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Research paper

Refining late Quaternary plunge pool chronologies in Australia's monsoonal 'Top End'

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ABSTRACT

Plunge pool deposits from Australia's 'Top End' are considered as important archives of past monsoonal activity in the region. The available chronology of these deposits was so far based on thermoluminescence (TL) dating and indicated maximum flood magnitudes during the Last Glacial Maximum in contrast with more arid conditions as deduced from other archives of the region. This study revisits plunge pool deposits at Wangi Falls by applying multiple and single-grain Optically Stimulated Luminescence (OSL) dating of quartz and high-resolution gamma spectrometry, supported by radiocarbon dating of organic material. The aim is to reappraise the existing chronology and investigate if the deposits are affected by partial bleaching, post-depositional mixing and/or problems related to annual dose determination. The latter seems to have a minor impact on the ages at most. Equivalent Dose (D_e) distributions are broad, in particular for single grains, but apparently not result from partial bleaching or post-depositional mixing. Rather, microdosimetry caused by radiation hotspots in the sediment and zircon inclusions in the quartz grains is considered problematic for these sediments. The results presented here imply that the previous TL chronology overestimated the real deposition age of the sediments.

1. Introduction

Today, Australia's 'Top End' (the northernmost section of the Northern Territory) is dominated by a highly monsoonal climate (Fig. 1), with fluvial systems characterized by strong seasonal flood dynamics related to cyclone activity. Late Holocene variability in flood magnitudes and frequencies are directly related to the strength of the Australian Summer Monsoon (ASM) and its modulation by El Niño Southern Oscillation (ENSO). In contrast, our understanding of ASM variability, its main controls over longer timescales, and the impact of large-scale hydrological changes on the environment and fluvial systems is limited. Recently, an increasing number of site specific high-resolution datasets from Australasia have suggested mostly dry conditions during the Last Glacial Maximum (LGM, ca. 20 ka ago) with the return of the monsoon not before ca. 15 ka (Reeves et al., 2013). However, the only available terrestrial dataset from the 'Top End' is based on proximal flood sediments associated with waterfall plunge pools (Nott et al., 1996; Nott and Price, 1999), suggesting significantly increased flooding frequencies and magnitudes during the LGM. This interpretation is in conflict to the notion of an overall weakened monsoon during glacial times, but crucially relies on the accuracy of the thermoluminescence (TL) based chronology, which might be affected by two principal problems that have not been fully addressed in previous publications. Firstly, determination of Equivalent Dose (D_e) using a TL multiple-grain approach could have been affected by partial bleaching and/or post-depositional mixing, which could eventually lead to both over- and underestimation of depositional ages. Secondly, Nott et al. (1996) explain the apparent underestimation of some ages by the passage of soluble uranium salts within the water table that could have affected certain parts of the sediment body. However, their application of thick source alpha counting for dose rate determination did not allow to further investigate this issue nor check for radioactive disequilibrium.

In this study, we have re-sampled plunge pool flood sediments

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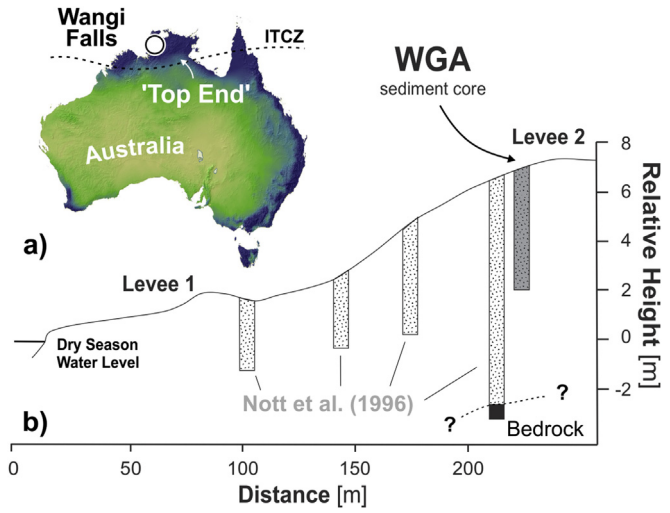

Fig. 1. Location map: a) Overview map Australia (dark shading indicates regions of high annual precipitation), b) cross-section of levee sample location.

in Litchfield National Park with the aim of assessing, refining and improving the plunge pool chronology at Wangi Falls (Fig. 1), and thereby test the validity of existing interpretations. Optically Stimulated Luminescence (OSL) multi-grain aliquot and single-grain dating of quartz in combination with high-resolution gamma spectrometry and ICP-MS are applied to overcome the technical limitations of previous studies. The four main objectives of this study are (i) to assess the possibility of dose rate related problems such as radioactive disequilibrium and uranium dissolved in groundwater, (ii) to investigate if partial bleaching and/or post-depositional mixing are affecting the sediments in a proximal waterfall setting, (iii) to test if the existing TL chronology is supported by radiocarbon and OSL dating, and finally (iv) to determine the most likely depositional ages for the flood sediments.

