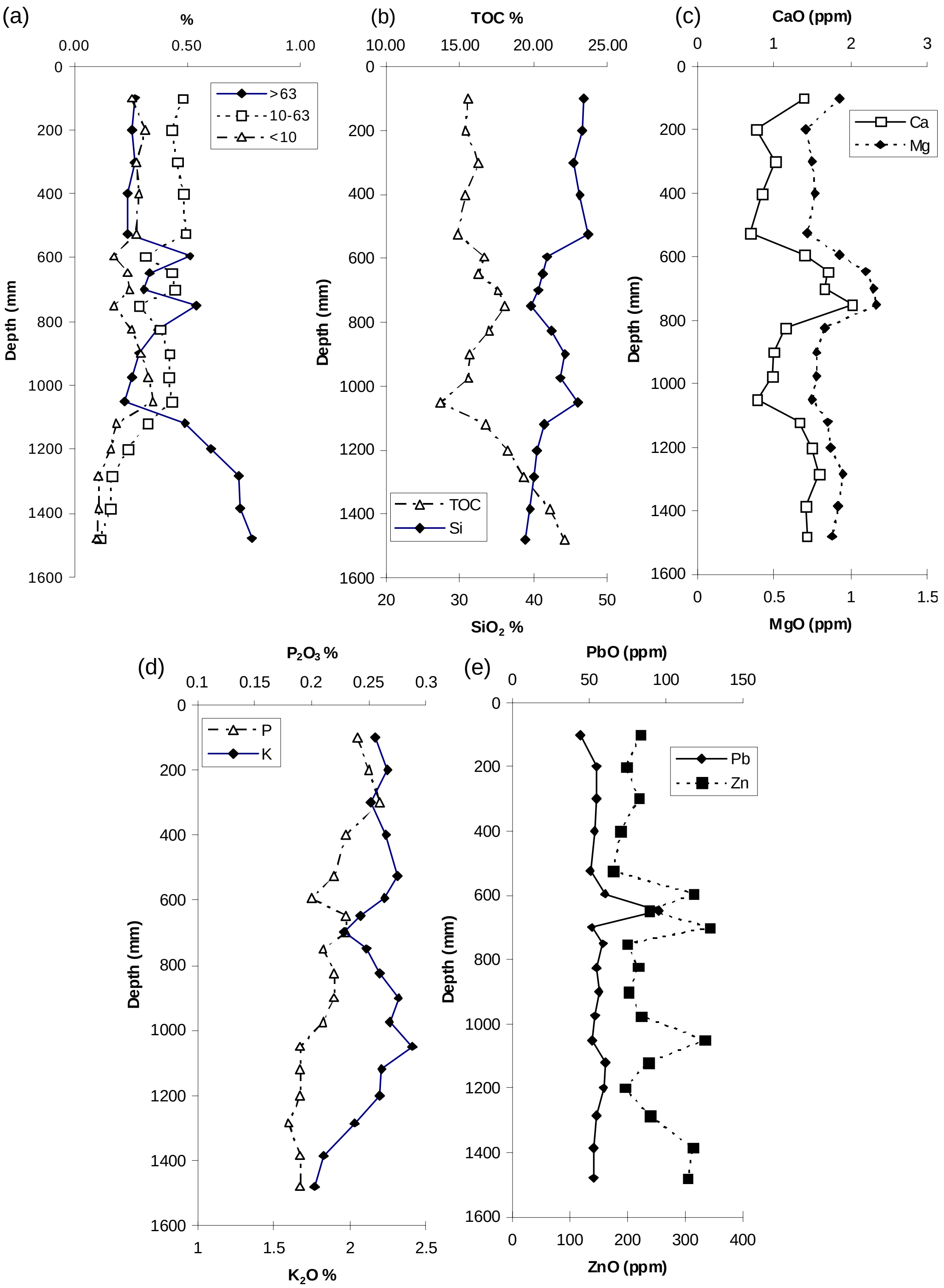

Fig. 4 Geochemical profiles of the sediment core taken from Lake Burragorang.

by ^{137}Cs evidence, not shown). It is suggested that the mid-core sandy layers correspond to two periods of low water level (during the latter of which the core site was exposed) associated with drought events in the 1980s. At this time the Nattai River inlet delta (i.e. the supply zone of sand) would have been in the proximity of the coring location. This implies that units E, C and A represent longer periods of lacustrine sedimentation. Given the fluctuations in water level during the history of the lake it is recognized that sediment deposition dynamics will have been strongly influenced by the proximity of the Nattai delta to the coring location. The geochemical profiles of the selected tracer properties are shown in Fig. 4(b)–(e). In general, the properties are enriched compared to source materials suggesting particle size controls below the <10-µm threshold. Comparison of the geochemical properties of units E, C and A indicates peak concentrations in CaO and MgO during the inferred 1980s lacustrine period. Units A and E have similar concentrations of CaO and MgO with an upward trend in the upper part of unit A which represents deposition following the 2000–2001 wildfire events. Patterns in PbO and ZnO also show peak concentrations in unit C. Profiles of P_2O_3 and K_2O show a dilution of signal in unit C and variable behaviour in units A and E. Differential behaviour of the key tracer properties suggests that, whilst the source signatures described in the preceding section indicate the important influence of wildfire on the geochemistry of mobilised slope material, additional factors are influencing the geochemical record of the lake sediment. Knowledge of changing sedimentation dynamics with fluctuating water levels and a more comprehensive appraisal of sediment source signatures across the drainage basin is required to permit robust numerical unmixing of downstream deposits and interpretation of the sediment record to progress.

CONCLUSION

Data from ridge-top sites of contrasting fire severity indicate that wildfire has an important influence over the geochemistry of mobilized slope material in accord with evidence from other studies. From a tracing perspective this is encouraging, although problems possibly arise with consideration of partitioning of geochemical properties between mineral and organic components. Furthermore, downstream signals will be complicated by those of eroding colluvial storage zones (cf. Blake *et al*., 2006), which must also be considered in rigorous unmixing of downstream materials. The geochemical profiles of reservoir sediment appear to offer a history of sediment delivery events but interpretation in terms of wildfire impacts is hampered by gaps in our knowledge of changing sedimentation dynamics with fluctuating water levels and the complexity of upstream sources.

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