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High-precision U-Pb CA-TIMS calibration of Middle Permian to Lower Triassic sequences, mass extinction and extreme climate-change in eastern Australian Gondwana

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ABSTRACT

Twenty-eight new high-precision Chemical Abrasion Isotope Dilution Thermal Ionisation Mass Spectrometry U-Pb zircon dates for tuffs in the Sydney and Bowen Basins are reported. Based on these new dates, the Guadalupian-Lopingian/Capitanian-Wuchiapingian boundary is tentatively placed at the level of the Thirroul Sandstone in the lower part of the Illawarra Coal Measures in the Sydney Basin. The Wuchiapingian-Changhsingian boundary is at or close to the Kembla Sandstone horizon in the Illawarra Coal Measures, southern Sydney Basin, in the middle part of the Newcastle Coal Measures in the northern Sydney Basin, and in the middle of the Black Alley Shale in the southern Bowen Basin. The end-Permian mass extinction is recognised at the base of the Coal Cliff Sandstone in the southern Sydney Basin, at the top of the Newcastle Coal Measures in the northern Sydney Basin, and close to the base of the Rewan Group in the Bowen Basin and is dated at c. 252.2 Ma. The end-Permian mass extinction is interpreted to be synchronous globally in both marine and terrestrial environments, and in high and low latitudes (resolution <0.5 my). The GSSP-defined Permian-Triassic boundary is interpreted to be approximately at the level of the Scarborough Sandstone in the lower Narrabeen Group, Sydney Basin, and in the lower Rewan Group, Bowen Basin. New dates presented here suggest that the P3 and P4 glacial episodes in the Permian of eastern Australia are early Roadian to early Capitanian, and late Capitanian to mid Wuchiapingian in age respectively. The greenhouse crisis in the uppermost Pebbly Beach and Rowan Formations of the Sydney Basin is interpreted as early mid Roadian, a mid-Capitanian age for the crisis at the base of the Illawarra/Whittingham Coal Measures is confirmed. Greenhouse crises in the upper Illawarra/Newcastle Coal Measures and lower Narrabeen Group of the Sydney Basin are dated as upper Changhsingian-Induan, and in the upper Narrabeen Group/lower Hawksbury Sandstone as upper Olenekian.

1. Introduction

The Middle Permian to Early Triassic interval includes some of the most severe biotic crises and climate-change events in the history of the Earth. The end of the Middle Permian (end-Guadalupian) saw a profound sea-level fall, cooling event, and extinctions of low-latitude marine biota (Isozaki et al., 2007a,b; Wignall et al., 2009a,b). Causative mechanisms are largely linked to the Emeishan Large Igneous Province volcanism (Shellnutt et al., 2012), however the global nature of the end-Guadalupian mass extinction has been questioned (Rubidge et al., 2013; Shen et al., 2013). The greatest mass extinction of life on Earth occurred in the late Changhsingian (latest Permian) with the loss of ~85–90% of marine species (Jin et al., 2000; Shen et al., 2011) and ~60% of terrestrial families (Benton, 1995) over a short period of time, estimated at several hundred thousands of years or less (Mundil et al., 2004; Huang et al., 2011; Shen et al., 2011; Burgess et al, 2014). Proposed killing mechanisms in the oceans include global anoxia associated with euxinia, hypercapnia (CO2 poisoning), ocean acidification, and extreme global warming. Kill mechanisms on land include increased CO2 and reduction of oxygen levels in the atmosphere (Schneebeli-Hermann et al., 2013), and injection of volcanic sulphate aerosols, and methane from clathrate reservoirs (Berner, 2002) with consequent global warming (Joachimski et al., 2012), aridity, wildfires, acid rain and mass wasting (Shen et al., 2013; Benton and Newell, 2014). Varied models have been proposed for the cause of the end-Permian extinction, and while hotly debated, the most widely accepted model identifies the consequences of the Siberian flood basalts as the principal cause. Following the end-

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Permian (late Changhsingian) mass extinction, there was a 5 million year period of continued global climatic and environmental upheaval which was characterized by significant carbon isotope excursions, the global "coal gap", "reef gap", "radiolarian gap", significant size reduction of many organisms, and a range of unusual facies and biota including microbialites, and flat pebble conglomerates. This Early Triassic period of environmental upheaval is referred to in the literature as the period of "delayed recovery" following the mass extinction.