2. Methodology

2.1. Sampling

Sediment cores down to 5 m depth were extracted in opaque plastic liners with a motor driven manual percussion corer from the crest of the flood levee at Wangi Falls (core WGA, 13.1631°S/130.6817°E; Fig. 1). The cores were subsequently opened in a red-light laboratory and sampled for OSL dating (STable 1). For this, sediment was taken from ca. 6 cm thick portions in the centre of the cores, whereas surrounding material was sampled for dose rate determination. To assess the potential effects of partial bleaching on D_e distributions, two additional samples were collected as modern analogues from Wangi Creek immediately after the flood season in April 2014; WG-Bar comes from a submerged bar at ca. 80 cm below water surface in the waterfall plunge pool, WG-552 from a subaerial bar associated with high-velocity flows immediately downstream of the plunge pool.

After sampling for OSL, all cores were described with regard to their stratigraphical and sedimentological characteristics (i.e. colour, grain size, angularity, organic material, charcoal) to establish a stratigraphic framework and identify material from hole collapse in the upper parts of the cores. Thin sections from each successive meter down-core were prepared from the in-situ sediment. Their micromorphological analysis encompassed their visual inspection under a polarization microscope, and the quantification of the main sedimentary constituents by point counting (see Supplementary Material). Sediment was sampled from 15 different depths, weighed, and then dried and weighed at 50 °C and 450 °C, respectively, in order to estimate field moisture and organic content (Loss on Ignition, LOI). Finally, organic layers and macroscopic charcoal were sampled for radiocarbon dating. Charcoal and organic material was prepared for standard AMS radiocarbon dating at Beta Analytics (US) and the University of Waikato (New Zealand) by washing in hot HCl, rinsing and treating with multiple hot NaOH washes. Then, the NaOH insoluble fraction was treated with hot HCl, filtered, rinsed and dried, to eliminate potential effects of contamination by younger humic acids. The resulting radiocarbon ages were calibrated using Calib 7.0 (Stuiver and Reimer, 1993) and the SHcal13 calibration curve (Hogg et al., 2013).

2.2. OSL sample preparation and measurement set-up

The ca. 65 km^2 catchment area of Wangi Creek exclusively contains quartzite, sandstone, and minor lateritic lithologies (Ahmad et al., 1993), and visual inspection confirmed that the sediment consists almost entirely of quartz grains. Therefore, we used a simplified preparation technique including sieving (160–250 μm and 180–212 μm), chemical pre-treatment with H_2O_2 to eliminate organic matter, and HF treatment (40% for one hour, followed by 15% HCl). Heavy minerals such as zircon are of much smaller grain size than used for quartz extraction and will hence not contaminate the samples. For multi-grain aliquot analyses, 2 mm of the surface of the sample carrier discs were covered with a thin film of silicon oil using a stamp. Measurements were performed using a Freiberg Instruments Lexsyg Research reader (Richter et al., 2013). Each disc was exposed to IR LDs (850 nm, 350 mW cm^{-2}, at 50 °C) to check for feldspar contamination but none showed any response. OSL was recorded at 125 °C during a 60 s exposure to blue LEDs (emission 458 nm, 60 mW cm^{-2}) using the combination of a Hoya U-340 (2.5 mm) and a Delta-BP 365/50 EX-Interference as detection filter (5 mm) and an Electron Tubes Ltd 9635Q photomultiplier. The initial 0.4 s minus the final 10 s subtracted as background were used for signal integration. For single-grain measurements, grains were loaded into mircohole discs and were stimulated with green (532 nm) laser light for 2 s at 125 °C in a Risø DA20 TL/OSL reader (Bøtter-Jensen et al., 2003). D_e values were estimated by summing the first 0.17 s of signal and using the final 0.3 s as background. The ultraviolet OSL emissions were measured using an Electron Tubes Ltd 9635Q photomultiplier tube fitted with a 7.5 mm Hoya U-340 filter. Laboratory irradiations were given using calibrated $^{90}Sr/^{90}Y$ beta sources attached to the readers.

The Single Aliquot Regenerative Dose (SAR) protocol has been applied and dose recovery experiments were used to assess the appropriateness of various preheat combinations, suggesting that most combinations are suitable for D_e estimation in the low dose range considered here (SFig. 1). Preheats of 230 °C for 10 s preceded all multi-grain aliquot OSL measurements (natural, regenerative, and test dose). Applying these preheat combinations we also performed paired multi-grain aliquot analysis on three samples to ensure reproducibility between laboratories and machines, and found excellent agreement (SFig. 2). For single-grain measurements, preheats of 230 °C for 10 s and 180 °C for 10 s preceded natural/regenerative and test dose measurements, respectively. For each sample at least 25 multi-grain aliquots and 500 individual grains were measured. Standard rejection criteria such as natural test dose signals and errors, recycling ratios, and a recuperation test were applied to both multi- and single-grain aliquots (STable 2; Murray and Wintle, 2000). An OSL-IR depletion ratio (Duller, 2003) was also applied for single-grain measurements.

Determination of dose rate relevant elements (K, Th, U) was