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Early Triassic (early Olenekian) life in the interior of East Gondwana: mixed marine–terrestrial biota from the Kockatea Shale, Western Australia

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ABSTRACT

A new terrestrial–marine assemblage from the lower beds of a thin outcrop section of the Kockatea Shale in the northern Perth Basin, Western Australia, contains a range of fossil groups, most of which are rare or poorly known from the Lower Triassic of the region. To date, the collection includes spinose acritarchs, organic-cemented agglutinated foraminifera, lingulids, minute bivalves and gastropods, ammonoids, spinicaudatans, insects, austriocaridid crustaceans, actinopterygians, a temnospondyl-like mandible, plant remains, and spores and pollen. Of these groups, the insects, crustaceans and macroplant remains are recorded for the first time from this unit.

Palynomorphs permit correlation to nearby sections where conodonts indicate an early Olenekian (Smithian) age. The locality likely represents the margin of an Early Triassic shallow interior sea with variable estuarine-like water conditions, at the southwestern end of an elongate embayment within the East Gondwana interior rift–sag system preserved along the Western Australian margin. Monospecific spinose acritarch assemblages intertwined with amorphous organic matter may represent phytoplankton blooms that accumulated as mats, and suggest potentially eutrophic surface waters. The assemblage represents a mixure of marine and terrestrial taxa, suggesting variations in water conditions or that fresh/brackish-water and terrestrial organisms were transported from adjacent biotopes. Some of the lower dark shaly beds are dominated by spinicaudatans, likely indicating periods when the depositional water body was ephemeral, isolated, or subjected to other difficult environmental conditions.

The biota of the Kockatea Shale is insufficiently known to estimate biotic diversity and relationships of individual taxa to their Permian progenitors and Triassic successors, but provides a glimpse into a coastal-zone from the interior of eastern Gondwana. Specialist collecting is needed to clarify the taxonomy of many groups, and comparisons to other Lower Triassic sites are required to provide insights into the pattern of biotic decline and recovery at the end-Permian crisis.

1. Introduction

During the end-Permian mass extinction, particular marine environments have been considered refuges, encouraging the distribution and multiplication of environmentally opportunistic organisms (e.g. the bivalve *Claraia* or brachiopod '*Lingula*'; Benton and Twitchett, 2003; Rodland and Bottjer, 2001), and harbouring rare organisms that were later re-established as Lazarus taxa (Flessa and Jablonski, 1983; Wignall and Benton, 1999). Based on studies of post-extinction ichnofaunas, Beatty et al. (2008) and Zonneveld et al. (2010) suggested that broad shallow-marine shelf environments above storm-wave base, and with a well-oxygenated seafloor, acted as refuges for some burrowing animals, although Hofmann et al. (2011) questioned this geographic restriction. Other postulated refuges have included marginal normal-marine environments with mixed siliciclastic–carbonate facies

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showing evidence of periodic salinity and temperature fluctuations (e.g. Mata and Woods, 2008), and brackish-water deltaic settings (e.g. Gall and Grauvogel-Stamm, 2005). Estuarine-like environments subjected to great diurnal, seasonal, and longer-period variability in water quality, and inhabited by a highly adaptable biota, may have allowed some species to survive the extinction event (e.g. the conservative organic-cemented agglutinated foraminifera that were prolific in shallow, restricted, intracratonic seas from the Carboniferous to the Cretaceous, as outlined by Haig and McCartain, 2010). Estuarine environments can be localized within the tidal ranges of rivers; e.g. see Ostrognay and Haig (2012) for a discussion of the high seasonal variability in modern microtidal rivers of southwestern Australia. Alternately, estuarine-like conditions may exist in large interior seas with periodic freshwater influx (e.g. the present-day Baltic Sea, and the large Permian and Cretaceous interior seas of Australia; Kunzendorf and Larsen, 2002; Haig, 2004). Therefore, the identification of estuarine-like Early Triassic environments, particularly in large interior seas, may lead to a greater understanding of why some groups survived the end-Permian extinction event. Although no single location is likely to preserve stratigraphically continuous estuarine-like facies, documentation of various facies at multiple localities and from different ages will allow reconstruction of the evolutionary history of a region's biota. Additionally, marginal-marine deposits of interior seas or estuaries may contain evidence of the terrestrial fauna and flora from the adjacent coastal plain, thereby providing a glimpse into biotas not otherwise preserved.

During the Early Triassic, an interior rift–sag system of basins—the East Gondwana rift of Harrowfield et al. (2005)—extended southwest, far into the interior of the supercontinent (Fig. 1A). Lower Triassic epicontinental marine deposits are known from a series of rift and sag basins along the western margin of Australia, extending from the Timor orogen in the north to the Perth Basin 2500 km to the south (Fig. 1B). Further southwest within this system, sedimentation along the Antarctic–Indian margin was primarily non-marine (Turner, 1991, 1993; Veevers and Tewari, 1995; McLoughlin and Drinnan, 1997). Marine mudstone is a major component of the Lower Triassic succession in most of the Western Australian basins, and regularly includes estuarine-like facies. Except in Timor-Leste, where stratigraphic sections were disrupted by late Neogene orogenesis, these rift–sag basins are relatively undeformed and become thinner towards basin margins. Consequently, outcrop along basin margins reveals incomplete stratigraphic successions; the most complete sections are from boreholes in central parts of these basins, but few of these are even partially cored.