Ongoing debates relating to the global nature and cause of the end-Guadalupian mass extinction, and on the synchronous or diachronous nature and cause(s) of the end-Permian extinction require more comprehensive data both stratigraphically and geographically, and especially from regions outside of the highly studied northern hemisphere and palaeo-equatorial shallow-marine Tethyan region, i.e. from high-latitude southern hemisphere Gondwana. A major impediment to comparative studies between Permian-Triassic low and high latitude sequences and between marine and non-marine sequences has been a lack of precise geochronological constraints to effect global correlation. The P-T of the southern hemisphere Gondwana supercontinent contains predominantly endemic biotas in both marine and terrestrial environments largely precluding precise correlation with standard international biozones and System/Stage boundaries. P-T marine correlations in Australian Gondwana have previously been effected largely using local endemic brachiopod and palynology zonation schemes (Briggs, 1998; Foster and Archbold, 2001). Conodonts, ammonoids and fusulinids, used globally for marine P-T biozonation are either absent (fusulinids) or rare (conodonts, ammonoids) in Gondwana and particularly in Australia due to cool-cold climatic conditions related to high southern palaeolatitudes and glaciation-influenced climatic conditions (Fielding et al., 2008a; Korte et al., 2008). High-precision dating of multiple volcanic tuffs in these sequences now provides a robust high-resolution temporal framework that can be globally correlated and can thus provide vital constraints on the nature of biotic crises, climate change and other geological events. We here present twenty-eight new high-precision U-Pb zircon CA-TIMS dates for P-T air-fall tuffs in the Sydney and Bowen Basins of eastern Australian Gondwana that provide vital international calibration and temporal framework for stratigraphy, biotic events, deep-time climate-change, tectonic evolution and resources.

2. Geological, tectonic and palaeogeographical setting

The Sydney, Gunnedah and Bowen basins of eastern Australia contain late Carboniferous, Permian and Triassic marine and non-marine sequences that contain substantial coal resources, particularly in the Upper Permian. These basins developed initially by back-arc extension in the late Carboniferous-Early Permian, followed by thermal sag and evolution into foreland basins in the Late Permian-Early Triassic (Korsch et al., 2009; Waschbuscha et al., 2009). In the Permian-Early Triassic Australia formed part of eastern Gondwana, the southern hemisphere component of the Supercontinent Pangea and was located in high southern palaeolatitudes. An Andean-type volcano-magmatic arc produced large quantities of volcanic ash which was deposited as multiple tuffs in the Permian-Early Triassic foreland basins of eastern Australia (Fig. 1).

Early Permian sedimentary fill of the Sydney, Gunnedah and Bowen basins, during back-arc rifting and thermal sag stages, was largely shallow-marine but in the Late Permian foreland basin stage sediments were largely non-marine terrestrial fluvial and swamp dominated with substantial coal measures development. Sequences in the Sydney-Gunnedah-Bowen basins have to date been largely correlated at the intra and inter-basin levels using shallow-marine biota (mainly brachiopods and forams) and palynology, and lithological and sequence stratigraphy underpinned by geophysics and borehole data. The brachiopod, foram and palynological zonal schemes utilise largely endemic biota and these cannot be used to any degree of confidence for international correlation. In addition, the palynological zones employed are mostly long-ranging and do not provide high-resolution correlation. Rapid sedimentary facies changes, including splitting and coalescing of coal seams, together with unconformities, driven by both eustatic and tectonic regressions and transgressions in a convergent margin setting, are features of all basins. Depositional rates for sediments in the basins are poorly constrained, but are vital for understanding basin evolution and tectonic development (Korsch and Totterdell, 2009).