The basin most distal from the continent–ocean boundary to come under marine influence during the Early Triassic was the Perth Basin (Fig. 1A, locality A), in which the Lower Triassic succession consists of the shallow-marine Kockatea Shale in the present-day north and the coeval fluviatile Sabina Sandstone in the present-day south. Fossils have long been known from the Kockatea Shale, but most groups are sparse in both outcrop and subsurface sections. Exceptions are the abundant palynomorphs (especially acritarchs) found at all levels, and beds low in the formation in which the bivalve *Claraia* is concentrated (Thomas et al., 2004). The shelly fauna (excluding *Claraia*) is dominated by pelagic and nektonic groups, rather than by benthic forms. Although many groups have been identified in previous studies, relatively few have been thoroughly described. Noted fossils include stromatolites and other microbialites (McLoughlin and McNamara, 2001; Lipps and Culver, 2002; Thomas et al., 2004; Mory et al., 2005; Metcalfe et al., 2008; Chen et al., 2012, 2014; Luo and Chen, 2014), marine phytoplankton (Balme, 1963, 1967; Medd, 1966; Dolby and Balme, 1976; Sappal, 1978; Thomas et al., 2004), organic-cemented agglutinated foraminifera (Jones, 1970; Metcalfe et al., 2008), inarticulate brachiopods (Dickins and McTavish, 1963), bivalves (Dickins and McTavish, 1963; Skwarko and Kummel, 1972; McTavish and Dickins, 1974; Thomas et al., 2004; Metcalfe et al., 2008), gastropods (Metcalfe et al., 2008), nautiloids (Skwarko and Kummel, 1972), ammonoids (Edgell, 1964; Skwarko and Kummel, 1972; McTavish and Dickins, 1974; Bolton et al., 2010; Chen et al., 2012), echinoid spines (tentatively identified; Metcalfe et al., 2008), spinicaudatans (previously referred to as 'conchostracans';

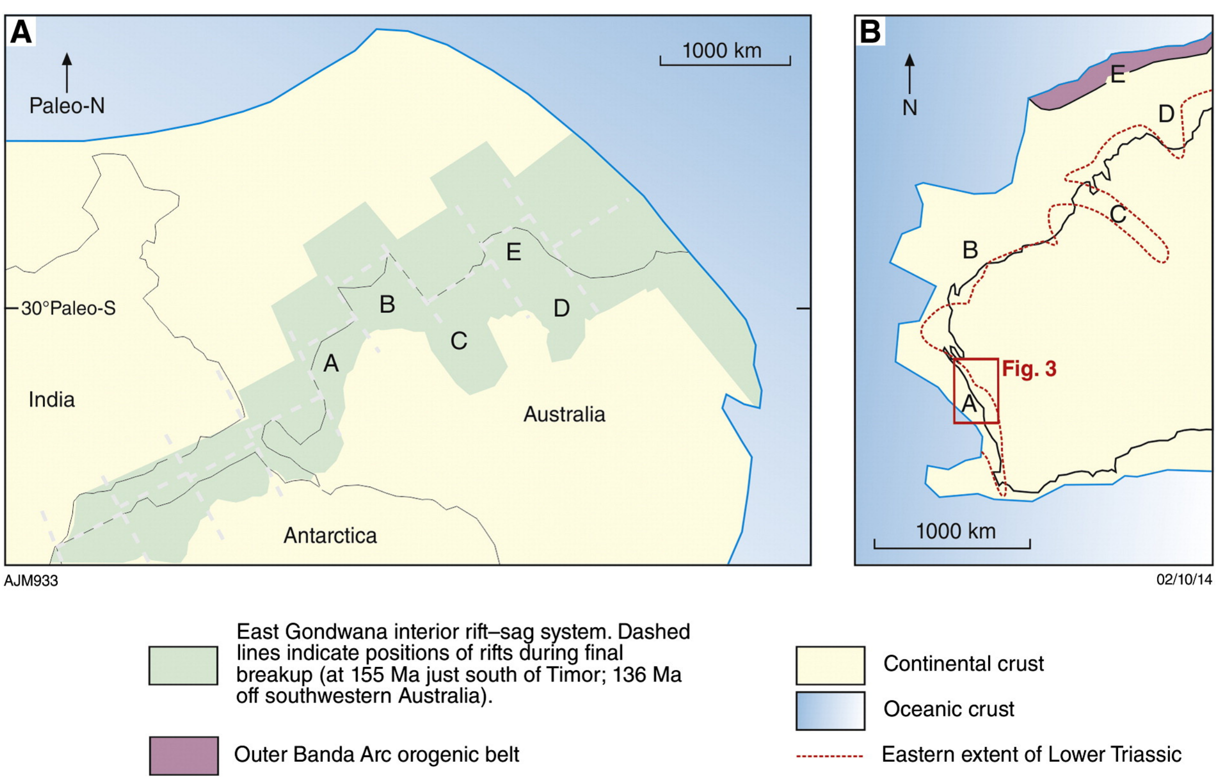

Fig. 1. Geological setting: A. Early Triassic palaeogeographic reconstruction, showing the basins within the East Gondwanan interior rift–sag system (modified from Harrowfield et al., 2005); B. Distribution of basins containing Lower Triassic strata in Western Australia. A = Perth Basin (Playford et al., 1976a; Mory and Iasky, 1996; Metcalfe et al., 2013), B = Northern Carnarvon Basin (Gorter, 1994), C = Canning Basin (Mory, 2010); D = Bonaparte Basin (Mory, 1988; Nicoll and Foster, 1998; Gorter et al., 2010); E = Timor-Leste (Charlton et al., 2009).