3. Previous U-Pb zircon dating of tuffs in the Permian-Triassic of Eastern Australia

There is only one previously published paper that provides U-Pb zircon TIMS ages for tuffs in eastern Australia. Gulson et al. (1990) reported an age of 256 $\pm$ 4 Ma for the Awaba Tuff, sampled in the BHP DDH N1561 corehole, 266 $\pm$ 0.4 Ma for the Thornton Claystone sampled in the roof of the Big Ben Seam near the base of the Four Mile Creek Subgroup, and 309 $\pm$ 3 Ma for the Matthews Gap Dacitic Tuff Member of the Patterson Volcanics, northern Sydney Basin. Zircons analysed by Gulson et al. (1990) were subject to air abrasion prior to analyses. These results lack the high-precision and accuracy of current CA-TIMS methodologies but they provided the first direct estimates for the duration of the Permian in eastern Australia and estimates of sedimentation rates for Sydney Basin sequences.

All other previously published U-Pb zircon dates for Permian-Triassic tuffs in Eastern Australia are Sensitive High Resolution Ion Microprobe (SHRIMP) dates. Recognition of the lack of precise international correlation and calibration of Carboniferous-Permian-Triassic sequences in eastern Australia led John Roberts and co-researchers to undertake an innovative program of tuff dating to address this problem (Roberts et al., 1995a,b, 1996). The results from these studies were controversial as they contradicted previously assigned ages based on biostratigraphy and in some cases indicated that rocks regarded as Permian were in fact Triassic (Draper et al., 1997). Unfortunately the Roberts et al. studies used the SL13 standard now known to have heterogeneous $^{206}Pb/^{238}U$. Further problems with unrecognised lead loss and matrix effects on the measured Pb/U render these SHRIMP ages unreliable (Black and Jagodzinsky, 2003; Black et al., 2003, 2004). SHRIMP U-Pb dating cannot achieve the fine level of time resolution required for precise timescale calibration and correlation in the Phanerozoic. Discrepancies between SHRIMP dates (Roberts et al., 1996) and early TIMS U-Pb dating in the Sydney Basin (Gulson et al., 1990) already highlighted the limitations of ion microprobe dating for time scale calibration. In this study we re-dated eight tuffs that were originally SHRIMP dated using the SL13 standard and reported by Retallack et al. (2011). CA-TIMS dates presented here are based on dating of zircons plucked from the original SHRIMP mounts for the samples reported in Retallack et al. (2011) providing a direct comparison of data (Fig. 2). Comparison of these high-precision CA-TIMS dates with the SL13 based SHRIMP dates confirms the unreliability of historic SHRIMP dating in eastern Australia.

In order to assess current SHRIMP dating of Phanerozoic tuffs using more reliable standards and as an initial screening prior to CA-TIMS dating, some of the Permian Tuff samples analysed in this study were dated by SHRIMP at Geoscience Australia. Whilst uncertainties on SHRIMP dates are still high with 2σ uncertainties of 0.4–0.8% compared to 0.05-0.1% for CA-TIMS, the accuracy of this method is now much improved (Bodorkos et al., 2012). Much larger individual $^{206}Pb/^{238}U$ uncertainties in the SHRIMP datasets do not allow for recognition of marginally older xenocrysts, antecrysts or detrital grains from the interpreted magmatic grain population. In addition, lead loss issues are difficult to address by the SHRIMP method although there has been an attempt at annealing and chemical abrasion prior to SHRIMP analyses (Kryza et al., 2012). Annealing and chemical abrasion of zircon grains prior to TIMS analyses does appear to largely (but not always completely) address lead loss. The advantages of the CA-TIMS method, compared to SHRIMP makes this the preferred dating method for high-precision dating of tuffs and timescale calibration in the Phanerozoic.